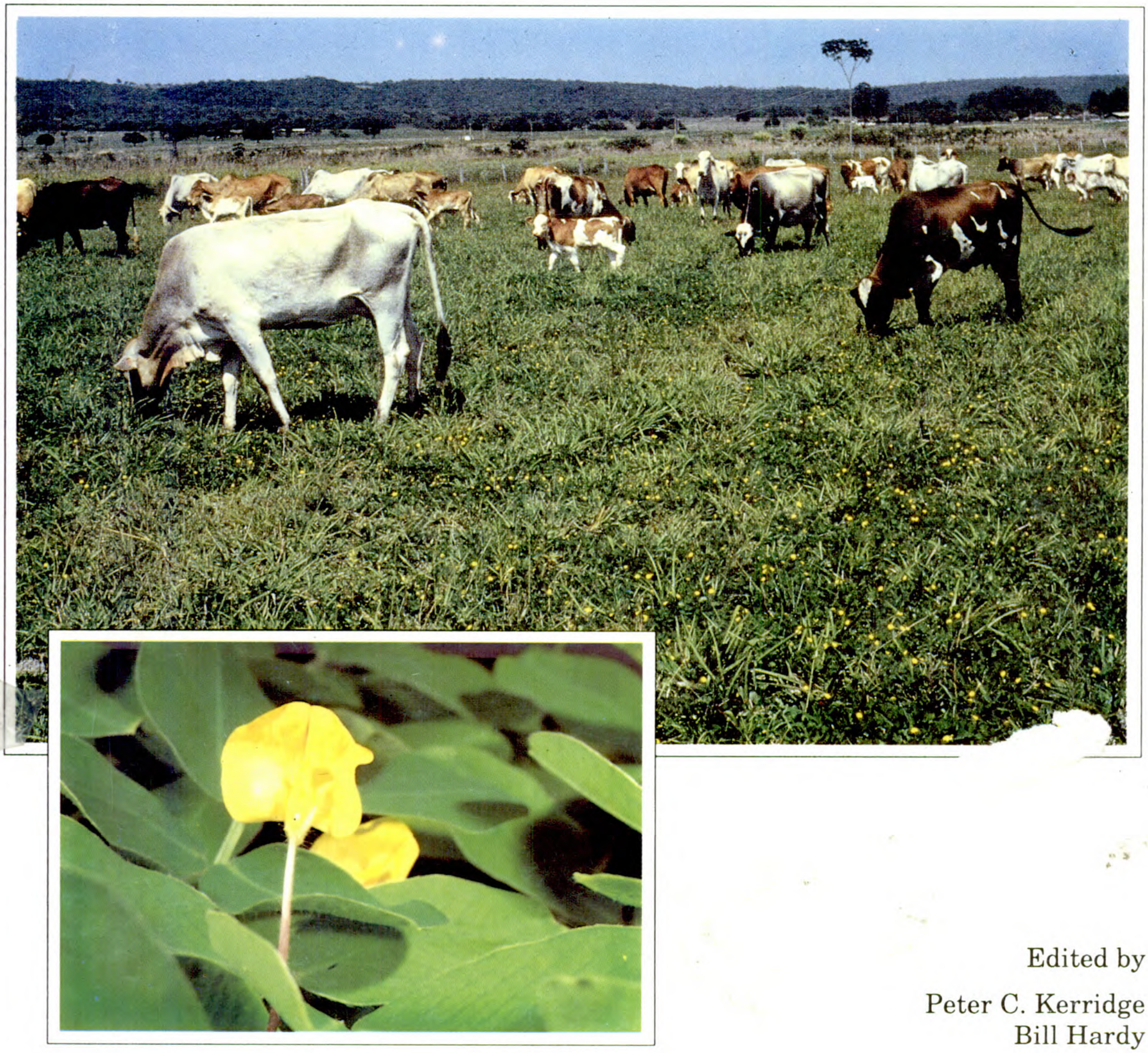
Biology and Agronomy of Forage *Arachis*



Edited by
Peter C. Kerridge
Bill Hardy

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

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Cover photos:

Cattle grazing a *Paspalum atratum-Arachis pintoi* pasture in Planaltina, Brazil. Both grass and legume are new accessions undergoing evaluation. (Inset: an *Arachis pintoi* flower.)

ISBN 958-9183-96-4

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Centro Internacional de Agricultura Tropical
Apartado Aéreo 6713
Cali, Colombia

CIAT Publication No. 240
ISBN 958-9183-96-4
Press run: 1000
Printed in Colombia
April 1994

Biology and agronomy of forage *Arachis* / edited by Peter C. Kerridge,
Bill Hardy. -- Cali, Colombia : Centro Internacional de Agricultura
Tropical, 1994. 209 p. -- (CIAT publication; no. 240)

1. *Arachis pintoi* -- Taxonomy. 2. *Arachis pintoi* -- Germplasm resources.
3. *Arachis pintoi* -- Plant physiology. 4. *Arachis pintoi* -- Diseases and pests.
5. *Arachis pintoi* -- Nutritive value -- Tropics. I. Kerridge, Peter C. II. Hardy,
Bill. III. Centro Internacional de Agricultura Tropical.

Contents

Preface

The initial idea behind this Workshop on the Biology and Agronomy of Forage *Arachis* was to hold an internal review of the research that had been done on the use of wild accessions of the genus *Arachis* with forage potential in order to prioritize future research. However, it was recognized that many others outside the International Center for Tropical Agriculture (CIAT) had been involved in the acquisition and evaluation of wild *Arachis* accessions and that we would gain from their experience. Thus, invitations were given to those who could complement the work of CIAT scientists to collaborate with us in this endeavor. Furthermore, as much of the research had not been published, it was decided that publication of the various reviews would be of value to others interested in the use of *Arachis* as a forage plant.

Agronomists working with the common peanut, *A. hypogaea*, have long had an interest in accessions of wild *Arachis* species as a source of resistance genes to overcome disease and other constraints in this crop plant. Considerable resources have been applied to collection and conservation, and studies on taxonomy and cross compatibility within the genus with a view to improvement of *A. hypogaea*. But there has been little interaction between this group of crop-oriented scientists and those interested in the forage and soil improvement attributes of *Arachis*. Thus, at an international workshop on "Genetic resources of wild *Arachis* species" held at CIAT in 1989, no one from the CIAT Tropical Pastures Program was involved. We are fortunate to have reviews by Valls and Simpson, who were participants in that 1989 workshop, and regret that some crop agronomists and geneticists could not attend this 1993 workshop.

Forage scientists have tended to work with few species and accessions of the large genus of *Arachis*. This has been in part because though only a few accessions of *A. pintoi* and *A. glabrata* were available, they showed huge potential. Hence, there was little need to look further afield. But now that the potential is realized, there is some urgency to acquire more accessions of the successful species.

There were gaps in the presentations at the 1993 workshop and in the representation of those with experience with *Arachis* as a forage. We regret that funds were not available to bring more to the workshop. Nevertheless, the workshop was stimulating for all those present. We hope that these proceedings not only describe the technical information about the genus but also convey some of the enthusiasm of the participants for the potential of the genus to make an impact in the forage area, as a cover crop and as an ornamental plant. Increased interest in these uses will also have a spinoff for those interested in wild *Arachis* as a source of genes to overcome constraints in the common peanut.

Finally, it is appropriate to mention that three other books with relevance to those interested in the genus *Arachis* will be published shortly:

Taxonomía del género *Arachis*, by A. Krapovickas, and W.C. Gregory to be published in Bonplandia in mid-1994.

Catalogue of the *Arachis* collections, by H.T. Stalker, to be printed and distributed by CIAT in mid-1994.

The groundnut crop: the scientific basis for improvement, edited by J. Smart, to be published by Chapman and Hall, London, in late 1994.

Biology and Agronomy of Forage Arachis. *1993. p. 1-18.*
Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Chapter 1

Taxonomy, Natural Distribution, and Attributes of *Arachis*

J.F.M. Valls
C.E. Simpson*

Abstract

Arachis is a leguminous genus with unique reproductive features in that seed is set below ground. In the absence of a comprehensive taxonomic treatment of the genus, associating morphological and reproductive characters has helped group species into sections and series. While most of the variation in *A. hypogaea* is in the pod and seed, wild species show much variation over all the plant. *Arachis* is naturally confined to Brazil, Bolivia, Paraguay, Argentina, and Uruguay. Recent intensive collection of *Arachis* germplasm has expanded the known area of distribution of many species and sections, and increased the number of species.

Most of the research into species with forage value has been limited to species of sections Caulorhizae (*A. pintoi* and *A. repens*), Rhizomatosae (*A. glabrata*), or Procumbensae. However, essentially all information is based on a few widespread accessions. Discrimination between some species, such as *A. pintoi* and *A. repens*, has become more difficult as more morphological variation has become evident from recent collections.

Species of other sections have forage potential and should be evaluated because of their forage quality, tolerance for water logging, and seed production, such as some accessions in section Procumbensae. A species in section Triseminalae from northeastern Brazil occurs in a very dry environment. Other species may offer alternatives for short rotations, hay production, or even as pioneer crops in the establishment of slow-growing stoloniferous or rhizomatous species of *Arachis*.

Taxonomic and Nomenclatural Aspects

The genus *Arachis* is a member of the Leguminosae-Papilionoideae (=Fabaceae *sensu stricto*), tribe Aeschynomeneae, subtribe Stylosanthinae (Rudd, 1981). It is unique among the Leguminosae because of the association of underground fruits originated from aerial flowers with a tubular hypanthium (Smith, 1950), distinctive types of anthers in the same flower, and a delicate seed tegument. It is naturally confined to Brazil (more than 60 wild species), Bolivia (15), Paraguay (14), Argentina (6), and Uruguay (2). About 60 of the probable 80 species are endemic to one of the above countries. The geographic distribution of wild populations tends to be in scattered small communities, with almost no gene flow between them (Krapovickas, 1973).

Arachis hypogaea, the common groundnut, was described by Linnaeus in 1753. Almost a century later, five wild species (*A. glabrata*, *A. prostrata*, *A. pusilla*, *A. tuberosa*, and *A. villosa*) were added to the genus by Bentham (1841). *A. marginata* and *A. hagenbeckii* were also validly described in the nineteenth century, while *A. diogoi*, *A. nambyquarae*, *A. helodes*, *A. monticola*, *A. paraguariensis*, *A. guaranitica*, *A. benthamii*, *A. martii*, *A. villosulicarpa*, *A. lutescens*, and *A. burkartii* were added as valid names

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* Curator of *Arachis* germplasm, Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia/ Empresa Brasileira de Pesquisa Agropecuária (CENARGEN/EMBRAPA), Brasília, Brazil; Professor, College of Agriculture, Texas A&M University, Stephenville, Texas, USA, respectively.

(Gregory et al., 1980) before 1958, when Handro described the first stoloniferous species, *A. repens*. Krapovickas and Gregory added *A. rigonii* in 1960. The latest species described are *A. batizocoi* and *A. glandulifera*, considered representatives of "B" and "D" genomes, respectively (Smartt et al., 1978; Stalker, 1991; Stalker et al., 1991).

Confusion in the application of names has always been a serious problem for most germplasm users, and information on *A. glabrata*, *A. prostrata*, *A. marginata*, *A. pusilla*, and *A. diogoi* needs to be taken with care, with a search for the correct passport data of each accession considered. The valid name *A. nambyquarae* is a synonym of *A. hypogaea* (Krapovickas and Rigoni, 1960), and *A. hagenbeckii* is, most likely, a synonym of *A. glabrata*. *A. angustifolia* is a valid name of uncertain application. *A. sylvestris*, also valid, is currently used to identify the wild *Arachis* species with the broadest natural area, but doubts persist on the correct circumscription of this name.

Many names without a formal Latin description or diagnosis, such as *A. cardenasii, A. duranensis, A. stenosperma, A. pintoi,* and a few others, are currently used in the literature (Gregory et al., 1973; Gregory and Gregory, 1979; Rao and Sadasivan, 1985). Although each of the above names is a *nomen nudum* (Resslar, 1980), most of them are based on single accessions of given species, and the obvious tendency is for their final validation by taxonomists in the next few years. Meanwhile, it is important that the scientists involved understand that the use of a *nomen nudum* for collections other than those specifically cited by the author of the name is a highly subjective decision, and may not agree with that author's concepts.

Variation and Taxonomic Structure of the Genus

It is evident from the above that the taxonomy of *Arachis* is in a state of flux. From time to time, the classification outline has been changed, especially for those receiving up-to-date information on the progress of germplasm collection work (Simpson, 1984, 1991; Valls et al., 1985). Proposed sections and series, still invalid from the nomenclatural point of view, have been periodically adjusted (Table 1), as their composition and circumscriptions were constantly modified by the study of new acquisitions. Table 2 shows the present taxonomic structure of the genus, with the estimated numbers of species per section, and lists the valid and invalid names currently in use. There are 24 valid names, 14 invalid names, and, thus, many unnamed species. Table 3 summarizes the distinctive biological and ecological features characterizing the sections and series, establishing the natural occurrence of each. Table 4 presents the numbers of known species of each section per country or countries of natural occurrence.

While *A. hypogaea* shows a lot of visible variation in pod and seed characters (Simpson et al., 1992), but not much in the underground structures and aerial vegetative features, wild species show much variation in all plant parts. Association of morphological and reproductive characters has allowed taxonomic grouping of species in sections and series. Among such characters, axonomorphic or tuberous roots, presence or absence of stolons or rhizomes, vertical to horizontal peg position as the ovary is pushed into the soil, and details of flower morphology, such as the different standard markings, have been generally accepted as important characters for the assignment of species to sections (Gregory et al., 1973; Krapovickas, 1973; Stalker, 1985). Within sections, diploid or tetraploid chromosome complement, annual or perennial life cycle, and number of leaflets determine placement in distinct series.

Subgeneric Framework

After the proposal of the first subgeneric framework, by Krapovickas (1969, *fide* Resslar, 1980), the taxonomic subdivision

Table 1. Evolution of the subgeneric classification of *Arachis* to the level of sections (CAPITAL LETTERS) and series (small letters), as proposed from 1969 to 1990.

Krapovickas (1969)*	Krapovickas (1973)	Gregory et al. (1973, 1980)**	Krapovickas (1990)
AXONOMORPHAE	ARACHIS	AXONOMORPHAE Annuae Perennes Amphiploides	ARACHIS Annuae Perennes Amphiploides
ERECTOIDES	TRIERECTOIDES	ERECTOIDES Trifoliolatae	ERECTOIDES Trifoliolatae
	TETRAERECTOIDES	Tetrafoliolatae	Tetrafoliolatae
		Procumbensae	PROCUMBENSAE
CAULORHIZAE	CAULORHIZAE	CAULORHIZAE	CAULORHIZAE
RHIZOMATOSAE	RHIZOMATOSAE	RHIZOMATOSAE Prorhizomatosae Eurhizomatosae	RHIZOMATOSAE Prorhizomatosae Eurhizomatosae
EXTRANERVOSAE	EXTRANERVOSAE	EXTRANERVOSAE	EXTRANERVOSAE
AMBINERVOSAE	AMBINERVOSAE	PSEUDAXONOMORPHAE	AMBINERVOSAE
		TRISEMINALAE	TRISEMINALAE

* *fide* Resslar (1980).
** In 1980: AXONOMORPHAE=ARACHIS; PSEUDAXONOMORPHAE=AMBINERVOSAE.

in sections and series has evolved, due to (1) close observation of the growing numbers of accessions and species collected, (2) intensive cytogenetic investigation of such germplasm, (3) the understanding that some previously established sections include divergent materials, and (4) the sporadic solution of traditional problems in the interpretation of specific circumscriptions.

The most persistent taxonomic problems in *Arachis*, starting with the scarcity of species with valid names, are likely to be solved in a short time, by the long-awaited publication and validation of scientific names by Professor Antonio Krapovickas and associates (Krapovickas and Gregory, n.d.). Therefore, the objective of the present work is to compile the available taxonomic information, stressing aspects related to species or groups of species with the greatest potential for forage use. The basic document for the following information is a "Taxonomic summary of *Arachis*," as proposed by Krapovickas in 1989 (Krapovickas, 1990). This document agrees with most ideas previously consolidated by Gregory et al. (1973, 1980), and Krapovickas (1973), although a few names, such as Axonomorphae and Pseudaxonomorphae, were changed. In short, the main points of this modern framework for *Arachis* (Table 2) are:

1. Sections Arachis (with three series), Caulorhizae, Extranervosae, and Rhizomatosae (this one with two series) are kept intact.
2. Section Erectoides, previously proposed as two sections, and later considered as one section with three series, now retains series Trifoliolatae and Tetrafoliolatae, while series Procumbensae was raised to the sectional level.
3. Sections Ambinervosae (the previous Pseudaxonomorphae) and Triseminalae are definitively accepted as two distinct groups.
4. Two new species names are added to the list of those available in the literature: *A. sylvestris*, valid, but never listed as a species by itself in previous taxonomic schemes, and

Table 2. Present taxonomic structure of the genus *Arachis*, with the estimated numbers of species per section and series, and the valid and invalid names in use.

Section/series[a]	Probable no. of species	Valid species names available	Most relevant invalid names (*nom. nud.*)
CAULORHIZAE	2	*A. repens* Handro	*A. pintoi* Krap. & Greg.
RHIZOMATOSAE			
Eurhizomatosae	2	*A. glabrata* Bentham *A. hagenbeckii* Harms (syn. *A. glabrata*?)	
Prorhizomatosae	1	*A. burkartii* Handro	
PROCUMBENSAE	11	*A. rigonii* Krap. & Greg.	*A. lignosa* Krap. & Greg. *A. apressipila* Krap. & Greg.
TRISEMINALAE	1		*A. triseminalis* Krap.
ARACHIS			
Amphiploides	2	*A. hypogaea* L. *A. monticola* Krap. & Rigoni	
Perennes	18	*A. diogoi* Hoehne *A. helodes* Mart. ex Krap. & Rigoni *A. villosa* Bentham	*A. cardenasii* Krap. & Greg. *A. chacoensis* Krap. & Greg. *A. correntina* (Burk.) Krap. & Greg. *A. stenosperma* Greg. & Greg.
Annuae	11	*A. batizocoi* Krap. & Greg. *A. glandulifera* Stalker	*A. duranensis* Krap. & Greg. *A. ipaensis* Greg. & Greg. *A. spegazzinii* Greg. & Greg. (= *A. duranensis*?)
AMBINERVOSAE	4	*A. sylvestris* (Chev.) Chevalier *A. pusilla* Bentham	
ERECTOIDES			
Trifoliolatae	2	*A. guaranitica* Chodat & Hassler *A. tuberosa* Bentham	
Tetrafoliolatae	13	*A. benthamii* Handro *A. martii* Handro *A. paraguariensis* Chodat & Hassler	*A. oteroi* Krap. & Greg.
EXTRANERVOSAE	11	*A. lutescens* Krap. & Rigoni *A. marginata* Gardner *A. prostrata* Bentham *A. villosulicarpa* Hoehne	*A. burchellii* Krap. & Greg. *A. macedoi* Krap. & Greg.
Uncertain sectional placement	1	*A. angustifolia* (Chodat & Hassler) Killip	

a. Sequence of sections and series according to the potential use of their species as forage plants.

Table 3. Distinctive biological characteristics, ecological preferences and summarized geographic distributions of sections and series of the genus *Arachis*.

Sections and series[a]	Chromosome number and genomes	Ecological and morphological characteristics	Life cycle[b]	Natural occurrence[c]				
				ARG	BOL	BRA	PRY	URY
CA	2x C	Low areas Stolons	P			x		
RH/rh	4x A,E?	Well-drained soils	P	x		x	x	
RH/pr	2x R	Rhizomes	P	x		x		x
PR	2x E3?	Poorly drained soils Horizontal pegs from all branches	P		x	x	x	
TR	2x T	Poorly drained soils Inclined pegs often 3-seeded	P			x		
AR/am	4x AB	Variable ecology	A	x				
AR/an	2x A,B,D	Tap roots and vertical pegs	A	x	x	x		
AR/pe	2x A		P	x	x	x	x	x
AM	2x Am	Variable ecology Tap roots and variable pegs	A			x		
ER/tr	2x E1?	Well-drained soils	P			x	x	
ER/te	2x E2?	Horizontal pegs from base Tuberous roots	P			x	x	
EX	2x Ex	Mostly well drained soils Variable pegs Tuberous roots	P			x		

a. Sections and series: CA = Caulorhizae; RH = Rhizomatosae (rh = Eurhizomatosae; pr = Prorhizomatosae); PR = Procumbensae; TR = Triseminalae; AR = Arachis (am = Amphiploides; an = Annuae; Pe = Perennes); AM = Ambinervosae; ER = Erectoides (tr = Trifoliolatae; te = Tetrafoliolatae); EX = Extranervosae.

b. Life cycle: A = annual; P = perennial.

c. Countries: ARG = Argentina; BOL = Bolivia; BRA = Brazil; PRY = Paraguay; URY = Uruguay.

A. triseminalis, a name established to be used instead of *A. pusilla* for the only known species of Triseminalae (Krapovickas, 1990). Typical *A. pusilla*, an annual species, is now interpreted as a member of section Ambinervosae. Its valid name has been wrongly used to identify the only representative of section Triseminalae, a distinct perennial species.

The above changes have a major impact in two circumstances:

1. A significant part of the previous information on section Erectoides, especially cytogenetic and isoenzymatic data, and reports of crossing experiments and phytopathological reactions, really refers to section Procumbensae (Abdou et al., 1974; Atreya and Subrahmanyam, 1989; Cai et al., 1987; Cherry, 1975, 1977; Jahnavi and Murti, 1985b; Johnson et al., 1977; Joseph and Krishnappa, 1988; Murti et al., 1985; Stalker and Campbell, 1983; Stalker and Moss, 1987; Stalker et al., 1989; Subrahmanyam et al., 1985b). Most of that information is based on *A. rigonii* (GKP 10034) and GKP 9990, 9993, and 10002 (these are sometimes cited under *A. apressipila*).
2. Previous information on *A. pusilla*, taken from perennial accessions GK 12881 and 12922 (Cherry, 1977; Klozová et al., 1983; Jahnavi and Murti, 1985a; Stalker and Campbell, 1983; Subrahmanyam et al., 1985b), must refer to the new name *A. triseminalis*, which still characterizes the behavior of section Triseminalae.

Impact of Recent Collection and Characterization Efforts

Intensive collection of *Arachis* germplasm has greatly expanded the known area of distribution of many species and sections, and the number of species has increased in most sections. Knowledge on sections Arachis, Ambinervosae, Caulorhizae, and Extranervosae was increased by the new findings. The broad collection of Procumbensae, scarcely represented before, unveiled its marked differences, as a group, from the Erectoides.

Collection activities helped increase knowledge on geographic distribution and helped conserve genetic variability in *Arachis*. The subsequent characterization and preliminary evaluation of the acquired germplasm have improved knowledge on the genus. Intensive cooperative efforts to characterize and evaluate wild *Arachis* germplasm are under way in many institutions and countries, and involve taxonomy, cytogenetics, breeding behavior, genome analysis, wide crosses, resistance to pests and diseases, and potential for forage use. It is interesting to note that for wild *Arachis*, many scientists directly involved in characterization and evaluation have had one or several opportunities to participate in collecting missions. This productive link between those involved with the search for new germplasm and its immediate characterization and evaluation has given rise to a strong "collective awareness" affecting almost everyone involved. At the same time, it has engendered a general feeling among *Arachis* workers that much field research remains to be done.

Although previous estimates calculated 15 to 60 species in the genus, many new species have been found in the past decade. The numbers presented in Table 4 are obviously not complete, and it is possible that many species, so far thought to be endemic to one country, may be found in another as collection work progresses. But the high number of species exclusive to one country,

Table 4. Geographic distribution of the 80 species of *Arachis* so far known, including those with valid and invalid names and species not yet mentioned in the literature.

Countries	Sections[a]								
	CA	RH	PR	TR	AR	AM	ER	EX	Total
Argentina (ARG)	-	-	-	-	2	-	-	-	2
Bolivia (BOL)	-	-	2	-	8	-	-	-	10
Brazil (BRA)	2	-	6	1	12	5	10	11	47
Paraguay (PRY)[b]	-	-	1	-	3	-	-	-	4
Uruguay (URY)	-	-	-	-	-	-	-	-	0
Species in one country:	2	0	9	1	25	5	10	11	63
ARG/BOL	-	-	-	-	1	-	-	-	1
BOL/BRA	-	-	2	-	1	-	-	-	3
BRA/PRY	-	1	-	-	1	-	5	-	7
Species in two countries:	0	1	2	0	3	0	5	0	11
ARG/BRA/PRY	-	1	-	-	-	-	-	-	1
ARG/BRA/URY	-	1	-	-	1	-	-	-	2
BOL/BRA/PRY	-	-	-	-	1	-	-	-	1
Species in three countries:	0	2	0	0	2	-	-	-	4
Known species per section:	2	3	11	1	30	5	15	11	78

a. Section Arachis reaches 31 species with the inclusion of *Arachis hypogaea*, widely cultivated in all five countries. Sections and series: CA = Caulorhizae; RH = Rhizomatosae; PR = Procumbensae; TR = Triseminalae; AR = Arachis; AM = Ambinervosae; ER = Erectoides; EX = Extranervosae.

b. Includes *A. angustifolia*, a species of uncertain sectional location, originally described from Paraguay.

especially in the case of Brazil (47 species) and Bolivia (10 species), requires that concerted regional efforts be supported by strong national efforts in exploration, conservation, and use of each country's natural resources.

Most taxonomic work in *Arachis* has been centered, for obvious reasons, on *A. hypogaea* and its relationship with the other species, including the proposal of somewhat divergent sequences of gene pools, from primary to tertiary (Singh et al., 1990) or quaternary (Wynne and Halward, 1989) (Table 5). A different focus will be attempted here (Figure 1), as the priority is those species of the genus that are or may become important for forage production.

Forage Potential

Basically, every *Arachis* species produces green forage palatable to grazing animals. From the quality standpoint, most species are accepted as good forage plants. Crude protein content and in vitro organic matter digestibility (IVOMD) are generally equal to or better than in other commercial tropical forage legumes. However, emphasis is given, at this point, to species or accessions able to produce a significant volume of green forage, preferably well distributed over an extended period, which have one or more of the following characteristics: persistence under grazing, trampling, and competition from aggressive grasses; and reasonable resistance to long dry periods, flooding, cool temperatures, and diseases and pests.

From the standpoint of forage potential, reports on wild *Arachis* do not include references to sections. Most modern references concentrate on well-established species such as members of the sections Caulorhizae and Rhizomatosae, or refer to a single species, such as the 'Pantanal' peanut, without mention of the sectional affiliation. An attempt is made here to emphasize the sections, which include species with greater forage potential, while also pointing out the possible advantages of exploring a broader array of *Arachis* germplasm for different approaches to forage production.

Sections, Series, Species, and Their Attributes

Section Caulorhizae

Knowledge of section Caulorhizae among forage *Arachis* researchers is generally based on two widespread accessions, each representing one of the

Table 5. Proposed gene pools in the genus *Arachis*, considered from the standpoint of groundnut breeding, and taking *A. hypogaea* as the main species of reference.

Gene pools	Wynne & Halward, 1989	Singh et al., 1990
Primary	Cultivated varieties of *Arachis hypogaea* Landraces of *A. hypogaea* Breeding lines derived from the above	*Arachis hypogaea* and *A. monticola*
Secondary	*Arachis monticola* Other wild tetraploid forms in section Arachis (as yet uncollected)	Diploids in section Arachis cross-compatible with *A. hypogaea*
Tertiary	Diploid wild species of section Arachis	Species in all sections
Quaternary	Diploid and tetraploid species of other sections of the genus	

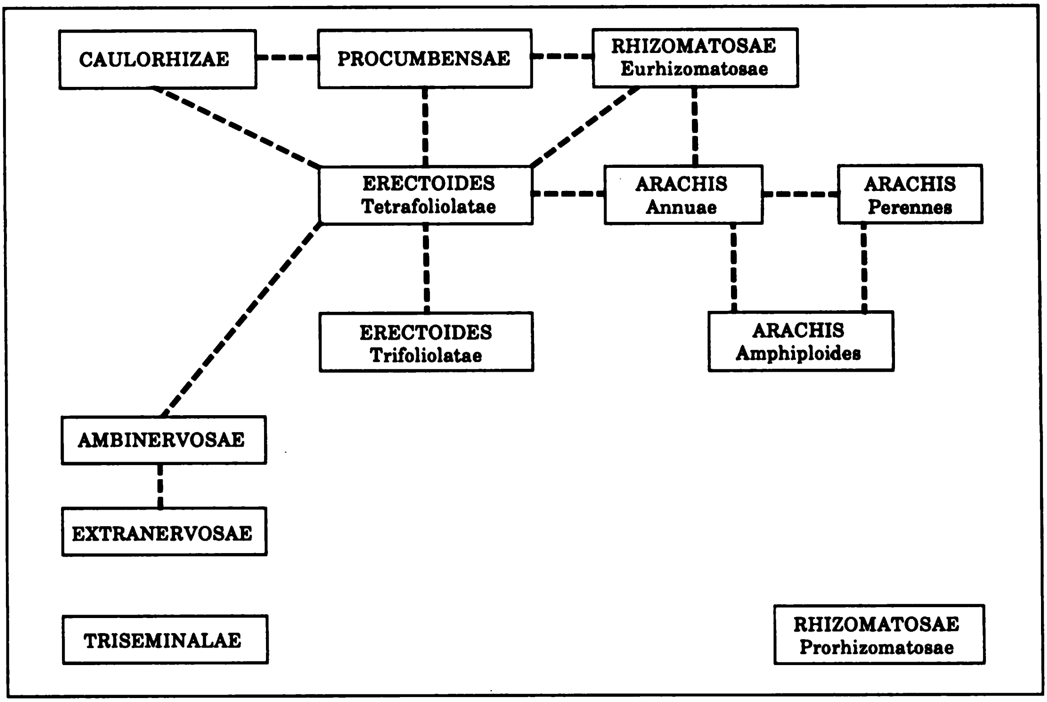
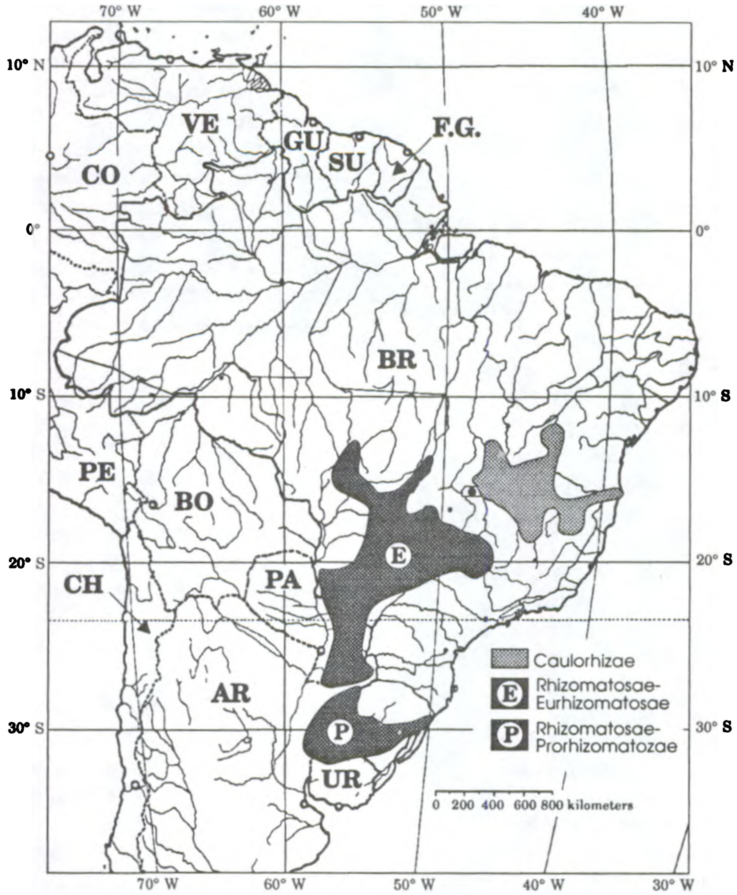


Figure 1. Crossing relationships in the genus *Arachis*, with emphasis on sections having species with the highest forage potential. Lines connecting sections and series indicate confirmed cross compatibility, at least in one direction. (Adapted from Gregory and Gregory, 1979.)

stoloniferous species recognized in the section. *A. repens* accession GKP 10538, always vegetatively propagated and never producing seed, is a clone, most probably representing a single genotype. The original accession of *A. pintoi* (GK 12787) has been alternatively propagated by seed or cuttings. Although seed propagation may keep some genetic variability in the samples, the numbers of individuals exchanged and increased have usually been small. Discrimination between *A. repens* and *A. pintoi*, based on these two accessions only, is easy, with the most distinctive characters being shape and size of the leaflets and the presence or virtual absence of bristles on the petioles and the back of the leaflets in *A. repens*.

The forage and ground cover attributes of the above accessions (Akobundu and Okigbo, 1984; Grof, 1985; Cook et al., 1990; Argel and Pizarro, 1992) and references to high resistance of *A. repens* to peanut stripe virus (Herbert and Stalker, 1981) and to an insect complex (Stalker and Campbell, 1983) make the collection and study of the genetic variability of the two species a high priority. As the valleys of the rivers Jequitinhonha and Araçuaí, São Francisco, and Paranã (a tributary of the river Tocantins, in central Brazil) were thoroughly searched, the available number of accessions increased rapidly, and the area of natural occurrence of the section was substantially expanded (Map 1).

As the almost 100 accessions now available in the section are considered, the morphological features that used to make it easy to distinguish between *A. repens* and *A. pintoi* are no longer adequate for making a distinction (Valls, 1992). The two original accessions seem to represent extreme morphological types on a continuum, with most of the accessions showing intermediate states or a reticular association of the characters. Forage and seed production, as well as disease and pest reactions, are also quite variable between accessions (Pizarro et al., 1993).



Map 1. **Known geographic distribution of sections.**
CO = Colombia, VE = Venezuela, GU = Guyana, SU = Suriname, F.G. = French Guiana, BR = Brazil, AR = Argentina, UR = Uruguay, PA = Paraguay, CH = Chile, BO = Bolivia, PE = Peru.

Whenever possible, collection of new accessions of section Caulorhizae has been broad and randomized, including cuttings and seeds from many plants of each population. As a consequence, these collections may include significant internal variability, which needs to be conserved and investigated. However, the usual increase and subsequent distribution of small subsamples, composed of only a few seeds or cuttings, may restrict and even in a short time differentiate the variability available for distinct germplasm needs.

Section Rhizomatosae

Accessions of section Rhizomatosae have been known to forage *Arachis* investigators for a long time (Otero, 1941; Prine, 1964). Most of the widespread rhizomatous accessions belong to series Eurhizomatosae. Although quite variable as a group, the majority of such accessions can be included, to the best of present knowledge, in *A. glabrata*. Some of them have been determined as *A. hagenbeckii*, and most are identified in the living collections only to the sectional level. A few other rhizomatous accessions belong to *A. burkartii*, of series Prorhizomatosae. These are generally characterized by low forage production under cultivation, and poor adaptation to other than their natural sites.

As most accessions of this section, including released cultivars, rarely produce any seed, exchange and increase have been based on vegetative propagation. As a consequence, each accession may represent a single genotype, but more than 300 accessions of distinct origins are involved. Much needs to be investigated concerning reproduction and variability within the rhizomatous species of *Arachis*.

Germplasm collections undertaken in the past decade did not significantly increase the known area of occurrence of both rhizomatous series, but there was a steady growth in the number of germplasm accessions per species, and a better geographic representation of the total area by new accessions. This is a clear consequence of the improvement of the road system, especially in the states of Mato Grosso and Mato Grosso do Sul, in Brazil (Map 1). Further exploration of the available germplasm, and additional collection in areas not yet covered, within the known limits of natural occurrence, may reveal many additional genotypes for forage production.

Section Procumbensae

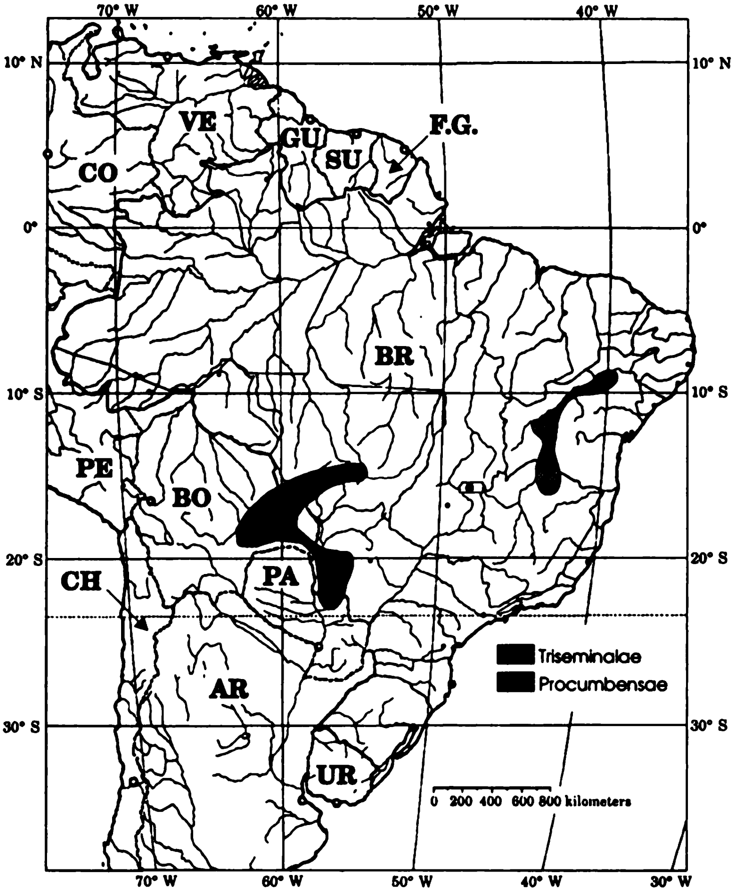
Not many accessions of section Procumbensae have been evaluated as potential forages, but the desirability of investigating more accessions of the section is emphasized by the promising 'Pantanal' peanut (Kretschmer and Wilson, 1988), not previously associated with this section, but most likely one of its members. Good forage quality, resistance to flooding, and high seed production are important features shared by many accessions collected in the same general area, in the state of Mato Grosso do Sul, especially in the municipalities of Miranda and Corumbá.

The known area of occurrence of this recently named section (Krapovickas, 1990) expanded significantly northeast from Bolivia, toward the northern limits of the Brazilian Pantanal, where the number of newly disclosed species is high. A similar increase occurred in the number of accessions and species collected at the southern limits of the Pantanal (Map 2). Although plants in this section do not produce true rhizomes or stolons, their prostrate basal branches may be partially covered by mud during floods, and buds may sprout from these branches, giving the impression of rhizomatous growth. Most Procumbensae species produce horizontal (or almost horizontal) pegs, sometimes very long. In this case, seeds tend to develop near the surface. This is a positive agronomic feature, as underground seed harvest is a necessity, and at the same time one of the most important problems associated with the commercial use of wild *Arachis* species.

Section Triseminalae

A perennial *Arachis* species that forms dense natural pastures in broad floodplains along the river São Francisco, near Juazeiro, in the state of Bahia, has attracted the attention of Brazilian and Australian agrostologists in the past (G. Pinto and R. Burt, personal communications). The species produces forage of high yield and quality in poorly drained clay soils during the rainy season, but remains alive under intensive overgrazing during the long dry season that characterizes Brazil's northeast. It shows some unique morphological features such as a fused, tubular base of the stipules and a tendency to produce a number of three-seeded fruits. For a long time, the species has been wrongly recognized as *A. pusilla*, and is generally represented in gene banks by two widespread accessions, GK 12881 and GK 12922. Accession GK 12922 presented high resistance to an insect complex (Stalker and Campbell, 1983) and immunity to groundnut rust (Subrahmanyam et al., 1985b).

Now called *A. triseminalis* (Krapovickas, 1990), this single recognized species of section Triseminalae was found to be more widely distributed. The known area of occurrence is no longer only the margins and adjacent floodplains of the São Francisco, as the species is found at slightly higher elevations along tributaries of the São Francisco in the states of Minas Gerais and Bahia (Map 2), from where additional germplasm accessions were obtained. As adequate machinery and techniques are developed for seed harvest of wild



Map 2. **Known geographic distribution of sections.**
CO = Colombia, VE = Venezuela, GU = Guyana, SU = Suriname, F.G. = French Guiana, BR = Brazil, AR = Argentina, UR = Uruguay, PA = Paraguay, CH = Chile, BO = Bolivia, PE = Peru.

Arachis species released as cultivars (Cook and Loch, 1993), it seems that other prolific species will attract more attention, especially those reasonably adapted to environments not suitable to the Caulorhizae, Rhizomatosae, and Procumbensae. *A. triseminalis* is clearly one such species.

Section Arachis

According to Singh and Singh (1992), *A. hypogaea* is grown in about 80 countries. World production is increasing and has reached 23 million tons (in the shell), according to FAO estimates. It is the most important oil seed in the developing world, and a valuable source of protein for human and animal nutrition. About 80% of the world production is from developing countries, and approximately 67% from the semi-arid tropics. According to Mangla (1992), two-thirds of the world production is crushed to extract edible oil. The residue, called groundnut oil cake, is used as animal and poultry feed, and ranks as a major export. This meal or cake, containing up to 45% crude protein, is considered one of the best protein sources for livestock feed (TAES/OAES, 1950).

Groundnut straw, a by-product of manual harvest and shelling, is well accepted by cattle, and traditionally used by smallholders to feed dairy cows in subtropical Brazil (Araújo, 1940). Also, the whole groundnut plant (including nuts), properly cured, produces a leafy, highly palatable hay, almost equal to good alfalfa for dairy and beef cattle. However, such use of an expensive crop tends to be restricted to lands where alfalfa grows poorly or not at all (TAES/ OAES, 1950).

The main economic constraints on the use of the entire crop as a forage are the annual life cycle, variable reseeding, poor competition with pasture grasses and weeds, and expensive seed (high amounts are required due to the large size of the seed) (Prine, 1964). In spite of these constraints, direct use of the groundnut for forage purposes is an established practice, especially on dairy farms in southern Brazil and Uruguay. It can be grown as a forage crop for 3 to 4 months and can thus occupy land that would otherwise remain bare fallow.

Selections of *A. hypogaea* for forage use are available in a few institutions. In addition, assorted germplasm accessions, although not specifically evaluated for forage purposes, have been originally collected for such use. Selections of leafier plant types, or of plants with a short cycle for use in rotation, may have their place in integrated agricultural systems.

At the same time, some annual wild species of section Arachis, that produce a reasonable amount of green foliage in a short time, could also be evaluated for use in short rotations, such as for hay production. They could even be used as associated pioneer crops in the establishment of slow-growing, but later more persistent, forage legumes, such as the stoloniferous or rhizomatous perennial species of *Arachis*. One such study was conducted by Beaty et al. (1968), who seeded *A. monticola* in established pastures of pensacola Bahiagrass and coastal Bermudagrass to determine the ability of the groundnut species to establish and persist in the dense sod. They found it persisted for at least 3 years, with perspectives of longer persistence on the basis of natural reseeding. Once again, these accessions will attract high interest only if improved machinery and technologies for seed harvest of wild *Arachis* are further developed.

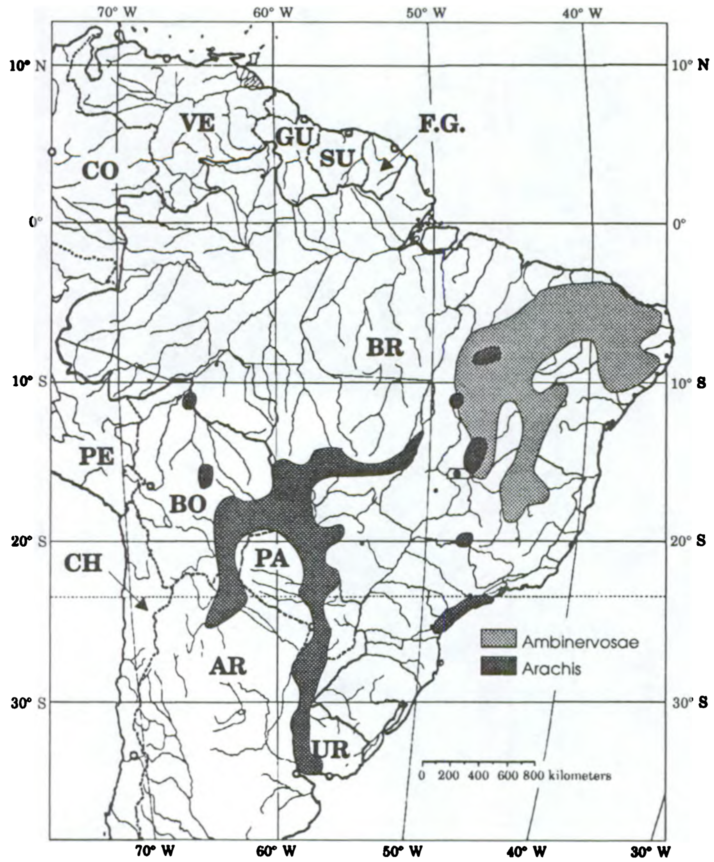
On the other hand, perennial species of section Arachis may be as promising as species of section Procumbensae, with which they share a similar growth habit, although they usually have more limited seed production (Lu et al., 1990).

Geographic knowledge on the section Arachis was strongly increased by recent germplasm collections. The eastern limits of almost continuous natural occurrence of the section now reach 47° W longitude, in a roughly vertical line, from 7° to 20° S latitude (Map 3). A short annual life cycle has allowed some species of this section to escape from the main continuous area centered in the Brazilian Pantanal, where the perennial species find a suitable environment. But the short life cycle also makes the location of natural populations in the field difficult (Valls, 1992).

Section Ambinervosae

Parallel to annual wild species of section Arachis, species of section Ambinervosae, such as *A. pusilla* and *A. sylvestris*, may produce a reasonable amount of green foliage in a short time. They could also be tried as alternatives for use in short rotations, or as associated pioneer crops in the establishment of slow-growing stoloniferous or rhizomatous perennial species of *Arachis*.

At first considered geographically isolated from section Arachis, and represented by a single species (Gregory et al., 1973, under Pseudaxonomorphae), section Ambinervosae, as now represented in gene banks, encompasses at least four species, with more than 100 accessions available, and partially overlaps with the area of section Arachis (Map 3). The highly variable *A. sylvestris* has been disregarded as a valid species in the literature for some 50 years, and was only known from three fragmentary herbarium specimens. In two rare references to the name, Hermann (1964) and Krapovickas and Rigoni (1957) independently included *A. sylvestris* in the synonomy of *A. hypogaea* and *A. pusilla*, respectively. *A. sylvestris* is now represented in



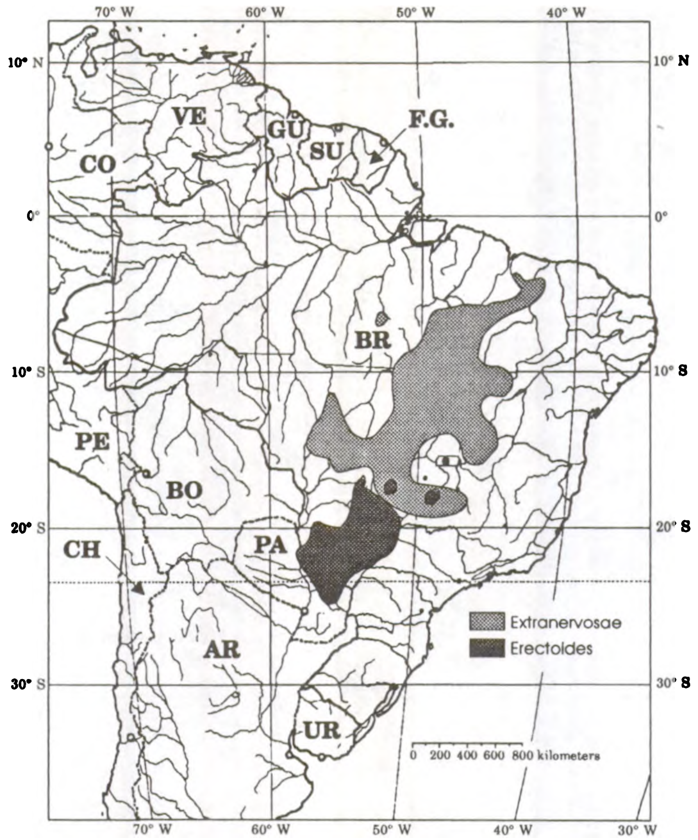
Map 3. **Known geographic distribution of sections.**
CO = Colombia, VE = Venezuela, GU = Guyana, SU = Suriname, F.G. = French Guiana, BR = Brazil, AR = Argentina, UR = Uruguay, PA = Paraguay, CH = Chile, BO = Bolivia, PE = Peru.

germplasm collections by more than 50 accessions, some recognized as resistant to *Didymella arachidicola* (Subrahmanyam et al., 1985a) and *Meloidogyne arenaria* (Nelson et al., 1989), and has the broadest natural area of occurrence of any species in the genus.

Accessions of section Ambinervosae tend to be prolific and easy to increase. Some species at first present a small number of normal, showy flowers, immediately followed by abundant flowers much reduced in size and difficult to see under the foliage, and possibly cleistogamous.

Section Erectoides

With a restricted distribution, the section is mostly concentrated in the Brazilian state of Mato Grosso do Sul, a few species reaching adjacent areas in the states of São Paulo and Minas Gerais, while others extend to eastern Paraguay (Map 4). Section Erectoides encompasses species with tuberous roots, erect growth habit, long horizontal pegs, and leaves with three or four leaflets, respectively, in the series Trifoliolatae or Tetrafoliolatae. Although able to produce tall plants, sometimes in large clumps, most of the Erectoides are slow growers, and do not likely resist grazing and trampling. Attention should remain focused on this group, however, due to its high resistance to diseases and insect pests (Subrahmanyam et al., 1985b; Stalker and Campbell, 1983), the great regenerative capacity of at least one of its species, *A. paraguariensis* (Still et al., 1987), and its confirmed crossability with species of the Caulorhizae, Rhizomatosae, and Procumbensae



Map 4. Known geographic distribution of sections.
CO = Colombia, VE = Venezuela, GU = Guyana, SU = Suriname, F.G. = French Guiana, BR = Brazil, AR = Argentina, UR = Uruguay, PA = Paraguay, CH = Chile, BO = Bolivia, PE = Peru.

(Gregory and Gregory, 1979), the three most important sections from the standpoint of forage production (Figure 1).

It is important to realize that successful hybridization of plants with desirable attributes from section Erectoides with any good forage species of the Caulorhizae or Rhizomatosae may reveal new plant types that, although sterile, may be quite adequate for vegetative propagation, if the stoloniferous or rhizomatous habit is inherited. As machinery and improved propagation methods for vegetative establishment of *Arachis* species have been developed for *A. glabrata* and *A. pintoi* (Adjei and Prine, 1976; Rincón C. et al., 1992), this may be another line for exploration and development of wild *Arachis* germplasm for forage purposes.

Section Extranervosae

This section is accepted as one of the most primitive in the genus (Gregory and Gregory, 1979; Jahnavi and Murti, 1985b; Stalker et al., 1989), having species highly adapted to harsh conditions, such as eroded soils, extremely low fertility, and long dry periods in the Brazilian Cerrados. For the most part, they are slow growers, with variable types of tuberous roots, long and horizontal pegs (*A. marginata*) or short and inclined pegs (*A. prostrata*), and leathery leaves.

Extranervosae species present interesting regenerative attributes, producing good results in tissue culture experiments (Pittman et al., 1983, 1984; Johnson and Pittman, 1986; Mansur and Lacorte, personal communication). The pegs of some species often produce adventitious roots able to form tubers. Although separated from the plants, as the pegs collapse after maturation of the fruits, such tubers can produce branches from apical buds, thus regenerating new plants. Like some species in the Ambinervosae, a few Extranervosae at first present a small number of normal, showy flowers, immediately followed by abundant small flowers, difficult to see and possibly cleistogamous.

There was a constant increase in the number of species and accessions of section Extranervosae as lower latitudes in central Brazil were explored (Map 4). Attributes for possible use in breeding, such as the ability to grow in shallow rocky soils (*A. prostrata*) or in dry, loose sand (*A. marginata*), and other adaptive features, are now available in more than 100 germplasm accessions. Maintenance of live plants and seed increase of this section *ex situ* are usually difficult, because of specific soil requirements for survival and seed production. Some species, like *A. marginata*, produce few fruits per year, even in their natural sites.

Distinct accessions of *A.villosulicarpa*, a cultigen only found in the Nambiquara and Minky Indian settlements in western Mato Grosso, Brazil, produce the largest plants in this section, with a high amount of foliage, both in open and shady conditions. They grow faster than their wild relatives, and could be evaluated for forage production.

Final Comments

In 1950, Ben Smith stated that "No plant of comparable interest to man has received less botanical attention in recent decades than the peanut, *Arachis hypogaea* L." He complained that "... *A. hypogaea* is not some obscure or exotic plant, little known and seldom seen, but one of the great economic plants, one of the staple crops of the tropical and subtropical world." He finally summarized that "...the long botanical history of *A. hypogaea* has been filled with error and controversy regarding the reproductive structures of this plant."

When Smith's statements were published, scientists such as V.A. Rigoni, A. Krapovickas, W.C. Gregory, and J. Pietrarelli were planting the seed in an intensive drive to collect and characterize *Arachis* germplasm, which provided the basic materials for most of the research now being conducted on several continents.

Forty-three years have passed, and the biological knowledge on the groundnut is now both broad and deep. Germplasm collection is intensive, and characterization of such germplasm is now more sophisticated. Groundnut breeding programs yield new cultivars for adoption all over the world, feeding more people and directing special attention to semi-arid environments. An important part of the activities and funds of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is, by mandate, related to groundnut research.

The search for genes for groundnut improvement has led to special priority for collection and conservation of germplasm, including the associated wild species. This effort revealed a wealth of valuable materials. Besides the two cultigens (*A. hypogaea* and *A. villosulicarpa*), four other species (*A. glabrata, A. repens, A. pintoi,* and *Arachis* sp.—the 'Pantanal' peanut) are now cultivated for distinct purposes. Others may follow, and better accessions may be found in those species already under cultivation. Breeding of such species may produce even more successful cultivars.

The positive impact of the adoption of new species and cultivars in different tropical environments shows the need for more investigation. Among the 80 species currently recognized in the genus, many of those with promise as forage crops and ground covers fulfill the need for species for soil improvement in sustainable agricultural systems.

Four of the cultivated species became commercial options less than 2 decades ago. One such species, collected by Geraldo Pinto 4 years after Smith's publication, is now being released in many countries, with great impact on forage quality and the improvement of environmental stability.

Collaborative research and the wise use of this natural resource show how science can help man to overcome ignorance in areas such as the ones Smith identified some 40 years ago. International cooperation has provided the basis for this drastic change, and it should be continued in the more specific aspects of investigation on *Arachis* as a forage and cover crop.

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Chapter 2

Collection of Wild *Arachis* Germplasm

J.F.M. Valls
E.A. Pizarro*

Abstract

The main difficulties for germplasm collection of wild *Arachis* arise from its underground seed formation, although many accessions with forage potential have been collected and exchanged as vegetative propagules. As propagation mechanisms in most species are inadequate for wide dispersal, populations may be dense, but not necessarily large, and minor visual obstacles may hide patches of *Arachis*. Priorities for collection have been periodically reviewed by groups of specialists from national and international institutions that also supported collection missions. Further evaluation of a broader array of wild *Arachis* germplasm for forage purposes may determine new taxonomic and geographical priorities for future collection.

Introduction

Plant collection to increase the availability of potentially useful germplasm depends on the wise interaction of the collector with the collecting environment. No matter how good the strategies, planning, timing, individual experience, team composition, available infrastructure, or sampling methods are, collectors will always face the need to make impromptu decisions while collecting germplasm. The history of collection of wild *Arachis* species with potential for forage production under cultivation has many examples of wise impromptu decisions.

The insight of agronomists such as W.A. Archer and A. Gehrt in 1936, J.R. Otero in 1941, G. Pinto in 1954, and A.E. Kretschmer and P. Rayman in 1976, in deciding to collect germplasm of *Arachis* species during field trips for generalized collection of forage plants, has provided farmers and smallholders worldwide with new agricultural options, such as *A. glabrata* PI 118457, from which cv. Florigraze was selected, *A. repens* and *A. pintoi*, and the 'Pantanal' peanut. Likewise, the commitment of a Brazilian technician (W.L. Werneck of CENARGEN/ EMBRAPA) has provided the scientific community with new accessions of *A. pintoi* (e.g., Werneck 34 and 47) that were located far away from the previous known area of occurrence. Such spontaneous activity has triggered an expanded program of *Arachis* germplasm collection that will certainly result in economic gain.

In this chapter, we point out some of the difficulties in the collection of *Arachis*.

Difficulties in the Collection of *Arachis* Germplasm

In any collecting mission, previous knowledge that a target species is in the area of search is important, but spotting it in an adequate condition is what really counts in effective germplasm collection. But wild *Arachis* germplasm poses a few additional and specific problems (Valls et al., n.d.), in

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* Curator of *Arachis* germplasm, Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia/ Empresa Brasileira de Pesquisa Agropecuária (CENARGEN/EMBRAPA), Brasília, Brazil; forage agronomist, Tropical Forages Program, CIAT, stationed in Brasília, Brazil, respectively.

comparison with the collection of other forage germplasm (Reid and Strickland, 1983). Most of the problems arise from the underground seed formation in *Arachis*, which causes problems when seed collection rather than vegetative material is the first priority.

Furthermore, fruit segments separate from the peg at maturity. In the cultivated groundnut, *Arachis hypogaea*, the pods remain attached to the mother plant by pegs, as those plants are removed from the soil at harvest. Maintenance of tight fruit attachment to the peg after maturation is an advanced character in the genus *Arachis*, obviously selected for in the process of domestication of the cultigen. In the wild species of *Arachis*, the basal and intercalary portions of the peg tend to collapse at maturity, so that, at seed maturity, the best time for germplasm collection, seeds of wild *Arachis* species are no longer attached to the plants, or break away easily if the soil is disturbed. The presence and amount of seed cannot be detected until the soil under plants is dug and sifted.

Seed set below ground also limits long-distance dispersal. The perimeter of an *Arachis* population may remain quite stable for decades. Dispersal in *Arachis* can only occur vegetatively through spread by rhizomes or stolons, or when seed is transported in eroded soil during heavy rains or floods. This may be just a few hundred meters over several years. Populations may be dense, but not necessarily large. Therefore, visual obstacles, such as sparse groups of trees, tall grass communities, variable vegetation types, and differences in soil levels may hide compact populations of wild *Arachis*. The monotony of disturbed roadsides, dominated by a small number of aggressive invaders, will frequently conceal the nearby occurrence of small patches of *Arachis*.

Seasonal variation and climatic instability may also work against collection efforts. Annual species may not germinate and grow every year in dry climates, and even perennials may not be obvious due to restricted growth.

Because of the improbability of a second visit to most sites of *Arachis* populations by the same collector, special abilities need to be developed to locate sparse and at times unobvious material. Collectors should also make themselves aware of all possible sources of information on the occurrence of *Arachis* species in the area of search.

Gathering accurate information from herbarium labels is a common practice among plant germplasm collectors, but such information is scarce for *Arachis* because of the low number of herbarium specimens.

Careful reading of previous reports, trips to the sites of previous collections, and a lot of walking are recommended procedures. Information from local people, who may associate the wild *Arachis* species with the cultigen, due to leaf and flower similarities, is extremely important when an expedition visits a new area. The knowledge of locally used vernacular names is also helpful. The recent discovery in April 1993 of the original site for *A. pintoi* in the municipality of Belmonte, Bahia, Brazil, was made possible by such local information.

A minor error was made in describing the location of the original *A. pintoi* population collected by Professor Geraldo Pinto in 1954 as "Rio Jequitinhonha, near the Atlantic coast in a sand bank between the mouth of the river and Belmonte City" (Gregory et al., 1973). An experienced team of *Arachis* collectors searched for this site in 1982 for almost a full day without avail, but later found several populations of *A. pintoi* some 400 km upriver, in the surroundings of Araçuaí, Minas Gerais. More than 40 stops along the Jequitinhonha River, between Belmonte and Araçuaí, did not produce a single *Arachis* population, leading the collectors to conclude that the presence of the species at the mouth of the river, almost 3 decades before, had been fortuitous, probably as a recent establishment of floating stolons transported downriver among tree trunks and other debris, periodically deposited by the Jequitinhonha in its floodplains. This hypothesis was reported (Valls, 1983), transcribed by subsequent authors (Cook et al., 1990), and again included in a review paper on the species (Valls, 1992).

When reviewing the 1992 paper, Professor Pinto stated that the information was incorrect for two reasons (G. Pinto, personal communication). First, he had collected *A. pintoi* in the municipality of Belmonte, but some 35 km upriver from the town of Belmonte, in the village of Boca do Córrego, only reachable by boat in 1954. Second, he had seen the same species in five additional places along the Jequitinhonha, between Belmonte and Araçuaí, on several trips. As Boca do Córrego is now reachable by road, another attempt was made to locate the original collection site in order to learn more about the genetic variability of the original population and obtain additional germplasm.

After one more frustrating search along the river edge, a local person, Raimundo Castro, said, "There is no use searching here. If you are looking for the 'amendoim brabo' (wild groundnut), you have to go 20 minutes upriver. I know it, and I live here for 57 years." He also said, "About 15 years ago, some visitors from Itabuna thought the plant looked very nice, and took it for gardening purposes." Itabuna is another city in Bahia, where a narrower leaflet form of *A. pintoi* had been observed in lawns and collected by the team, as a cultivated accession of unknown origin. The man could be right!

The team rented a boat, and, after 25 minutes, and already late in the day, there they were: Castro on his horse, with a glorious smile on his face, and a huge patch of *A. pintoi*, possibly the most variable population of the species ever seen, showing differences in plant types, leaflet shapes and sizes, densities and patterns of distribution of the long glandular hairs on the vegetative structures, and disease symptoms. The randomized collection of seeds and cuttings from the population will probably reveal greater genetic variability than that presently observed in the several progenies of materials obtained by different collectors 20 years ago from the plot maintained by G. Pinto in Cruz das Almas.

Collecting the Germplasm

Once a wild *Arachis* population is located in the field, the normal procedure is the collection of seed, preparation of herbarium specimens, collection of *Rhizobium* nodules, and an accurate description of the site and plant characteristics. Precise notes in field books and herbarium labels are necessary for subsequent collection. Latitude, longitude, and precise distance, preferably from stable geographical markers, are of great importance for eventual relocation. The use of satellite-based navigators to directly locate sites (Prendergast, 1993) helps to overcome previous limitations as to location.

Digging out entire plants (which are also adequate for herbarium and nodule collection) and sifting the soil underneath with large sieves is the most efficient way to harvest seeds of wild *Arachis* species, and it facilitates the collection of soil samples. Digging and sifting along transects across populations should help to sample the population variability.

Collection of live plants is frequently the only way to obtain germplasm of a given population, when seeds are not produced or are not available. Rhizomatous and stoloniferous plants, such as *A. glabrata, A. pintoi*, or *A. repens*, are easy to transplant. Clean cuttings wrapped in newspaper and put into plastic bags without additional water will survive for many days, especially when kept cool. In this way, initial multiplication steps can be saved, and field plots can be established quickly. Cuttings randomly collected from the whole population may also provide a good sample of the original genetic variability. For perennial species without rhizomes or stolons, direct transplanting into pots is advisable.

As seeds of wild *Arachis* are usually loose in the soil at maturity, it is difficult to be certain of the "mother" plant. Seeds may even come from other species occurring in the same area. Another restriction to the use of preestablished sampling techniques for wild *Arachis* species is that there has been little investigation on the pollination mechanisms. Wild species are generally accepted as autogamous, mostly by analogy to the cultivated *A. hypogaea*, but differences in stigma morphology and pollination behavior have been noted for both annual and perennial species (Banks, 1990; Lu et al., 1990).

Research Subsequent to Collection

An understanding of the genetic variability in a single accession and within the total germplasm available may be obtained concurrently with characterization. A knowledge of genetic variability not only influences decisions in breeding, but also allows for the identification of geographical areas of high variability where additional collection work may need to be done.

Intensive efforts to characterize and evaluate wild *Arachis* germplasm are under way in many countries and institutions, but only a few are related to assessing the potential for forage use (Cook et al., 1990; Grof, 1985; Kretschmer and Wilson, 1988; Pizarro et al., 1993; Prine, 1964).

Many scientists directly involved in the characterization and evaluation of wild *Arachis* have had an opportunity to participate in collecting missions (Table 1). Decisions on priority areas and priority species for subsequent collection have been reached in the last decade by international groups of specialists who have access to up-to-date information on characterization and evaluation, and who base their decisions on such knowledge (Valls et al., 1985; Simpson, 1990). Similar collaboration helped to develop a list of preliminary descriptors for wild *Arachis* germplasm (IBPGR-ICRISAT, 1990). Identifying additional descriptors to assess forage value would be desirable.

International cooperation has been essential for the gathering of most accessions of *Arachis* presently available in worldwide collections. Field activities have been partially supported by the International Board for Plant Genetic Resources (IBPGR), the United States Department of Agriculture (USDA), the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), and other local institutions. The International Center for Tropical Agriculture (CIAT) has supported the latest collections, which focused on *A. pintoi* and *A. repens* germplasm.

Historical Background of Forage *Arachis* Germplasm Collection

Three distinct phases can be defined for the acquisition of *Arachis* germplasm for forage production.

Early collections (1933-1948)

The earliest collections were carried out by W. Archer (Bureau of Plant Industries, USA), with support from A. Gehrt (Instituto Botânico de São Paulo, Brazil), during 1936-1937; by J.R. Otero, a Brazilian agrostologist, in 1933, 1939, and 1941; and by J.L. Stephens (Bureau of Plant Industries, USA) and W. Hartley (Australian Council for Scientific and Industrial Research), during 1947-1948. Archer, Stephens, and Hartley covered parts of Argentina, Paraguay, Uruguay, and Mato Grosso (including today's Mato Grosso do Sul), in Brazil. Their samples were sent to the USDA. Only a few of these are still available, but their voucher herbarium specimens, mentioned in botanical monographs (Hermann, 1964; Hoehne, 1940), provided excellent geographical information for new collections in the second phase of acquisition.

The chief objective of Archer's South American trip was to obtain as

Table 1. Expeditions for collection of wild *Arachis* germplasm in South America, 1981-1993, including number of accessions collected in each country and sections of species collected in each expedition.

Year	Collectors[a]	Countries[b]					Sections[c]							
		Arg	Bol	Bra	Pry	Ury	AM	AR	CA	ER	EX	PR	RH	TR
1981	V,W			6					+		+		+	
	V,Ve,Sv			7			+				+			+
	V,S,Gr		1	40				+			+	+	+	
1982	V,K,R,Sv			38			+	+			+			
	Sc,Vn	10					+							
	V,S,W			17			+		+		+			+
1983	V,K,Ve,Sv			27			+	+			+			+
	K,S,Sc	5	2					+						
	V,S,M,Ge,Sv			18				+					+	
1984	V,R,Ge,Sv			76				+		+		+	+	
	V,S,St,Gd,W			25				+			+		+	
1985	Mt					6		+						
	V,Ve,Sv			45			+	+			+			
	V,K,S,Sv			26				+			+	+	+	
	V,Po,Bi			27				+		+	+	+	+	
1986	V,S,W			14	1			+		+	+	+	+	
	V,Po,J,Sv			11				+		+		+		
1987	V,R,Sv			35			+				+			
	Ve,Sv			5						+			+	
1988	V,Q,Fd,Sv			11						+			+	
	Wi		4					+						
1990	Wi	5	4					+						
	V,Ga,Ro,Sv			9				+			+			
1991	V,Pm,Sv			22			+	+			+			
	V,Fa,Pz,Sv			13			+		+					+
1992	V,Pz,Va,W			29			+		+		+			
	V,S,Pm,Wi,Sv, Ve,Pz,Rs			17			+	+	+		+		+	
1993	W,Ws,Pn			28			+	+	+		+			+
	V,Pz,Bm,Va,Db			10				+	+					
Total:		20	11	556	1	6								

a. Bi = Bianchetti; Bm = Maass; Db = Bechara; Fa = Faraco; Fd = França-Dantas; Ga = Galgaro; Gd = Godoy; Ge = Gerin; Gr = Gripp; J = Jank; K = Krapovickas; M = Moss; Mt = Millot; Pm = Pittman; Pn = Pinheiro; Po = Pott; Pz = Pizarro; Q = Quarin; R = Rao; Ro = Rocha; Rs = Santos; S = Simpson; Sc = Schinini; St = Stalker; Sv = G. Silva; V = Valls; Va = Valente; Ve = Veiga; Vn = Vanni; W = Werneck; Wi = Williams; Ws = W. Silva.

b. Arg = Argentina; Bol = Bolivia; Bra = Brazil; Pry = Paraguay; Ury = Uruguay.

c. AM = Ambinervosae; AR = Arachis; CA = Caulorhizae; ER = Erectoides; EX = Extranervosae; PR = Procumbensae; RH = Rhizomatosae; TR = Triseminalae.

many materials as possible of the wild *Arachis* species, and the cultivated peanut (USDA, 1941). His collection of *A. glabrata* 3992 received the number PI 118457 and was later called 'Arb', as a cultivar. This accession has been widely distributed and is available in many germplasm banks. Cultivar 'Florigraze' probably descends from a seedling produced by 'Arb' at the edge of a plot in Gainesville, Florida, and was initially known as GS-1 (Gainesville Selection-1) (Prine et al., 1981).

Stephens and Hartley made more extensive collections of forage grasses and legumes, and also acquired *Arachis* germplasm from experimental stations. Otero, a Brazilian, visited many states in Brazil during several trips, and collected important native forage grasses and legumes (Otero, 1941). Most of his collections of *Arachis* came from today's Mato Grosso do Sul, and were maintained in plots at the Deodoro Experimental Station, near Rio de Janeiro. Some of his plots were sampled by Stephens and Hartley, so that germplasm he collected was soon duplicated in the United States. One of Otero's most outstanding collections was made in the state of Minas Gerais, along the river Jequitaí, a tributary of the São Francisco (not of the Jequitinhonha, as stated by Gregory et al., 1973). This is the type collection of *A. repens*, Otero 2999, taken to the United States by Stephens and Hartley, in 1948, under their collection number 277, which received the number PI 162801. This accession soon became widespread in Brazil, especially in experimental stations and as a lawn plant, and was reintroduced many times to the USA.

