SESSION 3B

BIOLOGY AND CONTROL OF WEEDS IN TROPICAL CROPS

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Papers	3B-1 to 3B-4

The origins of weeds and invasive plants

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ABSTRACT

There are numerous routes by which, otherwise benign, plant species become a nuisance to human activity. *Post hoc* analyses of case studies persistently fail to identify predictable indicators of potential weediness and historical precedent remains the most robust guide. The issue of limiting the damage caused by alien invaders has moved up the international political agenda mostly as result of an increasing awareness, particularly in the USA, of the huge economic costs which are incurred following introduction of harmful species. Also, the need to understand better the behaviour of plants prone to weediness has been highlighted during the current debate on the potential concerns of the escape from cultivation of genetically modified plants. This paper describes some of the pathways by which plants are known to have become problems and initiatives are described for means by which weed distribution and spread can be monitored internationally.

INTRODUCTION

Currently there is an unprecedented interest in understanding better the mechanisms by which plants, normally considered neutral, if not benign, can become a menace to human society. The ability to manipulate and alter the genetic structure of plants in ways that would have been unthinkable even five years ago has raised the question "what will happen if these organisms become weedy?" This paper describes some examples of how, under tropical conditions, plants have become weedy and considers how better knowledge of known plant distributions might provide predictive indicators of weediness.

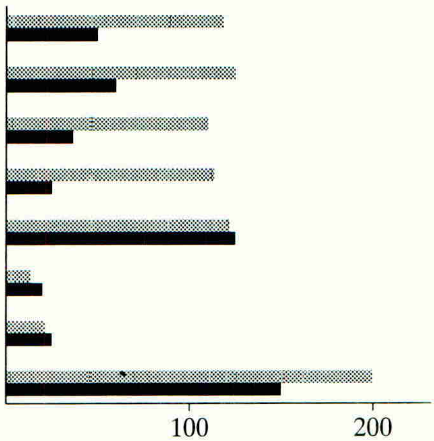
DISCUSSION

There are many examples of an oscillation between the weedy and the cultivated state. The biological characteristics of both groups can be remarkably similar and the status may shift quickly. An example of this is considered later, but it is not the only route by which plant species can become weedy.

There are examples of invasives being "released" from ecological constraint and becoming troublesome. Cronk (Fuller and Cronk, 1994) defines invasiveness as "an alien plant spreading naturally (without the direct assistance of people) in natural or semi-natural habitats, to produce a significant change in terms of composition, structure or ecosystem processes". However, in the Solomon Islands the weedy species of *Merremia* are undoubtedly native but become major invasive pests in forestry plantations when the native forest canopy is radically disturbed by timber removal (Miller, F. 1982, Bacon, P.S. 1982)

Table 1. Growth of imperata shoots 55 and 155 days after application.

Herbicide	Dose (kg a.e./ha)	Vol (l/ha)	*Imperata* shoots/m²
1. AC252925	0.5	20	
2. AC252925	0.75	20	
3. AC252925	1.0	20	
4. AC252925	1.0	350	
5. Glyphosate	1.08	20	
6. Glyphosate	2.16	20	
7. Glyphosate	2.16	350	
5. Untreated Control			

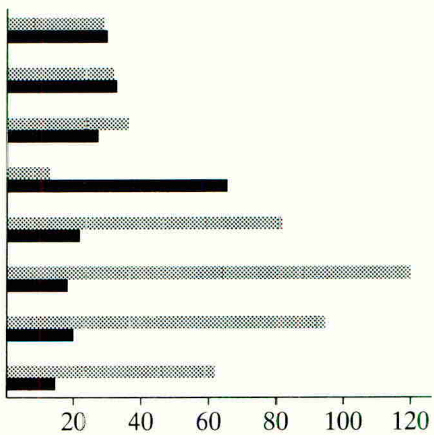


55 days after application $LSD_{0.05}$ C.V. 28.4%

155 days after application $LSD_{0.05}$ C.V. 49%

Table 2. Growth of two weed species 160 days after application.

Herbicide	Dose (kg a.e./ha)	Vol (l/ha)	
1. AC252925	0.5	20	
2. AC252925	0.75	20	
3. AC252925	1.0	20	
4. AC252925	1.0	350	
5. Glyphosate	1.08	20	
6. Glyphosate	2.16	20	
7. Glyphosate	2.16	350	
5. Untreated Control			



Aphaenondra uniflora plants per m² $LSD_{0.5}$ C.V. 36.2%

Cheilanthes tenuifolia plants per m² $LSD_{0.5}$ C.V. 41.8%

and hitherto largely unknown species can develop rapidly to become a serious threat to economic activity. This route to weedy behaviour is probably underestimated and the widespread assumption that plants in their native range are *de facto* benign is specious.

Under temperate conditions shifting weed floras associated with herbicide use are well documented and knowledge of this been widely incorporated into weed control strategies in temperate agriculture. In the tropics there is less information and fewer examples but the following describes one incidence of the emergence of a hitherto unknown species after a herbicide treatment regime.

The UK government funded a project based in Indonesia to examine the phenomenon of *Imperata* grassland and to investigate methods by which such areas might be put to some productive use. During the first phase from 1982 to 1985, attempts were made to evaluate a range of control methods which might be integrated with cropping practices and to this end a number of herbicide combinations and application techniques were tested (Bacon, 1985). Field sites proved to be surprisingly disparate despite the initial appearance of a uniform grassy savannah. The floras associated with the different sites affected the outcome of herbicide tests quite dramatically though the impact on *Imperata* - at the time reasonably well studied and understood - was consistent over sites and treatments. Following herbicide applications, *Imperata* control could be achieved successfully but a number of plants emerged which came to dominate the ground cover and became a limitation to crop establishment in treated stubbles. Some of these plants were largely unknown and their taxonomic status remains unclear. Tables 1 and 2 show how two herbicide regimes affected *Imperata* control and also illustrates how two species emerged following treatment.

The species *Aphaenandra uniflora* (Rubiaceae) proved difficult to identify but eventually it was checked against voucher specimens in the Bogor Herbarium. The Flora of Java (Backer and Backhuizenvandenbrink, 1965) describes it as an introduction to Java otherwise endemic to Sumatra. It was clear from the field experiments that it had considerable potential for weediness once it was released from competition from *Imperata*. Several other species belonging to the Rubiaceae also dominated the ground level flora after glyphoste application but these species did not emerge after application of the imidazolinone herbicide (still at that time in the development stage and coded AC252925). Plots treated with the imidazolinone herbicide were susceptible to domination by a common but rarely significant species of fern (*Cheilanthes tenuifolia*). The picture that emerged in the Imperata savannahs of Indonesia was that early optimism of establishing herbicide-based direct drilling types of systems was unfounded given the dramatic changes in flora following herbicide application.

Most attention has been focussed on non-native introduction particularly in the many examples of introductions to oceanic islands (Fuller and Cronk, 1994) and other ecosystems (Richardson *et al.* 1994). These introductions may be accidental or deliberate. Professionals concerned with the introduction of germplasm from one part of the world to the other have given thought to the risks associated with doing this (Hughes, 1994, Pheloung, 1995, Panetta, 1993). The common perception of the risk is probably overstated in the case of woody introductions (Hughes, 1994). Estimates agree that there is probably only a 1% chance of any given introduced species becoming weedy or invasive (Hughes,

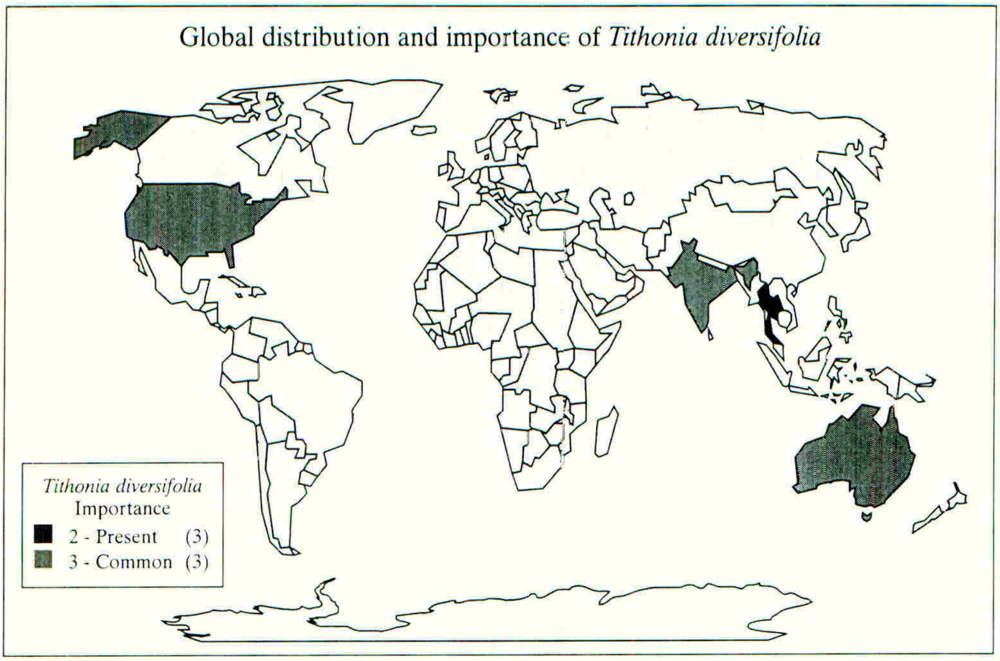


Figure 1. Original data from Holm *et al.* 1979.

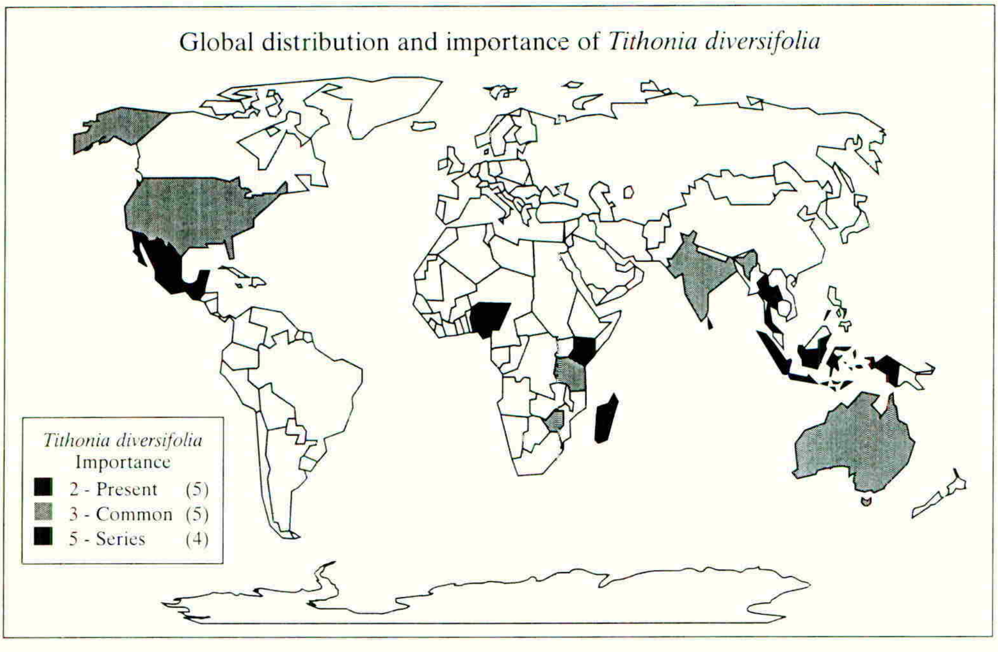


Figure 2. Revised data August 1999.

