SESSION 3C

BIOLOGY AND CONTROL OF WEEDS IN SUB-TROPICAL AND TROPICAL CROPS

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WEED COMPOSITION AND POPULATION DYNAMICS IN INTENSIFIED SMALLHOLDER FARMS IN WEST AFRICA[1]

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ABSTRACT

Weeds are an important constraint in smallholder farms in the humid and subhumid tropics of west Africa. Farmers reduced the impact of weeds and sustained land productivity by practising shifting cultivation. Recently, land-use intensification has occurred because of increasing human population pressure on limited arable land. This has resulted in increased soil impoverishment and weed pressure. This paper presents partial results from a long-term study initiated in 1989 to evaluate the influence of fallow management system and cropping intensity on weed composition and population dynamics. Fallow management systems were natural bush and *Pueraria phaseoloides* fallow. Within each fallow system, cropping intensities were continuous cropping, one year of cropping followed by one, two and three years of uncropped fallow. Weed abundance increased over time with fallow management system and cropping intensity. Natural bush fallow and continuous cropping consistently showed higher weed abundance and soil weed seed population over time. In contrast, planted fallow and cropping for one year followed by two to three years of fallow showed a lower weed population over time. There were differences in weed species composition between natural and planted fallow, and between continuous cropping and cropping followed by fallow. This study seem to suggest that planted fallow is an effective alternative to natural fallow for sustained weed management in intensifying smallholder farms.

INTRODUCTION

Weeds are one of the numerous constraints limiting agricultural intensification in the humid and subhumid tropics of west Africa (Weber *et al.*, 1995). Akobundu (1991) reported that weed management utilised more labour than any other single farm operation in smallholder production systems in Africa. Shifting cultivation, which involves periodic abandonment of crop land to natural bush, has been widely used to control weeds. During long fallow (10-15 years), reforestration occurs and the resulting shade suppresses weeds surviving from the previous cropping phase. When such fields are opened for cropping, weeds are rarely a problem in the first year of cultivation (Akobundu *et al.*, 1992, De Rouw, 1995). Short fallows have become inevitable due to increasing human population. Fallow length has declined from >10 years to <4 years in most farming systems in west Africa. Cropping intensification without extended periods

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of fallow leads to rapid soil degradation, i.e. reduced soil fertility and increased weed invasion (Nyoka, 1982, De Rouw, 1995). Weeds become more severe where low soil fertility limits vigorous crop growth.

Planted fallows with high dry matter productivity have been suggested for weed management in intensified farms as alternatives to bush fallow (Szott *et al.*, 1991). Akobundu (1980) showed that live-mulching with *Centrosema pubescens* and *Psophocarpus palustris* reduced weed dry matter and seed population in the soil. Similarly, Szott *et al.* (1991) found that weed dry matter and viable weed seed in the soil were lower in live mulching with *Pueraria phaseoloides, C. macrocarpum* and *Stylosanthes guianensis* compared to natural fallow within 8 to 17 months after fallow planting. Versteeg & Koudokpon (1990) showed that *Mucuna pruriens* suppressed the growth of *Imperata cylindrica*, one of the major weeds in smallholder farms in west Africa. Agroforestry based fallow systems such as alley cropping are equally effective weed management strategies (Szott *et al.*, 1991, Akobundu *et al.*, 1992).

Although planted fallows are being recommended for weed control, there is no information on their long-term effects on weed composition which is likely to occur over a long period of time. Knowledge of changes in weed composition during the process of land-use intensification can be used to develop management practices that prevent proliferation of noxious and difficult to control weeds. The work reported here presents partial results of a multidisciplinary study initiated in 1989 and expected to continue until 2001. The specific objective was to assess the influence of fallow management system and cropping intensity on weed composition and population shifts in maize intercropped with cassava in the transition forest zone of west Africa.

MATERIAL AND METHODS

Experiments were conducted at the International Institute of Tropical Agriculture research farm in Ibadan, Nigeria (3° 54' E, 7° 30' N) from 1989 to 1995. The experimental site had been secondary forest vegetation for 23 years prior to this study. The farm is located in the transition forest zone with annual temperature mean of 26°C (average minimum = 20.8°C; average maximum = 31.8°C). and annual average precipitation of 1250 mm with a bimodal distribution peaking in June and September. The soil type was an alfisol (replicate 1 and 2) and an entisol (replicate 3). Differences in soil type did not affect weed composition.

The experimental design was a split plot in a randomised block with three replications. Fallow management systems, i.e. natural bush and *Pueraria phaseoloides* fallow, were the main plots and subplots were four cropping intensities, i.e. continuous cropping, 1 year crop followed by 1, 2 and 3 years of uncropped fallow. Fallow treatments were in 2 to 4 phases to allow data collection in each year . Each subplot measured 12 m x 20 m.

At the beginning of each cropping season (usually in March) the standing vegetation in each subplot was cleared using traditional methods of brushing followed by burning. Maize (cv. TZSRW) was sown at a population of 40,000 plants ha^{-1} and cassava (cv. TMS 30572) at a population of 10,000 plants ha^{-1} in alternating rows. *P. phaseoloides* was seeded at 15 kg ha^{-1}. No herbicides or fertiliser were used on the site. Each subplot treatment was hand weeded twice, at 3 and 8 weeks after planting (WAP), during each cropping phase.

Weed species composition and abundance in each treatment were recorded from three quadrats measuring 1 m x 0.5 m placed along a diagonal transect before each weeding operation. Changes in species composition and abundance over time were assessed by comparing 1989 to 1995 data using multivariate analysis. Species composition of seed bank as affected by treatment was assessed with Redundancy Analysis (RDA) using CANOCO 3.1 (Ter Braak, 1990). Replicates and the various treatments were used as covariables and environmental variables, respectively. The Monte Carlo permutation test was used to evaluate the significance of the first ordination axis.

RESULTS

Weed species composition

The initial weed community (1989) was dominated by broadleaf weeds with annuals and perennials contributing 35% and 60%, respectively, to the total weed community. Grasses were minor and accounted for 3% (perennial grasses), 1% (annual grasses) and 1% (sedges) of the total weed community. Major annual broadleaf weeds included *Celosia trigyna, Ipomoea involucrata, Indigofera* sp., *Euphorbia hirta, Momodica* sp., and *Corchorus tridens. Amaranthus spinosus, Blumea aurita, Cyathula prostrata, Dissotis rotundifolia, Laggera* sp., *Phyllanthus amarus, Starchytapheta* sp., and *Tridax procumbens* contributed less than 1% each to the weed population. *Chromolaena odorata, Hippocratea* sp., *Paullinia pinnata* and *Sida veronicifolia* were the main perennial broadleaf weeds.

There was a shift and an increase in weed species composition over time. By 1995, some of the pioneer species had either disappeared (*Laggera* sp., *Momodica* sp., *Cnestis ferruginea, Hippocratea* sp., *Paullinia pinnata*, and *Rytigynia* sp.) or decreased in abundance. In general, a new set of species emerged. Although broadleaf weeds continued to dominate the weed community overtime, there was a shift from dominance by perennials to annual weeds in all fallow management systems with the exception of natural bush fallow plots cultivated after two years of fallow.

In natural bush fallow, annual broadleaf weeds contributed 88% to the total weed population with *Ageratum conyzoides* (45%), *Syndrella nodiflora* (11%) and *Tridax procumbens* (11%) being the most dominant in continuously cropped plots (Table 1). The populations of annual and perennial broadleaf weeds were 57% and 36%, respectively, in plots cultivated every other year. Perennial broadleaf weeds dominated plots cultivated every 2 years by 64%. In plots cultivated every year, major annual broadleaf weeds were *A. conyzoides, T. procumbens, S. nodiflora* while *Euphorbia heterophylla, Hibiscus* sp., *S. nodiflora* and *Urena lobata* were dominant in plots cultivated after 1 to 3 years of uncropped fallow. *Desmodium scorpiurus* dominated the perennial weed population in plots cultivated every other year. *C. odorata* and *T. triangulare* were dominant perennial broadleaf weeds in plots cultivated after 2 to 3 years of fallow. Although broadleaf weeds dominated the weed community in 1995, there was a general increase in the abundance and number of annual and perennial grass weeds in the system. There were more annual grass weeds in plots cultivated after 1 or 2 years of fallow; major grasses and sedges were *Cynodon dactylon, Setaria barbata, Brachiaria deflexa, Brachiaria lata* and *Mariscus alternifolius.*

In improved fallow (*P. phaseoloides*), annual broadleaf weeds dominated the system accounting for >80% of the weed community irrespective of cropping intensity (Table 1). The population of perennial broadleaf weeds was lowest in plots cultivated after two (2.1%) and three (2.8%) years of fallow. Annual grass weeds occurred more in continuously cultivated plots and decreased as fallow length was increased. There were no annual grass weeds in plots cultivated after 3 years. *A. conyzoides* (53%) and *S. nodiflora* (8%) dominated the weed community in plots cultivated every year while *Spigelia anthelmia* dominated (43%) plots cultivated after 1 to 3 years of fallow.

Table 1. Effect of fallow management and cropping intensity on percentage weed species composition

Class	Continuous cropping	1 year crop: 1 year fallow	1 year crop: 2 year fallow	1 year crop: 3 year fallow
Bush fallow				
ABL[1]	87.7	56.6	19.6	79.4
PBL	4.3	35.9	63.6	16.5
AGS	4.2	4.7	6.6	4.2
PGS	4.2	2.7	10.2	0.0
P. phaseoloides fallow				
ABL	85.3	82.7	93.7	90.2
PBL	3.6	8.8	2.1	2.8
AGS	8.1	4.1	3.6	0.0
PGS	3.0	4.4	0.6	7.1

[1]ABL, annual broadleaf; PBL, perennial broadleaf; AGS, annual grasses; PGS, perennial grasses

Soil seedbank

The soil seed population was similar at the beginning of the study ranging from 9 000 to 12 000 seeds m^{-2}. Over time, the seed population increased in all treatments. In 1995, the seed population was higher in natural bush fallow compared to planted fallow (Table 2). The seedbank was consistently higher in plots cultivated every year relative to plots which were fallowed after each cropping phase.

Table 2. Effect of fallow management system and cropping intensity on the weed seed population in the soil.

Cropping intensity	Bush fallow	*P. phaseoloides* fallow	Mean
	(seeds m^{-2})		
Continuously cropped	21,390	18,956	20,130
Cropped every other year	11,912	7,109	10,972
Cropped every two years	13,577	3,971	8,581
Cropped every three years	11,207	3,842	6,788
Mean	14,521	8,469	
S.E fallow management		± 1,416	
S.E cropping intensity		± 1,635	
S.E interaction		ns	

The effect of fallow management and cropping intensity on species composition was significant ($p<0.05$) with the first two axes accounting for 52% of the variation (Figure 1). In natural bush fallow systems, the soil seed bank in plots cultivated continuously was dominated by seeds of *A. conyzoides.* The abundance of this weed decreased as fallow length increased. Seeds of *Digitaria horizontalis*, *M. alternifolius* and *C. dactylon* were also associated with this treatment. *Solenostemon monostachyus*, *E. hyssopifolia* and *S. nodiflora* were the most abundant species in plots cultivated every other year. *C. odorata* dominated the seed bank of plots cultivated after 1 to 3 years of fallow.

Species composition of the seed bank in *P. phaseoloides* plots under continuous cultivation was completely different from that in plots cultivated after 1 to 3 years of fallow. *A. conyzoides* and *Setaria longiseta* dominated continuously cultivated plots. However, after 2 and 3 years of fallow, *S. anthelmia* (a very weak annual broadleaf) dominated the seed bank, whereas *E. heterophylla* and *Indigofera* sp. were the most abundant in plots cultivated after one year of fallow.

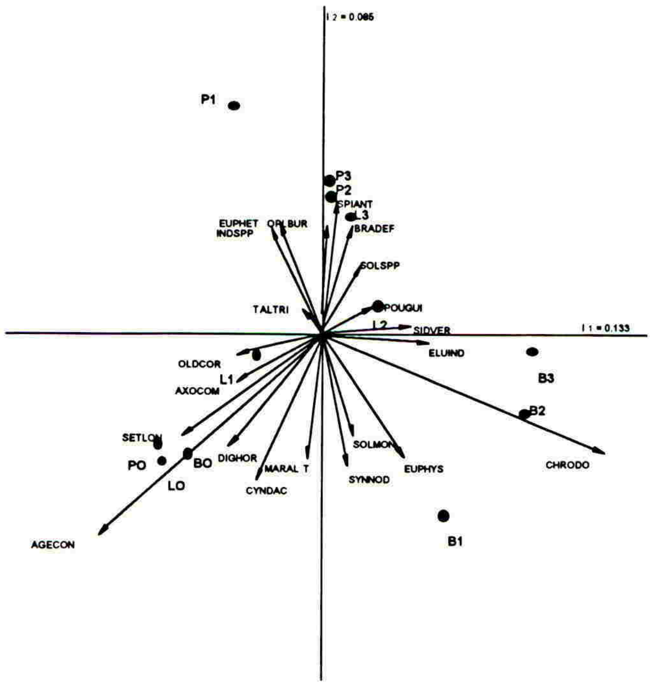

Figure 1. Ordination diagram of species-treatment biplot of 1995 seed bank data. Centriods of treatment are displayed. B0-B3 = 0 - 3 yrs; P0-P3 = *P. phaseoloides* (0-3 yrs); L0-L3 (not discussed). Species are AGECON=*Ageratum conyzoides*, SETLON=*Setaria longiseta*, Axocom=*Axonopus compressus*, DIGHOR=*Digitaria horizontalis*, CYNDAC=*Cynodon dactylon*, MARALT=*Mariscus alternifolius*, SYNNOD=*Synedrella nodiflora*, EUPHYS=*Euphorbia hyssopifolia*, SOLMON=*Solenostemon monostachyus*, CHRODO=*Chromolaena odorata*, ELUIND=*Eleusine indica*, SIDVER=*Sida veronicifolia*, POUGUI=*Pouzolzia guineensis*, SOLSSP=*Solanum* sp., BRADEF=*Brachiaria deflexa*, SPIANT=*Spigelia anthelmia*, OPLBUR=*Oplismenus burmannii*, EUPHET=*Euphorbia heterophylla*, INDSPP=*Indigofera* sp., TALTRI=*Talinum triangulare*.

DISCUSSION

Although Moody (1975) reported that over-cultivation changed the weed composition from dominance by broadleaf weeds to grasses in two seasons, we have observed continued dominance by broadleaf weeds seven years after opening the site. This weed composition appears to be a reflection of the initial seedbank composition which was dominated by the same. De Rouw (1995) found that reduction of viable seed in the soil occurred after ten years under continuous shading during fallow. The maximum fallow length in our study was four years which may not be effective for reducing the seedbank.

Weed abundance increased in fallow management systems and with cropping intensity, confirming previous reports showing that land-use intensification favours weed invasion (De Rouw, 1995). The rate of weed increase was lower in improved fallow and where the cropping phase was followed by 2 to 3 years of uncropped fallow. Szott *et al.* (1991) reported that weed dry matter was lower in *P. phaseoloides* because of continued shading from the planted fallow. They recommended that in shifting cultivation systems, where fields are abandoned primarily due to high weed infestation, planted fallow may be a quicker way of tackling the problem than natural fallow.

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INTEGRATED WEED MANAGEMENT FOR SUSTAINABLE PRODUCTION OF A PIGEONPEA BASED CROPPING SYSTEM

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ABSTRACT

Investigations were carried out for two consecutive years (1992-93 and 1993-94) in alluvial soil of the Indogangetic plains at Kanpur to develop an integrated weed management technology in rainfed pigeonpea. Results revealed that intercropping of greengram, pearl millet and sesame led to weed suppression in pigeonpea to the extent of 36.9, 50.8 and 36.6 per cent, respectively. The pigeonpea equivalent yield obtained under pigeonpea + greengram intercropping raised under unweeded conditions was comparable (1064 kg/ha) to the yield of sole pigeonpea with a single hand weeding (1072 kg/ha). Similarly, supplementing a single hand weeding in the pigeonpea + greengram cropping system resulted in a substantially higher pigeonpea equivalent yield (1507 kg/ha) than the pigeonpea sole cropping yield with two hand weedings (1311 kg/ha). Thus, merely by inclusion of greengram as an intercrop with pigeonpea, one hand weeding could be saved. Pigeonpea + sesame behaved in similar way. Intercropping of greengram with pigeonpea followed by pendimethalin (1.0 kg a.i./ha) as a pre-emergence treatment could be resorted to as an alternative when labour is scarce.

INTRODUCTION

India has the world's largest hectarage of pigeonpea and contributes about 90% of the global production. Pigeonpea has a unique place in traditional cropping systems. About 90% of pigeonpea crops are grown in dryland areas in intercrops or in mixed cropping systems (Aiyer, 1949).

Severe weed competition occurs in pigeonpea during the rainy season, resulting in yield losses of up to 90% (Saxena & Yadav, 1975). Crop competition is one of the important components of an integrated weed management system. Intercropping has proved to be superior to its single component crops in weed suppression (Bantilan & Harwood, 1973; Shetty & Rao, 1979) and, thus, it provides an opportunity to utilise the crops themselves as tools for weed management. However, weed suppression depends largely on the nature of the component crops in the intercropping system.