Collections from 1948 to 1980

The second phase of acquisition of forage *Arachis* germplasm was marked by the continuous participation of Professor A. Krapovickas (Instituto de Botánica del Nordeste—IBONE—Corrientes, Argentina). In this phase, he either collected by himself or with associates, especially with Dr. W.C. Gregory (North Carolina State University, Raleigh, USA) and J. Pietrarelli (Instituto Nacional de Tecnología Agropecuaria—INTA—Manfredi, Argentina), from 1959 to 1980 (Gregory et al., 1973; Simpson, 1984; Valls et al., 1985). In 1968, he accompanied the USDA collectors R. Hammons and W.R. Langford in their South American trip to acquire available *Arachis* germplasm and to collect in new areas. Accessions identified under HLKHe 552 to 577, GKP 9553 to 10139, and GK 10550 to 10596 encompass the main germplasm available of typical *A. glabrata* and related forms of the section Rhizomatosae. Most of them come from west central Brazil and Paraguay.

In 1961, Gregory, Krapovickas, and Pietrarelli obtained, at the Experimental Station of Sete Lagoas, Minas Gerais, an accession of *A. repens*, GKP 10538, said to have come from the Engenheiro Dolabela Railroad Station, by the river Jequitaí, the same site as Otero's type collection. Although the collection of this accession in nature was attributed to Thomas Dalton (Gregory et al., 1973), it is not clear whether it represents a genotype distinct from Otero's original accession. *A. repens* is vegetatively propagated. A few seeds were observed in one wild population, but never in lawns where *A. repens* is commonly used. This lawn material is probably derived from one or a few initial accessions from Engenheiro Dolabela. The accession GKP 10538 is maintained in many germplasm banks, and literature references to the species are usually associated with this specific accession.

In 1967, Krapovickas and Gregory visited Cruz das Almas, in the state of Bahia, taking germplasm from G. Pinto's new species of section Caulorhizae found in 1954. It was assigned the number GK 12787, and informally named *A. pintoi* (Gregory et al., 1973), after the collector. Later, Gregory provided seeds to the USDA, where the number PI 338447 was attached. In 1968, Hammons and Langford took plants of the same accession as seeds and cuttings from Krapovickas plantings in Corrientes, as HL 323 and 329, respectively, which received the numbers PI 338314 and 337361. Further distribution, especially of number PI 338314, has made *A. pintoi* now available to many institutions (see Figure 1, Valls et al., Chapter 3, this volume). Two visiting Australian collectors also obtained germplasm directly from G. Pinto, in Cruz das Almas, in 1972 (G. Pinto, personal communication), but the whereabouts of their samples are not known. Pinto's plot in Cruz das Almas was abandoned in the late 1970s, and not even volunteer plants could be located in the highly disturbed site during a recent inspection.

During this second phase, in 1976, a collection of a new accession of an unknown species in Miranda, Mato Grosso do Sul, by A.E. Kretschmer (USA) and P. Rayman (Rayman Seeds, Brazil), gave rise to the release of the 'Pantanal' peanut (Kretschmer and Wilson, 1988).

Recent collections (1981-1993)

The third phase, from 1981 to 1993, has been a period of intensive collection, especially in Brazil (Rao and Valls, 1987; Simpson, 1984, 1990; Valls, 1983; Valls et al., 1985, n.d.). In this phase, 32 scientists or well-trained technicians have directly participated in field missions, representing 14 institutions of six countries and collecting accessions from all eight taxonomic sections of the genus (Krapovickas, 1990; Table l). This new effort relied on the strong support and participation by Krapovickas and C.E. Simpson, who had accompanied and later replaced Gregory in the latest expeditions of the second phase of collection. This support was important in ensuring consistency in methodological procedures, and in providing information on taxonomic concepts and geographical gaps.

The main outcome of the third phase, in relation to *Arachis* species with forage potential, has been:

1. The collection of some 50 additional accessions of *A. glabrata*, within the same geographical region, but covering previously uncollected areas of the tetraploid Rhizomatosae (see Map 1, Valls and Simpson, Chapter 1, this volume).
2. An increase in the number of accessions of species of sections Procumbensae and Triseminalae, with an expansion of their known area of occurrence. Collections of Procumbensae from the southern limits of the Gran Pantanal, from Corumbá to Miranda, in Mato Grosso do Sul (the same general area as Kretschmer's collection) appear to have high forage quality (Map 2, Valls and Simpson, Chapter 1, this volume).
3. A large increase in the number of accessions of species of section Caulorhizae, including more than 70 accessions of variable morphology, that, to the best of our knowledge, are best identified as *A. pintoi* (Map 1, Valls and Simpson, Chapter 1, this volume).
4. A greater availability of germplasm of species of all other sections, some of which may have forage potential in distinct farming systems.

This third phase has resulted in an additional 604 accessions of wild *Arachis* species. In Brazil alone, 566 accessions of some 60 Brazilian species have been collected in this phase, and two-thirds of them are naturally restricted to that country. Some 50 Brazilian accessions of variable origin, collected sporadically in expeditions having other objectives than acquisition of *Arachis*, can be added to the above total. Also, some additional accessions have been collected in Bolivia and Uruguay. But gaps still exist. For example, three species collected previously in Brazil only for herbariums have not been relocated. New expeditions will be conducted in Brazil, and parallel efforts are expected to be undertaken in neighboring countries, especially Bolivia. Although the basic reason for the strong international support for current collection efforts is the continued search for important genes for the breeding of *A. hypogaea*, ways to increase the availability of germplasm of species with potential for the establishment of improved pastures will also be kept in mind. In this context, further search for and collection of sections Rhizomatosae and Procumbensae in Paraguay is an important recommendation.

Priorities for Continuing Collection

As *A. pintoi* is likely to be released as a cultivar in Brazil soon, its adoption and dispersal will affect areas of natural occurrence of the species. In a few years, it will be difficult to determine whether occurrence at a site is natural or due to nearby cultivation and secondary spread, especially downriver. The need for an accurate study of the genetic variability in this valuable species over its entire natural area requires intensified collection, covering new sites within the known distribution of *A. pintoi* (Map 1, Valls and Simpson, Chapter 1, this volume). This will take at least 2 years.

As most of the available accessions of *A. glabrata* were collected along or close to the few passable roads existing before 1970, further collection is highly recommended to better represent the region of occurrence. New collections in Paraguay and in Mato Grosso do Sul, south of the Pantanal, are likely to provide interesting new plant types. However, more emphasis should also be given to the agronomic evaluation of the new germplasm along with older accessions that have never been evaluated in South America.

Concerning the several new species of section Procumbensae, the two main areas of occurrence, north of the Pantanal, in Mato Grosso, extending to the west to Bolivia, and south of the Pantanal, in Mato Grosso do Sul, extending southward to Paraguay, should produce great variability. Forage quality seems to be higher in the southern area, with plants usually showing much tender foliage.

More specifically for drier areas, the germplasm presently available of the only species of section Triseminalae represents the expanded area of occurrence and needs to be evaluated. Wide gaps exist between collection sites, and further collection work is recommended. It would be advisable to search for additional germplasm of sections Caulorhizae, Rhizomatosae, and Procumbensae in marginal parts of their natural areas of occurrence with a lower average rainfall, ranging from 700 to 1000 mm, in the Caatinga, Cerrado, and Chaco.

Further evaluation of a broader array of germplasm, also encompassing annual species, for forage uses such as hay or silage, in distinct farming systems, may suggest additional taxonomic and geographical priorities for future collections.

Wild *Arachis* species are autochthonous to five countries only, but the administrative procedures for local support, legal requirements for collection, and technical support are different in each. Planning for plant exploration expeditions must begin months or even years in advance of the actual trips (Simpson, 1984). Expeditions should include the participation, and eventually the leadership, of national scientists, who remain in the area and can be involved in subsequent collection work.

Future involvement of more people, as well as an emphasis on training and maintenance, and institutional and personal collaboration are key requirements for the profitable continuation of germplasm collection of wild *Arachis*.

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Chapter 3

Genetic Resources of Wild *Arachis* and Genetic Diversity

J.F.M. Valls
B.L. Maass
C.R. Lopes*

Abstract

Genetic resources conserved of wild *Arachis* species doubled in the past decade. The species most represented in the world collection is *A. glabrata*, followed by *A. pintoi*. The largest collections are held at the Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia/Empresa Brasileira de Pesquisa Agropecuária (CENARGEN/EMBRAPA), Brazil, and the Texas Agricultural Experiment Station of Texas A&M University, USA. Although the number of available accessions increased significantly, germplasm flow of new material is relatively slow. The main reasons for this are little or no seed production and slow quarantine procedures.

The few studies of genetic diversity emphasizing wild species with forage potential, such as *A. glabrata*, *A. pintoi*, and *A. sylvestris*, showed a high degree of intraspecific variation. Methods that provide satisfactory results include morphological descriptors, isozyme patterns obtained by electrophoresis, and molecular markers.

Introduction

Among the international initiatives focused on genetic resources of the 1980s, the existing genetic resources of legume genera with forage potential, such as *Stylosanthes* and *Centrosema*, were appraised in two workshops (Stace and Edye, 1984; Schultze-Kraft and Clements, 1990). Wild *Arachis* species, however, were looked at mainly in the context of wild relatives of the cultivated groundnut (*A. hypogaea*). This genus was not even mentioned when the International Board for Plant Genetic Resources (IBPGR) prepared its global plan of action for forage genetic resources (Davies, 1984). The revision of existing genetic resources of wild species of *Arachis* (Valls et al., 1985) was thus carried out in the light of a genetic resource for the improvement of *A. hypogaea*.

Some forage researchers, however, have included wild *Arachis* species in their search for better legumes for pasture improvement or for ground cover in the tropics and subtropics since the early 1960s (Table 1) and have identified their potential. Therefore, in the past 2 decades, collecting and preserving wild *Arachis* germplasm has focused on broadening the genetic base of species with forage potential, such as *A. glabrata* and *A. pintoi* (Valls and Pizarro, Chapter 2, this volume). Because of these efforts, the amount of germplasm conserved doubled from 484 accessions of wild *Arachis* species in 1983 (Valls et al., 1985) to over 1000 accessions conserved in 1993 (Table 2).

Agronomic research on forage *Arachis* was also intensified, although few researchers included new germplasm in their evaluation programs (e.g., Pizarro et al., 1993; Quesenberry et al., 1993). Though research concentrates predominantly on two species, *A. glabrata* and *A. pintoi*, a wealth of other, often undescribed species is still awaiting discovery of

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* Curator of *Arachis* germplasm, Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia/ Empresa Brasileira de Pesquisa Agropecuária (CENARGEN/EMBRAPA), Brasília, Brazil; genetic resources specialist, Tropical Forages Program, CIAT, Cali, Colombia; molecular geneticist, head of Department of Genetics, Universidade Estadual Paulista (UNESP), Botucatu, Brazil, respectively.

Table 1. Species in the genus *Arachis* being used for forage or ground cover.

Species of *Arachis* (section)[a] Accession no.	Geographic region of study	Cultivars named (year of release)	Reference
A. glabrata (RH)			
PI 118457	Florida, USA	Arb	Prine, 1964, 1972
PI 262839		Arblick	Prine et al., 1981
GS-1		Florigraze (1978)	Prine and French, 1993
PI 262817		Arbrook (1986)	
A. monticola (AR)			
PI 263393[b]	Georgia, USA	-	Beaty et al., 1968
A. repens (CA)			
GKP 10578	Tropical Africa	-	Akobundu and Okigbo, 1984
A. pintoi (CA)			
CPI 58113[c]	Tropical Australia	Amarillo (1989)	Cook et al., 1990
CIAT 17434[c]	Colombia	Maní Forrajero Perenne (1992)	Grof, 1985 Rincón et al., 1992
	Honduras	Pico Bonito (1993)	Sec. Rec. Nat., 1993
Arachis sp. (PR)			
PI 446898	Florida, USA	'Pantanal'	Kretschmer and Wilson, 1988

a. AR = Arachis; CA = Caulorhizae; PR = Procumbensae; RH = Rhizomatosae.

b. = PI 219824.

c. Developed from PI 338314 (= GK 12787).

Table 2. Genetic resources of forage *Arachis* conserved at the main centers of conservation, as of May 1993 (sections in order of importance as a potential forage crop).

Section/	Accessions conserved[a]										
Species	CENARGEN	IAC[b]	INTA/ UNNA[b]	CIAT	TAES[b]	USDA[b]	NCSU[b]	U.Fla.[b]	ICRISAT	CSIRO	Total[b]
Caulorhizae											
A. pintoi	77	2	-	27	40	10	1	1	2	1	80
A. repens	16	1	-	5	3	1	1	-	2	2	16
Rhizomatosae											
A. glabrata	51	22	-	15	200	50	20	110	45	10	320
other spp.	19	-	-	-	6	6	3	-	1	21	19
Procumbensae											
Arachis. sp. 'Pantanal'	1	-	1	1	1	1	1	1	1	1	1
other spp.	29	7	10	-	40	15	8	-	-	9	45
Triseminalae											
A. triseminalis	8	1	2	-	6	2	2	-	-	1	12
Arachis (wild)											
Arachis spp.	138	44	50	1	150	70	80	-	165	18	200
Ambinervosae											
Arachis spp.	110	17	10	-	90	40	12	-	15	2	130
Erectoides											
Arachis spp.	71	20	10	-	50	15	20	-	12	9	71
Extranervosae											
Arachis spp.	134	9	5	-	50	20	15	-	2	1	135
Not identified	-	-	-	1	-	-	-	-	41	3	—[c]
Total	654	123	88	50	636	230	163	112	286	78	1029

a. CENARGEN = Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia, Brazil; IAC = Instituto Agronômico de Campinas, Brazil; INTA = Instituto Nacional de Tecnología Agropecuaria, Argentina; UNNA = Universidad Nacional del Nordeste, Argentina; TAES = Texas Agricultural Experiment Station, USA; USDA = United States Department of Agriculture; NCSU = North Carolina State University, USA; ICRISAT = International Crops Research Institute for the Semi-Arid Tropics; CSIRO = Commonwealth Scientific and Industrial Research Organisation, Australia; U.Fla. = University of Florida, Gainesville, FL, USA.

b. Estimated numbers of different accessions.

c. Probably included in other sections of total.

their potential utilization as forage. The purpose of this chapter is (1) to review the existing genetic resources of wild *Arachis* species, (2) to focus on germplasm utilization, and (3) to describe the genetic diversity encountered in wild *Arachis* species with forage potential.

Genetic Resources

Conservation

Numbers for *A. hypogaea* vary from zero in several collections to more than 10,000 at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), including many germplasm collections originally used for forage purposes. In wild *Arachis*, the largest collection of a single species is that of *A. glabrata*, followed by *A. pintoi* (Table 2). Other sections, such as Arachis, Ambinervosae, and Extranervosae, also contain considerable numbers of accessions (sections according to Krapovickas, 1990). The large increase in accessions in the sections Caulorhizae (>550%), Procumbensae (>350%), and Rhizomatosae (>250%), compared with the status of collections in 1983 (Valls et al., 1985), reflects the intensive search to broaden the genetic base of potential forage species (Valls and Pizarro, Chapter 2, this volume).

With more than 600 accessions each, the largest germplasm collections of wild *Arachis* species are held at CENARGEN/EMBRAPA, Brazil, and the Texas Agricultural Experiment Station (TAES) of Texas A&M University, Stephenville, Texas, USA (Table 2). The latter helps substantially to increase the accessions introduced into the United States Department of Agriculture (USDA) collection at Griffin, Georgia, USA. Other significant collections are maintained at ICRISAT, India, and North Carolina State University (NCSU), Raleigh, North Carolina, USA, in order of collection size. A large part of the collected material is conserved. Particularly, collections acquired prior to 1976 have been maintained and duplicated in several institutions. Some portion of the overall collection is duplicated in a few institutions, according to the use of the species.

Historically, collections at TAES, USDA, NCSU, and ICRISAT were intended to provide wild relatives for groundnut breeding programs. Those in Australia, the University of Florida (Fort Pierce and Gainesville), and CIAT were assembled for forage use. The large collection at CENARGEN and those at the Instituto Agronômico de Campinas (IAC) and in Argentina served conservation and characterization purposes. All activities related to germplasm maintenance in Brazil do not depend only on CENARGEN, but also involve other EMBRAPA centers (such as the Centro de Pesquisa Agropecuária dos Cerrados—CPAC).

Most institutions maintain plants in the field or in glasshouse collections that are complemented by seed conservation. Conditions for plant maintenance were described by Valls et al. (1985). Seed conservation in cold rooms is not always satisfactory because after some storage time, seeds may show dormancy or may lose their viability. Research on seed physiology to improve long-term storage of wild *Arachis* is urgently needed (Ferguson, Chapter 11, this volume).

Documentation

Origin of accessions. Documentation of the origins of accessions is an important part of germplasm management. The so-called passport data are maintained in computerized databases at all major institutions. The documentation of "old" germplasm accessions, however, is often erratic and information on the history and origin may be lost. Germplasm collected from 1976 to 1983 was documented in a catalog by Simpson and Higgins (1984). The passport information on more recently collected germplasm, in particular that collected in Brazil, is well documented in CENARGEN's *Arachis* database. A world catalog of wild *Arachis* germplasm would be a useful tool to make this information available to researchers.

Identification of accessions. Material may be identified by institutions and by collectors. There are institutional numbers of national character, such as BRA, CPI, and PI (Annex 1). Other institutional numbers are of local character, such as CIAT, CPAC, ICG, IRFL, and IRI, and assist internal control. Many accessions are also identified by the collectors' abbreviations, with letters such as G, K, P, S, V standing out (Annex 2). As collection of wild *Arachis* species has been an example of true international collaboration, most accessions are identified in the most important collections by the abbreviations of participating collectors.

The same accession has often received a number from each institution in which it is held. This is probably illustrated best by the first accession of *Arachis pintoi* collected by Geraldo Pinto in 1954. From the plot he planted at the Instituto de Pesquisa Agronômica de Leste (IPEAL) in Cruz das Almas, Bahia, several researchers received material to be incorporated into germplasm banks (Valls, 1992). The accession was thus registered under many different numbers, such as GK 12787, PI 337361, PI 338314, PI 338447, CPI 58113, CIAT 17434, IRI 2270, IRFL 4222, and I 44457 (Figure 1). Several of these denominations were ephemeral. To avoid unwanted duplication of

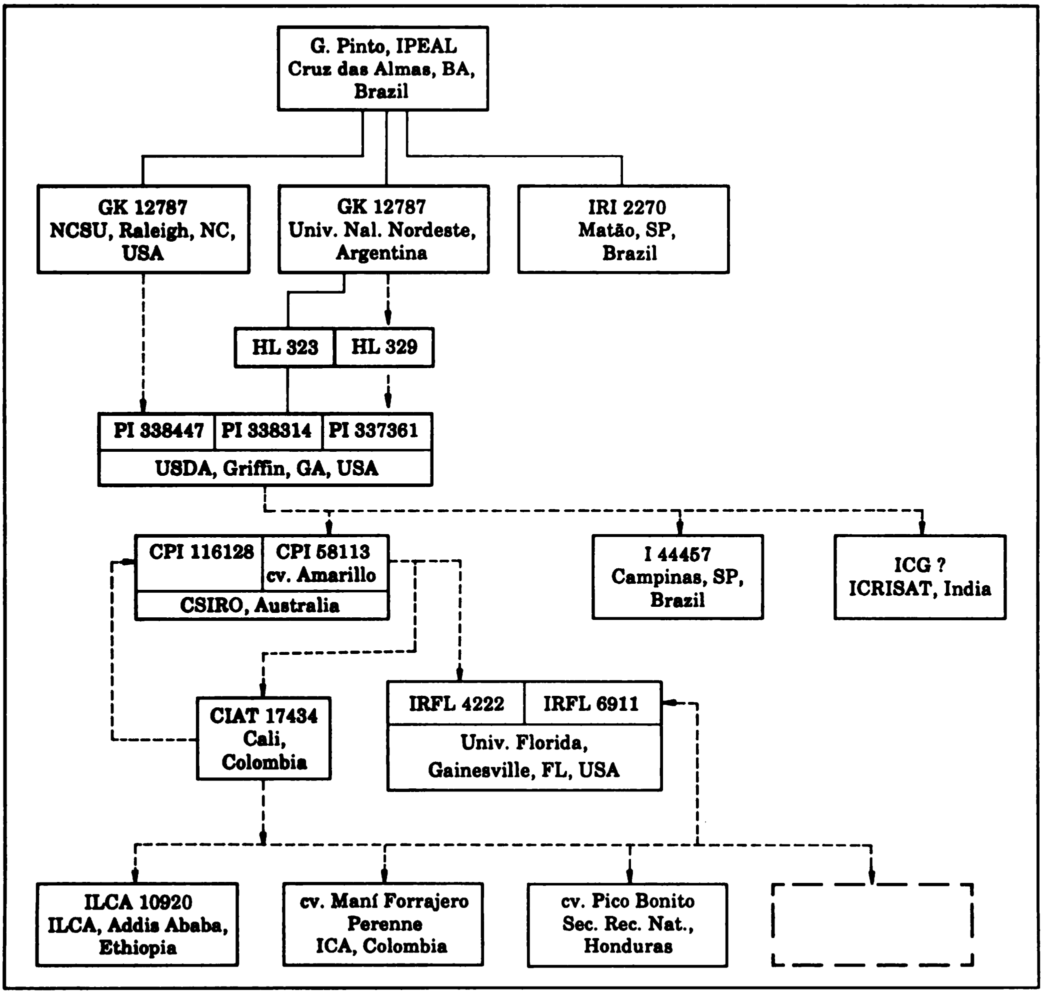

Figure 1. Multiple numbering and naming of one accession of *Arachis pintoi* (germplasm flow by seed ---→; by vegetative material ——).

accessions, the collector's abbreviation and number should always be stated when germplasm is moved between institutions.

Incorrect naming may occur when an accession is identified with a released cultivar, where this particular material was not part of the basic population or its descendants—as cultivars are defined. For example, CIAT 17434 should not be identified with cv. Amarillo because the CIAT accession is not from the basic population from which the cultivar was derived, or is just a progeny of that cultivar.

In the present situation of unclear taxonomic nomenclature, forage *Arachis* researchers tend to not be much concerned with identifying the species, but rather the particular accession they are working with. For example, the same accession of *A. glabrata* may be referred to in different publications as "*A. hagenbeckii*" and "*Arachis* sp. section Rhizomatosae."

Distribution

Germplasm accessions collected prior to 1976 have been distributed widely. From 1980 to 1992, CIAT's Genetic Resources Unit distributed 17 samples of *A. pintoi* accession CIAT 17434 to 14 countries in tropical America, Asia, Africa, and Europe, and only in 1990 began to distribute other accessions of *A. pintoi* collected in the early 1980s. "New" accessions of *A. pintoi* were introduced to CIAT from CENARGEN in late 1992 and still require initial increase before they will be available for distribution. ICRISAT supplied samples of 648 accessions of wild *Arachis* species to 52 users in different countries, after 1988 (M.H. Mengesha, personal communication).

Introduction of *Arachis* germplasm is usually a slow process because many accessions or species produce little seed, particularly under glasshouse conditions (Cook et al., Chapter 14, this volume). Thus, postentry quarantine and phytosanitary observations may delay the introduction process. Safe international shipments, however, are of high priority, and alternative methods of germplasm movement should be explored. For example, tissue culture may be used to handle and clean up material. Protocols are in place for several species of the genus *Arachis* (Valls and Simpson, Chapter 1, this volume; Simpson et al., Chapter 4, this volume).

Germplasm Utilization of Species with Forage Potential

Species of known value

Germplasm acquired prior to 1976 was the common base from which most characterization data were obtained. Evidence of the potential of the main species was often obtained from the first available accession of each. Thus, the first accession of *A. repens* Handro (GKP 10578) collected by Otero at Jequitaí, Minas Gerais, in 1941 has shown great potential as a ground cover, green manure, or ornamental plant. The first accession of *A. pintoi* (GK 12787) collected by Pinto at Boca do Córrego, Bahia, in 1954 (G.C. Pinto, personal communication, 1993), is now an international success as a forage and cover crop. Cultivar Florigraze originated from a seedling germinated next to a plot of *A. glabrata* (PI 118457), this one collected by Archer and Gehrt at Campo Grande, Mato Grosso do Sul, in 1936 (Prine, 1964; Prine et al., 1981). The 'Pantanal' peanut resulted from the direct adoption of a new germplasm accession, the first available in this species, collected by Kretschmer and Rayman in the lower Pantanal area of Mato Grosso, Brazil, in 1976 (Kretschmer and Wilson, 1988).

Data on the characterization and agronomic performance of *A. pintoi* and *A. glabrata*, respectively, are now being generated, in Florida, USA (Quesenberry et al., 1993), and from a nursery established at CPAC/EMBRAPA of recently collected material in Brazil (Pizarro et al., 1993). Given the strong increase in the available germplasm base, it is obvious that the genetic potential of recognized forage species is not known at this stage. There is a risk that researchers will continue to use the most popular accessions because of availability of seed or vegetative propagules for *A. glabrata* and *A. repens* and convenience, as has happened with practically all tropical forage legumes. Other species, such as the 'Pantanal' peanut, do not yet have sufficient germplasm available to begin studies of intraspecific variability.

Agronomically "new" species

Besides the two species, *A. glabrata* and *A. pintoi*, on which forage research has predominantly concentrated, a wealth of other, often undescribed species is still awaiting discovery of their potential, as comprehensively described by Valls and Simpson (Chapter 1, this volume). Research should include direct use of these species of mostly unknown agronomic value, and their use in interspecific breeding programs.

"New" species with the highest potential for agronomic use will probably be found in the section Procumbensae because of their high biomass production, general vigor, seed production potential, and their crossability with species of the sections Caulorhizae and Rhizomatosae (Gregory and Gregory, 1979). The germplasm base available of section Procumbensae, however, is still small (Table 2). Another promising section is Triseminalae because it contains perennial germplasm adapted to dry climates and hard, structured soils. As stated by Valls and Simpson (Chapter 1, this volume), the germplasm of this section needs to be increased. Species of little promise as forage plants may provide important genes for improving established forage species, especially when pests and diseases may become a problem in the future.

Genetic Diversity

Within the genus, most studies on genetic diversity were carried out on *A. hypogaea* and related wild species in the section Arachis. This research, including studies on morphology, phenology, agronomy, cytogenetics, reproductive biology, seed proteins, isozymes, and DNA, indicated that improved peanut cultivars and landraces represent an extremely narrow germplasm base with little genetic variation. Wild species, however, exhibit both genetic variation detectable by molecular analysis and a large amount of morphological and physiological variation (Halward et al., 1991; Kochert et al., 1991; Lu and Pickersgill, 1993; Paik-Ro et al., 1992; Stalker, 1990). The few studies on genetic diversity of wild species with forage potential, such as *A. glabrata* (Maass and Ocampo, n.d.), *A. pintoi* (Maass et al., 1993), and *A. sylvestris* (Veiga and Lopes, unpublished data), also showed a high degree of intraspecific variation.

Although *Arachis* species are expected to be mostly autogamous, little is known on the reproductive biology of wild *Arachis* species (Simpson et al., Chapter 4, this volume). Thus, no prediction can be made about the genetic identity and stability of germplasm accessions. In the case of *A. pintoi*, one accession is now widespread. It is thus important to investigate whether genetic erosion, shift, or drift has occurred since the original material was made available.

Most researchers have addressed genetic diversity in *Arachis* more at the interspecific rather than the intraspecific level. Such studies of morphological characters, seed protein, and isozyme patterns were helpful in classifying germplasm accessions, and assisted in gross taxonomic grouping of unidentified material (e.g., Lacks et al., 1991). For example, the enzymatic systems LAP and IDH made it possible to discriminate three species of section Extranervosae (*A. villosulicarpa*, VW 5913, and VKRSv 6556). In the same section, the species VPmSv 12939 (Terezina de Goiás) shows the exclusive MDH band 3 of zone three, the species VW 5913 (Araguari) is distinguished by ADH band 3, and *A. macedoi* by LAP band 9 (Table 3).

Table 3. Isoenzymatic variability in different accessions of section Extranervosae of the genus *Arachis*.

Isozyme zone, band		Species and accession[a]										
		A. villosulicarpa	*A. lutescens*	*A. prostrata*	*A. macedoi*	*Arachis* sp. Nobres	*Arachis* sp. Terezina de Goiás		*Arachis* sp. Carolina	*Arachis* sp. Araguari	*Arachis* sp. Araguaina	
		1	2	3	4	5	6	7	8	9	10	11
ADH (alcohol dehydrogenase)												
	2[b]	+	+	+	+	+	+	+	+	+	+	+
	3	-	-	-	-	-	-	-	-	+	-	-
IDH (iso citrate dehydrogenase)												
1	2	-	+	+	+	+	+	-	-	-	-	-
	3	-	-	-	-	-	-	+	+	+	+	+
2	1	-	-	-	-	-	-	-	-	-	-	+
	2	-	-	-	-	-	+	-	-	+	-	+
	3	+	-	+	+	+	-	+	-	-	-	-
	4	-	+	-	-	-	-	-	-	-	-	+
3	1	-	-	-	-	-	-	-	-	+	-	-
	2	+	-	-	-	-	-	-	-	-	-	+
	3	+	-	-	-	-	-	-	-	-	-	-
	4	+	-	-	-	-	-	-	-	-	-	-
LAP (leucine amino peptidase)												
	4[b]	+	+	+	-	+	+	+	+	+	+	+
	7	+	+	+	+	+	+	+	+	+	+	+
	9	-	-	-	+	-	-	-	-	-	-	-
MDH (malate dehydrogenase)												
1[b]	1	+	+	+	+	+	+	+	+	+	+	+
	2	+	+	+	+	+	+	+	+	+	+	+
3	1	+	+	+	+	+	+	+	+	+	+	+
	2	-	-	-	-	-	-	+	-	-	-	-
	3	-	-	-	-	-	-	+	-	-	-	-

a. Accessions: 1 = IAC; 2 = VW 5925; 3 = VKRSv 6638; 4 = VR 7533; 5 = VSStGdW 7861; 6 = VSW 9950; 7 = VPmSv 12939; 8 = VSStGdW 7821; 9 = VW 5913; 10 = VSStGdW 7784; 11 = VKRSv 6556.

b. Denomination of zones and bands exclude unresolved bands which do resolve in other accessions and/or species not presented here (e.g., see Table 5).

SOURCE: Galgaro and Lopes, unpublished data.

Other features, such as biotic and abiotic adaptation, are dealt with by other authors in this volume. But the amount of intraspecific genetic variation is practically unknown. In the following section, intraspecific, or at least intrasectional, variation of wild species will be emphasized.

Morphology

Morphological descriptions and classifications were carried out by Stalker (1990) for several species in the section Arachis and by Maass et al. (1993) for *A. pintoi* section Caulorhizae. According to Veiga and Lopes (unpublished data), the 18 accessions of *A. sylvestris* section Ambinervosae studied were discriminated by using characteristics such as plant size, stem branching pattern, branch size and pigmentation, presence or absence of trichomes on the leaflets, glossy leaflets, spots on the flower standard, and peg pigmentation. But it was not possible to correlate morphological characteristics and geographical distance among the different accessions.

Preliminary morphological descriptors compiled by IBPGR (1990) for wild *Arachis* species were utilized with adjustments. The usefulness of individual characters to describe intraspecific variation, however, depends on the species or section. As generalized descriptor lists tend to differentiate among species but not among accessions of each species, adjustments become necessary whenever several accessions of a single species are compared. Important characters, at this point, are those that allow for the best discrimination between accessions of a single species. Such characters are often good genetic markers, useful for studies of reproductive biology and population structure. Determination of morphological descriptors and characterization of new germplasm of *A. pintoi* are presently being carried out at CENARGEN and CIAT.

Biochemical markers

Several authors showed seed proteins to be a useful tool for classification (e.g., Klozová et al., 1983; Singh et al., 1991) in interspecific studies. The variation found among seed protein patterns made it possible to discriminate the three subspecies of *A. hypogaea* (Lopes et al., unpublished data). Data on intraspecific variation of seed proteins in wild *Arachis* species are not yet available.

Isozyme electrophoresis was used in some studies of genetic variation (Table 4). Several isozyme systems showed intraspecific polymorphism and were useful for describing existing variation and for fingerprinting accessions. Germplasm accessions of *A. sylvestris* and *A. villosulicarpa* showed strong polymorphism. Some accessions of *A. sylvestris* can be easily distinguished by specific bands, mainly with ACP and α, ß-EST (Table 4). Genetic variation was also detected within and among accessions of *A. villosulicarpa* studied with these same enzymatic systems, ACP and α, ß-EST (Galgaro and Lopes, n.d.).

Isozymes also may help to identify possible duplicate accessions in germplasm collections. Isozyme characterization has been initiated in seven available accessions of *A. villosulicarpa*, also involving the possible wild progenitor of this cultigen (Galgaro, 1991). Particularly useful isozymes researched across various species were esterases (Figure 2, Table 5). Several studies are presently being carried out that involve wild species of various sections of the genus *Arachis* to assess intra- and interspecific genetic diversity, such as studies on the isoenzymatic variability of different populations of *A. pintoi* from geographically isolated regions.

Molecular markers

Molecular markers have not yet been used in intraspecific studies of genetic diversity, except for the cultivated peanut and its wild relatives of section Arachis (Halward et al., 1991; Kochert et al., 1991; Paik-Ro et al., 1992). New and ongoing projects, however, intend to include RFLP and RAPDs in the characterization of intraspecific genetic diversity of wild *Arachis* species of other sections.

Table 4. Isoenzymatic variability in different accessions of *Arachis sylvestris*.

Isozyme bands	Accession[a]																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
ACP (acid phosphatase)																	
1	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
3	-	-	-	-	-	-	-	-	+	-	-	+	+	+	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+
6	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-
7	-	-	-	+	+	-	-	-	+	+	+	+	-	-	-	-	-
8	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-
14	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	+
15	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
16	-	-	-	-	-	-	-	+	+	+	-	+	-	-	-	-	-
17	-	-	-	-	+	-	-	-	-	-	-	+	-	+	-	-	-
18	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
19	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
21	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
22	-	+	-	-	-	-	-	-	-	-	+	+	-	-	+	-	-
23	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
ADH (alcohol dehydrogenase)																	
1	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
G-6-Phosphate																	
1	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
2	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	+	-
3	-	-	-	-	-	+	+	-	-	-	+	+	-	-	+	-	+
4	+	+	-	+	-	-	-	+	-	+	-	-	-	+	-	-	-
5	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
LAP (leucine amino peptidase)																	
1	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+
2	-	-	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
3	-	-	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
4	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
5	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
7	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PRX (peroxidase)																	
1	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
2	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+
3	+	+	+	-	+	-	-	-	-	+	+	-	+	+	+	+	+
4	+	+	+	-	-	-	+	+	-	+	+	-	+	+	+	+	+
5	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-
EST (esterase)																	
1	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	+	+	-	+	-	+
3	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	+	-
4	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
5	-	-	+	+	+	-	-	-	+	+	-	-	-	-	-	-	-
6	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
9	-	-	-	+	-	-	-	-	+	-	-	-	-	-	+	-	-
10	+	-	-	-	-	-	-	+	-	+	+	+	-	-	-	+	+
11	-	+	+	-	-	+	-	-	-	-	-	-	-	+	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
14	+	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-
15	-	+	-	-	+	+	-	+	-	-	-	-	-	+	+	-	-
16	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+
17	-	-	-	-	-	-	-	-	+	+	-	-	+	-	+	-	-
18	-	-	-	-	-	+	+	+	-	-	+	-	-	-	-	-	-
19	+	+	+	-	-	-	-	-	-	-	-	+	-	-	-	-	+
20	-	-	-	-	-	-	-	-	+	+	-	-	-	+	+	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
22	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	-
23	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-

a. Accessions: 1 = VVeSv 6001; 2 = VVeSv 6180; 3 = VKRSv 6547; 4 = VKRSv 6575; 5 = VKVeSv 7294; 6 = VVeSv 8494; 7 = VVeSv 8516; 8 = VRSv 10980; 9 = VRSv 11020; 10 = Bi 664; 11 = VKVeSv 7037; 12 = VKVeSv 7071; 13 = VVeSv 8345; 14 = VVeSv 8373; 15 = VVeSv 8386; 16 = VVeSv 8435; 17 = VVeSv 8520.

SOURCE: Veiga and Lopes, unpublished data.

Table 5. Isozymes used in intraspecific or intrasectional studies of genetic diversity in wild *Arachis* germplasm, polymorphism encountered, and resolution of system.

Isozyme system	*A. pintoi* (section Caulorhizae)[a]	*A. glabrata* (section Rhizomatosae)[b]	Section Arachis[c]		*A. sylvestris* (section Ambinervosae)[d]		Section Extranervosae[e]
	peg tip	rhizome tip	leaves	pollen	leaves	seeds	seeds
ACP (acid phosphatase)	++[f]	++	-	-	+	++	-
ADH (alcohol dehydrogenase)	-	-	o/-	-	o/o	+	-
AP (amino peptidase)	-	-	++	-	-	-	-
CAT (catalase)	-	-	-	-	o/+	o/+	-
DIA (diaphorase)	+	+	-	-	-	-	-
EST (esterase)	++	++	-	-	+	++	++
GOT (glutamate oxalo-acetate transaminase)	+	+	-	-	-	-	-
IDH (iso citrate dehydrogenase)	-	-	o/-	-	o/o	+	++
LAP (leucine amino peptidase)	-	-	-	-	o/o	+	++
MDH (malate dehydrogenase)	o/-	o/-	++	++	o/+	o/+	++
ME (malic enzyme)	o/-	o/-	o/-	++	o/o	o/+	-
MNR (menadione reductase)	-	-	++	++	-	-	-
6-PGDH (6-phospho gluco dehydrogenase)	-	-	o/-	-	o/o	o/+	-
PGI (phospho gluco isomerase)	-	-	++	++	-	-	-
PGM (phospho glucomutase)	o/-	o/-	++	-	-	-	-
PRX (peroxidase)	o/-	o/-	++	-	+	+	-
SKDH (shikimic dehydrogenase)	-	-	++	-	-	-	-

a. Maass et al. (1993).
b. Maass and Ocampo (n.d.).
c. Lu and Pickersgill (1993).
d. Veiga and Lopes (unpublished data).
e. Galgaro (1991); Galgaro and Lopes (unpublished data).
f. ++ = polymorphism existent, good resolution; + = polymorphism existent, acceptable resolution; o/+ = no polymorphism, good resolution; o/o = no polymorphism, bad resolution; - = not reported.

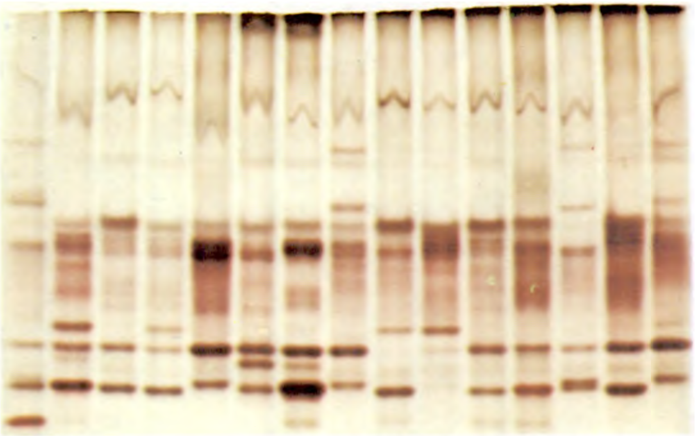

Figure 2.
Intraspecific variation in isozyme pattern of α, β–EST in rhizome-tip tissue of *Arachis glabrata* (Maass and Ocampo, unpublished data). (From left: CIAT 9086, 9095, 9097, 9079, 9093, 9098, 9085, 9083, 9081, 9073, 9092, 9072, 9078, 9100, 9075).

Molecular markers are better tools than biochemical markers, because they offer an almost infinite degree of polymorphism, are less affected by the environment, and can also be analyzed as Mendelian genes. Molecular markers are also used to address genetic diversity, classification, and phylogeny studies, relevant to germplasm management, and as a tool in breeding and selection by tagging genes and manipulating useful agronomic traits.

Acknowledgment

The authors wish to thank Dr. A.K. Singh, Genetic Resources Unit, ICRISAT, for providing data for Table 2.

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Annex 1. National and institutional prefixes of collection numbers for germplasm.

Abbreviation	Institution
BRA	Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia (CENARGEN), Brazil
CIAT	Centro Internacional de Agricultura Tropical, Cali, Colombia
CPI	Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
IAC	Instituto Agronômico de Campinas, Campinas, SP, Brazil
ICG	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India
ILCA	International Livestock Centre for Africa, Addis Ababa, Ethiopia
IRFL	University of Florida, Gainesville and Fort Pierce, FL, USA
IRI	Rockefeller Research Institute, Matão, SP, Brazil
PI	Plant inventory number of USDA, Beltsville, MD, USA

Annex 2. Identification of principal collectors of *Arachis* germplasm.

Abbr.	Collector, Institution, Country
Bi	L. Bianchetti, CENARGEN/EMBRAPA, Brasília, DF, Brazil
Bm	B.L. Maass, CIAT, Cali, Colombia
Db	M. Dib Bechara, UNESP, Botucatu, SP, Brazil
Fa	L. Faraco de Freitas, CENARGEN/EMBRAPA, Brasília, DF, Brazil
Fd	M.S. França-Dantas, CPAC/EMBRAPA, Planaltina, DF, Brazil
G	W.C. Gregory, NCSU, Raleigh, NC, USA
Ga	M.L. Galgaro, UNESP, Botucatu, SP, Brazil
Gd	I.J. Godoy, Instituto Agronômico, Campinas, SP, Brazil
Ge	M.A.N. Gerin, Instituto Agronômico, Campinas, SP, Brazil
Gr	A. Gripp, CENARGEN/EMBRAPA, Brasília, DF, Brazil
H	R.O. Hammons, USDA-ARS, Tifton, GA, USA
J	L. Jank, CNPGC/EMBRAPA, Campo Grande, MS, Brazil
K	A. Krapovickas, Universidad Nacional del Nordeste, Corrientes, Argentina
L	W.R. Langford, USDA-ARS, Tifton, GA, USA
M	J.P. Moss, ICRISAT, Patancheru, India
Mt	J.C. Millot, Facultad de Agronomía, Univ. de la República, Montevideo, Uruguay
P	J. Pietrarelli, INTA, Manfredi, Argentina
Pm	R.N. Pittman, USDA, Griffin, GA, USA
Pn	P. Pinheiro, CPAC/EMBRAPA, Planaltina, DF, Brazil
Po	A. Pott, CPAP/EMBRAPA, Corumbá, MS, Brazil
Pz	E.A. Pizarro, CIAT, Brasília, DF, Brazil
Q	C.L. Quarin, Universidad Nacional del Nordeste, Corrientes, Argentina
R	V.R. Rao, ICRISAT, Patancheru, India
Ro	D.M.S. Rocha, CENARGEN/EMBRAPA, Brasília, DF, Brazil
Rs	R.C. Santos, CNPA/EMBRAPA, Campina Grande, PB, Brazil
S	C.E. Simpson, Texas A&M University, Stephenville, TX, USA
Sc	A. Schinini, Universidad Nacional del Nordeste, Corrientes, Argentina
St	H.T. Stalker, NCSU, Raleigh, NC, USA
Sv	G.P. Silva, CENARGEN/EMBRAPA, Brasília, DF, Brazil
V	J.F.M. Valls, CENARGEN/EMBRAPA, Brasília, DF, Brazil
Va	S.E.S. Valente, UNESP, Botucatu, SP, Brazil
Ve	R.F.A. Veiga, Instituto Agronômico, Campinas, SP, Brazil
Vi	J.G.A. Vieira, CENARGEN/EMBRAPA, DF, Brazil
Vn	R.O. Vanni, Universidad Nacional del Nordeste, Corrientes, Argentina
W	W.L. Werneck, CENARGEN/EMBRAPA, Brasília, DF, Brazil
Wi	D.E. Williams, USDA, Beltsville, MD, USA
Ws	W. Silva, CPAC/EMBRAPA, Planaltina, DF, Brazil

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Chapter 4

Reproductive Biology and the Potential for Genetic Recombination in *Arachis*

C.E. Simpson
J.F.M. Valls
J.W. Miles*

Abstract

The *Arachis* genus, which probably antedates the Amazonian forest, has evolved into some diverse ecological niches, including semi-arid areas, lowland swamps, and many environments in between. Its floral biology shows a papilionaceous flower that is generally self-pollinated. But it may be cross-pollinated by various species of bees. The unusual geocarpic fruit of *Arachis* sets the genus apart from most other taxa and makes seed recovery more difficult. Variability in reproductive characteristics in this taxon is recognized. Vegetative propagation of several species is possible and has proven useful. Apomixis is indicated as a possible mode of reproduction for some types of *Arachis* under certain conditions, but the general rule for seed-producing species is sexual reproduction that allows for recombination and, thus, genetic change.

Introduction

The *Arachis* genus is an old taxon that probably antedates the Amazonian forest. It has contributed to the ecology of areas where the various species have evolved by providing plant material for direct consumption by animals, nitrogen for associated grasses and other nonleguminous plants, ground cover to prevent erosion, and a pollen source for bees and other insects.

The genus has evolved in some unusual niches, which range from semi-arid areas of northeastern Brazil, to schist outcrops or Cerrado pockets in the Amazon forest, to low, deep-soil alluvial flood plains and humus clay swamps of the Gran Pantanal (Simpson, 1984; Valls et al., 1985). In these and other environments, *Arachis* species have evolved through the process of sexual recombination, selection, and isolation. Various isolation mechanisms have developed, and as many as 80 species have evolved within the genus. Many species produce small amounts of plant mass in their native habitat, and these species do not appear useful in today's mechanized agriculture as "cultivated" pure stands of forage plants for hay or grazing. Certain interspecific combinations produce progenies that are quite vigorous. These need to be studied to determine if such hybrid progenies could be developed into forage varieties. A potential for apomictic reproduction has been observed in several *Arachis* species. The purpose of this chapter is to highlight the floral biology of *Arachis* and discuss its potential for genetic recombination. We will also discuss vegetative propagation and a potential for apomixis in *Arachis*.

Floral Biology

Gregory et al. (1973) have adequately described the floral anatomy and morphology of the peanut. Nigam et al. (1990) provided some excellent photographs of *Arachis* floral biology. We will present only a brief summary here, with photo-figures to illustrate the important structures.

Flowers are borne in the leaf axils of reproductive nodes in inflorescences

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* Professor, College of Agriculture, Texas A&M University, Stephenville, Texas, USA; curator of *Arachis* germplasm, Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia/Empresa Brasileira de Pesquisa Agropecuária (CENARGEN/EMBRAPA), Brasília, Brazil; forage geneticist, CIAT, Cali, Colombia, respectively.

comprised of one to nine potential bud-producing nodes. The cultigen, *Arachis hypogaea*, is recognized as having three arrangements of reproductive and vegetative nodes: alternate, sequential, and mixtures of both (Gregory et al., 1973). Wild *Arachis* species have varying combinations of these arrangements, but extensive study is needed to determine the relative prevalence, if any, by group or type. The authors' personal observations indicate that alternate branching might dominate in perennial types, while annual types include both alternate and sequential species or groups within species.

The first flowers appear on young plants within the *Arachis* genus between 14 and 55 days of age. Early maturity in *A. hypogaea* has been associated with early flower production (Gilman and Smith, 1977), but we have been unable to correlate days to first flower in wild *Arachis* with early maturity. Flower production strongly depends upon daylength, with 12-hour days being the critical minimum (Ketring, 1979), although not all species appear as strongly daylength sensitive as others. Wynne et al. (1973) found in *A. hypogaea* that greater vegetative growth occurred in long days, whereas there was greater reproductive potential in short days. *Arachis* flower colors include yellow, pastel, orange, reddish orange, cream-white, and white. Yellow has always predominated over the other colors in crosses made to this date by the authors of this chapter.

Developing flower buds usually become visible 36 to 48 hours before the flower buds open. The buds are supported on a calyx tube (Figure 1) (hypanthium in most texts), which begins accelerated growth about 24 hours before anthesis (flower opening). Growth of 6 to 8 cm in one day is common, and we have measured 24-hour calyx tube growth of 16.5 cm in one accession of *A. burkartii* (herbarium specimen, Stephenville, Texas, USA). *Arachis* corollas are papilionaceous (Figure 1), with a large, showy standard petal, two wing petals, and a keel petal enclosing the pistil and stamens. All of these are subtended by five calyx bracts (four of which are fused, except at their tips), which surround the standard petal in the unopened bud. Normal flowers contain either a feather- or club-like stigma and ten stamens. The stamens consist of four double-loculed, four globose, and two sterile staminodes. The stigma is supported on a long style that makes two sharp bends through the base of the standard/keel and continues down the center of the hollow calyx tube to the ovules in the leaf axil on the inflorescence. By splitting the calyx tube and pollinating the exposed style, we have proven with several species that the style is pollen receptive for much of its length. We are certain the resulting hybrids were from styler pollination because anthers and stigmas in the

Figure 1.

***Arachis* sp. flower 3.5 hours after anthesis, showing standard and wing petals supported by calyx tube.**

pollinated bud were removed well before pollen maturity; likewise, genetic markers (flower color, etc.) assisted in identifying hybrids.

Pollen matures approximately 6 to 8 hours before anthesis (Gregory et al., 1973; Pattee et al., 1991), but pollination does not usually occur until at or near flower opening (anthesis), which occurs at sunrise. We have pollinated with pollen from buds 6 hours prior to anthesis, which resulted in successful hybridization. Work by Pattee et al. (1991) confirms pollen maturity at this stage.

The calyx tube and flower wilt by mid-afternoon on a normal summer's day, and fertilization occurs within 12 hours after pollination (Gregory et al., 1973; Pattee et al., 1991). Low temperatures have a significant effect on flower opening and wilting, and delays of 12 to 18 hours are not uncommon with late season temperatures at or near 10 °C.

Various types of incompatibility and sterility factors that prevent self- and cross-fertilizations in several *Arachis* species have been studied (Pattee et al., 1991; Smartt and Stalker, 1982).

After fertilization, the young embryo undergoes four or five divisions, after which it becomes dormant. At the same time, an intercalary meristem becomes active at the base of the ovary and begins to grow a peg or "ovary stalk," which is positively geotropic. The direction of peg elongation will change if the branch is disturbed in a manner that orients the peg tip away from vertical. Peg length is under both genetic and environmental control, and this length ranges from 1 to 2 cm in one species of the section Extranervosae to more than 1 m in section Erectoides. The evolution of the short, strong pegs of *A. hypogaea* was critical to the use of this species as a (the) cultigen of choice by natives of South America. The long, "weak" pegs of most wild *Arachis* species complicate the use of these taxa for human food or animal forage. Because of poor peg strength, it is necessary to sieve the soil beneath the plants in order to recover enough seed for distributing the plants. Such sieving makes seed recovery time-consuming and expensive.

The peg, with the ovules at its tip, continues to grow, and as the peg enters the soil, it thickens in some species (e.g., sections Procumbensae and Triseminalae), but becomes very thin in other species (e.g., *A. sylvestris*). In *A. hypogaea*, the activity of the meristem at the base of the ovules is light sensitive, with divisions ceasing 24 to 36 hours after the peg tip enters total darkness in the soil. This has been proven by placing black electrical tape over aerial pegs. This technique has produced mixed success in curtailing growth of wild *Arachis* species pegs. In *A. hypogaea*, the two or three pod segments are not separate, but in virtually all the wild species that produce fruits, the pod segments are separated by an isthmus, similar to the peg, which grows between the segments, from an intercalary meristem. Two fruit segments and one isthmus occur in most wild species, but three and four pod segments are common in section Triseminalae. Three segmented fruits have also been observed in section Arachis. The isthmus places the subsequent fruit segments deeper into the soil and/or farther away from the mother plant. The subterranean fruit has undoubtedly evolved in the *Arachis* genus as an escape from fire and other unfriendly environmental factors, but the long pegs of the sections Erectoides, Triseminalae, and Ambinervosae have evolved as a distribution mechanism as well.

Recombination

The various wild *Arachis* species for forage have a different potential for genetic recombination and improvement. In the two species of greatest interest for forage, *A. glabrata* has a limited opportunity for recombination and *A. pintoi* has a higher possibility for genetic recombination. Interspecific hybridization in section

Rhizomatosae has usually been difficult, although Gregory and Gregory (1979), working with 12 tetraploid accessions, succeeded in 11 of 23 bi-parental combinations attempted. Only three reciprocal crosses (of 12 attempted) were successful in both directions. Some parental genotypes were easier to cross than others. Hybrids across ploidy level have not been successful (Gregory and Gregory, 1979), and it appears that distinct genomes are involved (Stalker, 1985; Stalker and Moss, 1987). Many of the species in the section Rhizomatosae are not, in any case, good seed producers, and the failure to obtain hybrids may be due to causes other than strict genomic or genetic incompatibility. On the other hand, pollen germination in *A. glabrata* seems to be high enough to not be an obstacle to successful hybridization (Niles and Quesenberry, 1992). Stigmas of *A. glabrata* (including a few accessions identified as *A. hagenbeckii*) show a small stigmatic area, considered characteristic of perennial, nonprolific species. Although small, this area is adequate to lodge at least two viable pollen grains, the same as the number of ovules in the ovary (Lu et al., 1990), and does not, in itself, constitute a definitive barrier to fertilization. If compatibility barriers can be understood and overcome, the forage potential of the Rhizomatosae/ Eurhizomatosae could be greatly enhanced by hybridization.

Most *A. glabrata* accessions produce few, if any, seeds in native or adapted habitats. Each seed produced grows into a seedling that represents a new genotype, which may or may not be a desirable type because the accessions are highly heterozygous. This presents another problem, because lines that are good seed producers for propagation may not be successful forage types. If a good seed-producing line is developed, it will lose its heterozygosity (because of inbreeding) and, thus, its hybrid vigor, and may be less likely to sustain high forage production. On the other hand, lack of seed production leaves vegetative propagation as the means of distribution—not a bad situation considering that many *A. glabrata* accessions produce rhizomes prolifically (Figure 2).

Thirty years ago, vegetative propagation of a forage species presented formidable distribution problems, but with the release of coastal Bermuda grass, quite efficient equipment has been developed for harvest and planting of vegetative sprigs. Similar equipment can be used to distribute *Arachis* rhizomes and/or stolons (Adjei and Prine, 1975; Rincón C. et al., 1992).

Arachis pintoi accessions are variable in seed production, but in most environments at less than 27° latitude, seed production is not a problem. The various accessions of *A. pintoi* appear somewhat typical of a self-pollinated species, exhibiting little or no heterozygosity but still having potential for cross-pollination and genetic recombination for plant improvement. Interspecific hybridization within section Caulorhizae has been far more successful

Figure 2.

Vegetatively established plant of section Rhizomatosae showing numerous and vigorous rhizomes.

than in Rhizomatosae. The F_1 of one cross attempted between species representing extreme types within the section had 86.8% pollen fertility, higher than that often found for intraspecific crosses in other sections (Gregory and Gregory, 1979).

A characteristic of section Caulorhizae is its rooting at the nodes. The root primordia appear early in the growth of the lateral branches, and as the laterals are covered by soil and debris, moisture stimulates the roots to grow. These root primordia make it easy to propagate Caulorhizae species vegetatively.

Techniques of embryo culture have been used to facilitate interspecific exchange of genes in *Arachis* (e.g., Moss et al., 1989). This work has focused on transferring genes for disease and pest resistance from "wild" *Arachis* species to the cultivated peanut (*A. hypogaea*). The potential for genetic recombination within the genus may be further expanded through genetic transformation. Whereas techniques for embryo rescue are fairly well known, regeneration of fertile plants from undifferentiated tissue culture (essential for application of the most efficient genetic transformation techniques) has been successful in only a limited number of *Arachis* species (Still et al., 1987; Dunbar and Pittman, 1992). Notable among these is the important forage species *A. pintoi* (Burtnick and Mroginski, 1985).

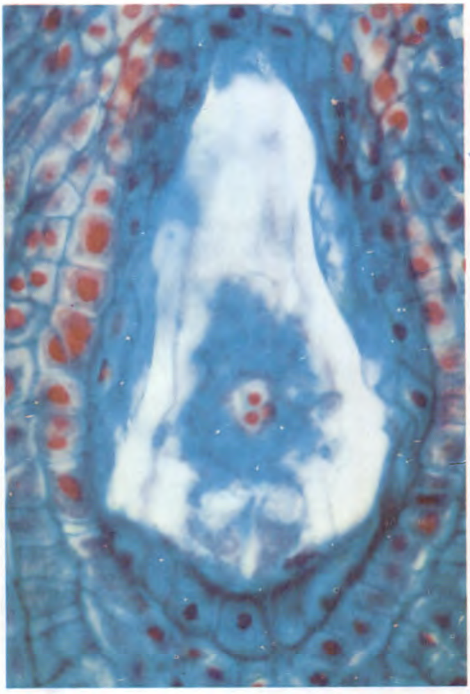
Newer DNA techniques using RFLP, RAPD, or PCR markers are taking advantage of polymorphisms in wild *Arachis* to construct molecular maps (Kochert et al., 1991; Halward et al., 1991, 1992; Newbury and Ford-Lloyd, 1993). As this information is correlated with morphological and agronomic characters, the DNA tools will become useful for *Arachis* improvement.

Mode of Reproduction

The peanut normally reproduces sexually, but the cytology and breeding behavior of some strains suggest the potential for apomixis. Apomixis is seed production without fertilization, or, stated another way, reproduction without sexual recombination (Gustafsson, 1947). In most *Arachis* materials that we have studied cytologically, as the young peanut ovules developed, the archesporial mother cell enlarged, divided meiotically, and formed a linear tetrad. The basal cell became the functional megaspore, and the other three cells degenerated. This megaspore enlarged and formed a typical Polygonum-type sexual embryo sac with an egg, two synergids, two polar nuclei, and three antipodals (Figure 3). A common characteristic in *Arachis* is for all the cells just outside the sexual embryo sac to take on a brick-like appearance with enlarged vacuoles and nuclei and with thick, heavily stained cell walls. In most cases, these meristematic cells do not appear to be actually involved in reproduction, but may be serving as nurse cells for the sexual embryo sac.

Beginning in 1968, the senior author began to recognize some of the characters of apomixis in *Arachis* materials, which are commonly evident in the apomictic grasses. The first character to attract attention was the many twin seedlings that occur in some accessions of *A. hypogaea* (Figure 4). Study of these twin plants and seed produced from them could possibly result in a higher gene frequency of an apomictic trait, which could lead to a pure-line apomict. Observations within certain inter- and intraspecific hybridizations indicated a great amount of uniformity among F_2 progenies, a second indication of apomixis. The observation of peg formation in some *A. hypogaea* lines and several wild species accessions after the removal of buds but well before pollen maturity and/or anthesis was a third indication of apomixis. Finally, the study of embryo sac development in several species, including at least five lines of *A. hypogaea*, gave cytological evidence of apomixis, reported here.

As mentioned, most *Arachis* materials studied cytologically appeared



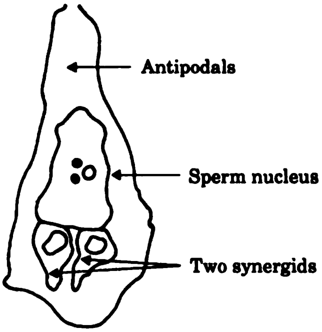


Figure 3.

Normal embryo sac of *Arachis hypogaea* cv. 'Spantex.' Note sperm nucleus adjacent to the polar nuclei and two synergids; antipodals not present in this section.

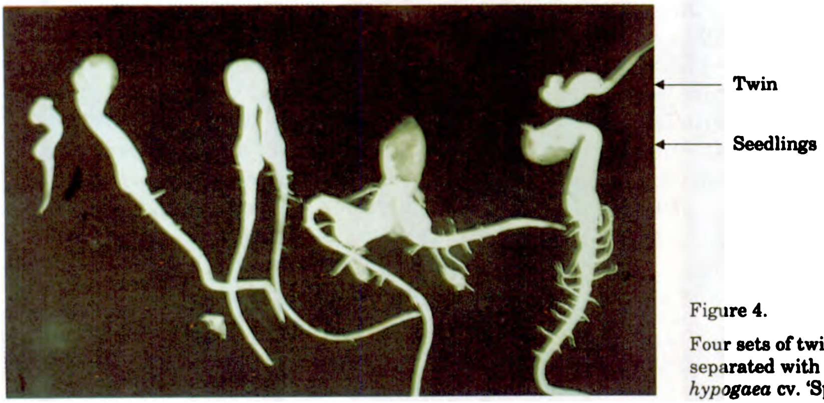


Figure 4.

Four sets of twin seedlings (two on ends separated with razor blade) of *Arachis hypogaea* cv. 'Spantex.'

to reproduce by normal sexual processes. But exceptions were common in some types. In one specific *A. hypogaea* line, cv. 'Spantex,' and in one wild species, *A. macedoi*, what appeared as disorganization of the nucellar activities within embryo sacs was common when pollination was prohibited, delayed, or altered from self-pollination. Bharathi et al. (1982) reported the same disorganization in an accession of *A. glabrata*. Another anomaly observed in the *Arachis* ovules was a strong propensity for many cells in and around the nucellus to be "active." The term "active," as it relates to apomixis, refers to the appearance of a cell in which the nucleus is enlarged and readily retains red stain when stained with safranin-O-fastgreen. The cytoplasm of these cells appears dense and stains easily, and the cell is enlarged (Gustafsson, 1947). Such cells were common in and around the sexual apparatus in most, if not all, *Arachis* ovules studied. Other anomalies (Figure 5) included enlarging active cells in the mid-nucellus and the antipodal regions.

When pollination was delayed, prevented, or substituted with a known incompatible species, unusual development occurred. For example, when Spantex was emasculated and then pollinated with a specific *A. glabrata* accession, fertilization was not common, and cells outside the embryo sac began to dominate. The sexual apparatus appeared to degenerate in the sexual sac, and adjacent cells and/or nuclei, apparently from the nucellus, became prominent. In several cases, multiple embryo sacs were observed in such material (Figure 6), and what appeared to be developing embryos in some multiple sacs were noted. Also, progeny resulting from Spantex x *A. glabrata* pollinations were uniform and maternal in all characters.

We were unable to determine the exact origin of the nuclei in these multiple embryo sacs. It appeared that it was definitely some form of apospory, but not clearly a form identified as occurring in other species (E.C. Bashaw, personal communication).

What appear to be cleistogamous flowers are common in at least three species of wild *Arachis*. We studied embryo sacs in one of these, *A. macedoi*, and found much the same type of abnormal embryo sac formation as noted when the *A. hypogaea* line Spantex was denied pollination. Parthenogenesis (development of an embryo from an unfertilized egg nucleus) and pseudogamy (requiring pollination) may both be involved in apomictic reproduction of the *A. hypogaea* line since we did not appear to get embryo development in nonpollinated ovules of Spantex. Parthenogenesis without pseudogamy was indicated in *A. macedoi* because seeds were obtained without pollination under certain environmental

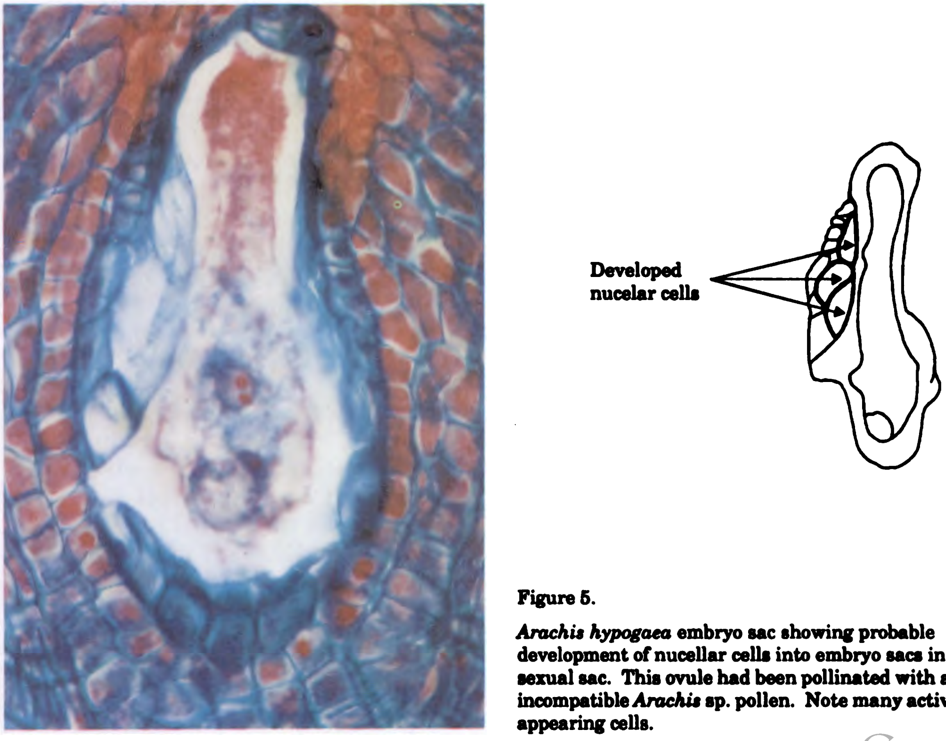


Figure 5.

Arachis hypogaea **embryo sac showing probable development of nucellar cells into embryo sacs in wall of sexual sac. This ovule had been pollinated with an incompatible *Arachis* sp. pollen. Note many active-appearing cells.**

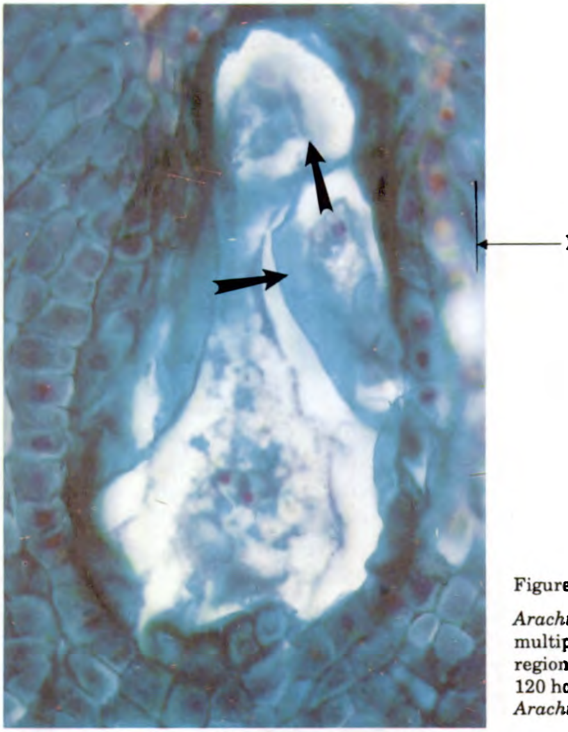


Figure 6.

Arachis ***hypogaea*** **cv. 'Spantex' ovule, 430x, showing multiple embryo sacs that developed in the antipodal region (arrows). This ovule was collected from material 120 hours after pollination with an incompatible wild** *Arachis* **sp.**

conditions. If apomixis operates in *Arachis*, it will be recognized as a form of facultative apomixis (Gustafsson, 1947).

Apomixis, viewed as an advanced character in polyploid groups, could have been (and might still be) a factor in the evolution of the large section Rhizomatosae. Almost all accessions that have produced fruits in our collections appeared to be highly heterozygous. It is important to note that *A. glabrata* and *A. monticola* are the only two polyploid wild *Arachis* species.

Apomixis is common in the Gramineae family and is recognized in more than 250 species that are not grasses. Although Stanford et al. (1972) and Bishop (1958) reported polyembryony, and Barnes et al. (1972) reported multiple embryo sacs in alfalfa (*Medicago sativa* L.), apomixis has not, to our knowledge, been reported in the Leguminosae. Reports of unusual embryo sacs occurring in *Arachis* are rarely found.

If apomixis could be developed in forage types of *Arachis*, it might be useful in producing stable heterozygous lines of desirable forage types.

Conclusion

Basically, two groups of *Arachis* are of immediate interest as forage plants—sections Rhizomatosae and Caulorhizae. Hybridizations of these with section Erectoides might well prove profitable for forage production.

We believe that several species from section *Arachis* could be useful forage producers as well. In addition, interspecific hybrids might produce desirable results. A possible advantage would be that most of the section Arachis species that would be of forage interest are prolific seed producers, as are many hybrids within the section.

Development of unreduced nucellar embryo sacs indicated that a possible form of facultative apomixis might be present in *Arachis*. Cytological data presented here provide evidence that some lines (species?) may have apomictic potential.

Acknowledgment

We wish to acknowledge the valuable interpretation of embryo sac development by Dr. E.C. Bashaw, geneticist, Agricultural Research Service, United States Department of Agriculture, College Station, Texas, USA. His assistance is much appreciated.

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Chapter 5

Some Ecophysiological Aspects of *Arachis pintoi*

M.J. Fisher
P. Cruz*

Abstract

The problems of growing tropical C_4 grasses and C_3 legumes in association are discussed, and from this basis we explore some of the physiological attributes that contribute to the success of *A. pintoi* as a pasture legume. It is tolerant of shade and relatively tolerant of water deficits. Although it develops leaf area index rapidly following defoliation, it appears better suited to grazing or use as a cover crop than to cutting. Its radiation use efficiency was not affected when it was grown in mixtures with grasses compared with pure swards, as it is well adapted to growth in those associations.

Under grazing, *A. pintoi* performed well in mixtures and its proportion increased from 20% to 40-50% of the forage over 3 years, largely independent of forage allowance for the grazing animals. Although regrowth primarily depended on residual leaf area, regrowth was apparently reduced by waterlogging both during growth and grazing.

The plant establishes more rapidly from seed than from stolons, although it is frequently planted vegetatively because seed is hard to harvest from the soil.