1994) though a single intentional introduction can have calamitous economic consequences. The dangers of this from commercial seed sources is well understood in the USA (Mack, 1991) and in many other countries. The search for robust indicators of the potential for weediness in any given species remains largely elusive but the following example may provide some clues.

An example of this uneasy relationship between cultivation and weediness is provided by the development and spread of the Mexican Sunflower *Tithonia diversifolia*. Accidentally introduced to Kenya in horse fodder it has become a major nuisance in many parts of Africa. It is widespread in Asia and it is a preferred fodder in Sri Lanka and in Indonesia as well as a green manure (Nagarajah and Nizar, 1982) despite the fact that it is known to have allelopathic qualities (Tongma *et al.*). It has many appealing characteristics for smallholder farmers and is being actively promoted by ICRAF and other organisations (Ganunga *et al.* 1998, Rao *et al.* 1998, Dreschel and Reck, 1997). In Indonesia and Sri Lanka it is sometimes mistaken for a weed when in fact it is being cultivated as a soil erosion control mechanism.

However, it has also become a major nuisance in parts of Nigeria (Ayenu, 1997, Smith and Anisu, 1997) where it was introduced in the early 60's and used as a green manure. The world wide distribution of *Tithonia diversifolia* is illustrated in Figure 3 from data given in Holm (Holm *et al.* 1973). This makes an interesting contrast to what is understood of the distribution today and Figure 4 gives an updated version of the distribution based on contemporary accounts from regional weed floras. This apparent dramatic spread of the weed might be attributed to anomalies in the original data collection but Table 1 shows the extensive coverage in three sample countries where *T. diversifolia* is currently known to be widespread and it is unlikely that *T. diversifolia*, if it had occurred, would have been so comprehensively overlooked.

This internal logic in a data-set, which has been criticised for being inaccurate, gives a useful corroborative triangulation when applied in this way. It also enables the estimation of the rate of spread and the potential for weediness elsewhere. It is noteworthy that *Tithonia* does not appear on the noxious weed lists either for the USDA or CSIRO in Australia. The political borders on the maps highlight the obvious anomaly between the biological boundaries and the political boundaries but this is the type of information required by those concerned with phytosanitary legislation. There is evidence that it is spreading southwards in Africa, probably following road lines. It receives a passing mention in Wild 1968 who records that it was introduced from Central America though the mode of introduction is not given.

Another species *T. rotundifolia* shares a similar range to *T. diversifolia* and also features as a weed in Zimbabwe (Drummond, 1984) but does not seem to be become troublesome elsewhere. It would surely be a high-risk species and attempts introduce it outside it's existing range must be ill-advised though this has been reported in Bulgaria (Cherneva and Vrbanova, 1987).

Attempts to create databases are becoming more unified (Bisby, 1994) and specific databases on weed distribution are now available (Bacon, 1998, Frost *et al.* 1996). The ability to manipulate data, hitherto available only as hard copy, electronically enhances its applicability significantly. The possibility of mapping the distribution and spread of plants will provide indicators of potential weediness and has implications for improving the understanding of climatic change.

CONCLUSIONS

Despite extensive research reliable indicators of weediness remain stubbornly elusive. The Australian department of quarantine have developed a risk assessment model (Pheloung, 1995). Similarly attempts have been made to establish determinants of spread and invadability for Pine in South Africa (Richardson *et al.* 1994). Independently, the two groups have devised a series of "loadings" or characteristics highly associated with invasive behaviour. The Australian model employs these features to inform decisions on possible introduction.

A global approach may well be applied to international decisions on plant movement making a knowledge of distributions essential. Existing knowledge tends to be rather parochial (Frost *et al.* 1996) with comprehensive data available for highly threatened countries such as Australia, New Zealand, America and South Africa with little sharing of data among countries. This approach fails to acknowledge the importance of understanding global occurrence as a determinant for risk. International organisations (such as IUCN and UNEP) have expressed an interest in becoming more involved in this area and they might make a suitable choice as coordinators of data collection, storage and dissemination given their geographical and political neutrality. The examples given of *Merremia* in the Solomon Islands and the experiences in Indonesia indicate that global mapping, while an important tool in monitoring the emergence and development of weedy species, will need to be supported and supplemented by an intimate knowledge of local floras and their taxonomy.

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Chromolaena odorata in the humid forests of West and Central Africa: management or control

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ABSTRACT

Chromolaena odorata, originally from the neotropics, was introduced to Western Africa in the first half of this century. Its rapid vegetative development and its massive production of air-borne seeds have allowed it to spread to large parts of the region. Once established, it develops into a dense thicket. The plant has become an important component of the natural succession in the bush fallow cropping systems of the humid forest and wetter savanna zones of West and Central Africa. It can cover the soil rapidly, return a substantial amount of nutrient-rich litter to the soil, and suppress the growth of noxious weeds like *Imperata cylindrica*. Nevertheless, *C. odorata* remains an important weed in the cropping phase of short fallow food crop systems.

Important research initiatives have been launched in the region to find a biological agent that is hoped will at least suppress the growth of *C. odorata*. However, what are the plant species that are going to replace *C. odorata* in unmanaged short fallow systems? What weed management implications does this shift have for resource poor farmers? Could an integrated *C. odorata* management strategy that targets both the fallow and the cropped stages of these systems be an alternative? Selected results from several studies conducted in southern Cameroon are presented which start to address these questions.

INTRODUCTION

Farmers in the humid forest zone of southern Cameroon practice a system of slash-and-burn agriculture. Traditionally, young and adult secondary forests, i.e. forests that have regrown after previous clearing, are underbrushed and smaller trees are felled. One to two months after this activity, the dead material is burnt, leaving larger trunks and branches lying around. This forest or "essep" field is then planted to a sole crop of plantain or intercropped with egusi melon (*Cucumeropsis manii*) and cocoyam (*Xanthosoma sagittifolium*). Generally no weeding is required during the nearly two-year cropping phase. The field is gradually allowed to go into a fallow phase dominated by forest pioneer species. Two to four years later, after the branches and smaller tree trunks have decomposed, the regrowth is slashed and burnt and a mixed food crop field ("afub owondo") of groundnut, maize, cassava, plantain and a varying number of vegetables are planted. A first light handweeding is often necessary about seven weeks later. Three months after planting, groundnut and maize are harvested. This pass over the field with a handhoe serves at the same time as a second weeding. Most of the cassava and plantain are harvested in the second year. The field is then fallowed for fifteen to twenty years, developing back into a secondary forest and allowing the soil to recover and the arable weeds to be shaded out.

In southern Cameroon, men and women have different tasks related to cropping. Men are responsible for all clearing activities and for planting and harvesting the forest fields cropped to plantain. They are primarily involved in cash crop production. In contrast, women are responsible for producing food for the family. They plant, weed and harvest the mixed food crop fields, also know as women's fields.

A system in change

Traditional cropping systems are sustainable if the fallow length permits the establishment of secondary forest. However, over the past decades, an increase in population densities and better access to markets in certain parts of the forest zone have started leading to land shortages. In other areas, families are short of young men to clear forests due to migration to towns and cities. In both cases, an increased reliance on fallows with durations of often less than five years has followed. This change has not only reduced the capability of the land to sustain yields and the soil resource base (Slaats, 1995), but has also altered the labour load. For men it is less tedious clearing these bush fallows that are dominated frequently by the exotic perennial *Chromolaena odorata* than having to cut down trees in a secondary forest (Dvorak, 1996). Women, in contrast, end up having to deal with more weeds (Akobundu, 1991; de Rouw, 1995; Slaats, 1995). After slashing and burning these fallows, they have to hoe out the rootstocks of *C. odorata*, an activity that can nearly double the planting time according to them. Furthermore, weed pressure at first weeding is often greater and frequently an additional weeding with a cutlass is required four to five months after groundnut and maize have been harvested to stop *C. odorata* from developing into a thicket before the cassava is harvested.

The advent of *Chromolaena odorata*

Chromolaena odorata, originally from the neotropics, was introduced to West Africa in the first half of this century via Asia (Gautier, 1992) Its rapid vegetative development and its massive production of air-borne seeds have allowed it to spread to large parts of the region. Once established, it develops into a dense thicket. These invasive thickets pose big problems during the establishment of tree crops in large-scale plantations and in extensively managed rangelands. *C. odorata* has also become an important component of the natural succession in bush fallow cropping systems of the humid forest and wetter savanna zones of West and Central Africa (Lucas, 1989; de Foresta & Schwartz, 1991; Akobundu & Ekeleme, 1996; Weise, 1996). Studies show that as a fallow species, it provides rapid ground cover, returns a substantial amount of nutrient-rich litter to the soil and improves the soil chemical and physical properties (de Foresta & Schwartz, 1991; Slaats, 1995; Norgrove *et al.*, 1999). Furthermore, it has been found to be able to suppress the growth of the extremely noxious grass *Imperata cylindrica* (Akobundu & Ekeleme, 1996). For example, older farmers in the Yaounde area in southern Cameroon remember when *I. cylindrica* was the main short fallow species. As *C. odorata* moved into the area in the late sixties, they welcomed it as "God sent". Nevertheless, it remains an important weed in the cropping phase of short fallow food crop systems (Akobundu & Ekeleme, 1996).

FARMER PERCEPTION OF WEEDS

Shifts in fallow length lead to shifts in weed communities during the cropping phase. Different weed species end up posing different challenges to the women and children weeding. We carried out a survey in June 1995 in six villages in southern Cameroon to take a closer look at these issues. The villages can be roughly classified into three groups according to the dominant length of fallow period before the planting of a mixed food crop field. In two of the villages (Akok and Ngat) these fields are commonly planted after clearing ten or more years of fallow vegetation, in three villages (Mengomo, Mvoutessi and Etoud) after five to ten years of fallow, and in one village (Nkometou) after less than five years. A total of 77 women were asked as they were handweeding their mixed food crop field which the three most common weeds were and what species were most difficult to manage.