Intercropping of short duration cultivars of pulses, oilseeds and cereals with long or medium duration pigeonpea has tremendous scope for use in weed suppression and needs exploitation (Singh, 1993). Since weed suppression is directly related to canopy coverage of component crops, it is, therefore, imperative to quantify the weed suppressive effect of the various intercrops, i.e. sesame, greengram and pearl millet in association with pigeonpea. This will enable development of an integrated weed management technology involving cropping and chemical methods which could fit into existing cropping systems in central and northern regions of India.

MATERIALS AND METHODS

Four cropping systems (sole pigeonpea, pigeonpea + sesame, pigeonpea + greengram and pigeonpea + pearl millet) were grown with four weed control measures (no weeding, manual weeding at 20 days after sowing, manual weeding at 20 and 40 days after sowing and pendimethalin at 1.0 kg a.i./ha in a three - replicate, randomised block design at the Students' Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur for two consecutive years (1992-93 and 1993-94). The soil of the experimental field was a sandy loam in texture, deficient in nitrogen but medium in phosphorus and potassium, and slightly alkaline. The rainfall received during the cropping periods was 588 mm and 620 mm during first and second years of field experimentation, respectively. Pigeonpea-Bahar (260 days duration) was sown in rows 90 cm apart during the second fortnight of July during both years. Two rows each of greengram - T 44 (60 days duration), pearl millet - manupur (130 days duration) and sesame - T 4 (95 days duration) were sown between two rows of pigeonpea. Pigeonpea and greengram received 18 kg N/ha and 46 kg P_2O_5/ha as basal applications. Applications of 30 kg N/ha and 15 kg P_2O_5/ha to sesame and 50 kg N/ha and 25 kg P_2O_5/ha to pearl millet were applied in the rows. Pendimethalin (1.0 kg a.i./ha) in 600 l/ha of water was applied on the second day after sowing using a knapsack sprayer. Pigeonpeas were harvested during the second week of March in both years. The intercrops were harvested at maturity. The grain yields obtained from intercrops in the different cropping systems were converted into pigeonpea yield equivalent on the basis of prevailing market prices of different commodities to make the proper comparison.

RESULTS AND DISCUSSION

Effects on weeds

The major weeds infesting the experimental fields were amaranthus (*Digera muricata*), day flower (*Commelina benghalensis*) niruri (*Phyllanthus niruri*), jungle rice (*Echinochloa colona*), nutgrass (*Cyperus rotundus*), crow - foot grass and (*Dactyloctenium aegyptium*).

inclusion of intercrops between the rows of pigeonpea caused an appreciable reduction in weed weight (Table 1). Intercrops smothered the weeds substantially and reduced the weed competition for space, nutrients and light. In the present investigation, average reductions in weed dry weight, in unweeded treatments, was 36.9% 50.8% and 36.6% due to intercropping of greengram, pearl millet and sesame, respectively. These findings corroborate earlier findings (Tewari et al., 1989). Pendimethalin (1.0 kg a.i./ha) gave effective control of the associated weeds except C. benghalensis and C. rotundus, confirming earlier findings (Tewari & Rathi, 1995).

Table 1: Weed dry weight (kg/ha) (pooled over 1992-93 and 1993-94)

Cropping systems	No Weeding	Manual Weeding once	Manual Weeding twice	Pendimethalin (1.0 kg/ha)	Mean
Pigeonpea sole	2672	564	250	1120	1151
Pigeonpea + greengram	1684	429	130	880	781
Pigeonpea + pearl millet	1314	388	166	472	585
Pigeonpea + sesame	1694	453	259	722	782
Mean	1841	458	201	798	

LSD at 5%
cropping system (C) = 158 Weed control (W) = 158 C x W = 317

Yield of component crops

The growing of pearl millet and sesame with pigeonpea was detrimental to grain yield of pigeonpea (Table 2). The mean depression in the grain yield of pigeonpea for all weed control treatments was 28.6% and 27.7% due to pearl millet and sesame, respectively. Substantial reductions in grain yield of pigeonpea in association with pearl millet and sesame were also reported by Giri & Gayke (1983) and Kumar & Ahlawat (1986), respectively. However, intercropping of greengram in association with pigeonpea caused an insignificant reduction in the yield of pigeonpea. Similar results were reported by Ali (1985). Two hand weedings at 20 and 40 days after sowing gave conspicuously better yields of the component crops than the unweeded treatment. Pendimethalin gave an appreciable increase in the yield of component crops as a result of reduced weed competition. However, this herbicide was phytotoxic to sesame.

Pigeonpea equivalent yield

It is evident that highest pigeonpea equivalent yield was obtained with the pigeonpea/greengram mixture (1448 kg/ha), followed by the pigeonpea/sesame mixture (1096 kg/ha) (Table 3).

Table 2: Yields of components crops (kg/ha) (mean of 2 years)

Cropping systems	No weeding	Manual weeding once	Manual weeding twice	pedime-thalin (1.0 kg/ha)	Mean
Pigeonpea sole	794	1072	1311	1111	1072
Pigeonpea + greengram	709 (338)	972 (510)	1164 (684)	848 (468)	923 (499)
Pigeonpea + pearl millet	571 (633)	779 (849)	948 (1125)	763 (936)	765 (886)
Pigeonpea + sesame	555 (191)	771 (283)	948 (347)	825 (130)	775 (238)

Figures in parenthesis are yields of intercrops

Table 3: Pigeonpea equivalent yield (kg/ha) (pooled over 1992-93 and 1993-94)

Cropping systems	No weeding	Manual weeding once	Manual weeding twice	Pendime-thalin (1.0 kg/ha)	Mean
Pigeonpea sole	794	1072	1311	1111	1072
Pigeonpea + greengram	1064	1507	1882	1339	1448
Pigeonpea + pearl millet	697	949	1173	951	942
Pigeonpea + sesame	832	1181	1452	920	1096
Mean	847	1177	1454	1080	

LSD at 5%
Cropping system (C) = 108 Weed control (W) = 108 C x W = 215

Intercropping of greengram with pigeonpea has been reported to be more remunerative than intercropping of cereals (Saxena & Yadav, 1979). The yield of sole pigeonpea with two manual weedings done at 20 and 40 days after sowing was similar (1311 kg/ha) to the pigeonpea equivalent yield of pigeonpea + greengram intercropping weeded only once at 20 days after sowing (1507 kg/ha). Thus, intercropping saved one weeding. Likewise, Rao & Shetty (1981) reported that inclusion of cowpea or greengram as an intercrop in sorghum virtually replaced one hand weeding without reducing sorghum yield. Pendimethalin was an alternative to a single hand weeding in all cropping systems, except for sesame which was damaged by this herbicide. These results are in agreement with the observations of Singh & Tewari (1992).

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WEED CONTROL METHODS IN INTEGRATED PEST MANAGEMENT OF CITRUS IN ADANA AND IÇEL PROVINCES OF TURKEY

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ABSTRACT

In this study, densities of weed species and effects of different weed control methods were determined in seven IPM citrus orchards in Adana (in Seyhan, Yüreğir and Kozan districts) and İçel (in Mersin, Erdemli, Tarsus and Silifke districts) provinces in 1995 and 1996. Based on the surveys, 88 weed species belonging to 32 families were identified. Whereas disc harrow + mowing was the most effective method of weed control between rows, mowing was found to be the most effective and the cheapest method within rows.

INTRODUCTION

Citrus is a valuable crop growing in the coastal, subtropical regions of the Mediterranean and Aegean Sea as well some isolated areas along the Black Sea. Turkey ranks 11th of the citrus production countries in the world and 3rd in the Mediterranean basin with a production of more than 1.8 million tonnes per year. Citrus is one of the most important crops of Turkey and more than half of the total production is produced in Adana and İçel provinces in the Mediterranean Region (Anonymous, 1994).

Weed control strategies in citrus Integrated Pest Management (IPM) systems were established according to previous studies on the biology, morphology, population dynamics and methods of controlling dominant weeds in citrus orchards. During a two-year study, weed species and populations were examined in IPM orchards. Appropriate weed management was done as and when necessary. The efficiency of integrated weed management was determined by comparing previous years' records with conventional weed control strategies.

This paper lists the weed species which are present in citrus IPM orchards and discusses the efficacy of control under grower conditions.

MATERIALS AND METHODS

The projects was carried out in seven different citrus orchards in Adana (Seyhan,Yüreğir and Kozan districts) and İçel (Mersin, Erdemli, Tarsus and Silifke districts) provinces in 1995 and 1996. Citrus IPM orchards are characterised in Table 1.

Each orchard was surveyed in spring (April-May) and summer (July-August). Weeds growing in winter and spring were assessed in the spring survey; weeds growing in summer were determined in the spring and summer surveys. Densities and distributions of weeds between and within rows were recorded (Uygur, 1993).

IPM orchards were observed at one-month intervals, when weed densities were recorded. As soon as weed coverage reached 15% during the year, control methods were applied in IPM orchards. Information on control methods in the IPM orchards is shown in Table 2. The current total cost of all control methods is given.

RESULTS

The weed survey of IPM orchards identified 88 species belonging to 32 families. Weed coverage rates, where they exceeded 5%, are presented in Table 3. Although various weed control methods were used, some weed species were dominant in orchards. These dominant species and their control costs per hectare are given in Table 4.

CONCLUSIONS

- Although only seven citrus orchards were surveyed, a very rich weed flora was found which contained 88 species belonging to 32 families,

- Some weeds are considered important in citrus orchards because of their ground cover was more than 5%, including: *Portulaca oleracea, Echinochloa colonum, Convolvulus arvensis, Cyperus rotundus, Amaranthus retroflexus, Xanthium strumarium, Setaria verticillata, S. viridis, Parietaria judaica, Cynodon dactylon, Equisetum arvense, Alopecurus myosuroides, Lolium rigidum, Avena sterilis, Hordeum murinum, Malva neglecta, Stellaria media, Capsella bursa-pastoris, Poa annua, Malva parviflora, Galium spurium* and *Bromus sterilis.*

- Between rows: disc harrowing + mowing were most effective weed management treatments but disc harrows can damage the root systems of trees and need to be used carefully,

- Within rows: mowing + hand hoeing + glyphosate were the most effective treatments but mowing was the cheapest. Although mowing + hand hoeing + glyphosate was effective, it was more expensive than mowing alone.

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Table 1. Information about citrus IPM orchards in Adana and Içel provinces

Specification of IPM orchards	A D A N A			İ Ç E L			
	SEYHAN	YÜREĞİR	KOZAN	MERSİN	ERDEMLİ	TARSUS	SİLİFKE
Number of trees	1600	3400	1500	725	230	1000	300
Citrus species and variety	Lemon (Interdonate) Orange (Washington Navel)	Lemon (Interdonate) Minneola tangelo Grapefruit	Orange (Washington Navel) Mandarin	Orange (Washington Navel and Hamlin) Mandarin (Satsuma) Grapefruit (Marsh seedless)	Orange (Washington Navel) Lemon (Lamas-local variety)	Orange (Washington Navel)	Lemon (Kütdiken-local variety)
Orchard age	21	16	24	21	20	14	13
Planting size	7 m x 7 m	7 m x 7 m	6 m x 6 m	7 m x 7 m	7 m x 7 m	7 m x 7 m	6 m x 6 m
Soil type	Heavy clay	Heavy clay	Medium clay	Medium clay	Sandy-loam	Medium clay	Sandy-loam
Irrigation	Float, 7 times	Float, 5 times	Float, 5 times	Float, 4 times	Float, 8 times	Float, 7 times	Float, 6 times
Fertilisation	Nov. 1995: -1kg N (urea)/tree -0.5 kg potassium sulphate. March 1996: ammonium sulphate	Dec 1995: 2 kg potass-ium sulphate + 1 kg triple phosphate. Feb. 96, May 96 and July 96: in total 8 kg ammon-ium sulphate	Organic fertiliser in 1995. Feb. 1996 and May 1996: ammonium sulphate 5 kg/tree	Feb. and July 1995 and 1996: ammonium sulphate 4 kg/tree	Feb. and June 1995: in total 4 kg/tree ammonium sulphate. June 1996: 500 g zinc sulphate + 300 g manganese sulphate + 400 g soda/100 l water March 1996: 2 kg/tree NPK, 0.5 kg/tree potassium sulphate. July 1996: 1 kg/tree ammonium sulphate	May 1996: ammonium sulphate 3 kg/tree	Dec. 1995: 1 kg/tree potass-ium sulphate. Feb. 1996 and May 1996: in total ammon-ium sulphate 4 kg/tree

Table 2. Weed control methods applied in IPM orchards in 1995 and 1996

		Provinces	ADANA			İÇEL			
		Districts	SEYHAN	YÜREĞİR	KOZAN	MERSİN	ERDEMLİ	TARSUS	SİLİFKE
Between rows	Weed Control Methods	Disc harrow	8 times	8 times	7 times	8 times	-	8 times*	-
		Mowing	-	-	-	-	7 times**	2 times**	6 times**
		Hand hoeing	-	-	-	-	2 times*	-	2 times*
		Herbicide (glyphosate 6 l ha^{-1})	-	-	-	-	-	-	1 time***
		Mowing	-	8 times	6 times**	7 times**	7 times**	2 times	6 times**
In rows		Hand hoeing	8 times	-	2 times*	2 times*	2 times*	7 times	2 times*
		Herbicide (glyphosate 6 l ha^{-1})	-	-	1 time***	-	-	-	1 time***

* : First treatment
** : Second "
*** : Third "
\- : Untreated

Table 3. Weed species with more than 5% cover in orchards

Provinces	ADANA			İÇEL			
Districts	SEYHAN	YÜREĞİR	KOZAN	MERSİN	ERDEMLİ	TARSUS	SİLİFKE
Summer period	*Portulaca oleracea* *Echinochloa colonum* *Convolvulus arvensis* *Cyperus rotundus*	*C. rotundus* *P. oleracea* *Amaranthus retroflexus* *Xanthium strumarium*	*Setaria verticillata* *P. oleracea* *A. retroflexus* *S. viridis*	*P. oleracea* *A. retroflexus* *S. verticillata* *C. rotundus* *E. colonum*	*S. viridis* *Parietaria judaica* *P. oleracea* *A. retroflexus* *Cynodon dactylon*	*C. rotundus* *E. colonum* *A. retroflexus*	*C . dactylon* *Equisetum arvense*
Winter and spring periods	*Alopecurus myosuroides* *Lolium rigidum* *Avena sterilis* *Hordeum murinum* *Malva neglecta*	*A. sterilis* *Stellaria media* *A. myosuroides* *Capsella bursa-pastoris* *M. neglecta*	*S. media* *Poa annua* *L. rigidum* *H. murinum* *M. parviflora*	*Galium spurium* *S. media* *H. murinum*	*H .murinum* *Bromus steliris* *L. rigidum*	*C. bursa-pastoris* *B. sterilis* *C. rotundus*	*E. arvense* *B. sterilis* *C. dactylon* *A. myocuroides*

Table 4. Dominant weed species observed in orchards and their control costs

Provinces	ADANA			İÇEL			
Districts	SEYHAN	YÜREĞİR	KOZAN	MERSİN	ERDEMLİ	TARSUS	SİLİFKE
	Portulaca oleracea *Cynodon dactylon* *Echinochloa colonum* *Lolium rigidum* *Avena sterilis*	*Sorghum halepense* *A. sterilis* *P. oleracea* *Cyperus rotundus*	*Setaria verticillata* *P. oleracea* *L. rigidum* *C. rotundus*	*P. oleracea* *S. verticillata* *C. rotundus*	*S. virids* *P. oleracea* *Hordeum murinum*	*C. rotundus*	*Cynodon dactylon* *Equisetum arvense* *Avena sterilis* *Lolium rigidum*
Control costs ($\$ ha^{-1}$)	240	240	210	240	550	340	600
	E. colonum *P. oleracea* *L. rigidum* *Alopecurus myosuroides* *A. sterilis*	*P. oleracea*	*S. verticillata*	*S. verticillata* *P. oleracea*	*S. verticillata* *P. judaica*	*C. rotundus* *Bromus sterilis* *P. oleracea*	*E. arvense* *C. dactylon* *A. myocuroides*
Control costs ($\$ ha^{-1}$)	800	400	600	550	550	800	500

ON-FARM WEED CONTROL IN MAIZE USING CULTURAL, PHYSICAL AND CHEMICAL METHODS

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ABSTRACT

Maize is the major staple food crop in Kenya. One of the major constraints to its production is inadequate weed control. Weeding is the most labour demanding activity on the farm while hand-weeding, although it is laborious, expensive and ineffective, is the commonest weed control method. On-farm trials were conducted in central Kenya to determine the effects of two bean spatial arrangements, hand-weeding and a pre-emergence herbicide metobromuron + metolachlor on weed control in sole maize, sole beans and two maize/bean intercropping systems. Results showed that at two weeks after seedling emergence (ASE), plots treated with herbicide in all cropping systems were weed-free. At seven and 15 weeks ASE, weeds were best controlled by a combination of two rows of beans between two maize rows spatial arrangement and the herbicide. Farmers wanted to adopt this weed control method because it was effective and labour saving. Total grain yields were not significantly affected by weed control methods.