A. pintoi comes close to being an ideal pasture legume ideotype, although there are some reservations about its suitability as a species for ley systems.

Introduction

Tropical forage legumes have a fundamental problem. They are C_3 species that must associate with C_4 grasses, which generally have higher growth rates, to form pastures that are stable in the longer term. The associated legume is therefore at a large disadvantage unless it has some other advantage. Yet we tropical pasture workers expect tropical legumes to emulate the successful legume-grass pastures of the temperate regions, where both legume and grass are C_3's. Most of us believe that temperate legume-grass pastures are a general success story. But examination reveals that there are only a few instances of stable and persistent legume-grass pastures in temperate regions, of which white clover with perennial ryegrass in New Zealand is the outstanding example (Marten et al., 1989). Nevertheless, we believe that the tropical legume *Arachis pintoi* fulfills our most unreasonable expectations.

In this paper, we attempt to explain why *A. pintoi* is successful by reviewing the available literature and our own work. In doing so, we try to answer some of the questions implicit in the opening paragraph. We first discuss in general terms the relations between tropical legumes and grasses in association. Using this as a framework, we then examine the environmental responses of one accession, *A. pintoi* CIAT 17434, and use these to explain its observed behavior in associations with grasses.

Behavior of Tropical Grasses and Legumes in Association

As part of a study to model grass-legume associations under grazing (Fisher and

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* Ecophysiologist, Savannas Program, CIAT, Cali, Colombia; ecophysiologist, Station Agropedoclimatique de la Zone Caraibe, Institut National de la Recherche Agronomique des Antilles et de la Guyane (INRA), Guadaloupe, French Antilles, respectively.

Thornton, 1989; Thornton and Fisher, 1993), it was postulated that the behavior of a bi-specific mixture in a pasture could be described by seven response functions:

1. Leaf area index (LAI) as a function of biomass,
2. Growth rate as a function of LAI,
3. Senescence rate as a function of biomass,
4. Competition as a function of botanical composition,
5. Consumption as a function of biomass on offer,
6. Diet selection as a function of composition of the feed on offer, and
7. The proportion of new recruits of one component in the association as a function of the proportion of adults in the existing population.

While these functions obviously do not offer a complete description of the behavior of two components of a pasture under all circumstances, they appear to offer a reasonable starting point, and to account for most of the important factors that govern the dynamics of two species growing in association.

Their C_4 photosynthetic pathway and associated anatomical characteristics give tropical grasses the potential for higher intrinsic rates of growth compared with plants that have the C_3 photosynthetic pathway, which includes all tropical legumes. Therefore, we expect a bi-specific mixture of a tropical (C_4) grass and a tropical legume to move inexorably toward grass dominance unless:

1. The grass has an atypically low growth rate that matches that of the legume. This may be because the grass has an intrinsically lower growth rate or because some other factor limits its growth rate, such as a low level of soil N. In this case, the grass depends upon the associated legume to supply its N, and its growth rate will be constrained accordingly.

2. The legume competes with the grass for factors other than space. However, it is noteworthy that Hall (1974) demonstrated that the legume *Neonotonia wightii* suffers from competition for K from the grass *Setaria sphacelata* when grown in association with it in K-deficient soils in Australia. Likewise, the grass *Andropogon gayanus* competes more strongly for K with *Stylosanthes capitata* (a forage legume) on the Oxisols and Ultisols of the Colombian Llanos (Valencia, 1981). Recent evidence suggests that other grasses also compete with legumes for K in these soils (M.J. Fisher, unpublished data), although legumes can compete successfully for P (Rao and Kerridge, Chapter 6, this volume).

   Nevertheless, there is obviously scope for selecting aggressive legumes, which was the objective in exploiting those with twining growth habits to overtop, and therefore shade, the grasses. But twining legumes have a disadvantage in that their growing points are readily accessible to grazing animals, which limits their ability to withstand heavy grazing (Clements, 1989).

3. Pasture composition may be changed in a desired direction by using management tools such as burning, cultivation, and levels of fertilizer at specific times. Unfortunately, there are few data on the effects of these practices, either on survival or on recruitment, so that in grazing systems they must be applied empirically.

4. Grazing animals preferentially select grass. There is evidence that cattle often select the grass component in a grass/legume association (Lascano, 1987). In doing so, they favor the legume, but preference seems to vary during the year. Using grazing animals to "manage" pastures implies using their selection preferences to meet a goal of a "desirable" pasture composition, however it is defined.

It is worth re-emphasizing that the tendency of the grasses to go to dominance can be lessened if the grass species chosen during the selection process have lower growth rates. The summary above suggests that other growth criteria may be more appropriate than higher growth rate. For example, a grass species that has lower recruitment (is less stoloniferous or tillers less) or has lower dry matter yield (implying a lower growth rate) may be more desirable in terms of legume compatibility. Susceptibility to diseases or insects in the grass may be another factor. For example, although there is only anecdotal evidence, the susceptibility of *Brachiaria decumbens* to spittlebug appears to contribute to the persistence of legumes growing in association with it.

Growth

In general, tropical legume pastures are less productive than their temperate counterparts, such as alfalfa (*Medicago sativa*) and white clover (*Trifolium repens*). Studies with *A. pintoi* under defoliation in Guadaloupe (P. Cruz, unpublished data) have confirmed that, although both its initial development and its capacity to intercept light are good, its regrowth in pure swards is not as high as that of temperate legumes reported in the literature. The highest rates of regrowth measured at 30-40 days are approximately 80 kg/ha/day of dry matter. While this is not a high figure, in comparison with C_4 grasses, we have not found higher figures for other perennial tropical legumes in the literature.

In periods of regrowth longer than 40 days, the burden of senescence in *A. pintoi* becomes important and the net growth rates fall, demonstrating that it has a limited capacity to accumulate dry matter above-ground. This, as well as the good soil cover that it provides because of rapid development of a high leaf area index (LAI), clearly defines it as a plant for grazing or as a cover crop rather than a plant for cutting.

Environmental Responses of *A. pintoi*

Water deficit ("drought")

Because seasonal drought is such a dominant feature of the savanna environment, adapted pasture plants must be able to tolerate considerable desiccation. For animal production, however, maintenance of green leaf during drought is a desirable characteristic for providing feed for grazing animals. But maintenance of leaf tissue imposes a continued transpiration burden on the plant, which must maintain its tissues at a water content above the level at which they die. Plants adapted to dry environments usually have tissues tolerant of desiccation, or have well-developed mechanisms that minimize water loss (Sheriff and Ludlow, 1984; Sheriff et al., 1986).

Water stress tolerance is defined as the minimum water potential of the last remaining leaf of droughted plants (Fisher and Ludlow, 1984), and is a measure of the ability of plants to tolerate tissue desiccation. The time taken to reach that stage is a measure of the rate at which the plants lose water. Both measurements taken together give some insight into the mechanisms involved.

Because *A. pintoi* appears to shed much of its leaf during drought in the field, it is thought not to be particularly drought tolerant. To investigate the true nature of its ability to tolerate water deficits, *A. pintoi* CIAT 17434 was contrasted with seven other pasture legumes (a range of *Centrosema* species, *S. capitata*, and *Desmodium ovalifolium*), all of which had the reputation of being well adapted to drought (Table 1) (CIAT, 1991). Well-watered plants were grown in soil in cylinders 30 cm in diameter and 1.2 m deep for 8 weeks after seedling emergence, after which no further water was applied. The drought treatment continued until only one leaf remained on the plant, after which plants were re-watered to verify their ability to recover from the level of desiccation imposed.

Table 1. Water stress tolerance of *Arachis pintoi* compared with five accessions of *Centrosema* spp., *Stylosanthes capitata*, and *Desmodium ovalifolium*.

Species	Minimum water potential (WP) (- bars)	Time to minimum WP (weeks)	Relative water content (RWC) (%)	Time to minimum RWC (weeks)
A. pintoi CIAT 17434	61.9	13.3	41.4	14.8
C. brasilianum CIAT 5657	28.9	16.8	46.9	17.5
Centrosema hybrid CIAT 5933	38.5	14.0	69.2	15.0
C. acutifolium CIAT 5568	60.8	13.2	52.3	13.5
C. macrocarpum CIAT 5629	42.5	15.8	56.2	15.8
C. macrocarpum CIAT 5713	52.4	13.3	41.3	13.0
D. ovalifolium CIAT 13305	65.7	14.8	30.6	21.0
S. capitata CIAT 10280	65.9	21.5	51.6	25.0
S.E. of means	4.84	0.97	6.09	0.97
P	***	***	**	***

*** = $P < 0.001$, ** = $P < 0.01$.

There was a broad range of adaptation to drought in the legume accessions tested and the time taken to achieve minimum levels of tissue hydration (Table 1). *A. pintoi* CIAT 17434 and three other accessions (*S. capitata* CIAT 10280, *D. ovalifolium* CIAT 13305, and *Centrosema acutifolium* CIAT 5568) all achieved the minimum measurable water potential (-65 bars, dictated by the capacity of the apparatus used). In contrast, *C. macrocarpum* CIAT 5629, *Centrosema* hybrid CIAT 5933, and especially *C. brasilianum* CIAT 5657 maintained their water potentials relatively high. Although *A. pintoi* was relatively tolerant of water deficits, *S. capitata* CIAT 10280 and *D. ovalifolium* CIAT 13305 maintained green leaf for considerably longer periods (for 25 and 21 weeks without water, respectively, compared with 15 for *A. pintoi*).

Water excess ("flooding")

The effects of flooding were contrasted with the effects of drought in an experiment in which *A. pintoi* CIAT 17434 was again established in cylinders 30 cm in diameter and 1.2 m tall, containing 70 kg of soil, and grown with a complete fertilizer mixture (CIAT, 1991). When the plants were well grown, three treatments were imposed, consisting of a well-watered control contrasted with no further water for 16 weeks and a treatment in which free water was maintained on the soil surface at all times for the same period.

The data demonstrated that *A. pintoi* does indeed shed its leaves in response to both drought and flooding (Figures 1 and 2). After the initial effects of a shortage of water, however, the plant maintained leaf area production. Although the leaves appeared wilted, the actual leaf area was little different from that of the well-watered controls. Flooding seriously restricted plant growth, with leaves showing severe chlorosis typical of that observed in the field. It is of interest to note that leaf turnover was also substantial in the control plants to which we have referred above.

Arachis pintoi maintained a large proportion of its aerial parts in spite of drought, but at the expense of roots in the upper levels of the soil (Figure 3a). Deep-rootedness (Figure 3b) is a characteristic that can confer drought tolerance by allowing the plant access to water deeper in the profile.

Light

Many tropical grasses are tall-growing, so that the associated legume

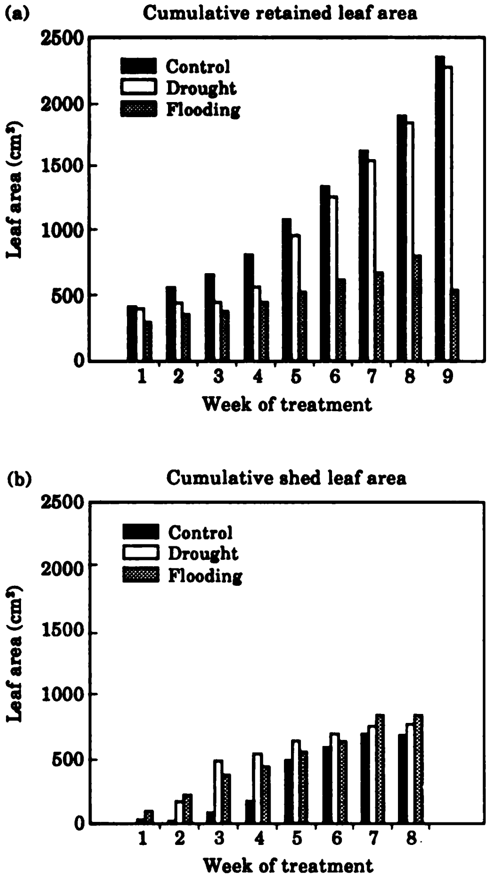

Figure 1. The influence of drought and flooding on (a) the accumulation and (b) shedding of leaf area by *Arachis pintoi* CIAT 17434.

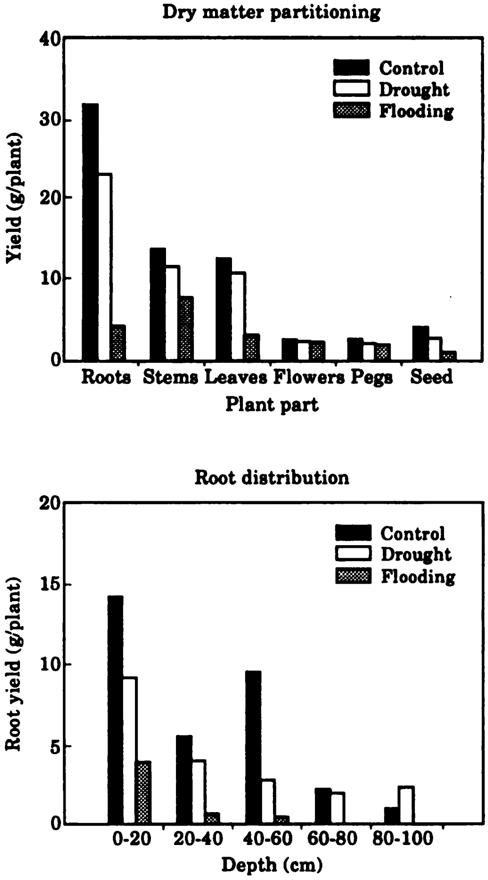

Figure 3. The influence of drought and flooding on (a) dry matter partitioning and (b) root distribution by *Arachis pintoi* CIAT 17434.

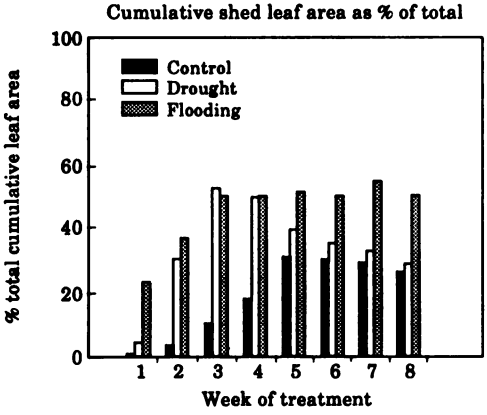

Figure 2. The influence of drought and flooding on the relative loss of leaf area by *Arachis pintoi* CIAT 17434.

frequently grows in shade. The physiological effects of shade on plants having contrasting pathways of photosynthesis are well documented, but the differential responses may lead to an advantage for the legumes in, for example, extended periods of cloudy weather, such as occurs in the humid tropics. *A. pintoi* appears to tolerate shade, and indeed to grow better under shaded conditions than in full sun. This was confirmed in an experiment in which *A. pintoi* was grown in pots of 3.5 kg of soil at 70%, 50%, or 30% full sun (obtained with shade cloth of different densities) compared with an unshaded control (CIAT, 1991). Differences in air temperature because of the shading were less than 1 °C, although leaf temperatures (not measured) may have been higher in the full-sun plants. The full-sun plants had less leaf area, and only about three-quarters of the specific leaf area (leaf area per unit leaf mass). The shaded plants also had higher above-ground biomass, although the underground biomass did not differ significantly between treatments (Table 2). The strong adaptation of *A. pintoi* to shade partly explains its success as a cover crop for plantation crops such as coffee and oil palm. It also explains why it is able to compete and grow in association with grasses that apparently compete with it for light.

The regrowth dynamics of *A. pintoi* were studied in some detail in experiments in Guadaloupe (P. Cruz, unpublished data) to obtain more precise data about the regrowth potential, the dynamics of leaf area accumulation, and their consequences on interspecific relations with associated grasses. LAI develops rapidly after defoliation in pure swards, reaching values of 3 after as little as 2 weeks growth (Figure 4), which demonstrates the plant's capacity for rapid soil cover and its high competitiveness for light at the start of regrowth. In associations with grasses, however, LAI is reduced compared with pure swards because of the lower density of growing points.

The relation between LAI and efficiency of the interception of photosynthetically active radiation (PAR), E_i, was determined by measuring light interception with linear light sensors, and then calculating the light extinction coefficients (k). The k value was found to be 0.92, which is close to that of other legume species (alfalfa, clovers, *Vigna*, etc.) with horizontal leaves. The relation of E_i as a function of LAI showed that with an LAI of 3, *A. pintoi* intercepted approximately 90% of the incident radiation, which confirms its competitive capacity during regrowth. The conversion efficiency to dry matter of the intercepted PAR, E_b (g of dry matter per MJ of intercepted PAR), during regrowth cycles with high growth rates (80 kg/ha/day) was 1.17 g/MJ of intercepted radiation. This confirms the relatively low growth potential of *A. pintoi* compared with that of temperate legumes (alfalfa = 1.77 g/MJ, Durand et al., 1989), tropical

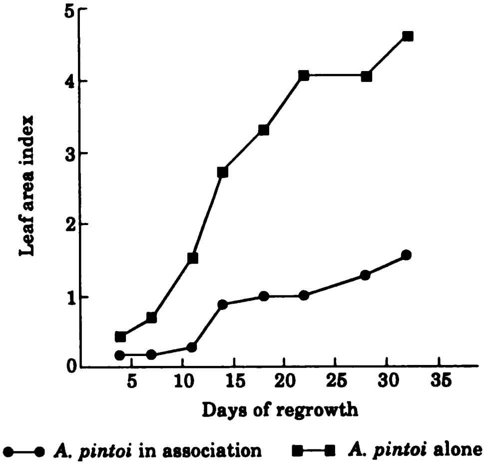

Figure 4. Accumulation of leaf area index of *Arachis pintoi* CIAT 17437 when grown alone and in association with *Digitaria decumbens*.

Table 2. The effects of different levels of shade on the growth of *Arachis pintoi* in pots at Palmira, Colombia, May-November, 1990.

Shade treatment	Leaf area	Leaf number	Specific leaf area	Above-ground biomass	Under-ground biomass
Full sun	659	457	150	9.77	25.2
70% full sun	1001	401	204	11.24	26.7
50% full sun	1103	423	216	12.56	28.5
30% full sun	1147	442	214	12.98	28.7
S.E.	25.6***	13.1 ns	6.4***	0.32**	2.0 ns

*** = $P < 0.001$, ** = $P < 0.01$, ns = $P > 0.05$.

annual legumes (*Vigna* = 1.63 g/MJ, Gosse et al., 1986; *Canavalia* = 1.64 g/MJ, Marín et al., n.d.), and C$_4$ perennial grasses (2.5 g/MJ, Gosse et al., 1986; Cruz, n.d.).

Mycorrhizal relations

Arachis pintoi is sometimes difficult to establish. While evidence supporting this assertion is largely anecdotal, there have been problems associated with its establishment in some large experiments (>20 ha) at Carimagua, Colombia. In general, its growth during the second and third years following seeding is reported to be slow, with yellow, unthrifty plants. Moreover, when *A. pintoi* is grown in pots, its growth is usually slow, and the plants exhibit a general chlorosis, which cannot be overcome by nutrient application. This problem can be readily overcome by applying to each pot just after emergence a small amount of the supernatant made by suspending a sample of soil from a healthy stand of *A. pintoi* in water.

It was hypothesized that the soil often used in pot experiments has been dried and stored for a number of months, that its biological activity is low, and that the supernatant contains mycorrhizae. In a pot experiment, this response was documented (Table 3) and clearly demonstrated the advantage of inoculation with the soil suspension in both the above- and below-ground yield of *A. pintoi*.

In order to test this hypothesis in the field, a factorial experiment was established in the field at Carimagua on a soil with 12% sand, using stolons as planting material (CIAT, 1991). No nitrogen was applied, but the Carimagua recommended basal fertilizer was applied. Treatments included a mixture of additional macronutrients (P, K, S, Mg) to double the amounts applied, micronutrients (Mo, B, Cu, Zn), inoculation with *Bradyrhizobium* (inoculated with the supernatant of a suspension of soil taken from a healthy, vigorous stand of *A. pintoi*), and dolomitic lime.

There was an interaction between additional macronutrients and lime (Table 4), with lime giving a response in the absence of additional macronutrients, but not when they were applied. Lime alone presumably releases some macronutrients from the soil, but when additional macronutrients are applied, this effect is masked. There was no significant response to the application of the supernatant, which was puzzling in view of the response observed in the pot experiment. Inoculation with mycorrhizae in the field, however, rarely produces positive results, so we do not regard the result as conclusive.

Table 3. The effects of soil inoculation and fertilizer on the growth in pots of *Arachis pintoi*.

Component	Biomass			Leaf area	Chlorophyll
	Above-ground (g/pot)	Below-ground (g/pot)	Total yield (g/pot)	(cm^2/pot)	(mg/m^2)
Normal fertilizer	4.68	12.9	17.5	733	6.42
Double fertilizer	5.77	13.9	19.6	767	6.65
S.E.	0.23***	0.75 ns	0.85 ns	30 ns	0.28 ns
No inoculation	4.73	11.9	16.7	664	6.40
With inoculation	5.72	14.8	20.5	835	6.67
S.E.	0.23**	0.75*	0.85**	30 ns	0.28 ns

*** = $P < 0.001$, ** = $P < 0.01$, * = $P < 0.05$, ns = $P > 0.05$.

Table 4. The effects of calcium and a mixture of P, K, S, and Mg on visual scores of early growth of *A. pintoi* at Carimagua, Colombia (2 November 1989).

	Basal macronutrients	Additional macronutrients
Lime, nil	24	81
Lime, 1 ton/ha	47	75

Competition

The maintenance of a desirable legume content in tropical pastures on acid, infertile soils in tropical America is partly constrained by edaphic factors, which include competition for mineral nutrients, compaction, waterlogging, and soil acidity. It is commonly observed that any one association may react differently under the same management on sites with contrasting soil textures. We must understand the factors responsible for the different reactions if recommendations for pasture management are to be soundly based. It is difficult to see how soil texture itself could affect plant growth, except in unusual circumstances. Of the possible edaphic factors, it seems that soil nutrient status and competition for nutrients are the most likely to be responsible for plant growth.

The major mineral nutrients deficient on the Colombian Llanos include the macronutrients phosphorus, potassium, magnesium, and sulfur. A study was carried out in the field at Carimagua (Kessels, 1990) to determine the influence of application of these four major mineral nutrients on the competitive relations between the components of five grass-legume associations, including *Brachiaria dictyoneura* CIAT 6133 with *Arachis pintoi* CIAT 17434, when grown on soils of contrasting textures. Four sites on Oxisols were chosen, with sand contents ranging from 10% to 52%.

Plants were established individually in a spatial arrangement to give a replacement series (de Wit, 1960) of five proportions, 0.00, 0.25, 0.50, 0.75, and 1.00. In one group of treatments, a factorial arrangement of both P and K was superimposed with basal dressings of S and Mg. In the other group, a factorial of both S and Mg was applied with basal dressings of P and K.

Data for relative dry matter yields (yield of the component in the mixtures compared with its yield in pure swards) show that *A. pintoi* generally stimulated *B. dictyoneura*, but was itself little affected by the presence of the grass (Figure 5). The proportion of *A. pintoi* tended to be higher on the less sandy soils.

Concentrations of K, P, Mg, S, and N in the plants were higher on clay soils than on sandy soils, and both K and Mg were more consistently taken up than either P or S. Differences in mineral concentration in the plants, however, were not reflected consistently in either their relative or total yields.

Responses to Mg and K occurred more frequently than responses to P or S, and occurred more frequently on sandy soils than on clay soils. This shows that Mg and K may play a relatively more important role in maintenance of established pastures. In this respect, the availability of sulfomag (containing both K and Mg) is of practical interest.

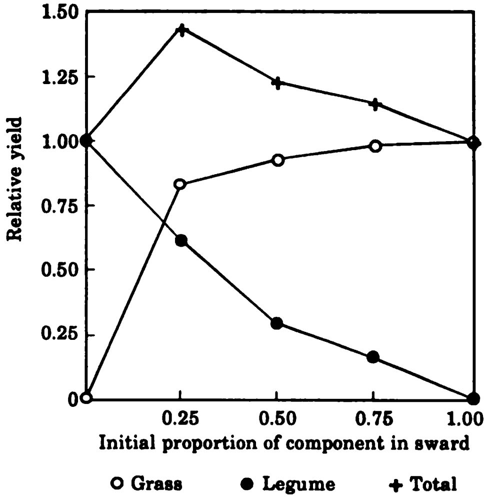

Figure 5. Relative yield proportions for *Brachiaria dictyoneura* and *Arachis pintoi* CIAT 17434 grown in a replacement series experiment in the field at Carimagua, Colombia.

In contrast, *A. pintoi*, which appears somewhat less efficient in its utilization of applied P than some other tropical legumes, is also more responsive to it at levels less than 20 kg/ha (Rao and Kerridge, Chapter 6, this volume), and competes more vigorously for it, so that its competitive position is improved as P is applied.

Compatibility with Grasses

Growth analysis in plots of *A. pintoi* in pure stands based on the efficiencies of E_i and E_b may be made with *A. pintoi* in association if one can separate the light interception of each species in a mixture. The radiation balance of an association cannot be measured experimentally, and for this reason we have relied on modeling. In the particular case of *A. pintoi* and *Digitaria decumbens*, the E_i of incident PAR was estimated using a simulation model of radiation interchange derived from Sinoquet et al. (1990). This model calculates the radiation balance of a crop assuming homogeneity in the horizontal plane. The canopy is divided into horizontal strata that contain one or both species; in the latter case, the mixture is considered to be homogeneous. Each stratum is defined in terms of the LAI of each of the species, their mean angle of foliar inclination, and their leaf reflectance. Other parameters entered are soil reflectance (albedo), the height of the sun, the ratio of diffuse to direct radiation, and the incident PAR.

The simulation of partitioning of light between the two species, compared with interception within pure stands, gave the following results (Figures 6 and 7):

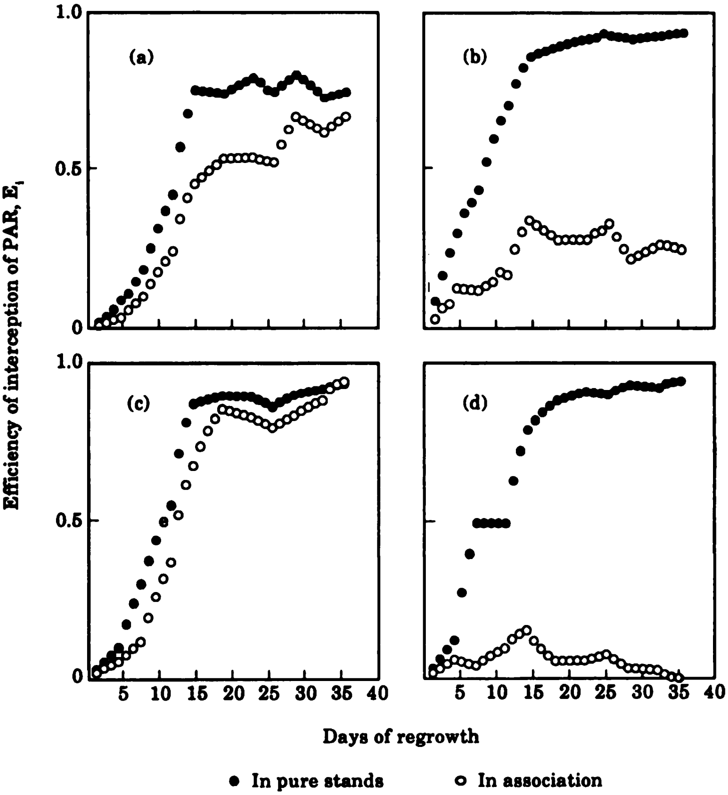

Figure 6. Changes during regrowth of the efficiency of interception of photosynthetically active radiation (PAR) in pure stands and in an association of *Digitaria decumbens* (a, c) and *Arachis pintoi* CIAT 17434 (b, d). The pastures were grown both without nitrogen (a, b) and with 150 kg/ha N (c, d) after defoliation.

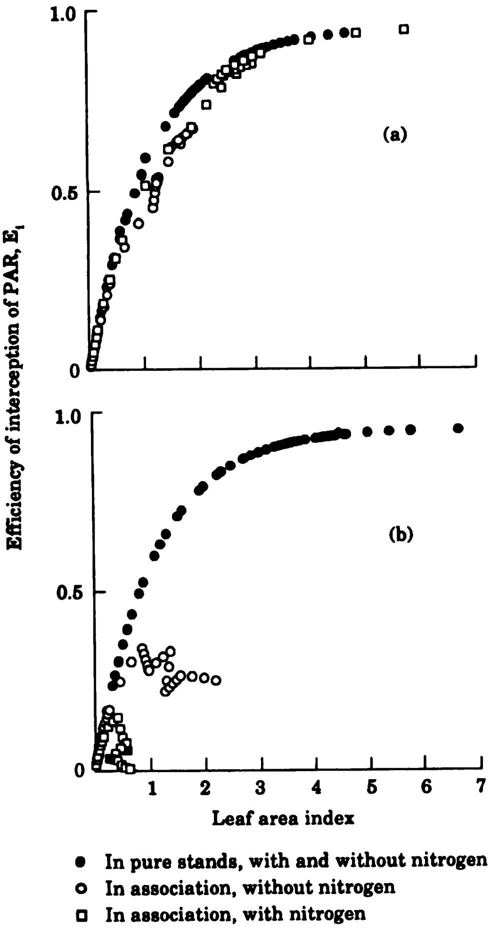

Figure 7. The efficiency of interception of photosynthetically active radiation (PAR) as a function of leaf area index in pure stands and in an association of *Digitaria decumbens* (a) and *Arachis pintoi* CIAT 17434 (b). The pastures were grown both without nitrogen and with 150 kg/ha N after defoliation.

- In spite of the rapid development of LAI, *A. pintoi* does not interfere to any important extent with the interception of light by the associated grass. Over the whole cycle of regrowth, shading by *A. pintoi* reduced the energy intercepted by the grass by less than 30%. This is a consequence of the legume's low height, which permits the grass to grow most of its foliage over the leaves of *A. pintoi*.

- Conversely, in natural growth conditions, that is, without any N fertilizer, *A. pintoi* intercepted only 25% of the incident radiation, which is equivalent to one-third of that which it intercepts in the absence of a grass. With heavy applications of fertilizer (150 kg/ha of N at the start of regrowth), light interception by *A. pintoi* at the end of the cycle was virtually zero, which would lead to its disappearance. N fertilizer thus affects the stability of the mixture indirectly by altering the competition for light.

Modifying the amount of PAR intercepted by each species influences its radiation use efficiency (RUE), that is, the efficiency of conversion of light to carbon. The consequences were (Figure 8):

- Neither of the two associated species varied significantly in their RUE compared with the respective pure stands, which shows that they behave neutrally in mixtures.

- In *Digitaria*, there was little reduction in its light interception, showing that the legume has little influence on the E_b of the grass.

- *Arachis pintoi* in association maintained its RUE at about that of pure stands, which confirms that it is well adapted to shade. It therefore appears to be an appropriate species to associate with C_4 grasses, which generally dominate for light. The response of *Arachis* to competition from the grass is thus a morphological and not a trophic response in that it produces a reduction in LAI, but does not modify RUE. Without N fertilizer, the values of the slopes for both species are similar.

Performance in Grazed Swards

Time course of composition and effect of forage allowance

An experiment was established in the field at Carimagua in 1986, which

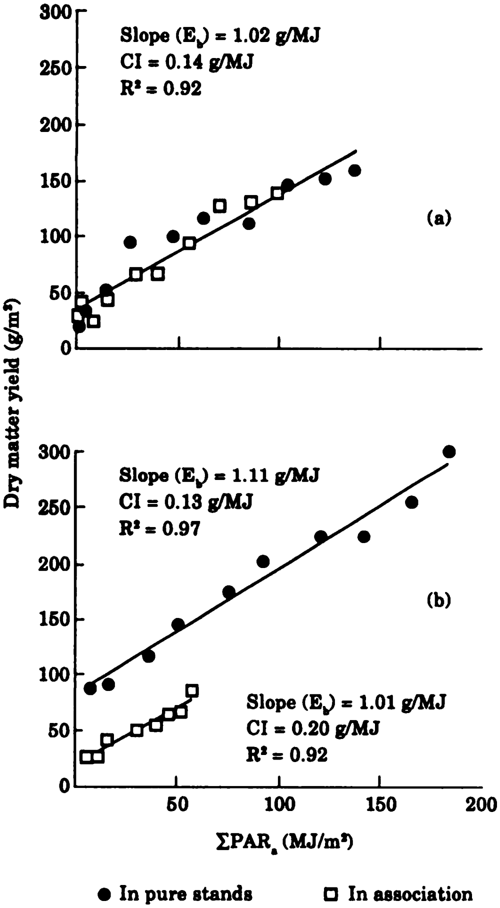

Figure 8. Dry matter yield as a function of accumulated intercepted photosynthetically active radiation (PAR) in pure stands and in an association of *Digitaria decumbens* (a) and *Arachis pintoi* CIAT 17434 (b). The slopes of the relations are a measure of the efficiency of utilization of the intercepted radiation.

included an association of *Brachiaria dictyoneura* CIAT 6133 and *Arachis pintoi* CIAT 17434, established in three ratios of grass to legume (high, medium, and low).

Despite the capacity of the plants to compensate for different densities, the proportions of grass and legume were maintained by cutting to different heights within the grass and legume rows. Cutting continued until grazing started to give the different compositions needed to determine the response functions related to composition.

The three composition treatments were grazed by cattle with esophageal fistulae, starting at the beginning of the wet season in June 1987, at three levels of forage allowance: high, low, and intermediate. The actual levels of forage allowance were varied as necessary to avoid overgrazing in the lowest forage allowance treatment. The cattle grazed in a rotational system of a 35-day cycle with a maximum occupation of each subplot of 3½ days. The occupation time was lessened when necessary to obtain the required grazing pressure, and the same group of cattle grazed the association to avoid changes of preference. When these cattle were not grazing the experimental plots, they were placed in a pasture of the same association next to the plots.

Samples were clipped at ground level from four quadrats allocated by ranked sets, immediately before the animals entered the plots and immediately after they left. Each sample was clipped into 10-cm strata, and further separated into leaf, stem, and dead material of each component. Samples were collected from the fistulated steers at the start of each grazing period in each plot.

In the establishment year, there was some severe chlorosis in *A. pintoi*, concentrated in the older leaves, suspected to be iron toxicity (tissue analysis gave concentrations of 1500 ppm, about three times more than expected) due to unusually wet conditions in July and August. Subsequently, during the dry season, the stolons of these plants were severely affected by *Rhizoctonia*, and many of them died or became depauperate. Recovery during the second year was extremely slow, but there was a spectacular improvement during 1988, and in 1989 the association was outstanding. The cattle gained in excess of 630 g/day of liveweight during the 6 months to 31 October 1989, and the proportion of the legume increased to between 30% and 50% of the biomass (in all forage allowance treatments) (Figure 9).

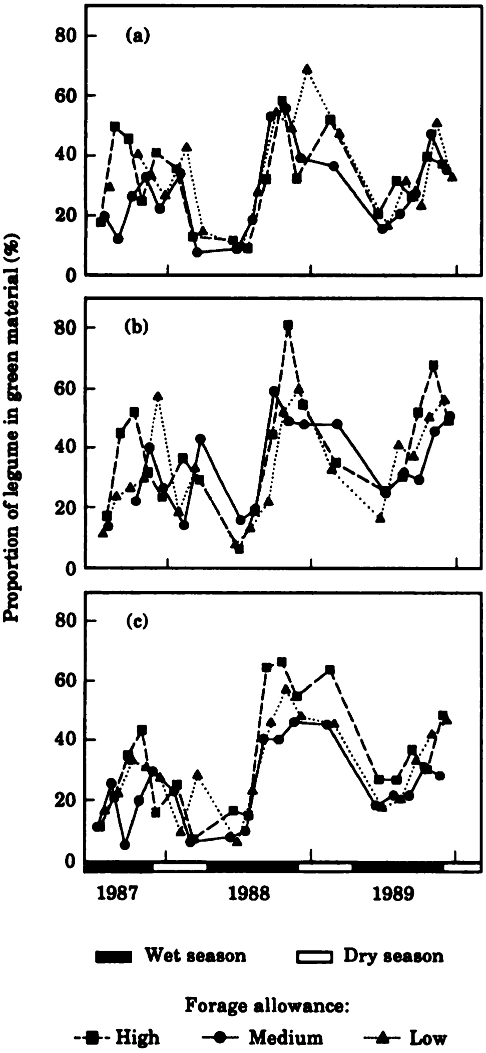

Figure 9. The time trends of the proportion of *Arachis pintoi* CIAT 17434 in an association with *Brachiaria dictyoneura* under a rotational system of 3½ days grazing at three levels of forage allowance (FA), followed by 31½ days rest at Carimagua, Colombia. Different proportions of legume (a, high; b, intermediate; c, low) were created prior to the first grazing cycle by using different seeding rates and cutting management.

Under the grazing management imposed in this experiment, *A. pintoi-B. dictyoneura* achieved a satisfactory balance between grass and legume, despite the different proportions at establishment. The factors that appear to be responsible are the characteristics of *A. pintoi* that allow it both to tolerate competition from the companion grass and to resist damage from grazing animals.

The stolons of *A. pintoi* establish aggressively and form independent plants, which are able to survive the dry season at Carimagua, in contrast to many other stoloniferous legumes. Moreover, the stolons are prostrate so that growing points are not readily consumed by cattle. *A. pintoi* grows larger leaves of a much darker green color when a stolon crosses through a tussock of the associated grass. The reasons for this behavior are unclear, but the implications as an adaptive mechanism for competitive growth with associated species are obvious. *A. pintoi* produces a large volume of buried seed, and the seedlings are vigorous by virtue of the large seeds. In many of its characteristics, *A. pintoi* is remarkably similar to white clover, and it appears to conform to the ideotype of a desirable plant for grazed pastures.

Analysis of environmental influence

Analysis of the behavior of an association in terms of the functions outlined earlier implies that growth as a function of leaf area is a key response of pasture growth. This function is equivalent to unit leaf rate (ULR), which invites an examination of how ULR and its associated measures of plant efficiency, relative growth rate (RGR), and leaf area ratio (LAR), developed during growth, and which external factors might control them.

RGR is growth rate per unit of plant biomass, and is a measure of plant efficiency. ULR is growth rate per unit leaf area, and is a gross measure of the efficiency of the photosynthetic system. LAR is leaf area index per unit of plant biomass, and is a measure of the relative size of the photosynthetic system. For any growth period with no discontinuities, the three indices are related mathematically by

$$RGR = ULR * LAR,$$

so that changes in RGR may be described by changes in either ULR or LAR, or in both.

RGR, ULR, and LAR were calculated for the association, but they showed no clear trends with time, except for a tendency for higher values during the growing season, as might be expected. This prompted an examination of the relation between RGR, ULR, and LAR and estimated soil water storage, calculated using a simple water balance model.

The overall data for both grass and legume indicate that a general relation exists, but with large variation when the estimated soil water is more than 90% of maximum (Figure 10). Examination of the meteorological data shows that many of these growth periods coincided with periods of heavy rainfall, during which there was concomitant flooding, indicated by an excess of precipitation over the sum of estimated soil water deficit and evapotranspiration.

When the data for the growth periods with more than 12 days flooding are excluded, the regressions of RGR, ULR, and LAR on estimated soil water were greatly improved (Table 5). Excluding data for the periods when flooding occurred during grazing did not improve the coefficients of determination. There were no consistent relations between either RGR, ULR, or LAR and the number of days of flooding during the growth cycle.

Flooding during the growth period explained much of the lack of fit between RGR, ULR, and LAR and estimated soil water balance. When growth cycles with more than 12 days of flooding were excluded, estimated soil water balance explained a substantial amount of the variance (Figure 11). Flooding during grazing had little effect on either the overall data or the restricted data set.

The legume and the grass react differently to water deficits as revealed by the differences between RGR, ULR, and LAR. RGR in the legume is more affected by water deficits than in the grass, as indicated by the difference of the slopes of the relations (Table 6).

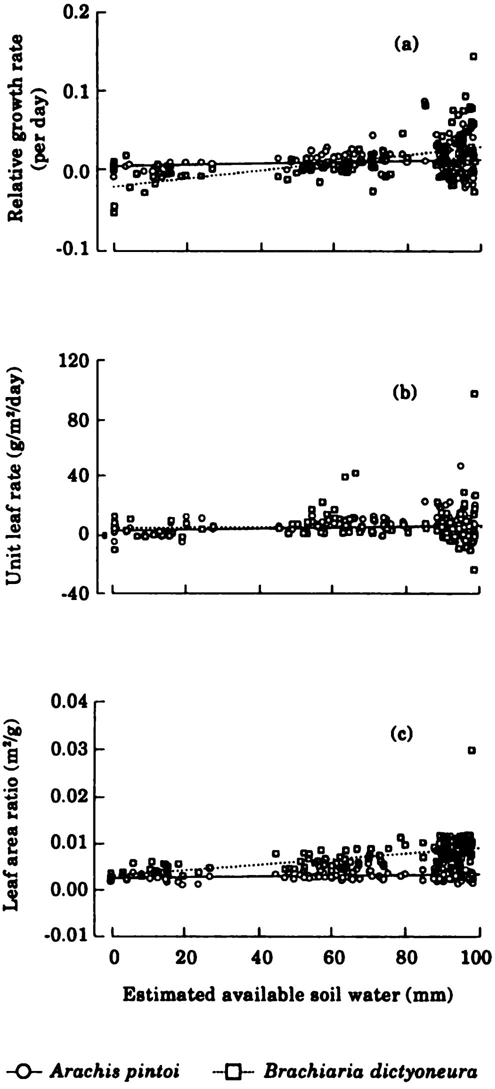

Figure 10. The influence of estimated soil water balance on (a) the relative growth rate, (b) unit leaf rate, and (c) leaf area ratio of an association of *Arachis pintoi* CIAT 17434 and *Brachiaria dictyoneura* during 31½ days of regrowth in a rotational grazing experiment at Carimagua, Colombia, over three years.

Although ULR in the grass was more sensitive to water deficit than in the legume, the differences were compensated by the higher LARs of the legume in comparison with those of the grass. Thus, the legume obviously sheds leaves in response to water deficits, but it maintains a higher level of photosynthetic efficiency. It presumably

Table 5. The coefficients of determination of the relations between growth indices and estimated soil water deficit for the association *Arachis pintoi-Brachiaria dictyoneura* under grazing at Carimagua, Colombia, 1987-1989. The numbers demonstrate the improvement in fit when data for flooding during grazing (see footnote) or for various levels of flooding during growth were excluded.

Days of flooding included during		Growth index					
Grazing	Growth	Relative growth rate		Unit leaf rate		Leaf area ratio	
		Grass	Legume	Grass	Legume	Grass	Legume
All	All	0.03	0.27	0.02	0.01	0.03	0.31
All	≤ 15	0.04	0.33	0.03	0.01	0.06	0.05
All	≤ 12	0.31	0.39	0.21	0.07	0.10	0.50
All	≤ 10	0.34	0.38	0.25	0.08	0.15	0.60
Restricted[a]	All	0.03	0.30	0.02	0.01	0.04	0.31
Restricted	≤ 10	0.33	0.43	0.24	0.08	0.17	0.59
Divided by grazing pressure							
Restricted	≤ 10						
High grazing pressure		0.46	0.50	0.30	0.14	0.34	0.55
Medium grazing pressure		0.43	0.55	0.30	0.10	0.18	0.53
Low grazing pressure		0.28	0.34	0.17	0.02	0.07	0.71

a. Data for a growth cycle were excluded if during the grazing period there were 20 mm or more of flooding in total, or if there were 10 mm or more in total with flooding on 3 consecutive days.

does this by shedding the older leaves, thus maintaining a higher level of activity in the remaining leaves.

The relation between growth rate and the amount of residual leaf material is central to understanding how systems of grazing management influence plant relations. The growth of legumes and grasses in association under grazing was examined in another experiment at Carimagua to understand in more detail the behavior of the associations in evaluation under grazing (Fisher and Thomas, 1989). The regrowth phase of accessions of *Brachiaria* species grown with *A. pintoi* and accessions of *D. ovalifolium* grown with *B. dictyoneura*, both grazed rotationally, was measured.

Treatments were forage allowances of 3 and 6 kg of dry matter/100 kg of animal liveweight, with two replicates, and plots were individually grazed for 2 years in a 5-week rotation. Samples were cut to ground level before the animals entered and immediately after they left, and the yield of leaf and stem of each component was determined.

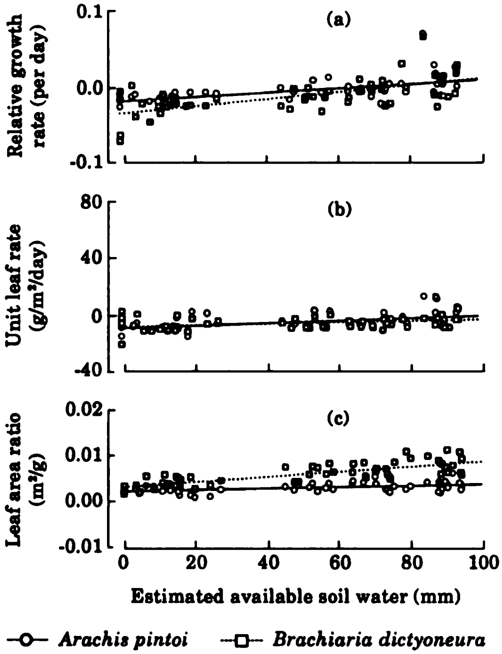

Figure 11. The influence of estimated soil water balance on (a) the relative growth rate, (b) unit leaf rate, and (c) leaf area ratio of an association of *Arachis pintoi* CIAT 17434 and *Brachiaria dictyoneura* during 31½ days of regrowth in a rotational grazing experiment at Carimagua, Colombia, over 3 years. Data for those harvests during which the soil was estimated to be saturated for more than 10 days were excluded.

Table 6. The slopes and intercepts of the relations between growth indices and estimated soil water for the association *Arachis pintoi-Brachiaria dictyoneura* under grazing at Carimagua, Colombia, 1987-1989. Data are for the restricted data set for flooding during grazing and growth (see Table 5).

	Relative growth rate		Unit leaf rate		Leaf area ratio	
	Grass	Legume	Grass	Legume	Grass	Legume
Coefficient	$2.7*10^{-4}$	$4.6*10^{-4}$	$8.1*10^{-2}$	0.043	$1.3*10^{-5}$	$5.5*10^{-5}$
±S.E.	$5.3*10^{-5}$	$7.2*10^{-5}$	$1.9*10^{-2}$	0.020	$3.9*10^{-6}$	$6.2*10^{-6}$
Intercept	$8.0*10^{-4}$	-0.017	0.55	1.88	$2.3*10^{-3}$	$3.2*10^{-3}$
±S.E.	0.014	0.018	4.9	4.9	$9.9*10^{-4}$	$1.5*10^{-3}$

The amount of leaf material during the regrowth stage should control the growth rate of a component unless some other factor interferes with the relation. Therefore, data were pooled between associations, and mean growth rate for each rest period was regressed on the mean leaf mass for each component in each of the treatments. A robust technique was used to fit the linear regressions, which identified outliers in the data.

Four features are evident from the regressions (Figure 12).

1. Within the same forage allowance treatment, common regressions fitted the data for the two legume species and all the grass species, despite the different associations, sites, and ages of the pastures.
2. The slopes of the regressions (equal to unit leaf rate, ULR) for the legumes were substantially lower than for the grasses, reflecting the different photosynthetic pathways of the C_3 legumes and the C_4 grasses. The difference in photosynthetic efficiency between tropical grasses and legumes has profound consequences on the prospects for the selection and management of compatible mixtures of tropical grasses and legumes (Fisher and Thornton, 1989).
3. ULR for both grasses and legumes was lower when forage allowance was higher. Biomass throughout the regrowth phase was higher in these treatments, so that it is likely that their mean leaf age would have been older. Therefore, we speculate that difference in mean leaf age was responsible for lower mean photosynthetic efficiency and hence lower ULR. Although shorter swards are more efficient, animal intake may be reduced, and absolute growth rates are lower. Thus, to achieve optimum pasture performance, we must strike a balance between animal intake and residual leaf mass.
4. There were a number of outliers in the data, all of which had lower growth rates than expected. Most of the outliers were for data measured in July, August, and September, which are among the 4 wettest months in Carimagua, and which were especially wet in both 1986 and 1987 (31% and 32% above the long-term mean total of 836 mm). It is unclear whether the lower growth rates were caused by one or a combination of factors such as nutritional problems associated with waterlogged soil, low levels of radiation caused by cloudy weather, or damage to plants by trampling during grazing when the soil was very wet.

This analysis showed the importance of residual leaf material as a primary determinant of regrowth capacity of grazed swards, although other factors may modify the relation. The legumes appear more sensitive to these other factors than the grasses.

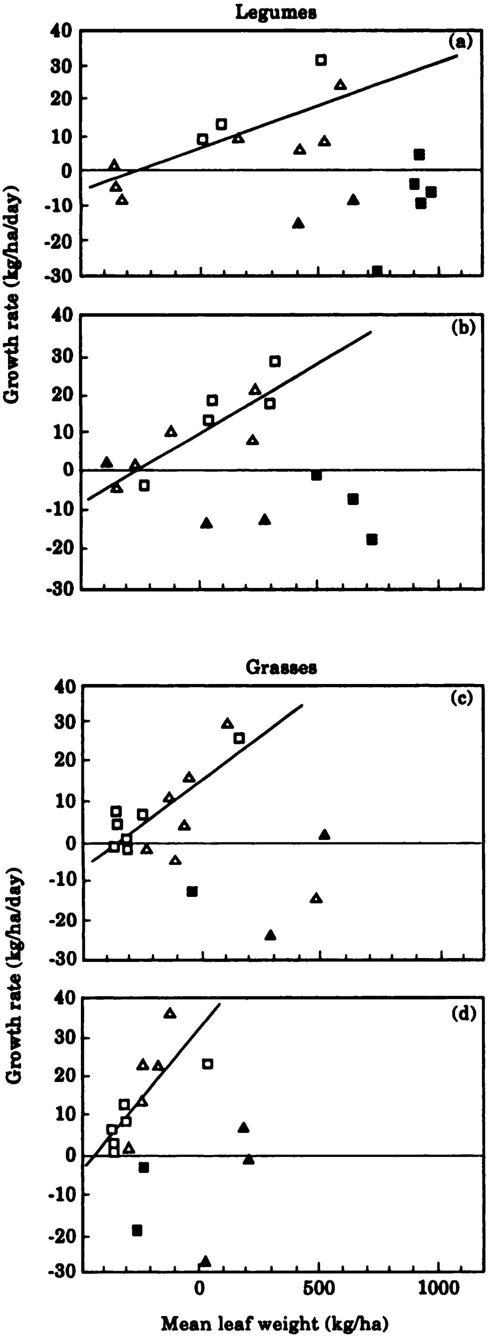

Figure 12. The relation between mean leaf mass and growth rate during 41 28-day regrowth cycles of the grass and legume components of associations of *Arachis pintoi* CIAT 17434 with a range of accessions of *Brachiaria* species, and a range of *Desmodium ovalifolium* accessions with *B. dictyoneura*. The pastures were grazed in a 35-day rotation at a forage allowance of 7 kg/100 kg of animal liveweight, (a) and (c), and 3 kg/100 kg, (b) and (d).

Establishment

The buried seed of *A. pintoi* is difficult and expensive to harvest, so that vegetative material is frequently used to establish new pastures. Establishment is at times reported to be slow, and especially so from vegetative material. During extended rainy periods, when the soils become waterlogged, *A. pintoi* becomes yellow, associated with high levels of iron in the tissues.

Either seed or stolons (consisting of two nodes bearing roots, and 10 cm of stolon) were grown in both a sandy and clay-loam soil from Carimagua in 6 kg of soil in cylinders 10 cm in diameter and 50 cm tall. Sequential harvests were made to measure plant growth, root extension, and leaf area over a 14-week period (Baruch and Fisher, 1992).

The data clearly show the superior rates of production of dry matter and leaf area of plants from seed compared with those from vegetative material (Figures 13 and 14). At the end of the

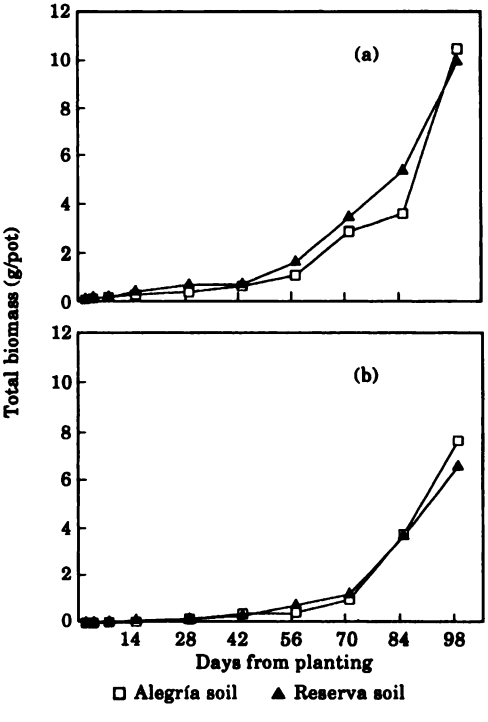

Figure 13. The influence of planting seed (a) or stolons (b) on the yield (roots and shoots) of *Arachis pintoi* CIAT 17434 grown in cylinders of soil.

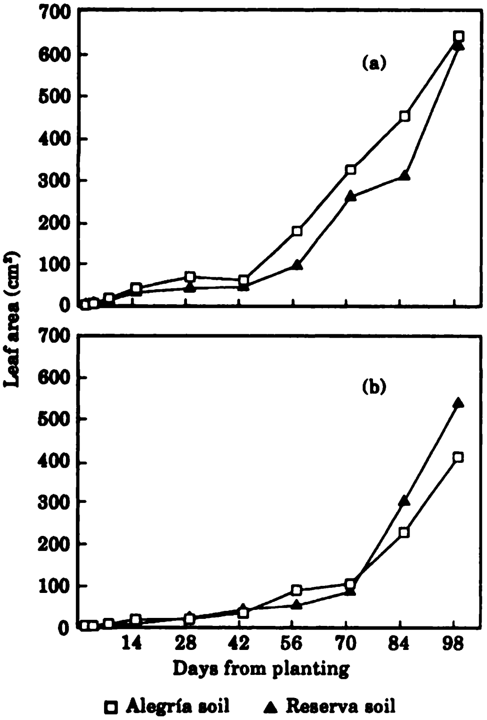

Figure 14. The influence of planting seed (a) or stolons (b) on leaf area accumulation of *Arachis pintoi* CIAT 17434 grown in cylinders of soil.

growth period, the seed plants had produced more than 50% more dry matter and leaf area as those from stolons. The seed plants were not much affected by the different soils, but the plants establishing from stolons tended to perform better in the sandier soil.

Suitability as a Ley Species

The performance of *A. pintoi* under cultivation deserves some comment. An old pasture of *A. pintoi-B. dictyoneura* was cultivated to sow a rice crop in 1990. After application of desiccant herbicide, burning, and each cultivation, plants regenerated profusely from stolons, root fragments, and seed, to the extent that there was severe competition with the germinating rice (contrast the amounts in Table 7). It is clear that with this species, we will need to give careful attention to agronomic practices to avoid problems. Timely cultivation during the early dry season, possibly with a moldboard plough, may be appropriate land preparation.

Table 7. Yields of paddy in some fertilizer treatments in rice sown following a 4-year-old pasture of *Arachis pintoi-Brachiaria dictyoneura*.

	Fertilizer (kg/ha)		
Phosphorus	12.5	25	100
Nitrogen	0	80	160
	Yield (kg/ha)		
Unweeded	860	1550	1710
Hand weeded	1080	4500	6780

Conclusions

Arachis pintoi clearly comes close to an ideal pasture legume ideotype. It is resistant to grazing by virtue of its procumbent stolons, which also allow it to readily invade any bare ground. The stolons root freely, so that, in contrast to trailing plants, damage or fracture by animals' hooves is unimportant. The nature of its compatibility with aggressive tropical grasses is still not completely clear, but its ability to tolerate shading, and even to grow better under shade, are obviously important. It is able to regenerate freely from seed, root fragments, and stolons, all of which contribute to its ability to persist and resist the effects of mismanagement.

Among the problems as yet unresolved are the agronomic questions of successful establishment, and the underlying physiological processes. There are some doubts as to the potential of *A. pintoi* as a weed if it were used as a ley species.

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Chapter 6

Mineral Nutrition of Forage *Arachis*

I.M. Rao
P.C. Kerridge*

Abstract

Information on the mineral nutrition of forage *Arachis* is limited to one accession of *A. pintoi* (CIAT 17434) and a few cultivars of *A. glabrata*. Although *A. pintoi* shows good adaptation to acid soils, its maximum growth appears to be limited below pH 5.4. Adaptation to low-fertility soils is associated with the maintenance of photosynthetic activity per unit leaf area.

One striking characteristic of *A. pintoi* and *A. glabrata* is the ability to acquire phosphorus from low-P soils. In one study using *A. pintoi*, this was associated with intensive fine root development on a fine-textured soil and high vesicular-arbuscular mycorrhizal activity on a coarse-textured soil. The ability of *A. pintoi* to acquire P in competition with grasses would contribute to its persistence when grown in association with grasses.

A study of the nutrient requirements of *A. pintoi* compared with those of other tropical forage legumes indicated a relatively low requirement for copper, molybdenum, and lime, and a moderate requirement for phosphorus, potassium, and zinc. However, it appears that *A. pintoi* does not use nutrients as effectively as some other legumes and grasses in terms of dry matter produced per unit uptake of a nutrient.

Diagnosis of mineral nutritional deficiencies using visual symptoms and plant tissue analysis has been developed for *A. pintoi.*

Further research is required on the comparative nutrition of accessions other than *A. pintoi* CIAT 17434, and other *Arachis* species, the importance of mineral nutrition on nitrogen fixation, acquisition of nutrients, maintenance fertilizer requirement, interaction of mineral nutrition and moisture stress, and nutrient requirement for seed production.

Introduction

Perennial *Arachis* species have only recently received widespread attention as forages and cover crops. But the increasing use of and interest in forage *Arachis* is such that it is likely that it will rank as high as *Stylosanthes, Desmodium, Centrosema*, and *Leucaena* as a forage legume in the tropics. To date, forage *Arachis* has only been used commercially in the southeastern United States, Australia, Colombia, and Costa Rica. Use has been limited in these countries to one accession of *Arachis pintoi* (called CIAT 17434 or Maní Forrajero Perenne in Latin America, CPI 58113 or Amarillo in Australia) and, in the USA, several accessions of *Arachis glabrata*. Information on mineral nutrition is largely limited to these accessions.

The objective of this review is to appraise the available information on the mineral nutrition of forage *Arachis* as a basis for assessing research priorities. Much of the information has not been published. Reference to the accession of *A. pintoi* is made according to the source of the seed and thus location of the research.

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* Plant nutrition physiologist and soil fertility agronomist/leader, respectively, Tropical Forages Program, CIAT, Cali, Colombia.

Mineral Nutrient Requirements

Edaphic adaptation

The released line of *A. pintoi*, CIAT 17434, has proved to be productive and persistent on a range of Oxisols and Ultisols of low pH and low exchangeable base status (Grof, 1985; Argel and Pizarro, 1992). But not all forage *Arachis* spp. tolerate low-fertility acid soils. Forty-five accessions of forage *Arachis* representing six species (*A. benthamii, A. glabrata, A. monticola, A. pusilla, A. villosa*, and *A. villosulicarpa*) were evaluated for their adaptation to conditions of low-fertility acid soils (Ultisol with 71% clay; pH 5.1; 4.1% total C; exchangeable cations (cmol/kg) 2.7 Al, 0.7 Ca, 0.5 Mg, 0.36 K; 1.8 mg/kg extractable P (Bray II); and 64% Al saturation) at the CIAT-Quilichao station (CIAT, 1981). All accessions grew poorly and produced little seed.

Wild *Arachis* accessions have been collected from a range of soils. Soil texture has varied from sand to clay and pH from < 5.0 to 7.5. It is thus not surprising that there is considerable variation in edaphic adaptation.

Soil acidity, pH, Ca, Mg, Al, Mn

The major factors affecting plant growth in acid soils are deficiencies of Ca and Mg and toxicities of Al and Mn. Macronutrients P and S and micronutrients Mo, Zn, Cu, and B are often deficient. Sometimes these factors are difficult to separate because of factor x factor and species x factor interactions. With legumes, the symbiosis, in particular nodulation and N fixation, is usually affected to a greater degree than the growth of the host plant (Kerridge, 1991).

We can assume that *A. pintoi* CIAT 17434 is well adapted to acid-soil conditions because of high forage and seed yields when grown on an isohyperthermic soil (Oxisol with 37% clay; pH 5.0; 2.0% total C; exchangeable cations (cmol/kg) 2.6 Al, 0.21 Ca, 0.1 Mg, 0.06 K; 2.1 mg/kg extractable P (Bray II); and 89% Al saturation) at Carimagua, in the Llanos of Colombia (Grof, 1985), with inputs of (kg/ha) 20 P, 20 K, 12 Mg, and 12 S. Other accessions of *A. pintoi*, such as CIAT 18744, 18748, and 18751, have shown equally good growth on acid soils (Ultisol with pH 4.6; 5.2% total C; exchangeable cations (cmol/kg) 3.0 Al, 0.9 Ca, 0.38 Mg, 0.17 K; 2.0 mg/kg extractable P (Bray II); and 70% Al saturation) at San Isidro, Costa Rica. These accessions had a darker green foliage than CIAT 17434.

CIAT 17434 is often quite yellowish, as though it were N, S, or even K deficient, and there have been few responses to applications of N, S, and K fertilizer. Some accessions do not turn yellow when grown alongside CIAT 17434. Increased shoot growth and darker green leaves under shade suggest there may be damage due to photoinhibition in open sunlight (Fisher and Cruz, Chapter 5, this volume). In Australia, shading has eliminated this yellowing, with no difference in yield between shaded and unshaded areas (B.G. Cook, personal communication). These observations suggest that the commonly observed yellow symptoms are not necessarily due to nutrient deficiency.

The differential effects of soil acidity on plant growth and symbiosis (nodulation and N fixation) were examined in a liming experiment where *A. pintoi* cv. Amarillo was grown with or without added N and basal P, S, K, Zn, Cu, Mo, and B on an acid subsoil of pH (H_2O) 4.3; exchangeable cations (cmol/kg) 0.49 Ca, 1.77 Mg, 0.28 K, 0.18 Na; and 72% Al saturation (Table 1; P.C. Kerridge, unpublished data). There was a moderate yield response to liming, with a greater response in the absence of mineral N. Thus, plants grown with mineral N produced 80% of the maximum yield without added lime, while those depending on symbiotic N fixation required 1000 kg/ha lime to produce 80% of the maximum yield. In the absence of mineral N, nodulation and N fixation gradually increased with increasing lime application, which could be due to increased soil Ca or a reduction in soluble

Table 1. Differential effects of soil acidity on plant growth and symbiosis of *A. pintoi* cv. Amarillo.

Plant parameters	Lime (kg/ha) as CaCO$_3$ and resultant pH					
	0	100	500	1000	2000	4000
	4.6	4.6	4.8	5.0	5.4	5.9
Yield with 200 kg/ha N (g/pot)	5.9	6.5	6.5	6.7	7.5	7.6
Yield with nil N (g/pot)	3.1	3.3	3.8	4.4	5.1	5.7
Nodulation[a]						
Nodule wt. (g/pot)	0.04	0.10	0.17	0.19	0.24	0.29
Nodule number (no./pot)	54	152	316	357	514	503
Nutrient concentration[a] (g/kg)						
N in YEL[b]	19.0	20.3	23.1	21.9	26.6	32.3
N in whole shoot	15.7	16.5	17.5	17.0	18.1	20.5
Ca in whole shoot	3.2	6.2	9.3	12.4	16.0	18.0

a. Nil N treatment.
b. YEL = youngest expanded leaf.
SOURCE: P.C. Kerridge, unpublished data.

Al, or both. Plants were dark green with mineral N but chlorotic without added N, except in the higher lime treatments. N concentration increased more rapidly in the youngest expanded leaf than in the whole shoot. These results demonstrate that while the plant is adapted to acid soil, maximum growth in this soil was limited by the effectiveness of nodulation and N fixation below pH 5.4. In the N treatment, nodules were white and sparse, and only occurred with ≥ 500 kg/ha of lime.

A. pintoi CIAT 17434 appears to adapt to low-fertility acid soils by maintaining its photosynthetic activity per unit leaf area when there is less growth and thus less leaf area production (Table 2; Rao et al., 1993a). Shoot and leaf growth and leaf area were increased by higher fertilizer application, but photosynthetic activity per unit leaf area remained the same at both fertilizer levels. This is noteworthy as P is known to limit photosynthesis (Terry and Ulrich, 1973; Bouma, 1983). In this experiment, the main response was most likely due to P and K.

Adaptation to low P supply

A glasshouse experiment comparing the response of *A. pintoi* to P fertilizer on a sandy loam soil (Oxisol with 17% clay; pH 5.1; 0.52% total C; exchangeable cations (cmol/kg) 0.7 Al, 0.13 Ca, 0.08 Mg, 0.03 K; 2.0 mg/kg extractable P (Bray II); and 77% Al saturation) and a clay loam soil (Oxisol with 37% clay; pH 5.0; 2.0% total C; exchangeable cations (cmol/kg) 2.6 Al, 0.21 Ca, 0.1 Mg, 0.17 K; 2.1 mg/kg extractable P (Bray II); and 89% Al saturation) from Carimagua, Colombia, allows us to make some observations on adaptation to low soil P (Rao et al., 1993b,c). The P response is shown in Figure 1, and other measured variables in Table 3. P application was not high enough for an asymptote to be reached. Plant P concentrations did not increase greatly after the first level of P application, indicating that the P was being used efficiently for growth. Moreover, there was little change in adaptive characteristics after the first level of added P. Without added P, there was a higher root-to-shoot ratio, a finer root system, and much higher mycorrhizal infection. The difference in adaptation of *A. pintoi* between soils was that in the sandy loam soil there was higher mycorrhizal infection but fewer fine roots than in the clay loam soil. In the field at Carimagua, *A. pintoi* grows and persists better on the clay loam soil than the sandy loam soil. This may be attributable to poorer fine-root development, lower availability of K, and greater moisture stress in the sandy loam soil.

In the same experiment, *A. pintoi* took up more P per unit root length than the grass, *Brachiaria dictyoneura*, but produced less growth per unit of P taken up (Rao et al., 1993b,c).

Table 2. Influence of soil type[a] and two levels of added fertilizer[b] on some shoot characteristics of *A. pintoi*.

Shoot characteristics	Sandy loam		Clay loam		LSD (P = 0.05)
	Low fert.	High fert.	Low fert.	High fert.	
Shoot biomass (g/pot)	3.9	8.1	4.5	8.6	1.6
Leaf biomass (g/pot)	1.9	2.8	2.0	3.5	0.8
Leaf area (cm^2/pot)	460	790	460	820	320
Specific leaf area (m^2/kg of leaf wt.)	25	27	23	23	NS
Net photosynthesis (μmol/m^2/s)	10.4	10.8	12.6	13.2	NS
Leaf P concentration (g/kg)	1.1	1.2	1.3	1.8	0.2
Leaf K concentration (g/kg)	8.8	14.4	9.7	15.1	1.6

a. Chemical analyses for the two soils are given in the text, p. 73.

b. Low fertilizer (kg/ha): 20 P, 20 K, 50 Ca, 14 Mg, and 10 S; high fertilizer (kg/ha): 40 N, 50 P, 100 K, 100 Ca, 28 Mg, 20 S, and micronutrients.

SOURCE: I.M. Rao, unpublished data.

Table 3. Influence of varying P supply and soil type on some plant parameters related to P supply in *A. pintoi*.

Plant parameter	Soil type	P supply[a] (kg/ha)				LSD (P = 0.05)
		0	10	20	50	
Leaf N concentration (g/kg)	Sandy loam	25.4	25.9	28.5	28.8	
	Clay loam	34.0	28.7	29.2	27.5	3.6
Leaf P concentration (g/kg)	Sandy loam	0.8	1.8	1.9	2.0	
	Clay loam	0.9	1.3	1.7	1.9	0.3
Root length mycorrhizal (%)	Sandy loam	57	25	5	13	
	Clay loam	10	5	2	<1	6
Specific root length (m/g)	Sandy loam	25	17	13	13	
	Clay loam	47	33	33	28	11

a. P added as calcium dihydrogen phosphate.

SOURCE: Rao et al., 1993c.

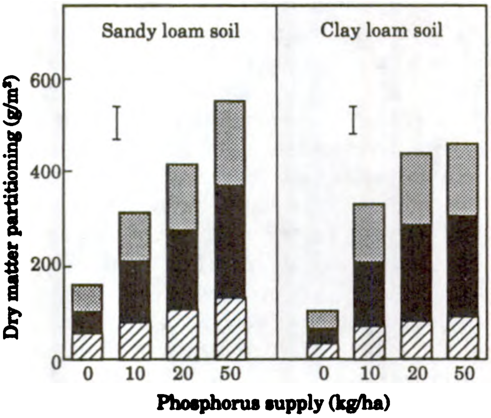

Figure 1. Influence of varying phosphorus supply and soil type on dry matter partitioning in *A. pintoi* among root ▨, stem ■, and leaf ▩. Vertical bars represent LSD, P = 0.05.

A. pintoi is able to take up more P than the grass, *B. dictyoneura*, when soil P is low or P is added in less soluble forms than calcium dihydrogen phosphate (Figure 2; CIAT, 1993). Shoot-P uptake by *A. pintoi* from the unfertilized clay loam soil or with P added as aluminum phosphate, organic phosphate, or dung at 20 kg/ha P was significantly higher than for the grass. But when the grass and legume were grown together, we can see that the effect was not additive, indicating that both grass and legume are exploiting the same source of P. Nevertheless, in an association with a grass, this ability of *A. pintoi* to acquire P in competition with a grass could be one characteristic that contributes to its persistence in a mixture.