Fallow length and dominant weed species

The villages with longer fallows, particularly Akok but also Ngat, are surrounded by secondary forest. Under these conditions *Trema orientalis*, a forest regrowth species, and *Triumfetta cordifolia* are common weeds at first weeding in mixed food crop fields (Table 1). Their importance declines as fallow lengths decrease, and species like *Ageratum conyzoides*, *Sida corymbosa* and *Sida rhombifolia* take over. *Stachytarpheta cayennensis*, an introduced ornamental species that has spread to fields, appears to be common primarily in areas with medium fallow length. In Nkometou, where fallows are often less than five years, there is another shift in the weed community: *Mucuna pruriens* var. *pruriens* and *Euphorbia heterophylla* become dominant, while *Dioscorea bulbifera* increases in importance. The most common species across all villages is *C. odorata*. Depending on the village, between one third and 100% of all the questioned women ranked it amongst the top three. It was least common at both ends of the spectrum, i.e. in areas of long fallows (Akok) and areas of very short fallows (Nkometou).

Table 1. Most common weed species at first weeding of mixed food crop fields as identified by women farmers in southern Cameroon (percentage of fields where species were amongst the top 3 mentioned).

Village: (number of fields):	Akok (16)	Ngat (10)	Meng (15)	Mvou (12)	Etoud (12)	Nkom (12)	Mean
Chromolaena odorata	38	100	100	58	92	33	69
Ageratum conyzoides	25	40	40	67	67	17	42
Sida spp.	19	40	20	58	42	8	30
Stachytarpheta cayennensis	0	0	80	67	0	0	26
Triumfetta cordifolia	44	40	20	17	0	0	21
Trema orientalis	56	40	0	0	17	0	19
Dioscorea bulbifera	6	0	7	8	33	25	13
Mucuna pruriens var. *pruriens*	0	0	0	0	0	67	10
Euphorbia heterophylla	0	0	0	0	0	58	9

Note: The villages of Akok, Ngat, Mengomo, Mvoutessi, Etoud, and Nkometou represent sites with increasingly shorter fallow periods.

Problem weeds

Based on the answers of the women farmers, we were able to identify six main categories of problems associated with weeds at first weeding, i.e. handweeding in the groundnut stand (Table 2):

- Plant species that grow more rapidly than the crop or wrap themselves around it end up shading out the crop (SHADE). Furthermore, climbing species are difficult to separate from the crop at weeding. Farmers associated *C. odorata* and *E. heterophylla* with aggressive growth, while *D. bulbifera* and *M. pruriens* var. *pruriens* were mentioned as climbers that wrap themselves tightly around the crop.
- Other species produce thick mats of seedlings in large patches or numerous shoots that are resprouting from low-lying stem parts and roots (DENSE). Women find weeding such patches takes more time and is more tedious. *S. cayennensis*, *E. heterophylla*, *A. conyzoides* and, to a lesser extent, *C. odorata* fall into this category.
- Several species were identified as being hard to pull out by hand because they rapidly develop woody stems and have strong tap roots (HARD). These are: *S. corymbosa*, *S. rhombifolia* and *S. cayennensis*. Other species can carry bristly hair that can strongly irritate the skin (e.g. on pods of *M. pruriens* var. *pruriens*).
- Farmers point out that weeding species like *E. heterophylla* and *A. conyzoides* is tedious because if not weeded carefully, they easily break off close to the ground allowing them to produce new shoots (BREAK).
- Farmers have observed that species like *S. corymbosa*, *S. rhombifolia* and *S. cayennensis* dry out the soil and so allegedly reduce crop yields (DRIES).
- Some weed species like *A. conyzoides*, *S. cayennensis*, *S. corymbosa* and *S. rhombifolia* are associated with certain pests and diseases of crops (PEST).

Table 2. Problems associated with common weed species of mixed food crop fields as identified by women farmers in southern Cameroon (number of crosses indicate increasing level of severity).

Problem type:	Shade	Dense	Hard	Break	Dries	Pest
Chromolaena odorata	XXX	X				
Ageratum conyzoides	X	XX		XX	X	X
Sida spp.	X	X	XXX		XXX	X
Stachytarpheta cayennensis	XX	XXX	XX		XX	X
Triumfetta cordifolia						
Trema orientalis		X				
Dioscorea bulbifera	XXX					
Mucuna pruriens var. *pruriens*	XXX		XX			
Euphorbia heterophylla	XXX	XXX		XXX		

Note: Responses by 77 farmers in 6 villages. Severity classes are based on the frequency a species was associated with a specific problem and its occurrence amongst the top 3 most common species. Problem types are explained in the text.

Besides problem weeds, there are species found frequently in different weed communities of mixed food crop fields that do not pose any particular problem to the farmer, e.g. *T. orientalis* and *T. cordifolia* in fields cleared from longer fallows. Not only are they easy to handweed, but generally weed pressure is lower after longer fallows. However, there is a clear shift in dominance of weed species as the fallows become shorter, i.e. a shift from *T. orientalis* and *T. cordifolia* to problem weeds like *A. conyzoides*, *Sida* species, *E. heterophylla*, and *M. pruriens* var. *pruriens* that increase the tedium of weeding dramatically.

TOWARD FALLOWS WITHOUT *CHROMOLAENA ODORATA*

Besides Africa, *C. odorata* has also invaded parts of South and Southeast Asia and a number of Pacific islands (Gautier, 1992; McFadyen & Skarratt, 1996). Researchers in these regions have embarked on developing biological control options using arthropods and pathogens, spurred on by its successful control on the island of Guam in the 1980s by the larvae of a moth (see various papers in Muniappan & Ferrar, 1991 and Prasad *et al.*, 1996). There has been significant debate in Africa over the past decade as to the role *C. odorata* plays in various agroecosystems (Slaats, 1995; Akobundu & Ekeleme, 1996; de Foresta, 1996) and linked with it the appropriateness for the biological control of this plant (Prasad *et al.*, 1996). The Third International Workshop on Biological Control and Management of *Chromolaena odorata* thus recommended that studies be initiated particularly in relation to the fallow-based cropping systems of West Africa (Prasad *et al.*, 1996).

Suppressing *Chromolaena odorata*

A study was initiated in 1995 in 3 villages in southern Cameroon to assess the impact *C. odorata* has on fallow species composition, weed pressure, soil properties and crop yield, and to compare this with planted herbaceous fallows. Four types of fallow were established in 2 fields per village and 3 replicates per field after cassava of the previous cropping period had been harvested. The fallow types were natural fallows dominated by *C. odorata*, natural fallows with *C. odorata* suppressed through periodic manual removal, fallow planted to a perennial legume (*Pueraria phaseoloides*), and to an annual one (*Mucuna pruriens* var. *utilis*). After 3 years of fallow, the fields were slashed and burnt and planted to an intercrop of groundnut, maize, and cassava in April 1998.

The manual removal of *C. odorata* from the fallow led to a marked shift in plant species composition as assessed by degree of ground cover 14 months after the previous crop had been harvested (Table 3). Potentially more problematic species for weeding like *Sida* spp. and *S. cayennensis* increased substantially. Mid-way through this fallow cycle, grass weeds such as *I. Cylindrica* and *Paspalum conjugatum* did not increase their ground cover overall across the 3 villages. However, their cover appeared to increase from 3.3 to 11.7% (P=0.0624) in Nkometou Village, which is in an area where fallows have been shortened to less than 5 years. Species not considered to pose substantial problems during cropping doubled their contribution to ground cover with *T. cordifolia* being the most dominant.

After clearing the fallow vegetation and planting a mixed food crop in April 1998, weed density and composition at first weeding was assessed 6 weeks after planting (Table 4). Independent of the overall weed density in a village, the natural vegetation fallows where *C. odorata* had been removed resulted in twice as high weed densities during subsequent cropping compared to *C. odorata*-dominant ones. The proportion of *C. odorata* in the weed flora was not affected by fallow type. This is to be expected since viable seeds were probably still present in the seed bank after only one fallow cycle and new seed could fly in from the surrounding area. The proportion of 5 species identified by farmers as being problem weeds (*S. cayennensis*, *Sida* spp., *E. heterophylla*, *I. Cylindrica*, and *P. conjugatum*) was twice as high in the *C. odorata*-removed fallow plots. The highest weed density and proportion of problem weeds was found in Mvoutessi Village. This was mainly driven by an elevated presence of *S. cayennensis* and to some extent *Sida* spp.

Table 3. Plant composition of *Chromolaena odorata*-dominant fallows and fallows with periodic removal of *Chromolaena odorata* in southern Cameroon (cover percentage 14 months after fallow establishment).

Fallow type:	*Chromolaena odorata*-dominant fallow	Fallow with removal of *Chromolaena odorata*
Chromolaena odorata	68.1 a	0.0 b
Grassy weeds	2.2	6.1
Broadleaf weeds	6.6 b	44.7 a
Sida spp.	0.6 b	24.7 a
Stachytarpheta cayennensis	4.2 b	19.4 a
Other plants	16.4 b	35.3 a
Triumfetta cordifolia	6.1 b	15.0 a

Note: Only species were considered that contributed at least a 5% cover in any given plot. Different letters within rows indicate significant difference between fallow types at P=0.05.

Table 4. Weed density and composition at first weeding (6 weeks after planting) in mixed food crop fields following 4 types of 3-year-old fallows in 3 villages in southern Cameroon.

	Weed density (no./m^2)	Proportion of *Chromolaena odorata* (%)	Proportion of 5 key problem species (%)
Fallow type means:			
Chromolaena odorata dominant	70.7 b	19.1	23.6 b
Chromolaena odorata removed	144.7 a	14.8	52.2 a
Pueraria phaseoloides	67.8 b	12.1	27.9 b
Mucuna pruriens var. *utilis*	61.5 b	18.3	19.7 b
Village means:			
Mengomo	38.7 b	27.8 a	23.9 b
Mvoutessi	156.3 a	12.8 b	56.1 a
Nkometou	63.5 b	7.6 b	12.5 b

Note: Different letters in columns indicate significant differences between fallow types and between villages at P=0.05. The 5 key problem species considered are *Stachytarpheta cayennensis*, *Sida* spp., *Euphorbia heterophylla*, *Imperata cylindrica* and *Paspalum conjugatum*.