INTRODUCTION

Maize (*Zea mays* L.) is the main staple food crop for the majority of Kenya's population. It is grown as a sole crop or an intercrop. Intercropping of maize and beans (*Phaseolus vulgaris* L.) is a popular and predominant cultural practice among resource-poor farmers in central Kenya (Ikombo *et. al,* 1994). However, an important constraint to maize production, particularly in central Kenya where this study was carried out, is inadequate weed control. During a farm survey in central Kenya, weeding was reported as the most labour demanding activity among the farm enterprises. Also, hand-weeding was the commonest weed control method which farmers reported to be expensive, laborious and ineffective (Chui *et al.*, 1996). Herbicides were not used to control weeds in subsistence crops and bean spatial arrangements were never considered to have a weed smothering effect. Hence, farmers in this region have as high demand for better weed control methods.

The main objective of this on-farm trial was to determine the effects of bean spatial arrangements, hand-weeding and a pre-emergence herbicide metobromuron + metolachlor (Galex - trade name) on weed control in sole maize, sole beans and maize/bean intercropping systems.

MATERIALS AND METHODS

On-farm adaptive research was conducted during the long rains-LR (March-May) of 1996 and short rains-SR (October - February) of 1996/97 in an agroecological zone UM2 (main coffee zone) situated in Githunguri Division, Kiambu District in Central Kenya. The soils of the area are classified as Nitisols.

Crops, cropping systems and planting

Maize (var. H625 for the LR and H512 for the SR) and beans (cv. Rose coco) were planted in four cropping systems: sole maize planted at 75 cm between rows by 30 cm within rows (SM); sole beans planted at 75 cm between rows by 11 cm within rows (SB); maize planted as in sole cropping and then intercropped with beans in two spatial arrangements: one row of beans between two maize rows with beans planted at 75 cm between rows by 11 cm within rows (M/1B); and maize planted as in sole cropping and and then intercropped with two rows of beans between two maize rows, with beans sown at 37.5 cm between rows by 22 cm within rows (M/2B). Maize and bean populations were aimed at 45,000 plants/ha and 240,000 plants/ha in all cropping systems, respectively. Planting of trials was done by farmers, researchers and the extension workers. This was done in March and November for the LR 1996 and SR of 1996/97 respectively. Thinning of maize was done three weeks after planting.

Weed control methods

a) One hand-weeding - 3 weeks after seedling emergence (ASE) - 1W
b) Two hand-weedings- first as in 1W and second 4 weeks later (7 weeks ASE) - 2W
c) Herbicide (metobromuron 25% + metolachlor 25%, 2.5kg total a.i./ha - pre-emergence) applied 2-4 days after planting - Herb.
d) Herbicide as in (c) plus one hand -weeding at 7 weeks ASE - Herb.+ 1 W

Experimental design

A split-plot arrangement was used. The four cropping systems formed the main-plots while the four weed control methods formed the sub-plots. There were four cooperating farmers and each farm was used as a replicate. The total number of treatments per replication was 16. The plot size was 4.5 m x 4.0 m.

Management of trials and data collection

The trials were managed by the farmer, researcher and extension worker, although hand-weeding was done by the cooperating farmers. At planting, diammonium phosphate (DAP-18:46:0) fertilizer was applied at the rate of 60 kg P_2O_5/ha (26 kg P/ha) and 23 kg N/ha. Calcium ammonium nitrate (CAN-26%) was used to top-dress the crops at the rate of 37 kg N/ha three weeks ASE. Dipterex was used against maize stalkborer while dimethoate was used against aphids on beans.

Weed samples were taken three times in a growing season using a quadrat measuring 0.5 m by 0.5 m. A quadrat was placed at random in a plot and two samples taken per plot. In a quadrat, weeds were uprooted, counted, bulked and then taken to laboratory to determine dry weight. Weeds were dried for 48 hours at 60^0C. During the long rains of 1996, the first weed sampling took place 2 weeks ASE, the second at seven weeks ASE and the third one at 15 weeks ASE (at bean harvest). During the second planting season of the short rains of 1996/97, the drought that was experienced by the whole country interfered with the trials and no conclusive data were taken.

The data taken during the LR of 1996 included weed count, weed dry weight, dry matter yields and grain yields of maize and beans. These data were subjected to analysis of variance and standard errors were calculated to compare the treatments means. Weed dry weight and grain yields of LR of 1996 will be reported here.

Results and Discussion

Weeds

Data on weed dry weight are given in Table 1. Two weeks ASE, there was no hand-weeding done yet. At this time, plots treated with a pre-emergence herbicide had significantly lower weed dry weight than plots without herbicide. Herbicide treated plots were generally weed-free. At seven weeks ASE only one hand-weeding was done in 1W treatment, and the best weed control methods were herbicide treatments in an intercropping system of two rows of beans between two maize rows. On the other hand, herbicide treatments on average performed worse than hand-weeding in sole cropping of maize and beans and in an intercropping system of one row of beans between two maize rows.

At 15 weeks ASE, all weed control methods had been applied. Weed dry weights were on average about three times higher in sole cropping of beans and maize than in the two intercropping systems. The best cultural practice (cropping system) in weed control was intercropping two rows of beans between two maize rows. The second best was intercropping one bean row between two maize rows followed by sole maize while sole bean cropping system was the least effective. In both sole maize and beans, herbicide alone had significantly higher weed dry weight than the other treatments. In M/1B intercropping, the herb. + 1W had significantly lower weed dry weight than the other treatments while 1W performed the worst. In M/2B intercropping, the 1W had significantly higher weed dry weight than the other treatments which did not differ significantly. There was a trend however which indicated that, herbicide + 1W performed the best in both sole maize and M/1B while in M/2B it was herbicide alone. This effective weed control by a combination of M/2B and herbicide could be attributed to the fact that, the pre-emergence herbicide was inhibiting the growth of weeds while the closing up of the bean canopy had an added effect of smothering the weeds. Probably, in the case of bean sole cropping and M/1B intercropping, the 75 cm row spacing of beans was too wide to facilitate closing up of bean canopy and thus smothering the weeds. Hence, beans in both sole and intercropping systems seemed to require a narrower row spacing to effectively smother the weeds.

Table 1. Effect of weed control methods and cropping systems on weed dry weight (g/m^2) during the long rains of 1996.

Cropping system	Weed control method	Weed sampling in weeks ASE 2	7	15
sole maize	1 weeding	1.63	11.55	75.3
	2 weedings	5.66	7.01	42.7
	herbicide	0.16	10.89	104.0
	herb.+ 1 W	0.00	15.53	40.0
sole beans	1 weeding	1.50	10.16	53.3
	2 weedings	4.17	11.16	130.7
	herbicide	0.00	14.10	268.0
	herb.+1 W	0.33	25.96	109.3
maize/1 bean	1 weeding	2.53	12.79	83.3
	2 weedings	2.25	15.12	39.3
	herbicide	0.00	9.68	38.7
	herb.+1 W	0.00	21.40	14.0
maize/2 bean	1 weeding	3.46	12.65	95.3
	2 weedings	8.90	5.56	14.7
	herbicide	0.16	2.07	2.2
	herb.+ 1W	0.00	2.04	21.3
S.E(±)		0.61	1.52	19.9

Weeds that were resistant to the metobromuron + metolachlor herbicide included *Oxygonum sinuatum*, *Commelina benghalensis*, *Rhynchelytrum scabidum*, *Cyperus rotundus* and *Tagetes minuta.*

Grain Yields

Grain yields are shown in Tables 2, 3, 4. The data indicate that the intercrops experience competition from the association. The yields of intercrops in M/1B and M/2B intercropping systems were significantly reduced to 37% and 62%, respectively, that of the sole beans (Table 2) while yields of maize in the former system were significantly lowered to 80% and non-significantly in the latter to 82% that of sole maize (Table 3).

The intercropping systems with two rows of beans between two maize rows which was the best in weed control also gave significantly higher grain yields of beans (292 kg/ha) and non-significantly higher grain yields of maize (125 kg/ha) than those in the intercropping system with one row of beans between two maize rows. In sole beans and M/1B cropping systems, herbicide treatments performed worse than hand-weedings although the reverse was true in M/2B cropping system (Table 2). The M/1B and M/2B intercropping systems had significantly lower maize seed yields than the maize sole cropping (Table 3).

Probably, the beans in M/1B intercropping system did not suppress weeds as the M/2B did since the former had higher weed dry weights on average at 15 weeks ASE than the latter, thus resulting in more competition between intercrops and the weeds.

Table 2. Effect of weed control methods and cropping systems on bean seed yield (kg/ha) during the long rains of 1996.

Cropping	Weed	control	methods		
systems*	1 W	2 W	Herb.	Herb.+1W	SE(±)
sole beans	1384	1417	744	1195	123
M/1 B	660	429	281	397	60
M/2 B	601	721	799	816	62
SE(±)	149	161	128	133	

* interaction between cropping systems and weed control methods was significant at P=0.05

Irrespective of cropping systems, the treatment of herbicide alone gave the lowest bean seed yield and the effect was significant relative to one weeding or two weedings (Table 2). On the other hand, all weed control methods did not affect maize seed yield significantly (Table 3). There were significant interactions between cropping systems and weed control methods on seed yields (Tables 2 &3). This implied that weed control methods did not perform uniformly across the cropping systems.

Table 3. Effect of weed control methods and cropping systems on maize seed yield (kg/ha) during the long rains of 1996.

Cropping	Weed	control	methods		
systems*	1 W	2 W	Herb.	Herb.+ 1W	SE(±)
sole maize	6889	4389	6166	6445	420
M/1 B	5222	3278	5000	5611	446
M/2 B	3944	6889	4111	4667	658
SE(±)	674	700	532	599	

* interaction between cropping systems and weed control methods was significant at P=0.02

The combined total grain yields of maize and beans which is a measure of land productivity per unit land area is given in Table 4. The total grain yields obtained from sole maize, M/1B and M/2B intercropping systems did not differ significantly. Also, the weed control methods did not affect total grain yields significantly. This implied that the intercropping systems which were controlling weeds better than sole cropping of maize could be adopted by the farmers. But there was no recommendation for the best weed control method because no economic analysis was done to the data. Nevertheless, even without the economic analysis of the data farmers wanted to adopt the herbicide applied in two rows of beans between two maize rows intercropping system. They found the method effective and highly labour saving since it is done together with planting.

Table 4. Effect of weed control methods and cropping systems on combined total grain yields (kg/ha) of maize and beans

Cropping	weed	control	methods		
systems*	1 W	2 W	Herb.	Herb.+1W	SE(±)
sole maize	6889	4389	6167	6445	420
M/1 B	5882	3707	5281	6008	464
M/2 B	4546	7610	4910	5482	642
SE(±)	616	754	472	556	

* interaction between cropping systems and weed control methods was significant at P=0.03.

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WEEDING - ITS CONTRIBUTION TO SOIL WATER CONSERVATION IN SEMI-ARID MAIZE PRODUCTION

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ABSTRACT

Excessive weed growth has long been recognised as one of the most important single limiting factors in maize production at the smallholder level in sub-Saharan Africa. Weed management is therefore beneficial and not only reduces competition for nutrients and light between the crop and the weed, but also influences the availability of soil water. On-station trials carried out on a sandy soil in semi-arid Zimbabwe assessed the effects of eight hand weeding treatments on maize yield and soil water regimes. Results from two very different seasons show that soil water regimes and crop yields are strongly influenced by the timing and frequency of weeding. In terms of crop water use efficiency and grain yield, a combination of weeding carried out two, four and six weeks after crop emergence performed the best, whilst a single weeding two weeks after crop emergence was the worst of the weeding regimes. As expected the driest soil profiles and lowest yields were observed under the unweeded control.

INTRODUCTION

The semi-arid areas of Zimbabwe are marginal for the production of most annual crops due to their unreliable rainfall and infertile soils (Chivinge, 1984; Riches *et al.,* 1997). As in most of sub-Saharan Africa, at the smallholder level excessive weed growth is one of the major constraints to the adoption of conservation farming practices (Shumba *et al.,* 1992; Vogel, 1994; Klaij & Hoogmoed, 1996) and increased crop production (Chivinge, 1984). Weed management is therefore beneficial, and not only reduces competition for nutrients and light between the crop and the weed, but also influences the availability of soil water (Clegg, 1996; Riches *et al.,* 1997).

Farmers in semi-arid Zimbabwe recognise the need to weed their crops at least once or twice in a season, both to kill weeds and to allow enhanced water capture (Riches *et al.,* 1997). Although the optimum time to weed has been established, the frequency of weeding and its impact on crop water usage is poorly understood. In this study we describe the impact of time of weeding and the frequency of weeding in maize on water use efficiencies (WUE) and yields.

MATERIALS AND METHODS

Trials were conducted in Masvingo Province, Zimbabwe at Makoholi Experimental Station (MES), (19°50'S 30°47'E, elevation 1204 m) during the 1991/92 and 1992/93 cropping seasons. The climate at the site is characterised by a unimodal rainy season from October/November to March, when most of the rain falls as sporadic 'heavy' convectional storms, followed by a dry season from April to May. The 15-year seasonal average rainfall is 478 mm (1982-1996), with a range of 260 to 1150 mm.

Table 1. Rainfall distribution (mm) at Makoholi for 1991/92 and 1992/93 crop seasons

Season	October	November	December	January	February	March	Total
1991/92	10	52	35	115	6	52	270
1992/93	75	92	268	108	201	29	773

The soil at MES is a deep granitic sand of the Fersiallitic Soils Group (Chemistry and Soil Research Institute, 1979), and correspond to an Ustic Quartzipsamment (USDA) or a Ferralic Arenosol (FAO). These are typical of soils used by smallholder farmers in Zimbabwe and represent a large and (if properly managed) valuable resource (330 Mha) in sub-saharan Africa. Dependant on the availability and condition of draught animals and implements, they are normally cultivated annually to a depth of 75 to 200 mm. A typical topsoil at MES, consists of 94% sand, 3.5% silt and 2.5% clay. The change from topsoil to subsoil occurs at about 300 mm, with a 1% increase in clay content, which continues to increase with depth from a loamy sand to sandy clay loam. Bulk density was 1.38 t /m^3 in the top 300 mm after cultivation, increasing to 1.45 t/m^3 at depth. The plant-available water capacity (AWC) at MES defined as the amount of soil water freely available to plants and held between -0.01 and -1.5 MPa, was estimated by Twomlow (1994) to be 6.2% by volume. This low AWC means that crops grown on these soils are prone to drought, as any extra water quickly drains below the rooting zone.

The trial was maintained on the same site for two years. After an overall spring ploughing with a single-furrow, ox-drawn mouldboard, the trial site was laid out in randomized blocks with four replications of each hand weeding treatment. These were hand weeding at: A) 2 weeks, B) 2 and 4 weeks, C) 2, 4 and 6 weeks, D) 4 weeks, E) 4 and 6 weeks, F) 4, 6 and 8 weeks after crop emergence, G) weed free, and H) no weeding. Maize hybrid R201 was hand planted 80 mm deep at a 0.9 m by 0.3 m spacing, in plots measuring 10 m by 5.4 m on 10 December 1991 and 28 November 1992. Fertilizer, 12 kg N, 21 kg P, and 14 kg K/ha, was applied at planting and crops were top dressed with 52 kg/ha of N at four, six and eight weeks after planting. Total crop biomass and grain yield, adjusted to 12.5% moisture content, were determined. Total weed numbers were recorded from quadrats of 0.6 by 0.45 m at five random positions in each plot prior to each weeding operation and total weed biomass was sampled at harvest. Weed and crop data was subjected to an analysis of variance and treatment comparisons were made using Fishers protected LSD ($P < 0.05$).

Soil water content profiles were determined with a Wallingford Neutron Probe Moisture Meter, calibrated for this soil (Riches *et al.*, 1997), at weekly intervals from planting in 1991.

Measurements were made within the crop row on three replicates of treatments A, C, D, G and H at 100 mm depth intervals to a maximum of 800 mm. These were supplemented by volumetric sampling of the top 150 mm of the profile. Volumetric water content was subjected to an analysis of variance by date and by treatment. Comparisons of means were made using Fishers protected LSD ($P < 0.05$). Total seasonal water use was calculated from rainfall and the soil-water balance between the date of sowing and the harvest of the crop. No attempt was made to distinguish between soil evaporation and crop transpiration. The ratio of total above-ground dry matter production (crop biomass) to total seasonal water use provided an estimate of water use efficiency (WUE) at harvest. WUE was expressed as:

WUE (kg/ha/mm) = crop biomass (kg/ha) / water use (mm).

RESULTS AND DISCUSSION

Total rainfall, and its seasonal distribution at MES varied considerably between the two cropping seasons (Table 1). Drought conditions prevailed throughout the 1991/92 season and no grain was produced by the test crop of maize, which died in early March 1992. However, weeding frequency did have a very significant ($P<0.001$) effect on stover production in 1991/92 (Table 2). As might be expected, most stover was harvested from plots that had been kept weed free all season. Plots left unweeded, or weeded only once 2 weeks after emergence yielded significantly less than the other treatments. Lowest weed dry weights at harvest were recorded on plots weeded at 2 and 4 weeks, but there was no significant difference in weed dry weight between unweeded plots and those weeded at 4 weeks, 4 and 6 weeks or 6 and 8 weeks (Figure 1) .