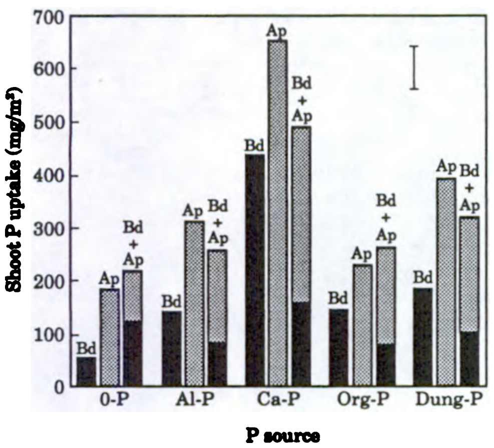

Figure 2. Shoot phosphorus uptake per square meter of soil surface area for *Brachiaria dictyoneura* (Bd ■), *Arachis pintoi* (Ap ▨), and an association of Bd + Ap grown in a clay loam soil with nil P or added as 20 kg/ha P from different sources (Al-P = $AlPO_4$; Ca-P = $CaHPO_4$; organic-P = phytic acid). Twenty plants per container in monoculture and 10 plants of each species in associations. Vertical bar represents LSD, P = 0.05.

Mycorrhizae and P requirement

Vesicular-arbuscular mycorrhizae are important for P supply to forage legumes and grasses in tropical Oxisols (Arias et al., 1991; Sieverding, 1991). It is thus important to ensure that there is a satisfactory mycorrhizal level or that the soil is inoculated when we assess the requirement for and response to P. When the soil has a low mycorrhizal population or inoculation is not used in pot experiments, then the short-term results of the P requirement may be misleading.

A. pintoi appears to depend less on mycorrhizal acquisition of P than some other plant species. Mycorrhizal infection increased shoot and root production and total uptake of P, N, K, and Ca in *A. pintoi* and other legumes and grasses, but it had little effect on nutrient composition (Table 4; Saif, 1987). The mycorrhizal dependency (as determined by expressing dry weight of mycorrhizal plants as a percentage of dry weight of nonmycorrhizal plants) for *A. pintoi* was 220% compared with 299% for *Stylosanthes capitata* and 541% for a grass, *Brachiaria dictyoneura* (Saif, 1987). But this finding is for relatively young plants (8-10 weeks), and could change in more mature stands.

Table 4. The effects of inoculation with vesicular-arbuscular mycorrhizae on growth and nutrient concentration of *A. pintoi* grown in sterilized clay loam Oxisol from Carimagua, Colombia.

Plant parameter	Nonmycorrhizal	Mycorrhizal
Shoot dry wt. (g/pot)	0.92	2.03
Root dry wt. (g/pot)	0.52	0.87
Nutrient concentration (g/kg)		
N	36.6	33.3
P	2.5	1.9
K	16.8	16.1
Ca	9.6	10.0
Utilization of soil P (initial available soil P + P applied) (%)	10.87	30.16

SOURCE: Saif, 1987.

Mycorrhizal infection decreased with the increase in P supply to *A. pintoi* in soils from the Llanos of Colombia (Table 3). The percentage of root length that was mycorrhizal was lower for *A. pintoi* than for the grass, *B. dictyoneura*, but *A. pintoi* still absorbed more P per unit root length than the grass (Rao et al., 1993c).

Potassium

There is no evidence of adaptation to low potassium availability. *A. pintoi* CIAT 17434 has responded strongly to K fertilizer when soil exchangeable K is less than 0.06 cmol/kg. There was a response to additional K fertilizer when *A. pintoi* was grown with *B. dictyoneura* on a sandy loam soil using the standard Carimagua pasture fertilizer mixture (Table 5; A. Rincón, M. Ayarza, and I.M. Rao, unpublished data). This was during establishment; an even higher response might be expected subsequently.

Salt tolerance

A. pintoi cv. Amarillo showed only moderate tolerance of high salinity

Table 5. Response of *A. pintoi* CIAT 17434 to fertilizer application as influenced by soil texture during the rainy season at Carimagua, 1991. Plants were harvested 5 months after establishment.

Mixture	Fertilizer application							Dry matter yield	
	N	P	S	Ca	Mg	K	Micro.	Sandy loam	Clay loam
				(kg/ha)				(kg/ha)	
Nil	-	-	-	-	-	-	-	60	160
P + Ca	-	20	-	50	-	-	-	230	330
Low (L)[a]	-	20	12	50	20	20	-	340	390
L + Micro (LM)[b]	-	20	12	50	20	20	+	380	440
LM + N	40	20	12	50	20	20	+	410	410
LM + P	-	60	12	50	20	20	+	440	340
LM + S	-	20	36	50	20	20	+	380	350
LM + K	-	20	12	50	20	100	+	570	400
LM + Ca	-	20	12	200	20	20	+	460	420
LM + Mg	-	20	12	50	60	20	+	410	420
High[c]	80	60	24	150	40	100	+	610	510
LSD ($P = 0.05$)								80	

a. Pasture fertilizer mixture (kg/ha): 20 P, 20 K, 50 Ca, 20 Mg, and 12 S.

b. Micronutrients (kg/ha): 2 Zn, 2 Cu, 0.1 B, and 0.1 Mo.

c. Crop fertilizer mixture (kg/ha): 80 N, 60 P, 100 K, 150 Ca, 40 Mg, 24 S, and micronutrients.

SOURCE: A. Rincón, M. Ayarza, and I.M. Rao, unpublished data.

(Keating et al., 1986). The conductivity at 50% maximum growth was 7.9 dS/m for *A. pintoi* compared with 16.4 dS/m for a moderately salt-tolerant grass, *Panicum coloratum*, and 5.6 dS/m for the low salt-tolerant *Stylosanthes scabra*.

Comparative Nutrient Requirement

A. pintoi cv. Amarillo was one of several legumes compared for their relative nutrient requirements for P, S, K, Cu, Zn, and lime (P.C. Kerridge, unpublished data). Response curves were obtained using soils from southeast Queensland, Australia, known to be deficient in a particular nutrient. Nutrients other than the ones under investigation were added as a basal application. Legumes were inoculated and grown without added mineral N. Table 6 shows the relative requirements. *A. pintoi* had a relatively low requirement for Cu, Mo, and lime, and a moderate requirement for P, K, and Zn. Nevertheless, without added P, K, Zn, and Cu (with other nutrients nonlimiting), *A. pintoi* produced as much or more shoot growth than the other species.

Centrosema pascuorum was the only species that was more tolerant of soil acidity than *A. pintoi*. An interesting contrast between the two legumes was that while *C. pascuorum* had lower Al shoot concentrations (40-60 mg/kg) than the other legumes, suggesting it was excluding Al, *A. pintoi* had the highest shoot Al concentration (600-800 mg/kg), suggesting there was some chelation or compartmentalization of the Al. Al concentrations did not decrease proportionally with increased lime application.

A. pintoi and *Stylosanthes guianensis* did not show a response to Mo, whereas the other species produced only 20% to 60% of their maximum yield without Mo and required from 40 to 400 g/ha Mo for maximum yield.

A. pintoi and *V. parkeri* had higher relative yields than the other legumes without added Cu and required the lowest amount of additional Cu for maximum yield. In addition, other noteworthy features for the Cu nutrition of *A. pintoi* were (1) that the critical nutrient levels for Cu were higher than for the other species, being 8 mg/kg in the youngest expanded leaf (YEL) and 5 mg/kg in the whole shoot (WS), with the values for other species ranging from 1.5 to 3 (YEL) and 2 to 4 (WS) mg/kg,

Table 6. Comparative requirement of pasture legumes for nutrients based on response, where 1 = low and 5 = high.

Species	P	S	K	Cu	Zn	Mo	Lime
Stylosanthes scabra	1	3	1	1	2	1[a]	3
Cassia rotundifolium	2	1	2	3	4	4	2
Arachis pintoi	3	2	3	1	3	1	1
Aeschynomene falcata	3	1	2	2	3	3	3
Centrosema pascuorum	4	2	3	3	2	nd[b]	1
Macroptilium atropurpureum	4	4	4	3	1	3	3
Indigofera schimperi	5	4	2	3	2	nd	5
Aeschynomene americana	3	3	3	4	4	2	4
Vigna parkeri	3	5	1	1	4	3	4

a. *S. guianensis.*
b. nd = not determined.
SOURCE: P.C. Kerridge, unpublished results.

and (2) there was a greater accumulation of Cu than in other species when it was added in excess of requirement, with a Cu concentration of 22 mg/kg being observed with the addition of 1.62 kg/ha Cu.

This study and that of Rao et al. (1992, 1993c) also suggested that *A. pintoi* does not use nutrients as effectively as some other species in terms of dry matter produced per unit uptake of a nutrient. The responsiveness to added nutrients in the linear portion of the response curve was moderate for P and lime and low for S and K.

Diagnosis of Mineral Nutrient Disorders

Diagnostic techniques of visual symptoms, plant tissue analysis, soil analysis, and greenhouse and field trials have been developed to a limited extent for *A. pintoi* and *A. glabrata.*

Visual symptoms

Most nutritional deficiencies of forage *Arachis* will produce visible symptoms that are useful for diagnostic purposes. Figure 3 shows the nutritional disorder for Mn toxicity and the nutrient deficiencies of N, P, S, K, Ca, Mg, Zn, and Cu for *A. pintoi.* Table 7 describes some key characteristics of the visual symptoms.

Using visual symptoms for diagnosis has several limitations. Growth is usually severely reduced by the time visual symptoms are observed, there may be multiple deficiencies, and these deficiencies may be confused with disease and insect damage and physiological stresses. However because symptoms, or extreme nutrient deficiency, usually occur in patches, visual symptoms can be used together with foliar analysis to define a particular nutrient deficiency.

The first step in identifying nutrient disorders by visual symptoms is to observe plant growth and development. The second step is to note what plant part is affected. The third step is to recognize the nature of the symptoms (e.g., chlorosis, necrosis, deformation). If symptoms appear on the older leaves, there is a possibility of deficiency of mobile nutrients such as N, K, and Mg. If deficiency symptoms first occur on young leaves, deficiency of immobile nutrients such as Ca, Zn, Fe, S, B, or Mn may be suspected. Mo deficiency in legumes will first appear as N deficiency in plants depending on symbiotic N fixation. Symptom diagnosis may also be verified by comparing nutrient concentration in affected and healthy tissue of the same age and plant part.

Plant tissue analysis

Plant tissue analysis for diagnosis of nutrient deficiencies uses the "critical

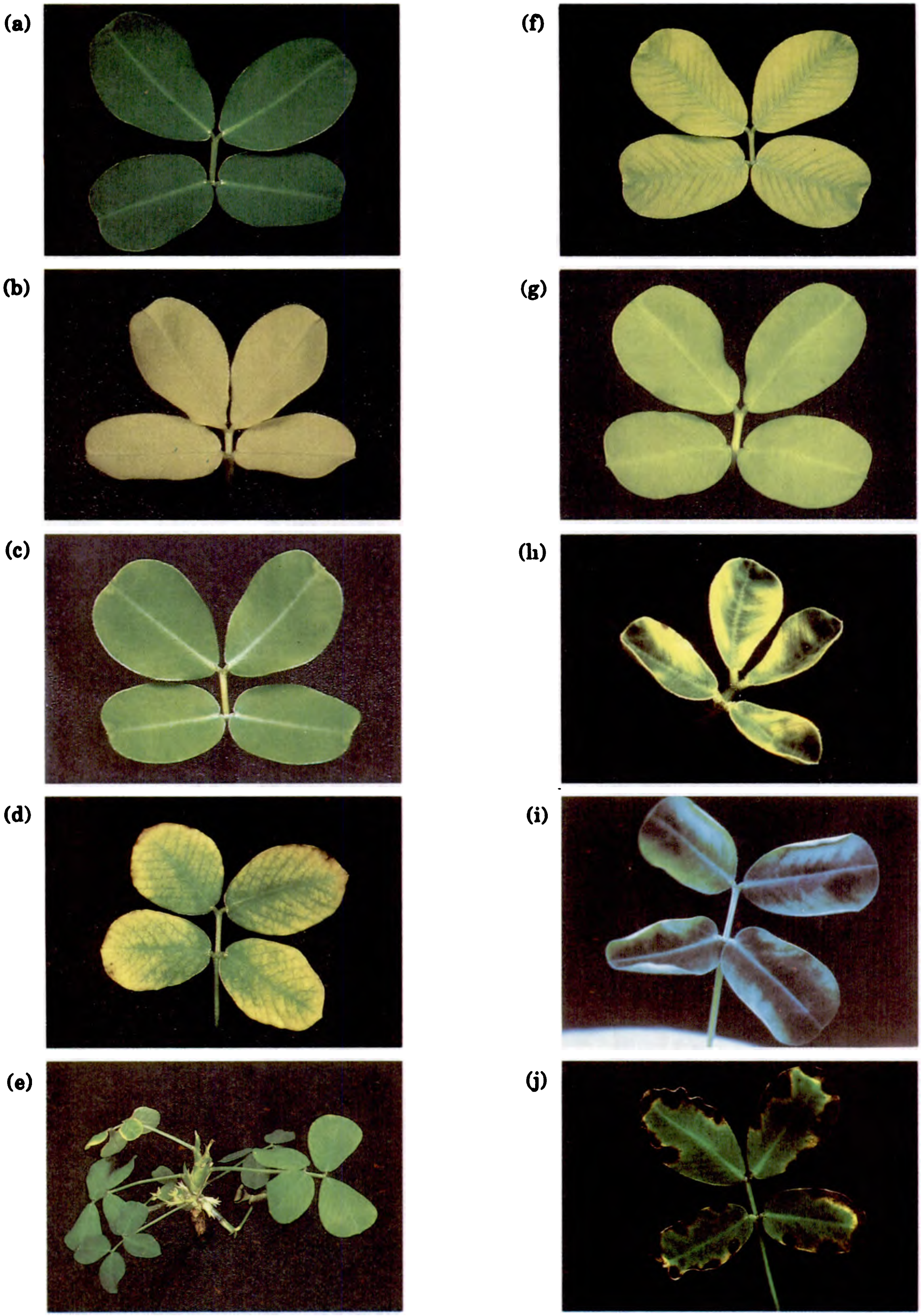

Figure 3. Visual symptoms of nutrient disorders on leaves of *A. pintoi*: (a) control; (b) nitrogen deficiency; (c) P deficiency; (d) potassium deficiency; (e) calcium deficiency; (f) magnesium deficiency; (g) sulfur deficiency; (h) zinc deficiency; (i) copper deficiency; and (j) manganese toxicity.

Table 7. General description of visual symptoms of nutrient disorders in *A. pintoi*.

Nutrient disorder	Visual symptoms
Deficiency:	
N	Chlorosis developing in older leaflets, developing into general chlorosis of the whole plant.
P	Stunted growth; new leaflets dark green in color and smaller in size than those of normal plants.
K	Older leaflets show interveinal chlorosis with marginal and apical necrosis.
Ca	New leaflets become white; growing points die and curl; older leaflets remain dark green.
Mg	Interveinal chlorosis, developing into marginal chlorosis, occurring first on older leaves.
S	Chlorosis of younger leaflets; older leaflets initially remain darker green in color. In severe deficiency, symptoms are similar to those of N deficiency.
Zn	Younger leaflets are smaller and have some crinkling; interveinal chlorosis develops; margins of leaflets that are still expanding cup upward.
Cu	Younger leaflets with whitish color on margins and leaflets curling inward.
Toxicity:	
Mn	Leaf margins of fully expanded leaves develop necrotic patches; leaflet veins turn dark brown in color.

value" concept, that is, a value or range above which there is no further response to addition of a nutrient. There is a need to establish such values or ranges by calibration. Furthermore, because of nutrient concentrations that vary with tissue sampled, the physiological stage of growth, the treatment of the sample prior to analysis, and environmental variables affecting growth (Smith, 1986), there is a need to ensure that samples collected for diagnostic purposes have been grown under conditions similar to those used for calibration.

Table 8 shows the critical values or ranges for *A. pintoi* cv. Amarillo together with those of *A. hypogaea* and some other tropical legumes. *A. pintoi* would appear to have higher critical levels for P and Cu than other tropical legumes.

Soil analysis

Soil analysis data can be of considerable predictive value, indicating likely nutritional problems on a particular type of soil. There is usually less variation due to environmental variables in soil tests than in plant analysis, but errors resulting from spatial variation can be large. When available nutrients are low, soil tests can be less sensitive to slight increases in available nutrients than is plant growth.

It is also necessary to calibrate soil tests against actual plant responses and on different soil types before they are used to predict nutrient deficiency or requirements, and to state the method used when reporting the results (Salinas et al., 1990). This has not been done for any of the forage *Arachis* species. The critical levels of soil nutrients suggested for *Centrosema* species (Salinas et al., 1990) may be used as a guide.

Greenhouse and field trials

These trials are useful for specific soils and locations, but the results cannot be extended to other locations unless they have been correlated with soil analyses. These results may be useful in monitoring field fertilizer requirements and in developing indices for species grown in mixtures.

An additive type design was used in a glasshouse experiment to identify Ca, Mg, and S as major nutrient deficiencies, in addition to P, for *A. pintoi* on two acid soils from the Llanos of Colombia (CIAT, 1985).

In a field experiment at Carimagua, on the Llanos of Colombia, an additive design was used to assess the adequacy of the recommended "pasture fertilizer mixture" during

Table 8. Values or ranges for critical concentrations or adequacy (+) of various nutrients of *A. pintoi* shoots compared with other forage legumes and *A. hypogaea*, the peanut.

Nutrient	*A. pintoi*		*C. pascuorum*		*C. pubescens*	*Stylosanthes*	*A. hypogaea*
(g/kg)	YEL[a]	WS	YEL	WS	WS	WS	YEL (prior to pod set)
N	—	—	—	—	—	21.0-31.0	35.0-45.0^{+}
P	2.1	2.3	1.7	1.6	1.6-2.0	1.7-2.5	2.8-3.0^{+}
K	13.0	5.0	9.0	5.0	7.5-14.0	7.8-9.2	28.0-30.0^{+}
Ca	—	18.0^{+}	—	—	6.0-13.0	8.0-14.0	12.5-17.5^{+}
Mg	—	—	—	—	2.4-4.6	2.3-3.1	3.0-8.0
S	1.3	1.1	5.0	4.0	1.5-1.9	1.1-1.5	2.0-3.0
(mg/kg)							
Zn[b]	24	16	21	11	20-25	16-24	20
Cu	8	5	>2	2	4-6	4-6	10
B							18
Mo							<1
Fe							100-250^{+}
Mn					1660 (threshold)		10

a. YEL = youngest expanded leaf; WS = whole shoot; + = adequate.

b. Zn deficiency may occur at values equal to or greater than these values due to a "Steenbjerg" effect.

SOURCES: P.C. Kerridge, unpublished data; Salinas et al., 1990; Salinas and Gualdrón, 1989; Small and Ohlorogge, 1973.

establishment of an *A. pintoi-B. dictyoneura* pasture on two soil types (A. Rincón, M. Ayarza, and I.M. Rao, unpublished data). There were responses on the sandy loam soil to additional amounts of P, K, and Ca but not to extra S and Mg or to 40 kg/ha N and micronutrients (Table 5). There were no additional responses on the clay loam soil. But the legume responded to the higher fertilizer mixture, as recommended for crops and which included 80 kg/ha N, on both soils. The response to application of the high-fertilizer mixture may have been due to the extra supply of P, K, and Ca it contained and to the N fertilizer overcoming some limitation on N fixation.

The above information was obtained with *A. pintoi* CIAT 17434. There are also a few reports concerning fertilization of *A. glabrata*. Niles et al. (1990) conducted exploratory field trials on 12 sites in northern Florida (USA) to investigate the influence of soil amendments such as lime, P, K, Mg, and S on Florigraze rhizoma peanut (*Arachis glabrata* Benth.) during the establishment year. The range of values for soil chemical characteristics of 12 sites was: pH 5.2-7.9; total C (%) 0.58-2.56; and Mehlich-I extractable elements (mg/kg) 21-436 Al, 28-2080 Ca, 4-126 Mg, 4-102 K, and 11-317 P (Mehlich, 1953). Niles et al. (1990) found no beneficial effects of any of the soil amendments applied. Lime application was found to be detrimental to Florigraze establishment. Low pH and abundant moisture favored rapid establishment.

Blue et al. (1989) tested the response of Florigraze rhizoma peanut to P supply in pot experiments using a highland soil from northwest Cameroon (pH 6.0; total C (%) 3.08; Mehlich-I extractable elements (mg/kg) 810 Ca, 300 Mg, 28 K, and 4.4 P). In rhizoma peanut, there was good growth, with no response to applied P, whereas white clover, alfalfa, and *Desmodium uncinatum* responded strongly.

Rice (1993) examined the response of Florigraze rhizoma peanut to fertilizer treatments over a 4-year period using a missing nutrient technique at three locations (pH 5.18-6.22; Mehlich-I extractable elements (mg/kg) 8.44-31.59 Mg, 8.48-15.22 K, and 14.53-41.34 P). Florigraze responded to annual inputs of a complete fertilizer package by the third year after establishment, with K and S being the most limiting nutrients. The four macronutrients, P, K, S, and Mg, were equally limiting to hay production in established Florigraze.

Mineral Nutrient Composition

A. pintoi had higher nutrient concentrations of Ca and K compared with other forage legumes such as *Centrosema* spp. and *Stylosanthes* spp. (Salinas and Gualdrón, 1989; Salinas et al., 1990). An appreciably higher Cu concentration than that of other legumes was noted in a study on comparative response to Cu (P.C. Kerridge, unpublished data). In a liming experiment, Ca concentrations were high, similar to those in two *Stylosanthes* species but higher than those in *Centrosema* and in other legumes (P.C. Kerridge, unpublished data). The K concentration was similar to that of the other legumes. But nutrient concentrations will be affected by available soil nutrients. For example, in the liming experiment referred to above, shoot Ca concentrations in *A. pintoi* increased from 3.2 g/kg without lime to 18.0 g/kg at the highest lime application (Table 1).

There are conflicting reports on the change in nutrient concentration between seasons. Thus, one report from Carimagua noted that the Ca concentration decreased from 29 g/kg in the wet season to 17 g/kg in the dry season, with the P nutrient concentration remaining constant (CIAT, 1984). Another showed that in both leaf and stem the Ca concentration remained constant while the P concentration declined in the dry season (Carulla, 1990). This illustrates the need to standardize sampling procedures or at least report those used.

Maintenance Fertilizer Application

There have not been any studies of the fertilizer requirement of forage *Arachis* under grazing. Useful information is available from two grazing experiments at Carimagua in the Llanos of Colombia with pastures of *B. humidicola-A. pintoi* established in 1987 and *B. dictyoneura-A. pintoi* established in 1988, which have been grazed continuously since then. Legume content in the pastures has increased and animal productivity has remained high (Lascano, Chapter 10, this volume). We can thus assume that fertilization has been adequate. The pastures were established on a clay loam soil (Oxisol with pH 5.0; 2.0% total C; 2.1 mg/kg extractable P (Bray II); exchangeable cations (cmol/kg) 0.21 Ca, 0.1 Mg, 0.06 K; and 89% Al saturation). They received an initial fertilizer application of (kg/ha) P 20, Ca 100, K 20, Mg 14, and S 22 and have received one-half this amount every second year. Legume content may have increased due to an increase in nutrients supplied by the maintenance fertilizer or due to a natural increase of the legume, which is known to establish slowly.

In general, observations at Carimagua and elsewhere suggest that *A. pintoi* requires slightly higher P and Ca and soil pH levels for maximum productivity than some of the legumes previously selected for acid-soil tolerance, namely, *Stylosanthes capitata* and *Centrosema acutifolium*. It is important to maintain an adequate supply of K, particularly on K-deficient sandy loam soils.

Lack of response to both P and K fertilizer was reported for grazed Florigraze stands over a 3-year period (Prine et al., 1986). Yearly maintenance fertilizer applications (kg/ha) of 25 P and 150 K produced an average forage yield of 10.5 t/ha compared with 10.3 t/ha obtained in nonfertilized stands. The lack of response to maintenance fertilizer application was attributed to the ability of deep-rooted rhizomes to explore the sandy soil profile up to 3-m depths (E.C. French, personal communication). But there will be strong responses when material is removed for hay (Rice, 1993).

Future Research Priorities

There are several future research priorities.

1. There is a need for comparative nutrient studies on different

species and accessions of forage *Arachis*. Most knowledge on forage *Arachis* has been obtained with one accession of *A. pintoi* (CIAT 17434) and a few accessions of *A. glabrata*. There is no information on the extent of adaptation to soils of different pH and fertility status. This work is more urgent as more promising lines of *A. pintoi* are identified (Argel, Chapter 12; Pizarro and Rincón, Chapter 13, this volume) and the range of adaptation as forage and for soil improvement is extended.

2. The importance of P and Ca on N fixation requires investigation. Though there is good evidence that N fixation is largely related to plant growth (Thomas, Chapter 7, this volume), large increases in N fixation with increasing Ca and P supply have been observed. Furthermore, N fixation in tropical legumes is usually enhanced at lime applications higher than those required to neutralize Al and Mn (Munns et al., 1977).
3. Acquisition and internal mobilization of nutrients require further investigation to increase the understanding of the nutrition of the species and to help determine maintenance fertilizer requirements.
4. Maintenance fertilizer requirement should be investigated by a combination of small-plot residual response experiments and monitoring the response in large grazing trials through *in situ* small-plot addition or substraction experiments.
5. Studies on the interaction of mineral nutrition and moisture stress will become important as accessions more tolerant of moisture stress are identified.
6. More specific information on nutrient requirements when *Arachis* is grown for seed production and used for purposes other than forage is required.

Acknowledgments

The authors wish to thank P.J. Vanden Berg, V. Borrero, P. Herrera, and R. García for their technical assistance and M.A. Ayarza and A. Rincón for providing unpublished data.

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Chapter 7

Rhizobium Requirements, Nitrogen Fixation, and Nutrient Cycling in Forage *Arachis*

R.J. Thomas*

Abstract

Rhizobium requirements, rates of nitrogen fixation, and rates of release of nutrients from litter of forage *Arachis* species are reviewed. Evidence presented indicates that although *A. pintoi* nodulates promiscuously with native *Bradyrhizobium* strains, the symbiosis can be ineffective. Thus, positive responses to inoculation can be obtained. To determine the requirement for inoculation, a need-to-inoculate test is recommended for *A. pintoi* when it is grown in new areas or when N deficiency symptoms are observed. Field and glasshouse data suggest that the establishment of forage *Arachis* species may benefit from starter doses of N fertilizer.

A. pintoi fixes a large proportion of its N requirements (>80%) on low-fertility acid soils; thus, rates of N fixation depend directly on the amount of legume present in a pasture. The initial release of nutrients (N, P, K, and Ca) from litter of *A. pintoi* is extremely rapid, suggesting that it could be a suitable legume for use prior to the establishment of a crop for which nutrient demands are high.

Areas for future research on rhizobial requirements and ecology, N fixation, and N cycling are discussed.

Introduction

This review focuses on rhizobium requirements of forage *Arachis* species, rates of nitrogen fixation measured in the field, and the potential for nutrient cycling in different agroecosystems. Reviews of some of these topics as related to the main commercial species of *Arachis*, namely, the groundnut (*A. hypogaea*), are available elsewhere (Giller et al., 1987; Nambiar et al., 1982; Nambiar, 1990).

Rhizobium Requirements

The genus *Arachis* has long been known to nodulate with rhizobia from diverse species of plant hosts, but relatively few rhizobium strains are capable of high levels of fixation (Allen and Allen, 1940, 1981).

In spite of these early observations, some researchers have classified *Arachis* as promiscuous effective (e.g., Date, 1977; Peoples et al., 1989), after the system described by Graham and Hubbell (1975) and Date (1977). This means that the species will nodulate effectively with a range of rhizobia from many different legumes. However, as pointed out by Giller and Wilson (1991) and Singleton et al. (1992), the classification of tropical legumes, and especially forage legumes, as promiscuous effective, promiscuous ineffective, or specific, after Date (1977), tends to lose its usefulness as wider ranges of rhizobium strains are tested and increasing numbers of exceptions to the classification scheme are reported.

Work at CIAT on *Arachis pintoi* CIAT 17434 is an example of this trend. Sylvester-Bradley et al. (1988) tested 30 rhizobium strains in a glasshouse study and four strains in a field study with *Arachis pintoi* CIAT 17434 and reported that some strains increased the

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* Nitrogen cycling specialist, Savannas Program, CIAT, Cali, Colombia.

above-ground N content of plants by threefold or more when compared with an uninoculated control in an Oxisol containing native rhizobia (Figure 1). These increases were observed even though abundant and apparently active nodules were present on plants from the uninoculated controls. Further work extended this observation to *A. pintoi* CIAT accessions 18745, 18746, and 18751, originating from Minas Gerais, Brazil, and CIAT 18747, coming from Bahia, Brazil (Table 1). This latter study resulted in the addition of CIAT strains 2138 and 3806 with 3101 in the list of strains suitable for the inoculation of different *A. pintoi* accessions. Strain 1670 was notable for its inferior performance compared with the uninoculated control (Table 1).

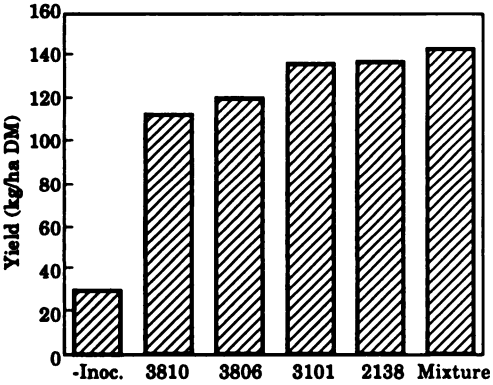

Figure 1. The effect of inoculation with different *Bradyrhizobium* strains on the yield of field-grown *A. pintoi* 17434.

Data after 10 weeks growth in an Oxisol. Mixture consisted of the four strains (Sylvester-Bradley et al., 1988).

When strains isolated from nodules of *A. pintoi* CIAT 17434 growing on fertile volcanic soil (Dystrandepts) in the coffee zone of Colombia near Manizales were tested with plants grown on an infertile Oxisol from the plains of Colombia, only lab strains 2704 and 2708 of the 10 isolates appeared to be effective in N fixation (Table 2). Several of the other isolates nodulated *A. pintoi*, and produced numerous nodules that were red internally. But the plants were yellow in appearance, thus indicating N deficiency (Table 2).

In a study on the serological relationships among 91 rhizobium strains isolated from *Centrosema* and *Arachis* spp. (Bolaños et al., 1993), the 15 strains originally isolated from *Arachis* spp. were typed in six of the 19 serogroups identified. The relative distances between these groups are shown in Figure 2, which indicates the relatively wide serological diversity of the strains capable of nodulating *Arachis*. Similarly, Dadarwal et al. (1974) distinguished 27 rhizobium serotypes from 44 isolates obtained from nodules of *A. duranensis, A. prostrata, A. villosa, A. glabrata,* and *A. marginata* growing in India. These data taken

Table 1. Total above-ground nitrogen (mg N/pot) of different *Arachis* accessions inoculated with different strains of *Bradyrhizobium*.

Strain no.	*A. pintoi* accessions				
	18746	18747	17434	18751	18745
- Inoc.	92	76	43	75	73
2434	110	89	60	86	80
3806	124	92	77	93	81
3101	119	89	84	101	96
1670	61	69	46	60	71
2138	114	102	77	105	101
3649	109	94	58	99	90
3810	110	95	67	94	96
3144	89	99	69	86	105
+ N fertilizer	200	171	143	187	188

LSD ($P < 0.05$) = 6.

Table 2. Growth parameters of *A. pintoi* 17434 when inoculated with *Bradyrhizobium* strains isolated from nodules of *A. pintoi* grown in the coffee zone of Colombia. Plants were sampled after 9 weeks.

Lab strain identification no.	Above-ground yield (g/plant)	Nitrogen (mg/plant)	Nodules (no.)	Nodule color
2684	1.14	12.3	15	Red
2688	1.00	11.5	13	Red
2689	1.40	11.4	22	Red
2690	0.78	9.3	23	Red
2691	0.61	6.0	19	White
2692	0.74	7.8	13	Red
2704	1.66	20.8	54	Red
2705	0.80	8.2	17	Red
2706	0.96	9.3	23	Red
2708	1.89	26.9	55	Red
CIAT 3101	1.69	24.4	33	Red
Uninoculated	0.95	9.2	15	Red
N fertilized[a]	1.93	22.0	2	Red
LSD ($P < 0.05$)	0.28	6.5	15	

[a] 90 kg/ha N as urea.

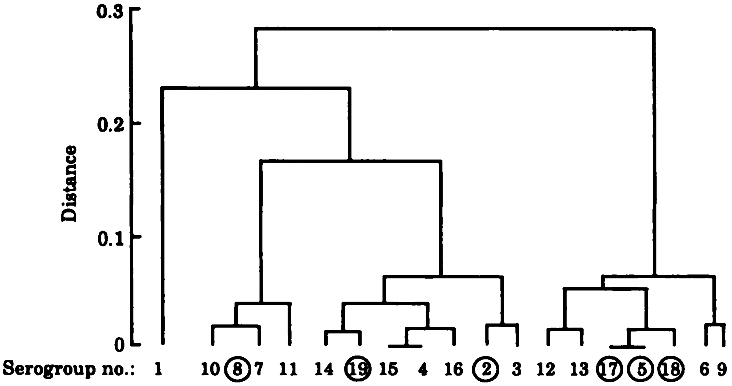

Figure 2. Dendrogram of serogroups of *Bradyrhizobium* strains classed by Ward's minimum variance cluster analysis.

Ringed serogroup numbers are those containing strains isolated from *Arachis* spp.

together indicate that *Arachis* spp. could be considered promiscuous ineffective rather than promiscuous effective.

Several factors determine the need to inoculate forage legumes, including whether or not a forage or other legume has been grown in the area before. Some factors affect the persistence of native rhizobia in soils and others affect the ability of inoculant rhizobia to infect legumes, such as low pH and associated problems of aluminum and manganese toxicity, calcium deficiency, salinity, soil moisture, the presence of microbial predators, and levels of N mineralization (Lowendorf, 1980; Woomer and Bohlool, 1989). Given these factors and the increasing number of reports citing responses to inoculation, even with promiscuous effective legumes, it is advisable to carry out a simple need-to-inoculate test using field trials or undisturbed soil cores (Vincent, 1970; Date, 1977; Sylvester-Bradley, 1984). Basically, these tests involve a comparison of uninoculated and inoculated plants plus a third treatment receiving doses of N fertilizer of 30 kg/ha N every 2 weeks. The uninoculated control will reveal the presence of native rhizobia and their effectiveness when compared with the other treatments. The inoculated treatment will examine the effectiveness of the chosen inoculant strain and the N fertilized treatment will indicate growth potential in the absence of an N limitation (see Date, 1977, for further interpretation of results obtained from such trials). Information obtained from the need-to-inoculate tests can then be used to decide whether or not the forage legume requires inoculation. In farmers' fields, however, the final decision to inoculate or not will depend not just on the results of the need-to-inoculate test. It will also depend on other factors such as the presence of an inoculant supplier, the availability of a suitable carrier (such as peat) for the inoculants, and the shelf life of the inoculants, particularly under tropical conditions (Bohlool et al., 1992).

The differences observed between the amounts of N per plant in the uninoculated and inoculated treatments (Table 1) are examples of the benefits that can be obtained by using the existing knowledge of strain selection and inoculant technology. However, it should be noted that there were even bigger differences between the amounts of plant N obtained with the most effective strains and those obtained with a nonlimiting supply of fertilizer N (Table 1). It may be possible to reduce these differences by improving the legume-rhizobium symbiosis via genetic manipulation of *Bradyrhizobium* strains or by improving host-plant factors affecting the establishment and functioning of an effective symbiosis, e.g., the identification of plant factors controlling *nod* gene activation such as flavonoids (Phillips et al., 1990). No information exists on these factors for forage *Arachis* spp.

Attempts are now being made to develop and use models that take into account the size of the native rhizobium population and the N status of the soil to predict the likelihood of success and the magnitude of the response to rhizobial inoculation (Thies et al., 1991). However this work is at an early stage and cannot replace the simple need-to-inoculate tests described above.

Ecology of *Bradyrhizobium* Strain 3101

As with other rhizobia of forage legumes, little is known about their ecology (Vincent, 1988). Strain 3101, or QA 1091 in Australia, is currently recommended for *A. pintoi* and *Centrosema* spp. This strain, originally isolated from *Centrosema plumieri* in Santa Marta, Colombia, has shown competitiveness with indigenous strains from an Oxisol from Carimagua when used to inoculate *C. macrocarpum* and *A. pintoi* (Figure 3). Around 68% of the nodules examined from both *C. macrocarpum* and *A. pintoi* contained the inoculated strain 3101 after 6 weeks growth (Bolaños et al., 1993). Little is known about the persistence of inoculant strains in the soil beyond 1 or 2 years, and this area requires further study.

Inoculation

Seeds

CIAT recommends using peat inoculants (50 g/kg seed) with a seed pelleting procedure. A kg of scarified seed, free of fungicides, is mixed with 30 ml of an adhesive solution, usually gum arabic (40 g gum to 100 ml water, left for 12 h to dissolve), sugar (25% w/v), or methylcellulose (5% w/v), and the recommended amount of inoculant.

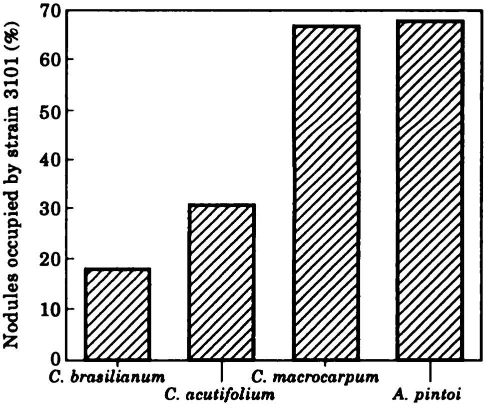

Figure 3. The percentage of nodules occupied by *Bradyrhizobium* strain 3101 after 6 weeks growth.

Pelleting is done immediately after inoculation by adding 300 g of rock phosphate/kg of seed, mixing, and drying. Seeds are then sown within 24 h to avoid loss of rhizobium viability.

Vegetative material

Where *Arachis pintoi* is sown vegetatively in furrows using 20-cm stolon sections, with 0.5 m x 0.5 m spacing, 2 kg of inoculant, 1.2 liters of diluted molasses, and 40 liters of water are required per hectare. Spacings will vary depending on whether or not *Arachis* is sown as a monoculture or with a grass. For example, a spacing of 0.35 m is recommended for monoculture and 1.0 m when sown with a grass.

As with seeds, the inoculant should be added and mixed just before sowing. Care should be taken not to prepare too much material at any one time to avoid desiccation in the field prior to sowing. A note on the methods for preparing material for inoculation has been published in Spanish (Asakawa and Ramírez, 1989).

Nodulation

The mode of infection of *Arachis* is, like that of *Stylosanthes*, rather unusual as rhizobia enter the plant via wound or crack infections at the junction of lateral roots rather than via the classical mode of entry through root hairs (Chandler, 1978; Sprent and Sprent, 1990). In stoloniferous species such as *A. pintoi*, nodules can be observed frequently in the axils of roots emerging from stolons.

The nodules of *A. hypogaea* are further distinguished from those of other legumes in that they have an unusually low number of viable rhizobial cells per unit biomass of nodule tissue. In these nodules and in those of *A. erecta*, *A. nambyquarae*, and *A. villosulicarpa*, the bacteroids (the swollen or distorted forms of rhizobia within the nodules) appear to take on the unusual appearance of spheroplast-like structures (Staphorst and Strijdom, 1972). These structures were later found to have a distinct cell wall or outer membrane (Bal et al., 1985). Unusual lipid bodies called oleosomes have also been reported in peanut nodules (Jayaram and Bal, 1991), and their role in providing energy for N fixation during photosynthate stress has been suggested (Siddique and Bal, 1992).

We know little about the significance of these observations, either in terms of the efficiency of N fixation in *Arachis* spp., or in terms of the requirements for inoculation. Sprent and Zahran (1988), however, have suggested that the mode of infection via wounds or cracks in *Arachis* could confer greater resistance to stresses such as salinity compared with species infected via root hairs.

Abundant nodules were observed on *A. pintoi* CIAT 17434 2 weeks after inoculation with strain 3101 in a pot experiment in a glasshouse. Nitrogen fertilizer in the form of ammonium-N or nitrate-N inhibited nodulation at levels equivalent to 100 kg/ha N or more at 8 weeks growth (Table 3). Growth and leaf area were not significantly increased by levels of fertilizer greater than 50 kg/ha N (Table 3). These results suggest that 50 kg/ha N as ammonium-N

Table 3. Effect of fertilizer N on above-ground dry weight, number of nodules, and leaf area of *A. pintoi* 17434. Plants were grown in pots in an Oxisol from Carimagua, Colombia. Data shown is after 8 weeks growth.

N source (kg/ha N)	Above-ground plant yield (g/pot)	Nodules (no./plant)	Leaf area/ plant (cm^2)
0	1.56	43	80
10 NO_3 - N	1.66	45	92
20 NO_3 - N	1.69	47	99
50 NO_3 - N	2.09	38	126
100 NO_3 - N	1.95	19	135
150 NO_3 - N	1.72	2	114
LSD ($P < 0.05$)	0.08	12.6	9
10 NH_4 - N	1.45	42	87
20 NH_4 - N	1.66	39	108
50 NH_4 - N	1.61	35	104
100 NH_4 - N	1.98	24	122
150 NH_4 - N	1.71	17	107
LSD ($P < 0.05$)	0.14	11	14

or nitrate N may be applied to *A. pintoi* as a starter dose without unduly affecting infection and nodulation. This suggestion needs to be confirmed in the field in areas where establishment of *Arachis* is slow and where plants are responsive to additions of N fertilizer.

Similar results have been reported for the nodulation of pure stands of field-grown rhizoma peanut (*A. glabrata*) in Florida (USA), where 50 kg/ha N as ammonium nitrate had little effect on nodule weight compared with the application of 100 kg/ha N, which decreased nodulation during early growth (Valentim, 1987). This study showed a strong interaction among climate, N fertilization, and nodulation. The application of 100 kg/ha N fertilizer to rhizoma peanut when grown in association with Bermudagrass (*Cynodon dactylon*), on the other hand, had little or no effect on nodulation, but increased early legume growth. Thus, the application of starter doses of N fertilizer may be beneficial to forage *Arachis* species whose rate of establishment is generally slow.

Rates of Fixation

Rates of fixation for peanut (*Arachis hypogaea*) range from 68 to 206 kg/ha N when measured by a variety of methods, with the proportion of the plant's N obtained from fixation ranging from 47 to 92% (Giller and Wilson, 1991). For *A. pintoi* grown in a pasture with *Brachiaria dictyoneura* at two different fertility levels and on two Oxisols, the rates of fixation varied from 1 to 12 kg/ha N over a 16-week period (Table 4). The low rates of fixation can be attributed to a low percentage of legume in the pasture. Increased fertility increased the estimated rates of fixation mainly by increasing the amount of legume in the pasture as there were only relatively small differences between the estimates based on a unit of legume dry matter (Table 4). Similarly, there was only a small effect of increased fertility on the percentage of plant N derived from fixation (% Ndfa), which ranged from 81 to 89% (Table 4). If the latter finding holds true for other infertile acid-soil environments, then an estimate of legume biomass will be sufficient to estimate the amount of N fixed/ha. **The data thus suggest that the amounts of N fixed are directly related to growth, and any factor limiting growth, such as disease or drought stress, will similarly affect N fixation.**

In the coffee zone of Colombia near Chinchiná (1350 m.a.s.l., 2500 mm rainfall) on fertile volcanic soils (Dystrandepts) with rates of N mineralization on the order of >100 kg N/ha/year, *A. pintoi* fixed between 9 and 27 kg/ha N over 3 weeks when sown in a pasture with *B. decumbens* (Table 5). In spite of the apparently high levels of soil N mineralization, *A. pintoi* fixed, on average, 63% of its N as measured by ^{15}N isotope dilution (Suárez-Vásquez et al., 1992). In this area, *A. pintoi* did not respond to inoculation.

Table 4. The amount of N fixed by *A. pintoi* 17434 over 16 weeks in two soil types and with two levels of added fertilizer.[a]

Soil type	Fertility	N (kg/ha)	Legume in pasture (%)	DM of legume (kg N/t)	Ndfa[b] (%)
Sandy loam	Low	1.4 ± 0.3	4.0 ± 0.9	15.6 ± 0.8	84.9 ± 2.5
	High	12.3 ± 2.6	17.7 ± 1.5	20.3 ± 2.3	89.2 ± 0.1
Clay loam	Low	1.5 ± 0.3	1.9 ± 0.3	15.8 ± 0.5	80.5 ± 3.3
	High	11.4 ± 3.2	10.0 ± 1.6	19.0 ± 1.4	87.8 ± 2.8

a. Fixation was measured by ^{15}N isotope dilution in pastures with *B. dictyoneura* at Carimagua, Colombia. Results are means of six estimates ± S.D. The low-fertility treatment received (in kg/ha) 20 P, 20 K, 50 Ca, 20 Mg, 12 S, and micronutrients, but no N. The high-fertility treatment received three times the above amount.

b. Ndfa = percentage of plant N derived from fixation.

Table 5. Amounts of N fixed by *A. pintoi* in a *B. decumbens-A. pintoi* pasture at Romelia, Chinchiná, Colombia[a] (Suárez-Vásquez et al., 1992).

Weeks after sowing	g N fixed/ plant/21 days	Approx. kg N fixed/ha/ 21 days	Ndfa[b] (%)
19	0.09	27.1	64
22	0.05	15.0	65
25	0.04	12.0	62
28	0.03	9.0	60
Mean	0.05	15.8	63

a. N fixation measured with ^{15}N isotope dilution for four 3-week periods. Each plant occupied an area of approximately 332 cm^2.

b. Ndfa = percentage of plant N derived from fixation.

Nutrient Cycling

The benefits of a legume for forage or crop production depend to a large extent on the amounts of N fixed and the transfer of this N to other plant species. The mechanisms whereby legume N is made available to other pasture plants or crops include the decomposition of above-ground parts such as fallen leaves and other residues, leaching of nutrients from tissues into the soil, and gaseous ammonium loss and subsequent re-uptake by other plants. Below-ground mechanisms include root and nodule senescence and decomposition, root exudation or rhizodeposition, and direct transfer via mycorrhizal connections.

The exact routes of transfer of N and other nutrients are seldom known, but shoot and root residues are thought to play major roles via decomposition (Henzell and Vallis, 1977; Steele and Brock, 1985; Ledgard and Steele, 1992). Nutrient cycling in grazed pastures via the animal or plant litter varies with the degree of pasture utilization and, in tropical pastures, which are generally underused (Wetselaar and Ganry, 1982), cycling via the litter may be quantitatively more important than cycling via excreta (Thomas, 1992).

Table 6 shows the half-lives of forage leaf litter during the wet and dry seasons, including *A. pintoi*. Decomposition of leaf litter in litter bags was faster in *A. pintoi* and *Stylosanthes capitata* during the wet and dry seasons when compared with four other forage legumes and two grass species. Litter of *A. pintoi* is particularly enriched with N (2.1%) and calcium (1.2%) compared with other forage species (Thomas and Asakawa, 1993). Figure 4 shows the relative patterns of release of the major nutrients from leaf litter of *A. pintoi* during the wet season. As with other litters, the rate of release of potassium from *A. pintoi* is much greater than that of the other nutrients. Nitrogen and phosphorus have similar patterns of release but, quantitatively, more nitrogen is released as a result of its higher concentration in the litter compared with P (2.1% N vs. 0.08% P). Despite the rapid rates of decomposition, it has been estimated that the release of N from leaf litter of *A. pintoi* over the wet season is likely to supply only about 8-16% of the requirement of a tropical grass-legume pasture (Thomas and Asakawa, 1993). Low levels of litter biomass are likely to be constraints to the recycling of significant amounts of nutrients via leaf litter of *A. pintoi*.

More data on leaf litter production are needed from different ecosystems where production of *A. pintoi* is known to vary by as much as two- to threefold (Argel and Pizarro, 1992) in order to assess its potential role in nutrient recycling.

Decomposition of Roots

In a glasshouse study, roots of different forage grasses and legumes were classified in two diameter classes,

Table 6. Half-lives (days) of forage species leaf litter.

Species	Litter half-life	
	Wet season	Dry season
Arachis pintoi	47	150
Centrosema acutifolium	120	250
Desmodium ovalifolium	153	251
Pueraria phaseoloides	115	218
Stylosanthes capitata	48	85
Brachiaria decumbens	108	244
Andropogon gayanus	95	175

SOURCE: Thomas and Asakawa, 1993.

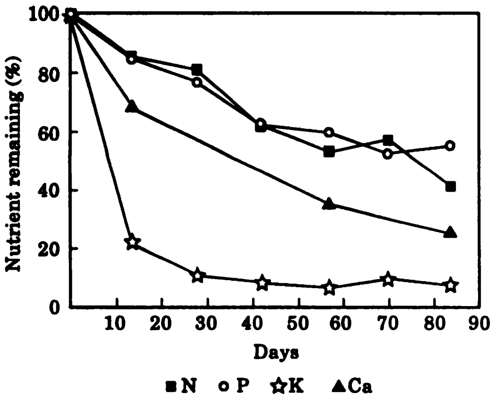

Figure 4. Release of nutrients from leaf litter of *A. pintoi* 17434.

<2.0 mm (fine) and >2.0 mm (coarse), and each class was incubated in litter bags and buried in large boxes of an Oxisol soil. One-half of the bags also contained soil to improve the soil-root contact (A. Celis and R.J. Thomas, unpublished data). As with leaf litter, rates of decomposition were greater in *A. pintoi* compared with those of other species (two legumes and three grasses, data not shown). Table 7 shows the decomposition constants and litter half-lives for *A. pintoi*. Treatments that included soil in the litter bags decomposed fastest, with little or no difference between fine and coarse roots. However, in a field study with a similar soil type, rates of decomposition of coarse roots (>1 mm) were greater than those of fine roots (<1mm) (Table 7), suggesting that close contact with the soil is an important factor in studies on the decomposition of large diameter roots. The half-lives and decomposition constants were similar for fine roots (1-2 mm diameter) in both the glasshouse and field study (Table 7). Of the roots recovered from the field study, 54% were classified as coarse roots (>1 mm) and 46% as fine roots (<1 mm).

The data indicate a slightly greater rate of decomposition of root material of *Arachis* compared with leaf litter material under field conditions. More data are needed on the rates of production of both root and leaf litter to estimate potential rates of nutrient cycling via *Arachis* litter. It is apparent from these data that nutrient cycling via litter of *A. pintoi* will be rapid in most situations compared with a similar biomass of other legume and grass species. *A. pintoi* could thus fit a niche where rapid nutrient release is required, such as for crop establishment.

Research Priorities

Rhizobium requirements/ ecology

As the numbers of forage *Arachis* accessions increase, we will need to determine rhizobium requirements initially on a case-by-case basis until sufficient information has been obtained to make generalizations. Until then, it will be important to at least conduct a need-to-inoculate test for each new situation (considering locality, land use history, climate, soil type, and *Arachis* accession or species) where *Arachis* is grown.

Knowledge of the ecology of introduced rhizobial strains in tropical soils is in its infancy. The development of new rapid screening techniques using marker genes (Wilson et al., 1991) can

Table 7. Decomposition parameters for roots of *A. pintoi*.[a]

	Half-life (days)	K (per day)	
Coarse roots (> 2 mm)	39 (13)	0.014 ± 0.002	(0.025 ± 0.004)
Fine roots (< 2 mm)	33 (32)	0.014 ± 0.003	(0.015 ± 0.003)
Coarse roots + soil	30	0.021 ± 0.002	
Fine roots + soil	25	0.020 ± 0.003	

a. Data obtained from a glasshouse study where roots were placed in litter bags and buried in soil. Decomposition parameters were obtained by fitting a single exponential decay function, ± S.E., $X_t = X_0 e^{-kt}$. Half-lives were calculated from the exponential function. Data in parentheses are from a field study in an Oxisol at Carimagua, Colombia (Maldonado, unpublished data).

be expected to increase our knowledge of rhizobial competition and, perhaps, persistence in the field of inoculant strains. This information will help determine the merits of inoculation of species such as *Arachis*, especially when used in the agropastoral systems envisaged for the newly opened savanna regions of Latin America (Vera et al., 1993). We will need rhizobium persistence data to determine whether there is a need to re-inoculate the forage legumes at each sequence where they appear in the rotation.

Nitrogen fixation/cycling

We need to quantify both the rates of N fixation and the percentage of N derived from fixation in different environments and with different accessions of *A. pintoi* to assess its role in providing an input of N into an ecosystem. In particular, we lack information on the effect of mineral N on the fixation process. Similarly, we need to know the sensitivity of the fixation process to environmental stresses such as drought, soil acidity, mineral deficiency, and effects of light and temperature.

Routes, rates, and patterns of transfer of N and other important nutrients, such as calcium, from *Arachis* to other pasture and crop plants need to be identified and quantified to maximize the efficiency of nutrient cycling in pastoral and agropastoral systems where *Arachis* has a major role. Such information should be integrated via a modeling approach using models similar to the CERES crop models and the CENTURY plant-soil ecosystem model for the major nutrients (Parton et al., 1988).

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Chapter 8

Diseases and Pests of Wild *Arachis* Species

S. Kelemu
S. Lapointe
F. Morales*

Abstract

Plant diseases and insects are important constraints to cultivated peanut (*Arachis hypogaea*) production. The three most economically important diseases of cultivated peanuts on a worldwide scale, two leaf spots (caused by *Cercospora arachidicola* and *Cercosporidium personatum*) and rust (*Puccinia arachidis*), are reported to attack some *Arachis* species. But there are no documented cases of diseases and insects of economic importance in wild *Arachis* species. Several species of *Arachis* have been reported to confer higher levels of resistance to a number of diseases and insects than the cultivated peanut. This report summarizes reported diseases and potential pests in wild *Arachis* species, and explains future research emphases.

Diseases of *Arachis*

The genus *Arachis* consists of more than 70 species (Wynne and Halward, 1989). The cultivated peanut, *Arachis hypogaea*, is the best studied of these species. Published work on diseases of wild *Arachis* species is scarce. In most cases, disease reactions have been documented to identify sources of resistance to diseases of the cultivated peanut (Stalker and Moss, 1987; Subrahmanyam et al., 1983, 1985) as diseases are significant constraints to peanut production. The three most economically important diseases of *A. hypogaea* on a worldwide scale, two leaf spots (*Cercospora arachidicola* and *Cercosporidium personatum*) and rust (*Puccinia arachidis*), have been reported to infect some species of *Arachis* (Table 1). Sources of resistance to these diseases are available within cultivated peanuts. But high levels of resistance and/or "immunity" to the diseases have been identified among wild *Arachis* species.

Peanut mottle virus is the most widespread of the virus diseases of peanut (Reddy et al., 1978). Morales et al. (1991) reported infection of forage *Arachis* by potyviruses related to peanut mottle virus. Other economically important virus diseases are restricted geographically. Resistance to peanut rosette, peanut mottle, peanut stunt, and tomato spotted wilt viruses has been identified in some wild *Arachis* species (Demski and Sowell, 1981; Gibbons, 1969; Herbert and Stalker, 1981).

Diseases caused by nematodes are of economic importance in some peanut-growing areas. The main pathogenic species are in the genera *Meloidogyne, Pratylenchus, Belonolaimus,* and *Macroposthonia* (Porter et al., 1982). Some sources of resistance are known in wild *Arachis* species (Banks, 1969; Castillo et al., 1973). Nelson et al. (1990) reported resistance to the root-knot nematode *Meloidogyne arenaria* in *A. batizocoi* and *A. cardenasii,* which are cross-compatible to *A. hypogaea*. They provided some evidence that the mechanisms of resistance to *M. arenaria* differ in these two species. No source of resistance has been identified in the thousands of *A. hypogaea* genotypes. In a survey of three trial areas in Colombia, Stanton et al. (1989) reported nematodes

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* Plant pathologist and entomologist, respectively, Tropical Forages Prograsm, CIAT; plant virologist, Virology Research Unit, CIAT, Cali, Colombia.

Table 1. Diseases reported in wild *Arachis* species.

Arachis species	Disease	Pathogen	Location and/or reference
A. glabrata	Leaf spot	*Cercospora arachidicola*	Brazil, Colombia (Lenné, 1990); Stalker & Moss, 1987
	Leaf spot	*Cercospora personata*	Brazil, Colombia (Lenné, 1990); Stalker & Moss, 1987
	Anthracnose	*Colletotrichum gloeosporioides*	Brazil, Colombia (Lenné, 1990)
	Pepper spot	*Leptosphaerulina arachidicola*	Brazil, Colombia, Costa Rica, Peru, USA (Lenné, 1990); Stalker & Moss, 1987
	Rust	*Puccinia arachidis*	Brazil (Lenné, 1990); Stalker & Moss, 1987
	Blight	*Rhizoctonia solani*	Brazil, Colombia, Peru (Lenné, 1990)
	Scab	*Sphaceloma arachidis*	Brazil (Lenné, 1990)
A. hagenbeckii	Leaf spot	*Cercospora canescens*	Malawi (Lenné, 1990)
A. monticola	Pepper spot	*Leptosphaerulina arachidicola*	USA (Graham & Luttrell, 1961)
A. pintoi	Leaf spot	*Cercospora* sp.	Colombia (Lenné, 1990)
	Leaf spot	*Periconia* sp.	Colombia (Lenné, 1990)
	Leaf & stolon lesions	*Colletotrichum gloeosporioides*	Colombia (Lenné, 1990)
	Stolon dieback	*Colletotrichum truncatum*	Colombia (Lenné, 1990)
	Pepper spot	*Leptosphaerulina arachidicola*	Colombia, Costa Rica, Ecuador, Peru (Lenné, 1990)
	Foliar blight	*Rhizoctonia solani*	Brazil, Colombia, Costa Rica, Peru (Lenné, 1990)
	Scab	*Sphaceloma arachidis*	Brazil, Colombia (Lenné, 1990)
	Virus	Peanut stunt virus	Stalker & Moss, 1987
	Virus	Potyvirus related to peanut mottle virus	Morales et al., 1991
A. pusilla	Leaf spot	*Colletotrichum gloeosporioides*	Australia (Vinijsanun et al., 1987)
	Leaf spot	*Mycosphaerella arachidis*	Nigeria (Lenné, 1990)
	Leaf spot	*Myrothecium roridum*	India (Lenné, 1990)
A. villosa	Leaf spot	*Cochliobolus lunatus*	Nigeria (Lenné, 1990)
	Foliar blight	*Colletotrichum capsici*	Nigeria (Lenné, 1990)
	Seed associate	*Fusarium* sp.	Colombia (Lenné, 1990)
Arachis sp.	Nematode	*Aphasmatylenchus straturatus*	Burkina Faso (Germani et al., 1982)
	Nematode	*Ditylenchus destructor*	Wheeler et al., 1951
	Nematode	*Scutellonema cavenessi*	Senegal (Germani et al., 1982)
	Rust	*Puccinia arachidis*	India (Subrahmanyam et al., 1983)
A. monticola	Leaf spot	*Cercosporidium personatum*	India (Subrahmanyam et al., 1985)
	Rust	*Puccinia arachidis*	India (Subrahmanyam et al., 1983)
	Leaf spot	*Cercospora arachidicola*	Stalker & Moss, 1987
	Virus	Peanut stunt virus	Stalker & Moss, 1987
A. batizocoi	Leaf spot	*Cercospora arachidicola*	Stalker & Moss, 1987
A. cardenasii	Virus	Peanut stunt virus	Stalker & Moss, 1987
A. chacoense	Virus	Peanut stunt virus	Stalker & Moss, 1987
A. repens	Leaf spot	*Cercospora arachidicola*	Stalker & Moss, 1987
	Leaf spot	*Cercosporidium personatum*	Stalker & Moss, 1987
A. rigonii	Virus	Peanut stunt virus	Stalker & Moss, 1987
A. oteroi	Leaf spot	*Cercospora arachidicola*	Stalker & Moss, 1987
	Leaf spot	*Cercosporidium personatum*	Stalker & Moss, 1987
A. paraguariensis	Virus	Peanut stunt virus	Stalker & Moss, 1987
A. margenata	Leaf spot	*Cercospora arachidicola*	Stalker & Moss, 1987
	Leaf spot	*Cercosporidium personatum*	Stalker & Moss, 1987

Helicotylenchus sp., *H. pseudopaxilli, Pratylenchus brachyurus,* and *P. zeae* to be associated with roots in a *Brachiaria* + *Arachis pintoi* pasture. But the authors did not demonstrate whether these nematodes are in fact pathogenic to the pasture species and, in particular, to *A. pintoi.*

Although it is difficult to predict accurately which of the known pathogens of cultivated peanut (Table 2) will be most devastating to forage *Arachis* species, it is safe to say that some of them may prove to be important in some regions as forage *Arachis* production increases.

Table 1 lists reported fungal, viral, and nematode diseases of *Arachis*. We know of no report of bacterial diseases of wild *Arachis*, although bacterial pathogens are known to attack *A. hypogaea*, such as *Pseudomonas solanacearum* (Tomlinson and Mogistein, 1989). Table 2 lists some important diseases of *A. hypogaea*.

Wild *Arachis* Species as Sources of Disease Resistance

Wild species of *Arachis* are useful sources of resistance to peanut diseases and for widening the genetic base of cultivated peanut. Many *Arachis* species have been evaluated for disease reactions (Abdou et al., 1974; Gibbons and Bailey, 1967; Subrahmanyam et al., 1983, 1985). High levels of resistance to major fungal pathogens, viruses, and nematodes have been reported in wild *Arachis* species in the sections Arachis, Caulorhizae, Extranervosae, and Rhizomatosae (Stalker and Moss, 1987; Subrahmanyam et al., 1983, 1985). Several wild *Arachis* species were tested for their reactions to

Table 2. Some pathogens of *Arachis hypogaea*.

Bacteria and mycoplasmas	Fungi	Viruses	Nematodes
Pseudomonas solanacearum	*Aspergillus niger*	Peanut mottle	*Meloidogyne hapla*
Mycoplasma-like organism	*Sclerotium rolfsii*	Peanut stunt	*Pratylenchus brachyurus*
Rickettsia-like organism	*Cylindrocladium crotalariae*	Tomato spotted wilt	*Belonolaimus*
	Diplodia natalensis	Turnip mosaic	*Macroposthonia*
	Cercospora arachidicola	Peanut clump	
	Cercosporidium personatum	Peanut green mosaic	
	Didymosphaeria arachidicola	Peanut stripe	
	Leptosphaerulina trifolii	Tobacco streak	
	Rhizoctonia solani	Yellow spot	
	Puccinia arachidis	Rosette disease	
	Sclerotinia sclerotiorum	Bean yellow mosaic	
	Verticillium dahliae	Blackeye cowpea mosaic	
		Cowpea chlorotic mottle	
		Cowpea mild mottle	
		Cucumber mosaic	
		Groundnut chlorotic spotting	
		Groundnut crinkle	
		Groundnut eyespot	
		Horsegram yellow mosaic	
		Passion fruit woodiness	
		Peanut chlorotic leaf spot	
		Peanut chlorotic leaf streak	
		Peanut chlorotic ring mottle	

the major diseases of cultivated peanuts in Australia. All susceptible accessions were removed from further evaluations (Cook et al., Chapter 14, this volume). The desire to diversify the available genetic pool for disease resistance and other economically important traits drives researchers to acquire wild plant germplasm. It is believed that wild plant species may have different mechanisms of resistance to diseases and insect pests than cultivated peanuts. If this is proven, sources in wild germplasm may lead to a broader genetic base and to development of cultivars with durable resistance.

In addition, advances in tissue culture and biotechnology may make it possible to transfer desirable genes across the various sections of the genus *Arachis*.

Pathogens have several mechanisms of pathogenic variability. As production areas of forage *Arachis* increase, diseases could increase in significance as well. The centers of origin of host plants are presumed to be the centers of diversity for their pathogens, as plants and their respective pathogens co-evolved over a long period of time.

Future Research Emphases

The following areas of research should be considered in the near future.

1. **Survey and document diseases of *Arachis* species**. The survey should be done in primary centers of origin (such as Mato Grosso, Brazil). Germplasm specialists, agronomists, breeders, etc., who collect germplasm materials, help collect disease samples and collaborate with plant pathologists. B. Maass, CIAT germplasm specialist, observed variable anthracnose infections in *A. pintoi* on a recent collecting expedition to Araçuaí, Minas Gerais, Brazil. *A. pintoi* V13363 showed a high level of natural anthracnose infection at Araçuaí (B. Maass, personal communication). Seed introductions can be used to monitor pathogens associated with seeds while ensuring pathogen-free germplasm.
2. **Monitor disease in evaluation plots and seed production plots**. An apparent disease devastated seed production of *A. pintoi* in two plots in Costa Rica in 1992-93 (R. Bradley, personal communication). The causal agent appears to be an insect, *Cyrtomenus bergi*, which predisposes the plant to fungal attack. This report needs to be verified. Some wilting disease symptoms occurred in CIAT's *A. pintoi* seed plots in Costa Rica in 1992 (P. Kerridge, personal communication).
3. **Standardize methods and coordinate efforts**. Some confusion exists in the literature on disease reactions in wild *Arachis* species. Some reported differences in disease reactions could be due to variability in the pathogen population and within the host species, environmental variations, different methods of inoculations and disease evaluations, or a combination of these factors. Because of this, we need to standardize research methods and coordinate efforts.

Potential Pests of *Arachis pintoi*

Little published information is available on arthropod pests of *A. pintoi*. Observations come entirely from pure stands in evaluation plots. Better information should emerge as this promising forage legume is released in more countries and adopted throughout Latin America. During the evaluation process on experiment stations and in the International Tropical Pastures Evaluation Network (RIEPT), no significant pests were reported. The predominant pests of groundnut reported from the semiarid tropics (probably from the paleotropics) include the groundnut aphid (*Aphis craccivora*), and species of thrips, leafhoppers (*Empoasca*), and armyworms (*Spodoptera* spp.) (Amin, 1985). While termites are a problem for groundnuts in Africa, leaf-cutter ants, found exclusively in the New World, may represent a larger problem in the neotropics.

Although reports of groundnut pests may indicate potential pests of *A. pintoi*, the minimum-tillage systems used for pasture establishment and renovation probably favor diversity of insect species and numbers of predators and parasites (Shenk and Saunders, 1984; Troxclair and Boethel, 1984). Thus, we may expect relatively few pest problems for *A. pintoi* in pasture systems compared with those of cultivated groundnuts. Also, the complexity of an associated pasture compared with a monocrop may facilitate natural control of herbivores.

We will now summarize arthropod species collected from *A. pintoi* and species that attack related hosts and are known to be present in Latin America.

Leaf-cutter ants

Leaf-cutter ants of the genus *Atta* (Hymenoptera: Formicidae). While grass-cutters of the genus *Acromyrmex* are not a problem, *Atta laevigata* has been observed defoliating *Arachis pintoi* in pure stands in Colombia. Significant damage has not been observed in association with cultivars of *Brachiaria*. It may be that association with grasses that resist leaf-cutter ants, such as *B. humidicola* cv. Pasto Humidicola or *B. brizantha* cv. Marandú, protects the legume component as well (Lapointe et al., 1993).

Lepidopter~~an~~ larvae

The leaffolder *Hedylepta indicata* (Lepidoptera: Pyralidae) ("Lagarta-enroladeira," "Pega hojas"). This pest was observed infesting pure stands of *Arachis pintoi* BRA 15598 at the Centro de Pesquisa Agropecuária dos Cerrados (CPAC), Planaltina, Brazil. But it is not considered a significant pest and is usually well controlled by natural enemies when it occurs on other hosts (soybeans, beans, cowpea) (King and Saunders, 1984). In Colombia, this species is known as "Pega-pega de la soya," and occurs in Valle del Cauca Department on soybean and cowpea (ICA, 1970). In India, *H. indicata* is a minor pest on lucerne (*Medicago sativa*), green gram (*Phaseolus aureus*), and horse gram (*Dolichos biflorus*). It is also found on cowpea (*Vigna sinensis*) and chrysanthemum (*Chrysanthemum indicus*), and on soybeans during the rainy season. Kapoor et al. (1972) present data on life history, fecundity, and new records of parasitoids. *H. indicata* feeds on leaf parenchyma of soybeans. Previously cited as a secondary pest of soybean, population densities of the pest were high in Brazil during 1982-83 (Lourenção et al., 1985).

***Spodoptera frugiperda* (Lepidoptera: Noctuidae) ("Gusano cogollero del maíz," black armyworm, fall armyworm).** This potential pest is a generalist known to attack groundnut, maize, rice, and pasture grasses. It is widely distributed throughout Latin America. Infestations tend to be sporadic, and the species has a large number of natural enemies.

***Elasmopalpus lignosellus* (Lepidoptera: Pyralidae) (lesser cornstalk borer).** This species is known as a pest of soybeans and groundnuts, and has been reported to cause damage to germinating seedlings of forage plants in Brazil (J. Spain, personal communication). It is the most damaging subterranean pest of peanuts in the USA (Stalker and Moss, 1987).

***Stegasta bosquella* (Lepidoptera: Gelechiidae) (red-necked peanutworm).** A minor pest of groundnut, it also attacks inflorescences of *Stylosanthes capitata*. Although it can reduce seed yield, the authors do not believe it affects persistence of *S. capitata* in swards.

Coleopterans

***Colaspis* spp. (Coleoptera: Chrysomelidae).** This pest, when eating leaves, was collected from *A. pintoi* at Carimagua. Five species are reported in Colombia to attack cowpea and bean, among other crops. Larvae of *C. brunnea* are subterranean root feeders, whereas adults feed on leaves (southern USA). Members of this genus have a wide range of hosts, including soybean, common bean, maize, rice, banana, plantain, and a number of weed species (King and Saunders, 1984).

***Diabrotica* spp. (Coleoptera: Chrysomelidae) (rootworms).** These pests are found at Florencia, Caquetá, and Carimagua, Colombia. They are common leaf-eaters. Species of this genus are widespread in Latin America. An example is *Diabrotica* pos. *balteata* (Coleoptera: Chrysomelidae) collected at Guápiles, Costa Rica. *Diabrotica undecimpunctata* (spotted cucumber beetle) and the southern corn rootworm (*Diabrotica undecimpunctata howardi*) are also widely distributed.