Planted fallows

Planted fallows, often only considered for their potential to improve soil fertility, constitute a significant alternative to the introduction of biological control agents for the suppression of *C. odorata* fallow thickets. In the above trial, *P. phaseoloides*, a perennial herbaceous legume, was able to overgrow *C. odorata* once it established and dominated the vegetation in the second and third fallow years (data not shown). *Mucuna pruriens* var. *utilis*, an annual herbaceous legume, was able to completely smother *C. odorata* in the first year, but then as it died back, a dense stand of *C. odorata* was able to develop. At first weeding during cropping in 1998, weed density and the proportion of problem weeds was distinctly less in these planted fallows than in the fallows where *C. odorata* had been periodically removed (Table 4). In this first fallow cycle, no such differences were found between the planted fallows and fallows dominated by *C. odorata*. However, the planted legume fallows increased maize grain yield by nearly 40% (P=0.0498). The groundnut component of the mixed food crop field was not affected by any of the fallow types. Cassava yields appeared to be greatest after a *C. odorata* fallow and lowest when *C. odorata* was manually removed (P=0.0924).

In another fallow experiment established in mid-1996 in 6 villages in southern Cameroon, a woody legume, *Calliandra calothyrsus*, was planted in various spatial arrangements, but all containing about 3900 trees/ha. The trees were planted with equidistant spacing, to form alleys, in clusters, and as a fence around the border of mixed food crop fields. The different planting patterns were expected to affect labour requirements for different field operations, weed pressure, soil properties, and yield. Fallow species composition was assessed in 18 fields in early 1999 before they were slashed and burned and planted to a mixed food crop (Table 5). The canopy cover exhibited by *C. calothyrsus* gradually decreased from equidistant to alley to cluster and to fence planting. This was inversely related to the amount of ground cover provided by weedy plants. The visible ground in the unmanaged fallow dominated by *C. odorata* is a reflection of the *C. odorata* leaf loss at the peak of the dry season. The ground cover of *C. odorata* under a canopy of trees planted equidistant was reduced by nearly two-thirds compared to this unmanaged fallow. One can expect that after several crop-fallow cycles, weed pressure will be reduced during cropping.

Table 5. Plant composition of *Calliandra calothyrsus* fallows planted in 4 spatial patterns compared to a *Chromolaena odorata* fallow in southern Cameroon (canopy and ground cover percentage 30 months after fallow establishment).

Planting pattern:	Equidistant	Alley	Cluster	Fence	Control
Canopy above weeds:					
Calliandra calothyrsus	61.8 a	55.2 a	39.8 b	23.5 c	0.4 d
Ground cover by weeds:					
Chromolaena odorata	16.9 c	22.4 c	27.8 bc	38.8 ab	46.7 a
Other dicotyledon	12.3 c	12.8 c	18.0 bc	19.9 ab	23.6 a
Other plants	7.2	9.6	11.0	7.3	8.2
Visible ground	63.2 a	54.0 a	42.4 b	33.1 b	20.6 c

Note: Different letters within rows indicate significant difference between fallow types at P=0.05. Two-year-old *C. odorata* fallows were the controls.

CONCLUSION

As a naturally occurring fallow species, *C. odorata* plays an important role in regulating the weed flora in short fallow-food crop systems in the humid zone of West and Central Africa. Its removal or suppression in these systems through biological control agents could lead to the development of more severe weed problems for the small-holder farmer. Planted herbaceous and tree fallows provide a clear alternative: they can suppress *C. odorata* and other weeds through competition as well as take on some of the soil fertility-related functions of *C. odorata* in short fallows. Much of the past effort going into the development of planted fallow systems in West and Central Africa has concentrated on addressing soil fertility constraints. New opportunities need to be identified from a weed management perspective.

Nevertheless, in the short to medium term, unmanaged fallows will continue to play an important role in the food crop systems of the region. This necessitates the development of management options, which reduce the tedium associated with weeding *C. odorata*, but do not remove it from the system. They include:

- crop sequencing so subsequent crops can profit from previous weedings,
- crop planting patterns and intercropping that suppress weed growth,
- selection of more competitive crop cultivars,
- delayed planting to allow the first weed flush to be controlled at planting,
- mulching or burning depending on the plant material available,
- targeted use of herbicides.

A significant amount of work has already been done on the above themes over the past decades. However, most of the experience is on-station based. These options now need to be taken to farmers' fields and tested in partnership with farmers to ensure that the weed management tools fit their specific needs and constraints.

Finally, in the long term, the most viable option may be converting *C. odorata* short fallow lands in the humid zones to perennial multi-purpose, multi-species, small-holder agroforests.

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Integrated management of itchgrass (*Rottboellia cochinchinensis*) in maize in seasonally-dry Central America: Facts and perspectives

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ABSTRACT

Itchgrass (*Rottboellia cochinchinensis*) is a serious and persistent weed problem in many tropical agricultural and conservation areas. In Central America it is one of the most noxious and serious weeds in several upland crops, causing severe yield losses. Experimentally, pre-emergence control with herbicides, weed elimination during the fallow period and zero tillage reduced itchgrass populations in comparison to conventional practices used by growers (no fallow management, soil preparation by disc harrowing and limited use of in-crop herbicides). Additional improvement in itchgrass management is brought about by inter-sowing legume cover crops. Of several legumes evaluated, mucuna (*Mucuna deeringiana*) and *Canavalia ensiformis* controlled the weed better and covered the soil, especially if planted simultaneously with maize. Itchgrass suppression by mucuna usually corresponded with increased grain yields but competition by the cover crop could reduce yields; a good compromise is to delay mucuna planting by two weeks in relation to maize. Integrated tactics to control itchgrass were evaluated in on-farm validation plots. Pendimethalin controlled itchgrass at the onset of validation plots and facilitated the establishment of the cover crop. Itchgrass densities were lower in validation plots than in grower's fields while infestation levels and the soil seed bank decreased over three years with integrated management. In general, corn yields were also higher in validation plots. Integrated itchgrass management also proved economically feasible for smallholders. A promising alternative is biological control with the itchgrass smut, *Sporisorium ophiuri*, which prevents seed set and is host specific.

INTRODUCTION

Itchgrass (*Rottboellia cochinchinensis* [Lour.] W.D. Clayton) is a pantropical grass weed native to the Old World which probably was introduced to the New World at the beginning of the century. Here, in its exotic range, infestations are considered to be the most severe (Ellison & Evans, 1992) probably as a result of several contributting factors including improved climatic compatibility, mans activity's in disseminating the grass, favourable

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agronomic practices, and the absence of co-evolved natural enemies. It it estimated that itchgrass affects more than 3.5 million hectares in Central America and the Caribbean (FAO, 1992). In Central America itchgrass is found infesting both annual and perennial crops and has been reported causing significant yield loss in maize, sugar cane, upland and rain-fed rice rice, beans and sorghum (Herrera, 1989). Itchgrass infestations can result in up to 80% crop loss, or even abandonment of agricultural lands (Holm *et al.*, 1977). In this paper we address key elements for the integrated management of itchgrass with emphasis on the maize production systems of seasonally-dry areas of Central America.

LOCAL SURVEYS OF ITCHGRASS DISTRIBUTION AND IMPORTANCE

According to surveys in 1994, farmers in the Pacific region of Costa Rica, where most of the research referred to here was conducted, cultivated an average 5.6 ha of monocrop maize or maize-beans, with an estimated 34% of total inputs used solely on itchgrass control. All farmers considered itchgrass to be a troublesome weed, citing its rapid growth and yield reducing effects as the most detrimental characteristics. Control was mainly by a combination of manual (slashing) and chemical methods. Two-thirds used paraquat to control itchgrass and those that relied exclusively on herbicides (23% of the sample) sprayed an average of 2.5 times during the cropping season (Calvo *et al.*, 1996). Similar results were obtained in 1995 in the Atlantic zone of Costa Rica (Merayo *et al.*, unpublished results), where more than three-quarters of the farmers considered itchgrass a problem, the most commonly cited reasons being effects on crop growth (46%), "yellowing" (nitrogen deficiency induced by competition) of the crop (36%) and the large amount of seed produced. All farmers used chemicals to control itchgrass; almost half (43%) additionally rely on physical methods. The most widely used herbicide was paraquat; glyphosate was also used as well as the tank mixture of atrazine plus paraquat. Chemical control of itchgrass accounted for 26% of the income obtained from selling the grain.

Itchgrass is also important in other areas of Mesoamerica. Recent surveys (Valverde *et al.*, unpublished) defined the importance and distribution of the weed in Mexico. Important infestations occur in maize in Campeche state where farmers rely on nicosulfuron and slashing for its control. Serious widespread infestation of maize, rice and sugar cane crops were also found in Veracruz (Tres Valles and Tierra Blanca area) and Oaxaca (around Tuxtepec, Jalapa de Diaz and Nopaltepec). Itchgrass, along with *Sorghum halepense*, is a particular problem in maize production that is now dependent on herbicide use for its control, especially pre-emergence applications of an ametryne/2,4-D ester mixture and directed applications of paraquat, supplemented by slashing if required. In the highlands, maize is grown with a sesame relay crop and here growers have adopted the use of paraquat, followed by two manual weedings, to avoid complete lost of maize yield. Prior to the introduction of itchgrass only hand weeding was used. Moving north in Veracruz itchgrass has already reached Martinez de la Torre where it has become a troublesome weed in citrus production. It seems almost certain that itchgrass was introduced as a contaminant of rice seed and subsequently spread on tillage equipment used for sugar cane grown in rotation with rice or when rice is replaced due to increasing weed pressure.

Most farmers cultivate maize plots of less than 5 ha, and the great majority (about 80%) recognised itchgrass as a troublesome weed. Two thirds of the interviewed farmers use herbicides (nicosulfuron, paraquat and glyphosate) to control itchgrass either alone or in combination with slashing; some rely exclusively on manual (slashing) control.

BIOECOLOGICAL ASPECTS RELATED TO MANAGEMENT

Itchgrass is an erect, strongly tufted, annual grass, characterized as a vigorous competitor and for being able to reach a height of up to 4 m (Holm *et al.*, 1977). It is a weed of warm season crops but its habitat varies widely across the world, being reported as a weed of 18 crops in 28 countries (Holm *et al.*, 1977). Itchgrass reproduces by seeds which are disseminated by water, farm machinery, birds, and, over long distances, as a crop seed contaminant. There are indications of such type of dissemination in rice seed movements from Colombia to Brazil in 1961 (Millhollon & Burner, 1993). Itchgrass seed has been found in rice-seed lots received at the International Rice Research Institute in the Philippines (Huelma *et al*, 1996). In Costa Rica, we estimated a maximum seed production between 7400 and 8900 seeds/m^2 with a single itchgrass plant growing in isolation producing between 700 and 820 seeds. Seed dormancy and germination habits vary substantially across the world (Holm *et al.*, 1977). In a seed burial study, Rojas *et al.* (1994) showed that little viable seed remained after 18 months in the soil, underlining the importance of prevention of seed set in the weed's management. Seed on the surface and buried at 5 and 10 cm substantially lost its persistence; at 20-cm deep less than 10% of seeds remained viable. Itchgrass evolves distinct biotypes. Millhollon & Burner (1993) divided biotypes gathered from 34 countries or territories into five broad groups based primarily on the effect of day length on flowering, but also on general morphology and pattern of growth. Biotypes can also be distinguished by isozyme analyses, particularly esterases (Fisher *et al.*, 1987). In Costa Rica, biotypic differentiation also has been documented (Rojas *et al.*, 1992, 1993c) according to plant morphology (height, tillering, pubescence) and vegetative cycle under comparable conditions.