Table 2. Maize grain and stover yield (kg/ ha) responses to time and frequency of weeding at Makoholi Experimental Station

Weeding Treatment	1991/92	1992/93	
	Dry stover yield kg/ha	Dry stover yield kg/ha	Grain yield @12.5% m.c. kg/ha
A - weed at 2 wks	416	1266	1436
B - weed at 2 + 4 wks	870	1449	2135
C - weed at 2+4+6 wks	740	1605	2262
D - weed at 4 wks	814	1152	2081
E - weed at 4+6 wks	703	1232	2108
F - weed at 4+6+8 wks	879	1133	2050
G - kept weed free	990	1345	1684
H - unweeded control	268	485	520
s.e.d.#	132.17***	252.6*	545.4

Significant treatment effect * $P > 0.05$; *** $P>0.001$

Yields during the 1992/93 season, when seasonal rainfall was above average (Table 1), were again associated with the level of weed control (Table 2). Plots that received their first

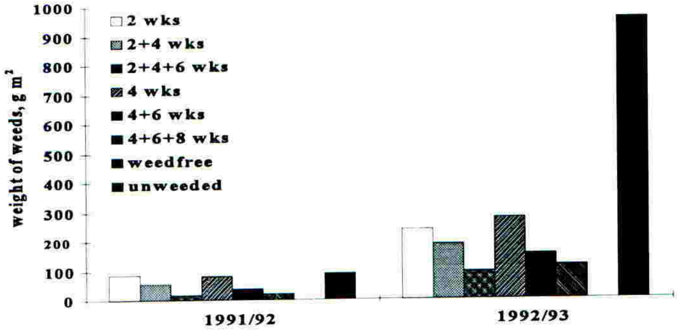

Figure 1. Weed dry weights (g/m^2) at harvest after eight different weeding regimes in 1991/92 (s.e.d 18.87) and 1992/93 (s.e.d. 195.43)

weeding 4 weeks after emergence yielded less stover than plots weeded at 2 weeks. However, these effects were not repeated for grain yield; plots weeded once 2 weeks after emergence yielded the least of the weeded plots. The lowest yields were recorded on the unweeded plots, which produced significantly (*P <0.001*) less stover and less grain than the weeded plots (Table 2) and had the highest weed biomass at harvest (Figure 1). For the other weeding treatments weed biomass at harvest declined with increasing frequency of weeding, the plots weeded once at either 2 or 4 weeks having a greater weed biomass than plots weeded two or three times. The significant effects of time and frequency of weeding on weed numbers can be seen in Table 3 and the build up of weeds on plots that had received a single weeding.

Table 3. Number of weeds per m^2 prior to weeding at 4,6 or 8 weeks, and at 10 and 12 weeks after crop emergence and at harvest in 1992/93 at Makoholi

	Weeks after emergence					
Weeding Treatment	4	6	8	10	12	Harvest
A - weed at 2 wks	10.6	36.2	32.4	21.9	24.3	20.0
B - weed at 2 + 4 wks	5.8	5.2	0.8	1.6	3.7	7.7
C - weed at 2+4+6 wks	5.8	4.1	0.9	0.6	1.8	1.7
D - weed at 4 wks	23.9	46.8	20.3	13.5	30.9	16.3
E - weed at 4+6 wks	16.8	30.8	1.4	0.5	4.8	7.8
F - weed at 4+6+8 wks	14.2	42.4	1.2	0.0	7.1	10.3
H - unweeded control	33.7	95.4	31.6	46.0	46.2	22.6
s.e.d.#	7.77**	32.6	8.8***	12.09***	14.30*	3.61***

Significant treatment effect * *P<0.05;* ** *P < 0.01;* *** *P<0.001*

Rooting patterns of common weed species on the trial plots over the two seasons varied considerable. The dominant grass species, *Eleusine indica,* and the broad leaf species *Gisekia pharnaceoides*, which can grow rapidly early in the season, root in the zone above the maize roots and apparently compete for available soil moisture directly with the crop. Two other common weed species, *Hibiscus meeusei* and *Richardia scabra,* have deep tap roots that penetrate much more deeply into the soil and exploit a larger soil volume than the maize crop.

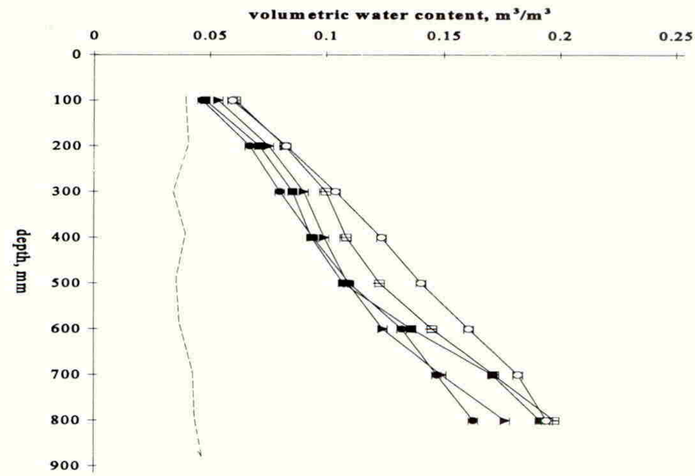

Figure 2. Variation in average volumetric water (m^3/m^3) for five different weeding regimes at Makoholi for the 1992/93 season □ 2 weeks: ■ 2+4+6 weeks: ▴ 4 weeks: ◦ weedfree: •unweeded control: --------- unavailable water content: ⊢ s.e.d.

These qualitative observations are supported by quantitative measurements of soil water content made throughout each growing season. Figure 2 shows the *in situ* variation in average seasonal soil water content with depth for five treatments A, C, D, G and H. As expected, Treatment G, the weed free control is significantly (*P<0.001*) wetter than the other treatments. With the exception of Treatment A, the single weeding at 2 weeks, the other treatments behave very similarly in the top 500 mm of the profile. However, below this depth under Treatment D, weeding at 4 weeks, and Treatment H the unweeded control, it became significantly drier than following weeding at 2, 4 and 6 weeks. These differences can be attributed to lower levels of weed infestation (Figure 1 and Table 3) and the dominance of *Hibiscus* and *Richardia* inTreatments D and H.

Data for total crop biomass production, water use and WUE by the crop in response to Treatments A, C, D, G and H are summarised in Table 4. Water consumption by the crop

Table 4. Total crop biomass (kg/ha), total crop water use (mm/ha) and water use efficiency (WUE, kg/mm) in response to time and frequency of weeding at Makoholi

Weeding Treatment	1991/92			1992/93		
	Biomass	Crop water use	WUE	Biomass	Crop water use	WUE
A - weed at 2 wks	760	218.9	3.47	3143	396.4	7.89
C - weed at 2+4+6 wks	1350	210.3	6.42	4147	367.9	11.17
D - weed at 4 wks	1485	214.9	6.91	3235	411.2	8.13
G -kept weed free	1805	163.8	11.01	3178	393.1	8.09
H - unweeded control	489	210.0	2.33	1014.0	465.4	2.17
s.e.d.#	132.1***	6.63***	1.75***	496.5**	11.12***	1.467**

Significant treatment effect ** *P < 0.01; *** P<0.001*

clearly reflects the impact of seasonal rainfall and weed control. In 1991/92, crop water use varied between 160 and 220 mm, with the weed free crop consuming significantly (*P<0.001*) less water than the other treatments. This is in contrast to 1992/93 when the unweeded control consumed significantly (*P<0.001*) more water than the other treatments. However, total biomass production and WUE varied dramatically between seasons and weeding systems. Over the two seasons, weeding at 2,4 and 6 weeks had the best biomass and WUE, which were significantly (*P<0.01*) greater than the other treatments in 1992/93. The unweeded control performed significantly (*P>0.001*) worse than any of the other treatments.

CONCLUSIONS

Results from two very different seasons show that soil water regimes and crop yields are strongly influenced by the timing and frequency of weeding. In terms of crop WUE and grain yield, weeding at 2, 4 and 6 weeks after crop emergence performed best, whilst a single weeding two weeks after crop emergence was the worst of the weeding treatments. As expected, the driest profiles and lowest yields were observed under the unweeded control.

ACKNOWLEDGEMENTS

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CONSTRAINTS AND OPPORTUNITIES FOR WEED MANAGEMENT IN RAINFED LOWLAND RICE

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ABSTRACT

In the rainfed lowlands of S.E. Asia, the yield of dry direct seeded rice is routinely constrained by rapidly growing weed communities that establish during the early life of the crop. We investigated the opportunity of using a stale seed bed (rotovation and glyphosate application prior to crop sowing) for early weed control in comparison to conventional farmer practice (rotovation, furrowing and immediate seeding on arrival of rains). These treatments were factorially combined with two pre-emergence herbicide treatments, butachlor and oxadiazon, and with and without additional manual weeding. Stale seed bed land preparation showed two positive benefits - the potential for yield increase in rice and the control of a major weed, *Echinochloa colona*. However early indicators of yield potential (high stand count, and tiller number) were not translated into final grain yield because of the onset of drought, and farmer practice gave higher final yield. Pre-emergence application of butachlor and oxadiazon caused *Cynodon dactylon* and *Cyperus rotundus* to increase in relative abundance in the weed community regardless of land preparation method. Conventional land preparation and herbicide application was most effective in controlling *Fimbristylis miliacea*. These data illustrate the complexity of weed management in the rainfed tropics and point to the need for improved weed control techniques.

INTRODUCTION

Dry direct seeding of rice (DSR) is a traditional practice developed by rice farmers to suit agro-ecological conditions, particularly rainfall uncertainty, in the tropics (Hossain, 1995). Several million hectares are dry direct seeded each year, DSR being used extensively in India, Thailand, Philippines, Vietnam and Indonesia. In rainfed lowlands, farmers await the onset of rains at the end of the dry season and, given sufficient soil moisture, cultivate and sow. Typically, weed communities establish concurrently with the crop. Dry seeded rice may be broadcast, drill seeded in rows or planted in hills and the latter two methods give greater opportunity for post emergence weed control by inter-row cultivation and manual weeding which occurs before canopy closure. With increasing labour shortages, farmers recognise that herbicides can provide effective alternative weed control. However, herbicide efficacy for weed management is potentially very variable due to the interaction of a wide range of environmental and biotic factors (Moody *et al.*, 1986). Moreover the repeated use of herbicides in association with DSR in irrigated lowlands has led to shifts in weed community composition and the persistence of hard-to-kill weeds (Itoh, 1991).

Castin and Moody (1985) pointed to the need for continued research to develop appropriate land preparation methods as part of an integrated weed management approach for dry seeded rice for small scale farmers. Cultivation coupled with the use of non-selective herbicides is one approach to providing a stale seed bed prior to crop establishment that provides an opportunity to reduce dependency upon post emergence weed control. We report here a field trial comparing weed management achieved by conventional farmer practice with that resulting from the use of a stale seed bed and its effects on rice yield and weed community structure under dry seeded rainfed lowland rice cropping.

MATERIALS AND METHODS

The experiment was conducted on farm land at the Rainfed Lowland Consortium Site at Tarlac, Luzon in the Philippines in the wet season of 1996. Earlier surveys identified land with a visually homogeneous weed flora.

Land preparation treatments contrasted conventional farmer practice (rotovation, furrowing and immediate seeding) with the use of a stale seed bed technique (rotovation and glyphosate, applied at each of two rates, prior to crop establishment). Details of the treatments, crop husbandry and sequence of operations are given in Table 1 and Figure 1.

Table 1. Experimental treatments. ([1] Days after sowing; [2] Days after emergence).

Land preparation treatments

S1	Stale seed bed preparation.	Land rotovated and left for 22 days for weed emergence, then sprayed with glyphosate at a rate of 0.96 kg a.i. ha^{-1}. One day later, rice was sown by dibbling seed to a depth of 1-2 cm at a rate of 70 kg ha^{-1} on a regular grid.
S2	Stale seed bed preparation.	As S1, but with glyphosate sprayed at a rate of 1.2 kg a.i. ha^{-1}.
C	Conventional planting.	Land was rotovated, furrowed and seeded on the same day. Rice was dry seeded by hand in furrows to 1 - 2 cm depth at a rate of 110 kg ha^{-1} and then covered.

Weed control treatments

1. Butachlor (1 DAS [1]) at a rate of 1.5 kg a.i. ha^{-1}.
2. Butachlor (1 DAS) at a rate of 1.5 kg a.i. ha^{-1} + 1 manual weeding (28 DAE [2]).
3. Oxadiazon (1 DAS) at a rate of 0.625 kg a.i. ha^{-1}.
4. Oxadiazon (1 DAS) at a rate of 0.625 kg a.i. ha^{-1} + 1 manual weeding (28 DAE).
5. Manual weeding (7, 28 and 40 DAE) - weed free check.
6. Unweeded.

Rice seed (cv. IR72) was manually sown in rows. Conventional farmer practice is to use a higher seed rate than that chosen here for the stale seed bed treatment, based on past trials. The pre-emergence herbicides butachlor (for annual grass and sedge control) and oxadiazon (grass and broad-leaved weed control) were applied by boom sprayer immediately after seeding. These treatments were compared with and without additional manual weeding.

The experiment was conducted using a split plot randomised block design with four replicates. Land preparation treatments were main plots with subplots (5 x 4 m) being weed control treatments. Forty four days after emergence, when rice tillering had ceased and canopy closure had occurred, destructive harvests were taken to estimate weed biomass (dried to constant weight) remaining after weed control treatments. Two 50 x 50 cm randomly placed quadrats were destructively sampled in each subplot.

RESULTS

In comparison to conventional planting, the stale seed bed preparation delayed crop sowing by 22 days to allow weed emergence. In consequence, crops received different precipitation patterns (Fig. 1) during their growth period.

Crop yield

Averaging across main plots, crop grain yield per unit area in plots subject to weed control (Treatments 1 - 4, Table 1) was significantly ($P \leq 0.001$) greater than in the unweeded plots. However no significant differences were found amongst weed control treatments in final grain yield. A mean yield increase of 47% resulted from weed control treatments.

Yield component analysis of rice from weed free plots illustrated that final yield construction differed in relation to the effects of initial land preparation (Table 2). Noticeable compensatory processes occurred throughout crop development. Under conventional land practice C, 58% of sown seed failed to establish. Stand density was significantly improved by use of the stale seed bed, although the higher rate of glyphosate (S2) appeared to damage the crop. Higher stand density was translated into higher number of productive tillers per m^2, this being at least two fold higher in glyphosate treated plots (S1 and S2) than in conventional ones (C). However higher potential yield was not realised in these plots because delayed planting exposed the crop to increasing drought (Fig. 1) in late October 1996 with consequent failure of grain fill. Final grain yield per unit area was highest in conventionally prepared plots (Table 2).

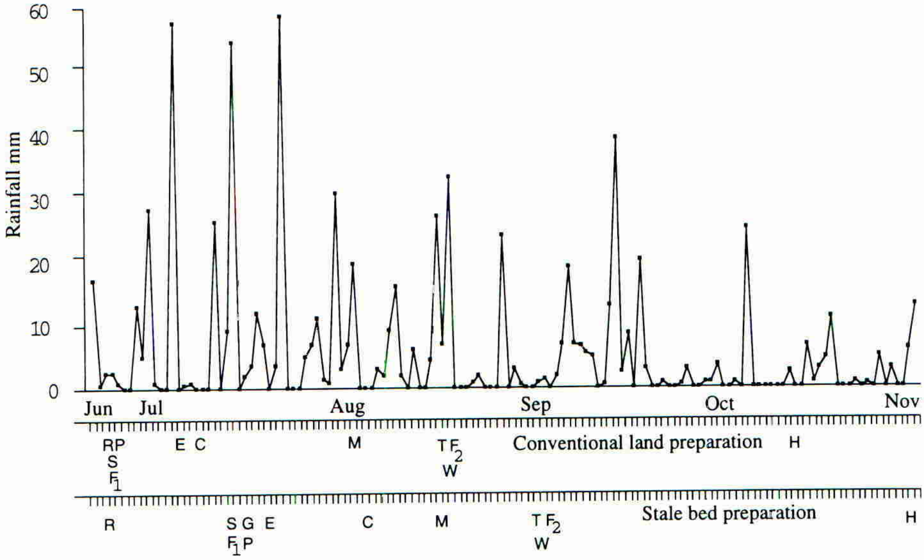
Table 2. Rice yield components in weed free plots (Treatment 5, Table 1) in relation to land preparation. C = conventional practice, S1 and S2 stale seed beds.