***Omophoita* sp. (Coleoptera: Chrysomelidae).** This pest is found in the humid tropics of Guápiles, Costa Rica. It has been observed in the humid tropics of Colombia feeding on leaves in cedar nurseries.

Hemiptera

Under laboratory conditions, *Arachis pintoi* is highly attractive to *Cyrtomenus bergi*, a polyphagous, subterranean, burrowing, sucking bug. This insect is also a pest on cassava, potatoes, onions, asparagus, peanuts, maize, sorghum, coffee, sugarcane, and pastures (L. Riis, personal communication). This pest has recently been found in *Arachis* fields in Costa Rica and Colombia. It can predispose plants to infections by soil-borne pathogens such as *Fusarium* spp. and thus cause low seed set.

Mites

Spider mites have been observed colonizing leaves of *A. pintoi* in pure stands. To our knowledge, spider mites have never been observed infesting *A. pintoi* in associated pastures. We do not have specimens, but speculate that species of *Tetranychus* predominate.

Thrips

***Caliothrips braziliensis* (Morgan) (Thysanoptera: Thripidae).** This pest is found at Palmira, Colombia, according to one report from CIAT headquarters. The principal thrip pests of groundnut worldwide are species of *Frankliniella*, including tobacco thrips, *F. fusca*. To date, thrips have not been reported to attack *A. pintoi* in Latin America.

Future Research Needs

Arthropod pests of *A. pintoi* will only be discovered as this new legume achieves significant adoption in Latin America. We therefore need to evaluate *A. pintoi* in associations, not only in pure stands. As adoption proceeds, pest and disease problems will likely become more evident. Currently, we know of no significant arthropod constraint to the use of *A. pintoi* in Latin America.

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Chapter 9

The Contribution of *Arachis pintoi* as a Ground Cover in Some Farming Systems of Tropical America

R. de la Cruz
S. Suárez
J.E. Ferguson*

Abstract

While *A. pintoi* is still a novel species under evaluation, principally for its utility as a forage, it has shown high potential as a cover crop in coffee, banana, oil palm, macadamia, and hearts of palm. Preliminary research has indicated its general capacity for weed control, as well as nematode control in tomatoes and coffee. A high potential for nitrogen fixation is indicated because 64% of its N is fixed from the atmosphere. Use as an ornamental in urban areas is increasing. Farmers appear to be quick to recognize the wide range of nonforage uses, such as ground cover, weed control, soil protection and improvement, and contributions to integrated pest management. The nontwining habit of *A. pintoi* is an additional advantage compared with some other tropical legumes. The main difficulty exposed to date is slow establishment and the possibility of competition for nutrients in some situations.

Introduction

Soil cover crops are a promising tool in programs that focus on preventing soil degradation and controlling various pests of plantation crops. Soil degradation often causes decreased productivity and environmental deterioration, particularly in the hill farming systems of Latin America (Reiner, 1992). Likewise, the excessive use of pesticides for weed control can result in an unacceptably high level of noxious chemicals in plant products. The use of appropriate soil covers can reduce soil loss, enhance retention of rainfall, provide nitrogen input, reduce the need for pesticides where weeds are a problem, and reduce the costs of weed control.

Arachis pintoi, with its stoloniferous growth habit and good adaptation in the lowland humid tropics, has shown great potential as a cover crop in several farming systems. This paper summarizes nonforage-related research conducted with *A. pintoi* in several production systems in Central America and Colombia.

Establishment as a cover crop

A. pintoi has been evaluated as a cover crop for coffee, banana, oil palm, macadamia, and hearts of palm.

A combination of agronomic practices was used to establish *A. pintoi* in a palm plantation in Costa Rica that was heavily infested with *Paspalum fasciculatum, Panicum maximum, Tripogandia nudiflora*, and *Pseudolephantepus spicatus*. Glyphosphate was applied before planting and 10 days later stolons of *A. pintoi* were planted. A month later, a postemergent application of fluazifop-butyl was made to control perennial grasses. Finally, a light mowing at 3 months resulted in a well-established cover.

Several legumes were compared during the establishment of cocoa

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* Weed agronomist, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica; agronomist, Centro Nacional de Investigaciones de Café (CENICAFE), Chinchiná, Colombia; forage seeds agronomist, Tropical Forages Program, CIAT, Cali, Colombia, respectively.

(Domínguez, 1990). The species with the best adaptation, fastest cover, and best weed control were *Pueraria montana, Mucuna* sp., and *A. pintoi*. The first two are climbers and hence had to be cut back around young trees. There was some unevenness in the establishment of *A. pintoi* due to varying soil moisture, but it did not twine about the trees.

This research has provided us with good experience as to the capacity of *A. pintoi* to establish and cover the ground surface. The time required to reach a uniform and dense cover varies from 4 to 6 months. Factors such as land preparation, type of soil, soil moisture during the first month after planting, seeding rate, seed viability, and time of cutting prior to planting (in the case of vegetative planting) can all play an important role. Several of these factors frequently interact (Domínguez, 1990).

Figure 1 illustrates the importance of adequate rainfall during establishment. *A. pintoi* was planted in mid-December 1991. The high rainfall in April 1992 greatly increased plant development and growth, following rather low rainfall during the preceeding 3 months (Vallejos, 1992).

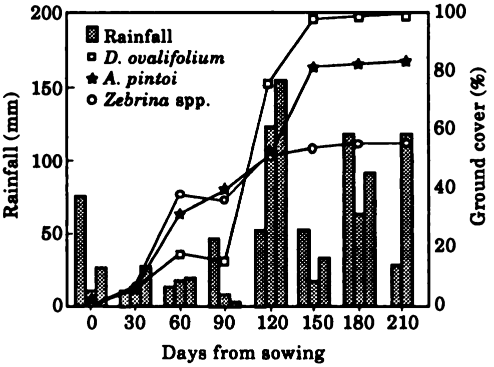

Figure 1. Relation between ground cover and rainfall (cumulative over 10 days). (Adapted from Vallejos, 1992.)

Suárez (1990) compared several legumes, known to be adapted (Suárez et al., 1985; Suárez and Machado, 1988), in the central coffee-producing area of Colombia for their ability to establish rapidly when grown (1) alone with other crops such as coffee, (2) with naturalized pasture, or (3) with *Brachiaria decumbens*. *A. pintoi*, established from seed, showed the best response in terms of cover and dry matter production (Figure 2) and may be established with native or naturalized pastures. If native *Paspalum* species are the dominant

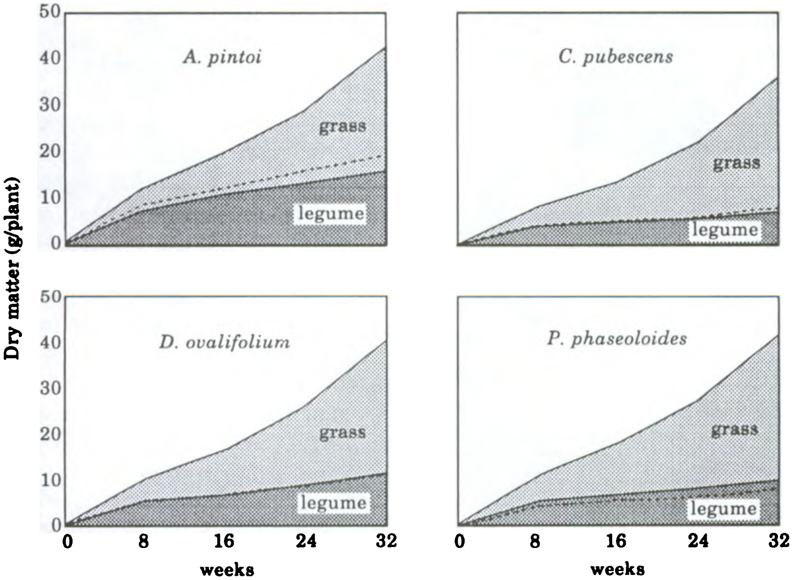

Figure 2. Cumulative dry matter production of four legumes and *B. decumbens* when grown together (shaded areas) and for the legume when grown alone (---). (Adapted from Suárez, 1990.)

native grasses, herbicides need to be used during establishment. This is not necessary in the case of *B. decumbens*, with which the legume establishes readily. *A. pintoi* and *B. decumbens* planted together cover the area faster and produce a greater amount of dry matter than if they are planted separately. This is practical for soil management of hillsides and the improvement of naturalized pastures in the coffee-producing zone, an area of more than 2 million hectares in Colombia. Establishment, production, and persistence of the other legumes was slower, thus increasing the risk of soil erosion.

Establishment of a complete *A. pintoi* cover may require weeding and herbicide application in some situations in addition to other costs. For example, the establishment of *A. pintoi* in a recently established palm kernal crop in Costa Rica cost US$280/ha. This included costs of an initial weeding before planting, hand hoeing, cutting and planting vegetative material for establishment, and three to four weedings before full cover.

In Nicaragua, the cost of establishing an *A. pintoi* cover crop was compared with that of traditional weeding and weeding plus herbicides (Table 1; Bradshaw and Simón, 1992). In the first year, the cost of the cover crop was similar to that of the system using herbicides, but over 3 years it was similar to that of traditional weeding. Overall costs of the cover crop would be reduced in subsequent years. No account was taken of the value of the nitrogen contribution of *A. pintoi* to the coffee crop. Other estimates of the costs of establishment of *A. pintoi* range from US$141 to US$270 (H. Sánchez, personal communication).

Table 1. Comparative costs of weed control using manual weeding, herbicides, and an *A. pintoi* cover crop, Costa Rica.

Weeding system	Control practice	Cost (US$)	
		Year 1	Years 1-3
Traditional	3 slashings/year	30	90
Herbicide	1 weeding + herbicide	97	290
A. pintoi cover	Weeding, planting, 4 weedings in total	89	101

SOURCE: Bradshaw and Simón, 1992.

Slow establishment limits the success of *A. pintoi* as a cover crop and helps explain higher costs, especially where there is a high weed population. H. Sánchez (personal communication) observed an increase in the cover of *A. pintoi* from 5% at 30 days to 42% at 110 days and 76% at 190 days.

In Colombia, weeds are normally cut every 3 to 4 months during the establishment and production of coffee. *A. pintoi* can be planted in the center and along the rows of coffee across a slope. Later, weeds are cut with a machete to the level of the legume. Selective herbicide weeding is recommended for highly competitive weeds such as grasses. Using this management system, *A. pintoi* successfully competes with weeds on both sides of the planted row, resulting in a minimum cost for establishment.

Ability to compete with weeds

Arachis pintoi has been compared with other crops for its ability to suppress weeds. It was slightly less effective than a *Mucuna* sp. and *Pueraria montana* in suppressing weeds on a cocoa crop at 150 days after establishment (Figure 3; Domínguez, 1990). In this experiment, weeding was carried out for the first 2 months after establishment. In an experiment with coffee, in Nicaragua, with three manual weedings, *D. ovalifolium* and *Commelina* sp. reached 90% cover in 4 months, while *A. pintoi* only reached 70% cover. Another study was made of the competitive relationship between *A. pintoi* and other cover crops with weeds under coffee. Two and 3 months after the last weeding in all treatments, an evaluation of weed biomass was conducted (Figure 4; Vallejos, 1992). The

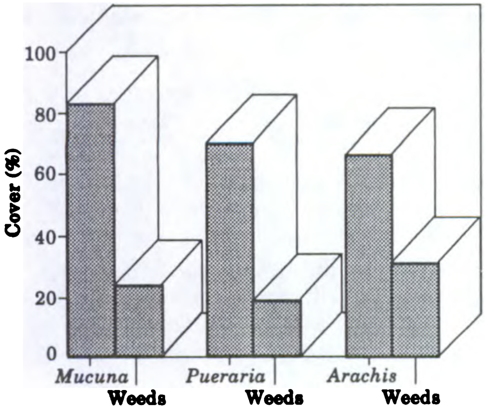

Figure 3. Cover from legume and weeds at 150 days from sowing for three legume species. (Adapted from Domínguez, 1990.)

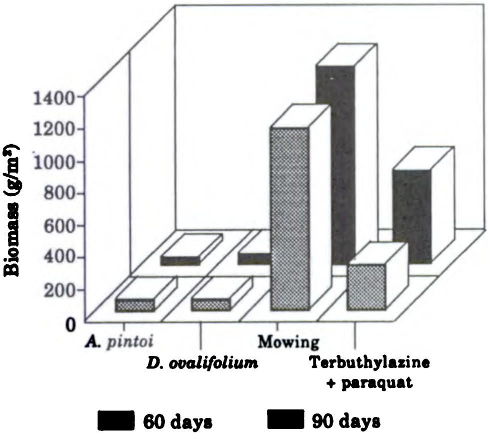

Figure 4. Weed biomass at 60 and 90 days from the last herbicide application, for four weed control strategies. (Adapted from Vallejos, 1992.)

covers *A. pintoi* and *D. ovalifolium* were quite effective in preventing weed regrowth. An efficiency index for the various weed control treatments was derived (Table 2).

Table 2. Variable costs and efficiency index of weed control treatments in coffee.

Treatment	Efficiency (%)	Variable costs (US$)	Efficiency index
A. pintoi	92.79	117	174.58
D. ovalifolium	87.34	104	164.86
Zebrina spp.	78.96	117	205.16
Terbuthylazine + paraquat	66.17	152	316.14
Mowing	64.63	163	348.13

SOURCE: Vallejos, 1992.

Nematode control

In preliminary research (Domínguez et al., 1990) on the effect of various ground cover legumes associated with tomatoes, results showed that these covers protected the crop against infection caused by the nematode *Meloidogyne arabicide*. Of the covers used (*A. pintoi, Pueraria phaseoloides*, and *Centrosema pubescens*), *A. pintoi*, besides protecting the crop against the nematode, was shown not to be a host of the nematode.

Recently, Vallejos (1992) studied the behavior of nematodes in coffee plants when grown with *Zebrina* sp., *Desmodium ovalifolium*, and *A. pintoi* in screenhouses. In coffee plants, the root knotting produced by the *Meloidogyne exigua* nematode was much less when the crop was associated with *D. ovalifolium* and *A. pintoi*. The former was a good host for the nematode, while the latter was almost free from this pest (Figure 5). It would seem that *D. ovalifolium* attracts the nematode and thus protects the crop, while *A. pintoi* has a negative effect on the development of the nematode.

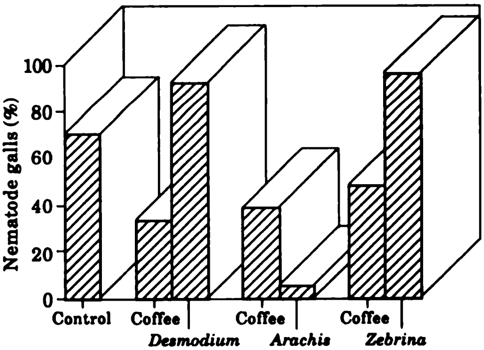

Figure 5. Nematode galls of *Meloidogyne* in coffee associated with *D. ovalifolium*, *A. pintoi*, and *Zebrina* sp. (Adapted from Vallejos, 1992.)

Soil protection and improvement

Soil is mostly lost from hillsides during crop establishment. Associations of *Brachiaria decumbens-Arachis pintoi* were established into native pastures in Andosol soils with more than 50% slope and 2750 mm of average annual rainfall without increasing erosion significantly (Suárez, 1990). The erosion observed in all treatments was less than 1 t/ha (below levels considered undesirable in the coffee-producing region of Colombia). Mulch produced by dead *Paspalum* spp. from herbicide application decomposed over a period of 3 months and significantly reduced soil loss through erosion while grass-legume associations were being established. Soil erosion increased when soil was not protected (Table 3).

Further studies are needed to determine possible chemical and biochemical changes in the soil from *A. pintoi* cover. During a short-term study of establishment of *A. pintoi* cover under hearts of palm (*Bactra gosipens*), strong competition for nitrogen was observed with yellowing and reduced stem diameter of the palms (Domínguez and de la Cruz, 1990).

Some observations on ditch bank protection conducted at CATIE show that when a cover of *A. pintoi* was established in the ditch bank, the degree of erosion was notably reduced. Also, a solid cover on the ditch bank helps avoid the establishment of some grass species whose manual removal causes the soil to be exposed to erosion. Well-conserved ditches have also been observed with strips of grasses alternating with strips of *A. pintoi*.

We expect that the presence of the legume *A. pintoi* over time would increase soil N. To date, studies have concentrated on microbial activity for symbiotic nitrogen fixation. *A. pintoi* introduced directly into an established grass sward did not respond to inoculation with *Rhizobium* CIAT 301, but was shown to fix 64% of its N from the atmosphere (Figure 6; Suárez, 1990).

Ornamental use

Planting *A. pintoi* in gardens is becoming common. Under these conditions, *A. pintoi* is attractive because of its low-growing habit, intense green foliage color, and frequent brilliant yellow flowering.

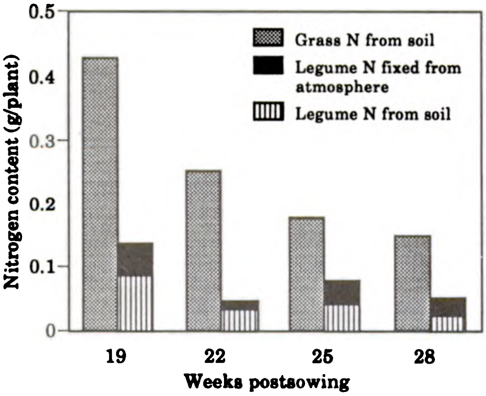

Figure 6. Nitrogen contents of grass (*Brachiaria decumbens*) and legume (*Arachis pintoi*) from both soil and atmospheric sources, at four times postsowing. (Adapted from Suárez, 1990.)

Table 3. Soil erosion under three management systems: soil without cover, soil with legume-grass (*Arachis pintoi-Brachiaria decumbens*) cover, soil with natural (*Paspalum* spp.) cover.

Soil management system	Average soil loss (kg/ha)		
	March-June	July-October	March-October
Without cover	8.7 a*	420.6 a	198.8 a
Legume-grass	8.0 a	18.6 b	13.3 b
Natural cover	3.3 a	7.5 b	5.2 b

* Similar letters in the same column do not differ significantly.

SOURCE: Suárez, 1990.

Experiences of early adopters in Yapacani, Bolivia

The forage seed enterprise SEFO-SAM began contracting seed production of *A. pintoi* with small farmers in the Yapacani region of Bolivia in 1990. Within this rain forest colonization region, small areas of approximately 0.1 ha were established with selected farmers on well-drained sites. As seed production was the primary objective, cattle were either excluded or their access controlled to these areas. In 1991, four farmers conducted seed harvesting for the first time, followed by five others in 1992. In early 1993, a survey was conducted with eight of these farmers to determine their perceptions of both the current and future use of *A. pintoi* within their farming systems (E. Ramírez and G. Sauma, personal communication). Table 4 summarizes the results.

At present, as seed production was the entry point of *A. pintoi* into their farming system, all eight farmers were practicing this form of utilization and plan to continue. Additionally, all farmers recognized the value of the foliage and flowers as a feed source for poultry; most recorded the use of seeds as an occasional supplemental food source for the farm family; and several are already using *A. pintoi* for weed control in crops of cassava, citrus, pineapples, and plantains.

In the future, these mixed farmers also plan to use *A. pintoi* as a forage, both pure and associated with *Brachiaria* spp., and as a soil cover. Of note is their concept of potential use as a quality legume hay for dairy cattle and horses.

These results indicate the rapid recognition of a wide range of attractive and complementary uses of *A. pintoi* and its adoption by small farmers in a mixed farming system.

Conclusions

Research results indicate that *A. pintoi* is a multiple-use ground cover crop with a high potential to contribute to sustainable agricultural systems. This is due to its contributions to physical-chemical improvement and protection of the soil, nutrient recycling, forage and organic matter production, and contribution to integrated pest management.

Compared with traditional cover species such as Centro and Kudzu,

Table 4. Summary of use in farming systems of *A. pintoi* by eight pioneer small farmers in Yapacani, Bolivia.[a]

Use in farming systems	Practiced	Planned
Seed production, under contract to SEFO-SAM[b]	8	8
Forage		
Pure stand	1	-
Associated with *Brachiaria* sp.	0	-
Legume hay	0	-
Browse for poultry	8	-
Soil cover		
Weed control in crops[c]	3	5
Erosion control	0	6
Green manure	0	0
Human food		
(occasional supplement of seeds)	6	6

a. Mixed farmers in forest margin colonization zone.
b. Entry point into farming system in 1990.
c. Cassava, plantain, citrus, pineapple.

SOURCE: E. Ramírez and G. Sauma, personal communications.

A. pintoi has the advantage of a nontwining habit, which reduces maintenance costs. The main difficulty exposed to date is slow establishment.

Some aspects that require more attention, preferably through multidisciplinary groups, are:

1. Improvement of techniques for establishment and management in specific environmental conditions.
2. Contribution to nitrogen fixation and soil organic matter.
3. Competition with associated crops for nutrients and water.
4. Relation to other beneficial and harmful organisms.
5. On-farm demonstrations of multiple uses of this legume, and some economic analysis of the benefits.

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Chapter 10

Nutritive Value and Animal Production of Forage *Arachis*

C.E. Lascano*

Abstract

The nutritive value of *Arachis glabrata* cv. Florigraze and *A. pintoi* CIAT 17434 is higher than that of most tropical legumes of commercial importance. Forage *Arachis* species have high levels of digestible energy (i.e., 60-70% dry matter digestibility) and fermentable nitrogen (i.e., 13-25% crude protein). Relatively low levels of condensed tannins in forage *Arachis* could result in protein being partially protected from degradation by rumen microbes.

In pastures based on *A. pintoi* CIAT 17434, grazing animals select legume year-round and in a proportion slightly higher than in the forage-on-offer, provided they have been previously exposed to the legume.

Annual liveweight gains in pastures with *A. pintoi* have ranged from 160 to 200 kg/head and from 250 to 600 kg/ha, depending on species of the companion grass and dry season stress of the location. In pastures based on *A. glabrata*, daily gains have been as high as 1 kg. The inclusion of *A. pintoi* in grass pastures has resulted in increased liveweight gains and milk yields of 20-200% and 17-20%, respectively, compared with the grass-alone pastures; the highest gains occurring when there is 30% legume in the pasture. This increase is due to both the increased quality of the companion grass and to legume. Even in heavily grazed pastures and in the dry season, liveweight gains are higher in pastures with *A. pintoi* than in pastures with grass alone.

A. pintoi CIAT 17434 and *A. glabrata* cv. Florigraze can grow with aggressive grasses and persist under a wide range of grazing management, including continuous grazing. Heavy grazing appears to favor increased legume content, particularly in areas with little dry season stress.

Introduction

The benefit of using legumes to increase animal production is well documented in the literature. Recent publications show that in grass-legume pastures grown in acid, infertile soils, milk production can be increased by 20% (Lascano and Avila, 1991) and liveweight gain by 40% (Lascano and Estrada, 1989). In spite of these good experimental results, legume adoption by farmers in the tropics is limited, partly because of lack of persistence of released commercial cultivars under grazing. As a consequence, forage agronomists have continued to search for high-quality legumes that persist under grazing. A result of this effort was the release of commercial cultivars of *Arachis glabrata* in Florida, USA (Prine et al., 1981) and of *A. pintoi* in Australia (Cook et al., 1990) and Colombia (Rincón et al., 1992).

This chapter summarizes results of experiments on the nutritive value of forage *Arachis* species and on animal production in pastures based on commercial *Arachis* cultivars, namely, *A. glabrata* cv. Florigraze and *A. pintoi* CIAT 17434.

Feed Quality

Quality of forage *Arachis* species

A few studies have documented the nutritive value of commercial forage

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* Ruminant nutritionist, Tropical Forages Program, CIAT, Cali, Colombia.

Arachis species. Crude protein (CP) and in vitro organic matter digestibility (IVOMD) in hay of four cultivars of *A. glabrata* ranged from 9 to 17% and from 58 to 69%, respectively (Table 1). The highest CP and IVOMD values were found in Florigraze, which was released in Florida in the early 1980s (Prine et al., 1981). Values for CP and in vitro dry matter digestibility (IVDMD) for hay made from *Arachis pintoi* CIAT 17434 were not found in the literature. But CP and IVDMD in leaves of *A. pintoi* CIAT 17434 have ranged from 13 to 22% and 60 to 67%, respectively. A similar range in CP and IVDMD was found in leaves of Florigraze. Differences in CP and IVDMD among accessions were found in a small germplasm collection of *A. pintoi* in the Cerrados of Brazil (Table 1). But we need more information before concluding that forage quality varies in accessions of *A. pintoi*.

Protein level and dry matter digestibility in *A. glabrata* and *A. pintoi* are higher than the average found by Minson (1990) for tropical legumes (17% CP and 55% IVDMD) in a review of the world literature. Although CP and IVDMD of leaves of *A. glabrata* and *A. pintoi* are similar to values recorded in the leaf tissue of important commercial legumes (i.e., *Stylosanthes guianensis*, *S. hamata*, *S. capitata*, *Centrosema pubescens*), they are considerably higher than in some *Desmodium* species that contain tannins (Abaunza et al., 1991).

Reports on mineral content of forage *Arachis* species are scarce in the literature. Calcium (Ca) and phosphorus (P) concentrations in leaves of *A. pintoi* grown in an acid soil with low P (i.e., Carimagua, Llanos of Colombia) have been on the order of 1.7% and 0.2%, respectively (Carulla, 1990). Similar P concentrations are found in other legume species selected for acid soils (Abaunza et al., 1991). Ca concentration in *A. pintoi* is similar to concentrations in *Leucaena leucocephala*, but higher than in other tropical legumes species, such as *Stylosanthes* spp. (0.9%), *Centrosema* spp. (0.6-0.7%), and *Desmodium* spp. (0.6%) (Lascano et al., 1990; Abaunza et al., 1991).

As expected, CP in leaves of *A. glabrata* and *A. pintoi* is higher than

Table 1. Crude protein (CP) and in vitro dry matter (IVDMD) or organic matter (IVOMD) digestibility of forage *Arachis* species. Values are percentages.

Species/cultivars	CP	IVDMD	IVOMD	Observations	Source
A. glabrata					
cv. Arb	9-11	-	58-62	Hay harvested over five growing seasons, Jay, ARC, Florida	Prine et al., 1981
cv. Arblick	11-15	-	62-64	Hay harvested over five growing seasons, Jay, ARC, Florida	
cv. Florigraze	13-16	-	64-69	Hay harvested over five growing seasons, Jay, ARC, Florida	
cv. Arbrook	11-17	-	58-68	Values reported are for hay	Prine et al., 1990
A. glabrata					
cv. Florigraze	15-25	-	60-70	Leaves harvested in the growing season, Beevile, Texas, and Gainesville, Florida	Romero et al., 1987; Ocumpaugh, 1990
A. pintoi					
CIAT 17434	13-22	60-67	-	Leaves harvested in the dry and wet seasons in grazed pastures in Carimagua, Llanos of Colombia	Carulla et al., 1991
A. pintoi accessions	16-19	48-58	-	Leaves from six accessions harvested in small plots in the Cerrados of Brasil	CIAT-EMBRAPA, Brazil, unpublished data

in stems, whereas differences between stem and leaf digestibility are small, particularly in *A. pintoi* (Table 2). It is well known that protein, fiber, and digestibility of leaf and stem fractions of forage plants can be significantly affected by season of the year. But cell wall content and digestibility of leaves and stems of *A. glabrata* and *A. pintoi* do not change significantly as the growing season progresses in regions with well-defined seasons (Table 2). Small decreases in digestibility (1 to 3% per month) have been observed in leaves and stems of *A. glabrata* from mid-summer through autumn in Florida and Texas (Saldivar et al., 1990; Ocumpaugh, 1990). With *A. pintoi* grown in tropical areas that have well-defined dry and wet seasons, small changes have been observed between seasons in leaf CP, digestibility, and neutral detergent fiber (NDF), that is, cell wall content (Table 2).

Tannin and protein degradability in forage *Arachis* species

When examining the nutritive value of forage species, it is important to look for antiquality factors such as tannins. Limited results indicate that *A. glabrata* cv. Florigraze and *A. pintoi* CIAT 17434 have low levels of condensed tannins, which could explain the relatively slow rates of in situ protein degradation that have been measured, when compared with *Centrosema* species high in soluble protein. On the other hand, the rate of in situ protein degradation in *Arachis* species is faster than in *Desmodium ovalifolium* with high tannin levels (Table 3). This suggests that condensed tannins in forage *Arachis* species may be partially protecting protein from degradation in the rumen, such as in *Leucaena leucocephala* (Flores et al., 1979), but at the same time these forage *Arachis* species are an adequate source of fermentable nitrogen (i.e., rumen ammonia). In vitro studies have shown that ammonia released in the digestion process is twice as high in *A. pintoi* than in *D. ovalifolium* (Figure 1). Studies under grazing have also shown that rumen ammonia levels are higher in steers grazing pastures based on *A. pintoi* CIAT 17434 (134 mg/liter) than in pastures based on *D. ovalifolium* CIAT 13089 (57 mg/liter) (Hess et al., 1992).

Rate and extent of dry matter digestion of *A. glabrata* cv. Florigraze

Table 2. Crude protein (CP), neutral detergent fiber (NDF), and in vitro and in situ dry matter digestibility of leaf and stem fractions of forage *Arachis* species as influenced by season of the year. Values are percentages.

Species/ cultivars	Season	Leaf				Stem				Source
		CP	NDF	DM digestibility		CP	NDF	DM digestibility		
				in vitro	in situ			in vitro	in situ	
A. glabrata										
cv. Florigraze[a]	Summer	19	53	-	54	9	58	-	46	Romero et al., 1987
	Fall	20	50	-	62	9	56	-	50	
A. pintoi										
CIAT 17434[b]	Dry	13	50	67	-	9	55	64	-	Carulla et al., 1991
	Wet	18	51	62	-	11	51	65	-	
A. pintoi										
CIAT 17434[b]	Dry	14	-	67	-	11	-	63	-	Lascano and Thomas, 1988
	Wet	18	-	60	-	11	-	62	-	

a. Hay samples, Gainesville, Florida.

b. Samples taken in grazed pastures in Carimagua, Llanos of Colombia.

Table 3. Condensed tannin (CT) content and in situ rate of nitrogen disappearance (K) of some tropical legumes including forage *Arachis* species.

Legumes	CT (%)	K[a] (%/hr)	Source
A. glabrata cv. Florigraze	0.3	6.4	Romero et al., 1987
A. pintoi CIAT 17434	2.5[b] (8.2)[c]	6.7	CIAT, unpublished results; Carulla, 1990
Centrosema arenarium (CIAT 5236)	1.2	31.1	CIAT, unpublished results
C. macrocarpum (CIAT 5065)	1.0	24.2	CIAT, unpublished results
Desmodium ovalifolium (CIAT 350)	22.5	3.2	CIAT, unpublished results

a. Parameter estimated by fitting the model $Y = Ae^{-Kt}$.

b. Use of vanillin-HCl method and catechin as the standard.

c. Number in parentheses is extractable condensed tannins using Butanol-HCl and *A. pintoi* tannins as standards.

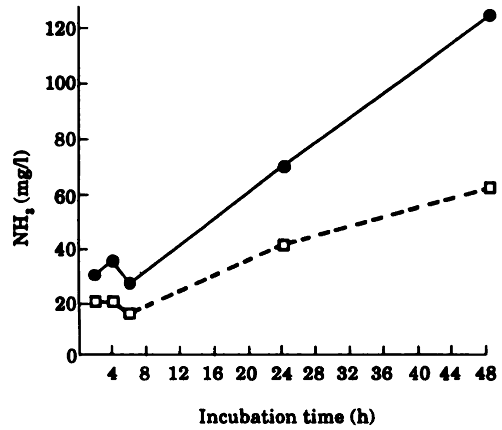

Figure 1. In vitro ammonia production with *Arachis pintoi* (-●-), low in tannins, and *Desmodium ovalifolium* (-□-), high in tannins. (Adapted from Carulla and Lascano, unpublished results.)

forage have been shown to increase with decreasing particle size (Emanuele and Staples, 1988). Therefore, future studies designed to measure rate of protein degradation of forage *Arachis* species should consider several particle sizes for in situ rumen incubation.

Researchers in the U.S. have compared the nutritive value of forage *Arachis* with that of alfalfa. For example, Romero et al. (1987) found lower levels of CP in *A. glabrata* cv. Florigraze than in alfalfa; however, the same authors found that in situ rate of protein degradation was faster in alfalfa, even though in vivo protein digestibility was similar for both legume species. Based on these results, the authors suggested that the nutritive value of Florigraze is nearly equal to that of alfalfa. In another study, Gelaye et al. (1990) found that dry matter and cell wall digestion were higher in goats fed hay of *A. glabrata* than in those fed alfalfa hay. This was associated with more liveweight gain and better feed conversion in goats fed the forage peanut. In this study, it was also interesting to note that animals fed alfalfa and peanut forage had similar nitrogen intakes, but urinary nitrogen was higher in animals fed forage peanut (10 g/day) than in those fed alfalfa (8.5 g/day). This suggests that protein of forage peanut hay was more degraded in the rumen than protein from alfalfa, which somewhat contradicts the suggestion that one of the advantages of forage peanut over alfalfa is its greater level of potential bypass ruminal protein (Romero et al., 1987).

From the evidence reviewed, it is clear that the nutritive value of *A. glabrata* cv. Florigraze and *A. pintoi* CIAT 17434 is as high or higher than that of most tropical legumes in commercial use. These forage *Arachis* species are not only a good source of rumen fermentable nitrogen but also of digestible energy (i.e., high dry matter digestibility). The presence of condensed tannins in forage *Arachis* species may have nutritional significance, but the evidence available is scarce and conflicting.

Grazing Selectivity

In this review, only two studies on grazing selectivity in pastures with forage *Arachis* species were found. Both studies were carried out in Carimagua, Llanos of Colombia, in pastures based on *A. pintoi* CIAT 17434. In the first study, Lascano and Thomas (1988) measured the proportion of *A. pintoi* in the diet of fistulated steers grazing mixtures with four *Brachiaria* species. The legume content in the forage on offer was high, and varied from 28% in the dry season to 58% in the wet season. Corresponding values in the diet selected by esophageal-fistulated steers were 37 and 60%, indicating that animals selected legume in a slightly higher proportion than what was present in the pastures. As a consequence of high legume selection throughout the year, the diet was high in crude protein (10-16%) and dry matter digestibility (61-62%).

A second study on selectivity of *A. pintoi* by grazing animals involved an association with *B. dictyoneura* cv. Llanero (Carulla et al., 1991). This pasture was grazed by esophageal-fistulated steers and by intact steers used to monitor liveweight gain. Results show that esophageal-fistulated steers, with previous grazing experience on *A. pintoi* pastures, selected a high proportion of legume in all sampling periods (Table 4). As in the first study, legume in the diet of esophageal-fistulated steers was slightly higher than legume-on-offer. But the results in Table 4 also indicate that selection of *A. pintoi* CIAT 17434 may be influenced by previous experience of the grazing animals. Intact animals in group 1, with 4 months previous experience in the pasture, selected a high proportion of *A. pintoi*, which was similar to that selected by esophageal-fistulated steers with previous exposure to the grass-legume pasture. In contrast, intact animals in group 2, with less previous experience than animals in group 1, selected a lower proportion of legume than esophageal-fistulated steers previously accustomed to the pasture, regardless of sampling period.

The relationship between previous experience and selectivity under grazing of *A. pintoi* has implications in experiments designed to measure liveweight gain or milk production. Animal production may be underestimated if the animals used in the experiment have not been exposed to the legume for at least 4 months, as the data of Carulla et al. (1991) suggest. Possible solutions would be to use the same animals for longer periods of time

Table 4. Legume-on-offer and legume selected by esophageal-fistulated and intact steers grazing *Brachiaria dictyoneura-Arachis pintoi* CIAT 17434 pastures in Carimagua, Llanos of Colombia.

Sampling periods	Legume-on-offer	Legume selected[a] (%)		
	(%)	Fistulated[b]	Intact[c] (Group 1)	Intact[d] (Group 2)
Sept.-Oct., 1988	54	-	57	-
Nov.-Dec., 1988	56	47 a*	43 a	-
Jan.-Feb., 1989	37	43 a	-	8 b
Mar.-Apr., 1989	30	45 a	-	21 b
May-June, 1989	32	27 a	-	15 b

a. Legume selected estimated using $\delta^{13}C$ in feces.

b. Steers with previous grazing experience on pasture based on *A. pintoi*.

c. Steers introduced in the pasture in May 1988.

d. Steers introduced in the pasture in December 1988.

* Means in the same row are different (P<.05).

SOURCE: Carulla et al., 1991.

or expose them to the legume prior to beginning the experiment.

In general, results on grazing selectivity in pastures based on *A. pintoi* indicate that grazing animals with previous experience select legume year-round and in a proportion slightly higher than that in the forage-on-offer. This is contrary to what has been observed in other tropical grass-legume pastures, where animals select less legume (i.e., *D. ovalifolium*) than that on offer (Lascano et al., 1991) or select more legume (i.e., *Pueraria phaseoloides*, *Stylosanthes capitata*) during the dry season than during the wet season (Böhnert et al., 1985).

Animal Production

Liveweight gains of steers grazing pastures based on forage *Arachis* species

Controlled grazing experiments designed to measure liveweight gain or milk production in pastures based on *A. pintoi* CIAT 17434 have been restricted to the Llanos of Colombia and to humid areas of Costa Rica. Studies to measure liveweight gains in pastures based on *A. glabrata* cv. Florigraze have been conducted mainly in Florida, USA.

Annual liveweight gains of steers grazing well-managed pastures with *A. pintoi* have ranged from 160 to 200 kg/head and from 250 to 600 kg/ha (Table 5). In Carimagua, Llanos of Colombia, with a well-defined dry season (3-4 months), maximum gains have been on the order of 180 kg/head and 400 kg/ha in an association of *A. pintoi* with *B. dictyoneura* cv. Llanero under rotational grazing. In the piedmont of the Llanos of Colombia (La Libertad-Villavicencio) with a short dry season, individual animal liveweight gains in pastures with *A. pintoi* have been only slightly higher than in Carimagua. In contrast, liveweight gains per hectare in the piedmont are 70% higher than in Carimagua, mainly due to higher carrying capacity of the pastures. In the

Table 5. Annual liveweight gain (LWG) of steers grazing well-managed pastures based on *Arachis pintoi* CIAT 17434 in different locations of tropical America.

Location	*Brachiaria* grasses in association with *A. pintoi*	Annual LWG		Observations	Source
		(kg/head)	(kg/ha)		
Carimagua, Llanos of Colombia (2500 mm of rain and 3-4 months dry season)	*B. humidicola* *B. decumbens* cv. Basilisk	160 189	320 246	Values are an average of 5 years; alternate grazing management (7-14 days on/ 7-14 days off)	Rincón et al., 1992
Carimagua, Llanos of Colombia (2500 mm of rain and 3-4 months dry season)	*B. dictyoneura* cv. Llanero	183	432	Values are an average of 4 years; rotational grazing management (7 days on, 21 days off)	CIAT, unpublished results
La Libertad, piedmont, Llanos of Colombia (2900 mm of rain and 2-3 months mild dry season)	*B. humidicola* *B. dictyoneura* cv. Llanero *B. decumbens* cv. Basilisk *B. brizantha* cv. La Libertad	176 180 200 203	528 540 600 609	Values are an average of 3 years; alternate grazing management (7-14 days on/ 7-14 days off)	Pérez and Lascano, 1992
Guápiles, Costa Rica (4500 mm of rain, no dry season)	*B. brizantha* cv. Diamantes	183	550	Value is an average of 2 years; rotational grazing management (7 days on, 21 days off)	CIAT-MAG-Costa Rica, unpublished results

humid forest of Costa Rica (Guápiles), with no dry season stress, animal production in *B. brizantha* cv. Diamantes in association with *A. pintoi* has also been high, both in terms of individual animal gains and production per hectare (Table 5).

Individual animal liveweight gains in pastures based on *A. glabrata* cv. Florigraze have been high. Sollenberger et al. (1987) reported that in two grazing seasons steers in a Florigraze pasture gained, on the average, 980 g/head/day. In Brooksville, Florida, animal liveweight gains during the grazing season ranged from 680 to 900 g/head/day in a mixture of *Cynodon* and *Paspalum* spp. with *A. glabrata* cv. Florigraze (Williams et al., 1989).

The high potential animal production per unit area in pastures based on *A. pintoi* is evident in tropical areas with no dry-season stress. However, even in areas with 3-4 months dry season (i.e., Llanos of Colombia), the productivity of *A. pintoi*-based pastures is high, particularly when compared with other grass-legume pastures. For example, in Carimagua, the highest liveweight gain in pastures of *A. gayanus*-*S. capitata* or *B. decumbens*/*P. phaseoloides* has been on the order of 280-300 kg/ha (Lascano and Estrada, 1989; Lascano and Thomas, 1990), which is 30-40% less than the highest gain per hectare obtained in pastures based on *A. pintoi*.

Advantage of forage *Arachis* pastures over grass-alone pastures in animal production

Animal production has been measured in pastures with and without forage *Arachis* species in grazing trials in Florida (USA), the Llanos of Colombia, and the humid forest of Costa Rica (Guápiles). Table 6 summarizes the

Table 6. Liveweight gain (LWG) when animals graze pastures based on *Arachis pintoi* CIAT 17434 and *A. glabrata* cv. Florigraze compared with the corresponding grass-alone pastures.

Location	Legume + grass	LWG				Source
		Grass		Grass-legume		
		(kg/head)[a]	(kg/ha)[a]	(kg/head)[a]	(kg/ha)[a]	
Carimagua, Llanos of Colombia	***A. pintoi*** **+**					
	Brachiaria brizantha	155	155	190	190	Rincón et al., 1992
	B. decumbens	148	192	189	246	
	B. dictyoneura	136	204	178	267	
	B. humidicola	75	150	160	320	
Carimagua, Llanos of Colombia	***A. pintoi*** **+**					
	B. humidicola	61-115	230-288	89-151	302-390	CIAT, unpublished results
	B. dictyoneura	106-124	248-369	124-166	332-459	
Guápiles, Costa Rica	***A. pintoi*** **+**					
	B. brizantha	126-164	246-378	183-188	282-548	CIAT-MAG-Costa Rica, unpublished results
		(g/head/day)[b]		(g/head/day)[b]		
Gainesville, FL	***A. glabrata*** **+**					
	Paspalum notatum	370	-	980	-	Sollenberger et al., 1987
Brooksville, FL	***A. glabrata*** **+**					
	P. notatum and *Cynodon dactylon*	503-522	-	681-904	-	Williams et al., 1989

a. Per year.

b. Per growing season.

advantages in animal production obtained with pastures based on *A. pintoi* CIAT 17434 and *A. glabrata* cv. Florigraze over the corresponding grass-alone pastures. In the Llanos of Colombia, liveweight gains have been 20 to 200% greater in pastures with *A. pintoi* than in the grass alone. Part of this variation appears to be related to quality of the companion grass and to legume content in the forage-on-offer. In a grazing experiment involving several *Brachiaria* species in association with *A. pintoi* and with high legume content (30 to 60%) in all pastures (Rincón et al., 1992), the greatest increment in liveweight gain (213%) over the grass alone was in the association of *A. pintoi* with *B. humidicola*—a grass known to be deficient in protein (Hoyos and Lascano, 1985). But in a second grazing experiment in Carimagua also involving *B. humidicola*, but with a relatively low proportion of *A. pintoi* (10%), liveweight gains were only 36% higher in the grass-legume pastures compared with pastures with no legume (C.E. Lascano, unpublished results). In Guápiles, Costa Rica, liveweight gain in *A. pintoi* pastures was 15% higher than in grass alone when legume content was low (6%) in the forage-on-offer, and 45% higher when the pasture had a high legume content (30%) (Table 7). Animal performance in pastures based on *A. glabrata* cv. Florigraze also appears to be related to legume content in the pasture. In Brooksville, Florida, animal liveweight gains in an association of Florigraze with *P. notatum*-*C. dactylon* were 30% greater in a rainy spring than in a dry spring, which was mainly related to more legume content in the pastures in the rainy spring (Williams et al., 1989).

Table 7. Effect of grazing management on seasonal average daily gain (ADG) and annual liveweight gain (LWG) of steers grazing pastures with and without *Arachis pintoi* CIAT 17434.

Pasture	Grazing management[a]	ADG Dry	ADG Wet	Annual LWG	Observations	Source
		(g/head/day)		(kg/head)		
B. humidicola						
No legume	2 head/ha-A	250	323	115	Values are the average of 4 years; Carimagua, Llanos of Colombia	CIAT, unpublished results
	3 head/ha-A	130	320	96		
	4 head/ha-A	44	228	61		
+ *A. pintoi*	2 head/ha-A	335	413	151		
	3 head/ha-A	232	401	130		
	4 head/ha-A	71	300	89		
B. dictyoneura						
No legume	2 head/ha-A	361	286	113	Values are the average of 3 years; Carimagua, Llanos of Colombia	CIAT, unpublished results
	3 head/ha-A	200	311	100		
	3 head/ha-R	251	375	122		
+ *A. pintoi*	2 head/ha-A	451	467	168		
	3 head/ha-A	273	380	126		
	3 head/ha-R	337	456	152		
B. brizantha						
No legume	1.5 head/ha-R	-	-	164	Values are the average of 2 years; Guápiles, Costa Rica	CIAT-MAG-Costa Rica, unpublished results
	3.0 head/ha-R	-	-	126		
+ *A. pintoi*	1.5 head/ha-R	-	-	188		
	3.0 head/ha-R	-	-	183		

[a] A = alternate grazing (7-14 days on/7-14 days off); R = rotational grazing (7 days on/21 days off).

The effect of *A. pintoi* CIAT 17434 on milk production has been measured in a number of experiments in Turrialba, Costa Rica. In an association of *A. pintoi* with the aggressive star grass (*C. nlemfuensis*), milk production increased 17% over that of the grass alone fertilized with nitrogen (van Heurck, 1990). A similar increment in milk poduction was recorded in a pasture of *B. decumbens-A. pintoi* in Quilichao, Colombia (C.E. Lascano, unpublished results). In this pasture, however, milk production increased significantly over the grass alone only when the proportion of *A. pintoi* in the forage-on-offer was at least 10%.

In most tropical grass-legume pastures, a quadratic relationship has been observed between liveweight gain per head and legume content in the pasture. For example, in pastures of *Brachiaria mutica*, *B. decumbens*, and *Panicum maximum* each sown with a mixture of *Centrosema pubescens*, *Macroptilium atropurpureum*, and *Stylosanthes guianensis*, liveweight gain per head increased up to 15% legume content in the pasture, after which there was little change (Watson and Whiteman, 1981). The evidence available suggests that the quadratic relationship between individual animal gains and legume content in the pasture may not hold true for pastures based on forage *Arachis*.

In general, annual production in pastures with forage *Arachis* species is high in terms of both individual animal gains and production per hectare. Animal production per hectare in well-managed pastures based on *A. pintoi* is higher than in most other tropical grass-legume pastures grown in areas with acid soils and dry season stress (Lascano and Estrada, 1989; Lascano et al., 1990; Lascano and Thomas, 1990). Likewise, the benefit of the associated legume for individual animal liveweight gain and daily milk yield over the pure grass pasture is as high or higher than for other tropical grass-legume pastures (Lascano and Estrada, 1989; Lascano and Avila, 1991).

Grazing Management

Grazing management and animal performance in pastures based on *Arachis pintoi*

Few grazing experiments have been designed to measure animal performance in pastures based on forage *Arachis* species under different management systems. Two large experiments in Carimagua were designed to measure the effect of stocking rate and grazing method on liveweight gain of steers grazing pastures with and without *A. pintoi* CIAT 17434. Results summarized in Table 7 show that after 4 years stocking rate had a large effect on seasonal liveweight gain of steers grazing *B. humidicola-A. pintoi* pastures. Annual liveweight gains decreased by as much as 70% when stocking rate increased from 2 to 4 head/ha. But with the grass alone, the reduction in annual liveweight gain due to stocking rate was considerably greater (i.e., 90%) than in the pasture based on *A. pintoi*.

A second ongoing grazing experiment in Carimagua involves pastures of *B. dictyoneura* with and without *A. pintoi*, managed with different grazing methods (i.e., alternate and rotational). In the grass-legume pastures, animal performance has been more affected by stocking rate than by grazing method (Table 7). After 3 years of grazing with an alternate system, increasing stocking rate from 2 to 3 head/ha reduced animal liveweight gains by 34%. In contrast, weight gains have only been 20% lower with alternate grazing, compared with rotational grazing, at the same stocking rate.

In the *B. humidicola* pastures with or without *A. pintoi*, animals gained weight during the dry season, regardless of stocking rate, but gains were 50% higher in the association than in the grass alone. This is interesting, because a negative attribute of *A. pintoi* is low tolerance of drought. As a result, legume content in the pasture drops considerably in the dry season (Grof, 1985; Lascano and Thomas, 1988; Carulla et al., 1991). In *B. dictyoneura* pastures, liveweight gains during the dry season have been exceptionally high, even in the grass-alone pastures, whereas liveweight gains in the dry season have been 25-40% higher in the pastures with *A. pintoi* (Table 7).

Table 7 also shows annual liveweight gains of steers grazing *B. brizantha* with and without *A. pintoi* in the humid forest of Costa Rica. After 2 years of grazing, stocking rate has reduced liveweight gain of animals grazing the grass pastures, but has had no effect on animals grazing the association. The high liveweight gain at the high stocking rate in the *A. pintoi-B. brizantha* pasture is associated with a higher legume content in the more heavily stocked pasture (Table 8).

It is clear from the results reviewed that grazing management, particularly stocking rate, can affect the performance of animals grazing pastures based on *A. pintoi*. But even at high stocking rates and during the dry and wet season, liveweight gains are considerably greater in pastures with *A. pintoi* than in pastures with grass alone.

Effect of associated grass and grazing management on legume availability in pastures based on forage *Arachis* species

Researchers working with tropical forages face an important challenge—finding legumes that can be sown in mixtures with aggressive and stoloniferous grasses and that persist under heavy grazing. The good associative ability of *A. pintoi* CIAT 17434 with four *Brachiaria* spp. was well documented by Grof (1985) in Carimagua. After 2 years of grazing, legume content in the forage-on-offer varied from 20% in the mixture with *B. dictyoneura* to 45% in the mixture

Table 8. Legume-on-offer in the rainy season in pastures based on *Arachis pintoi* CIAT 17434 under different grazing management.

Pasture	Grazing management	Legume-on-offer (kg DM/ha)		Observations	Source
		First year	Last year		
B. humidicola-A. pintoi	**Alternate**				
	2 head/ha	160	550	Results are after 4 years of grazing; Carimagua, Llanos of Colombia	CIAT, unpublished results
	3 head/ha	140	650		
	4 head/ha	100	500		
B. dictyoneura-A. pintoi	**Alternate**				
	2 head/ha	770	730	Results are after 3 years of grazing; Carimagua, Llanos of Colombia	CIAT, unpublished results
	3 head/ha	350	350		
	Rotational				
	3 head/ha	380	270		
Brachiaria spp.-*A. pintoi*	**Alternate**				
	3 head/ha	100	200	Results are the average of 4 pastures after 3 years of grazing; La Libertad, Llanos of Colombia	Pérez and Lascano, 1992
B. brizantha cv. Diamantes-*A. pintoi*	**Rotational**				
	1.5 head/ha	600	400	Results are after 2 years of grazing; Guápiles, Costa Rica	CIAT-MAG-Costa Rica, unpublished results
	3.0 head/ha	800	1300		

with *B. ruziziensis*. Legume content in the pastures also increased over time in the four associations in spite of year-round heavy grazing (2.5 head/ha). Tolerance of *A. pintoi* to heavy grazing was also observed in contrasting sites in the subtropics of Australia, when it was sown into cultivated strips in existing grasslands (Cameron et al., 1989).

Dunavin (1992) examined the associative capacity of *A. glabrata* cv. Florigraze with three grasses under cutting. *A. glabrata* was found to be persistent after 8 years, when grown in association with 'Tifton 44' bermudagrass (*Cynodon dactylon*) and "Floralta" limpograss (*Hemarthria altissima*), but was not persistent with "Pensacola" bahiagrass (*Paspalum notatum*). In another study, the association of Florigraze with "Pensacola" bahiagrass, Tifton "Hybrid-81" bermudagrass, and "Survenala" digitgrass resulted in a 100-300% increase in total dry matter yield compared with that of pure grasses (Valentin et al., 1986). In this study, Florigraze was also able to compete with the sown grasses and weeds even when high levels of N were applied.

Legume persistence under grazing can only be assessed in long-term experiments under different management systems. Legume in the forage-on-offer has been monitored in a few grazing experiments involving pastures based on *A. pintoi* CIAT 17434. In the Llanos of Colombia, the availability of *A. pintoi* in association with *B. humidicola* increased after 4 years of grazing, regardless of stocking rate (Table 8). But the content of *A. pintoi* in pastures with *B. dictyoneura* has been relatively stable after 3 years of grazing with an alternate system and contrasting stocking rates. In this association, there is a trend for rotational grazing at a high stocking rate to favor the grass over the legume. In contrast, in the humid forest of Costa Rica, a high stocking rate under rotational grazing has favored *A. pintoi*, whereas a low stocking rate has favored the grass (Table 8). In subtropical areas such as Gainesville, Florida, *A. glabrata* cv. Florigraze has been productive and persistent over a wide range of grazing frequencies and grazing intensities (Ortega-S. et al., 1989). In these pastures, however, availability of Florigraze was reduced by high grazing intensities, regardless of length of rest period.

The evidence available clearly shows that *A. pintoi* and *A. glabrata* can be associated with aggressive grasses and that both species are productive and persistent under a wide range of grazing management. But it would seem that, in areas with little dry season stress, light grazing can result in low legume content in the pasture, with the consequence of decreasing long-term pasture productivity.

Research Priorities

The overall nutritive value of commercial forage *Arachis* species is high in terms of crude protein, digestibility, and acceptability by animals that have become accustomed to it. But there is some evidence of variability in quality among cultivars of *A. glabrata* and accessions of *A. pintoi*. Therefore, collections of *A. pintoi* species should be subject to screening not only for agronomic performance but also for nutritive value measured at different stages of regrowth under full sunlight and shaded conditions (i.e., relevant to silvopastoral systems).

Low levels of condensed tannins found in *A. glabrata* cv. Florigraze and *A. pintoi* CIAT 17434 could be partially protecting protein from degradation in the rumen, even though the available evidence is conflicting. Thus, future research should determine the type of condensed tannins present in forage *Arachis* species and the extent to which these tannins protect protein from degradation by rumen microbes. The effect of heating or sun drying (relevant in hay production) on formation of tannin-protein complexes should also be investigated.

Results reviewed suggest that animal production in forage *Arachis* pastures is highly dependent on legume content in the pasture. Thus, available and future data should be analyzed to determine the effect of proportion of legume in the forage-on-offer and diet selected by grazing animals on milk and beef production.

Experimental results clearly show that animal production (i.e., liveweight gain and milk) can be significantly increased in pastures based on *Arachis* species under a wide range of grazing management. In addition, forage *Arachis* can associate with stoloniferous grasses and tolerate heavy grazing. These important attributes are considered essential for adoption of legume technology by graziers. But livestock producers in the American tropics need to be made aware of the potential benefits of pastures based on *Arachis*. Therefore, we urgently need to promote and carry out on-farm research projects designed to demonstrate the productivity of pastures based on *Arachis pintoi* in terms of carrying capacity and animal production compared with grass-alone pastures.

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Chapter 11

Seed Biology and Seed Systems for *Arachis pintoi*

J.E. Ferguson*

Abstract

Arachis pintoi, a stoloniferous perennial, is geocarpic, and most pods abscise at maturity. With adequate crop management, potential seed yields can reach 5 tons/ha. Harvested seed yields commonly range between 1 and 2 tons/ha at 15-18 months postestablishment, using either manual or mechanical harvesting.

Seed quality characteristics include a high pod unit weight and low hardseededness. Freshly harvested seeds have high levels of dormancy (60-80%), which may continue for 6-8 months. Dormancy is not based in the seed pod and can be reduced by predrying (14 days at 40 °C). Some seed lots show high loss of viability after 10 months in storage. Seed is susceptible to mechanical damage during harvesting. Technology for packaging and storage in tropical regions is inadequate.

Seed has been produced commercially by intensive management and mechanical harvesting at Gympie, Queensland, Australia, and by manual harvesting by small farmers at Yapacani, Bolivia, under contract to a seed enterprise.

The principal constraints to effective seed systems are: novelty of the species to farmers, lack of promotion, low demand, low availability, high price, cost of harvesting, lack of relevant storage technology, and lack of seed quality assessment techniques and relevant market standards.

Priority research areas include: propagation and establishment methods; intercropping for seed production; seed harvesting equipment; seed quality assessment; seed storage and packaging technology; peg and pod set efficiency; proactive on-farm projects to evaluate *A. pintoi* within farming systems and promote an expansion of demand; and monitoring both the release process of new cultivars and the experience of pioneer adopters.

Introduction

Arachis pintoi is both a relatively new and novel species to both researchers and farmers. Experience is confined to a few localities in Australia, Bolivia, Brazil, Colombia, and Costa Rica. There is good evidence, however, of multiple uses and wide adaptation, so both the genus and *A. pintoi* warrant an increased research emphasis.

This study summarizes the existing knowledge on seed production, seed quality, and seed systems of *A. pintoi* and indicates areas for future priorities related to the components of seed systems for *Arachis* species.

Seed Formation

Morphology

Cook et al. (1990) and Ferguson et al. (1992) have briefly described the morphology of *A. pintoi*.

A. pintoi flowers in short, ancillary racemes that are sessile and arise from linear stipuliform bracts. The flowers are yellow, with deep orange striations

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* Forage seeds agronomist, Tropical Forages Program, CIAT, Cali, Colombia.

on the standard. Seeds are produced on pegs that are 1-27 cm long and penetrate the soil obliquely, mostly to a depth of less than 7 cm, producing mainly a single pod with one seed (rarely two), but occasionally two and infrequently three pods separated by varying lengths of peg. There are 6000-8000 seed in pods per kg (Cook et al., 1990).

Valls (1985) drew attention to the contrast between *A. pintoi* and *A. hypogaea* in pod retention. Wild species such as *A. pintoi* have a well-defined abscission layer in the peg, which collapses after pod maturity. As a result, pods separate from the plant. In *A. hypogaea*, however, reflecting a long period of domestication, the abscission layer has been lost, and most mature pods remain attached to the plant. This difference has major implications for developing methods of seed harvesting.

Whereas *A. pintoi* flowers prolifically, little is known of the efficiency of seed set other than what can be interpreted from differences in seed yield over a range of environments. Seed set has two sequential components: "peg set" is the proportion of flowers that form pegs; possible determinants are genotype, pollination and fertilization, soil moisture, temperature, nutrients, and light intensity; "pod set" is the proportion of pegs that form pods with seeds. Possible determinants are soil moisture, nutrients, soil density and texture, and active plant growth.

Seed Production

Effect of genotype

The variation in seed yield between accessions in Chinchiná and Guápiles, Costa Rica, suggests that genotype x environment differences occur and should be investigated further (Table 1). Higher seed yield occurred at Chinchiná, in Colombia's coffee zone, possibly due to use of seed at establishment and higher soil fertility of this site. The results indicate that the pioneer cultivar CIAT 17434, while selected for forage value, has a high seed production capacity.

Crop management

Establishment is feasible from seed or vegetative material. At Puerto López, Colombia, a pure stand established from seeds gave a lower shoot yield but much higher seed yield (Table 2; Ferguson et al., 1992). As many multiplication plots are planted with vegetative material, the importance of using seed rather than vegetative material to establish seed plots warrants further investigation.

Cook and Loch (1993), Hawton et al. (1990), and Argel and Valerio (1992) have reported on chemical weed control used in seed production plots. The well-known preemergence or preplant-incorporated herbicides, pendimethalin and trifluralin, are effective in weed control while selective toward, *A. pintoi*. Various herbicides are useful for postemergence control of broadleaf and grass weeds. Stands derived from vegetative material withstand a wider range of herbicides than those established from seeds (Argel and Valerio, 1992).

While it is recognized that *A. pintoi* responds to increased soil fertility, only a few studies have focused on the effects of fertilizer upon seed yield. While the need for high soil calcium for seed formation in *A. hypogaea* is clear, Ferguson et al. (1992) and Cook and Loch (1993) found no response of increased seed production in *A. pintoi* to calcium application.

Table 1. Seed yield of three accessions of *A. pintoi* at three locations.

CIAT	Seed yield (kg/ha)		
accession	Colombia	Costa Rica	
no.	Chinchiná[a]	Guápiles[b]	San Isidro[b]
17434	7280 a*	960 a	800 a
18744	4500 b	160 c	770 a
18748	4160 b	490 b	720 a

a. Single harvest, at 14 months postestablishment, established from seed.

b. Average of three or four harvests, between 8-20 months postestablishment, established from vegetative material.

* Means followed by the same letter are not significantly different from each other.

SOURCES: Ferguson et al., 1992; Argel and Valerio, 1993.

Table 2. Effect of planting material and seed density upen shoot and seed yield of *A. pintoi*, in Matazul, Puerto López, in the Eastern Plains of Colombia.

Planting material	Shoot yield H1/18 mo[c]	Seed yield[b] (kg/ha)		
		H1/18 mo	H1/30 mo	H2/H1+12 mo
Stolons[a]	10,400 a*	250 b	150 c	420 b
Seeds[b] (10 kg/ha)	6,000 b	1,720 a	1,880 ab	1,200 a
Seeds (20 kg/ha)	5,900 b	1,680 a	1,700 ab	1,240 a
Seeds (40 kg/ha)	2,600 b	2,209 a	1,405 b	935 ab
Seeds (85 kg/ha)	6,900 b	1,900 a	2,390 a	1,290 a

a. Vegetative material was planted at 1 cutting/m².

b. Seed rates at establishment: 10, 20, 40, 85 kg/ha.

c. H1 = first harvest, H2 = second harvest, mo = months postestablishment.

* Means followed by the same letter are not significantly different from each other.

SOURCE: Ferguson et al., 1992.

Regular defoliation just above flower height is reported to favor strong flowering in dense, older stands of *A. pintoi* (Cook and Loch, 1993).

Seed harvesting

The geocarpic character of *Arachis* presents a challenge for seed harvesting from two perspectives: methodology and availability of equipment.

Mechanical seed harvesting was pioneered by Cook and Franklin (1988), using rotary screens in a field separator fed by the manual uplift of loosened soil. From this successful prototype, a large machine, which both lifts loose soil and separates soil from seed, was developed by the Queensland Department of Primary Industries (QDPI) in Australia.

Ferguson et al. (1992) compared a range of harvesting methods (Table 3). Manual harvesting gave the highest yield, but with a high labor requirement. A partially mechanized method, using a small rotary separator, recovered 80% of the yield of the manual method, but with a reduction of 50% in labor requirement and doubling of the relative efficiency of labor.

Mechanical harvesting and handling are probably associated with a degree of mechanical damage that can lead to reduced seed quality and longevity. This should be investigated and procedures sought to minimize such losses.

Methods of harvesting will vary among countries and producers, depending upon relative costs, availability of labor and machinery, and the scale of production. In the future, new seed producers can be expected to modify machines already available (e.g., peanut, cassava, and potato diggers/pullers/harvesters) for use in harvesting *A. pintoi*.

Seed conditioning

As a large, round seed, *Arachis* is relatively easy to handle, clean, and grade. Cleaning can be done with appropriate screens and air flow or flotation in water or solvent (perchlorethylene). Grading can be achieved with air flow and gravity separation.

Several aspects, however, are challenging and/or problematic:

1. **Removal of soil.** Depending on soil texture and harvest method, soil particles adhere to the testa. Drying and handling tend to reduce this. Removal of soil may be desirable either for phytosanitary reasons or to enhance appearance. Washing in water is the simplest approach, but requires subsequent drying. Brushing the seed or agitating it with coarse sand are other alternatives.

Table 3. A comparison of harvesting methods in two regions of Colombia.

Descriptor/ Region	Harvesting method Manual	 Mechanical[a]
Recovered seed yield (kg/ha)		
Eastern Plains	3090 a*	2370 b
Coffee zone	7400 a	6210 b
Germination 8 months postharvest (%)		
Coffee zone	72 a	61 b
Manual labor input (man-days/ha)		
Eastern Plains	529 a	193 b
Coffee zone	670 a	283 b
Relative labor use (kg seed/man-day)		
Eastern Plains	6 b	12 a
Coffee zone	11 b	21 a

a. Soil shoveled by hand first to a rotary, then to a vibrating field screen separator.

* Means followed by the same letter are not significantly different from each other.

SOURCE: Ferguson et al., 1992.

2. **Mechanical damage**. With a large and relatively soft seed and a slightly protruding radicle, *Arachis* is prone to mechanical damage during seed harvesting and handling. No work has yet been done to characterize the magnitude, sources, or consequences of this problem.
3. **Artificial drying**. When seed is mechanically harvested and handled, or when it is produced in humid regions, artificial drying will be needed. While technology from *A. hypogaea* can be applied initially, we need to better understand the effects of temperature on seed viability of *A. pintoi*.
4. **Packaging**. There is a real need for small, hermetically sealed packaging to reduce loss of viability in storage, especially in humid tropical regions.
5. **Handling**. To the extent possible, *A. pintoi* should be handled with minimum physical shock. Rubber or pneumatic conveyors and minimum mechanical handling can aid in this.

Seed Storage

With seed supply so incipient, storage has only been viewed to date in the context of germplasm conservation. The requirements for medium-term storage (1-5 years) of commercial volumes (100-5000 kg) must be based on an understanding of the influence of moisture content, temperature, and humidity upon seed viability, dormancy, and longevity. This information is not available. Storage strategies need to be developed for both large volumes in modified artificial environments as well as small volumes in on-farm situations.

Seed Quality

In contrast to other tropical legumes, *A. pintoi* seed is larger and softer (less hard-seededness), is tightly enclosed by a thin pod (husk or endocarp), and has a high oil content. Seed quality can be viewed from the following perspectives:

Physical (or mechanical) purity

High (>90%) seed purity is easily attained. Inert matter contaminants of seed can include soil clods, charcoal, stones, and seeds of other species (e.g., nuts of *Cyperacae* spp., which could be a dangerous contaminant).

Physiological quality

A characterization of five manually harvested seed lots from Yapacani, Bolivia, showed the following average (and range) of values at 6 months postharvest: tetrazolium viability 95% (91-100%), total viability 81% (64-94%), normal germination 53% (39-61%), and dormancy 37% (19-54%) (Table 4). Obviously dormancy is present for long periods in some lots, and this complicates the assessment of quality.

Freshly harvested seed can have high levels of dormancy. Predrying (14 days at 40 °C) fresh seeds caused a marked reduction in dormancy, with a concurrent increase in germination (Table 5). The effects were the same for both pods and seeds, indicating that dormancy is not located in the pod but within the seed.

An exploratory study was conducted on the reaction of four seed lots to different storage conditions over an 18-month period at Palmira, Colombia. Loss of germination began at 10 months with storage under ambient conditions, whereas negligible loss occurred in storage at 18 °C/60-70% r.h. Some deterioration occurred at -20 °C/95% r.h. and 10 °C/30% r.h. Seed lots with higher initial germination showed less deterioration over time. Although *A. pintoi* is not vulnerable to storage problems, seed lots do deteriorate rapidly after 10 months of storage under ambient conditions.

Phytosanitary conditions

The main concerns to date have been with potyvirus (Morales et al., 1991), which can be detected by an

Table 4. Estimates in percentages of physiological seed quality components in six seed lots of *A. pintoi*, at 6 months post-harvest.

Seed lot[a] (no.)	Tetrazolium viability[b]	Total viability[c]	Germination[d]	Dormancy[e]
1	92	84	55	34
2	91	64	52	19
3	95	81	39	52
4	95	80	59	26
5	96	81	52	36
6	100	94	61	35

a. Harvested in July 1992 at Yapacani, Bolivia.
b. Topographical tetrazolium test.
c. (Germination + tetrazolium test of remaining fresh seeds) + 100.
d. Normal seedlings at 21 days.
e. (Viable fresh seeds + total viability) x 100.

Table 5. The effect of predrying of fresh seeds upon germination and dormancy of *A. pintoi* 17434.[a]

Pre-treatment	Germination[b] (%)			Dormancy[c] (%)		
	Seed	Seed in pod	Mean	Seed	Seed in pod	Mean
Nil (control)	25	18	22 a*	66	73	82 a
Predried, 14 days at 40 °C	69	71	70 b	23	20	21 b
Average	47 a	45 a		45 a	47 a	

a. "Fresh" refers to 6 weeks postharvest.
b. Normal seedlings at 21 days.
c. (Viable fresh seeds + total viability) x 100.
* Means followed by the same letter are not significantly different from each other.

ELISA assay of plant material. Transmission by seed is relatively low (F. Morales, personal communication). Virus-free seed of new germplasm is obviously highly desirable.

Genetic (or varietal) purity

We can assume that during the next decade several new species and cultivars of *Arachis* will be released. This will raise considerations of varietal identification, maintenance of genetic purity, and a possible need for seed certification. This will require a case-by-case analysis of implications.

Chemical composition

A. hypogaea has a fat content of 48% (Bewley and Black, 1978), which provides a point of reference for *A. pintoi*. In a comparison of 75 accessions of various *Arachis* species (but not including *A. pintoi* or *A. repens*), Stalker et al. (1989) reported oil percentages similar to those of *A. hypogaea*. While differences were recorded in fatty acid content (ratio of oleic to linoleic acid), values were not higher than those of *A. hypogaea*.

Seed Supply Systems

Initial multiplication

First-stage multiplication has been at the level of the planthouse or a few spaced plants in the field. Such multiplication has been conducted by various institutions involved in germplasm acquisition and conservation.