In the Pacific region of Costa Rica, Rojas *et al.* (1993b) determined that the critical period of interference of itchgrass on maize was from planting to between 45 and 60 days at itchgrass densities between 66 and 74 plants/m^2. When itchgrass was allowed to compete unrestricted with the crop it reduced maize yields between 46% and 54%. Similarly, Bridgemohan *et al.* (1992) determined in Trinidad that the critical period of interference was from 0-63 days after emergence at 55 itchgrass plants/m^2 with yield reductions of about 50% in unweeded plots.

Improved control tactics and their integration for sustainable itchgrass management

A long term trial on the effects of integration of control tactics on itchgrass populations in the seasonally arid zone of NW Costa Rica provided useful information for its sustainable management (Rojas *et al.*, 1993a). There are typically three cropping seasons per year: maize, maize or beans, and a fallow dry season. The four-year study addressed itchgrass management in a maize-beans-fallow rotation begining in 1991. Tactics evaluated were fallow management: handweeding, paraquat application (0.5 kg/ha) and no weeding; tillage practices: zero tillage and conventional tillage (one pass of a disk plough to 20 cm depth plus two passes of a disk harrow) and in-crop control: 1.0 kg/ha pendimethalin plus 2.4 kg/ha alachlor (H1), 1.25 kg/ha pendimethalin (H2), 1.5 kg/ha pendimethalin (H3), and no control (H4). Herbicides were applied pre-emergence following planting in both crops. Fallow management practices were initiated during the dry season of September 1991, prior to the maize planting of a maize-bean rotation in May 1992. Subsequently, maize was planted each year at the beginning of the rainy season in May and beans were planted immediately after the maize harvest in September. Adverse weather conditions resulted in the bean crop being lost every year. Average itchgrass population on the trial site in September 1991 (before implementation of the treatments) was 58 plants/m^2.

Itchgrass density was substantially higher in plots without control in the fallow period but use of in-crop herbicides decreased the weed populations to similar levels regardless of fallow management (Table 1). Lower itchgrass populations also were observed in plots with zero tillage compared with conventional tillage. In-crop control by herbicides had the largest effect on itchgrass populations during the crop cycle and this was greater than the effect of either tillage or fallow management. The lowest itchgrass population was observed in plots with the higher rate of pendimethalin (data not shown). Maize yields were always lower in plots with no fallow and in-crop itchgrass control. When the weed was controlled chemically early in the cropping season, yields were moderately higher in plots with fallow management. However, there was no evidence of maize-yield improvement in plots with zero tillage compared to conventional tillage.

Table 1. Effect of integrated control tactics on itchgrass density and maize yield over four sowing cycles. Guanacaste, Costa Rica, 1992-1994[1]. Maize and beans planted in May and September respectively.

Control tactic	Itchgrass density at 45 DAP (plants/m^2)					Maize Yield (kg/ha)		
	5-92	9-92	5-93	9-93	5-94	10-92	10-93	10-94
With in-crop control by herbicides[2]								
Fallow management								
Zero tillage	14.0	4.8	4.0	3.6	1.6	3525	2908	2996
Conventional tillage	16.4	10.0	6.0	4.4	2.0	3688	2917	3983
No Fallow management								
Zero tillage	12.8	5.2	8.0	3.6	2.4	3708	2617	2267
Conventional tillage	18.0	11.6	8.4	10.0	3.6	3618	2158	2906
Without in-crop control nor fallow management								
Zero tillage	75.6	26.0	41.6	55.6	56.0	2396	650	0
Conventional tillage	74.0	44.4	54.0	69.6	64.4	2146	700	758

[1]Adapted from Rojas *et al.* (1993) and unpublished data.
[2]Data are means for the three herbicide treatments H1-H3 (see text for details).

Legume cover crops as the basis of integrated itchgrass management.

Thirteen legume species were originally screened for their adaptation and usefulness for itchgrass suppression in the Guanacaste region in Costa Rica (de la Cruz *et al.*, 1994). The best cover crops were *Mucuna deeringiana*, *Pueraria phaseoloides*, *Canavalia ensiformis*, *Vigna unguiculta* and *Dolichos lablab*. Of these, mucuna (*M. deeringiana*) was the most suppressive of itchgrass and the species of choice for further development as a cover crop.

Three of the legumes (mucuna, *C. ensiformis* and *V. unguiculata*) were further evaluated as cover crops in 1994. Itchgrass density was reduced about 60% in the presence of either mucuna or *C. ensiformis* and by 55% with *V. unguiculata* compared to the unweeded control, 90 days after planting (DAP). Itchgrass substantially reduced maize yields which were almost ten times higher in the presence of the suppressive legumes. Itchgrass suppression and ground cover was better when the cover crops were planted simultaneously with maize or a week later, compared to two weeks after maize planting but there was no interaction between cover crop and planting time. Itchgrass suppression by the legumes corresponded with increased maize grain yields. Of the two most effective legumes, mucuna seemed more suitable for grower's adoption since it is an annual species, easier to manage and with a better growth habit.

Valverde *et al.* (1995) reported reductions of itchgrass biomass at maize harvest between 75 and 95% when mucuna was intercropped with maize at either 50 000 or 80 000 plants/ha. On the other hand, itchgrass density did not affect mucuna biomass nor were differences found between the two mucuna densities. However, both mucuna (planted one week after maize) and itchgrass reduced grain yield up to 40%. These results prompted additional research to better define planting dates and densities for the cover crop in order to minimize negative effects on crop yield.

The interaction between mucuna, maize and itchgrass was further studied in the first cropping season of 1996 and 1997. The locally adapted "*Criollo*" and an improved "*Diamantes*" maize variety were grown in association with mucuna (two varieties differing in the colour of their seeds, variegate and grey seeded, respectively) in presence and absence of the natural itchgrass infestation. Although initial itchgrass densities (15 DAP) were low (3 - 7 plants/m^2) in both years, both mucuna selections supressed itchgrass populations, especially at or after 60 DAP (Table 2). Fresh weight evaluations better described the suppressive effect of the cover crop indicating that itchgrass plants also grew smaller in plots where mucuna was planted than in plots without the legume. By the end of the critical period of competition (45 DAP) mucuna suppressed itchgrass biomass from 60% to 80%. No major differences were observed between the two varieties, except that the variegate-seeded mucuna covered the ground faster than the grey seeded variety and produced more biomass up to 45 DAP in 1996.

Table 2. Effect of maize and mucuna varieties on itchgrass density and fresh weight and grain yields in Guanacaste, Costa Rica, 1996-1997[1].

Treatment		Itchgrass density (plants/m^2) at days after planting (DAP)			Itchgrass fresh weight (kg/m^2)		Maize yield (kg/ha)
		45	60	90	45 DAP	60 DAP	
1996							
Maize variety	Criollo	9.95 a[2]	10.18 a	7.87 a	0.170 a	0.095 a	2194 b
	Diamantes	10.44 a	9.26 a	6.02 a	0.129 a	0.084 a	3560 a
Mucuna variety	Grey seed	10.07 a	8.68 a	5.56 ab	0.069 b	0.038 ab	2796 a
	Variegated seed	9.72 a	6.60 a	3.47 b	0.063 b	0.022 a	2910 a
	Without mucuna	10.76 a	13.90 a	11.81 a	0.316 a	0.209 b	2926 a
1997							
Maize variety	Criollo	17.13 a	4.17 a	7.87 a	0.269 a	0.227 a	1554 a
	Diamantes	21.99 a	12.96 b	21.99 b	0.310 a	0.418 a	903 b
Mucuna variety	Grey seed	16.67 a	7.90 a	4.20 a	0.179 a	0.090 a	1131 a
	Variegated seed	18.06 a	5.90 a	10.74 a	0.207 a	0.193 a	1148 a
	Without mucuna	23.96 a	11.81 a	29.86 b	0.481 a	0.684 a	1394 a

[1] Partial data from experiments conducted by Valverde *et al.* (unpublished).
[2] Means followed by the same letter within main effect (maize or mucuna variety) within year are not significantly different according to Tukey's multiple range test at 5%.

In the first year the improved variety (Diamantes) yielded more than the local (Criollo) variety and mucuna did not decrease maize yield. However, in 1997 mucuna slightly reduced maize yield and the criollo variety was more competitive with itchgrass and yielded about 70% more grain (1554 kg/ha) than Diamantes (903 kg/ha). This could be associated with a shorter cycle of the local variety that decreased the negative impact of severe water stress late in the cropping season. Yields were lower than normal in 1997 because of drought.

Repeated experiments in 1996 and 1997 studied the impact of mucuna density (25 000 or 50 000 plants/ha) and planting time (0, 5, 10 or 15 DAP) on itchgrass and maize (cv Diamantes). Mucuna was more effective in reducing itchgrass density at 50 000 plants/ha than at 25 000 plants/ha throughout the experiment in both years (Table 3). Better soil cover by mucuna was obtained when it was sown simultaneously with maize than when planted later in relation to the crop, probably because of the competition imposed by maize on the cover crop. At 45 DAP mucuna (planted at 50 000 plants/ha simultaneously with the crop) reduced itchgrass density to 23 and 46% of that recorded in the unweeded controls in 1996 and 1997, respectively (data not shown). Concomitantly, itchgrass biomass decreased between 10 and 15% when mucuna density increased from 25 000 to 50 000 plants/ha, although these differences were not statistically significant. The same tendency was observed as the mucuna planting date was closer to that of maize. Lower maize grain yields were obtained in both experiments when maize was grown in association with mucuna at its highest density and, especially, when the cover crop was planted simultaneously with maize (data not shown). Itchgrass itself decreased maize grain yield by about 46% in both years; yields in 1997 were substantially lower than in 1996 because of drought (data not shown).

Table 3. Effect of mucuna density and planting date on itchgrass density and fresh weight and on mucuna ground cover at 45 days after planting maize. Guanacaste, Costa Rica, 1996-97[1].