	Land preparation			LSD ($P \leq 0.05$)
	S1	S2	C	
Seeding rate (seeds m^{-2})	320.0	320.0	468.0	
Established stand density (plants m^{-2})	288.1	232.7	195.3	42.9
Productive tillers (tillers m^{-2})	619.0	663.0	290.0	115.1
Grain yield (kg ha^{-1})	885.3	979.8	1775.4	376.2

Weed community structure

In general in all weed control treatments, total weed biomass at the time of canopy closure 44 DAE (Table 3) tended to be higher in S2 than S1 plots although differences were mostly non-significant. Weed biomass was higher in conventionally prepared plots, C, except where there was no weed control. Weed biomass was similar in plots treated with butachlor and oxadiazon, and was further reduced by additional manual weeding.

Figure 1. Rainfall and timing of crop husbandry and treatment applications in 1996.



Weed free check manually weeded 7, 28 and 40 DAE (7 and 22 July)

R = rotovation and furrowing; S = rice seeding; E = Emergence
F_1 = basal fertiliser (60-60-60 NPK / ha); F_2 = top dressing fertiliser (40 N / ha)
G = glyphosate application; P = pre-emergence herbicide; M = manual weeding;
C = stand count ; T= productive tiller count; W = weed biomass sampling; H = crop harvest

Figure 2. Weed community structure according to weed mangement.

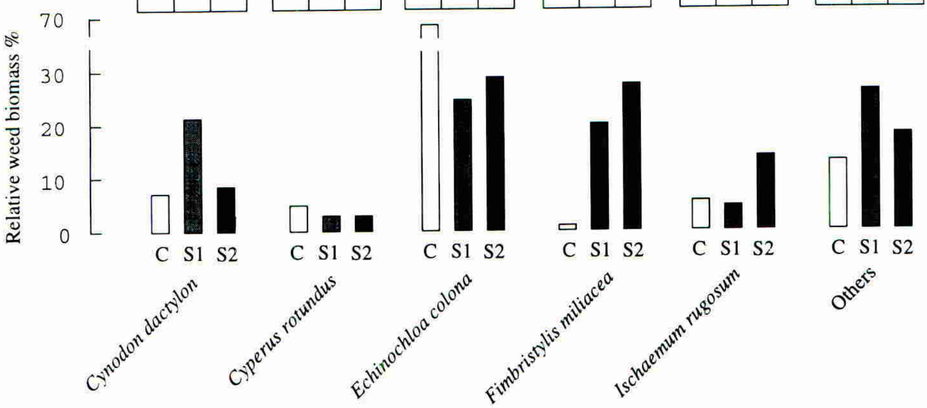
a) Bars show the contributions of five major weed species and others in the unweeded plots (Treatment 6, Table 1) according to initial land management as % composition of the total weed biomass, 44 DAE.

b) Grids display the multiplicative changes in biomass allocation by species as a result of pre-emergence herbicide treatments. Values > 1 signify increase, < 1 decrease and - absence of the species. 'Others' comprise 16 weed species common to rainfed lowlands in the Philippines.

b)

Pre-emergence herbicide																		
Butachlor	3.4	2.7	3.4	7.5	4.6	4.4	0.5	0.1	0.4	-	0.1	0.6	0.2	1.9	0.9	0.3	0.6	0.3
Oxadiazon	5.5	2.7	6.9	8.6	4.9	1.7	0.3	0.2	0.1	-	-	-	-	2.8	0.3	0.1	0.5	0.6

a)



Initial land preparation affected the subsequent composition of the weed flora. Stale seed bed techniques noticeably reduced the relative proportion of *Echinochloa colona* (Fig. 2 a) but encouraged *Fimbristylis miliacea* in the weed community. The use of selective chemical control (butachlor and oxadiazon) altered these proportions further (Fig. 2 b). Both chemicals imposed reductions on *E. colona* and *F. miliacea* but increased the proportion of *Cynodon dactylon* and *Cyperus rotundus*. The highest increase in abundance of these latter species was generally seen under conventional land preparation. Contrastingly, an increase in the proportion of *Ischaemum rugosum* was evident under S1 land preparation but not under S2 and C treatment. The remaining species in the community ('Others') also declined proportionally under chemical control.

Table 3. Mean weed biomass (g dw m^{-2}) in plots 44 days after crop emergence in relation to land preparation and weed control treatment. See Table 1 for details. LSD ($P \leq 0.05$) = 28.6.

	Land preparation		
Weed control treatment	S1	S2	C
Butachlor	92.8	121.7	266.0
Butachlor + 1 hand weeding	5.9	25.7	90.3
Oxadiazon	87.1	117.4	264.3
Oxadiazon + 1 hand weeding	7.9	5.3	76.3
Unweeded	169.2	306.7	262.9

DISCUSSION

Cousens & Mortimer (1995) comment on the need to understand the importance of tillage practices in determining weed community dynamics and this study illustrates some of the complexities and processes occurring in weed-crop interactions in direct seeded rice that result in yield under rainfed lowland farming.

Stale seed bed land preparation using glyphosate showed two positive benefits - the potential for yield increase in rice and the control of *Echinochloa colona*. However, glyphosate application rate clearly had an important impact on rice-weed interactions. The higher rate appeared to damage the crop and resulted in lower rice stand establishment thus altering the crop density in the early life of the weed-crop community. Noticeable mortality of rice seedlings was not visible, suggesting that reductions occurred soon after germination but the precise mechanisms are unknown. Elevated weed biomass in S2 compared to S1 may therefore be a consequence of reduced competition from rice. Despite this, compensatory tillering resulted in similar productive tiller densities in S1 and S2, 44 DAE (Table 2), which were double those observed under conventional practice, C, from a higher seeding rate. The cause of seedling losses in conventional practice is unclear but may have resulted from shallow seeding.

Pre emergence application of butachlor and oxadiazon resulted in significant reductions in weed biomass but there was no additional benefit from further hand weeding. This is in contrast to findings elsewhere (e.g. Moody, 1991) which indicate that economic returns can be accrued from supplementing normal weed management practices of farmers.

The data also suggest that particular weed species (*C. dactylon, F. miliacea* and *I. rugosum*) were encouraged in stale bed treated plots (Fig. 2 a) but not at the expense of others. Subsequent pre-emergence application of butachlor and oxadiazon acted as additional agents of interspecific selection, *C. dactylon* and *C. rotundus* increasing in relative abundance in the weed community. Given the routine use of these chemicals in subsequent monocropping, the data suggest that weed species substitution may occur, *C. dactylon* and *C. rotundus* replacing *E. colona* and *F. miliacea*, at rates governed in part by their relative reproductive capacities.

Adoption of a new weed control technology is contingent on the associated risk of crop failure. This experiment illustrates the underlying importance of early crop establishment, well known to farmers of rainfed lowlands. Uncertainty of the length of the growing season will be a major factor causing reluctance to consider protracted seed bed preparation treatments for weed control. Twenty two days elapsed in this study to promote substantial weed growth after rotovation prior to glyphosate application. This time period probably may be shortened or cultivation initiated earlier in the season but such opportunities will be dependent on local rainfall patterns early in the season. The trade-off between the advantage of substantial weed control early in the season as against the disadvantage of risk of drought at grain filling is likely to make lowland rice farmers risk averse and to encourage the use of early planting and post emergence weed control practices. A second source of risk, however, is long term change in the weed flora for future crops. It may be inferred from these data that continued use of butachlor and oxadiazon will result in increases in *C. rotundus* and *C. dactylon*. The former is particularly undesirable due to the noted difficulties in managing this weed (Doll, 1994). Whilst the use of glyphosate coupled with early land preparation may reduce weed species abundance and the rate of increase of *C. dactylon* and *C. rotundus*, additional pre- or post-emergence weed management will still be required for high rice yields.

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THE RESPONSE OF *O. GLABERRIMA*, *O. SATIVA* AND AN INTERSPECIFIC HYBRID RICE CULTIVAR TO WEED COMPETITION

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ABSTRACT

Weeds are a major constraint to rice production in the uplands and rainfed lowlands of West Africa. The availability of rice cultivars which are competitive with weeds would make a major contribution to improving the returns to traditional farming systems.

In a field experiment, a cultivar of *Oryza glaberrima*, two *O. sativa* cultivars and an *O. sativa* x *O. glaberrima* interspecific hybrid were grown with and without competition with weeds. The growth of weeds and rice was recorded at regular intervals throughout crop duration. The *O. glaberrima* had less weed growth than the improved *O. sativa* cultivars by the end of the crop growth. The *O. glaberrima* produced a larger number of tillers, more leaves, and a higher leaf area index and specific leaf area than the *O. sativa* cultivars. These characteristics make important contributions to competitiveness with weeds. The interspecific hybrid shared some, but not all of these characteristics with the *O. glaberrima*. The potential for further development of a weed competitive rice plants is discussed.

INTRODUCTION

Upland rice is the major rice production system in West Africa and is largely grown by farmers with scarce resources. In a farm survey, weeds were the most cited rice pest and almost 80% of farmers questioned stated they would increase the rice area grown if weeds were less of a problem (Adesina *et al.* 1994). Similar situations are found elsewhere in the world, where upland rice provides the staple for 100 million people (Arraudeau, 1995). In Asia, Latin America and Africa, yield losses in rice caused by weeds are thought to be 15-21% (Oerke *et al.*, 1995) with the highest losses tending to occur in the upland and rainfed lowland systems.

In the humid forest zone of West Africa, rice tends to be grown after the forest has been cut and burnt, and following one or two crops the land is left as fallow. In the savanna zones, the land may be cropped for longer periods before being left to fallow. Increasing demands for land is causing cropping intensification and with it, increasing levels of weed infestation. Commonly, farmers rely on hand weeding to control the weeds in the crop and use few purchased inputs, only a small proportion of farmers rely on herbicides (Adesina *et al.* 1994). Farmers usually weed the rice crop at least once, though due to the demands of other crops or labour shortage, this is often delayed.

Asian farmers who replaced traditional, tall rice cultivars with short statured improved cultivars reported that more time was required for weeding, either suggesting that more weeds grew with the modern varieties, or that farmers were expecting a higher return from weeding (Moody, 1979). Differences in the response of rice cultivars to weed competition have been recorded mainly in Asia (Moody, 1979; Garrity *et al.*, 1992), but also in Africa (Merlier and Deat, 1978; Fofana *et al.*, 1995). In Latin America, Kawano *et al.* (1974) concluded that high vegetative vigour and tall stature were major factors influencing the competitive ability of rice plants with weeds. Similar findings have recently been reported for wheat (Lemerle *et al.* 1996).

Weed competitiveness is an important criteria for the selection, at the West Africa Rice Development Association, for rice cultivars able to produce high and stable yields under low input conditions. In earlier studies, within a wide selection of plant types grown in the region, including *Oryza glaberrima*, and traditional and improved *O. sativa*, lower weed weights at harvest were correlated with those cultivars with more tillers and higher leaf area indices in the vegetative stages of growth (Fofana *et al.*, 1995). The *O. glaberrima* while not producing the highest yields under clean weeded conditions, were able to produce better yields and were more competitive with weeds than most of the *O. sativa* cultivars tested. The low yield potential and the tendency for the grains to shatter and the crop to lodge, has led to *O. glaberrima* being replaced in the majority of the cropping systems by *O. sativa*. However, competitiveness with weeds is one of the attributes which makes this species attractive for use in breeding programmes (Dingkuhn *et al*, 1996), and recent advances in plant breeding has enabled *O. sativa* to be crossed with *O. glaberrima* (Jones *et al.*, 1997).

In West Africa, weed competitive rice cultivars will have an important role to play in the upland, hydromorphic, and direct seeded systems, where the losses due to weeds tend to be greatest. In order to gain a better understanding of crop growth in competition with weeds, detailed studies were conducted. In these experiments, the cultivars used were representative of distinct plant types of relevance to the plant breeders.

METHODS

The experiment was sited on a free-draining Alfisol, 300 m amsl, near Bouaké in Côte d'Ivoire (5' 06 W 7' 52 N) and grown during the main wet season and sown on June 29, 1996. Overhead sprinkler irrigation was used to supplement rainfall, to ensure the rice received a minimum of 200 mm of rainfall per month during the experiment. Mean maximum and minimum temperatures (1981-94) for the area were 28.1 and 20.8 °C. The site is within the derived savanna zone and had been cleared from natural vegetation in 1994, and maize was subsequently grown. The land was ploughed and harrowed at the end of the dry season in preparation for the experiment. Fertilizer applications to all plots were 20 kg P and 50 kg K ha^{-1} to the seedbed, and 46 kg N ha^{-1} in two equal split applications between 28 and 56 days after emergence (DAE).

The experiment comprised two factors, rice cultivars and weed management, in a complete randomized block design, with 6 replications. The rice cultivars were: IG10, an *Oryza* *glaberrima*; Moroberekan, a traditional *O. sativa* upland *japonica*; IDSA 6, an improved *O. sativa* upland *japonica*, and V4 (WAB 450-24-3-2-P18-HB) a hybrid *O. glaberrima* x *O. sativa* from parents other than those above. The weed management regimes were: W0 = weed free throughout crop, with an application of oxadiazon 0.875 kg ha^{-1} followed by hand weeding; W14 = maintained weed free 0-14 DAE by hand weeding, after which weeds allowed to grow; W28 = one hand weeding 28 DAE. The experiment included plots with no rice where weed growth was monitored, and these were managed as for the rice except that in W0, the plots were unweeded. To make the weed growth in the experiment more uniform, 1.5 g of seed of each *Ageratum conyzoides* and *Digitaria horizontalis* were broadcast on each plot.

Plots were 5 m x 3.5 m and were divided into an area for destructive sampling and another for non-destructive data collection and harvest data. Rice was dibble sown in holes 25 cm apart, with 3 seeds per hole, thinned to two seedlings at 7 DAE. At 21, 35, 49, 63, 77 and 91 DAE, the number of green leaves and number of tillers from 10 rice hills was recorded, and the leaf area index of the canopy measured with a LI2000 meter (Licor Inc., Lincoln, USA). At these dates, in two 0.25 m^2 sample areas, the rice plants were cut, separated into stem, green and dead leaf, and weeds were cut at ground-level, separated by species. Specific leaf area (SLA), or leaf area for given dry leaf weight, was measured for the rice cultivars in all treatment combinations. Relative growth rates (RGR) for the exponential and linear growth phases were calculated following Hunt (1978). At harvest, tiller and panicle numbers, the proportion of filled and empty grains and rice plant dry weights, divided into stem and leaf weights, were recorded from 10 hills (0.6 m^{-2}) and grain weight was taken from a 4m^{-2} area.

RESULTS

The interaction effects of cultivar and weeding regime were not significant for LAI, SLA, tiller number, rice or weed weight, and hence only the main effects of cultivar are shown in Table 1. At 21 DAE, IG10 and V4 had the higher LAI than Moroberekan or IDSA6, though by 49 DAE, IG10 had 50% greater leaf area than V4 and almost twice the leaf area of the two *O. sativa* cultivars. At 49 DAE, IG10 and V4 had almost identical green leaf biomass, and some 22% more than Moroberekan and IDSA 6, which were also very similar (data not presented). The SLA of IG10, however, was about 50% higher than Moroberekan, IDSA6, or V4. Between 21-35 DAE, IG10 partitioned a higher proportion of the increasing biomass to leaf production rather than stem, with leaf partitioning coefficients for IG10, Moroberekan, IDSA6 and V4 of 0.506, 0.489, 0.468 and 0.432, SE $\pm$ 0.0099. IG10 produced the most tillers, followed by IDSA6, V4 and Moroberekan, and further, IG10 produced the first tillers at 15 DAE, or about 5 days before the other cultivars.

At 49 DAE, V4 had the highest rice plant weight followed by IG10, and by 91 DAE these cultivars had greater plant weight than either Moroberekan or IDSA 6 (Table 1). The relative growth rates of the rice between 0-35 DAE, did not differ between cultivars, but across cultivars were least for the plots weeded once at 28 DAE, with values for 10.5, 10.5, and 8.3 % day^{-1}, S.E $\pm$ 0.18 for treatments W0, W14 and W28 respectively. Between 35-63 DAE, the *O. sativa* cultivars had lower growth rates of 4.2% for IDSA6 and 4.3% for Moroberekan compared to 5.3 and 5.4% day^{-1} (S.E $\pm$ 0.23) for the hybrid and IG10 respectively.

Table 1. Rice and weed growth, main effects of cultivar (means across three weeding regimes), Côte d'Ivoire, 1996

	LAI		SLA m^{-2} kg	Tiller numbers m^{-2}		Rice plant wt g m^{-2}		Weed wt g m^{-2}	Grain Yield g m^{-2}	Relative yield[1]
	DAE									
Cultivar	21	49	56	49	91	49	91	91	-	-
IG10	0.112	1.42	32	245	202	109	453	58	238	0.74
Moro.	0.079	0.78	22	108	89	96	311	91	184	0.54
IDSA6	0.076	0.76	21	188	146	99	331	78	197	0.60
V4	0.107	0.94	21	145	128	141	435	83	223	0.57
No rice	-	-		-	-	-	-	202	-	-
SE[2] ±	0.0083	0.057	0.4	5.62	5.22	7.7	21.2	10.2	9.0	0.038

[1] Mean grain yield of plots with weeds (W14 & W28) as a proportion of weed-free plots W0.
[2] Based on 61 df

At 84 DAE, Moroberekan at 120.1 cm was the tallest cultivar followed by V4 117.6, IG10 107.3 and IDSA6 104.1, S.E ± 2.04. Across weeding regimes, the rice was shortest in W28, and W0 and W14 did not differ in height; there were no interaction effects. At 91 DAE, there was more than twice the weed growth in those plots where no rice was sown, compared to where rice had been sown and where the weeding regimes were identical. The least weed growth occurred in the plots sown to IG10.