Second-stage multiplication, that is, to provide both seed for research purposes and basic seed, has been undertaken mainly by QDPI and CIAT. Table 6 summarizes an example of a multiplication effort within CIAT. This also shows the relatively early and effective use of contract multiplication with seed enterprises prior to official release. Larger scale multiplication has also provided a basis for preliminary research on seed production technology.

Relevant experiences with Rhizoma peanut, *A. glabrata*, in Florida highlight both the need for and value of continuous interaction among researchers, extension workers, and seed producers in the development of production technology (Prine and French, 1993).

Table 6. Summary of production and distribution of *A. pintoi* seeds by the Seed Biology Section of CIAT's Tropical Forages Program, 1984-1992.

Year	Production		Distribution			
	Internal (kg)	External contract (kg)	Within CIAT Requests (no.)	Within CIAT Volume (kg)	External[a] Requests (no.)	External[a] Volume (kg)
1984	15		-	-	4	<1
1985	6		1	<1	4	1
1986	59		18	8	50	8
1987	24		10	7	49	14
1988	30		15	7	53	14
1989	106		21	122	47	28
1990	303		52	120	52	56
1991	882	1198	39	171	82	96
1992	156	207	62	215	79	444
Total	1575	1405	218	651	420	664

a. Includes seeds for regional trials and NARDs within the International Tropical Pastures Evaluation Network (RIEPT).

Commercial seed production and marketing

The first release of an *A. pintoi* cultivar was in Australia in 1987. Accession CPI 58113 was named cv. Amarillo or Pinto Peanut (Cook et al., 1990). Plant variety protection is held by QDPI and the license to produce commercial seed was granted to Sauer & Sons Pty. Ltd. Sauer & Sons also purchased the large-scale mechanical harvester initially developed by QDPI. This machine has a baffle-lift system to raise soil and seed to the counter-rotating screens and pelletized bins for seed collection. Recent modifications helped solve problems of structural rigidity, wearing of chains, and dust problems. Seed crops, located on sandy soils near Gympie, Queensland, expanded from 1 to 8 ha between 1987 and 1991. Approximately 7 tons of seed were produced in 1991. Retail prices are still relatively high (Aust.$18/kg) because harvesting represents about 70% of the production cost (Cook and Loch, 1993).

In Colombia, the Instituto Colombiano Agropecuario (ICA) released accession CIAT I7434 (= CPI 58113) as Maní Forrajero Perenne (perennial forage peanut) in 1992 (Rincón et al., 1992). Basic seed, produced by two seed enterprises under contract to CIAT, was distributed to four seed enterprises for commercial production. Seed should come on the market in 1994. Meanwhile, some planting is being done by vegetative means.

In Bolivia, the seed enterprise Sefo-Sam grew seed under contract to CIAT in 1990-1991. After achieving high seed yields at Yapacani, Sefo-Sam then involved small farmers in seed production and produced approximately 3 tons in 1992 by essentially manual means (Ferguson and Sauma, 1993; Table 7). Seed has been exported to Brazil and Colombia.

In Costa Rica, the seed enterprise Sericasa Ltda. established seed crops by vegetative propagation in 1992. While good seed yield in situ was observed, an unidentified pod rot then destroyed most seeds, rendering harvesting uneconomical (R. Bradley, personal communication). This is a classic example of the problems and risks faced by pioneer seed producers.

General observations

A. pintoi has the potential for high seed yield, in the range of 3-5 tons/ha (Ferguson et al., 1992). Recovered yields using a range of manual and mechanical methods range from 1 to 5 tons, but mostly from 1 to 2 tons/ha at 14-18 months postestablishment (Table 8). If we assume a planting rate of 10 kg/ha and an average recovered seed yield of 1500 kg/ha at 15 months, the average multiplication rate is 120 kg/yr. This compares more than favorably with other tropical legumes, such as Kudzu, *Stylosanthes guianensis*, and *Centrosema pubescens*.

Table 7. Summary of seed production and seed yields of *A. pintoi* by Sefo-Sam with small farmers at Yapacani, Bolivia, 1989-1992.

Year	Seed farmers (no.)		Crop age	Total seed production	Seed yield (kg/ha)	
	Total[a]	Harvested[b]	(mo)[c]	(kg)	Range	Average
1989	2	0	-	0	-	-
1990	17	2	12	234	200-800	500
1991	15	4	18	550	1000-3000	2000
1992	15	9	16-30	2750	1000-4000	2200

a. With seed crops under management.

b. Actually completed harvesting and delivery.

c. Average crop age in months postestablishment.

Table 8. Summary of seed yield of *Arachis pintoi* (cv. Amarillo or CIAT 17434) in various countries.

Country/ Location	Latitude	Altitude (m)	Crop age (mo)[a]	Harvest method	Seed yield (kg/ha)	Observations	Source
Australia							
Gympie	22° S	50	12	Mechanized	1000		Cook and Franklin (1988)
		24		Mechanized	1800		Cook and Franklin (1988)
		12		Commercial harvester	1200		Cook and Loch (1993)
		12+12		Commercial harvester	1700	Second harvest, 12 months after first	Cook and Loch (1993)
		24		Commercial harvester	3700		Cook and Loch (1993)
Bolivia							
Yapacani	17° S	250	10	Manual	500	1990	G. Sauma (pers. comm.)
		18		Manual	2000	1991, average of 4 farms	G. Sauma (pers. comm.)
		16-30		Manual	2200	1992, average of 9 farms	Ferguson and Sauma (1993)
Brazil							
Planaltina	15° S	1000	16	Manual	1240	1991	E. A. Pizarro (pers. comm.)
		28		Manual	890	1992	E. A. Pizarro (pers. comm.)
Colombia							
a) First harvest							
Altillanura	4° 36' N	200	72	Manual	758-1040	1989	Ferguson et al. (1992)
Puerto López	4° 05' N	182	16-20	Semi-mech.	790-2540	1990-1991	Ferguson et al. (1992)
			30	Semi-mech.	1500-2000	1992	Ferguson et al. (1992)
Coffee zone	4° 59' N	1370	14	Semi-mech.	3600-5211	1991	Ferguson et al. (1992)
			26	Semi-mech	2924	1992	Ferguson et al. (1992)
			37	Semi-mech.	2800	1990	Ferguson et al. (1992)
Valle del Cauca	3° 15' N	1200	14	Semi-mech.	786	1991	Ferguson et al. (1992)
			24	Manual	5304	1989	Ferguson et al. (1992)
b) Second harvest							
Puerto López	4° 05' N	182	12	Semi-mech.	1032	1992	J.E. Ferguson, unpublished data
Coffee zone	4° 59' N	1370	7	Semi-mech.	743	1992	J.E. Ferguson, unpublished data
Costa Rica							
Guápiles	10° 13' N	250		Manual	1965	1988	Diulgheroff et al. (1990)
Guápiles				Manual	600	1989	Diulgheroff et al. (1990)
Guápiles			8	Manual	893	1992	Argel and Valerio (1993)
Guápiles			16	Manual	963	1992	Argel and Valerio (1993)
San Isidro	9° 22' N	703	8	Manual	480	1992	Argel and Valerio (1993)
San Isidro			16	Manual	1378	1992	Argel and Valerio (1993)

a. mo = months postestablishment.

Seed crops are best produced in regions with a prolonged wet season, or by the use of supplementary irrigation, and require adequate fertilizer and weed control. Seed harvesting is facilitated by the choice of sandy or high-organic-matter soils.

Constraints and Limitations

On the **demand** side, the analysis of constraints indicates the following:

1. **Novelty of the species to farmers**. The proportion of farmers who are now aware of *A. pintoi* by name or use is quite low. This is difficult for many researchers to comprehend. While it translates into the cause of low demand, it also presents an opportunity.
2. **Low, but expanding, market demand**. Effective demand is now low and rather dispersed geographically. But it is expanding. If one optimistically visualizes the multiple uses of *A. pintoi*, a significant market in 3-5 years is predicted.
3. **Lack of promotion**. Technical and commercial aspects of promotion are currently minor, and confined to a few focal points.

On the **supply** side, the analysis of constraints indicates the following:

1. **Low seed availability**. Outside of Queensland, seed availability is low, irregular, and confined to a few sources. The same could be said for vegetative material. There is no case of organized efforts of multiplication and distribution by a national program.
2. **High retail seed price**. The price is high (US$15-30 per kg), reflecting low availability and high costs of harvesting. We can assume that price will decline as production both expands in gross terms and the number of multipliers and distributors increases. Prices will need to decline by 50% if *A. pintoi* is to become available to small farmers.
3. **Lack of seed quality assessment techniques and quality standards**. Only QDPI now has a seed laboratory offering quality assessment. Minimum standards for purity and germination are 90% and 40%, respectively. Elsewhere, seed enterprises and seed farmers have yet to face the issue of quality assessment and assurance. Seed enterprises will progressively face decisions on seed storage and seed export, which will require quality assessment information.
4. **Lack of storage technology**. We currently know little about the reaction of *A. pintoi* seeds to storage. Susceptibility to mechanical damage and high oil content mean that their storage potential is probably lower than that of most other tropical forage legumes. Their high monetary value and market potential in humid tropical regions increase the need for storage technology.

Research Priorities for Effective Seed Systems

The following areas need attention to ensure the development of effective seed systems for cultivars of *Arachis* species.

Agronomic

1. **Propagation methods**. For both seed and vegetative material, planting densities, cultural practices, and mechanization need to be defined and understood. Additionally, farmers' experiences should be monitored.
2. **Intercropping for seed**. Seed could be produced by intercropping *A. pintoi* with crops such as oil palm, bananas, and citrus, etc. This is regarded as the most relevant strategy for lowering both costs and risks of seed production.

3. **Seed harvesting.** While basic strategies, both manual and mechanical, have been defined, we need further options for seed farmers. The modification of potato, peanut, and cassava diggers/harvesters is the most relevant strategy. This will most likely evolve from local adaptation or custom-building of the aforementioned machines.

Seed science and technology

1. **Seed storage.** There is a need to define appropriate storage conditions, both under on-farm and controlled environment conditions, and the reaction of different seed lots to storage. The high value of seeds, their market potential in humid regions, and high oil content combine to make storage technology a critical need.
2. **Seed quality assessment and assurance.** There is a need for simple and precise methods to assess physiological seed quality (viability, germination, dormancy, and vigor). A package of technologies to promote the availability of an expanding supply of good-quality seed should be developed. This will require identification of practices in production, conditioning, storage, and distribution that first attain and then maintain high-quality seed. These practices must respond to the progressive evolution of market standards for physical, physiological, phytosanitary, and genetic aspects of quality.
3. **Efficiency of peg and pod set.** There is a need to determine the factors that influence peg and pod set because of their influence on seed yield. Mineral nutrition, soil moisture, and soil texture are obvious variables for study. More consistent and higher seed yields, plus more efficient rates of recovery, could result from such studies.

Complementary Activities

In this context, a diverse but relevant array of themes includes:

1. **Experiences of early adopting farmers.** The experiences of early adopting farmers and seed enterprises should be monitored. Regional foci for such monitoring exist at Chapare and Yapacani, Bolivia; San Isidro, Costa Rica; and the coffee and piedmont zones of Colombia.
2. **Evaluation in farming systems.** Beyond a small part of the research community, *Arachis* and its potential uses are virtually unknown. On-farm research and development (R & D) initiatives are required to expose *Arachis* to farmers and better define its role within farming systems. This implies collaborative, multi-institutional multidisciplinary projects that also involve community-based organizations (farmers' organizations and seed enterprises) in several relevant regions and farming systems. Whereas the range of activities of such projects obviously transcends seed production activities, part of the rationale for these projects is also to increase the magnitude of demand for seeds and thereby provide more opportunities for seed production to become a viable economic activity.
3. **Chemical composition of seeds.** There is a need to determine oil content and its composition, and aflatoxin properties, and also explore eating quality, both fresh and processed.
4. **Release process for new cultivars.** While not an "orthodox" research area, this subject is an important part of the future of *Arachis*, but it is not well conceived in some countries. There is a need for communication, coordination, and planning so that relevant new materials will reach farmers

quickly, without confusion as to identity or merit, and without mixing or misrepresentation.

Conclusions

Achieving an adequate seed supply of *A. pintoi* poses special challenges. Compared with other tropical forage legumes, it is an unorthodox species because of its geocarpic seed formation and the need to exhume the abscised pods from the soil profile.

This species has a high potential seed yield, on the order of 5 tons/ha. Harvested seed yields of 1-2 tons/ha at 12-16 months postestablishment have been achieved, both with manual and fully mechanical harvesting. With an appropriate location and management, an average multiplication rate of 100-120 kg/ha/yr appears feasible.

Seed supply is incipient but expanding. Initial foci of commercial seed production include intensive management and mechanical harvesting at Gympie, Queensland, Australia; and manual harvesting by small farmers at Yapacani, Bolivia, under contract to a seed enterprise.

Some seed lots show a high loss of viability after only 10 months of storage. Technology for packaging and storage in humid tropical regions is inadequate.

The principal constraints to effective seed systems are: novelty to farmers, lack of promotion, low availability, high price, low demand, cost of harvesting, lack of relevant storage technology, lack of seed quality assessment techniques and relevant market standards, and lack of harvesting equipment.

Research priorities for the promotion of effective seed systems include: propagation and establishment methods, intercropping for seed production, seed harvesting equipment, seed quality assessment, seed storage and packaging technology, peg and pod set efficiency, proactive on-farm R & D projects to evaluate *A. pintoi* within farming systems that concurrently promote an expansion of demand, and monitoring both the experiences of pioneer adopters and the release process of new cultivars.

Such an agenda calls for multidisciplinary and multi-institutional collaboration, including participation from research, development, and community sectors.

Acknowledgments

The substantial contributions of Carlos Iván Cardozo, Manuel Sánchez, and Gastón Sauma are gratefully acknowledged. Bill Hardy provided excellent editorial assistance.

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Chapter 12

Regional Experience with Forage *Arachis* in Central America and Mexico

P.J. Argel*

Abstract

Forage *Arachis* evaluated during the past 13 years in Central America and Mexico has been exclusively accessions of *A. pintoi*, except for *Arachis* sp. IRFL 2273.

Arachis has been evaluated in different ecosystems, ranging from tropical rainforest with no dry period during the year to subhumid subtropical forest with 5-6 dry months, and on soils ranging from highly acidic Ultisols with high aluminum concentrations to moderately fertile Inceptisols. *Arachis* shows better adaptation in areas of high rainfall with moderate soil fertility. At sites with more than 4 dry months, the plant defoliates and some stolons die.

A. pintoi CIAT 17434 (cv. Amarillo in Australia, Maní Forrajero Perenne in Colombia) is the most advanced accession in regional evaluations. Grown with star grass, it increased daily milk production of dual-purpose cows in Turrialba, Costa Rica, by 14%. It has persisted well with *Brachiaria brizantha* CIAT 6780 (cv. Diamantes 1 in Costa Rica, cv. Marandú in Brazil) at Guápiles, Costa Rica, and produced a mean animal liveweight gain of 500 g/an/day at 3.0 AU/ha.

A. pintoi CIAT 17434 flowers and sets seed in a range of environments throughout the region, although unidentified soil pathogens at San Isidro, Costa Rica, have caused a significant loss of mature seeds. Mean seed yields are around 1 ton/ha.

A. pintoi CIAT 18744 and CIAT 18748 are other promising accessions, particularly as cover crops.

Introduction

Agronomic evaluation of the forage value of the genus *Arachis* is relatively new in Central America and Mexico. CIAT's Tropical Pastures Program, in collaboration with the International Tropical Pastures Evaluation Network (RIEPT), made the first plant introductions to the area in 1980. Most of the plant material distributed was *A. pintoi* CIAT 17434 (cv. Amarillo in Australia, Maní Forrajero Perenne in Colombia). More recently, new accessions have been evaluated in the region, including *Arachis* sp. IRFL 2273 (CIAT 20693).

Records kept in the RIEPT database indicate that the eight countries in the region have requested *Arachis* seed for evaluation in the past 12 years (Franco et al., 1992). But information on adaptation and other agronomic measurements is limited, mainly due to negligible dry matter (DM) yields observed in pure stands of *A. pintoi*. This plant has a prostrate growth habit, which caused researchers to overlook the species when using the criteria recommended for evaluation in small plots (CIAT, 1982). In particular, the dense mat of rooted stolons with short internodes and abundant buried seed that contribute to the persistence of the plant are overlooked in plant evaluation plots.

This chapter will focus on the legume's agronomic and grazing

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* Forage agronomist, Tropical Forages Program, CIAT, stationed in San José, Costa Rica.

performance in Central America and Mexico. Most of the available data are on *A. pintoi.*

Adaptation and Seasonal Dry Matter Production

A. pintoi adapts well to a range of tropical environments from 0 to 1800 m.a.s.l. with a total annual rainfall of 2000-3500 mm well distributed throughout the year (Valls et al., 1985; Argel and Pizarro, 1992). It grows well in a variety of soils, but is reported to do best on sandy soils with more than 3% organic matter content and where moisture is available (Asakawa and Ramírez, 1989). *A. pintoi* has the potential to be widely used throughout the region, because the tropical rainforest ecosystem, where humidity for plant growth is not limited, accounts for 35% of the area in Costa Rica, 48% in Panama, 29% in Honduras, and 14% in Mexico. A high proportion of the soils in these areas are Ultisols and Inceptisols of moderate fertility (RIEPT, 1987). This type of environment predominates along the Atlantic side of the Central American isthmus, where a great deal of cattle farming is presently carried out, and in the southern part of Mexico.

Table 1 shows different sites in the region where *A. pintoi* CIAT 17434 has been or is currently under evaluation. The ecosystems vary from tropical rainforest with high annual rainfall and no dry months, like Guápiles in Costa Rica, to subhumid tropical dry forest with 5 to 6 dry months, like Jutiapa in Guatemala. The sites vary in soil pH, aluminum saturation, and phosphorus availability. San Isidro in Costa Rica, Soná in Panama, and Huimanguillo in Mexico are sites with soils of low pH and high soluble aluminum, a characteristic of Ultisols in the region.

Adaptation of *Arachis* was marginal at Jutiapa (Roldán, 1988). Neither *A. pintoi* CIAT 17434 nor *Arachis* sp. IRFL 2273 produced measurable DM yields 3 months after planting, although plant cover was

Table 1. Predominant ecosystems, rainfall, and soil characteristics of *A. pintoi* CIAT 17434 evaluation sites in Central America and Mexico.

Country	Site	Ecosystem[a]	Rainfall		Soil			
			mm/yr	dry months	pH (H_2O)	Al (%)	P (ppm)	Type
Mexico	Martínez de la Torre	TSSF	1980	5-6	5.0	—	2.5	Ultisol
Panama	Tortí	TRF	2200	3-4	6.4	Tr[b]	7.8	Ultisol
	Soná	TRF	2750	4-5	5.1	64	1.1	—
	Capira	TRF	—	3-4	5.8	Tr	4.5	Ultisol
	Gualaca	TRF	4000	3-4	4.7	8	1.5	Inceptisol
El Salvador	Itzalco	WHSF	2134	5-6	6.1	Tr	Tr	—
Guatemala	Jutiapa	TDF	1038	5-6	5.8	Tr	Tr	—
Costa Rica	San Isidro	TSSF	2900	3-4	4.6	73	2.4	Ultisol
	Guápiles	TRF	4000	0	5.5	Tr	8.3	Inceptisol
	San Carlos	TRF	3062	2	6.0	Tr	5.5	Entisol
	Guácimo	TRF	3489	0	5.2	22	8.5	Inceptisol
	Turrialba	TRF	2636	2	5.0	Tr	18.0	—
Mexico	Isla	TSWDi	997	5-6	4.8	—	13.5	Ultisol
	Donají	TSSF	2358	5	4.9	—	5.3	—
	Huimanguillo	TSSF	2200	3	4.2	55	—	Ultisol
Honduras	Comayagua	STDF	875	4-5	6.5	—	5.9	—
	La Ceiba	TSSF	2930	2	4.5	—	3.6	Ultisol

a. TRF = tropical rainforest; TDF = tropical dry forest; TSSF = tropical semievergreen seasonal forest; WDSF = warm, dry subtropical forest; WHSF = warm humid subtropical forest; STDF = subtropical dry forest; TSWDi = tropical savanna well drained isohyperthermic.

b. Tr = trace.

SOURCE: RIEPT, 1987.

greater for the former than the latter species, 58% and 9%, respectively. IRFL 2273 yielded much less than CIAT accessions 17434, 18744, 18747, 18748, and 18751 at Guápiles, Costa Rica (CIAT, 1990).

Most of the growth of *A. pintoi* CIAT 17434 occurs in the rainy season (Table 2). An exception was at Itzalco, El Salvador, where it was irrigated during the dry season (Cruz, 1992). No explanation was given for the high yield during the dry season at Martínez de la Torre, Mexico (Hernández et al., 1990).

The DM yields reported are similar to those found at other sites in Latin America (Argel and Pizarro, 1992), and it is clear that plant growth of *A. pintoi* is closely related to moisture availability, because in Guápiles, with no dry period, yield is the highest. At sites with a 3-4-month dry season, growth ceases and defoliation occurs. At sites with 5-6 months of drought, like Jutiapa, a high proportion of the stolons die, although the plant survives because of soil seed reserves.

Plant cover of *A. pintoi* is higher in conditions of tropical rainforest than in other ecosystems. In Tortí, Panama, for instance, accession CIAT 17434 had 100% soil cover 8 weeks after planting (CIAT, 1987), which corresponds to similar results observed in Guápiles (CIAT, 1990) and in Rivas, Costa Rica, at 1480 m.a.s.l. (H. Chi Chan, personal communication). Franco et al. (1992) reported a mean of 43% soil cover 12 weeks after planting when CIAT 17434 was evaluated in the humid tropics, and a mean of only 11% cover in the seasonal evergreen tropical forest ecosystems of the region.

Accessions of *A. pintoi* in the region have shown differences in DM yield (CIAT, 1990). In Guápiles, accession CIAT 18744 outyielded CIAT 17434, 18747, 18748, and 18751, with average DM yields of 4.9, 4.1, 4.0, 3.8, and 3.7 t/ha, respectively, over 2 years of evaluation.

Similar results have been observed outside the region on an Oxisol in Puerto Rico (E. Valencia, unpublished data). In this case, CIAT 18744 at 16 weeks postplanting yielded 2.1 tons/DM/ha, which was significantly different ($P < 0.05$) from that of other accessions (CIAT 17434 was not included in the study).

A. pintoi CIAT 18744 produces a high amount of stolons per unit area (Argel and Pizarro, 1992), a characteristic that favors using this accession as a cover crop in banana plantations of Costa Rica (F. Román, personal communication).

We have had no reports of serious foliar pests and diseases in *Arachis* in the region. Low incidence of foliar blight caused by *Rhizoctonia* and leaf lesions caused by *Leptosphaerulina crassiasca* have been observed in pure-stand plots of *A. pintoi* in Costa Rica. The presence of mycoplasma (little leaf) was also

Table 2. Results of adaptation and seasonal dry matter yield of *A. pintoi* CIAT 17434 evaluated in forest ecosystems of Mexico and Central America.

Country	Site	Adaptation[a]	DM yields (12-week period)		Source
			Minimum rainfall	Maximum rainfall	
Mexico	Martínez de la Torre	G	1.6	1.2	Hernández et al., 1990
El Salvador	Itzalco	G	1.1	2.1	Cruz, 1992
Panama	Capira	G	—	1.3	Franco et al., 1992
Costa Rica	San Isidro	G	—[b]	2.6	CIAT, 1990
	Guápiles	E	—[b]	4.1	CIAT, 1990

a. G = good, E = excellent.

b. No yield was measured during the dry season in San Isidro; no dry period is experienced in Guápiles.

observed in single plants of *A. pintoi* CIAT 18748 at San Isidro, but the symptoms subsequently disappeared. A serious problem in seed production was observed near San Isidro, Costa Rica (R. Bradley, personal communication). Near-mature seeds were rotting, infected by the fungus *Fusarium oxysporum*. Subsequently, the insect *Cyrtomenus bergi*, which can predispose seeds to pathogen attack (see Kelemu et al., Chapter 8, this volume), was identified in the same fields. Other pathogens such as *Penicillum* sp., *Aspergillus* sp., *Rhizoctonia* sp., and *Sclerotium rolfsii* have been associated with similar problems in seed production in Australia (B. Cook, personal communication).

Low incidence of damage due to leaf-eater insects and cutting ants has been reported throughout the region.

Evaluation under Grazing

Controlled grazing of *A. pintoi* has been carried out mainly in Costa Rica. Grazing plots also exist in Panàma, Honduras, El Salvador, and Guatemala, but no reports on performance are yet available.

A. pintoi CIAT 17434 has been under grazing for 5 years in association with star grass (*Cynodon nlemfuensis*) at Turrialba, Costa Rica, a site classified as premontane tropical rainforest, with 2636 mm annual rainfall, soils of pH 5.0, 7.5% organic matter, 18 ppm of P, and a mean temperature of 22.3 °C. The legume has persisted and contributes 38% of the total dry matter of the pasture (Table 3; González, 1992). Both grass-legume associations suppressed the invasion of weeds and native grasses. *A. pintoi* is more acceptable to cattle than *Desmodium ovalifolium* CIAT 350 (Table 4). *A. pintoi* in association with the grass increased daily milk production of dual-purpose cows from 9.5 to 10.8 kg/cow/day compared with the grass fertilized with 100 kg/ha of N (Table 5). Similar results were observed by van Heurck (1990) in the same pasture. Other components of the milk were not altered, except for the urea, which was higher in the grass-legume associations.

Table 3. Botanical composition (%) of star grass (*C. nlemfuensis*) pastures grown without legume or with *A. pintoi* CIAT 17434 and *D. ovalifolium* CIAT 350, five years from sowing, Turrialba, Costa Rica.

Pasture	Grass	Legume	Weeds	Native grasses
Star grass + 100 kg/ha N	37 a*	0	10 a	53 a
Star grass + *Arachis*	37 a	38 a	2 b	23 b
Star grass + *Desmodium*	38 a	33 a	1 b	28 b

a. Values in columns followed by the same letter are not significantly different, P = 0.05.

SOURCE: González, 1992.

Table 4. Proportion (%) of forage selected by esophageal-fistulated steers in star grass (*C. nlemfuensis*) associated with the legumes *A. pintoi* CIAT 17434 and *D. ovalifolium* CIAT 350, Turrialba, Costa Rica.

Pasture	Grass	Legume	Native grasses	Dead material
Star grass + *Arachis*	47 a*	38 a	5 a	10 a
Star grass + *Desmodium*	65 a	17 b	5 a	13 a

* Values in columns followed by the same letter are not significantly different, P = 0.05.

SOURCE: González, 1992.

A. pintoi CIAT 17434 has persisted for more than four years under grazing at Guápiles (soil of pH 5.5, 10.8% organic matter, 8 ppm of P, and 4000 mm annual rainfall). *A pintoi*, *Stylosanthes guianensis* CIAT 184, and *Centrosema macrocarpum* CIAT 5713 were grown in association with *Brachiaria brizantha* CIAT 6780 (cv. Diamantes 1) and *B. humidicola* CIAT 6369 in a rotational grazing system of 5 days grazing, 30 days rest, and stocking rates of 1.75 and 3.0 AU/ha (M. Ibrahim, unpublished data).

The *A. pintoi-B. brizantha* association stabilized with 22% legume and little weed invasion, whereas in the *A. pintoi-B. humidicola* association, growth of the grass was less and there was considerable weed invasion of *Paspalum fasciculatum* and *Mimosa pudica*. The other legumes failed to persist and these associations became extremely weedy (Table 6).

The crude protein content and in vitro dry matter digestibility (IVDMD) of the associated grasses were higher when *A. pintoi* was the companion legume (Table 7). This indicates effective nitrogen fixation and transfer by the legume.

Liveweight gain has been measured in a *B. brizantha*-*A. pintoi* pasture in a

Table 5. Daily milk production and milk composition of dual-purpose cows grazing star grass (*C. nlemfuensis*) in monoculture and associated with the legumes *A. pintoi* CIAT 17434 and *D. ovalifolium* CIAT 350, Turrialba, Costa Rica.

Pasture	Daily milk yield (kg/cow)	Protein (%)	Fat (%)	Total solids (%)	Urea (ppm)
Star grass + 100 kg/ha N	9.5 b*	3.6 a	3.9	13.0 a	16.3 b
Star grass + *Arachis*	10.8 a	3.4 a	3.9	13.0 a	35.0 a
Star grass + *Desmodium*	9.4 b	3.3 a	3.9	12.8 a	30.3 a

* Values in columns followed by the same letter are not significantly different, P = 0.05.

SOURCE: González, 1992.

Table 6. Mean dry weight percentage in the past five grazing cycles of the legumes *A. pintoi* CIAT 17434, *S. guianensis* CIAT 184, and *C. macrocarpum* CIAT 5713 associated with *B. brizantha* cv. Diamantes 1 and *B. humidicola* CIAT 6369 grazed at two stocking rates at Guápiles, Costa Rica.

Legumes	Grasses			
	B. brizantha (cv. Diamantes 1) at AU/ha		*B. humidicola* (CIAT 6369) at AU/ha	
	1.75	3.0	1.75	3.0
A. pintoi CIAT 17434	8.4	22.4	18.6	30.6
Weeds	2.1	6.7	17	35.0
S. guianensis CIAT 184	0	0	4.5	2.4
Weeds	2.8	9.0	44.0	59.0
C. macrocarpum CIAT 5713	0	0	0.8	4.5
Weeds	9.0	4.8	88.8	59.4

SOURCE: M. Ibrahim, unpublished data.

Table 7. Crude protein (CP) and in vitro dry matter digestibility (IVDMD) of the two grasses, *B. brizantha* and *B. humidicola*, grown in association with *A. pintoi*, *S. guianensis*, and *C. macrocarpum* at Guápiles, Costa Rica. Values are percentages.

Legumes	Grasses			
	B. brizantha (cv. Diamantes 1)		*B. humidicola* (CIAT 6369)	
	CP	IVDMD	CP	IVDMD
A. pintoi CIAT 17434	13.0	63.0	12.0	64.0
C. macrocarpum CIAT 5713	10.0	60.2	11.0	54.4
S. guianensis CIAT 184	10.5	59.6	9.0	60.3

SOURCE: M. Ibrahim, unpublished data.

grazing trial at Guápiles. The trial is a rotational grazing system of 7 days grazing, 21 days rest, at two stocking rates (1.5 and 3.0 AU/ha). Mean animal liveweight gains were similar in the grass-legume associations after 16 cycles of grazing (Table 8). With *B. brizantha* alone, liveweight gain was significantly lower at the high stocking rate (M. Hernández and P.J. Argel, unpublished data).

Table 8. Mean animal liveweight gains in pastures of *B. brizantha* cv. Diamantes 1 in monoculture and associated with *A. pintoi* CIAT 17434 after 16 cycles of grazing at Guápiles, Costa Rica. A grazing cycle was 7 days grazing and 21 days rest.

Pasture	Stocking rate (AU/ha)	Daily animal liveweight gain (g/an.)
B. brizantha-A. pintoi	1.5	515 a*
B. brizantha-A. pintoi	3.0	501 ab
B. brizantha	1.5	449 b
B. brizantha	3.0	345 c

* Values in columns followed by the same letter are not significantly different, $P = 0.05$.

SOURCE: M. Hernández and P.J. Argel, unpublished data.

Flowering and Seed Production

Flowering in *A. pintoi* is not controlled by photoperiodic response, which allows the plant to flower throughout the year. Flushes of flowering occur during the rainy season, in response to cutting or rain following a dry period (Cook et al., 1990).

A field study carried out in Guápiles, Costa Rica, showed that mean flower number per m^2 of *A. pintoi* CIAT 17434 was not affected by cutting frequency during a period of 69 weeks (Table 9). But more frequent cutting significantly reduced daily flower production in *A. pintoi* CIAT 18744, which also produced fewer flowers than accession 17434 (P.J. Argel, unpublished data).

Cutting every 2 months significantly reduced seed yields in both accessions of *A. pintoi* (Table 9). This reduction cannot be associated with flowering intensity in CIAT 17434, as the number of flowers per unit area was not affected by cutting frequency. Therefore, it seems that the height of cutting imposed (8 cm above ground level) affected gynophore development at the 2-month cutting interval, consequently reducing seed formation.

Table 9. Mean daily number of flowers and seed yield as affected by frequency of cutting in two accessions of *A. pintoi* established at Guápiles, Costa Rica.

CIAT accession no.	Cutting frequency (months)	Mean daily number of flowers (no./m^2)	Mean	Seed yield[a] (kg/ha)	Mean
17434	0	18 a*		1450 a*	
	8	17 a	18 a	1450 a	1240 a
	4	18 a		1330 a	
	2	19 a		760 b	
18744	0	13 a		640 a	
	8	13 a	12 b	360 b	370 b
	4	11 b		320 b	
	2	11 b		160 b	

a. 90% purity.

* Values in columns followed by the same letter are not significantly different, $P = 0.05$.

SOURCE: P.J. Argel, unpublished data.

Similarly, this may have occurred for CIAT 18744 at 2-, 4-, and 8-month cutting frequencies. We know that CIAT 18744 produces a denser mat of stolons at Guápiles (CIAT, 1990), which may increase the time the gynophores need to reach the ground and bury the seed. In other words, cutting this accession to stimulate flowering and seed production is detrimental at Guápiles.

These seed yields are within the range of those reported for CIAT 17434 at the same site (Diulgheroff et al., 1990), but below those observed elsewhere (Argel and Pizarro, 1992). Accession CIAT 18744 yielded less seed than CIAT 17434 at Guápiles, but had a similar seed yield to that of other *A. pintoi* accessions at San Isidro (Table 10; Argel and Valerio, 1993). Although there are soil and climatic differences between the two sites, more detailed studies are needed to explain the differences in seed yield.

Availability and Use

Because *Arachis,* as a forage, is relatively new to the region, its commercial use by graziers is limited, and commercial seed is not readily available. Official release will create a new awareness of the species' value and assist in its promotion and adoption, and thus create demand for seed.

This is happening in Honduras where *A. pintoi* CIAT 17434 has just been released as 'Pico Bonito' (Secretaría de Recursos Naturales, 1993). Costa Rica proposes to release it in early 1994. Panama is producing significant amounts of seed, and seed increase is being planned in the Dominican Republic.

On-farm demonstration plots have been established at La Ceiba, Honduras, and at Guápiles-Rio Frío, Costa Rica. In the latter region, *A. pintoi* associated with *Brachiaria* spp. has been established on 10 different dual-purpose cattle farms. The grass-*Arachis* associations range from 1.0 to 2.5 ha. Reports indicate that an increase of 0.8 kg/cow/day in milk production is obtained in the grass-legume associated pastures compared with the pure-grass pastures fertilized with N (CATIE, 1992).

There are high expectations for using *A. pintoi* as a cover crop in permanent plantations such as banana, oil palm, coffee, and pepper (de la Cruz et al., Chapter 9, this volume). It has been suggested that *A. pintoi* CIAT 18744 is more suited as a cover crop plant than *A. pintoi* CIAT 17434 because of its more vigorous stoloniferous growth habit (F. Román, personal communication). In banana plantations, the species is host to the nematode *Rapopholus* sp., but soil population numbers of this pathogen are not increased because of the *A. pintoi.*

Table 10. Yield of seed in pods of *A. pintoi* accessions harvested at different times postestablishment at San Isidro and Guápiles, Costa Rica.

CIAT accession no.	Site and harvest time (months postestablishment)								
	Guápiles					San Isidro			
	8	12	16	20	Mean	8	16	20	Mean
17434	890	1040	960	930	960 a*	480	1380	550	800 a
18744	170	100	190	170	160 c	480	970	870	770 a
18748	710	470	330	460	490 b	230	1340	600	720 a
Mean	590 a	540 a	500 a	520 a		400 c	1230 a	670 b	

* Mean values within sites followed by the same letter are not significantly different, P = 0.05.

SOURCE: Argel and Valerio, 1993.

Suitability for Different Farming Systems

The high forage quality of *A. pintoi* and its good acceptance by the grazing animal make it a desirable forage legume on dual-purpose or milk production farms. It is also a legume that can rejuvenate degraded pure-grass pastures such as star grass that predominate throughout the region in the humid tropical areas. Because *A. pintoi* can be easily propagated vegetatively, it is attractive to small farmers who are accustomed to this type of propagation.

Arachis pintoi tolerates shade (CIAT, 1991), and thus is suited to silvopastoral systems in the region, particularly in the humid tropics.

Arachis pintoi CIAT 17434 regenerates abundantly from soil seed reserves following destruction of the top growth. For this reason, it is regarded as unsuitable for pasture-crop rotations. Furthermore, this plant is highly competitive during the establishment phase of a companion crop such as Pejibaye (*Bactris gasipaes*) (Domínguez and de la Cruz, 1990).

Limitations to Adoption

The adoption of pasture legumes by farmers throughout the region is low. Producers and the extension service are not aware or totally convinced of the benefit of legumes; farmers may not have the financial capacity to apply the new technology; and the seed supply is inadequate. Two other factors also limit the adoption of *A. pintoi*.

Firstly, demonstrations at the farm level to document the benefits of the legume in terms of animal production and soil enhancement are lacking. Farmers are willing to adopt new varieties of grasses, but do not accept legumes unless they are convinced of the advantages of the new technology.

Secondly, seed is scarce. The species has the potential for high seed yields, but the absence of a proven seed production technology and a still latent seed market have limited commercial seed initiatives.

Priorities for Research and Development

There is a need to widen the genetic base of the present collection of *Arachis* in the region. Only eight accessions of *A. pintoi* and one *Arachis* sp. have been evaluated. New germplasm of forage *Arachis* is required. It would be desirable to have the following germplasm:

1. **Germplasm with more tolerance of dry conditions,** namely, ones with better growth and leaf retention at sites with a dry period of more than 4 months. In Central America and Mexico, a large proportion of the cattle industry is located along the Pacific coast, which is characterized by long dry periods.

2. **Germplasm that establishes more rapidly**. Current accessions of *A. pintoi* are slow to establish, particularly when planted in association with grasses. Farmers look for quick results and do not appreciate that the benefits of the legume only occur once it forms a major part of the association.

3. **Germplasm suitable for crop-pasture rotations**. *A. pintoi* CIAT 17434 is the accession most widespread throughout the region, but it could compete with subsequent crops because of the plant's good recovery from soil seed reserves.

4. **Germplasm adapted to cooler temperatures**. Well-adapted germplasm is required for altitudes above 1500 m.a.s.l., where dairying is important and farmers have a real need to increase pasture quality.

In addition to seeking new germplasm, research should also be undertaken in the following areas:

1. **Seed production technology studies**. These should include studies on seed harvesting, identification of sites suitable for seed production, and management of seed multiplication plots, including irrigation and fertilization to maximize seed yield.

2. **Studies of nutritional requirements of the plant**. *A. pintoi*, particularly accession CIAT 17434, responds to inoculation, phosphorus, and lime applications (P.J. Argel, unpublished data). But the plant shows intense chlorosis that may be associated with an interaction of nutrient deficiency, rhizobium survival, or intolerance of direct sunlight. No data are available on the effect of this chlorosis on plant productivity.

3. **Characterization studies of promising materials**. It seems that within the present accessions some are more suitable as cover crops and others for grazing; some may perform as well under grazing as CIAT 17434. We also need to study plant adaptation to altitudes above 1500 m.a.s.l.

4. **Establishment**. In addition to seeking germplasm that establishes more rapidly, agronomic studies should be carried out to hasten establishment. Only one study on establishment has been conducted in the region (Argel and Valerio, 1993).

Conclusions

The species *A. pintoi* has agronomic attributes that make it a highly promising forage for grazing and ground cover for rainforest areas of Central America and Mexico. This plant adapts well to a range of soils, including poor, acidic Ultisols; tolerates foliar pests and diseases; is a prolific seeder; and shows compatibility with stoloniferous grasses like star grass and *Brachiaria*.

Animal performance on *A. pintoi* sown with grasses has been superior to that of the grass alone and fertilized with moderate amounts of nitrogen.

Arachis pintoi has shown potential as a cover plant in permanent plantations such as banana, pepper, and oil palm.

Limitations on seed availability and sound demonstration at the farm level have restricted the adoption of this legume by farmers. In addition, the narrow genetic base of *Arachis* needs to be widened.

Acknowledgments

I gratefully acknowledge the assistance of Alfredo Valerio, from CIAT's Tropical Forages Program, for his contribution to the preparation of this paper.

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Biology and Agronomy of Forage Arachis*. 1993. p. 144-157.*
Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia

Chapter 13

Regional Experience with Forage *Arachis* in South America

E.A. Pizarro
A. Rincón*

Abstract

This paper presents an historical perspective of the evaluation of forage *Arachis* in South America. Evaluation of agronomic adaptation has been carried out in savanna and humid tropics ecosystems in locations from Colombia to Uruguay. Available information on agronomic attributes, seed production, disease and pest resistance, drought tolerance, nutritive value, and animal performance is discussed. Some preliminary data on the drought tolerance attributes of *A. pintoi* BRA-031143 (CIAT 22160), for the well-drained soils of the Brazilian Cerrados are presented. Activities to minimize the constraints of technology for seed harvesting, slow establishment, and available germplasm are suggested as priorities for research.

Introduction

Most evaluation has focused on *A. pintoi*. A set of 36 *Arachis* accessions, which included representatives of seven species, was evaluated by CIAT at Quilichao in 1976 (Grof, 1985a). But this germplasm was not considered to have much potential because of poor growth and susceptibility to diseases and pests. *A. pintoi* was collected by Geraldo Pinto in Brazil in 1954 and then distributed to various places, including Australia. From there it was introduced to Colombia in 1979 and evaluated at Carimagua. It showed such high potential as a forage legume (Grof, 1985a) that it was quickly multiplied and distributed for evaluation in savanna and humid tropics ecosystems by the International Tropical Pastures Evaluation Network (RIEPT) (Figure 1). Although *Arachis* species occur widely in various regions of Brazil, Argentina, Bolivia, Paraguay, and Uruguay, and though they are recognized in some areas for their forage value, they have not been deliberately propagated as a forage.

This chapter presents a historical perspective of evaluation of forage *Arachis* in South America. It reviews the available information on evaluation, adaptation to climate and biotic constraints, present use, suitability for different farming systems, limitations for adoption, and priorities for research and development.

Regional Experience

Savannas

Llanos of Colombia. Most evaluation of *A. pintoi* in the savanna ecosystem has been carried out in Colombia using accession CIAT 17434 (Grof, 1985b; Pizarro, 1992). Table 1 summarizes this regional evaluation. All data are for accession CIAT 17434. Performance in these regional evaluations was considered poor to regular in relation to other legumes. Dry matter yield at 12 weeks of regrowth, using the RIEPT agronomic evaluation technique (Toledo, 1982), ranged from 0 to 472 kg/ha DM during the rainy season and from 0 to 250 kg/ha DM during the dry season. Ground cover ranged from 0 to 80%.

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* Forage agronomist, Tropical Forages Program, CIAT, stationed in Brasília, Brazil; agronomist, Instituto Colombiano Agropecuario (ICA), stationed in Carimagua, Colombia, respectively.

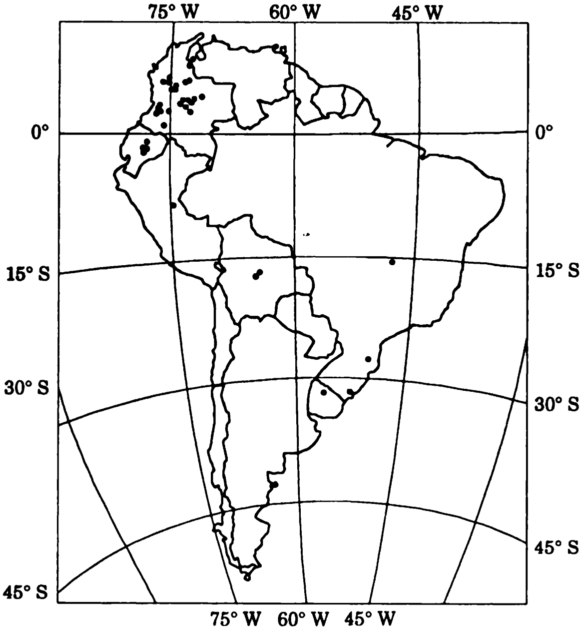

Figure 1. Geographic distribution of RIEPT regional trials with *A. pintoi* CIAT 17434.

Table 1. Results of adaptation and seasonal yield evaluation of *A. pintoi* CIAT 17434.

Location/ precipitation (mm)	Soil characteristics			Agronomic adaptation[a]	Dry matter yield over 12 weeks (kg/ha)		Ground cover (%)	Source
	pH (H_2O)	P (ppm)	Al sat. (%)		max. precip.	min. precip.		
Pto. López (2280)	5.1	3.2	76	R	0	0	4-75	Franco et al., 1992
Carimagua (2100) (La Reserva)	4.5	1.5	91	R	0-464	0	1-60	Avila et al., 1992a
Carimagua (La Alegría) (2100)	4.8	2.1	76	R	0-321	0	1-30	Avila et al., 1992b
San Martín (2527)	3.9	6.9	83	R	30	15-56	6-15	Díaz & Schultze-Kraft, 1992a
Pto. Lleras (2004)	4.8	3.8	76	R	261	30-106	3-33	Díaz & Schultze-Kraft, 1992b
Villanueva (2640)	4.8	3.0	96	D	-	-	0-40	Acosta & Pérez, 1992a
Arauca (1576)	4.8	9.0	62	R	55	0	50-80	Acosta & Pérez, 1992b
Pto. López (2281)	4.6	1.3	90	D	201-368	0	2-57	Franco & Díaz, 1992a
Pto. Gaitán (2355)	4.4	1.5	86	R	289-472	0-30	3-33	Franco & Díaz, 1992b
Pto. Gaitán (2062)	5.0	1.7	85	R	0-83	0-3	1-20	Díaz et al., 1992a
Pto. López (2096)	4.8	3.1	86	P	23-103	0-3	2-30	Díaz et al., 1992b
Pto. Gaitán (2355)	4.4	2.8	86	P	80-150	0-25	1-18	Díaz & Franco, 1992
Carimagua (Yopare) (2083)	4.1	1.5	87	P	0-36	73-250	2-38	Cárdenas & Díaz, 1992

a. E = excellent; G = good; R = regular; P = poor; D = disappearance.

Despite this relatively poor performance in single plots under cutting, the performance of *A. pintoi* in association with grasses in animal production experiments was superior to that of other legumes (C.E. Lascano, Chapter 10, this volume). This accession has now been released in Colombia as the commercial cultivar 'Maní Forrajero Perenne' (Rincón et al., 1992). This experience suggests that the standard evaluation procedures for stoloniferous legumes such as *A. pintoi* need to be modified.

Cerrados of Brazil. In the Cerrado landscape, high, well-drained plains dominate, but these are intersected with low-lying poorly drained areas that comprise 30% of the total area. Thirty-three accessions of *Arachis* species were evaluated in pure swards in one of these lower areas at CPAC/EMBRAPA at Planaltina in 1990. The soil was a low, humid gley soil (pH 5.4, 2.3 ppm P) that remains flooded from January to March each year, with a water table varying from 0.60 cm to 1.20 m in July and August, the driest months. Nine accessions, consisting of six *A. pintoi* accessions, two of *A. repens*, and one of *A. glabrata* were considered to have high potential for forage (Pizarro et al., 1993).

Total dry matter yield ranged from 5 to 13 t/ha in the first year and from 3 to 11 t/ha in the second year, with an accumulated total dry yield for the whole period of 9 to 24 t/ha (Table 2). The highest yields were produced by *A. pintoi* accessions, and ranged from 2 to 9 t/ha in the wet season and from 2 to 4 t/ha in the dry season. Edible green dry matter during the wet season ranged from 2 to 6 t/ha. Underground root accumulation over 14 months ranged from 6 to 14 t/ha, with root-to-shoot ratios being 0.1:1 for the low-yielding *A. repens* and 0.5 to 1.1:1 for the more productive accessions of *A. pintoi*.

There has only been preliminary evaluation of *Arachis* on the well-drained soils of the higher parts of the landscape. Several species grown in pure stands have survived the 5-month dry period. Accession *A. pintoi* BRA-031143 is outstanding in that it retains considerable green leaf during the dry season (Figure 2).

Humid tropics

All regional evaluation was initially based on one accession, *A. pintoi* CIAT 17434 (Keller-Grein, 1990). Adaptation was much better than in the savanna

Table 2. Dry matter yield of shoot and roots, percentage of yield occurring in the dry season (in parentheses), root-to-shoot ratio, and seed yield of nine *Arachis* accessions grown on seasonally flooded land of the Cerrados, Planaltina, Brazil.[a]

Species	Accession		Shoot yield (t/ha)		Root yield[b] (t/ha)	Root-to-shoot ratio[c]	Seed yield[d] (kg/ha)	
	BRA	CIAT	Year 1	Year 2			16	28
A. pintoi	031844	—	12.8(24)[e]	9.2(38)	12.7	0.8:1	440	310
	031852	—	9.4(31)	7.6(36)	6.1	1.1:1	830	650
	013251	17434	9.4(37)	9.5(36)	10.2	0.6:1	1240	890
	015121	18748	6.9(30)	6.8(29)	9.8	0.5:1	1170	1350
	015598	—	11.1(27)	9.7(37)	12.8	0.6:1	—	—
	031143	22160	13.0(31)	11.0(30)	13.3	0.7:1	540	580
A. repens	031861	—	5.2(53)	5.8(45)	10.6	0.2:1	5	20
	012106	—	5.8(43)	5.6(56)	14.1	0.1:1	—	—
A. glabrata	017531	—	6.2(37)	2.8(48)	5.6	0.7:1	50	30

a. Planted Jan. 1990; year 1, wet season Nov. to March (1391 mm), dry season April to Oct. (175 mm); year 2, wet season (1512 mm), dry season (188 mm).
b. Accumulated root yield from Jan. 1990 to May 1991.
c. Using shoot yield at time of determining root yield.
d. Months postplanting.
e. Percentage of yield in the dry season.

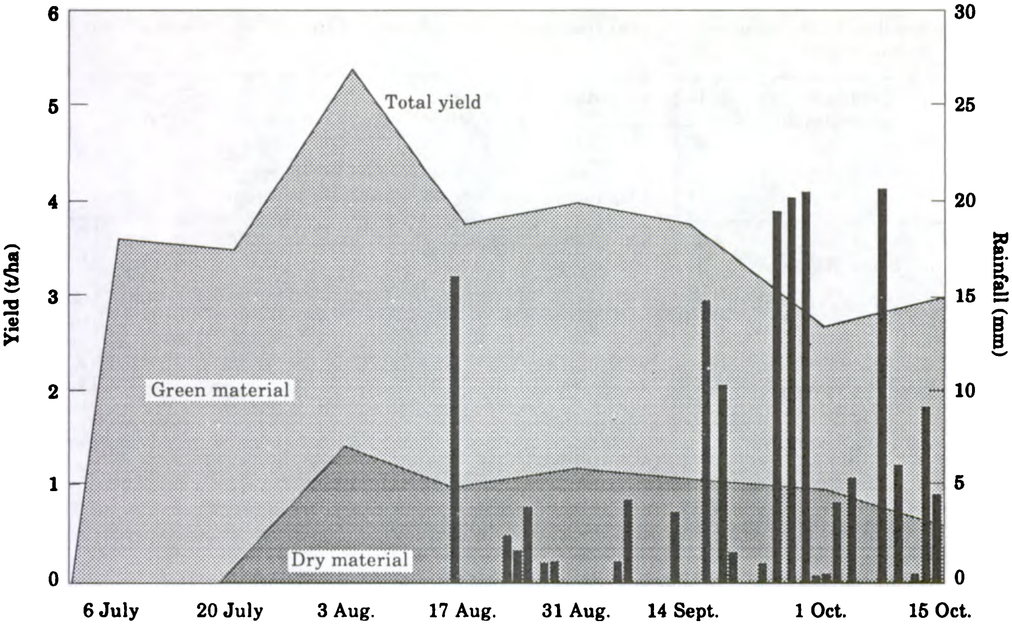

Figure 2. The change in total yield (green + dry), and the green and dry components of a standing crop of *A. pintoi* BRA-031143 during the 1992 dry season sown in Feb. 1991 on a well-drained Ultisol at Planaltina, Brazil. ■ = rainfall.

ecosystem, with performance ranging from poor to excellent (Table 3). Dry matter yield accumulated at 12 weeks of regrowth ranged from 0 to 2.7 t/ha in the rainy season and from 0.04 to 2.8 t/ha during the minimum precipitation period, with ground cover ranging from 1% to 100%.

Seven additional accessions of *A. pintoi* are being evaluated by PROFOGAN in El Puyo, Ecuador, using a modified Regional Trial A design (Toledo, 1982). Table 4 presents results from the first cut, 8 months from sowing. Two accessions, CIAT 18751 and CIAT 18748, gave higher yields than CIAT 17434. Ground cover ranged from 40% to 100%. These results suggest that more accessions of *A. pintoi* should be evaluated in other locations. This is important for determining the ability for rapid establishment in the humid tropics.

From Pucallpa, Peru, the preliminary information from new trials is not so encouraging. Three *A. pintoi* accessions (CIAT 17434, 18745, and 18752) are under evaluation. Dry matter yield is low, varying from 280 to 400 kg/ha after 6 weeks regrowth. Whereas there was tolerance of shade under *Elasis guianensis*, there was not under *Piper nigrum, Myrciaria dubia*, and *Paullinis cupana*. Seed production was negligible—0-1.5 kg/ha (J. Vela, personal communication).

Range of adaptation

A. pintoi has been evaluated widely (Figure 1) and data (Tables 2 and 3) confirm that although it has a wide range of adaptation, the accession evaluated—CIAT 17434—grows best under humid tropical conditions between 0 and 1800 m.a.s.l. with a total annual rainfall of 2000-4000 mm well distributed through the year. Limited data obtained at Planaltina confirm that *A. pintoi* can survive dry periods of five months, although drought stress produces defoliation (Figure 2) and reduces the leaf-to-stem ratio.

Severe frosts as in Pelotas, Brazil, reduce growth, but plants usually recover quickly with the onset of the warm, rainy

Table 3. Results of adaptation and seasonal yield evaluation of *A. pintoi* CIAT 17434 in regional trials in the humid tropics.

Country	Location/ precipitation	Soil characteristics			Agronomic adaptation[a]	Yield over 12 weeks (kg/ha DM)		Ground cover	Source
		pH (mm)	P (H$_2$O)	Al sat. (ppm)	(%)	max. precip.	min. precip.	(%)	
Bolivia	Valle del Sacta (3850)	4.6	3.6	82	R-G	1820	2560	8-100	Gutiérrez et al., 1990
	Chipiriri (4668)	4.2	5.9	68	R	176	186	15-49	Ovando & Ferrufino, 1990
Brazil	Paragominas (1744)	5.5	1.3	—	R-E[b]	—	—	—	Dias Filho et al., 1990
	Itabuna (2083)	—	—	—	P	—	—	—	Pereira (pers. com.)
Ecuador	Manabí-F. Alfaro (1562)	5.7	1.8	—	R-G	—	—	—	Ramírez et al., 1990
	Manabí-El Carmen (1926)	5.3	—	—	R-E	—	—	—	Ramírez et al., 1990b
	Manabí-Maicito (2612)	5.3	16.5	—	R-G	—	—	—	Ramírez et al., 1990c
	Archidona (4440)	5.3	3.0	1.4	R-G	416	840	36-91	González, 1990
	Misahualli (4200)	5.9	4.0	0.1	G	2360	2330	1-100	González, 1990b
	Palora (4000)	5.5	0.8	66	R-G	530	—	5-89	González, 1990c
Colombia	Guaviare (2775)	4.3	2.0	65	G	540	327-1210	7-98	Dohmen & Quejada, 1990
	Florencia (3600)	4.8	6.0	41	G	0-2770	1030-2830	36-91	González, 1990a
Pucallpa	Pucallpa (4200)	4.1	1.9	75	R	50-510	40-120	9-63	Passoni et al., 1990

a. E = excellent; G = good; R = regular; P = poor; D = disappearance.
b. Poor performance in the dry season.

Table 4. Results of evaluation of *A. pintoi* accessions at El Puyo, Ecuador, at 8 months after establishment.[a]

CIAT accession no.	Height (cm)	Ground cover (%)	Yield (kg/ha)
17434	8	100	990
18744	7	53	490
18745	4	40	250
18746	5	80	460
18747	8	67	680
18748	17	100	1680
18751	24	100	1980
18752	5	80	510

a. Precipitation = 4438 mm/year.
SOURCE: C. Farfán and O. Paladines (personal communications).

seasons. Data are available from that site for CIAT accessions 17434, 18748, 18749, and 18750 (J.C. Leite Reis, personal communication). *A. pintoi* CIAT 17434 gave yields of 0-2 t/ha at Santa Catarina, southern Brazil (Almeida and Flaresso, 1991). In Tacuarembó, Uruguay, it is reported that *A. pintoi* (possibly CIAT 17434) recovers well after the winter (M. Bemhaja, personal communication).

A. pintoi grows well on a wide range of soils with textures varying from heavy clay to sand, but seems to grow better in sandy loams if moisture is not limiting. Asakawa and Ramírez (1989) reported that *A. pintoi* is well adapted to low-fertility acid soils with a high aluminum saturation (70% or more) and performs better in soils with more than 3% organic matter content. As mentioned earlier, *A. pintoi* grows well in areas with a seasonal high water table (Pizarro et al., 1993). In general, dry matter yield of *A. pintoi* in different ecosystems is a response to differences in soil and climatic conditions.

Agronomic Attributes

Establishment

The slow establishment of *A. pintoi* CIAT 17434 is well recognized from the experience in regional RIEPT trials conducted in savannas and the humid tropics (Keller-Grein, 1990; Pizarro, 1992). The rate of increase in ground cover seems to be related to availability of moisture and soil fertility. Results of a multilocational trial (CIAT, 1986) show differences of 40% in ground cover 12 weeks after establishment, which are related to the increase in soil fertility and rainfall extending from La Reserva, Carimagua, to the piedmont in Villavicencio (Figure 3). At Villavicencio, under better soils and higher rainfall, ground cover was considerably higher than at the other sites with poorer soils and lower rainfall. Fertilizer placement close to the seed using macro-pellet or paper bag techniques increased the rate of establishment of *A. pintoi* (N. Kitahara, personal communication).

There are big differences in the rate of ground cover increase in the new available germplasm. Data from an experiment conducted at Planaltina, Brazil, in seasonally flooded land (Pizarro et al., 1993) showed differences among accessions from 2.4 to 6.4 m^2 at 167 days from sowing (Table 5). At 480 days from planting, differences still remained high. BRA 31143 was the outstanding accession in rapidity of establishment.

There is large variation in a new trial in which 39 new *A. pintoi* accessions are under evaluation. The range of ground cover at 9 weeks of growth varied from 65% to 100% for different accessions. Although *A. pintoi* is slow to establish, there is scope for improvement through the use of new available germplasm, fertilization, and perhaps the association with *A. hypogaea* for rapid ground cover.

Persistence

A. pintoi is well recognized for its persistence under grazing. Several factors contribute to this characteristic: (1) large volumes of buried seeds that produce vigorous seedlings at the onset of rains, (2) a stoloniferous, prostrate growth habit with growing points protected from grazing, and (3) tolerance of trampling and defoliation.

Table 6 shows observations carried out in Carimagua, Colombia, on soil seed reserves and seedling number of *A. pintoi* (Grof, 1985a; Rocha et al.,

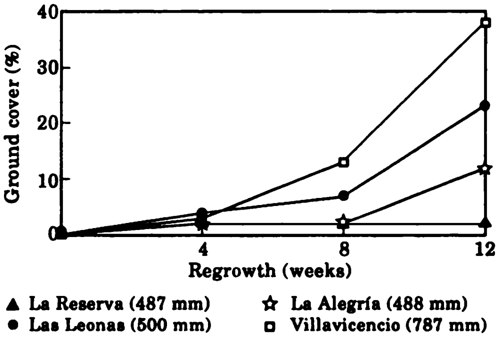

Figure 3. Ground cover of *A. pintoi* CIAT 17434 during establishment at four sites in Colombia. (Adapted from CIAT, 1986.)

Table 5. Increase (m^2) in ground cover over time in nine accessions of *Arachis*.[a]

Accession (BRA no.)	Days from sowing		
	167	243	480
31844	3.0	4.2	9.4
31861	3.5	—	9.3
31852	2.7	3.5	8.2
12106	3.0	—	8.9
13251	3.5	3.6	8.8
15121	3.0	—	7.7
15253	2.9	5.2	8.5
15598	2.4	4.3	9.1
31143	6.4	9.6	11.9

a. Plot size was 3 x 2 m^2. *Arachis* accessions were planted vegetatively 0.50 m apart in a 3-m line.

Table 6. Soil seed reserves and number of seedlings of *A. pintoi* CIAT 17434 in monoculture and associated with two grasses at Carimagua, Colombia.

Pasture	Seed		Seedlings
	(no./m^2)	(g/m^2)	(no./m^2)
A. pintoi (ungrazed)	6540 ± 290	611 ± 30	-
A. pintoi + *B. humidicola*	620 ± 210	57 ± 20	130 ± 20
A. pintoi + *B. dictyoneura*	670 ± 180	48 n.a.	150 ± 20

SOURCES: Grof, 1985; Rocha et al., 1985.

1985). At the onset of rains in May 1984, a large number of seedlings were observed in both *A. pintoi-Brachiaria humidicola* CIAT 679 and *A. pintoi-B. dictyoneura* CIAT 6133 pastures, but none in the ungrazed *A. pintoi* stand. No observations have been made on the survival rate of seedlings or the longevity of mature plants.

Grazing experiments conducted in Carimagua and elsewhere report excellent persistence of *A. pintoi* under grazing (Lascano and Thomas, 1988; CIAT, 1990, 1991; Carulla et al., 1991). Table 7 shows the legume's persistence after 5 years under grazing. Independent from the amount of the legume planted initially, it now accounts for up to at least 50% of the total biomass in *B. decumbens* pastures and 30% in *B. humidicola* pastures. The higher amount in the *B. decumbens* pastures is probably due to greater susceptibility of *B. decumbens* to spittlebug attack.

Table 7. Legume proportion in *A. pintoi* CIAT 17434-*Brachiaria* spp. pastures after five years under grazing at Carimagua, Colombia.

Pasture	Proportion of legume (%)	
	Wet season	Dry season
Row planting[a]		
B. decumbens + 20% *A. pintoi*	50	16
B. humidicola + 20% *A. pintoi*	29	12
Strip planting		
B. decumbens + 50% *A. pintoi*	57	27
B. humidicola + 50% *A. pintoi*	50	23

a. Initial coverage of the area was either 20% or 50%.

Drought tolerance

Although the peanut, *A. hypogaea*, is considered relatively drought tolerant, there was a suggestion that increased tolerance might be transferred from wild species (Smartt and Stalker, 1982). However, no investigation has focused on drought tolerance in wild *Arachis* up to now.

Arachis appears to have some drought avoidance and tolerance traits such as leaflet folding, leaf thickness, long fruiting period, and deep rooting. These features should be further explored. Ketring et al. (1982) reported the association of lower water potential with better yielding genotypes under drought conditions. Stomatal closure likely occurs at the same threshold turgor potential in the different genotypes, but deep rooting may improve water extraction and delay the time to reach the threshold for stomatal closure.

Tolerance of the dry periods experienced in the Cerrados of Brazil and Llanos of Colombia is a most desirable characteristic. Experience varies for drought tolerance of *A. pintoi*. It appears to be best adapted to the lower lying areas of the Cerrados—both in Planaltina and Campo Grande. The question is: Can it be grown successfully in association with grasses on the higher parts of the landscape in the Cerrados where moisture stress is much more severe through the dry season?

Preliminary results obtained with *A. pintoi* BRA 31143 sown on a red-yellow Latosol at Planaltina in February 1991 are encouraging. In the second dry season after establishment, green dry matter percentage ranged from 15% to 38% and total green dry matter yield from 1.7 to 4.0 t/ha (Figure 2). Root biomass and distribution were estimated in July 1992. Total root dry matter yield was 17 t/ha, with 60% of the roots in the top 30 cm but with roots up to 1.95 m in depth (Table 8). This persistence of *A. pintoi* needs to be determined in association with a grass. Persistence was poor on the higher part of the landscape at Campo Grande.

Shade tolerance

The capacity of *A. pintoi* to compete and grow in association with aggressive grasses such as the brachiarias may in part be explained by its tolerance of shade. Being a plant that tolerates shade has opened up alternative uses for the legume, such as a ground cover for soil improvement (CIAT, 1991). Ground covers are a cost-effective method of reducing the loss of valuable topsoil and the resultant decline in soil fertility and structure and, hence, productivity of plantation orchards. In addition, legume cover crops reduce weed invasion and the use of pesticides, and provide nitrogen input to the plantation crops. Two major factors contribute to the suitability of *A. pintoi* as a cover crop and soil conservation plant: the ability to grow under shade, and the dense mat of rooted stolons that protects the soil from high-intensity rainfall. Only a few studies report on nutrient competition of *A. pintoi* as a cover crop during the establishment of a permanent plantation. More research is needed in this area. Ground cover, green manure, and soil conservation practices using *Arachis* are likely to become more important with time.

Table 8. Biomass and distribution of roots in *A. pintoi* BRA 31143 grown on a red-yellow Latosol in the Brazilian Cerrados 18 months after planting.

Depth (cm)	Root yield (kg/ha)	Distribution (%)
0 - 15	6575	38.0
15 - 30	4190	24.0
30 - 45	1141	8.0
45 - 60	2027	12.0
60 - 75	995	5.8
75 - 90	709	4.1
90 - 105	603	3.6
105 - 120	172	1.0
120 - 135	150	0.8
135 - 150	75	0.4
150 - 165	150	0.8
165 - 180	114	0.6
180 - 195	148	0.8

Disease and Pest Resistance

There is little published data and only general comments and observations have been made on susceptibility to diseases and pests (Lenné, 1991; Kelemu et al., Chapter 8, this volume). Pizarro et al. (1993) made some observations during an agronomic evaluation of 33 accessions of *Arachis* spp. from the sections Caulorhizae and Rhizomatosae. The only destructive disease was rust, and this occurred mainly on accessions of *A. glabrata*. Only one accession of *A. glabrata* (BRA 17531) was resistant to rust. The other diseases and pests detected were *Cercospora* leaf spot, anthracnose (*Colletotrichum gloeosporioides*), "peanut mottle virus," and spider mite (*Tetranychus urticae*).

At Planaltina, it has been observed that spider mite (*Tetranychus urticae*) is a seasonal and sporadic pest, but without major devastation. It is common to find patches within a sward and in adjacent areas infected with spider mite. Similar attacks have been observed in the wild, for example, at the Jenipapo farm, Goiás, Brazil, in March 1993. According to Poe and Smith (1990), mites are found in all parts of the world where peanut grows. Although buildup of spider mites in the field is unpredictable, cultural practices such as weeding help to overcome the problem.

It is reported in the literature that *A. pintoi* is resistant to peanut rust (*Purcinia arachidis*), to leaf spot (*Mycosphaerella* spp.), and to some root-knot nematodes (*Meloidogyne* spp.) (see Argel and Pizarro, 1992).

In Colombia, a potyvirus closely related to peanut mottle virus (PMoV) has been isolated in *A. pintoi* CIAT 17434 (Morales et al., 1991). This virus induces mottling and ring spots in infected plants.

Current studies are investigating the effect of this virus on forage quality, DM yield, and seed production of *A. pintoi.* There are no specific control programs against potyvirus, but PMoV-free seeds can be produced under rigorous selection and isolation procedures. Kuhn and Demski (1990) noted that resistance to PMoV had not been found in *A. hypogaea*, but several lines of *A. glabrata* are resistant and research efforts are being made to hybridize the two species.

At Campo Grande, in the state of Mato Grosso do Sul, Brazil, some preliminary data are available on accession CIAT 18750, the most outstanding of the three accessions introduced there. Although leaf symptoms similar to the ring spot caused by tomato spotted wilt virus and *Cercospora* spp. have been noted, pests and diseases have not been a serious problem (C.D. Fernandes, personal communication).

In Argentina, in the germplasm collection at the Instituto Nacional de Tecnología Agropecuaria (INTA), in Manfredi, the main diseases recorded were *Cercospora arachidicola* and *Cercosporidium personatum*, while pests have not been important (E. Giandana, personal communication).

It would be useful to prepare a compendium of diseases and pests of *Arachis* to enable RIEPT collaborators to better identify potential problems, because it is a fairly new legume. Regional trials would thus become an important avenue for identification and quantification of pests and diseases.

Seed Production

Data collected to date confirm that *A. pintoi* is a prolific seeder (Argel and Pizarro, 1992; Cook and Franklin, 1988; Diulgheroff et al., 1990; Ferguson et al., 1992; Grof, 1985a; Pizarro et al., 1993). Aspects of seed physiology, seed yield potential, and seed production systems are presented in more detail by Ferguson (Chapter 11, this volume).

Experience at Planaltina, Brazil, has shown that seed production is quite variable among accessions and does not appear to be related to biomass yield (Table 2). The amount of seed did not increase from 16 to 28 months. Table 9 shows some other records of seed production from Planaltina. It is noteworthy that the addition of Ca did not increase seed yield. These results also confirm little change in seed yield after 15 months.

Since potential seed yield is not a limiting factor, other features such as suitable field seed harvesting techniques and equipment and effects of physical damage on pods or seed need to be investigated. Peanut seed is among the world's most delicate seed to handle in commerce (Ketring et al., 1982).

Nutritional Quality

The nutritive value of *A. pintoi* for livestock is high (Lascano, Chapter 10, this volume; Thomas, 1988; Pizarro et al., 1993). In vitro digestibility and crude protein were measured on nine promising accessions evaluated at Planaltina (Table 10; Pizarro et al., 1993). There was some variation in nitrogen concentration and IVDMD among accessions. There is a need to determine whether this variation persists in different seasons and locations.

Table 9. **Recovered pure seed yield in yields of *A. pintoi* accessions harvested manually in different soil types in the Brazilian Cerrados.**

BRA no.	Crop age (months)	Soil texture	Pure seed yield (kg/ha)
031143	15	Clay[a] (irrigated)	1540
	18	Clay (irrigated)	990
	21	Clay (irrigated)	1150
031143	18	Clay[a]	720
031143	21 + Ca	Clay[a]	600
	21 - Ca	Clay[a]	600
015598	15	Clay[a] (irrigated)	720
	18	Clay (irrigated)	600
	21	Clay (irrigated)	360
015598	24	Sandy loam[b]	560

a. Clay = 65%.
b. Sand = 35%.