Main treatment or Factor		Itchgrass density (plants/m^2)		Mucuna ground cover (%)		Itchgrass fresh weight (kg/m^2)	
		1996	1997	1996	1997	1996	1997
Density (plants/ha)	25,000	20.0 a[2]	71.2 a	32.81 a	26.25 a	0.497 a	0.655 a
	50,000	12.2 b	77.6 a	44.37 b	42.00 b	0.450 a	0.576 a
Planting date (DAP)	0	10.0 b	53.8 a	79.37 a	54.37 a	0.402 a	0.477 a
	5	14.5 b	82.3 a	33.75 b	35.62 b	0.495 a	0.693 a
	10	14.5 b	86.8 a	21.25 c	23.57 c	0.450 a	0.737 a
	15	25.5 a	74.6 a	20.00 c	20.62 c	0.545 a	0.558 a
Unweeded control	-	26.0	111.1	-	-	1.076	0.997

[1] Partial data from experiments conducted by Valverde *et al.* (unpublished).
[2] Means followed by the same letter within main effect (density or planting date) and year are not significantly different according to Tukey's multiple range test at 5%.

Efforts were also made to adapt legume cover crops for itchgrass suppression in the maize monoculture and cassava-maize systems in the Atlantic region of Costa Rica, where itchgrass is also a key weed (Merayo *et al.*, 1998). This region is characterized for a long rainy season (average rainfall at experimental site is 4440 mm) and the absence of severe dry periods during the year. None of four legume species (*M. deeringiana*, *C. ensiformis*, *V. unguiculata* and *P. phaseoloides*) gave satisfactory ground cover or provided adequate suppression of the high infestation of itchgrass present at the experimental site. Where maize and cassava were grown in association, these cover crops also failed in suppressing itchgrass probably because of the early emergence of the weed and the poor ground cover obtained. Additionally, cover crops reduced maize yields compared to those obtained in plots with the grower's management (hand mowing at 15 and 30 DAP) and prevented production of the associated cassava crop.

Validation of improved itchgrass management in grower's fields

Integrated tactics to control itchgrass were evaluated for three years in on-farm validation plots (about 1000 m^2 each) beginning in 1995 in small, subsistance growers fields at three locations in Guanacaste, Costa Rica (Valverde *et al.*, 1999). At two of the sites (Arado and Corralillo) maize is grown twice per year; in the third location (Palmira) the cropping system is based on a maize-dry beans-fallow rotation. Validation plots integrated no-tillage, use of the selective herbicide pendimethalin in the first maize crop (to lower the initial density of itchgrass), planting of mucuna between maize rows, and prevention of itchgrass seed set in the fallow period. In grower's plots itchgrass control was based on a combination of slashing and direct applications of paraquat. Pendimethalin effectively controlled itchgrass and allowed the establishment of mucuna during the first maize crop. At all sites, itchgrass densities were lower in validation plots than in grower's fields and infestation levels decreased throughout the years with integrated management (Figure 1). In general, maize and dry beans yields were higher in validation plots at all locations and cropping seasons; however soil fertilization regimes and sometimes maize varieties differed between validation and grower's plots, preventing direct yield comparisons. Soil core samples also revealed substantial reductions in the itchgrass soil seed bank in validation plots (Merayo *et al.*, unpublished results). On average, 1.1 seeds/kg germinated and emerged from soil samples taken from validation plots at 0-10 cm whereas in the grower's plots germinating seeds amounted 5.22, 17.23 and 17.00 per kilogram in 1996, 1997 and 1998, respectively. Germinating seeds at 10-20 cm depth ranged between 0.12 and 0.48 seeds/kg and 0.23 to 2.12 seeds/kg in validation grower's plots, respectively. The sustained depletion of the soil seed bank corroborates the biological suitability of integrated itchgrass management. Partial budget analyses demonstrated that integrated itchgrass management also is economically feasible for smallholders (data not shown). Weed management costs were usually higher in validation plots than using grower's technology; pendimethalin was one of the inputs that increased costs. However, increased yields at most sites and years balanced the higher production costs and improved profitability.

Prospects for classical biological control of itchgrass

A very promising and complementary alternative for itchgrass management is classical biological control. Of several itchgrass pathogens screened as possible biocontrol agents a head smut, *Sporisorium ophiuri* (P.Henn) Vanky (Ustilaginales), has been thoroughly studied (Ellison 1987, 1993, Reeder *et al.*, 1996). The smut is a soil-borne, systemic pathogen, infecting itchgrass seedlings before they emerged from the soil. Experimentally, significant reductions in seed set was achieved when plants were infected. In the endemic range of the weed, natural epiphytotics of the smut are common, often with a high percentage of plants infected within a population. Isolates of the smut were found to be itchgrass-biotype specific but one from Madagascar was found to infect a wide range of biotypes including a number from Latin American, and hence selected for a comprehensive host range screening. The smut was found to be extremely host specific; none of 49 species/varieties of graminaceous test plants other than itchgrass became infected. Screened species included pastures, weedy grasses, gramineous crops (rice, sugar cane, maize, sorghum) and the maize ancestor *Zea (Euchlaena) mexicana* (teosintle).

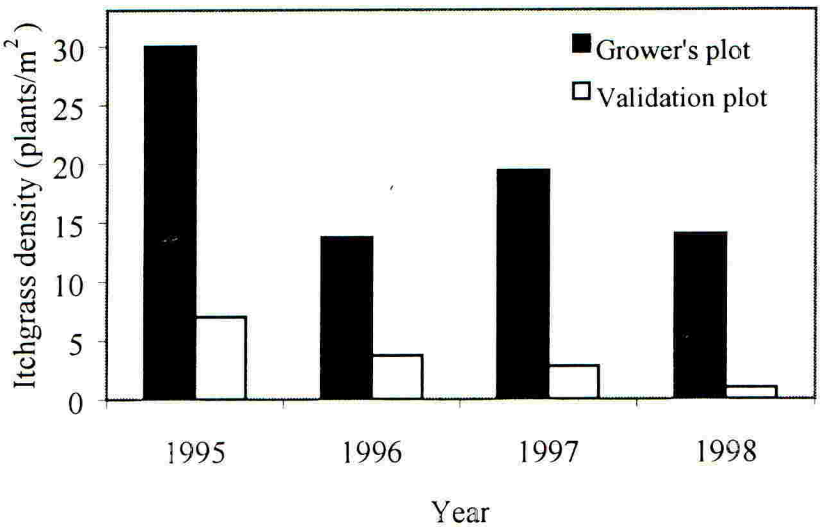

Figure 1. Itchgrass density in validation and grower's plots at 60 DAP (data are averages across three validation sites). Guanacaste, Costa Rica.

The dynamics of the itchgrass-head smut system was explored within a modeling approach (Smith *et al.*, 1997). This work suggested that a very high annual infection rate (above 85%) would be required for the smut to be effective as the sole agent of control. Further refinement of the model and additional simulations suggested that the smut in combination with a cover crop could be highly effective. A low density cover crop plus 50% smut infection rate resulted in 2 plants m^{-2} in each crop. Simulations of a high density crop plus smut predicted a reduction of itchgrass density to 0.1 plant m^{-2} (Smith *et al.*, unpublished).

A leaf rust, *Puccinia rottboelliae* P&H Sydow (Uredinales), also was observed to cause severe damage to itchgrass in the field, particularly to seedlings, and could complement the effect of the smut fungus by reducing the competitive ability of the weed within a cropping system (Reeder *et al.*, unpublished). Unfortunately, none of the rust strains screened proved sufficiently virulent towards any of the South American biotypes that were challenged, therefore, further host range screening was suspended.

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Weed management for sustainable agriculture in the forest margins of lowland Bolivia

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ABSTRACT

This presentation outlines recent work on weed management in forest margins in lowland Bolivia. The research formed part of a multidisciplinary effort to generate and validate annual and perennial cropping systems which are an alternative to current, unsustainable, slash and burn practices. The development of appropriate weed management strategies was of fundamental importance and took into account constraints faced by farmers in terms of limited cash and labour. The use of legume cover crops for the management of weeds and soil fertility was a central theme.

INTRODUCTION

Slash and burn agriculture is common to many countries of the humid tropics. When applied by indigenous forest dwellers this practice can be ecologically sensitive, sophisticated and sustainable (Posey, 1985). In contrast, the slash and burn methods used by colonist farmers in the Amazon Basin are unsustainable and destructive and have resulted in the degradation of soil, forest and biodiversity resources over large areas. Colonist farmers in the forest margins of Bolivia often have abundant land (30-50 ha), very limited labour and capital, and an immediate shortage of cash. This leads to the adoption of unsuitable practices which require low inputs of labour and cash, but are wasteful of natural resources (Richards, 1997).

Recently arrived colonists begin to cultivate upland rice in high forest. When all high forest on their farm is exhausted, they cultivate in the cleared bush regrowth. Under current practices, once cultivation begins in the bush regrowth there is a rapid increase in weed numbers and a shift in species composition from a flora of predominantly shrub and broad leaved species to one dominated by aggressive grasses (Webb & Gonzales, 1989). This results in lower yields and increased production costs, and means that farmers can rarely cultivate annual crops in the bush fallow for more than 1, or at most 2, consecutive years. This short cropping period causes farmers to return prematurely to land under fallow where regrowth has been insufficient to eliminate weeds or fully restore soil fertility. The problem becomes progressively more severe with each cropping cycle until a time is reached when it is no longer worthwhile for the farmer to continue. This is referred to as the "bush fallow crisis" (Maxwell & Pozo, 1981) and, at this point, the farmer is forced to acquire new land or change the farming system.

While weeds are the main constraint to sequential cropping in the short term (Webb & Gonzales, 1989; Uhl *et al.*, 1991), over the longer term soil factors are also important (Barber & Díaz, 1994). A further critical factor limiting sustainability of the current farming system is the lack of locally verified income generating opportunities that justify investment in the land. Colonist farmers are currently highly dependent on upland rice for both food and cash.

The situation faced by farmers is complex and dynamic, and weeds, while constituting a serious constraint, are but one of many factors which need to be taken into account in the development of sustainable systems. This presentation outlines recent work on weed management in forest margin agriculture in Bolivia, though the findings are relevant also to slash and burn farmers elsewhere. The research formed part of a multidisciplinary effort to generate and validate alternative cropping systems. The development of appropriate weed management strategies took into account constraints faced by farmers in terms of limited cash and labour. The use of legume cover crops, both for the management of weeds and soil fertility, was a central theme.

METHODOLOGY

The research was conducted in the Department of Santa Cruz, Bolivia, in a zone which includes the Choré Forest Reserve and the margins of the Amboró National Park, a leading area of biodiversity which is under threat from migrant agriculture. The project was co-ordinated by the Natural Resources Institute (NRI) in collaboration with the Centro de Investigación Agrícola Tropical (CIAT, Bolivia). Several government and non-government organisations actively collaborated in the planning and execution of the research and in the dissemination of results. The central aim of the work was to: (i) evaluate novel crops and cropping systems under local conditions; (ii) monitor their adoption and adaptation by farmers and (iii) adopt and adapt participatory methodologies within the local research environment. The work was conducted over a five year period from February 1994 to March 1999.