Across the weeding regimes, V4 and IG10 had a higher grain yield than Moroberekan and IDSA6. Under weed free conditions, there were no significant differences between the cultivars, with V4 giving the highest value of 313 g m^{-2} and a mean yield across cultivars of 279 g m^{-2}. The grain yield in competition with weeds relative to the clean weeded plots, i.e. relative yield, was greater with IG10 than the other cultivars.

DISCUSSION

The *O. glaberrima*, IG10, had the lowest weed growth in the plots and the most stable yield across weeding regimes among the cultivars grown and this competitive ability with weeds is consistent with the findings of Fofana *et al.*, (1995). In these subsequent and more detailed studies it has been shown that IG10 has high RGR in the vegetative stages of the crop and partitions a higher proportion of the increasing biomass to the leaves compared to other cultivars. The high SLA of IG10 compared to the other cutivars, enables the production of a greater leaf area for a given leaf biomass and gives a considerable advantage in the early establishment of a leaf canopy. The *O. glaberrima* x *O. sativa* hybrid, V4, shared a number of characteristics with IG10, such as the high biomass accumulation, and early establishment of a high LAI, but did not however have the advantage of the higher SLA. In the clean weeded plots V4 produced the highest grain yield, but this was reduced considerably in competition with weeds.

Tiller production is an important characteristic in many low input situations. Koffi (1980) reported the high tiller production of *O. glaberrima* and a capacity to produce tillers after a late hand weeding, which was not found in *O. sativa*. Tillering enables the rice plant to adapt to variable plant populations and "expand into gaps" in the crop area, a situation common in upland fields where establishment can be variable. An ability to tiller early, facilitates rapid ground cover, while late tillering enables the crop to recover after a late weeding. In this experiment, V4 did not show the high tillering capacity of IG10, and this characteristic should be sought among other *O. sativa* x *O. glaberrima* hybrids.

The *O. glaberrima* genepool has the potential to introduce a number of characteristics such as rapid establishment of a crop canopy, good suppression of weeds and good yield stability across a range of conditions. To introduce these characteristics into hybrids of *O. sativa* and *O. glaberrima*, without sacrificing the potential for high grain yield in good growing conditions and resistance to other pests and diseases remains a major task. The breeding programme to develop suitable "low management" plant types is currently producing a large number of progeny from *O. sativa* and *O. glaberrima* parents. To fully exploit these materials, improved mass screening methods and "tools" are required to identify desirable plant types at the earliest possible stage in the breeding process, and this is currently the subject of intensive study.

ACKNOWLEDGEMENTS

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MECHANICAL WEED CONTROL : THE CASE OF HAND WEEDERS

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ABSTRACT

Four hand weeders, the badza, garden hoe, side grip and the T-bar were evaluated from an ergonomic and mechanical point of view, for three seasons (1992-95) in Zimbabwe. Eight women, experienced in the use of these weeders, carried out the weeding operations in maize while the data on heart rate, work-rate, weeding efficiency and working posture was collected. The relationship between weeders and work-rates versus heart rates and weeding efficiencies and energy demand was established. The results, indicated that manual weeding is strenuous and physically demanding and that the highest work rate may be achieved with a garden hoe with little discomfort.

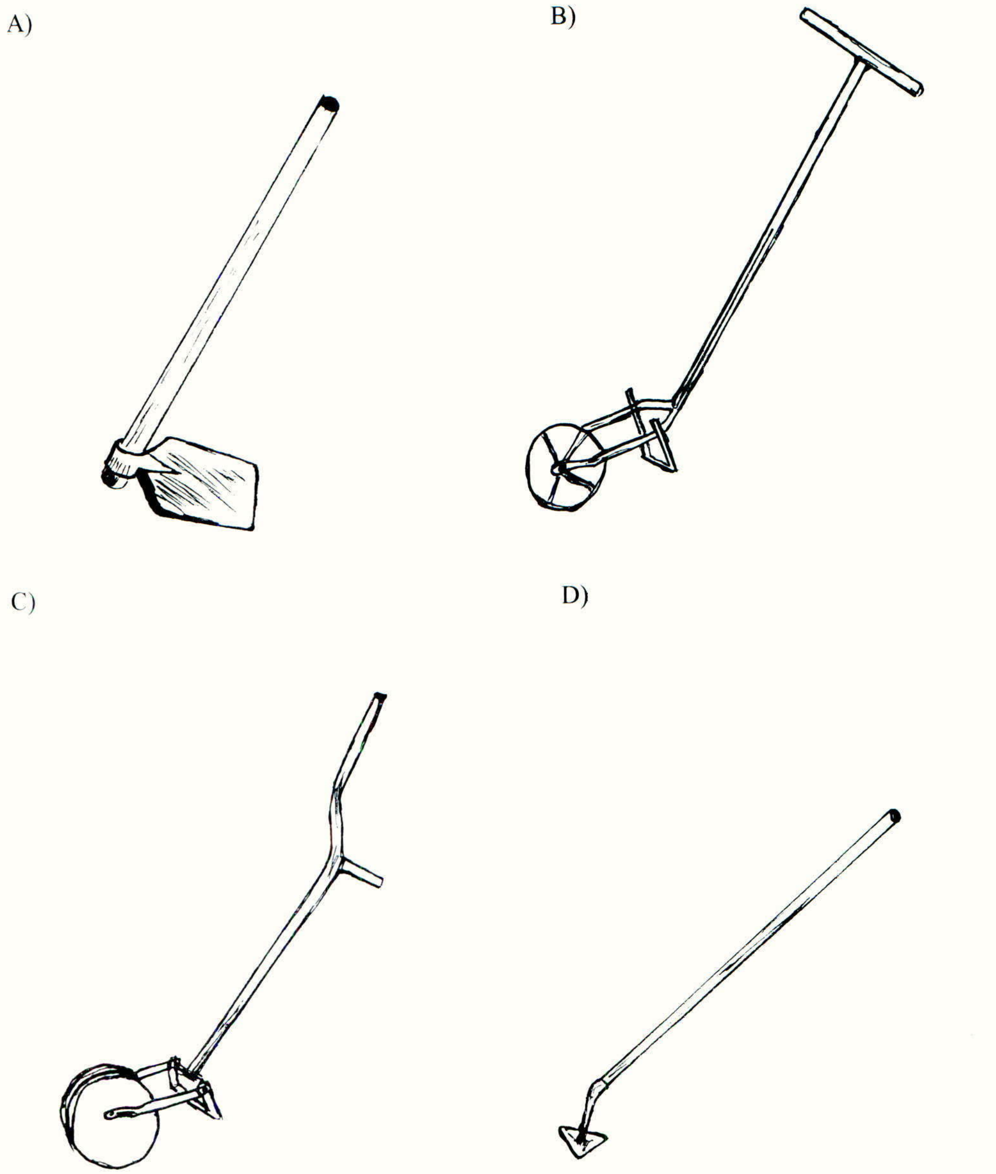
INTRODUCTION

Weed control is a major problem contributing to low yields within the Zimbabwean farming sector, and takes up to 50% of the labour used in crop production (Chatizwa, & Vorage., 1993). This varies from communal areas to the large scale commercial farms. While most of the communal farmers resort to hand weeding, labour is often inadequate for proper timely weed control. This farming community, needs to increase farm output in order to meet direct household consumption needs as well as generate surplus net farm cash. Improved weed control has an important role to play in increasing farm output. A study was carried out on four types of hand weeders locally available in terms of their weeding efficiency, workrate and users comfort. User comfort relates to subjective assessment of operating posture and objective assessment from the users perception of workload. In the operation of agricultural equipment, postural discomfort is a major factor affecting work rate (Gite, 1996).

MATERIALS AND METHODS

A series of trials to evaluate the four hand weeders were conducted between 1992-95 at Domboshawa Training Centre (Latitude 17° 10'S longitude 31° 10'E altitude 1 560 m above sea level) in Northern Zimbabwe . The badza (Figure 1A) is a commonly used traditional hand weeding tool with a steel cutting blade and a wooden handle. The introduced tools are the T-bar (Figure 1B), a tool with a cutting blade, supported by a metal wheel. The tool is pushed using a symmetrical handle attached to the end of the shaft in a T-shape. The side grip (Figure 1C), is a tool with a cutting blade and four cutting discs which act as wheels, and the garden hoe (Figure 1D), a tool of Dutch origin but further developed to incorporate a double edged triangular cutting blade. These implements vary in design, cost and the operational postures adopted when using them. The aim is to establish the relationship, if any between heart rate, weeding efficiency and workrate for the selected women (subjects). The experiment was a complete randomised block design with four replicates. Analysis of variance (ANOVA) was done using SPSS (Marija, 1990). Before starting work, the subjective data and initial heart rates were noted from the subjects. The work started at about 7.30 am and continued until the plots were the weeded. Four subjects wired to data loggers used their tools between the crop rows while the remaining four non-logger wearers weeded the intra-rows.

Figure 1. The four weeders tested in the field . A) The Badza; B) the T-bar; C) the Side-grip; D) the Garden hoe.



The physical characteristics of the four women who wore heart rate loggers during the trials are shown in Table 1.

Table 1. Physical characteristics of the four women monitored while using different weeding tools.

Subject No	Age (years)	Resting Heart rate	Weight (cm)	Left Hand (cm) Length	width	Right Hand Length	width	Body wt (kg)
1	34	65.5	161.9	19.3	8.7	19.5	8.8	59.5
2	35	58.8	160.6	19.5	8.8	19.0	8.3	57.3
3	39	76.8	162.7	18.7	8.1	19.2	8.3	56.3
4	37.5	72.5	157.9	18.3	8.3	18.4	8.5	67.3

During the course of the trials both objective and subjective data were collected. The objective data related to the subjects physiological responses, while the subjective data was related to the subjects feelings and perception of the work throughout the test period.

Objective Data

Data on heart rate gives an indirect assessment of a workload as outlined by (Rodahl, 1989). Grandjean (1980), also observed the linear increase in heart rate with energy expended, provided the work is dynamic and is performed in a steady rhythm. From this data the work pulse (max. working heart rate (HR) – resting HR) is computed. Photographs of the subjects working postures were taken during the weeding exercises. Body temperatures were recorded before and after the trials. Heavy physical demands on the body cause the temperature to rise. The environmental conditions influence both the degree of physiological stress imposed on the subject and the individuals perception of discomfort. The data collected related to relative humidity, black globe temperature and air temperature.

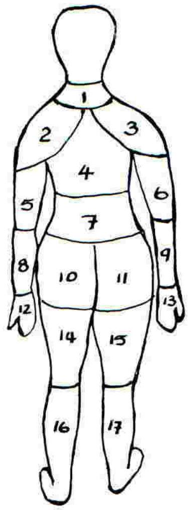
Subjective Data

At the beginning of each day, subjects reported the overall body discomfort (OBD) using a five point psychological scale (0= no discomfort, 4= extreme discomfort) adapted from Collet and Bishop (1976). Before each trial and at 20 minute intervals, subjects were requested to identify body parts experiencing discomfort using the Body Part Diagram (Figure 2) of Collet and Bishop (1976).

Field Test

Maize crop chosen for the experiment had a row spacing of 90 cm. The plot size was 356 m^2. The weeding was done between rows and the test period ranged from December to February. While working under field conditions, the heart rate of the subjects was recorded, and at every 20 minute interval, they responded to the discomfort level they were experiencing. Each plot was weeded by one team using the same implement per working day. The field performance measurements and the area weeded per minute were recorded in the case of each weeder. From the data, hours per hectare and the weeding efficiency were computed. The weeding efficiency indicate how successful the implement eradicated weeds and is expressed as a percentage of the weeds destroyed per square meter. *Ricardia scabra* was the most dominant weed followed by *Hebiscus meeusei* which was prevalent in about a third of the plots.

Figure 2. Body Part Map used by women to identify areas of discomfort during weeding



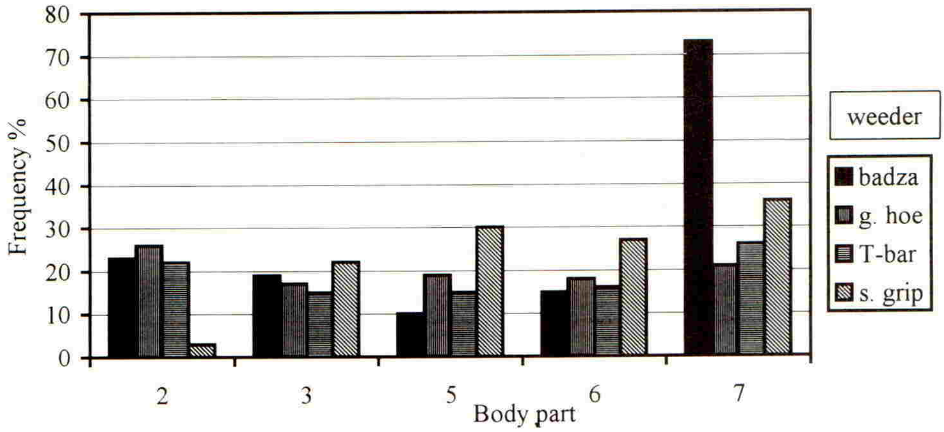
RESULTS AND DISCUSSION

The variation in design and operation of the weeders affected the postures, which contribute to the differences in physiological responses. The mean frequency of parts of the body giving discomfort are shown in Figure 3. The average work pulse rate for the four weeders used by the four subjects varied from 103–135.5 beats / minute with significant variation among the subjects for each weeding method. Using the Ovako Working posture Analysis System (OWAS) evaluation technique (Karhu et al, 1977), the side grip (411), had the most undesireable working posture followed by the badza (211), T-bar and garden hoe (111). The postures adopted when using the implements though dynamic maybe classified as undesirable.

A three-way ANOVA on implement, season and subject showed a significant interaction ($P<0.001$), between subject, season and treatment (Figure 4). A two-way ANOVA with two factors, implement and subject carried out separately for each season, also showed interaction between subject and implement for all three seasons on weeding efficiency, heart rate, and work rate. Evidence of implement preference by each subject was apparent; each preferred a certain implement. However, there was no significant interaction between subject and implement for overall body discomfort and therefore only main effects were considered. With one-way ANOVA, significant difference between implements was observed for all seasons, but there was no significant difference between subjects.

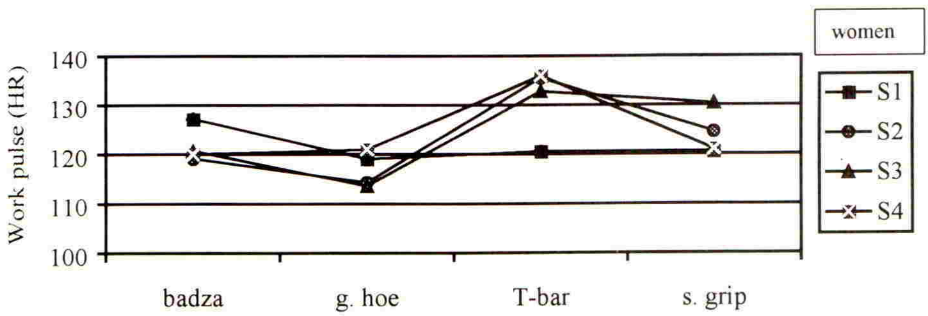
The body temperatures were recorded before and after each trial. It was anticipated that the temperatures would rise. Out of 128 trials, a rise in temperature occurred in 69 instances. The fact that body temperatures did not consistently rise over the course of the trials, could indicate that though the work was physically demanding, it was not making excessive demands as the women worked at their sustainable work pace. The relative humidity ranged between 35 and 78% during the weeding exercises for the three seasons, while the air temperatures were between 20 - 29 ^{0}C. Low relative humidity and high air temperatures were recorded during the second season (1993-94) when the exercise was carried out during February (mid season drought was severe). A close analysis is still required to ascertain the effect of environmental conditions on the women's overall performance.

Figure 3. Frequency of body part experiencing discomfort during weeding with the four weeders.



The Body Part Discomfort (BPD) score showed that the lower back (part 7) suffered localised discomfort particularly with the use of the badza and the side grip (Figure 3). The awkward postures adopted to operate the Side-grip and badza could have been the major contributing factors. The use of the side grip resulted in high discomfort levels.

Figure 4. The heart rates of four women induced by use of four weeders in Zimbabwe



The work rates ranged from 32.2 hrs/ha – 49.9hrs/ha with garden hoe the fastest (32.2 hrs/ha), followed by the T-bar and badza (45.2hrs/ha). The badza (85%) was the best in terms of weeding efficiency and the Side grip (71%) having least efficiency. To operate comfortably, weeding tools should be operated in an erect body posture as far as possible (Tewari, 1985). Any deviation from the normal erect standing posture results in metabolic cost. The badza operator, bends over when using the tool, resulting in localised discomfort on the back. Under dry conditions, all the implements killed the weeds equally well except the side grip which could not penetrate the ground and hence failed to cut the weeds. Women generally preferred to use the garden hoe in annual weeds, two to three weeks after germination, and the badza where the weeds are over grown or perennial.