Table 10. Total N concentration (%) and in vitro dry matter digestibility (%) of different plant components of nine accessions of *A. pintoi*. Mean values of three replicates.

Species	Accession (BRA no.)	Leaf		Stem		Litter	Root
		N	IVDMD	N	IVDMD	N	N
A. pintoi	0033	2.8	58	1.9	43	1.4	2.8
	0045	2.6	54	2.1	48	1.2	2.3
	13251[a]	2.8	60	2.3	47	1.7	3.3
	15121	3.0	56	2.1	45	1.3	2.8
	15598	2.8	48	2.4	43	1.7	3.1
	31143	2.7	58	2.4	49	2.5	3.4
A. repens	0043	3.6	51	2.5	43	1.5	2.7
	12106	3.2	52	2.8	46	—	3.1
A. glabrata	17531	—	65	—	41	3.1	2.4

a. CIAT 17434.

The high-quality nutritive value of *A. pintoi* plus the high intake by animals during both the dry and wet seasons highlight its potential (Carulla et al., 1991).

Animal Performance

Animal performance is being recorded in pastures of *B. humidicola* and *B. dictyoneura* grown alone or in association with *A. pintoi*, under several stocking rates and different grazing systems, in ongoing experiments at Carimagua, Colombia.

The association of *A. pintoi* with *B. humidicola* has resulted in consistent increases in liveweight gain during the dry season. In the rainy season, during the first 2 years when legume content was only 5-10%, there was no difference in liveweight gain between the legume-grass association and the pure-grass pastures. However, in the third and fourth years, when legume content increased to 15%, there was a 46% higher liveweight gain in the legume-grass association at all stocking rates. Legume content was higher at the high stocking rate. This shows that *A. pintoi* in association with an aggressive grass establishes slowly, but is able to compete and increase its contribution in the pasture with time.

The average liveweight gain/head in the *B. dictyoneura*-*A. pintoi* pasture has been 180 kg/ha/yr with a carrying capacity of 3 animals/ha. Thus, an average production of more than 500 kg/ha can be expected. This is higher than for any other legume-grass association developed at Carimagua.

In Itabuna, Bahia, Brazil, liveweight gains of 556 g/head/day have been recorded in a *B. dictyoneura*-*A. repens* pasture with a legume content ranging from 21% to 37% (J. Marques Pereira, personal communication). Liveweight gains of 360 g/head/day have been recorded during the first 112 days of a grazing trial on a pasture of *Paspalum atratum* BRA 9610-*A. pintoi* BRA 31143 at CPAC, Planaltina.

Dual-production systems of beef and milk are important in many tropical areas of Latin America. There is thus a need to evaluate the contribution of *A. pintoi* to such systems.

Limitations and Research Priorities

Seed harvesting

Seed must be available at a reasonable price, <US$10/kg, before there is widespread adoption. The main limitation to increased seed availability is the lack of an appropriate seed harvesting technology. Conventional peanut (*A. hypogaea*) cultural and harvesting practices are not suitable

because of the sward-forming growth habit and asynchronous seed set of *A. pintoi*. In addition, *A. pintoi* differs from the commercial peanut in that seeds are not concentrated at the plant crown and separate from the peg.

Slow establishment

Slow establishment will also be a limitation to adoption as producers like to see quick results. However, as mentioned previously, more rapid establishment should be feasible using a combination of new accessions and agronomic practices.

Available germplasm

An increased availability of germplasm may overcome some of the present limitations.

In a case study presented on *A. pintoi* (Argel and Pizarro, 1992), it was noted that although forage peanut was a highly promising species, only eight accessions were available for evaluation at that time.

Since then, several collecting trips have been conducted by CENARGEN/EMBRAPA and CIAT, increasing the availability from eight to 80 accessions in 1993. Still, this is a narrow genetic base for a species known to have wide natural distribution in South America. In the immediate future, priority should be given to collecting and identifying germplasm that is adapted to lower rainfall (700-1000 mm) and lower temperature, including areas with frost. Much dual-purpose livestock farming is carried out in elevated hillside situations in Latin America, where average temperatures are 20 °C or less. The RIEPT network should be used to evaluate such germplasm.

Alternative uses

More information is needed on both the contribution made by *Arachis* as a ground cover in various plantation crops and the competition for nutrients and water with the crop.

Some landscape designers are now using *A. pintoi* and *A. repens* to landscape areas around public buildings, such as at the Unaí Hospital in Minas Gerais, the Brasília Federal District, UNACAO-Bahia, and CIAT headquarters, Cali, Colombia. Thus, the use of *Arachis* species for landscaping and gardens needs to be more fully explored.

Acknowledgments

The authors would like to thank E. Giandana, INTA, Manfredi, Argentina; G. Sauma and E. Ramírez, SEFO-SAM, Bolivia; J.M. Pereira, CEPLAC, Brazil; C.D. Fernandes, CNPGC/EMBRAPA, Brazil; J.C. Leite Reis, CPATB/EMBRAPA, Brazil; J.A. Flaresso, EPAGRI, Brazil; M. Ayarza, CIAT-CPAC/EMBRAPA, Brazil; M.A. Carvalho, CIAT-CPAC/EMBRAPA, Brazil; R. Pérez and A. Acosta, ICA, Colombia; O. Paladines, REPAAN, Ecuador; H. Muñoz, IICA, Guyana-Suriname; J. Vela, INIA, Pucallpa, Peru; and M. Bemhaja, INIA, Uruguay, for their contributions to this work.

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Chapter 14

Regional Experience with Forage *Arachis* in Australia

B.G. Cook
R.M. Jones
R.J. Williams*

Abstract

Wild *Arachis* types were first evaluated as forages in Australia more than 50 years ago, but were rejected in favor of higher yielding species such as *Stylosanthes guianensis*. An erectoid variety still persists from this work, whereas most other legumes have died out. Since then, a wider range of *Arachis* germplasm has been introduced at different stages, representing sections Rhizomatosae, Arachis, Erectoides, Procumbensae, Caulorhizae, and Triseminalae. These have been tested, at least superficially, over a diversity of soil types in humid to semi-arid environments in the tropics and subtropics. Several members of the Rhizomatosae have been identified for their value in humid to subhumid areas in terms of persistence under grazing and productivity, on soils that are often low in fertility. *A. pintoi* from section Caulorhizae has been made commercially available as a result of its value as a forage and shade-tolerant ground cover in humid areas. Individuals from other sections are showing potential in the subhumid zone. A list of accessions held in Australia is appended.

Introduction

Interest in *Arachis* as a forage in Australia has fluctuated over the past 50 years since it was initially evaluated in central Queensland. Despite early promise, there was a legitimate fear that the various wild types being assessed might carry disease that could adversely affect the economically important commercial peanut crop. During the 1970s, evaluation of wild *Arachis* stagnated to some extent, partly on the basis of its being an alternative host for disease and partly due to its being overshadowed by the more eye-catching twining legumes such as *Macroptilium atropurpureum* cv. Siratro. But it gradually became apparent that the twining legumes required a level of management that most landholders were unwilling to, or not able to, provide, and the legume component of pastures based on these legumes often declined within 5 to 7 years of planting. At the same time, it was noticed that *Arachis* in abandoned evaluation sites was not only persisting but also spreading under conditions of management that were detrimental to twining legumes. This, coupled with the advent of *A. pintoi* in the late 1970s, and the recognition of its potential as a forage and ground cover, reawakened interest in the genus.

This paper outlines the history of *Arachis* evaluation in Australia, and suggests the adaptational limits of the sections tested. The progress of *A. pintoi* into commerce is described.

The Australian Collection

Buoyed by the success of J.F. Miles at Fitzroyvale (see below), W. Hartley, also of CSIRO, and J.L. Stephens, of the United States Department of Agriculture (USDA), undertook a plant collecting expedition in 1947-1948 to Argentina, Brazil, Paraguay, and Uruguay, with one

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* Principal pasture agronomist, Department of Primary Industries, Gympie, Queensland, Australia; senior principal research scientist and principal research scientist, respectively, Cunningham Laboratory, Commonwealth Scientific and Industrial Research Organisation (CSIRO), St. Lucia, Queensland, Australia.

of their prime objectives being to collect wild *Arachis*. Only one of the 27 varieties collected still exists in Australia. Hartley's (1949) perceptions of *Arachis* in its native environment are worth noting. Referring to *A. prostrata* (*A. glabrata* in the current taxonomy), he states, "Agriculturally, this species is of great interest. It frequently forms dense mats of foliage similar to that of white clover over a considerable area, and appears to be very well grazed." He goes on to describe *A. glabrata* and *A. diogoi*, which were both most likely procumbent or erectoid species. Of the former, he states, "In agricultural importance, this species is perhaps second only to *A. prostrata*. It frequently forms almost pure stands or close swards with short rhizomatous grasses. In such situations, it is closely grazed, and appears to be quite palatable." Of the latter, he says,

"... it is a much-branched, perennial herb, 40 to 60 cm tall, with long, rather narrow leaves ... (in cultivation) it is considered one of the most promising forage species, being taller than the others and producing a good bulk of foliage.... The foliage is palatable and readily eaten by cattle. Seed production is better than of most other species, while the more erect growth makes the plants less susceptible to shading out by tall grasses. Under grazing the plants assume a more decumbent form, but they are less able to withstand heavy grazing than, for example, *A. prostrata* and *A. glabrata*."

Unfortunately, such enthusiasm is often lost in the archives. It should be noted that the section Caulorhizae had not come to the attention of science when Hartley was making the above comparisons.

Of the current collection, only nine accessions were introduced before 1971. An additional 15 were introduced from the USDA during the 1970s, and 32, mostly from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), during the 1980s. A set of 25 Rhizomatosae and 25 assorted seeding lines was brought in from ICRISAT in 1990-1991, but the vegetative material was destroyed in quarantine because of positive tests for virus. Some seeding lines failed to set seed in the glasshouse. The identity of some of the earlier nonrhizomatous material is in doubt, through incorrect identification, apparent outcrossing, or inadvertent mixing of seedstocks. Appendix 1 contains a list of accessions in the Australian collection.

Evaluation

Prior to 1960

The earliest record of evaluation of wild *Arachis* types in Australia relates to the work of J.F. Miles at Fitzroyvale, near Rockhampton, where he assessed a range of legume genera between 1936 and 1946. In his report (Miles, 1949), he mentions three species—*A. diogoi, A. nambyquarae*, and *A. prostrata*. Due to the confusion in *Arachis* taxonomy that prevailed for many years, the true identity of these lines is not known.

Most of Miles' work with *Arachis* involved the species he referred to as "*Arachis* sp. (? *prostrata* Benth)" and *A. nambyquarae*, which he described as perennial peanut species that "gave rich vegetative growth during summer, with free cropping of nuts in late summer and autumn." The average annual rainfall at the site is about 900 mm and the soil a coarse sandy clay of pH 5.7 and P level of 20 ppm (dilute H_2SO_4 extract). Over a 15-month period and growing with *Brachiaria brizantha*, which yielded 8.5 t/ha DM, the peanuts yielded about 1 and 0.2 t/ha DM, respectively, compared with 2 or more tons per hectare from *Stylosanthes guianensis*. In another experiment at this site, the *Arachis* sp. (*prostrata*) yielded 2.7 t/ha DM in association with annual weeds, but only 1 t/ha with *Panicum maximum*. These low figures probably reflect the effects of fairly vigorous grass competition and a lenient cutting regime. The most important outcome of this work relates to the 50-year persistence of what is assumed to be the line Miles called *A. diogoi* and described as "... a native to prairies in the state of Mato Grosso, Brazil, where it is reputed to be an excellent forage plant, green or dry. At Fitzroyvale, it gave promising growth, developing a strong crown, budding freely in the spring and summer months to produce numerous semi-ascending leafy stems, being somewhat similar in habit to lucerne." This species is not *A. diogoi* as we know it today, a perennial in section Arachis, but more likely one of the species in section Erectoides.

It may still be found growing in a moderately dense stand with vigorous grasses such as *Bothriochloa pertusa* and *B. insculpta*. Since completion of the work in the early 1940s, the area has been grazed extremely heavily over prolonged periods and has not received any fertilizer. Because of the uncertainty of its origin, this variety has been allocated the reselection number CQ1780. Seed has been collected and multiplied for use in current evaluation work.

1960-1980

There is no further published record of research activity with wild *Arachis* until 1963, when Evans (1967) planted a range of 40 legumes from 16 genera including *Arachis glabrata* CPI 12121 near Howard, some 290 km north of Brisbane. Soil in the area, which receives an average annual rainfall (AAR) of about 1100 mm, is a gleyed podzolic formed on sandstone, with a fine loamy sand A horizon to about 20 cm, overlying a medium clay B, with a dense layer of ferro-manganiferous nodules between. It has a pH of 5.6 and is low in P, K, Ca, S, Mo, Cu, and Zn. Deficiencies were corrected at planting and maintenance fertilizer dressings applied in the other 2 years of assessment. No fertilizer has been applied since. *Macroptilium atropurpureum, Trifolium semipilosum*, and *Lotononis bainesii* were identified as the most productive species, and *Arachis* was rejected as unproductive. Thirty years later, *L. bainesii* and *A. glabrata* are the only legumes persisting, the area having been grazed constantly and often heavily since terminating the experiment.

In 1970, R.J. Williams, CSIRO, established a range of *Arachis* introductions in association with pangola grass (*Digitaria eriantha* ssp. *pentzii*) in a yield comparison with siratro (*Macroptilium atropurpureum*), a variety of *A. hypogaea*, and pangola with and without nitrogen. Wild *Arachis* accessions assessed were CPI 12121, 19898, 22762, 22763, 28273, 29986, 29987, and 31927. The experiment was conducted on a gley soil on the Samford Research Station near Brisbane, in an area of 1100 mm AAR. Dry matter yields were measured two or three times per year over the following four growing seasons (Table 1).

The low yields probably reflect the effect of infrequent cutting and low rainfall for much of the trial period. After the experiment ended, the area has been used as a farm pasture and been invaded by *Paspalum notatum*. All rhizomatous *Arachis*, together with the stoloniferous CPI 28273, are still persisting well in 1993.

Similarly, CPI 12121 is still persisting in a lower rainfall (750 mm AAR), heavily frosted environment at Nanango, 160 km northwest of Brisbane. Plots were planted in 1967 into the

Table 1. Average annual dry matter yield of eight wild *Arachis* accessions, *A. hypogaea* CPI 13970, Siratro, and pangola grass with (N+) and without nitrogen (N-), 1970-1974, Samford, Queensland, Australia.

	CPI accession									Siratro	Pangola grass	
	12121	19898	22762	22763	28273	29986	29987	31927	13970		N-	N+
Legume	2170	1850	1480	910	760	1400	2240	690	90	190	-	-
Grass	3080	3200	2980	2690	3060	2940	3150	2280	2890	3620	2490	5730

SOURCE: R.J. Williams, unpublished data.

loamy sand surface (pH 5.5-6.0) of a duplex soil formed on granodiorite (Jones and Rees, 1972).

The ability of a legume to spread through grass is important, since this is a measure of its competitiveness. Unless it can invade stands of an associated grass, legume density may not reach desirable proportions in new plantings, nor is the plant likely to persist in the long term.

Another experiment compared the spread of six *Arachis* accessions, established from 15-cm diameter potted plants planted into a vigorous grass-dominant pasture at the CSIRO Research Station at Beerwah, 70 km north of Brisbane, in January 1971 (R.J. Williams and R.M. Jones, unpublished data). AAR for the area is 1600 mm and soils are nodular podzolics formed on sandstone. These are siliceous sands overlying yellow clay, with a nutrient status similar to the Howard site described earlier. Test lines were *A. glabrata* CPI 12121 and 29987, *Arachis* sp. CPI 19898 and 22762, *A. repens* CPI 28273, and *A. duranensis* CPI 31927. Thirty plants of each accession were planted at 2-m intervals in rows 6 m apart. Heavy dressings of P and K were applied initially, but little fertilizer was used after 1974. Available soil P levels, however, are still on the order of 17 ppm. The extent of spread of the *Arachis* was measured in October 1986 and again in December 1992 (Table 2). CPI 31927 was not measured in 1992 because germinating rains were late and seedlings were only starting to emerge.

Table 2. Total and mean radial spread of six *Arachis* accessions at Beerwah, Queensland, Australia.

Accession	15 October 1986		4 December 1992	
	Radios (cm)	Rate of spread[a] (cm/year)	Radios (cm)	Rate of spread[b] (cm/year)
CPI 12121	140	10	313	29
CPI 19898	187	13	304	20
CPI 22762	172	12	305	22
CPI 28273	158	11	288	22
CPI 29987	28	2	167	23
CPI 31927	73	5	-	-

a. 1971-1986.
b. 1986-1992.

Grazing pressure at the site has fluctuated from lenient to extremely heavy, the latter being more the case over the past 10 years. Grass cover of *Axonopus affinis*, *Digitaria eriantha*, and *Paspalum notatum* has remained dense. In 1992, *Arachis* density was highest in CPI 12121, 19898, and 22762, and lowest in CPI 29987. Other legumes persisting nearby are *Vigna parkeri*, *Aeschynomene falcata*, *Trifolium repens*, and *Lotononis bainesii*. In contrast, the trailing *Desmodium intortum*, known to be sensitive to heavy grazing pressure, did not persist although it showed early promise.

Since 1980

Arachis has been assessed in the Gympie district since 1980. Gympie, situated about 160 km north of Brisbane, is a center for beef and dairy industries. Rainfall in the district declines from about 1500 mm near the coast to 800 mm about 80 km inland. Soils are mostly acid and infertile. Evaluation has taken the form of multisite adaptation experiments and dry matter yield and spread trials at individual sites.

Because the commercial peanut (*A. hypogaea*) industry is of economic significance in parts of Queensland, commercial growers were concerned that a wild-type forage would act as a source of pathogen inoculum for their crops. In 1984, K.J. Middleton (unpublished data) screened all wild types available at the time (comprising all lines up to and including CPI 93490) for resistance to the major fungal pathogens. Susceptible lines (Table 3) were deleted from further testing.

A selected range of *Arachis* from various sections was grown on an alluvial sandy loam soil near Gympie, and dry matter yields were determined by cutting near ground level every 6 weeks. Table 4 shows cumulative annual yields and quality indicators.

Table 3. Accessions deleted from testing program due to disease susceptibility, Queensland, Australia.

Arachis species	Accession	Disease[a]	
		Rust	Leaf spot
A. monticola	CQ 990	s	s
	CPI 58112	s	ns
	CPI 58114	s	ns
A. duranensis	CPI 31927	s	s
A. sp.	CPI 54820	s	ns
A. pusilla	CPI 58115	s	s
	CPI 58116	s	s

a. s = susceptible; ns = not susceptible.

Second-year yields were influenced by poor rainfall conditions.

CPI 93483 was the highest yielding accession, producing up to 12 t/ha DM in a season. Low annual yields of less than 2.5 t/ha DM for CPI 86278 and CQ 1780 reflect their adverse reaction to frequent low cutting. All had high IVDMD values on the order of 70%, and crude protein levels of more than 15% of the dry matter. The accession showing the greatest potential from this experiment was CPI 93483 (Table 4).

In an experiment comparing the spread of a wide range of perennial *Arachis*, another rhizomatous accession, CPI 93475, was the most successful, spreading 140 cm in 5 years, compared with 70 cm for the high-yielding CPI 93483. CPI 29987, which yielded well in the earlier work at Samford, spread only 20 cm. In the Caulorhizae, *A. repens* spread up to 72 cm over 5 years compared with 20 cm in *A. pintoi*. Erectoid accessions did not spread at all in this favorable environment (fertile, sandy-loam alluvial soil, 1100 mm AAR), but have spread up to 50 cm over 5 years in a harsher environment (hard-setting infertile soil, 850 mm AAR). *Arachis* was subsequently included in other regional experimentation and in a coordinated statewide species evaluation project.

Similar adaptation work has been carried out at Grafton in northern New South Wales (G.P.M. Wilson, personal communication), at Townsville in north Queensland (R.L. Burt, personal communication), and near Darwin in the Northern Territory (A.G. Cameron, personal communication). Descriptive work and evaluation were carried out at Rockhampton in the early 1980s (M.T. Rutherford, personal communication). *Arachis* represented by four accessions was included in a large-scale shade tolerance screening project by the University of Queensland (W.W. Stür, personal communication). *A. pintoi* CPI 58113 was rated as extremely shade tolerant, *A. glabrata* CPI 12121 as highly shade tolerant, *A. repens* CPI 28273 as moderately shade tolerant, and *A. glabrata* CPI 29986 as having low

Table 4. Cumulative dry matter yield, crude protein content, and in vitro dry matter digestibility (IVDMD) of a range of wild *Arachis* near Gympie, Australia.

Arachis section	Accession	DM yield (t/ha)		Crude protein[a]	IVDMD[a]
		Year 1	Year 2	(%)	(%)
Rhizomatosae	CPI 12121	9.0	4.6	19.1	73.0
	CPI 22762	9.5	3.8	20.6	74.3
	CPI 29987	10.8	3.9	16.0	71.5
	CPI 93464	5.3	2.9	18.9	74.4
	CPI 93469	9.6	5.0	19.4	72.7
	CPI 93483	11.9	7.6	21.2	73.4
	CPI 93490	9.7	5.6	18.9	72.7
Caulorhizae	CPI 58113	6.5	5.2	19.7	73.3
Erectoides	CQ 1780	2.4	0.3	18.3	72.5
Procumbensae	CPI 86278	1.7	0.5	17.8	75.6

a. Means of four harvests (two in each year).

shade tolerance. Work is currently under way to screen a range of wild types against a range of *Bradyrhizobium* strains (R.A. Date, personal communication).

Adaptation and Use

Rhizomatosae

Members of this section have now been planted from Grafton (29° 30' S) to Silkwood (17° 30' S) on the east coast and at Berrimah near Darwin (13° S) in the north. A number have also been planted at Roma, which lies some 500 km inland in southern Queensland. Rainfall in these areas varies from 600 mm at Roma to 3000 mm at Silkwood, and 1500 mm in a strongly monsoonal distribution at Berrimah. Frost incidence varies from zero in the north to over 20 frosts per year at Roma, where grass temperatures may fall to as low as -9 °C. Topsoil textures vary from sands to clays, with pH from strongly acid to neutral or slightly alkaline, and surface condition from hard setting to friable. Using CPI 93469 as the test variety, G. Rayment (unpublished data) was unable to show any response to phosphorus in a pot experiment with soil of 12 ppm bicarbonate extractable P. Companion grasses have ranged from lower growing aggressive sward-forming species such as pangola (*Digitaria eriantha* ssp. *pentzii*) and bahia grass (*Paspalum notatum*) to taller tussock species such as spear grass (*Heteropogon contortus*) and setaria (*Setaria sphacelata* var. *sericea*). Rhizomatous peanuts persisted in most situations.

The Rhizomatosae have proved to be quite adaptable. They are drought tolerant and, although topgrowth is killed by frost, recover readily with the advent of warmer weather. Most varieties are highly persistent under grazing and are well selected by livestock. Of 22 lines tested, none was susceptible to Australian races of rust (*Puccinia arachidis*) or leaf spot (*Cercospora arachidicola, Cercosporidium personatum*) (K.J. Middleton, unpublished data). The main environmental constraint to vigorous growth of rhizomatous peanuts appears to be poor drainage.

At this stage, no lines are commercially available, although several have been accepted for prerelease. In the Australian evaluation process, promising material is listed on prerelease and targeted for more intensive assessment to determine suitability for release. Prerelease lines are CPI 22762, 93469, 93475, and 93483.

Rhizoma peanuts will almost certainly have an important role to play in intensive cattle grazing industries, particularly where large quantities of highly nutritious feed are required. They will fit well into farming systems using cool-season forages such as oats and ryegrass. Once established, the peanuts can be cultivated to allow introduction of a winter crop, and by the time the winter crop has run its course, the peanuts will be regenerating. It is unlikely that they will be used as a hay crop in eastern Australia. Too many harvests would be lost because of rain during the curing process. This may not be the case under irrigation in the seasonally dry tropics of north Queensland. Considerable interest has been shown in using members of this group as an ornamental or ground cover for bank stabilization.

The major constraint to farmer acceptance of rhizoma peanuts will be the complexity and cost of establishment. If they are to have an impact in the beef industry, low-cost establishment methods need to be found. This might entail low-density planting in conjunction with other legume species with an inherently shorter pasture life. There will need to be an appropriate infrastructure developed in each district with rhizome producers and contractors with equipment for digging and planting rhizomes.

While gains might be achieved through plant breeding, either within Rhizomatosae or between Rhizomatosae and Erectoides, the highest priority for research and development relates to establishment systems. The technology developed in Florida will have elements that can be immediately applied in Australia. But socioeconomic and physical conditions are sufficiently different to warrant adaptation rather than adoption of this technology to Australian situations.

Caulorhizae

The Australian collection contains only three accessions from this section, two of which, CPI 28273 and 93472, are most likely the same. *Arachis pintoi* and *A. repens* have now been tested in many of the same environments as were the various members of Rhizomatosae. *A. pintoi* has persisted from Grafton in the south to Innisfail in the north, growing in a range of soil types and rainfall environments. While it has persisted in areas with rainfall as low as 690 mm, it has only been productive in areas where soil moisture and humidity have been fairly high. The ideal rainfall is probably in excess of 1500 mm. *A. pintoi* has grown successfully on alkaline clays and acid clay loams and sands. It appears to need a higher phosphorus fertility than *A. glabrata*. In the same experiment mentioned in the previous section, Rayment obtained responses up to the equivalent of 50 kg/ha P. Similarly, Turnour (1987) and Kui (unpublished data) obtained responses to single rate applications of 100 and 40 kg/ha P in soils of 13 and 19 ppm (bicarb extract), respectively. The only failures with *A. pintoi* have been on poorly structured or "puggy" clays. Persistence is favored by its perenniality and high levels of soil seed (Jones, 1993). The half life of original plants in southeast Queensland was just over 2 years, and soil seed reserves built up to 250-450 seeds/m² over 7 years. It has combined with a range of stoloniferous and tussock grasses. In north Queensland, in areas of 2000 to 3000 mm AAR, it has formed a productive legume base to a signal grass (*Brachiaria decumbens*) pasture, supporting stocking rates similar to those of grass pastures fertilized with N. It has proven resistant to peanut leaf spot and rust and is resistant to or tolerant of a number of nematode species (Cook et al., 1990). A leaf spot caused by the fungus *Cylindrocladium* may be found on *A. pintoi*, but it causes little damage. It does, however, have the potential to seriously damage the leaves of custard apple or atemoya (*Annona* sp.). This could cause problems if *A. pintoi* were used as a ground cover under custard apples. Another problem that has arisen in a few instances is the development of large rodent populations attracted by the peanut seed. These animals may subsequently attack the fruit crop.

The value of *A. pintoi* as a ground cover in orchards stemming from its high degree of shade tolerance was one of the main reasons for its commercial release. Since its release in 1987, it has gained increasing acceptance in this role and as a forage (Cook and Loch, 1993). It has also attracted attention from landscapers and engineers for use as an ornamental and bank stabilization. In 1991, 9 tons of commercial seed were produced and sold.

The main limitation to adoption is seed price. There is little cost in actually growing a seed crop, but the seed harvesting process is slow and expensive and accounts for more than 70% of costs. Because *A. pintoi* is stoloniferous and perennial, conventional seed harvesting techniques were not appropriate. Cook and Franklin (1988) developed a simple principle whereby the topsoil is cultivated after the crop is mature and is fed into counter-rotating cylindrical screens. This principle has now been incorporated into a large-scale commercial machine. Seed yields of more than 1 t/ha/year are achievable. In experiments assessing laboratory germination requirements for *A. pintoi*, J. Butler (unpublished data) found that the best results were obtained by:

1. removing the pod or predrying at 40 °C for 5 or 12 days (see Table 5);
2. using rolled towels rather than compost;
3. using an alternating 20/35 °C temperature regime; and
4. carrying out the test over 21 days.

Table 5. Effect of pretreatment on germination (%) of *Arachis pintoi* seed.

Pretreatment	Sample 1 (fresh seed)	Sample 2 (sun-dried seed)	Sample 3 (previously dried seed)
Control	3	26	40
Dehulled seed	18	47	62
Predry (40 °C/5 days)	15	37	61
Predry (40 °C/12 days)	30	41	50

High levels of fresh ungerminated seed remained after the test shown in Table 5 was carried out at 25 °C. The recommended alternating temperature regime gave germination levels of about 90%.

There are no data on seed storage conditions. Seed held at room temperature in southeast Queensland, however, has maintained reasonable germination up to 2 years, although tropical warehouse moth can cause problems. Seed has been sold at Aust.$15-20/kg. If seed is planted at 10 kg/ha, which is necessary to produce a reasonable stand, seed cost/ha is too high for most farmers. But it is feasible to plant at lower rates in conjunction with a shorter term legume. *A. pintoi* has proven capable of spreading over 1 m/year through signal grass in the wet tropics (D.G. Cooksley, personal communication) and so will colonize from a fairly sparse stand. Higher sowing rates may be necessary in the subtropics, where rate of spread is lower (Cameron et al., 1989).

Arachis repens is apparently adapted over a range of environmental conditions similar to those of *A. pintoi*, but has suffered somewhat through having extremely low or zero seed set. In trials in Vanuatu, it has been much more productive than *A. pintoi* (T.R. Evans, personal communication), although there is doubt about the effectiveness of nodulation of *A. pintoi* at the site. In those parts of the world where labor is relatively cheap, vegetative propagation poses few problems. But for *A. repens* to be adopted in Australia, a mechanical system for stolon harvest and planting would need to be developed. This may be as simple as adapting existing grass turf machinery and technology.

Erectoides/Procumbensae

Few accessions from these sections have been evaluated to any extent in Australia. From limited experience, however, it is apparent that some members may have commercial potential. Although Kretschmer and Wilson (1988) identified the 'Pantanal' peanut, PI 446898, as having value in Florida, it has been disappointing to date in evaluation in Australia, being less persistent than *A. pintoi*, and showing susceptibility to root-knot nematode. On the other hand, the accession listed as CQ 1780 has persisted for over 50 years, as described earlier. This accession and *A. paraguariensis* CPI 91419 are showing agronomic merit in contrasting soils in an area receiving about 850 mm AAR. They have withstood drought, heavy grazing, and fire, and are slowly spreading from the evaluation plot. Neither has shown any promise in higher rainfall conditions, the former proving less persistent than the rhizomatous CPI 12121 at a number of humid sites in a multisite evaluation (Cameron et al., 1989).

Much of Queensland's beef, however, is produced in subhumid areas. Once again, high sowing rates are necessary to achieve a good stand, and profit margins may not be sufficient in the beef industry to warrant such an outlay. In this environment, *Arachis* would be competing for a role against such species as *Stylosanthes scabra, S. guianensis* var. *intermedia, Cassia* *rotundifolia*, and *Desmanthus virgatus*, all of which produce high seed yields relatively cheaply. These species have an additional advantage over *Arachis* by having stand density increased by seed spread in dung.

Other sections

Early promise has also been noted in *A. triseminalis* CPI 91423 on neutral to alkaline clays and clay loams in north and central Queensland, and in the section Arachis series Perennes accession CPI 58121 in less humid environments in southern Queensland. The former does not appear to be adapted to the subtropics.

Conclusion

Establishment is the main problem with *Arachis*. This was recognized by Hartley (1949), who completed the *Arachis* section of his collection report by first summarizing the desirable agronomic and forage characteristics of the genus, but then noting that "Their utilisation elsewhere will be dependent upon the successful solution of many problems, of which one of the most important is that of securing satisfactory establishment ... and devising satisfactory methods for harvesting the fruits." This is no less true today. If the full potential of *Arachis* is to be realized, considerable funding must be injected into the development of more economical methods of producing propagating material, be it seed, stolon, or rhizome. These problems should be solved before attention is directed toward developing improved types within the genus through plant breeding.

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Appendix 1. *Arachis* accessions currently held in the Australian collection.

CPI[a]	PI[b]	Section[c]	Series[d]	Species
12121	163452	RZ	Ez	*glabrata*
19898	-	RZ	Ez	-
22762	151982	RZ	Ez	-
22763	-	RZ	Ez	*glabrata*
28273	-	CA	-	*repens*
29986	-	RZ	Ez	*glabrata*
29987	-	RZ	Ez	*glabrata*
31927	219823	AR	An	*duranensis*
54820	-	-	-	-
58109	338325	RZ	Pz	*burkartii*[e]
58110	118457	RZ	Ez	*glabrata*
58111	262839	RZ	Ez	*glabrata*
58112	263393	AR	Ap	*monticola*
58113	338314	CA	-	*pintoi*
58114	210553	AR	Ap	*monticola*
58115	262133	TRI	-	*pusilla*[e]
58116	289628	TRI	-	*pusilla*[e]
58117	289638	ER	Pr	*rigonii*[e]
58118	338309	AR	Pe	*villosa*
58120	289639	-	-	-
58121	338279	AR	Pe	-
76972	446898	PR	-	-
85804	446898	PR	-	-
86278	446898	PR	-	-
91419	338297	ER	Te	*paraguariensis*[e]
91420	338280	AR	Pe	*stenosperma*
91423	338449	TRI	-	*triseminalis*
93463	338257	RZ	Ez	*glabrata*
93464	338316	RZ	Ez	-
93466	338263	RZ	Ez	*glabrata*
93468	262828	RZ	Ez	-
93469	262833	RZ	Ez	-
93470	262836	RZ	Ez	-
93471	262848	RZ	Ez	-
93472	-	CA	-	*repens*
93473	338284	RZ	Ez	-
93474	338262	RZ	Ez	*glabrata*
93475	262814	RZ	Ez	-
93476	262841	RZ	Ez	-
93477	262844	RZ	Ez	-
93478	262798	RZ	Ez	-

(Continued)

Appendix 1. (Continued).

CPI[a]	PI[b]	Section[c]	Series[d]	Species
93480	276233	RZ	Ez	-
93481	276233	RZ	Ez	-
93482	-	RZ	Ez	-
93483	231318	RZ	Ez	*glabrata*
93484	276233	RZ	Ez	-
93487	262812	RZ	Ez	-
93488	262807	RZ	Ez	-
93490	262796	RZ	Ez	-
Q22461	-	RZ	Ez	-
Q23099	-	ER	Pr	*rigonii*
Q23100	-	AR	Ap	(Manfredi 5)
Q23101	468168	AR	Pe	-
Q23102	475873	AR	Pe	-
Q23598	468142	AR	Pe	*diogoi*
Q25223	276235	AR	Pe	*chacoense*
Q25224	261877	ER	Te	-
Q25225	261878	ER	Te	-
Q25226	262140	ER	Te	-
Q25227	337350	ER	Te	*paraguariensis*
Q25229	-	EX	-	*villosulicarpa*
Q25230	468353	ER	Te	-
Q25231	262141	AR	Pe	*cardenasii*
Q25232	338280	AR	Pe	*stenosperma*
Q25233	468153	PR	-	-
Q25234	468146	AR	Pe	*helodes*
Q25236	468337	PR	-	
Q25237	468357	ER	Te	*paraguariensis*
Q25239	475986	PR	-	-
Q25240	476004	PR	-	-
Q25241	476011	AR	Pe	*cardenasii*
Q25242	476012	AR	Pe	*cardenasii*
Q25243	476012	AR	Pe	*cardenasii*
Q25244	476013	AR	Pe	*cardenasii*
Q25245	-	-	-	-
Q25246	262142	PR	-	*rigonii*
Q25247	276231	ER	Te	*paraguariensis*
CQ 990	-	AR	Ap	*monticola*
CQ1780	-	ER	Te	-

a. CPI = Commonwealth plant introduction number.
b. PI = U.S. plant introduction number.
c. AR = section Arachis; CA = section Caulorhizae; ER = section Erectoides; TRI = section Triseminalae; RZ = section Rhizomatosae; PR = section Procumbensae; EX = section Extranervosae.
d. An = series Annuae; Ap = series Amphiploides; Ez = series Eurhizomatosae; Pe = series Perennes; Te = series Tetrafoliolatae.
e. Doubtful identity.

Biology and Agronomy of Forage Arachis. *1993. p. 169-186.*
Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Chapter 15

Regional Experience with Forage *Arachis* in the United States

E.C. French
G.M. Prine
W.R. Ocumpaugh
R.W. Rice*

Abstract

In the United States, rhizoma peanut (*Arachis glabrata*) is a warm-season perennial legume with production extending to approximately 32° N latitude. It was introduced into Florida from Brazil in 1936. Dr. G.M. Prine, of the University of Florida, in cooperation with the United States Department of Agriculture Soil Conservation Service, released 'Florigraze' in 1978 and 'Arbrook' in 1986. Other *Arachis* species and accessions are currently being tested at several U.S. locations. Rhizoma peanut grows well under a wide range of soil types and pH levels, in well- to moderately drained soil. Yields approaching 14 t/ha have been reported. Mechanization of rhizome harvest and planting has made rhizoma peanut a commercially viable crop. It is persistent on droughty, low-fertility soils and is resistant to economically serious pests and diseases. Rhizoma peanut is quite palatable, supports excellent animal performance, and can be grazed or harvested as hay, haylage, or silage. Overseeding with other crops and forages has proven successful. Continuous interaction among researchers, extension workers, and producers has been instrumental in making rhizoma peanut a viable agricultural commodity in Florida, which has approximately 3000 ha (increasing at 40% per year), with considerably smaller areas in other southern states. Arbrook production now approaches 200 ha in Florida and South Georgia combined.

Introduction

This review focuses on the evaluation, investigation, and utilization of rhizoma peanut (*Arachis glabrata*) in the USA, particularly in Florida. Brief mention is made of the recent evaluation of forage *Arachis* accessions at other sites in the USA.

Rhizoma peanut is a long-lived, perennial, high-quality, deep-rooted, warm-season forage legume. It is adapted to well-drained soils in the warmer climates of the southern and Gulf Coast areas of the USA, a region extending north to about 32° N latitude and south to include the Virgin Islands and Puerto Rico (Figure 1).

Early evaluation and cultivar development

Rhizoma peanut was first introduced into Florida in 1936 by F.H. Hull when he received two rhizoma peanut accessions from W. Archer, a plant explorer in Brazil (Hull, personal communication). One of the accessions (PI 118457) was found to have desirable forage characteristics by Conway and Ritchey (1949), but they did not develop it into a potential forage crop. Accession PI 118457 was later collected from the site of Ritchey's trials by the USDA Soil Conservation Service (SCS), planted at the Brooksville and Arcadia Plant Materials Centers, and eventually named 'Arb' (Blickensderfer et al., 1964). In 1961, several promising

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* Associate professor and professor, Agronomy Department, University of Florida, Gainesville, FL, USA; professor, Texas A&M University Agricultural Research Station, Beeville, TX, USA; assistant professor, University of Florida, Everglades Research and Extension Center, Belle Glade, FL, USA, respectively.

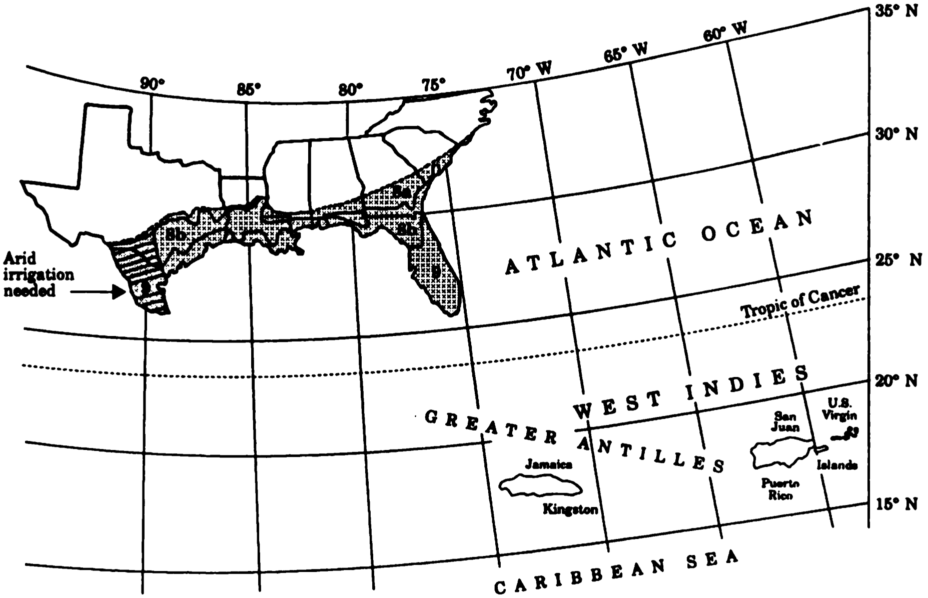

Figure 1. The humid lower south, USA, and Caribbean. The humid lower south includes the warmer portion of USDA hardiness zone 8a and zones 8b and 9. Northern limit is defined by dashed line. (Based on Misc. Publication 1475: U.S. Government Printing Office, Washington, D.C. 20402-9325.)

accessions, including PI 118457, were planted at Gainesville for an evaluation of forage yield and forage quality parameters (Prine, 1964). In 1962, Prine (1973) observed rapidly spreading plants between experimental plots of Arb (PI 118457) and PI 151982. This distinctly different plant material may have been the result of viable mutant seed arising from the serendipitous outcrossing between the two adjacent plant introductions (Prine, 1973; Prine et al., 1986b), or simply the ongoing process of segregating progeny from a selfed, highly heterozygous parent. The material was isolated and tested at the University of Florida as Gainesville Selection No. 1 (GS-1) and jointly released by the University of Florida and USDA SCS in 1978 as 'Florigraze' (Prine et al., 1981, 1986b). Florigraze currently dominates the rhizoma peanut industry in Florida.

'Arbrook' germplasm (PI 262817) was first introduced from Paraguay in 1959. Accession evaluations by the USDA SCS Plant Materials Centers in Arcadia and Brooksville and the University of Florida Institute of Food and Agricultural Sciences eventually led to the release of Arbrook in 1985 (Prine et al., 1986a, 1990).

Pest tolerance

Superior persistence and longevity of rhizoma peanut in Florida is due, in part, to superior insect resistance and low susceptibility to diseases, particularly early leaf spot (*Cercospora arachidicola*), late leaf spot (*Cercosporidium personatum*), and rust (*Puccinia arachidis*) (Ruttinger, 1989). Root-knot nematodes (*Meloidogyne* spp.) are serious pests in commercial peanut (*Arachis hypogaea* L.), yet Arbrook is highly resistant and Florigraze is virtually immune to *M. arenaria* (Neal) Chitwood race I, *M. javanica*, and *M. incognita* race I and race III (Baltensperger et al., 1986).

Cotton root rot (*Phymatotrichum omnivorum* (Shear) Duggar) infections have been documented in rhizoma peanut grown at Beeville, Texas (Barnes, 1990). The fungus is prevalent in calcareous clay-loam soils with a pH range of 7.0 to 8.5 and in areas with high summer temperatures. Infected areas appear as circular patterns throughout the field. Although the diameter of infection may increase from 2 to 10 m per year, the disease does not completely devastate the stand. Arbrook stands suffer greater losses than Florigraze. In infected rhizome nursery plots, in which forage is not harvested, normal top growth resumes within 2 to 3 years in Arbrook and within one growing season in Florigraze stands.

Isolated cases of leaf spot caused by *Phyllosticta* sp., *Stemplylium* sp., and *Leptosphaerulina* sp. have been observed in Florida, but no long-term damage has been reported. *Rhizoctonia* sp., *Pythium* sp., and *Fusarium* sp. infections have been isolated from rhizomes (Kucharek and Simone, 1979-1991), but infection is typically short-lived, with plant stands regaining full production the following season. Reports of insect damage are minimal and, to date, insects have not been an economic concern to rhizoma peanut production.

Current status of rhizoma peanut

Current rhizoma peanut area in Florida is 3000 ha, with over 95% of this area planted to Florigraze. Production is expanding at about 40% per year. Rhizoma peanut is well suited to the environment of the southern Gulf Coast region of the USA. To date, no other forage legume has consistently demonstrated an ability to rival the rhizoma peanut's forage quality, biomass production, long-term persistence, and broad spectrum of uses under Florida environmental conditions. Although Florigraze is markedly more persistent than alfalfa (*Medicago sativa* L.), it is colloquially termed "Florida's alfalfa" because it closely matches alfalfa's nutritive value profile (Tables 1 and 2) (French, 1991; French and Prine, 1991b; Lieb et al., 1993). Despite the rhizoma peanut's many favorable characteristics, widespread adaptation has been limited by two factors: a requirement for vegetative propagation and a relatively slow first-year establishment.

Table 1. Nutrient value profile (%) for Florigraze rhizoma peanut and sun-cured alfalfa hay.

Nutrient index	Rhizoma peanut	Alfalfa
Dry matter (DM)	88.5	87.6
Crude protein (CP)	15.9	19.7
Neutral detergent fiber (NDF)	51.0	42.8
Acid detergent fiber (ADF)	27.2	24.7
Digestible DM	49.6	54.3
DM digestibility	56	62
Gross energy digestibility	55	61
Digestible CP	11.1	15.6
CP digestibility	70	79
Digestible NDF	22	19
NDF digestibility	43	45
Digestible ADF	12	13
ADF digestibility	45	54
	(Mcal/kg)	
Gross energy	4.5	4.5
Digestible energy	2.5	2.8

Table 2. Amino acid profile (g/kg) for Florigraze rhizoma peanut and sun-cured alfalfa hay.

Amino acid	Rhizoma peanut	Alfalfa
Histidine	2.5	2.7
Arginine	5.0	6.4
Threonine	4.8	6.4
Methionine	0.7	0.9
Valine	5.9	6.4
Phenylalanine	6.0	5.5
Isoleucine	4.9	7.3
Leucine	8.9	9.1
Lysine	4.9	5.5
Serine	5.0	6.9
Arginine	5.0	7.2
Glycine	6.3	7.0
Tyrosine	4.3	4.6
Cystine	0.6	2.4

Potential uses of rhizoma peanut include hay, pellets and other dehydrated products, pasture, creep grazing, silage, haylage, ornamental, soil cover, living mulch, and alley crop. All animals tested to date have performed well on rations containing rhizoma peanut. These include horses, cattle (beef and dairy), sheep, goats, swine, rabbits, and poultry.

Recent Evaluation of Forage *Arachis*

Florida

Kretschmer and co-workers (Kretschmer and Wilson, 1988; Kretschmer et al., 1993) have evaluated a number of seed-propagated *Arachis* species for use on the poorly drained soils of South Florida. Individual plants do not necessarily survive multiple years, but genotypes have been isolated that produce an abundance of viable seed, ensuring stand survival from year to year. These authors have identified an *A. pintoi* (IRFL 4222) accession to be persistent under grazing, and another accession (IRFL 2273), named 'Pantanal', to be an early and prolific flowering type with good seed yield. No cultivar releases have been made to date.

Ruttinger (1989) began field evaluation of 120 *Arachis* accessions in 1987 at the University of Florida. The accessions studied included representatives of *A. glabrata* Benth. and representatives of *A. pintoi* and *A. repens* Handro (section Caulorhizae). Based on an overall selection index in which equal weight was placed on plant spread, plant vigor, rhizome weight, and flowering rate, University of Florida accession numbers 3b, 3c, 4a, 27c, 30b, 35d, 56, 57, 63, 65, 90a, 90b, and 98 (unnamed Arachis species), accessions 75 and 76 (*A. repens*), and accessions 34, 45, 84, and 106 (*A. glabrata*) demonstrated promising agronomic characteristics.

Further selection efforts made after Ruttinger's original collection in 1989 narrowed the field of potential forage-producing types to 15 accessions. Kelly and Quesenberry (1992a, 1992b) evaluated the agronomic characteristics of these 15 entries and compared their performances with those of the two commercially released cultivars, Florigraze and Arbrook. Following an establishment year, evaluations of second-year forage growth indicated that Florigraze and Arbrook yield potential (5.8 and 7.2 t/ha, respectively) compared favorably with the highest ranking experimental accessions. For yield potential, the most promising of the 15 tested accessions were UF 75 (6.9 t/ha), UF 76 (6.8 t/ha), and UF 99 (5.3 t/ha). Rhizome total nonstructured carbohydrate (TNC) concentrations (sampled in March) among the 15 entries varied considerably, ranging from 90 g/kg (UF 77b) to 250 g/kg (UF 45).

Texas

An evaluation of *Arachis* accessions revealed phenotypic variation for a number of agronomically important traits (Reed and Ocumpaugh, 1991; Rahmes and Ocumpaugh, 1992). The quest to identify rhizoma peanut genotypes that will perform favorably in ecological zones outside of Florida has led to selection trials for lines demonstrating superior winter hardiness and tolerance of calcareous soils. Field evaluations of 70 accessions at Overton, Texas, have identified several genotypes that may exhibit superior winter hardiness relative to Florigraze and Arbrook (G.R. Smith, unpublished data, 1993). Reed and Ocumpaugh (1991) have identified genetic variability for tolerance of iron-deficiency chlorosis, a nutritional disorder common to a number of crop species grown on calcareous soils. Plant introductions (PI) 262819 and 262821 have a high rate of spread and yield potential, and exhibit few to no symptoms of iron-deficiency chlorosis (Rahmes and Ocumpaugh, 1992). This characteristic will be important in the development of rhizoma peanut for parts of Texas and other regions containing high-pH, calcareous soils. These two genotypes are currently undergoing multilocational evaluations for potential cultivar release.

Puerto Rico

The performance of more than 70 accessions of *Arachis* was evaluated on Oxisol soils in Puerto Rico (Valencia et al., 1992a). Following initial screening, the *A. repens* accessions were excluded from subsequent selection efforts due to their minimal top growth and low, spreading growth habit. At a later date, two separate evaluation trials were conducted on plant material that included nine promising selections from the above evaluation: Arbrook (*A. glabrata*), two variants of *A. glabrata* acquired through the University of Florida, and six *A. pintoi* accessions obtained from CIAT. Four rhizoma peanut accessions were successfully established on Puerto Rican Oxisols, with UF 99 achieving the most rapid ground coverage at 100% soil coverage within 36 weeks, supporting average yields of 5.6 t/ha. Three stoloniferous accessions (CIAT 18744, 18747, and 18748) achieved more than 90% soil coverage within 16 weeks, with average yields of 4.7 t/ha within 36 weeks after planting.

In another germplasm screening trial conducted on Puerto Rican Oxisols, 71 rhizoma peanut accessions and six stoloniferous *A. repens* ecotypes were evaluated for persistence and yield under mob grazing 2 years after planting (Valencia et al., 1992b). Genotypes UF 30, UF 97, UF 99, and UF 108 produced the highest DM yield, with low weed infestation.

Genetic Improvement

Attempts have been made to initiate genetic improvement programs for rhizoma peanut in the USA, but these efforts have not been coordinated. Mark Elkins (personal communication) at Louisiana State University has been successful in producing seed from crosses made between a variety of rhizoma peanut genotypes. Niles (1989) experienced limited success with Arbrook ♀ x Florigraze ♂ crosses, with only eight pods forming from 116 separate cross pollinations. No pods were produced with the reversed Florigraze ♀ x Arbrook ♂ crossing strategy (with Florigraze serving as the pollen donor) or from Florigraze self-pollinations. Niles concluded that Florigraze seed production was limited by insufficient stigma moisture, which resulted in reduced pollen germination. Niles (1989) found that a high rate of embryo abortion in dense canopies was partially due to competition for light. Under cool, dry conditions, Florigraze pollen remained viable in the field for more than 24 hours after anthesis. Hypanthium length ranged from 10 to 200 mm and decreased with increasing temperature.

Establishment of Rhizoma Peanut

Rhizoma peanut is vegetatively propagated using underground rhizomes. Rhizomes are dug from a source field using a modified bermudagrass (*Cynodon dactylon*) sprig harvester and then planted either in rows, with a fairway or bermudagrass sprig planter, or broadcast over the soil surface prior to a disk-harrow and soil compaction operation. Although excellent establishment and full coverage have been achieved in a single year, a typical planting requires 2 to 3 years for complete stand development. Even under adequate management, a producer should not expect to harvest forage from a first-year stand, and may only achieve 50-66% of final production yield by the end of the second year (Prine, 1985).

Planting

Rhizoma peanut is traditionally planted in the winter (January to March) when top growth is absent and rhizomes are quiescent. A recent study confirmed that sprout emergence and end-of-season coverage were superior for material planted in the winter rather than the summer (Williams, 1993). This same study demonstrated that establishment was influenced by site preparation. A combination of bottom plowing with two disking operations minimized grass competition and supported better establishment compared with only disking or planting rhizomes directly into existing grass sod. These results are similar to those from an earlier study by Prine et al. (1984). Planting depth tended to be shallow with bottom plowing, which was associated with better sprout survival (Williams, 1993). Ahmed et al. (1985) demonstrated a linear decline in Florigraze shoot emergence as planting depth increased from 3.75 to 15 cm.

Many studies have addressed rhizoma peanut establishment from a management perspective. In a pot study, the incorporation of commercial inoculum supported 44% greater shoot dry matter (DM) and 36% greater rhizome DM accumulation relative to sterilized soil (Adjei and Prine, 1976). Early-season growth did not differ for treatments planted in inoculated soil and noninoculated native soil. A field study confirmed that inoculation does not accelerate the spread of rhizoma peanut and that native *Rhizobium* spp., either present in the target field or transferred along with freshly dug rhizomes, were adequate for establishment (Adjei, 1975).

Establishment is improved when weeds are controlled. First-year Florigraze forage cover and DM yields were doubled when both grass and broadleaf weeds were controlled relative to only controlling broadleaf weeds (Canudas et al., 1989). Digging rhizoma peanut rhizomes from fields infested with bermudagrass will transfer bermudagrass rhizomes into the target field. Preplant spraying of sethoxydim on a mixture of rhizoma peanut and common bermudagrass rhizomes provided 100% control over the grass, with no deleterious effects on rhizoma peanut rhizomes. Failure to pretreat the rhizome mixture prior to planting produced first-year rhizoma peanut growth rates and DM yields that were 50-75% less than when pretreatment herbicide was applied (Canudas et al., 1984).

Better establishment is associated with higher planting rates. First-year DM production increased linearly as rhizome planting rate increased from 0.35 to 3.8 t/ha (Canudas et al., 1989). Forage DM production response to planting rate was quadratic in the second year, with 90% of maximum yield obtained at an initial planting rate of 2.5 t/ha. Full coverage by the third year was considered possible with a low planting rate of 0.7 t/ha, given adequate weed control during the prior 2 years.

Early studies evaluated labor-intensive hand-planting strategies. Adjei (1975) recommended dividing 0.09-m^2 rhizome mat sod pieces into four sections and then dispersing them into separate hills within a 3-m^2 area, roughly equivalent to a 2.2-3.5 m^3/ha rate (Prine et al., 1981). In Florida, rhizome planting rates are based on a volume rather than a DM basis. Recommended planting rates have increased considerably over time, presumably reflecting efforts to address unsatisfactory first-year coverage. This documented trend is misleading since early planting rate studies were based on hand-packed, compressed volumes of rhizome material. Early studies led to the recommendation to plant 0.5-m rows at 3.5 m^3/ha with a sprig planter (Prine et al., 1981). This same rate was later considered the minimum recommendation, with suggested rates ranging from 5.3 to 7.1 m^3/ha (Prine et al., 1986a). These higher planting rates were based on loosely packed rhizome volumes and, from a mass perspective, do not reflect a doubling of the earlier recommended planting rates. Practical considerations for farmers in the field with respect to rhizome sales, wagon loading, and subsequent mechanics behind a smooth planting operation dictated that extension-oriented planting information be based on loosely packed rhizomes. Tightly packed rhizomes simply will not feed correctly into the planter (Prine and French, 1992). Current planting recommendations call for 7.1 m^3/ha of loosely packed rhizomes, but higher rates of 8.9-10.6 m^3/ha have been suggested if planting material is inexpensive (French and Prine, 1991a).

Parameters intrinsic to rhizome planting material influence first-year establishment performance. Shoot count at 80 days after planting, and rhizome and shoot mass accumulation at 180 days after planting, increased with increasing preplant rhizome TNC and N concentration (Rice, 1993). In a nonirrigated study, rhizomes with low TNC (67 g/kg) and N (12.7 g/kg) concentrations did not survive the establishment period during a dry year. Planting rhizomes with TNC >220 g/kg and N >20 g/kg will minimize the risk of a dry year. Higher planting rates were recommended when planting rhizomes with a TNC concentration range of 190-200 g/kg and N range of 17-18 g/kg (Rice, 1993). These results may help explain some of the poor establishment performances experienced during earlier research efforts on rhizoma peanut. This earlier work typically used rhizome planting material taken from fields where rhizome TNC may have been depleted by harvest schedules that would currently be classified as improper defoliation management.

Effect of fertilization

Establishment performance in response to fertilizer inputs has not been thoroughly investigated. Investigations on the effects of N fertilizer on establishment performance have produced somewhat contradictory conclusions. One field study determined that N applications reduced Florigraze spread and yield during first-year establishment (Adjei and Prine, 1976). Fertilizing at 168 kg/ha N reduced rhizoma peanut coverage by 30% and DM yield by 40% relative to the nonfertilized control. Another field study reported that rhizoma peanut performance during early establishment was improved with increasing N rate, presumably because N_2 fixation was ineffective during the first weeks following planting (Valentim et al., 1986). A greenhouse study demonstrated that while early shoot and root growth improved with N fertilization, both nodulation and nitrogenase enzyme activity were inhibited during the summer and fall growth periods (Valentim, 1987). In another greenhouse study, N inputs during establishment resulted in a declining nodule population, which was associated with poorer establishment performance (Adjei and Prine, 1976).

Fertilizer trials conducted on rhizoma peanut during first-year establishment at 13 farms resulted in no effect of P, K, S, Mg, or lime amendments on season-end stand density (Niles et al., 1990). Additional fertilizer studies are warranted since unseasonably dry weather during this single-year study may have reduced crop response to fertilizer inputs. Farm sites with low soil pH (<5.5) appeared to support better establishment and the current practice of liming was questioned (Niles, 1987). In a study conducted on P-deficient soils, Florigraze did not respond to P inputs nor to lime amendments, whereas four other popular pasture legume species experienced more than fivefold yield increases with added P (Blue et al., 1989). Current fertilizer recommendations for establishing rhizoma peanut in Florida, based on studies conducted in Alpin fine sand (thermic, coated Typic Quartzipsamments, fine sand extending below 2 m profile), include the following: 15 kg/ha P when Mehlich I-extractable soil P <30 mg/kg; 56 kg/ha K when Mehlich I-extractable soil K <20 mg/kg; 17 kg/ha Mg when Mehlich I-extractable soil Mg <30 mg/kg. Modify soil pH only when outside the 5.0-7.5 range (French and Prine, 1991a).

Companion Cropping

Producing companion crops along with newly planted rhizoma peanut may make the establishment period more profitable (Prine, 1973). Interplanting 'Florida 77' alfalfa with Florigraze resulted in a more uniform yield distribution of high-quality legume forage over a 4-year period than pure stands alone (Valentim et al., 1987). The alfalfa component dominated total forage yield for the first 2 years, but as rhizoma peanut establishment progressed, alfalfa declined and was eventually replaced by the rhizoma peanut component in the fourth year.

The introduction of tropical legume species into grass-based pastures offers a strategy for improving overall pasture forage quality in Florida (Kretschmer, 1974). In general, the association of C_3 legumes with C_4 grasses in tropical environments has been only moderately successful (Mott, 1981). A sustained contribution by the legume component is compromised by vigorous growth and high photosynthetic rates of C_4 grasses (Ludlow and Wilson, 1972). Williams (1988) evaluated the performance of 40 tropical forage legume accessions (16 genera) after planting directly into rototilled Pensacola bahiagrass (*Paspalum notatum* Flugge). Persistence of many annual legume species within the grass sod was limited by poor seed set and low seedling recruitment that resulted from dry summer weather and intermittent late-season frosts. Favorable performance by Florigraze and Arbrook rhizoma peanut was attributed to underground rhizome growth, which enhanced plant persistence within the grass sods.

Companion cropping has also been suggested for well-established rhizoma peanut pastures. Overseeding with cool-season annual rye (*Secale cereale* L.) and annual ryegrass (*Lolium multiflorum* Lam.) provided a successful winter forage crop during the rhizoma peanut rhizome-quiescent phase, with no adverse effects on rhizoma peanut forage production the following season (Dunavin, 1990). Overseeding cool-season crops into mixed grass-Florigraze associations supported stable grass-legume ratios over a 4-year period (Dunavin, 1992). The long-term persistence of Florigraze-grass associations was more stable with a 'Tifton 44' bermudagrass component than with the thicker bahiagrass sods.

Dry Matter Production

Early comparative trials demonstrated superior Florigraze establishment performance relative to earlier rhizoma peanut releases, Arb and 'Arblick' (Prine et al., 1981). Average Florigraze forage DM production (10.3 t/ha) over a 4-year period was higher than Arb (8.7 t/ha) and Arblick (5.2 t/ha). Maximum Florigraze yields for several studies ranged from 11.7 to 13.2 t/ha (Prine et al., 1981).

Mansfield (1990) reported that Florigraze produced most of its top growth during late spring and early summer, with declining production in the fall. Following an early-June staging, Florigraze harvested at 6-week regrowth followed by a second harvest at 12-week regrowth (6-12 weeks) produced only 5.9 t/ha (Romero et al., 1987). The reverse harvest strategy (12-6 weeks) exploited rapid summer growth and supported maximum yield of 10.5 t/ha, while the 9-9-week schedule produced 8.8 t/ha. Early-season DM accumulation can decline considerably under drought stress (Prine et al., 1981). Early-summer leaf senescence and leaf drop can occur in arid climates (Ocumpaugh, 1990). In areas where summer rainfall is limited, June and October harvests were suggested as a strategy for optimizing forage yields (Ocumpaugh, 1990). Early-season Arbrook production tends to exceed that of Florigraze, but both cultivars have similar seasonal forage production potentials (Prine et al., 1986a). In a number of comparative trials, Arbrook seasonal yields exceeded those of Florigraze by 17-36% (Prine et al., 1986a). Maximum Arbrook yields for these studies ranged from 12.4 to 12.8 t/ha, while Florigraze ranged from 10.3 to 10.5 t/ha. In one of the highest yield trials on record, Florigraze yield (15.7 t/ha) exceeded that of Arbrook (13.4 t/ha) by 17% (Prine et al., 1986a). In general, Arbrook production will likely exceed that of Florigraze on excessively drained soils and under dry climates typical of the southern Florida ridge area (Prine, 1985).

Effect of fertilization

Under a nonfertilized regime, an early rhizoma peanut release (Arb) produced 4.5-6.5 t/ha over a 3-year period (Prine, 1964). The addition of P-K fertilizer at 22-84, 44-168, and 66-252 kg/ha increased yields by only 4%, 7%, and 17%, respectively. Another study reported only a 1.6 t/ha yield increase after increasing P-K fertilization inputs from 14-25 to 68-130 kg/ha, although yield at the high rate was only 4.3 t/ha (Blickensderfer et al., 1964).

Information on fertilizer response in established rhizoma peanut stands is limited. Lack of response to both P and K inputs was documented on Florigraze stands over a 3-year period. Yearly P-K applications of 25-150 kg/ha produced average yields of 10.5 t/ha, similar to 10.3 t/ha obtained in nonfertilized stands (Prine et al., 1986a). Nearly doubling the yearly P-K rates to 50-240 kg/ha supported only slightly higher yields (11.2 t/ha). Arbrook did not respond to these P and K rates. Deep-rooted rhizomes that confer excellent drought tolerance in well-established rhizoma peanut stands (Albrecht et al., 1989; Mansfield, 1990) have also been implicated for the general lack of fertilizer response. Both roots and rhizomes have been found to exceed 3 m in depth, which may confer an unusually high capacity for nutrient uptake from deep within sandy soil profiles.

In a recent study, Florigraze rhizoma peanut did not respond to fertilizer inputs until the third year for plants grown on excessively drained, deep sandy soils with low Mehlich I-extractable soil nutrient levels (Rice, 1993). By the fourth year, plots receiving annual inputs of a complete fertilizer (P, K, S, Mg, Fe, Cu, Mn, Mo, B, Zn) supported higher yields (6.6 t/ha) than when P (5.7 t/ha), S (5.3 t/ha), or K (4.9 t/ha) were omitted from inputs. Omission of any single micronutrient over the 4-year period did not affect forage production response (Rice, 1993).

Uncertainty currently surrounds rhizoma peanut fertilizer recommendations because Mehlich I-extractable soil nutrient test levels have not been calibrated with measured forage yields. At present, soil tests cannot be interpreted accurately or used to tailor fertilizer recommendations for the specific purpose of eliciting a predictable, favorable yield response from rhizoma peanut.

Florigraze did not respond to N applications as high as 300 kg/ha, but fertilization may be warranted for mixed grass-Florigraze pastures as a way to improve overall forage crude protein (CP) concentration (Valentim et al., 1986). Many tropical grasses have CP concentrations of <70 g/kg, a value below which forage intake is seriously limited by N deficiency within the rumen (Milford, 1967; Minson and Milford, 1967). Tropical grass pastures can be improved by both N fertilization and incorporation of a legume component. With no N application, Pensacola bahiagrass, Tifton 'Hybrid-81' bermudagrass, and 'Survenola' digitgrass (*Digitaria umfolozi*) forage CP levels were less than 70 g/kg (Valentim et al., 1986). In association with Florigraze, overall forage CP levels increased to slightly more than 70 g/kg. Addition of N fertilizer to these grass-legume associations increased overall forage CP concentration to the 80-95 g/kg range.

Effect of defoliation on hay production

Clipping height and frequency are two important factors that determine rhizoma peanut hay yields. Grass competition is encouraged with increasing defoliation frequency (Breman, 1980). The Florigraze component of total forage increased from 76% to 96% as the rest interval between clippings increased from 2 to 12 weeks. The 12-week interval (two cuts per year) supported total forage yield of 8.0 t/ha with a high rhizoma peanut component yield of 7.7 t/ha (Breman, 1980). Van Horn and Romero (1986) concluded that rhizoma peanut needs more than 6 weeks of regrowth between cuttings and suggested that three harvests on a 9-week schedule would support similar DM yields, but of higher quality forage, than two harvests on a 12-week schedule. During a 24-week study, Florigraze DM yields increased from 8.0 to a maximum of 12.4 t/ha as cutting interval increased from 2 to 8 weeks. A 12-week interval supported yield (12.0 t/ha) similar to the 8-week schedule (Beltranena et al., 1981).

Harvest management influences long-term hay production potential. Rice

(1993) investigated the effect of different hay-harvest schedules, imposed over a 2-year period, on third-year forage production under a uniform harvest schedule. For schedules involving three defoliations per year, deferring the season-end harvest until mid-November supported higher third-year Florigraze production (12.2 t/ha) than with an earlier mid-October harvest (10.4 t/ha). For two cuts per year, the delayed harvest strategy supported higher third-year production (12.3 t/ha) relative to the earlier mid-October harvest (11.8 t/ha). Third-year Arbrook production trends were similar to those reported for Florigraze (Rice, 1993).

Current recommendations for Florida are to cut well-established rhizoma peanut three times annually on roughly an 8-week schedule starting in early to mid-June. While a 12-week schedule (two cuts per year) may produce similar hay yields, the benefit of reducing labor may come at the expense of reduced forage quality (Prine et al., 1986a). Ocumpaugh (1990) suggested that a two-cut system (June and October) may be best in semiarid areas of south Texas where there is a bimodal rainfall pattern.

Effect of defoliation by grazing

Forage production is influenced by the choice of grazing frequency and intensity, as expressed by the total residual DM of live herbage remaining in the pasture following grazing (Ortega-S. et al., 1992b). Florigraze herbage accumulation of 8.8 t/ha was supported when the grazing cycle exceeded 42 days and residual DM was 1500 kg/ha (roughly a 15-cm postgraze stubble height). Maintaining larger levels of residual DM of 2300 kg/ha (20-cm stubble) was recommended with a shorter 21-day grazing cycle. Maximum herbage accumulation of 10.1 t/ha was estimated with a 63-day grazing cycle and residual DM of 1800 kg/ha. Grass components of pasture increased with increasing grazing pressure.

Rhizome Dry Matter Production

Rhizome biomass represents a significant fraction of rhizoma peanut production. Maintenance of the rhizome-to-forage biomass ratio is important for long-term, consistent productivity of rhizoma peanut (Ortega-S. et al., 1992b; Saldivar et al., 1992b; Rice, 1993). Over a 2-year period, rhizome DM constituted roughly two-thirds of total biomass present at any given time through most of the growing season, and increased to 85% in the fall when top growth declined (Mansfield, 1990). During establishment, rhizome DM did not increase appreciably until late July (Saldivar et al., 1992b). Thereafter, rhizome mass increased steadily until November, when it comprised 64-71% of total biomass.

Rhizome DM accumulation in established stands is influenced by defoliation. Relative to the undefoliated control, clipping at an 8-week interval (three cuts per year) decreased season-end rhizome yield by 50%, while a greater reduction of 66% was observed for the 2- and 6-week clipping frequencies (Saldivar et al., 1992b). Defoliation imposed over a 2-year period at 4-, 8-, and 12-week intervals supported increasingly higher third-year Florigraze rhizome mass of 8.8, 10.6, and 12.2 t/ha, and Arbrook rhizome mass of 8.1, 11.1, and 14.0 t/ha (Rice, 1993). Restricting the defoliation schedule to a single event in mid-November over the 2-year period supported the highest Florigraze (19.2 t/ha) and Arbrook (20.8 t/ha) rhizome mass.

Rhizome mass declined from 3500 to 450 kg/ha over a 2-year period under severe grazing (Ortega-S. et al., 1992b). With a grazing intensity that maintained pasture residual DM of 1000 kg/ha, rhizome mass declined linearly as the grazing cycle decreased from a 63- to a 7-day interval. Different grazing cycles had little impact on rhizome mass, which was maintained at over 1700 kg/ha residual DM under light grazing.