The novel crops and systems were selected to address three central technical problems faced by resource poor farmers: weed build-up, declining soil fertility and structure, and the lack of agricultural income generating opportunities. The aim was to develop alternatives which would allow farmers to progress from unsustainable, migratory slash and burn agriculture to sustainable and stable farming systems. A soil use plan of the area (CORDECRUZ, 1994) was taken into account in the selection of appropriate crops and systems. Individual component crops were incorporated into simple "agro-ecosystems" and presented to collaborating farmers for testing. These "agro-ecosystems" were divided into four categories: perennial fruit crops, annual crops, pastures and agroforestry. This presentation will focus on the perennial fruit and annual cropping systems, where weed management was of central importance.

The development of these agro-ecosystems was driven by a set of technical principles including:

- affordable and effective weed management
- maintenance of soil productivity
- crop rotations, relay cropping, intercropping
- cropping sequences leading from annual to perennial systems
- integration of legume cover crops/green manures
- increased cash generation
- diversity and integration of farming activities

The methodology used by the project was one of farmer participatory research (FPR) supplemented by researcher-managed, formal trials. A critique of the project FPR methodology is given by Carreño *et al.* (1999). The FPR component consisted of approximately 200 on-farm plots distributed among 89 communities. The relationship between farmers and researchers in the trials corresponded to the "collaborative" FPR mode described by Biggs (1989). The trials were simple comparisons of farmer practice against one or more of the modified "agro-ecosystems". Each trial consisted of 1-3 sub-plots, and farmers managed and modified the plots according to their own resources, experiences and objectives. This was in accordance with one of the principal objectives which was to study how farmers integrate the new crops and cropping systems into their existing farming systems.

The data collected included quantitative measures (e.g. agronomic factors, soil analyses, economic and socio-economic records) as well as qualitative information based on farmers' opinions and experiences. Qualitative information was collected both through the register of spontaneous, unstructured comments made during farm visits, open-days and participatory workshops as well as through semi-structured interviews. Semi-structured interviews were also used to monitor the adoption and dissemination of research results. The FPR programme was supplemented by formal field trials. These addressed specific problems encountered during the selection or application of the FPR trials and were used when results could be achieved more efficiently and effectively under controlled conditions. The formal trials were conducted on-farm in order to reflect field conditions, but were managed by researchers.

WEED MANAGEMENT IN PERENNIAL SYSTEMS

Several perennial fruit-based systems were suggested for small to medium sized farms, particularly those on undulating land with fragile soils. The objectives were to diversify production and income generating opportunities, and identify associations of perennial, semi-perennial and annual crops which make it economically possible for smallholder farmers to diversify into perennial systems. The annual and semi-perennial crops were intended to offset establishment costs and provide a source of income in the short and medium term. All of the work in perennial systems was conducted in participation with farmers. The nature of the FPR method used meant that little "hard" quantitative data was obtained; there were many possible crop combinations and thus few replications of each. In addition, each farmer modified and managed the systems according to his/her own requirements so that, over time, each on-farm plot tended to become unique. The results and conclusions of the research were based principally on the opinions, experiences and actions of the collaborating farmers.

Identifying appropriate weed management strategies that took into account the shortage of labour and cash faced by farmers was essential to the success of the novel perennial systems. The aim was to suppress weeds in a way which minimised the need for external inputs, and the project proposed that this could be best achieved through the use of legume cover crops which, in addition to controlling weeds, would contribute to the maintenance of soil fertility/structure and protect against erosion. The identification of appropriate legumes became a central component of the research. Results from citrus and banana systems are given here as examples.

Citrus systems

Crops suggested to farmers for association with citrus (as alley crops) included annual food crops in years 1-2 (rice, beans, cowpea, maize), semi-perennial crops from years 1-5 (pineapple, papaya, cassava, banana) and other perennials (mango, tamarind, coconut, macadamia). In addition, several annual and perennial legume cover crops were recommended including *Arachis pintoi, Desmodium ovalifolium, Calopogonium mucunoides, Pueraria phaseoloides, Cajanus cajan, Mucuna pruriens* and *Canavalia ensiformis*. Over 40 on-farm citrus trials were established by collaborating farmers and these included a range of crop-cover combinations.

All of the legumes tested were compatible with citrus. In years 1-5 (with mixed annual/semi-perennial intercrops), *M. pruriens* and *C. ensiformis* were the most successful. Both provided excellent weed control and a much reduced labour requirement in comparison to citrus alone. Both had good acceptance among farmers due to their ease of establishment (with one or no weedings required after sowing), adaptation to a wide range of local conditions, and the extra income obtained from the sale of seed. Farmer preferences between the two varied. *M. pruriens* required less labour for sowing, but more labour for management in established stands.

In established citrus plantations (after year 5), *P. phaseoloides* was the most popular and successful of the perennial legumes. Labour requirements for weeding were much reduced in comparison to citrus alone. It also serves as a source of animal fodder. Results with the perennial *Arachis pintoi* (native to southern Bolivia) were variable. It proved popular in some locations due to low maintenance requirements once a good cover was achieved. However, labour requirements during establishment were high with as many as 5 hand weedings required. Performance was poor on low fertility or sandy soils and in field where there was an established population of aggressive weeds. In these circumstances it was rejected by farmers due to poor levels of weed control, failure to establish a complete cover and high labour requirements.

Banana

Bananas are commonly grown locally in small plantations (<1 ha) for subsistence and cash. Traditionally weed control is poor as the crop is of insufficient value to justify investment in labour or herbicides. In order to address this problem, *M. pruriens* and *C. mucunoides* were tested by farmers in small, established plantations to determine if the covers associate well with bananas and are effective in controlling weeds. Both legumes proved to be compatible with bananas. *M. pruriens* grew well in most conditions, while *C. mucunoides* was susceptible to flooding. The speed of development of both species was similar, giving effective weed control and considerably reducing labour requirements for weeding in comparison to the no-cover (hand weeded) control. Replanting the legumes each year was necessary to produce sufficient cover for weed suppression; natural regeneration from fallen seed was insufficient. *M. pruriens* provided more effective control of difficult perennial weeds such as *Imperata contracta*. Once established, *M. pruriens* was more vigorous and had a higher labour requirement; cutting with a machete was needed once per month to prevent it from climbing the bananas.

Conclusions

The results of the trials demonstrated that the cultivation of citrus in association with alley crops is agronomically and economically viable. Of the system tested, "citrus + pineapple + *M. pruriens* + maize" was the most promising and popular for the establishment phase, and citrus + *P. phaseoloides* for mature plantations. An economic model prepared by Cruz & Espinoza (1999) predicted a substantial net profit from the system over 10 years. Adoption of citrus systems by collaborating farmers was high. In a survey of 35 farmers 4 years after the work was initiated, 54% had expanded the area grown to citrus independently of the project. These farmers were tending to adopt mixed systems rather than monocrops, and were modifying the components and sequences in comparison to those originally introduced. Cover crops were shown to be effective in reducing weed build-up and weeding labour, and several farmers were incorporating cover crops into their own citrus systems.

In banana the use of *M. pruriens* and *C. mucunoides* for weed control was shown to be effective and again the technology was readily accepted by collaborating farmers.

WEED MANAGEMENT IN ANNUAL SYSTEMS

For poor farming families in the forest margins, upland rice plays a critically important role both as a subsistence and cash crop. While farmers diversify into alternative, more stable enterprises (such as perennial crops, livestock), in the short-term rice continues to provide their main source of food and capital. In recognition of this, the project included rice as a component of the perennial systems and additional research was conducted specifically to develop improved and more sustainable methods of rice production for the non-mechanised, smallholder farmer.

As noted earlier, the current method of rice cultivation under slash and burn is not sustainable. A rapid increase in problematic weed populations causes farmers to return prematurely to land under bush fallow. This problem was addressed through FPR trials supported by a series of formal field trials. The objective was to identify technologies which allow rice to be grown on a single plot for 3 years or more. Technologies were selected to reduce weed build-up, maintain soil fertility, and be viable for smallholder farmers in terms of labour and cost. The studies included rice-legume intercropping and rotation, and reduced-dose herbicide applications.

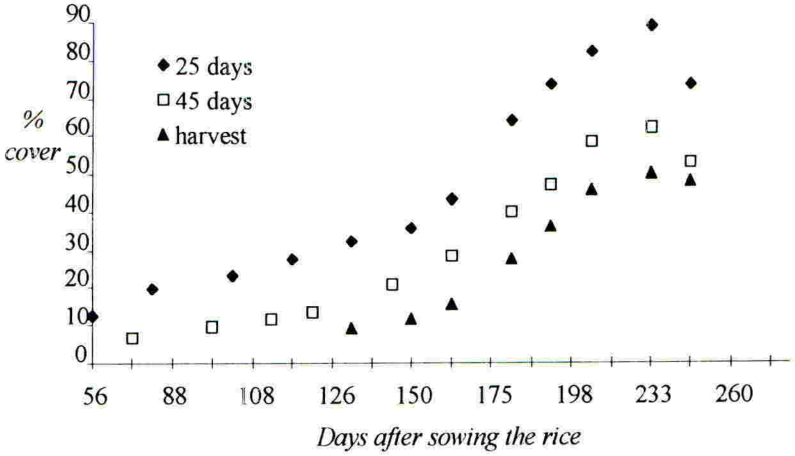
Intercropping upland rice with *Calopogonium mucunoides*

A rice-*C. mucunoides* intercrop was tested with the aim of reducing weeding labour, reducing weed build-up during the winter, and maintaining soil fertility. Plots where rice was sown simultaneously with *C. mucunoides* were compared to farmer practice in 20 on-farm FPR trials. Results were mixed; while farmers reported improved weed control, they experienced problems with lodging and an impeded harvest as the *C. mucunoides* tended to climb and cover the rice. Farmers who conducted the trials suggested further research to study alternative methods of establishment using different sowing dates and densities and short-cycle rice varieties. Based on these ideas, a field trial was initiated to identify the optimum sowing method and to compare weeds and soil fertility under a rice-*C. mucunoides* intercrop with the traditional system.

The trial was established at 2 locations and included short (90 day) and long (120 day) rice varieties. Treatments compared a control (2 hand weedings, no cover) with two sowing densities of the *C. mucunoides* (4 and 8 kg/ha) and three sowing dates: at first weeding (25 days after sowing the rice - DAS), at second weeding (45 DAS) and post-harvest. The trials were organised in a randomised block design with 4 replicates and data were analysed using factorial analysis of variance. Crop management was according to usual farmer practice. Open days were held at the trials to exchange information and opinions with collaborating farmers.

Cover provided by the *C. mucunoides* varied considerably according to sowing date (Figure 1). With a sowing at 25 DAS, good cover was provided throughout the winter, with a live cover until July and residue which maintained cover above 30-40% until the next season. Differences in cover between sowing densities were small (2.3 - 3.3%) and of no practical significance.