CONCLUSION

The badza had the highest weeding efficiency followed by the garden hoe. The garden hoe produced the highest work rate and required the least effort. A more exhaustive analysis is still required to determine the overall seasonal effect on implement and subject. The relationship between stature and weight against subjects performance also needs to be analysed. From the work pulses obtained, it can be concluded that manual weeding is a strenuous and physically demanding, resulting in localised discomfort on the back over extended weeding periods.

The garden hoe proved to be the best weeder under these conditions and should be further developed and made available to the smallholder farming community. The badza is a multi-purpose implement which can be used for other activities like planting and digging which other implements cannot do. The badza and the garden hoe can be acquired at about the same price. On–farm tests need to be conducted before a final decision is made by the farmer who needs to draw a balance between weeding efficiency, work rate, cost and timing of weeding operation as this has a bearing on the implement in use.

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IMPACT OF *IMPERATA CYLINDRICA* ON SMALLHOLDER RUBBER PRODUCTION

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ABSTRACT

The girths of young rubber trees grown from unselected seedlings or clonal material were measured over a period of two years on 85 smallholdings in South Sumatra, Indonesia in order to determine the effects of the perennial grass *Imperata cylindrica*. By use of linear models, the girth increments of 0-5 year-old rubber, at six ground covers of *I. cylindrica* infestation are predicted for two contrasting rubber-based farming systems. There is little difference between unselected seedling and clonal rubber in their responses to *I. cylindrica* infestations but trees in a low input system suffer more than those in an intensively managed multiple cash crop systems at high ground covers of *I. cylindrica*. This is relevant to management inputs required for bringing rubber plantations into production.

INTRODUCTION

Imperata cylindrica is a perennial grass which is cited as being a weed of 35 crops in 73 countries (Holm *et al.*, 1977). In SE Asia, considerable areas of land are infested with *I. cylindrica* including an estimated 16 million hectares in Indonesia, 1.6 million hectares of rubber in Malaysia and much of the grassland of the Philippines. No crops within the ecological range of *I. cylindrica* are free from the threat of infestation, but this weed has earned a well-deserved reputation for being a pest of rubber, oil palm, coconut, pineapple, tea and forestry, in addition to a wide range of annual crops, including upland rice, maize, groundnut, cotton and many others. Production of annual crops can be severely reduced but even the establishment of robust perennial crops is seriously delayed by *I. cylindrica*. Suryaningtyas & Terry (1993) have shown the vulnerability of seedling rubber in a nursery to competition from a weed flora, which included *I. cylindrica*. Research in Malaysia has shown that five-year-old rubber trees surrounded by *I. cylindrica* made only half the annual growth of trees which were free of weeds (Anon., 1938). In Indonesia, a 37% reduction in stem diameter has been observed in 15-month-old rubber trees growing in uncontrolled *I. cylindrica* (Menz & Wibawa, 1995). Mangoensoekardjo (1980) has claimed that the first tapping is delayed by three years when rubber trees are grown on land infested with *I. cylindrica*. These effects are undoubtedly due to competition for plant growth resources, but allelopathy may also be implicated.

Rubber production by smallholder farmers is expanding in Indonesia, particularly in Sumatra and Kalimantan. Characteristically, these areas have been cleared from natural forest in the recent or more distant past and often invaded by *I. cylindrica*. This poses a serious problem to resource-poor farmers, though not to more affluent growers who can afford to use glyphosate and other weed management options. In recent years, falling prices of glyphosate and increased availability [over 25 products containing glyphosate are available in Indonesia and more than 100 in Malaysia (Terry, 1996)] have brought this product within the domain of smallholders. Recognising this, the UK Department for International Development (DFID), formerly known as ODA, supported a four-year project on the management of *I. cylindrica* in smallholder farming systems in Indonesia. A major component of the project was a study of the socio-economics of smallholder rubber production in South Sumatra. The present paper describes work of the project to evaluate the impact of *I. cylindrica* on smallholder rubber, a first step in ascertaining practical and economical approaches to the management of this weed.

MATERIALS AND METHODS

The project worked with 85 farmers from locations in the Districts of Musi Banyuasin and Ogan Komering Ulu in South Sumatra where different farming systems were identified. The locations consisted of four villages (Tanjung Laut, Mulia Agung, Seterio and Kertajaya) in the Musi Banyuasin District, and three units (Unit 2, Unit 11 and Unit 12) in Batumarta Transmigration Area of the Ogan Komering Ulu District. Participating farmers in this study were selected on the basis that they own immature rubber trees of less than three years old or intend to plant rubber. In addition, various socio-economic factors including age of farmer, farmer origin, wealth and family-size were considered in farmer selection.

Information collected over a two-year period from participating farmers included baseline data, historical records and monitoring data. Baseline data collected at the beginning of the project covered information about the farm and household, the cropping system and the history of the plot that was to be monitored. The latter included the state of the plot prior to rubber planting (forest, bush or sheet *I. cylindrica*), date and method of land preparation, date of planting rubber and any *I. cylindrica* control practices undertaken subsequently. One plot (occasionally two) was monitored on each farm on a fortnightly basis to collect information on farmers' agricultural activities, including their *I. cylindrica* control methods and the percentage of *I. cylindrica* cover in the plot.

Girth (i.e. circumference) measurements were taken from 50 rubber trees selected in each monitored plot within an area of 0.5-1.5 ha. To minimise any edge effects, the trees were selected by choosing a block of 5 rows of 10 trees in the centre of the plot. Each tree in the monitored block was numbered, enabling girths of individual trees to be monitored. The girth of rubber trees was measured at 130 cm above ground level. For trees that were too small to use a girth tape, the stem diameter was taken using a micrometer and the girth was then calculated. Girths were measured at six-month intervals over a two-year monitoring period. Age of rubber at the time of each girth measurement was classified into 6-month bands, from 13-18 months up to 55-60 months. Data on girth increment since the measurement six months earlier were grouped according to the age of the rubber at the end of the period to which the increment applied, with age classified as above. A separate analysis of the effect of a number of factors on girth increment was then done for each age group. The analysis consisted of fitting a linear model to the data, using stepwise regression in order to identify what factors had an effect on growth and to estimate the magnitude of their effect. The statistical package GENSTAT was used for this purpose.

RESULTS

Four main types of rubber-based farming systems were found in South Sumatra: jungle rubber, low input plantation, transmigration system and a multiple cash crop system. The characteristics of two contrasting systems and their associations with *I. cylindrica* are summarised below.

Low input plantation system (LIP)

In this system, farmers plant their rubber, which may be unselected seedling or clonal material, with similar spacing to those used by estates. Their intercrop is usually upland rice, which is essentially a subsistence crop. External inputs are used sparingly. There are many villages in the Musi Banyuasin District where this system can be found and *I. cylindrica* tends to be widespread in uncultivated and cultivated plots of land. Use of glyphosate-based herbicide is rare; manual methods are the dominant approaches to weed control.

Multiple cash crop farming system (MCC)

This system is different from the LIP system in that the intercrops are primarily cash crops, such as chilli, which can be highly profitable. Smallholders in the Musi Banyuasin District often regard chilli as their most important crop. The rubber planting material is likely to be high-yielding clonal. This is an intensive, high-input/high-output system, requiring large amounts of labour, chicken manure (6 tonnes/ha) and inorganic fertilisers (N, P and K). Blanket cover of *I. cylindrica* is widespread. To open such land for chilli production, the area is normally hand-cultivated twice, with the second cultivation serving as a weeding. The planting beds are progressively developed throughout the growing season, which also serves as weeding since the rhizomes of *I. cylindrica* are removed. Farmers prefer to use manual labour to herbicides; the land has to be dug over anyway, so spraying is regarded as unnecessary. Intercrops are often grown for 2-3 years, after which time *I. cylindrica* becomes a serious problem, but only for a short period until shade from the tree canopy suppresses weed growth. The wealthier farmers are more likely to use herbicide-based technologies at this stage but some still use manual control practices.

Effects of *I. cylindrica* on rubber growth

Statistical analyses of the girth increment of rubber clearly demonstrated that the growth of rubber was affected by various factors, including the percentage cover of *I. cylindrica*, farming system, season and type of rubber planting material (clonal or seedling). The relationship between the girth increment and these factors was investigated by fitting a model of the form:

$$\text{Girth increment} = \text{constant} + b(\textit{Imperata}) + (\text{farming system})_i + (\text{clonal/seedling})_j + (\text{season})_k$$

where terms were included in the model when they were statistically significant at the 5% level.

Of the factors investigated, the evidence that percentage cover of *I. cylindrica* had an effect on rubber growth was the most consistent. Despite the high degree of variability in girth increments over the monitored plots, the evidence that *I. cylindrica* had an important effect on growth was strong for almost all age groups for which the analysis was done. Interestingly, there was some suggestion that its effect on growth was highest when rubber was less than three years old. Evidence of differences due to farming system and type of rubber planting material were also convincing. Predicted profiles of the growth of rubber for three different systems, with varying ground covers of *I. cylindrica*, are shown in Fig. 1.

It is worth noting that the percentage of the variability explained by the models was not particularly high (R^2 values averaged 27%), so that while the predicted profiles given by the models are very useful for indicating *mean* growth, it is expected that the growth of rubber on individual farmers' plots would show considerable deviation from them. However, given that the data are from on-farm plots where management practices are very variable, it is arguable that the R^2 values are remarkably high.

Using the linear model, it was possible to predict the girth increment of rubber at a given age, i.e. by substituting the appropriate values of parameter estimates in the model. Fig. 1 shows the predicted effects of *I. cylindrica* on the growth of (a) unselected seedling and (b) clonal rubber trees in a low input plantation system (LIP) and on (c) clonal tress in a multiple cash crop system (MCC).

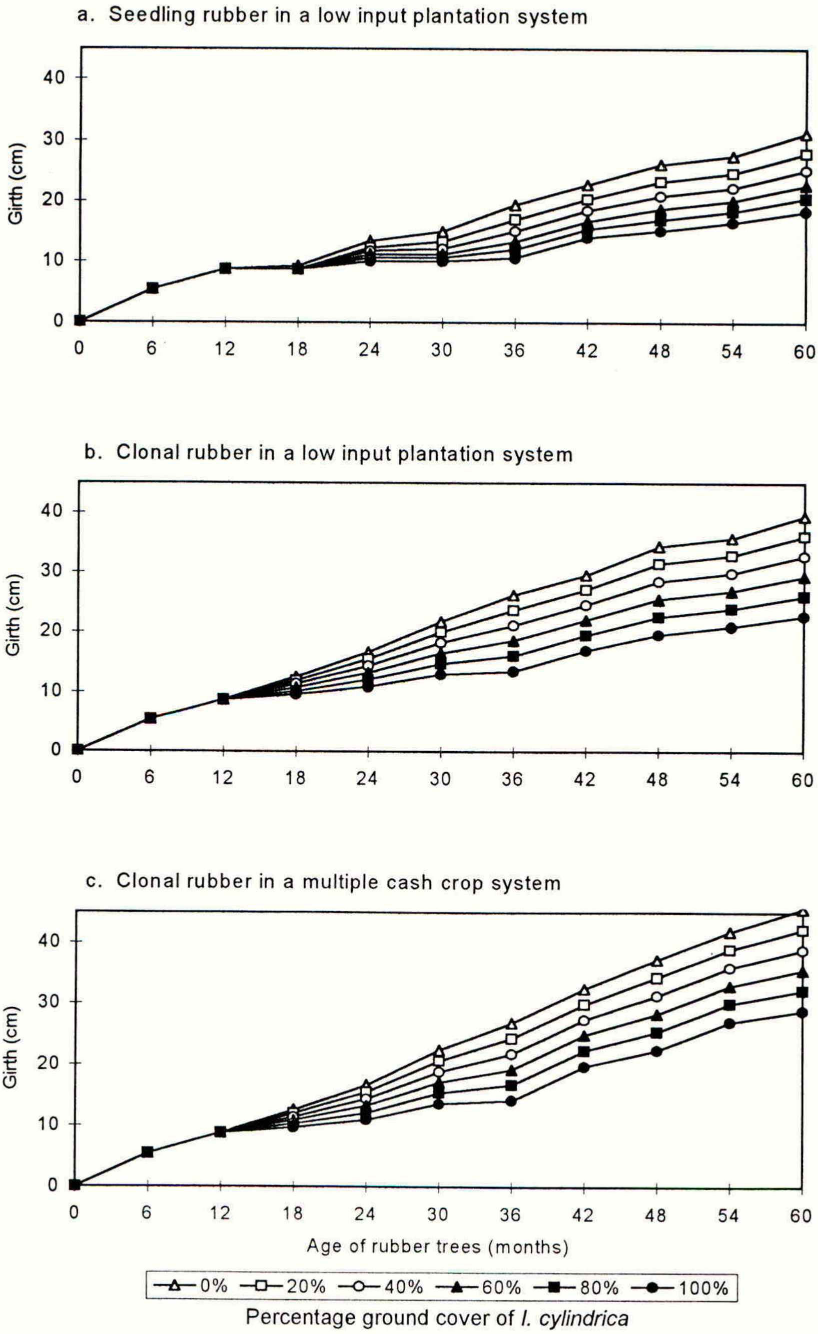
Regardless of whether unselected seedling or clonal rubber was used, the growth of rubber trees was inhibited by *I. cylindrica* infestation, even at a low average ground cover of *I. cylindrica* (20% cover). At this cover of *I. cylindrica* for five years in the low input plantation system, the girth of the rubber trees was 27.9 cm for unselected seedling (Fig.1a) and 36.1 cm for clonal rubber (Fig. 1b). This represents girth reductions of 10% and 8%, respectively, compared with the girths with no *I. cylindrica*. When the MCC system is used, with its higher inputs and different management system, the girth of 60-month old clonal rubber trees (39.5 cm) was much higher than that of the unselected seedling rubber (31.2 cm) in the low input plantation system.

DISCUSSION

The average ground covers of *I. cylindrica* were low in the MCC system and relatively high in the LIP, hence, the typical rubber growth profiles for these systems reflect these amounts of weed. After adjustment for *I. cylindrica* cover, there are clearly differences among the systems for rubber growth (other than the ground cover of *I. cylindrica* which is typical of them) that are not attributable to weed management. In the LIP system, farmers used very little or almost no input for intercrops and/or rubber and, therefore, a high degree of weed competition occurred in these farming systems. In the MCC system, however, farmers provided a high quantities of inputs, including organic fertilisers (e.g. chicken manure), for the intercrop (i.e. chilli). The residual effect of the fertiliser is beneficial to rubber growth and probably, to some extent, reduces weed-crop competition (primarily for soil nutrients).

The practical value of these findings is the demonstration that *I. cylindrica* should be managed as efficiently and as effectively as possible because of its inhibition of growth of young rubber trees. The product of rubber trees is latex, so it is important to promote the attainment of

Fig. 1. Predicted relationship between girth and age of rubber in three systems with *I. cylindrica* at six levels of percentage ground cover



tappable size, i.e. when girth is 45 cm. This was achievable in five years in the multiple cash crop system with no *I. cylindrica* but, by extrapolation, it could be as long as seven years for 80% cover of *I. cylindrica*. For unselected seedling rubber grown in a low input plantationsystem, the time to first tapping will be considerably longer. Economic aspects of *I. cylindrica* control in smallholder rubber plantations have been discussed by Menz & Wibawa (1995) and Grist & Menz (1995). Using mathematical models, these authors calculated that control of *I. cylindrica* in the early stage of tree establishment is most critical in generating economic returns. They also determined that the use of clonal seedlings has the most significant impact on the rubber trees' ability to control *I. cylindrica* and to provide a higher economic return. Our girth model suggests that, other things being equal, clonal rubber will grow faster than unselected seedling rubber.

A multiple cash crop farming system can provide substantial profits from a short-term cash crop and this is a strong incentive for farmers to open *I. cylindrica*-infested land, but this kind of system is only possible in areas with good access to markets, usually near large cities. Such a system is not only beneficial for the management of *I. cylindrica*, but also for the establishment of clonal rubber.

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HERBICIDES WITH ALTERNATIVE MODES OF ACTION FOR THE CONTROL OF PROPANIL- AND FENOXAPROP-P-RESISTANT *ECHINOCHLOA COLONA*

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ABSTRACT

Propanil-resistant populations of the annual grass jungle rice (*Echinochloa colona)* are widespread in rice in Central and South America following repeated use of this herbicide for the past 15 to 20 years. In recent years fenoxaprop-P has been used to control propanil-resistant *E. colona,* but now populations of jungle rice resistant to this herbicide have been reported. As part of an integrated strategy for managing propanil- and fenoxaprop-P-resistant *E. colona,* we have been evaluating herbicides on susceptible and resistant biotypes of *E. colona* that have different modes of action and/or different degradation pathways in the target weed. Glasshouse studies with pot-grown plants indicate that propanil and fenoxaprop-P-resistant biotypes of jungle rice can be controlled selectively in rice with quinclorac, pendimethalin, thiobencarb, bispyribac-sodium, pyriminobac-methyl, and pyribenzoxim. Clomazone also provided excellent control of *E. colona* but caused transient damage on rice and its vapour affected some non-target plants. Cyhalofop-butyl was selective in rice and effectively controlled propanil- but not fenoxaprop-P-resistant *E. colona*. Use of mixtures and sequences is now considered an essential component of resistance management and the suitability of the above herbicides will facilitate the effectiveness of this approach.