Carbohydrate Reserves in Rhizoma Peanut

Rhizomes are the primary carbohydrate storage organs in rhizoma peanut (Saldivar, 1983). Shoot TNC concentrations were not affected by year or season, averaging 115 g/kg, and were not considered useful in the analysis of rhizoma peanut carbohydrate status (Saldivar et al., 1992a). Mansfield (1990) also found little seasonal variation in stem and leaf TNC, which ranged between 58 and 69 g/kg throughout the year. Although rhizomes can be separated into two morphologically different classifications (Saldivar, 1983), both fractions displayed similar seasonal TNC concentration trends both during and after establishment (Saldivar et al., 1992a).

In an establishment year, rhizome TNC concentrations declined during early spring regrowth and ranged between 100 and 200 g/kg through most of the growing season, before accumulating to 400 g/kg during the fall storage period (Saldivar et al., 1992a). In contrast to TNC, rhizome N concentration did not follow a strong pattern of depletion during early regrowth or rapid accumulation in the fall. During an establishment year, several cycles of shoot emergence and shoot loss during drought conditions led to sharp declines in both rhizome mass and TNC concentration (Rice, 1993). In the absence of adequate photosynthetic capacity in the canopy, successive regrowth cycles relied heavily on stored rhizome carbohydrate. Evidence of stable or even increasing rhizome N concentrations during the same period suggests that N is not utilized in proportions to the extent that TNC is utilized in supporting initial growth processes (Rice, 1993).

Under favorable moisture conditions in established stands, rhizome TNC declined to around 100 g/kg during the hot summer months, but then accumulated to 300 g/kg in the fall (Mansfield, 1990). Similar seasonal patterns in established stands were observed by Saldivar et al. (1992a), but reported TNC concentrations were considerably higher, with mid-summer TNC of 350 g/kg increasing to 700 g/kg by late November.

Defoliation at a 4-cm height resulted in a lower rhizome TNC concentration (230 g/kg) than defoliation at an 8-cm height (270 g/kg) (Johnson et al., 1990). Plants defoliated at 2-, 6-, and 8-week intervals had similar rhizome TNC concentrations (450-500 g/kg) by late November, while rhizomes in the undefoliated control had concentrations of 700 g/kg (Saldivar et al., 1992a). High TNC concentrations in the 2-week treatment were not expected because frequent demands for regrowth would presumably generate appreciable declines in rhizome carbohydrate reserves over the course of the season. A decumbent growth habit became prevalent within 10 weeks of imposing the 2-week defoliation treatment, and considerable leaf area remained close to the ground after subsequent harvests. In contrast, little leaf area remained following defoliation at the 6- and 8-week intervals since shoots (with attendant leaves) had elongated above the 3.5-cm defoliation height. Continued photosynthetic capacity in plots cut every 2 weeks may have reduced reliance on rhizome reserves. For plots harvested at longer intervals, regrowth in the absence of leaves utilized reserves, resulting in similar concentrations across different defoliation treatments by season end (Saldivar, 1983; Saldivar et al., 1992a). Rice (1993) reported similar observations for prostrate growth habit in frequently cut Florigraze plants and little effect of defoliation frequency on rhizome TNC concentrations.

Ortega-S. et al. (1992a) reported that frequent grazing resulted in the utilization of stored rhizome carbohydrate. After 2 years of imposed grazing management, season-end rhizome TNC ranged from 58 to 210 g/kg. The lowest TNC levels were associated with heavy grazing that maintained little residual leaf area following frequent defoliation. The choice of grazing frequency (every 7, 21, 42, or 63 days) did not influence carbohydrate reserves when defoliation maintained herbage residual DM above 1700 kg/ha. Rhizome N concentration was not sensitive to imposed defoliation, supporting results reported by Saldivar et al. (1992a). Rhizome N concentration averaged 15.1 g/kg across all treatments during the first year and ranged from 12.8 to 15.6 g/kg during the second year.

Water stress was associated with seasonal rhizome TNC concentrations that were 18-69% higher than concentrations in the irrigated control (Mansfield, 1990). Forage DM accumulation declined in water-stressed treatments, indicating that photosynthate was preferentially partitioned to rhizome storage at the expense of top growth. With imposed water stress, yield reductions in both Arbrook and Florigraze were attributed to a combination of decreased photosynthesis and preferential accumulation of TNC in rhizomes at the expense of shoot growth (Albrecht et al., 1989).

Forage Nutritive Value

Florigraze forage nutritive value is considerably higher than that of earlier rhizoma peanut cultivars. Prine et al. (1981) reported that over a 3-year period, Florigraze forage CP (146 g/kg) and in vitro digestible organic matter (IVDOM) (666 g/kg) consistently exceeded forage nutritive values for Arb (101 and 601 g/kg) and Arblick (129 and 637 g/kg). Over a 4-year period, superior Florigraze nutritive value combined with higher forage production supported IVDOM (4917 kg/ha) and CP (1445 kg/ha) yields that were 14-29% higher than for Arb and double those of Arblick. Comparative studies between Arbrook and Florigraze over numerous seasons and different sites suggest that both cultivars have similar forage nutritive values. Florigraze also has a similar nutritive value to that of alfalfa (Tables 1 and 2).

Forage maturity can influence nutritive value. During an establishment year, Florigraze forage CP and IVDOM concentrations were characterized by a two-stage curve, with linear declines in nutritive value as early growth matured, followed by unchanging values from August through November. CP concentration ranged from 200 to 250 g/kg in April, but eventually stabilized at 125 g/kg for the rest of the season (Saldivar et al., 1990). Forage IVDOM concentration followed a similar decline from 740 to 610 g/kg during the course of the season. Romero et al. (1987) reported a linear decline in Florigraze CP concentration as stage of regrowth increased from 6 (144 g/kg) to 9 (137 g/kg) to 12 weeks (129 g/kg). Maturity had less effect on Florigraze IVDOM, which declined from 610 to 570 g/kg as regrowth stage increased from 6 to 12 weeks.

In a grazing trial, the average CP concentration of consumed forage was 200 g/kg, while IVDOM levels ranged from 660 to 750 g/kg, suggesting that Florigraze can maintain a high forage nutritive value over a range of herbage maturity (Ortega-S. et al., 1990). In a 24-week clipping trial, average Florigraze CP for 4-week regrowth (six cuts per year) was 207 g/kg versus 152 g/kg for 8-week regrowth and 142 g/kg for 12-week regrowth (Beltranena, 1980). Corresponding IVDOM values also declined from 699 to 616 to 561 g/kg. Crude protein yield was maximized at 6-week regrowth (1960 kg/ha), similar to the 1860 kg/ha achieved with 4-week regrowth.

The decline in nutritive value with the increasing interval between defoliations was associated with a decline in leaf-to-stem ratio. The leaf-to-stem ratio for 4-week regrowth was 6.3, and declined to 2.3 and 1.8 for 8- and 12-week regrowth, respectively. Saldivar (1983) reported similar declines in percentage leaf and nutritive value as regrowth stage increased. Higher leaf-to-stem ratios may be responsible for considerably higher IVDOM in rhizoma peanut relative to alfalfa. Over a 2-year period, alfalfa IVDOM ranged from 620 to 660 g/kg, whereas a higher range of 700 to 760 g/kg was reported for rhizoma peanut. Forage CP concentrations, however, were similar for both species, ranging from 190 to 204 g/kg (Valentim et al., 1987). Ocumpaugh (1990) reported that leaf blade CP concentration of Florigraze was 1.7 to 1.9 times greater than that of stems, with little variation in this ratio over two seasons of evaluation. Calculations performed on data reported by Romero et al. (1987) indicate that leaf CP concentration for 6- and 12-week regrowth was 1.9 to 2.3 times higher than for stems.

Animal Performance

Beef cattle

In a 3-year grazing study, average daily gain (ADG) on 'Mott' dwarf elephantgrass (*Pennisetum purpureum* Schum.) and Florigraze pastures was 0.97 and 0.93 kg, respectively (Sollenberger et al., 1989). Steer ADG for both plant species was superior to that of all other warm-season perennial forage crops previously evaluated at the University of Florida, greatly exceeding the 0.35 kg response on Pensacola bahiagrass. Introduction of Florigraze into bahiagrass pastures supported 54% greater ADG over a 2-year period than on bahiagrass alone (Williams et al., 1991). Kunkle et al. (1988) reported that freshly weaned steer calves grazing rhizoma peanut pastures had a higher 2-year ADG (0.79 kg) than those with access to only bahiagrass (0.52 kg). During good environmental conditions, ADG on rhizoma peanut was 0.91 kg compared with 0.51 kg on bahiagrass.

In a creep-grazing management study, Saldivar et al. (1981) reported that Brahman calves with free access to rhizoma peanut pastures experienced a higher ADG (0.78 kg) than calves restricted to bahiagrass pastures (0.62 kg). Over a 12-week period, lactating Brahman cows maintained on bahiagrass experienced high weight losses (24.1 kg) when calves were restricted to grass pastures, with much lower weight losses (4.1 kg) when calves had free access to rhizoma peanut pastures (Saldivar et al., 1981).

When pasture quality declines during winter months in Florida, expensive concentrates are often used as supplemental feeds in order to prevent weight loss in beef cows. The replacement of 0.91 kg/head/day of range cube concentrate (200 g/kg CP) with 2.3 kg/head/day of Florigraze hay (126 g/kg CP) had no adverse effect on weight gain, pregnancy rate, or reproductive performance (Padgett et al., 1990).

Milk cows

Staples and Emanuele (1988) reported that 4% fat-corrected milk yield increased by 0.7 kg/day for lactating dairy cows when 40% of the maize silage in a maize silage-grain concentrate supplement was replaced by rhizoma peanut silage. Completely replacing the maize silage with rhizoma peanut led to lower milk yields, but an economic analysis indicated that this diet was the most profitable. In an evaluation of forage source effects on Holstein and Jersey cow milk production, replacement of concentrate with alfalfa or rhizoma peanut supported similar milk yields (Romero, 1985). Romero et al. (1987) observed that more CP in rhizoma peanut diets passed through the rumen undegraded relative to alfalfa diets, indicating that a greater proportion of rhizoma peanut protein could be digested postruminally to supply amino acids for growth.

Gestating sows

The replacement of a standard lactating swine maize-soybean meal (150 g/kg CP) diet with 40%, 60%, and 80% rhizoma peanut hay had no effect on litter size and number of piglets surviving 14 days postpartum for three consecutive litters (López, 1990).

Meat goats

In a growth trial, goat ADG was greater on rhizoma peanut (63.8 g/day) than on alfalfa (46.2 g/day) diets and feed conversion to weight gain efficiency (g DM intake/g gain) was 32% higher with rhizoma peanut diets (Gelaye et al., 1990).

Horses

In a feeding trial involving mature geldings, voluntary forage intake (as a percentage of total body weight) was highest with rhizoma peanut hay (3.18%), with lower intakes on bermudagrass (2.77%), alfalfa (2.45%), and bahiagrass (1.52%) diets. Animal performance trends were similar to intake trends, with greatest ADG on rhizoma peanut hay (0.48 kg), followed by bermudagrass (0.17 kg), alfalfa (0.14 kg), and weight loss with bahiagrass (-1.22 kg) (Lieb et al., 1993).

Poultry

Rhizoma peanut compared favorably with yellow maize and alfalfa meal as a xanthophyll pigment source for egg yolk coloring, indicating that it contains adequate levels of the pigment for use as a commercial poultry feed additive (Janky et al., 1986).

Miscellaneous

Observations that wildlife are attracted to rhizoma peanut plots have encouraged both hunters and conservationists to establish this crop as a feed source for animals. Several review articles (French et al., 1987a, 1987b, 1988) provide condensed summaries of numerous studies that collectively evaluate the performance of a wide range of animal species fed diets containing rhizoma peanut.

Future Research Needs

Forage *Arachis* development and promotion efforts in the USA have documented rhizoma peanut's many desirable agronomic traits, both as a forage and as a ground cover crop. But several factors have detracted from its widespread use outside of Florida. Perhaps most important is a lack of knowledge of the potential of rhizoma peanut genotypes appropriate for different environments. A great number of accessions are stored in the USA perennial *Arachis* plant introduction collection, but few have been adequately evaluated. Future research efforts should include the evaluation of the entire collection, with a special focus on multilocational testing to identify sources of genetic variability that favor plant adaptation/tolerance to different environments and different uses. Florigraze and Arbrook, two successful commercial cultivars released in Florida, have already demonstrated many desirable agronomic traits. Some undesirable characteristics still persist, such as slow establishment, suggesting that there is room for genetic improvement. Progress in this direction would be favored by the comprehensive screening of the USA perennial *Arachis* collection in Florida. Evaluations on a limited number of *Arachis* accessions at Beeville, Texas, suggest that some accessions will establish more rapidly than Florigraze (Rahmes and Ocumpaugh, 1992). Whether these accessions also have the other desirable traits of Florigraze remains to be determined.

Rapid establishment rates, with full stands developing within one year, have been observed in Florida for Florigraze and Arbrook. The interaction of environment with physiological and genetic characteristics of the plant may be responsible for these infrequent events. Until all factors involved in the establishment process are better understood, modifications to current rhizoma peanut management practices will not likely lead to consistent first-year establishment.

Few studies have been conducted on Florigraze or Arbrook that address physiological aspects of the rhizome and root system, and none have been performed on any promising *Arachis* accessions. These studies need to be conducted because the current understanding of physiological and morphological aspects of this forage crop is limited. Saldivar (1983) made a number of observations regarding the growth and spread of newly establishing Florigraze, but did not impose enough variables to develop strong hypotheses that could help identify factors contributing to desirable plant growth habits. Studies conducted in the decade since Saldivar's research have contributed to our understanding of how various defoliation management practices influence the development and growth of the rhizome and root system (Ortega-S. et al., 1992a; Rice, 1993).

Casual observations in the field suggest that depth of rhizomes and roots differs with genotype, but these relationships have not been documented. Observations during evaluation of *Arachis* accessions suggest that extent of rhizome branching and number of shoots per unit of rhizome may be genetically controlled, but this information is not documented. A genetic propensity for greater rhizome and rooting depth, prolific rhizome branching, and increased shoot density may contribute to desired characteristics such as rate of spread during establishment, winter hardiness, and drought tolerance. Future crop improvement efforts will be predicated on identifying genetic factors underlying favorable rhizome and root system performance, and subsequent incorporation of these traits into currently successful agronomic genotypes, to produce an improved rhizoma peanut release.

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Chapter 16

Regional Experience with Forage *Arachis* in Other Tropical Areas: Asia, Africa, and the Pacific

W.W. Stür
J. Ndikumana*

Abstract

Widespread interest by researchers in the forage potential of *Arachis* species in Asia, Africa, and the Pacific is relatively recent. But there are a few instances where forage *Arachis* is being used by farmers for heavily grazed pastures or as a cover crop in fruit tree operations.

Forage *Arachis* species, particularly *A. pintoi*, are currently under evaluation in many countries and appear to be well adapted to a wide range of climatic and soil conditions in the humid and subhumid tropics. They persist and combine well in mixtures with a large range of grasses, even under heavy grazing. Other advantages are easy vegetative establishment, good spread, good shade tolerance, and the choice of seeding or nonseeding accessions. Limitations to adaptation of the currently available forage *Arachis* germplasm in Asia, Africa, and the Pacific are low rainfall (<1000 mm average annual rainfall), low-fertility acid soils (pH <5), and low-fertility, high-pH soils (pH >8) such as coralline soils in the Pacific.

The use of forage *Arachis* is being promoted for pasture improvement, particularly in livestock-tree cropping systems, and for heavily grazed pastures. Its potential use as a cover crop for nitrogen fixation, weed control, and erosion control has not been fully investigated.

Introduction

Widespread interest in the forage potential of *Arachis* species in Asia, Africa, and the Pacific is relatively recent, although wild *Arachis* species have been used in plant improvement of *Arachis hypogaea* in India and other countries.

Much of the forage *Arachis* germplasm evaluated so far in Asia, Africa, and the Pacific has been supplied by the Australian Tropical Forages Genetic Resources Centre (ATFGRC). Since 1982, the ATFGRC distributed more than 12,000 seed samples of tropical forage species to these regions, which included only 120 seed samples of forage *Arachis* accessions (ATFGRC database). Of these 120 samples, 56 went to Asia, 55 to Africa, and 9 to the Pacific. Additionally, some vegetative *Arachis* material was dispatched from the ATFGRC and the Queensland Department of Primary Industries (QDPI) in Gympie. Table 1 lists countries known to have received forage *Arachis* germplasm.

A major constraint to including forage *Arachis* germplasm in many species evaluation experiments was the lack of promising seed-producing lines, although interest has surged in the seed-producing *Arachis pintoi* recently. Vegetative lines were included in evaluations where material could be hand-carried, but there have been many reports of establishment failures.

Before 1960, *Arachis* material sent overseas from Australia included accessions then called *A. diogoi*, *A. prostrata*, and *Arachis* sp. (R.J. Williams, personal communication).

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* Forage agronomist, Tropical Forages Program, CIAT, stationed at IRRI, Los Baños, Philippines; coordinator, African Feed Resources Network (AFRNET), International Livestock Centre for Africa (ILCA), stationed in Nairobi, Kenya, respectively.

Table 1. Countries in Asia, Africa, and the Pacific known to have received forage *Arachis* germplasm.

Asia	Africa	Pacific
Bangladesh	Burundi	Fiji
Bhutan	Cameroon	Micronesia
China	Central African Republic	New Caledonia
India	Ethiopia	Papua New Guinea
Indonesia	Ghana	Tonga
Japan	Ivory Coast	Vanuatu
Laos	Kenya	Western Samoa
Malaysia	Mali	
Nepal	Mauritius	
Philippines	Mozambique	
Sri Lanka	Nigeria	
Thailand	Rwanda	
Vietnam	South Africa	
	Sudan	
	Tanzania	
	Togo	
	Zambia	
	Zimbabwe	

SOURCES: ATFGRC database, and B. Cook, D. Loch, and B. Grof, personal communications.

Since then, the range of *Arachis* species dispatched has increased and included species of the section Rhizomatosae (*Arachis* sp. CPI 19898 and 22762; *A. glabrata* CPI 12121, 22763, 29986, and 29987), section Caulorhizae (*A. repens* CPI 28273 and *A. pintoi* CPI 58113—released as cv. Amarillo in Australia), section Arachis (*A. duranensis* CPI 31927; *A. monticola* CQ 990 and CPI 58114; and *A. villosa* CPI 58118), section Triseminalae (*A. pusilla* CPI 58116), and *Arachis* sp. CPI 58109, formerly dispatched as *A. burkartii* (ATFGRC database). In the past few years, a far greater range of vegetative material (mainly section Rhizomatosae) has become available, and some of this has found its way into species evaluations in Asia.

Forage *Arachis* species were seldom recognized as promising material in nursery species evaluations. Recipients of seed samples from the ATFGRC in 1982 and 1983 were sent a questionnaire on the use and performance of accessions in 1984-1985 (B. Pengelly, personal communication). Of 77 respondents from Asia, Africa, and the Pacific, only two included forage *Arachis* accessions among the most promising accessions in their species evaluation experiments. This may reflect a bias towards higher yielding species and the often short-term nature of species evaluations, which cannot take into account long-term persistence. In the few instances when forage *Arachis* species were advanced from nursery evaluations for further testing, they were generally for use in mixtures designed for high grazing pressure (e.g., Nulik, 1987).

Experience in Asia

Indonesia

In the 1970s, some forage *Arachis* species were introduced at Maiwa Ranch (Government Ranching Corporation) on the western side of South Sulawesi (>2000 mm average annual rainfall, short dry season, weathered podzolic soils with low levels of organic carbon, N, P, and S). One *Arachis* accession has persisted since that time under sometimes extremely heavy grazing pressure, and has found its way into other evaluations in Indonesia. It is called *Arachis* sp. ex. Maiwa locally and is likely to be identical to *A. glabrata* CPI 12121.

In the early 1980s, the Forage Research Project (AIDAB [Australian International Development and Assistance Bureau]-funded project managed by the University of New England and the Indonesian Research Institute for Animal Production) evaluated a large range of forage species, including some *Arachis* spp., in single-row nursery evaluations over 2-3 years in Java, South Sulawesi, and Sumba (Ivory et al., 1985).

In South Sulawesi (2700 mm AAR, 4-6 months dry season, well-drained alluvial silty clay, pH 6.0 [1:5 water], low P), the performance of some of the *Arachis* accessions was outstanding, with *Arachis* sp. ex. Maiwa producing the highest average yield of the *Arachis* spp. (Table 2; R. Salam, unpublished data). Yield of this species was among

Table 2. Multilocational nursery evaluation of forage *Arachis* spp. and other herbaceous legumes in Indonesia.

Site and legume	Mean yield[a] (1-10)	Mean disease[b] (0-4)	Mean insects[b] (0-4)
Panawangan, Java (2350 mm AAR, Latosol, pH 5.3)			
Arachis pintoi cv. Amarillo	2.4	0.0	1.4
A. pusilla CPI 58116	1.3	0.4	0.4
Stylosanthes guianensis	8.1	0.3	0.9
Gowa, South Sulawesi (2700 mm AAR, alluvial, pH 6.0, 4-6 months dry season)			
Arachis pintoi cv. Amarillo	5.2	0.1	0.4
A. pusilla CPI 58116	4.3	1.5	0.4
Arachis sp. CPI 58109	0.8	0.4	0.4
A. monticola CQ 990	2.1	1.1	0.2
Arachis sp. ex. Maiwa	8.4	0.2	0.5
Centrosema plumieri	8.7	0.5	1.0
Macroptilium atropurpureum	8.5	2.0	1.5
Desmodium heterophyllum	7.3	1.5	1.0
Kabaru, Sumba (1000 mm AAR, Lithosol, pH 6, 4-6 months dry season)			
Arachis sp. CPI 58109	3.6	1.3	1.6
A. monticola CQ 990	2.9	1.4	1.0
Cassia rotundifolia	6.5	1.5	1.0
Stylosanthes scabra cv. Seca	4.6	1.1	0.7

a. Visual scoring of yield on a scale of 1 to 10, where 1 = lowest and 10 = highest.

b. Visual rating of disease and insect damage on a scale of 0 to 4, where 0 = unaffected, 1 = evidence, 2 = moderate, 3 = severe, and 4 = total.

SOURCES: Nulik (1987); R. Salam and M.E. Siregar, unpublished data from the Forage Research Project.

the highest recorded in this evaluation. Plots of seed-producing *Arachis* accessions were damaged by mice before control measures were introduced at this site.

In Sumba (1000 mm AAR, 4-6 months dry season, Rendzina, pH 6.0), *Arachis* sp. CPI 58109 produced a reasonable yield, although its yield was well below the highest yielding legumes (e.g., *Cassia rotundifolia*) at this site (Nulik, 1987).

At Panawangan, Java (700 m.a.s.l., 2350 mm AAR, low-fertility sandy loam, Latosol, pH 5.3 decreasing with depth, low available P and high Mn), none of the *Arachis* spp. tested grew well, particularly when compared with *Stylosanthes* spp. (M.E. Siregar, unpublished data).

In South Sulawesi and Sumba, *Arachis* species were selected for further testing for pasture mixtures under heavy grazing. Some legumes were grown in monoculture and in grass-legume mixtures in small, frequently cut plots.

In South Sulawesi, *Arachis* sp. ex. Maiwa was grown with *Digitaria milanjiana* CPI 41192 and *Brachiaria decumbens* cv. Basilisk. In the first year of the experiment, the *D. milanjiana*-*Arachis* sp. mixture yielded 15 t/ha of DM with an average legume content of 16%, while the *B. decumbens-Arachis* sp. treatment yielded 20 t/ha of DM with an average legume content of 6% (T. Ibrahim, unpublished data). The reason for the relatively low average legume content was the initially slow establishment and spread of *Arachis*. In both pasture treatments, the proportion of *Arachis* increased with time and reached 30-50% in *D. milanjiana* and 20-30% in *B. decumbens*.

In Sumba, *Arachis* sp. CPI 58109 was grown with either *D. milanjiana* CPI 41192 or *Urochloa mosambicensis* cv. Nixon for a 2-year period from 1985 to 1987 (J. Nulik, 1987). *Arachis* sp. CPI 58109 established well and quickly formed a good mixture with both grasses (legume content approximately 30%). But after the first flush of seed production, wild pigs developed a taste for *Arachis* seeds and virtually destroyed the plots. The plots recovered during the following wet season and again formed good grass-legume mixtures with more than 30% *Arachis*. J. Nulik introduced the nonseeding *Arachis* sp. ex. Maiwa before leaving Sumba, and observed that it established and spread well (J. Nulik, personal communication).

In Ciawi, Java (3700 mm AAR, no distinct dry season, red-brown clay loam, Latosol of pH 5.0 decreasing to pH 4.4 at depth, with low available K and Mg, and high levels of Mn), S. Yuhaeni evaluated 18 *Arachis* accessions from Florida, two accessions from Australia, and the *Arachis* sp. ex. Maiwa accession in three replicated small plots over 4 years (Yuhaeni, 1989). Cuttings were established in polybags and, 6 months later, plants were transplanted into 3 x 1 m plots at a spacing of 0.5 m. Plots were allowed to grow uncut for 1.5 years and treatments were then cut every 5 months for the following 2.5 years. The highest yielding accession was *Arachis* hybrid IRFL 3014, with an annual production of 6.1 t/ha, while most other accessions produced 2-3 t/ha/year (Table 3). Most accessions flowered, but only a few of these produced seeds; seed yield was always low. In almost all instances, yield increased with time, demonstrating the relatively slow establishment of forage *Arachis*. Persistence of all accessions, except *A. villosa*, was good and there were no major pest and disease problems,

Table 3. Productivity of several forage *Arachis* accessions at Ciawi, Indonesia.

Accession	Mean DM yield (t/ha/year)	Flowering	Seed production
Arachis glabrata cv. Florigraze	4.2	yes	low
Arachis hybrid IRFL 3014	6.1	no	no
Arachis hybrid IRFL 3015	0.9	no	no
Arachis hybrid IRFL 3099	1.3	yes	no
Arachis glabrata CPI 12121	3.0	yes	no
Arachis sp. CPI 27261	1.9	yes	low
Arachis sp. ex. Maiwa	3.0	yes	no
Arachis sp. IRFL 2273	2.6	yes	low
Arachis sp. IRFL 2275	2.8	yes	no
Arachis sp. IRFL 3041	2.4	yes	no
Arachis sp. IRFL 3042	2.4	yes	no
Arachis sp. IRFL 3043	2.5	yes	low
Arachis sp. IRFL 3046	1.9	yes	no
Arachis sp. IRFL 3053	3.4	yes	low
Arachis sp. IRFL 3059	3.1	yes	low
Arachis sp. IRFL 3060	2.5	yes	no
Arachis sp. IRFL 3062	3.1	yes	no
Arachis sp. IRFL 3064	3.5	yes	no
Arachis sp. IRFL 3074	2.9	yes	low
Arachis sp. IRFL 3080	2.6	yes	no
Arachis villosa IRFL 3112	0.0	—	—

SOURCE: Yuhaeni (1989).

although the *Arachis* hybrids were more susceptible to leaf-eating caterpillars (possibly *Biloba subsecivella*). S. Yuhaeni is continuing her research with forage *Arachis* and is currently investigating the effects of cutting frequency, compatibility with grasses, soil fertility, shading, and seed production.

The ACIAR-funded collaborative research project "Forages for Plantation Crops" among the University of Queensland (Australia); CSIRO Division of Tropical Crops and Pastures (Australia); Udayana University, Bali (Indonesia); Sam Ratulangi University, Manado (Indonesia); and the Rubber Research Institute of Malaysia has evaluated a large range of forage germplasm for use in tree plantations in Indonesia (coconuts) and Malaysia (rubber) since 1988.

In terms of yield, the performance of forage *Arachis* germplasm, included in the initial 2-year evaluation in small plots cut every 2 months, was not particularly impressive (Table 4).

In Bali (2070 mm AAR, 3-4 months dry season, fertile Latosol, pH 6) and Manado (2700 mm AAR with a relatively even distribution, fertile Latosol, pH 6), dry matter yields under mature coconuts ranged from 2 to 5 t/ha. Importantly, all *Arachis* species persisted well under coconuts in Indonesia, and *A. pintoi* and *A. repens* spread impressively.

A second set of forage species, which included four *Arachis* species of the section Rhizomatosae (*Arachis glabrata* CPI 93483; *Arachis* sp. CPI 93469, 93476, and 93490) and the accession *Arachis* sp. ex. Maiwa, was evaluated under coconuts in Bali (I.K. Rika, personal communication). *Arachis glabrata* CPI 93483 spread quickly, persisted well, and had the highest yield overall and during the dry season.

The effect of cutting frequency (3, 6, or 9 weeks) on the yield of *Arachis pintoi* cv. Amarillo when grown in a mixture with naturally occurring grasses or with *Paspalum wettsteinii* was investigated under coconuts in Manado over an 18-week period

Table 4. Dry matter yield (t/ha/year) of forage *Arachis* accessions under coconuts in Bali and Manado, and in rubber plantations in Malaysia.

Cultivars/accessions	Bali, Indonesia	Manado, Indonesia	Sungei Buloh, Malaysia	
	LT[a] = 59%	LT = 73%	LT = 53%	LT = 19%
Arachis pintoi cv. Amarillo	3.2	4.7	5.3	0.4
A. repens CPI 28273	3.5	4.4	1.7	0.4
A. glabrata CPI 12121	3.2	—[b]	4.0	1.8
A. glabrata CPI 29986	4.1	2.7	3.4	2.9
Arachis sp. CPI 19898	4.0	2.4	2.4	0.9
Desmodium intortum cv. Greenleaf	10.3	10.3	2.2	0.0
D. heterophyllum cv. Johnstone	3.2	4.6	1.7	0.1
Pueraria phaseoloides	4.2	4.3	3.4	0.4
Teramnus labialis cv. Semilla Clara	5.0	5.9	1.7	0.7
Stylosanthes guianensis CIAT 184	—	—	11.0	1.7

a. LT = light transmission (% PAR).

b. — = not planted.

SOURCES: Rika et al. (1991); Kaligis and Sumolang (1991); Ng Kim Foh (1991); Ng Kim Foh (personal communication).

(Monijung, 1991). *Arachis pintoi* was able to form stable mixtures in all pasture types and cutting frequencies, although the proportion of legume was negatively related to length of cutting interval (Table 5).

In Manado, the nutritive value of *Arachis pintoi* cv. Amarillo was determined in a pen feeding trial. When 6-week-old forage was fed fresh to four goats, the voluntary intake was 420 g/day with a dry matter digestibility of 68%, which compared favorably with other forage species (Kaligis and Mamonto, 1991).

It was concluded from these initial evaluations that forage *Arachis* offers great potential for use under coconuts in Indonesia, and several of these accessions are currently being further evaluated in grazed grass-legume mixtures (*A. pintoi* cv. Amarillo, *A. glabrata* CPI 93483, *A. repens* CPI 28273) and in large-scale grazing trials (*A. pintoi* cv. Amarillo). Initial observations indicate that all three *Arachis* species form good mixtures with a variety of low-growing grasses, such as *Stenotaphrum secundatum* and *Paspalum notatum* under coconuts in Indonesia.

Malaysia

At the RRIM Experimental Station in Sungei Buloh, Serdang (2250 mm AAR with a relatively even distribution, infertile Ultisol of pH 4.5), forage *Arachis* yields ranged from 1.7 to 5.3 t/ha in a 3-year-old rubber plantation with a light transmission of 53% to 0.4 to 2.9 t/ha as light level fell to 19% in species evaluation experiments conducted by the "Forages for Plantation Crops" project (Table 4). The rapid decline in the available light under rubber reduced the yield of all species, and it was observed that all *Arachis* accessions died out within two years of the end of the formal experiment (age of rubber 6-7 years, with a light transmission of 10-15%). Only *Arachis pintoi* cv. Amarillo was included in further trials under rubber in Malaysia, although it appears that this species lacks competitiveness on poor acid soils when grown with grasses such as *Brachiaria humidicola* and *Paspalum notatum*, and other legumes such as *Stylosanthes guianensis*.

This agrees with observations by Wong Choi Chee (personal communication) of the Malaysian Agricultural Research and Development Institute (MARDI), where *Arachis pintoi* CIAT 17434 or CPI 58113 (later released as cv. Amarillo) was introduced in 1985. At Serdang, dry matter yields were approximately 3 t/ha/year. While *A. pintoi* flowered profusely throughout the year, seed set was poor, resulting in low seed production. Efforts to establish this species on Bris soil (coastal marine sand) were not successful, as plants grew poorly and did not persist.

In the northern part of peninsular Malaysia (lat. 6° N, 1830 mm AAR with 3-4 months dry season), MARDI, in conjunction with the Southeast Asian

Table 5. Effect of cutting frequency on yield and botanical composition of *Arachis pintoi* cv. Amarillo in two pasture types under coconuts in Manado, Indonesia.

Cutting frequency	Dry matter yield (t/ha) and legume content (%)		
	Native grasses	Native grasses + *A. pintoi*	*Paspalum wettsteinii* + *A. pintoi*
3 weeks	2.2 (0%)	2.2 (16%)	3.0 (50%)
6 weeks	2.7 (0%)	3.0 (12%)	3.8 (35%)
9 weeks	3.7 (0%)	4.1 (10%)	5.3 (26%)

SOURCE: Monijung (1991).

Forage Seeds Project (CIAT-CSIRO), currently conducts research on flowering and seed production of *A. pintoi* cv. Amarillo. Seed yields of 500 seeds/m^2 (= >500 kg/ha) were recorded in the first year (A. Abdullah, personal communication). Research now concentrates on management and harvesting of seed crops.

Thailand

In northeast Thailand (14-19°N, 1000-1200 mm AAR with a distinct 5-6 months dry season), some *A. glabrata* accessions and *A. pintoi* cv. Amarillo are currently being evaluated at the Department of Livestock Development at Tha Phra near Khon Kaen, and *A. pintoi* cv. Amarillo is being evaluated at the Dairy Farming Promotion Organisation of Thailand at Muaklek (D. Loch, personal communication). These sites probably represent the lower rainfall limit for adaptation of forage *Arachis*. In Thailand, *A. pintoi* has also been used by R. Howeler of the CIAT Cassava Program on contour banks and as a leguminous ground cover for weed control and green manure (B. Grof, personal communication).

Philippines

Recently, B. Grof (personal communication) of the Southeast Asian Forage Seeds Project introduced eight *A. pintoi* accessions (CIAT 17434, 18744, 18745, 18747, 18748, 18750, 18751, and 18752) into the Philippines. At Los Baños, dry matter yields after the first wet season ranged from 2.7 to 3.6 t/ha, with no significant differences among six of the accessions (B. Grof, unpublished data). Accession CIAT 18751 was discarded because of heavy infection by foliar diseases during the wet season. *A. pintoi* cv. Amarillo and *A. pintoi* CIAT 18744 and 18750 have also been included in multilocational species evaluations in the Philippines. After the first year of observations, accessions CIAT 18744 and 18750 were considered highly promising. B. Grof (personal communication) observed that while *A. pintoi* cv. Amarillo was affected by the "yellow leaf syndrome" for several months after establishment, it gradually disappeared in the second season; this phenomenon was not noticed in accession CIAT 18750. He therefore concluded that variability exists among accessions of *A. pintoi* for this character. Seed multiplication of the most promising accessions of *A. pintoi* is currently being undertaken at several sites in the Philippines, and seed yields of 1060 kg/ha were recorded 14 months after establishment at Los Baños.

Experience in Africa

Little experience is available on evaluation or utilization of forage *Arachis* species in sub-Saharan Africa. *A. glabrata* or perennial peanut has been introduced in Mali and Cameroon, and *A. pintoi* was recently introduced in West and Central African countries as one of the CIAT forage species to be evaluated at multilocational sites in humid and subhumid ecological zones of the region. Before that period, *A. pintoi* and other forage *Arachis* accessions were introduced in the International Livestock Centre for Africa (ILCA) genebank, but except for some seed collection, no research has been carried out on this species at ILCA.

Arachis repens has been used as a ground cover in maize production experiments at the International Institute of Tropical Agriculture (IITA) in Nigeria (Akobundu and Okigbo, 1984).

In South Africa, an accession of *A. glabrata* has been used for erosion control and as a ground cover in tree plantations since the early 1980s. A larger range of forage *Arachis* germplasm has been introduced recently.

Cameroon

Arachis glabrata was introduced into Cameroon from Florida (USA) in

1989 and, since 1992, agronomic trials studying the effect of cutting frequency on yield and chemical composition as well as a study comparing the performance of *A. glabrata* with *Medicago sativa* and *Stylosanthes guianensis* were carried out and are still under way at Dschang University by Dr. Njwe and his team (Dr. Njwe, personal communication).

A trial on the effect of cutting frequency (30, 45, 60, 75, and 90 days) on yield of *A. glabrata* indicated that the highest dry matter yield (4.2 t/ha) was obtained at a 60-day cutting interval, after which yield declined.

Parallel to the agronomic studies with *A. glabrata*, a feeding trial investigating rumen degradation of elephant grass (*Pennisetum purpureum*) supplemented with various levels of perennial peanut using West African dwarf sheep has been undertaken by the same team at Dschang University. Elephant grass was supplemented with *A. glabrata* at the levels of 0%, 10%, 20%, and 30% proportion of dry matter offered. Dry matter digestibility increased significantly ($P < 0.05$) from 57% to 69% when the legume fraction in the ration was raised from 0% to 20%. A further increase in legume proportion did not result in a further increase in DM digestibility. *In sacco* dry matter degradability of elephant grass (48 hours incubation) increased from 34% to 42%, 43%, and 46% when the basal diet (elephant grass) was supplemented with 10%, 20%, and 30% *A. glabrata*, respectively.

Mali

Arachis glabrata was introduced into Mali in the early 1980s, probably from Brazil, and was grown in the forage germplasm collection at SOTUBA, Bamako (semi-arid zone). From preliminary observations, scientists concluded that the species appeared to be of high nutritive value, persistent under heavy grazing, and adapted to drought conditions. On the same station, M. Dicko investigated the productivity, persistence under frequent cutting, and palatability of *A. glabrata* when fed fresh or as dry meal to N'dama cattle in 1983 (M. Dicko, personal communication). During the rainy season, DM production of *A. glabrata* increased for the first 8 weeks to reach a yield of 5.7 t/ha. Yield was maintained until week 10 before decreasing with the onset of the dry season. When submitted to a severe cutting regime every 15 days for 12 weeks during the rainy season, cumulative DM production was 6.2 t/ha. The level of production was positively correlated to the amount of rainfall received. Yield was reduced drastically with the onset of the dry season. When looking at palatability of *A. glabrata*, it appeared that DM intake was higher for dried haulms than for fresh material.

West and Central Africa

Arachis pintoi is a recent introduction in Africa, and although it was introduced into the ILCA genebank around 1985, no research was carried out on that species until 1990, when it became one of the species distributed from CIAT to forage agronomists in nine West and Central African countries. The material is being evaluated in a CIRAD-CIAT-ILCA collaborative project in humid and subhumid zones under the RABAOC project within the framework of the African Feed Resources Network. Collaborating countries are Benin, Cameroon, Central African Republic, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, and Togo. In 1992, the same material was distributed to scientists in Burundi and Rwanda for evaluation on acid soils in the East African highlands. Preliminary results showed that establishment of *A. pintoi* was slow during the first 12 weeks after sowing, except at Bouaké, where coverage reached 90% (Table 6). But a good stand of *A. pintoi* was achieved at Avetonou, Kovie, and Bouaké during the second and third year. Yields were fairly high during the rainy season at all sites, except at Pokoase, where yield was low in the first season after a poor establishment. During the dry season, yields were usually poor, indicating that

Table 6. Soil cover and yield of *A. pintoi* after 12 weeks of regrowth during the rainy and dry season at seven sites in West and Central Africa.

Site	Coverage at 12 weeks (%)	DM yield (kg/ha)	
		Rainy season	Dry season
Kurmin Biri, Nigeria (600 m.a.s.l.)	48	1570	130
Shika, Nigeria (600 m.a.s.l.)	45	2940	180
Avetonou, Togo (50 m.a.s.l., 1100-1400 mm AAR)	58	2730	2000
Kovie, Togo (Sea level)	41	2710	1170
Bouaké, Cote d'Ivoire	90	3230	no data
Pokoase, Ghana (150 m.a.s.l., 1400 mm AAR)	<20	580	no data
Bossembele, Central African Rep. (500 m.a.s.l., 1200-1500 mm AAR)	13	1200	250

the legume was severely affected by drought. But *A. pintoi* had good seed production at most sites. The presence of seeds underground resulted in immediate germination at the beginning of the following rainy season, and this resulted in good establishment in the second season.

South Africa

A.J. Kruger of the Roodeplaat Grassland Institute has worked with forage *Arachis* since 1978 (A.J. Kruger, personal communication). He first noticed an accession of *A. glabrata* (possibly PI 118457) in an abandoned species evaluation at the Rietondale Research Station (25° S, 1370 m.a.s.l., frost incidence, 720 mm AAR, infertile sandy soil, pH [KCl] 3.9), where it was performing poorly. But when included in an evaluation at Burgershall (25° S, 720 m.a.s.l., frost-free, 970 mm AAR, fertile clay soil, pH [KCl] 5.2, decreasing with depth to pH 4.6), it grew extremely well and was planted in a demonstration block. It was quickly adopted by farmers for use in erosion control and as a ground cover in crops of granadillas, avocados, bananas, tea, and coffee. Farmers report that using *Arachis* has led to reduced water use (decreased runoff, increased infiltration), lower N fertilizer requirements of the tree crops, and reduced silting of irrigation dams. One problem with *Arachis* is weed control during the first year of establishment.

In formal experiments, the performance of this accession of *A. glabrata* was compared with that of other legumes at Burgershall and Roodeplaat (25° S, 1165 m.a.s.l., 660 mm AAR, frost incidence, infertile saline clay, pH [KCl] 7.4). Growth of *A. glabrata* was excellent at the more fertile Burgershall site, where yields of all species were higher than at Roodeplaat (Table 7). At the latter site, *A. glabrata* performed poorly. When grown with *Bothriochloa pertusa* at Burgershall, *A. glabrata* formed a stable mixture with a higher legume content than any other legume (Table 8).

Experience in the Pacific

Although forage *Arachis* germplasm was introduced in the past to countries in the Pacific, widespread testing of it is relatively recent.

In Fiji, S. Chand of the Ministry of Primary Industries, Forestry and

Table 7. Dry matter yield (t/ha/year) of *Arachis glabrata* and two *Glycine* species at two sites in South Africa.

Species	Burgershall[a]	Roodeplaat[a]
Arachis glabrata	4.9	1.1
Glycine tabacina	4.5	2.7
Glycine tomentella	4.1	2.6

a. See text for site description.

SOURCE: A.J. Kruger (unpublished data).

Table 8. Compatibility of *Arachis glabrata*, *Glycine* spp., and *Teramnus labialis* with *Bothriochloa pertusa* at Burgershall, South Africa.

Species	DM yield (t/ha/year)	Legume content (%)
Arachis glabrata	8.8	51
Glycine canescens	9.7	2
Glycine tabacina	8.1	10
Glycine tomentella	8.2	9
Teramnus labialis	10.6	19

SOURCE: A.J. Kruger (unpublished data).

Co-operatives has been working with *Arachis pintoi* cv. Amarillo since its introduction in 1986 (S. Chand, personal communication). Seeds were planted in small introduction plots at Koronivia (3000 mm AAR) and Sigatoka (1500 mm AAR), and growth was impressive. *A. pintoi* was therefore included with other legumes in a regional evaluation for the dry zone in small plots cut every 6 weeks. Yield of *A. pintoi* was highest at Sigotoka and, although its yield was considerably lower than that of other, more upright species, *A. pintoi* was persistent (Table 9). In a compatibility experiment at Sigatoka, which was cut every 3 months, *A. pintoi* combined well with both tall grasses such as *Setaria sphacelata* and prostrate grasses such as *Brachiaria humidicola* (Table 10). The proportion of *A. pintoi* in these mixtures was 26-38%, which was much higher than mixtures formed by other legumes such as *Cassia rotundifolia* cv. Wynn (2-18%) and *Desmodium heterophyllum* (11-17%). Currently, *A. pintoi* is successfully propagated vegetatively by using cuttings of two nodes with shoots. Future experiments will investigate fertilizer requirements, seed production, and milk and meat production of cattle grazing *A. pintoi*-based pastures.

In Vanuatu, several forage *Arachis* accessions are now being evaluated as part of the Vanuatu Pasture Improvement Project (Australian aid project funded by AIDAB). D. Macfarlane and B.F. Mullen are using *A. pintoi* cv. Amarillo in grass-legume pastures for heavy grazing and *A. pintoi* and *A. repens* as cover crops (B.F. Mullen and D. Macfarlane, personal communication). While *A. pintoi* performed well in heavily grazed *Brachiaria decumbens* pastures, its value as a cover crop is as yet unclear, as it may not have the necessary vigor to suppress weed invasion. In Vanuatu, both *A. pintoi* and *A. repens* CPI 28273 were attacked by a leaf spot fungus (probably *Cercospora*), but damage was minimal. *A. repens* planting material has been distributed to some 50 farmers for use in gardening systems and as a general cover crop. It establishes easily from cuttings and covers the ground quickly, but it is less effective in weed control and appears less drought tolerant than *Desmodium heterophyllum*. Disadvantages with *A. pintoi* are the high cost of seed and the rapid decline in germination percentage in humid environments, similar to tropical grasses. It was also observed that *A. pintoi* often takes at least 12 months to develop an apparently effective rhizobial symbiosis. Different forage *Arachis* accessions have

Table 9. Regional evaluation of legumes for the dry zone in Fiji.

Species	DM yield (t/ha/year)		
	Sigatoka (1500 mm AAR)	Uluisaivou (1500 mm AAR)	Yaqara (500 mm AAR)
Arachis pintoi cv. Amarillo	4.5	0.5	2.2
Macroptilium atropurpureum cv. Siratro	17.1	1.7	3.2
Centrosema pubescens	11.7	0.7	10.3
Stylosanthes scabra cv. Seca	4.9	11.8	13.2
S. guianensis cv. Graham	16.4	13.4	16.3
Neonotonia wightii cv. Tinaroo	16.5	2.5	2.7
Cassia rotundifolia cv. Wynn	3.0	1.4	2.7

SOURCE: S. Chand (unpublished data).

Table 10. Compatibility of *Arachis pintoi* cv. Amarillo with several grasses at Sigatoka, Fiji.

Association	DM yield (t/ha/year)	Legume component (%)
Setaria sphacelata cv. Nandi + *Arachis pintoi* cv. Amarillo	16.0	33
Pennisetum polystachyon + *A. pintoi* cv. Amarillo	16.0	38
Brachiaria decumbens cv. Basilisk + *A. pintoi* cv. Amarillo	19.1	26
B. humidicola + *A. pintoi* cv. Amarillo	16.9	26
Dichanthium caricosum + *A. pintoi* cv. Amarillo	13.3	34

SOURCE: S. Chand (unpublished data).

recently been introduced. B.F. Mullen and D. Macfarlane feel that there is a need to identify forage *Arachis* accessions suited to low-fertility, high-pH coralline soils. This would be relevant to many smallholders with cattle under coconuts in the Pacific region.

Recently, T. Evans took *A. pintoi* and *A. repens* planting material from Vanuatu to Western Samoa (T. Evans, personal communication). Initial growth of *A. repens* was superior to that of *A. pintoi.*

Conclusions

The potential of forage *Arachis* in Asia, Africa, and the Pacific is exciting. Accessions of forage *Arachis* appear to be well adapted to a wide range of climatic and soil conditions in the humid and subhumid tropics, and persist and combine well in mixtures with many grasses, even under heavy grazing. Other advantages are easy vegetative establishment, good spread, shade tolerance, and the choice of seeding or nonseeding accessions.

Limitations to the environmental adaptation of currently available forage *Arachis* germplasm in Asia, Africa, and the Pacific are low rainfall (<1000 mm AAR), low-fertility acid soils (pH <5), and low-fertility, high-pH soils (pH >8) such as coralline soils in the Pacific.

The use of forage *Arachis* is now being promoted for pasture improvement, particularly in livestock-tree cropping systems, and for heavily grazed pastures. Its potential use as a cover crop for N fixation, weed control, and erosion control has not been fully investigated.

Acknowledgments

We are grateful to the many research workers in Asia, Africa, and the Pacific who generously shared their experiences with forage *Arachis* with us and allowed us to include their data and observations in this review. In particular, we thank B. Grof (CIAT, Philippines); A.J. Kruger (Agricultural Research Council, South Africa); S. Chand (Ministry of Primary Industries, Forestry and Co-operatives, Fiji); R.J. Williams, B.D. Thomas, and B.C. Pengelly (ATFGRC-CSIRO, Australia); S. Yuhaeni (Balai Penelitian Ternak, Indonesia); and D. Macfarlane, B.F. Mullen, and T. Evans (Vanuatu Pasture Improvement Project, Vanuatu).

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Chapter 17

Future Prospects for Utilization and Research in Forage *Arachis*

P.C. Kerridge*

Abstract

This final chapter presents a synopsis of the summary statement and remarks made at the conclusion of the "Workshop on the Biology and Agronomy of Forage *Arachis*" and summarizes the points made during the working group sessions. There was unanimous expression that concurrent efforts were needed in technology transfer and in strategic research to more fully unfold the potential of the genus *Arachis* for uses other than as a food crop.

Concluding Statement

There is no question of the potential value of *Arachis* species for forage, hay, and cover crop usage. Potential as a forage has been demonstrated at the farm level in Australia, Colombia, and Costa Rica, as a hay crop in Florida, and as a cover crop in Colombia and Costa Rica. But the reality is that large areas have not been planted yet on a commercial scale. There are approximately 1500 ha planted for forage in Australia, 4000 ha for hay in the USA, and 1000 ha for forage and cover crop usage in Colombia and Costa Rica. This is far from the 800,000 ha of the legume *Stylosanthes* planted in Australia and 50 million ha of *the* grass *Brachiaria* in tropical South America. Yet most scientists and producers who have had experience with *Arachis* are enthusiastic about the legume.

Why is adoption so low? Some researchers feel the main limitation is that farmers are not aware of the product. But this is certainly not the only limitation. In terms of the cost of planting and the time before it makes a significant contribution in a grass-legume association (1-2 years), it is a relatively expensive technology for a farmer to introduce. It is interesting, in hindsight, that we have not had or did not invite any reports on the economics of the use of *Arachis* in a farming operation.

One is most likely to find adoption in areas with a high gross return per unit area, such as for hay production, as covers in plantation crops, and in dairying. There is an urgent need for research aimed at reducing the cost and ensuring the success of establishment.

There should thus be two streams of research efforts:

1. Continuing to exploit the most widely used forage and cover crop cultivar, CIAT 17434, and hay cultivars of *A. glabrata* via management research to lower costs of establishment and investment in technology transfer.
2. Seeking new accessions that will allow wider climatic and edaphic adaptation.

It is also obvious from experience in the USA, Australia, and Southeast Asia that a new evaluation of species other than *A. pintoi* should be made in tropical America.

The stability of *A. pintoi*-grass associations, that is, high persistence with vigorous grasses under heavy grazing over periods longer than 10 years, coupled with the increase in productivity of the association compared with the grass alone, is reason enough to pursue efforts for wider adoption.

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* Soil fertility agronomist/leader, Tropical Forages Program, CIAT, Cali, Colombia.

Future research will only be justified to the extent that *Arachis* is adopted by farmers.

But no matter how successful the present accessions are, we cannot rest satisfied with such a narrow gene base. A broader gene base is not only likely to increase the range of adaptation but will also ensure that there is sufficient variation to overcome limitations that arise as a species becomes more widely adopted. Furthermore, there is a responsibility to sample, collect, and study wild *Arachis* from the point of view of conserving the natural biodiversity.

As Valls points out, this requires and deserves an international effort. By pooling resources, we can more likely capitalize on funding sources that are responsive to an integrated approach. We probably also need to institutionalize some of the work to ensure continuity, though we all recognize that progress made to date has been much more due to committed individuals rather than institutional support per se. This infers that the "*Arachis*" story needs to be publicized in order to obtain widespread support and that resources must be obtained for training new scientists in all areas of research and development.

We in the forage area also need to form closer linkages with researchers working with *A. hypogaea*. First, there is much greater knowledge on and experience with the common peanut. Second, more resources will continue to be devoted to *Arachis* as a food crop than as a forage and cover crop.

Inferring that there will continue to be limited resources devoted to forage *Arachis* again raises the need for continued collaboration. Some bases for collaboration are:

1. To ensure that the other party benefits from its input toward a cooperative endeavor;
2. To take advantage of the present situation in which funding bodies are more responsive to collaborative efforts;
3. To foster confidence through communication of new information and ideas and the ready exchange of germplasm; and
4. To be a partner in a global endeavor or mega-project.

Our conclusion is that we need to build and nurture a network of active researchers on forage *Arachis*, with linkages to those working on *Arachis* as a food crop. A common interest in germplasm of wild *Arachis* should provide a firm basis for linkages between the crop and forage agronomists interested in *Arachis*.

Nevertheless, having spent 4 days hearing people enthuse about the potential of wild *Arachis* as a forage, one caution is that we need to maintain a balanced perspective of the role of *Arachis* along with other tropical forage legumes.

Individual Remarks

MJF. It is well to remember the paradox that in the regional trials, using the RIEPT methodology, *Arachis pintoi* performed very poorly, yet it has proven to be the most persistent and productive of all tropical legumes in heavily grazed grass-legume associations in the humid tropics. We should not be constrained by current methodologies or thinking when tackling some of the outstanding problems.

RJT. It often takes 15-20 years for a new cultivar to be developed and widely adopted. More emphasis on the multiple roles of *Arachis* in erosion control and soil improvement will speed up the rate of adoption.

BGC. It would be useful to compile a representative collection of *Arachis* accessions for widespread evaluation in a number of environments. Development of a network would assist those working individually.

CEL. The proceedings of this conference may be a good reference for researchers, to show that much research has been accomplished and highlight the need for more. But the emphasis should be on moving the material and information that we now have out to farms.

WWS. I agree that sufficient is known. There should be a major effort to get the good material out.

EAP. There is a need to move *Arachis* out to the private sector to speed up seed production and adoption.

JEF. It has been useful to share experiences. Others have confirmed my view of the multiple use potential of *Arachis*.

ECF. Low-growing types might be used as turf. The high costs of vegetative establishment are not a major problem for the turf industry. Funds are likely to be available for research support.

JFMV. There is an urgent need to conserve the full genetic variability that exists. Many areas where *Arachis* occurs are being developed for agriculture. There is also a need to have the taxonomy developed by Krapovickas published and new species described. Publication of a revised catalogue with cross references to different collections would prevent a lot of confusion about names.

BLM. We need to devote more effort to evaluation of species other than *A. pintoi* and *A. glabrata*.

PJA. More germplasm is needed for drier areas. It is also well to remember that *Arachis* will not become a weed in the traditional sense, as there is virtually no natural seed dispersal.

SS. *Arachis* used as a cover crop will decrease the cost of coffee production due to less need for nitrogen fertilizer, cheaper weed control, and soil improvement. It also has a role for use in pastures in the coffee area. Support is needed to get it out to farmers.

SK. There is a need to standardize the methodology if there is going to be widespread co-ordination.

SLL. It is good to hear there are not widespread reports of diseases and insect pests, but we should anticipate problems as *Arachis* becomes more widely used.

JWM. There is a need for studies on reproductive biology.

PCK. There is a need to ensure that when accessions of wild *Arachis* are being introduced into areas where *A. hypogaea* is grown commercially the accessions being introduced have been screened to ensure they do not act as alternative hosts to important diseases of the peanut. Likewise, it is unwise to encourage seed production of forage cultivars in areas where peanut is grown to avoid possible contamination and spread of viruses and diseases of the peanut through the forage seeds.

IMR. There is a need to compare the forage types with the common peanut with respect to seed quality and storage. There is scope for student projects on wild *Arachis* species.

Working Groups—Summary of Points of Discussion

Group 1. Germplasm acquisition, conservation, and genetics

Germplasm acquisition

Present status

- There are approximately 1000 germplasm accessions with forage potential in existing collections (mainly in sections Caulorhizae and Rhizomatosae).
- Significant genetic erosion is occurring, particularly in parts of the Brazilian Cerrados and in Paraguay.

Constraints

- Reliable taxonomic identification is lacking or confused for many germplasm accessions.
- Many species names are invalid, and the limits of species are uncertain.
- There are financial and phytosanitary barriers to free and expeditious germplasm exchange.

Research and development priorities

- There is an urgent need to validate species names. Once the taxonomy of Krapovickas is published, revision and new taxonomic studies will need to be carried out.
- Many currently held accessions need to be correctly identified.
- There is a need for studies on the methodology of germplasm collection to ensure that sufficient genetic variation is sampled.
- Expanded germplasm collection should be carried out in areas where little collecting has been done (e.g., Bolivia, Paraguay, and parts of the Brazilian Cerrados).

Germplasm conservation

Present status

- An updated germplasm catalogue has been prepared but has not been published.
- Most germplasm accessions are duplicated.

Constraints

- Much of the germplasm conservation has been on a personal, rather than institutional, basis.
- There is a need for a revised catalogue of germplasm accessions cross-referenced by accession number.
- Technology for long-term conservation is lacking (there has been a lack of relevant research in seed technology, physiology, and tissue culture).

Research and development priorities

- Effective conservation of genetic diversity in existing collections is uncertain.
- There should be secure conservation of germplasm in at least two institutions.
- There is a need for studies on seed physiology and seed quality with respect to long-term germplasm conservation.
- Publication of a comprehensive germplasm catalogue should be arranged.
- There is a need to assign responsibility for germplasm conservation of the different *Arachis* species to different institutions.

Genetics

Present status

- There is an incipient understanding of environmental conditions affecting the success of artificial hybridization in some species.
- Tissue culture protocols exist for species in sections Erectoides and Extranervosae.
- Meristem culture protocols exist for *A. glabrata*, *A. villosulicarpa*, and other species.
- Initial results from molecular and isozyme markers have been obtained.
- Broad genetic variation exists within and among species with forage potential.
- Genetic transformation for virus resistance has been achieved in *A. paraguaiensis* and *A. villosulicarpa*.
- Successful anther culture has been reported for several species (Mroginski).

Constraints

- Essentially nothing is known of the breeding behavior of species with forage potential.

- There is limited knowledge regarding cytology and compatibility between species with forage potential.
- Genetic variation has not been quantified to a sufficient degree.
- There is a need for genetic characterization of accessions using molecular "fingerprinting."

Research and development priorities

- More thorough study of germplasm in the sections Caulorhizae and Rhizomatosae.
- Increased collection and evaluation of other sections with forage potential:
    - Extranervosae for disease and insect resistance;
    - Erectoides for use in relatively dry environments;
    - Procumbensae for poorly drained environments and shallower seed development;
    - Triseminalae for environments with a long dry season;
    - Perennial Arachis for rapid initial growth;
    - Annual Arachis, Ambinervosae, and Extranervosae for fast establishment and high early yield.
- Rigorous characterization of genetic variability at molecular, physiological, and agronomic levels.
- Development of molecular markers (isozymes, RFLP, RAPD) for use in genotype identification and studies of breeding behavior.
- Studies of breeding behavior to understand the genetic structure of accessions and the design of multiplication and breeding methods.
- Quantification of genetic variation, inheritance of important traits, and identification of sources of traits of agronomic interest.
- Development of tissue culture protocols for all species with demonstrated forage value for use in future genetic manipulation/transformation, germplasm conservation for sterile or non-true breeding species, and safe germplasm exchange.
- Survey of accessible sources of genetic resistance for disease and insect pest resistance, and a survey of diseases in natural populations.

Participants: B.G. Cook, C.R. Lopes, B.L. Maass, J.W. Miles, A. Ortiz, J.F.M. Valls

Group 2. Biotic and abiotic constraints

Present status

- Abiotic adaptation

  There is a reasonable knowledge with respect to current cultivars of

  (1) adaptation to different climatic and edaphic environments,

  (2) competition and persistence under grazing, and

  (3) grazing management

  but a limited knowledge of

  (1) conditions necessary for successful establishment and

  (2) the role *Arachis* can play in soil improvement.

- Biotic adaptation

  There is a reasonable knowledge of viral infection but a limited knowledge of diseases and pests.

Constraints

- Slow establishment.
- Limited range of adaptation to different climatic and edaphic environments.

- Competitive effects on associated tree and field crops when grown as a cover crop.
- Persistence and thus competition with a succeeding crop in pasture-crop rotation systems.
- Lack of knowledge of grazing and nutrient management may limit sustainability and contribution to soil improvement.

Research and development priorities

- Establishment
    - Strategic research to identify the soil-plant factors that result in slow establishment of perennial *Arachis* species compared with that of the cultivated peanut.
    - Characterize existing germplasm collection for variation in rapidity of establishment.
- Adaptation to a wide range of climatic and edaphic environments
    - Evaluate a range of germplasm accessions under diverse climatic and edaphic conditions for productivity, flowering and photoperiod response, seed production, drought tolerance, adaptation to light and shade, and nutrient use efficiency.
- Competition and persistence
    - Evaluate accessions for lower competitive ability for nutrients and water with succeeding crops in crop-pasture rotations and with trees/shrubs when used as a cover.
- Biotic adaptation
    - Detect and monitor viruses to meet quarantine regulations when moving germplasm to different countries and regions.
- Management
    - There is a need to document productivity and persistence of the most promising accessions under the variable grazing management that would be practiced on-farm.
- The contribution of forage *Arachis* to soil improvement should be assessed in field trials in different agroecosystems.

Participants: R. de la Cruz, M.J. Fisher, S. Kelemu, P.C. Kerridge, N. Kitahara, S.L. Lapointe, I.M. Rao, R.J. Thomas

Group 3. Evaluation, seed systems, and delivery to farmers

Evaluation

Present status

- There is a high expectation regarding the potential of existing and new *Arachis* germplasm.
- The potential of *Arachis* species was not recognized in many evaluations due to the methodology used.
- The CIAT Tropical Forages Program has placed a major focus on *A. pintoi* CIAT 17434, with other species receiving little attention.

Constraints

- The rate of germplasm exchange between institutions should be speeded up and not be so dependant upon individuals and personal contacts.
- Limited seed and vegetative material of new germplasm.
- Limited participation by some national institutions in evaluation, e.g., the paradox between the large range of native germplasm but limited evaluation in Brazil.
- Quarantine regulations slow the movement of germplasm.
- A need for germplasm better adapted to drier regions.

Research and development priorities

- Evaluation methodologies need to be defined according to the expected form of utilization, such as:
  - grazed pastures, sown with a grass and grazed
  - cover crops, pure stands under shade
  - agropastoral rotation systems, in crop-pasture systems
  - soil improvement, quantification of N fixation
  - ornamental, in beds.
- Primary evaluation of germplasm should include assessment of the following characters:
  - in dry environments, leaf retention, root development, plant survival, and plant spread
  - in moist environments, for competition with weeds, vigor and rate of ground cover.
- Institutional participation in evaluation should include NGOs and producer organizations.

Seed systems

Present status

- Successful systems have been developed for smallholders in Bolivia and commercial contractors in Australia.

Constraints

- Seed multiplication is a low priority activity within many research institutions.
- The transfer of germplasm from institutions involved in acquisition and conservation to those conducting systematic evaluation is slow.
- Lack of satisfactory seed production technology for *Arachis* species in some situations.
- Lack of holistic focus on seed supply systems within pasture research institutions.

Research and development priorities

- Adequate resources for seed multiplication.
- Need to anticipate demand.
- Contract production should be considered, particularly for basic seed.
- Closer linkages are needed among those involved in germplasm collection, evaluation, and multiplication.
- Basic research in seed science and technology;
  - to ensure technologies for the production of high quality seed;
  - to define optimum conditions of temperature, relative humidity, and moisture content for seed storage and packaging under controlled and on-farm conditions.

Delivery to farmers

Present status

- The most widespread use of *Arachis* is that of *A. glabrata* in Florida, USA. In the case of cv. Florigraze, approximately 3000 ha are established in farmers fields. Market demand and farmer acceptance of *Arachis* for producing quality hay and forage are expanding. A perennial peanut producers association is active in promotion.
- Within Latin America, Australia, and Southeast Asia, farmer awareness and adoption are incipient and have not yet been the focus of any organized promotional effort.

Constraints

- This issue is rarely a focus for research institutions and the working group was quick to acknowledge its own limitations in this area.
- Technology transfer to farmers is a complex process. The process requires the concurrent forces of market demand and institutional participation.
- There is a lack of relevant management practices associated with the new *Arachis* technology.

Research and development priorities

- Proactive promotion of *A. pintoi* as a new forage technology with high potential utility and impact.
- Design and promote the execution of on-farm evaluation projects, with multi-institutional participation, to both evaluate and thrust *A. pintoi* into relevant production systems. This implies preselection of favored ecoregions and production systems, a farming systems perspective, the definition of relevant management technologies, and active farmer participation.
- This activity should be followed by the development of relevant linkages and complementary support activities such as feedback to research, training, commercial promotion, and provision of credit facilities.
- The following ecoregional niches appear appropriate for on-farm activities with *A. pintoi* CIAT 17434: the humid tropics in general, but with primary focus on the coffee zone and Caquetá Department in Colombia; the hillsides and humid tropics of Central America; and Chapare in Bolivia.

Participants: P. Argel, J.E. Ferguson, E.A. Pizarro, C. Lascano, G. Keller-Grein, W.W. Stür, E.C. French, B.G. Cook, S. Suárez, C. Lopes

Appendix 1

Acronyms and Abbreviations

AAR	average annual rainfall
ACIAR	Australian Centre for International Agricultural Research
ADG	average daily gain
AFRNET	African Feed Resources Network
AIDAB	Australian International Development and Assistance Bureau
APREA	American Peanut Research and Education Association, USA
APRES	American Peanut Research and Education Society, USA
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CENARGEN	Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia, Brazil
CENICAFE	Centro Nacional de Investigaciones de Café, Colombia
CIAT	Centro Internacional de Agricultura Tropical, Colombia
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France
CNPA	Centro Nacional de Pesquisa de Algodão, Brazil
CNPGC	Centro Nacional de Pesquisa de Gado de Corte, Brazil
CP	crude protein
CPAC	Centro de Pesquisa Agropecuária dos Cerrados, Brazil
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
DM	dry matter
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
FA	forage allowance
FAO	Food and Agriculture Organization of the United Nations, Italy
IAC	Instituto Agronômico de Campinas, Brazil
IBONE	Instituto de Botánica del Nordeste, Argentina
IBPGR	International Board for Plant Genetic Resources, Italy

ICA	Instituto Colombiano Agropecuario
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics, India
ICTA	Instituto de Ciencias y Tecnología Agropecuaria de Guatemala
IITA	International Institute of Tropical Agriculture, Nigeria
ILCA	International Livestock Centre for Africa, Ethiopia
INRA	Institut National de la Recherche Agronomique des Antilles et de la Guyane, French Antilles
INTA	Instituto Nacional de Tecnología Agropecuaria, Argentina
IVDMD	in vitro dry matter digestibility
IVDOM	in vitro digestible organic matter
IVOMD	in vitro organic matter digestibility
LAI	leaf area index
LAR	leaf area ratio
MARDI	Malaysian Agricultural Research and Development Institute
NCSU	North Carolina State University, USA
NDF	neutral detergent fiber
OAES	Oklahoma Agricultural Experiment Station, USA
PAR	photosynthetically active radiation
QDPI	Queensland Department of Primary Industries, Australia
RGR	relative growth rate
RIEPT	Red Internacional de Evaluación de Pastos Tropicales
RUE	radiation use efficiency
SCS	Soil Conservation Service, USA
TAES	Texas Agricultural Experiment Station, USA
TNC	total nonstructured carbohydrate
UNESP	Universidade Estadual Paulista, Brazil
UNNA	Universidad Nacional del Nordeste, Argentina
USDA	United States Department of Agriculture

Appendix 2

List of Participants

CIAT Staff

J.E. Ferguson
M.J. Fisher
S. Kelemu
G. Keller-Grein
P.C. Kerridge
N. Kitahara
S.L. Lapointe
C.E. Lascano
B.L. Maass
J.W. Miles
F. Morales
A. Ortiz de Acosta
I.M. Rao
R.J. Thomas
F. Torres
CIAT
A.A. 6713
Cali, Colombia
Fax: (57-23) 647243
E-mail: CGI264

P.J. Argel
CIAT/IICA
Apartado Postal 55
2200 Coronado
San José, Costa Rica
E-mail: CGI304

E.A. Pizarro
CIAT/CPAC
Caixa Postal 08.223
63.301 Planaltina, D.F.
Brazil
Fax: (55-61) 3893016

W.W. Stür
CIAT-IRRI
Los Baños, Laguna
c/- P.O. Box 933
1099 Manila, Philippines
Fax: (632) 8178470

Others

M.C. Cardona
CENICAFE
Chinchiná, Caldas, Colombia
Telex: 83454 CENIC CO

B.G. Cook
QDPI
P.O. Box 395
Gympie, Queensland 4570, Australia
Fax: (61-74) 821529

R. de la Cruz
CATIE
Turrialba, Costa Rica
Fax: (506) 561533

E.C. French
Agronomy Department
University of Florida
P.O. Box 110500
Gainesville, FL 32611, USA
Fax: (904) 392-1840

C.R. Lopes
UNESP
Campus de Botucatu
Instituto de Biociencias
Botucatu, SP - Rubião Junior, Brazil
CEP 18610
PBX 22-0555 Brazil
Fax: (55-149) 213744

A. Rincón
ICA
Carimagua Research Station
Carimagua, Meta, Colombia
Fax: (987) 565901

C.E. Simpson
Texas Agricultural Experiment Station
Texas A&M University
P.O. Box 292
Stephenville, TX 76401, USA
Fax: (817) 9653759

S. Suárez
CENICAFE
Chinchiná, Caldas, Colombia
Telex: 83454 CENIC CO

J.F.M. Valls
CENARGEN/EMBRAPA
Caixa Postal 10.2372
70.000 Brasilia, Brazil
Fax: (55-61) 2743212

CIAT Publication No. 240

The Tropical Forages Program
and the Communications Unit

Editorial assistance:	Gladys Rodríguez N.
Production:	Graphic Arts Unit, CIAT Julio César Martínez (cover design)

ISBN 958-9183-96-4