Figure 1: Growth of *C. mucunoides* in site 1, year 1, by sowing date



Results confirmed that when sown in association with rice, *C. mucunoides* reduces weed numbers during the winter period in comparison to the traditional system (Table 1). The higher and more persistent levels of cover provided with a sowing at 25 DAS meant that weed numbers were lowest in this treatment, while sowing post-harvest gave results similar to the control. By year 3, numbers of grass weeds were significantly lower in treatments with *C. mucunoides* than without, and lowest in the 25 DAS treatment. However, though the cover reduced grass weed build-up in comparison to the traditional system, there was nevertheless a considerable increase in weed numbers over the three years.

Table 1: Number of grass and broad leaved weeds (per m^2) in year 3 at the end of winter and at 25 days after sowing the rice (varieties and densities combined); Site 1.

	End of winter		25 DAS	
Sowing date of *C. mucunoides*	Grasses	Broad leaves	Grasses	Broad leaves
25 days	19.37	44.81	30.75	69.12
45 days	32.75	49.43	34.87	66.06
Post-harvest	35.12	80.00	44.81	57.81
No cover (control)	55.50	65.12	56.25	64.25
S.E.M of treatment	4.64	4.89	3.86	5.14
S.E.M. of control	6.57	6.91	5.47	7.28

By year 3, lower weed numbers in the 25 DAS treatment were reflected in a lower requirement for weeding labour (Table 2). Despite the time required to sow the legume, total labour requirements were also consistently lower than in the control. Unlike results with simultaneous sowing, a later sowing of *C. mucunoides* did not impede or increase time required to harvest.

Table 2: Labour for weeding and total labour requirements (days/ha) in year 3

Sowing date of	Weeding labour		Total labour	
C. mucunoides	Site 1	Site 2	Site 1	Site 2
25 DAS	32.88	27.89	57.11	42.34
45 DAS	53.33	29.66	62.42	43.88
Post-Harvest	62.90	41.06	76.19	59.74
No cover (control)	52.76	35.78	66.36	46.67

There was no evidence that *C. mucunoides* reduced rice yield on any occasion, indicating that the legume did not compete strongly with the rice at the sowing dates and densities tested. In Site 2, where growing conditions were less favourable and weed populations (e.g. *Scleria* spp.) high, rice yields were significantly higher in years 2 and 3 in treatments with *C. mucunoides* ($p=0.005$; $p=0.011$). Given that there were no measurable changes in soil characters during the study period, this effect is most likely due to the impact of the cover on weeds. However, over the three years of the trial there was still a marked decline in mean yield in both Site 1 (from 4274 to 1438 kg/ha) and 2 (2205 to 663 kg/ha). This decline was similar to that occurring under the traditional system and only slightly affected by presence of the *C. mucunoides.*

While there were benefits from the *C. mucunoides* in terms of reduced weed build-up and labour requirements, the results did not meet the principal objective of the trial which was to identify a method which permits continuous cultivation for 3 years or more on a single plot. The presence of the cover alone was not sufficient, and the system needs to be accompanied by improved weed management within the rice to have greater impact on weeds and yield. Nevertheless, collaborating farmers considered the system to have potential. They suggested taking advantage of the benefits provided by the cover by following 1 or 2 years of rice with a less demanding crop such as cassava or maize. They also suggested rotating 1-2 years of the intercrop with 1-2 years of *C. mucunoides* alone as an improved fallow. Both suggestions warrant further study.

Rotation of upland rice with winter legumes

Winter cropping in rotation with rice is currently rare in the area due in large part to the lack of agronomically or economically viable crops. A winter crop could offer advantages in terms of reducing weed build-up and labour requirements for land preparation, as well as providing alternative sources of income or fodder. A field trial was conducted over 2 years to study the performance in this location of a range of legume species sown in winter in rotation with upland rice. These were compared with the traditional practice (winter fallow). The trial was arranged in a randomised block design with 4 replicates. Management of the rice was according to usual farmer practice. Edible grains were harvested, while all other species were cut at flowering to maximise biomass return. Rice was direct sown into the residues without tillage.

The species included in the trial were *Canavalia ensiformis, Mucuna pruriens var. utilis, M. deeringiana,* 4 local cultivars of cowpea *(Vigna unguiculata*), 2 local cultivars of beans *(Phaseolus* spp.), *Cajanus cajan, Crotalaria juncea* and tropical alfalfa. *M. pruriens, C. ensiformis* and *C. cajan* provided cover for most or all of the winter period; they also provided greatest cover and accumulated most biomass. Alfalfa, beans and cowpea gave only 3-4 months of cover and provided least biomass. Over time, clear differences became evident between the legumes in their ability to reduce weed build-up; total weed numbers after 2 years were significantly lower following legumes which provided the greatest cover/biomass (*C. ensiformis, M. pruriens, C. cajan*). Table 3 shows weed density in year 2 before first weeding in the rice. The results demonstrate that the suppression of weeds in the winter (with a corresponding reduction in the production of weed seeds) reduced weed numbers (particularly grasses, the principal target) in the following summer crop. Results confirmed that the presence of short-cycle winter crops (beans, cowpea) favour weed proliferation in comparison to the traditional fallow by allowing greater flowering and seeding of annual species.

Table 3: Weed density (m^2) in year 2 before first weeding in the rice

Legume Species	Grasses	Broad leaves	Cyperaceae
C. ensiformis	21.50	29.50	44.00
M. pruriens	7.75	28.00	11.75
M. deeringiana	54.25	40.75	28.50
C. cajan	32.00	55.75	26.75
Tropical alfalfa	142.25	35.75	19.50
Bean cultivar I	131.75	38.00	50.75
Bean cultivar II	106.50	49.25	31.75
Cowpea I	99.50	56.75	36.00
Cowpea II	73.50	52.25	15.50
Cowpea III	54.50	40.25	27.00
Cowpea IV	44.25	64.75	41.25
C. juncea	70.00	22.25	24.75
Winter fallow	18.75	27.00	30.50
S.E.	16.10	9.29	12.36

In conclusion, long cycle, high biomass species showed most promise as winter covers in rotation with rice. The covers had a considerable effect on weeds, though had no significant effect on rice yield within the study period. At least 1 collaborating farmer is known to be successfully rotating rice with *M. pruriens* (in a citrus plantation) and is achieving acceptable yields after 3 years. Short-cycle winter crops increase weed build-up, but following these with another, short-cycle crop such as maize may be a viable alternative and worthy of investigation.

Reduced dose herbicides in upland rice

Farmers normally conduct two weedings in slash and burn rice using a mixture of methods. Herbicides are used mainly as a means of reducing labour requirements and are followed by supplementary hand hoeing. Herbicides are usually restricted to broadleaf control (2,4-D or 2,4-D + picloram) and, to reduce cost, are often applied only to the most densely infested patches. Regulation of dose rate is poor, sometimes causing crop damage. The use of propanil is limited. Weeding is generally at approximately 25 and 45-55 days after sowing the rice (DAS), though is often delayed by wet conditions; a later weeding is rare. While the strategy currently used may be appropriate in terms of yield and cost in the short term (1-2 years), over the longer term (>2 years) the build-up of problematic weeds means that it is not sustainable.

A field trial was conducted over 2 years in 2 locations to develop improved weed control recommendations using methods familiar and available to colonist farmers and at a cost comparable to traditional practices. The treatments included a second weeding which was later (70 DAS) that the traditional practice in an attempt to prevent flowering and seeding of grass weeds; to reduce labour and costs, this was by machete/hand pulling rather than hoeing. Herbicide treatments were also a modification of the traditional practice. Propanil and/or 2,4-D were applied as a blanket treatment at 4 and 0.5 l/ha respectively; this is half the recommended dose rate and allowed them to be applied early (15 DAS) without risk of crop damage. Given that farmers generally apply in patches rather than a blanket spray, the total quantity of herbicide used was similar. Herbicide applications were supplemented by hand hoeing (as under traditional practice) at the usual time (25 DAS). The herbicide treatments were compared with the control: hand hoeing at 25 DAS and 70 DAS.

The reduced dose herbicides in combination with hoeing were effective. Yield was significantly higher in treatments receiving applications of reduced dose 2,4-D in both years (Table 4). This is consistent with the fact that broad leaved weeds predominate in recently cleared bush fallow, and indicates that they were better controlled by the early reduced-dose 2,4-D application than by hand weeding at the usual time (25 DAS). In year 2, propanil also showed a yield response; by this time, competition from grass weeds was also important, and the reduced dose propanil application gave better control of grasses than hoeing alone at 25 DAS.

Table 4: Rice yield (t/ha) in site 1 in years 1 and 2.

Treatment	Year 1	Year 2
Hoeing at 25 & 70 DAS	4045	2234
Hoeing at 25 DAS, slashing at 70 DAS	4073	2219
2,4-D (15 DAS), hoe (25 DAS), slashing (70 DAS)	4423	2571
Propanil (15 DAS), hoe (25 DAS), slashing (70 DAS)	4107	2468
Propanil+2,4-D (15 DAS), hoe (25 DAS), slashing (70 DAS)	4547	2681
S.E.D. between means	88.0	117.3

Data on inputs and yield were used to conduct an economic analysis of results from year 1 (Sandóval, 1999). This showed the marginal rate of return to be highest in treatments receiving reduced dose applications of 2,4-D due to lower labour requirements and increased yield. The results clearly demonstrated a benefit from early (15 DAS) weed control which was permitted with reduced dose herbicide applications (but is not possible using full applications or manual weeding alone) and at a cost comparable to or less than traditional practices. However, despite benefits in terms of weed control within years, the treatments tested did not prevent a build-up of weeds between years. A late weeding in the rice was not sufficient to prevent the flowering and seeding of weeds, particularly grasses, during the latter stages of the crop and the period immediately post-harvest. The increase in weed numbers was associated with a decline in yield.

Conclusions

While all the systems tested provided clear benefits, neither the use of a legume intercrop, winter covers or improved herbicide treatments were sufficient in isolation to maintain yield at levels recorded during the first year following bush fallow clearance. The results suggest that an integrated approach is needed which combines improved weed control in the rice crop with appropriate rotation and intercropping systems, with judicious weeding at all stages to prevent weed flowering and seeding. In addition, while legume crops and covers produced no marked changes in soil fertility or structure over the study period, more information is needed on their effect on the availability to the crop of micro- and macro- nutrients.

Yields in the first year after clearance of high forest are exceptionally high and labour requirements low such that other non-mechanised systems of rice production cannot compete. However, in the foreseeable future, when many farmers in this area no longer have access to such land, the use of systems which allow sequential cropping will become increasingly necessary and attractive. Continued research to develop these systems is essential.

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