INTRODUCTION

Propanil, a photosystem 2 inhibitor herbicide, is widely used in Latin America for the control of annual jungle rice (*Echinochloa colona*), other grasses and several broad-leaved weeds. Repeated use of this herbicide has resulted in the development of propanil-resistant populations which are widespread in Costa Rica, El Salvador, Guatemala, Nicaragua and Panama (Garita *et al.*, 1995). Propanil-resistant biotypes have also been reported in Colombia and are suspected elsewhere in Latin America. One response to the evolution of propanil-resistant *E. colona* has been to make late post-emergence applications of the acetyl CoA carboxylase inhibitor herbicide, fenoxaprop-P. However, on some farms populations of jungle rice resistant to this herbicide have developed after as little as three seasons' use in Costa Rica (Riches *et al.*, 1996).

It is now widely accepted by the agrochemical industry, researchers and farm advisers that integrated approaches to weed management are required and for high input systems a key component is the use of sequences and mixtures of herbicides with different modes of action and contrasting chemistry (Jutsum & Graham, 1995). Thus, the tubulin biosynthesis inhibitor pendimethalin effectively controls both propanil-susceptible and resistant *E. colona* (Riches *et al.*, 1997). Further alternatives to propanil would allow growers to reduce the selection pressure for resistance imposed by any one particilar mode of action and chemistry. The aim of this study was to evaluate some recently introduced and older rice graminicides for activity against fenoxaprop-P- and propanil-resistant *E. colona*.

MATERIALS AND METHODS

E. colona plants were grown from seed samples originally collected from rice fields in Colombia and Costa Rica and previously determined as resistant (R) or susceptible (S) to propanil and/or fenoxaprop-P. The following accessions of *E. colona* were used:-

EC 93.001 ex Costa Rica - propanil R and fenoxaprop-P R
EC 93.002 ex Costa Rica - propanil R and fenoxaprop-P S
EC 93.007 ex Costa Rica - propanil R and fenoxaprop-P S
EC 92.007 ex Colombia - propanil S and fenoxaprop-P S

Pregerminated seeds (4 per pot) were sown in 9 cm diameter plastic pots containing sandy loam soil amended with a slow release fertilizer and 30% grit to improve drainage. The seeds were covered with 1 cm of soil and after emergence the seedlings were thinned to 3 per pot. Seeds of the Costa Rican rice cultivar CR5272 were sown at the same time. The plants were raised in a glasshouse with supplementary lighting and maintained at 30/28 ± 2°C day/night respectively with a 16 hour photoperiod. Prior to spraying, the pots were kept close to field capacity by overhead watering. After herbicide treatment, the pots were sub-irrigated via capillary matting except for the pots treated with ALS inhibitor herbicides which were placed in aluminium foil dishes and watered via the soil surface to avoid possible cross contamination with herbicide. The herbicides were applied to *E. colona* and rice plants with either 1-2 or 3-5 leaves using a laboratory pot sprayer fitted with a SpraySystems 8001 nozzle and calibrated to deliver 200 litres/ha. Clomazone, fenoxaprop-P, propanil and thiobencarb were applied alone while the other herbicides were tank mixed with adjuvants as follows:- cyhalofop-butyl plus 0.2% Polyglycol; quinclorac plus 0.2% Agral; bispyribac-sodium, pyribenzoxim and pyriminobac plus 2% FAL 040 (methylated vegetable oil). The five doses applied of each of these herbicides are shown in Figures 1 and 2. There were three replicates of each treatment and the pots were set out on the glasshouse benches in a fully randomised block design. Fresh weight of shoots was assessed 11 to 15 days after treatment depending on the progression of symptoms.

RESULTS

Bispyribac-sodium and pyribenzoxim at 10 and 24 g a.i./ha, respectively, and above killed all

Figure1. Effect of bispyribac, pyriminobac, pyribenzoxim, fenoxaprop-P and propanil on R and S biotypes of *E. colona* at the 3 - 5 leaf growth stage, 13 - 14 days after treatment.Fresh weight as % of untreated control

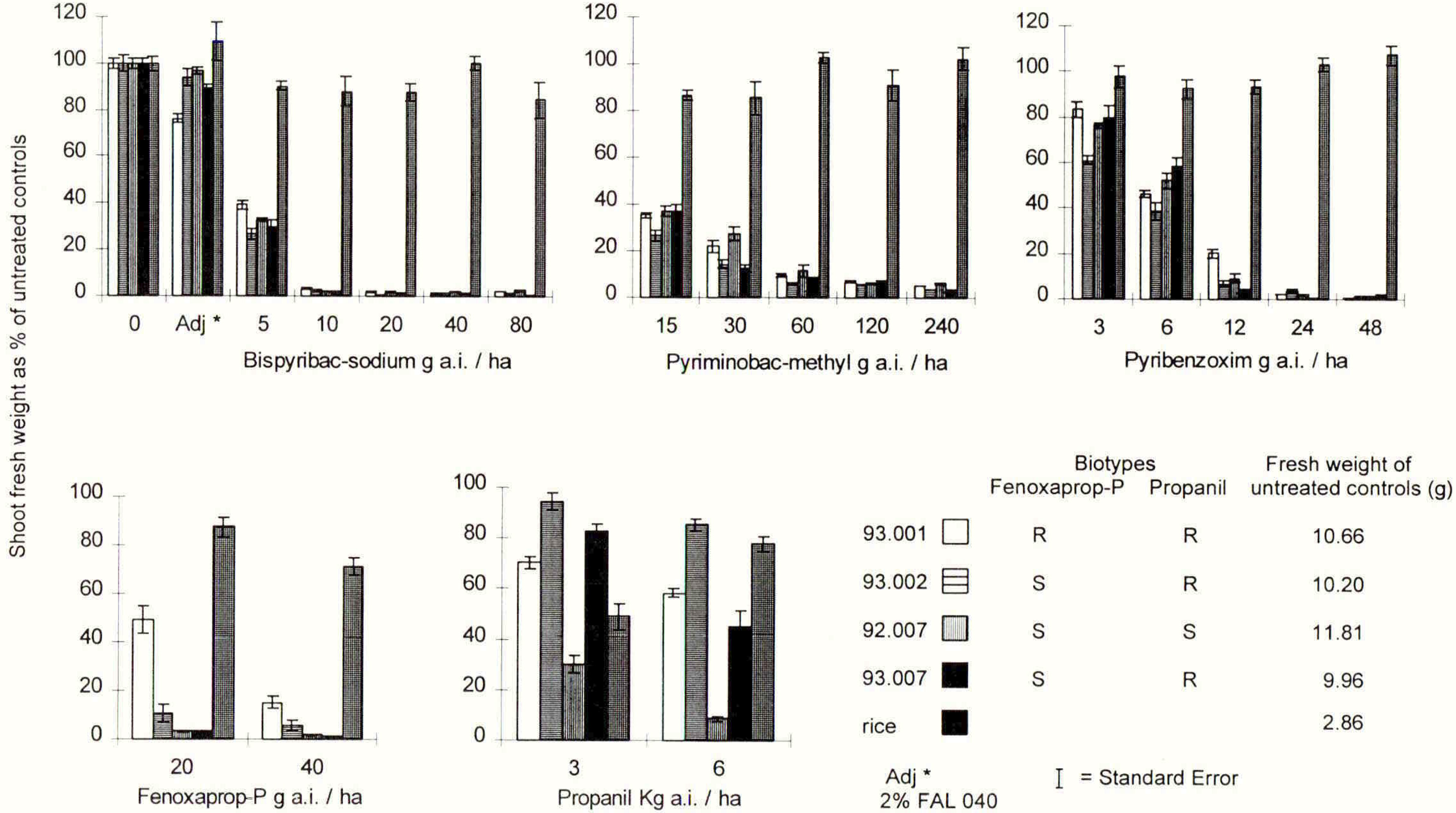
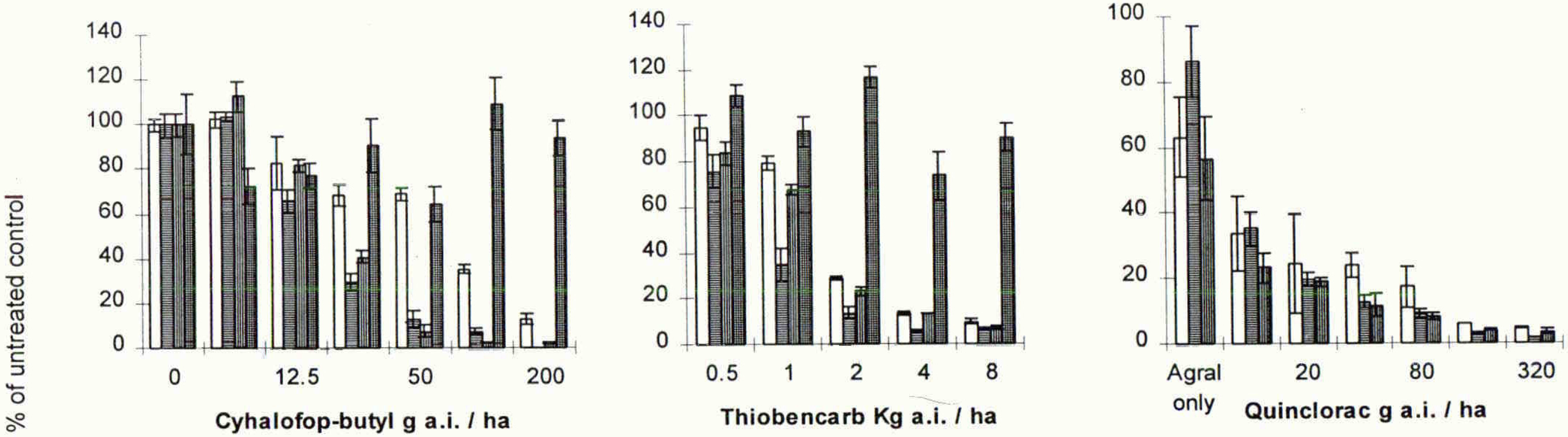


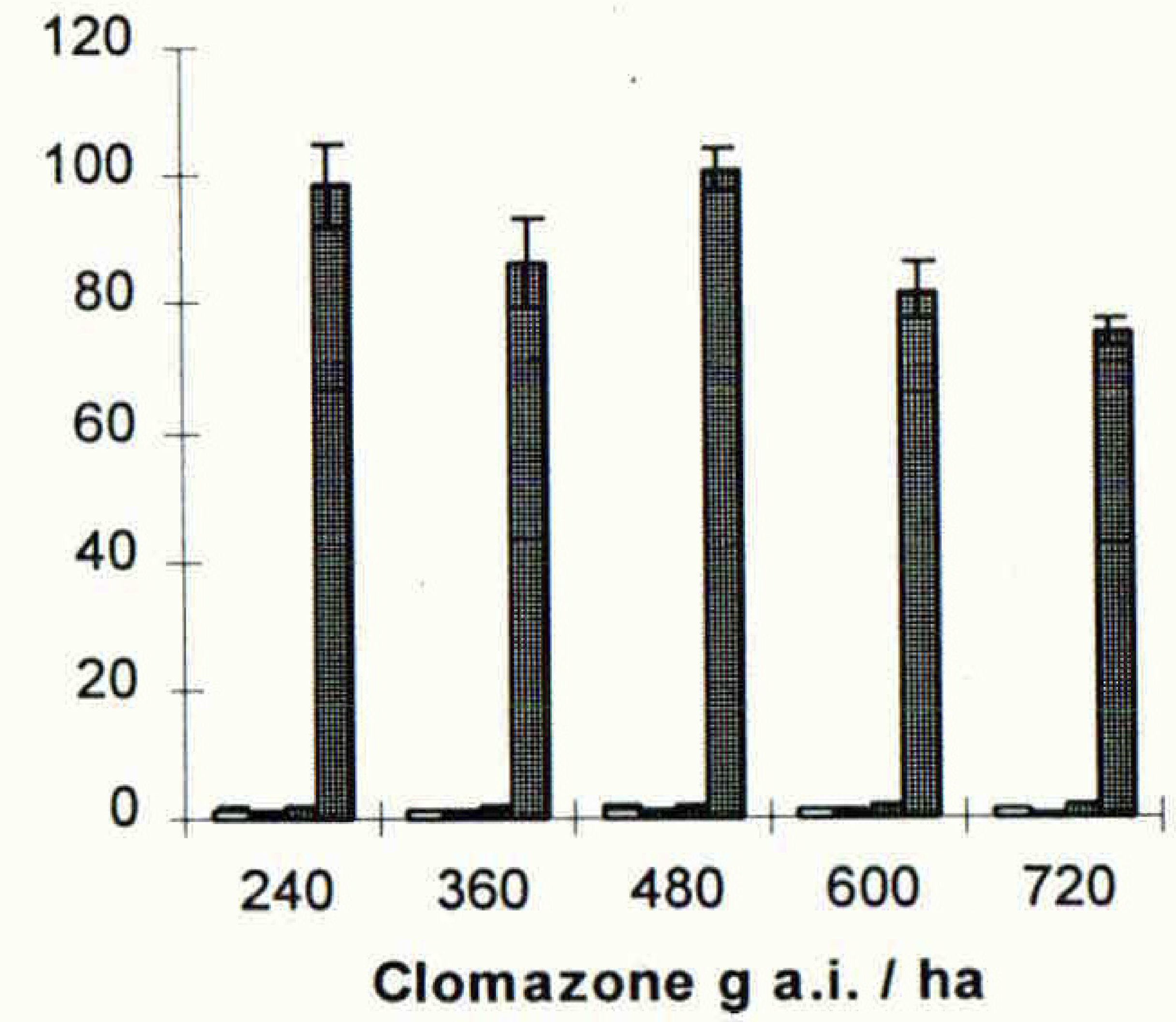
Figure 2. Effect of clomazone applied to R and S biotypes of *E. colona* at the 1-2 leaf growth stage and cyhalofop-butyl, quiclorac and thiobencarb at the 3-5 leaf growth stage, 13-15 days after treatment. Fresh weight as % of untreated control



	Biotype		Fresh weight as % of untreated control (g)			
	fenoxaprop	propanil	thiobencarb	cyhalofop	quinclorac	clomazone
93.001 ☐	R	R	12.89	12.67	12.06	11.55
93.002	S	R	13.03	12.30	13.44	9.0
92.007	S	S	15.27	10.78	7.49	10.6
rice			3.69	3.2		2.94

Adj* 2% polyglycol

I = Standard Error



the *E. colona* accessions. Following treatment with pyriminobac-methyl, growth of all plants was inhibited but, at 13 days after treatment, there were some stunted survivors with green tissue at the highest dose of 240 g a.i./ha. The most propanil-resistant accession, 93.002, tended to be more susceptible to all three acetolactate synthase (ALS) inhibitors than the other accessions, but otherwise R and S biotypes were equally well controlled (Fig.1).

The acetyl CoA carboxylase (ACCase) inhibitor herbicide cyhalofop-butyl killed all the accessions at 50 g a.i./ha except fenoxaprop-P-resistant 93.001 (Fig.2). Multi-site of action thiobencarb killed all biotypes at 8 kg a.i./ha at 14 days after treatment with the most propanil-resistant succession 93.002 being more susceptible. Quinclorac, a herbicide of unknown mode of action, effectively controlled all the biotypes tested at 160 g a.i./ha and above. Clomazone killed fenoxaprop-P- and propanil-resistant and -susceptible *E. colona* at the lowest dose of 240 g a.i./ha when applied at the 1-2 leaf growth stage. Some bleaching of young rice leaves was observed soon after application, but the crop was growing away from these symptoms 10 days after treatment.

DISCUSSION

The results in Figures 1 and 2 show that all the candidate herbicides controlled propanil R and S biotypes of *E. colona* and only cyhalofop-P failed to control the fenoxaprop-P R biotype. This cross-resistance was expected following our earlier studies with other acetyl CoA carboxylase (ACCase) inhibitors against this biotype (Riches *et al.*, 1996). However, as we found cyhalofop-butyl to be very selective on young rice plants, it could be useful in an integrated weed management programme.

The acetolactate synthase inhibitors, bispyribac-sodium and pyribenzoxim provided good control of all the accession tested and high selectivity in rice. It is probable that the slower acting pyriminobac-methyl would have been lethal at doses below 240 g a.i./ha had the final assessment been made later (K Maturani, Kumiai - personal communication). Experience with other ALS inhibitors shows that they need to be used in integrated weed management programmes to reduce the incidence of ALS resistant weeds (Saari *et al.*, 1994) and this strategy should be applied to these rice herbicides.

Clomazone is a carotenoid synthesis inhibitor which controlled all the *E. colona* biotypes. Current information suggests there is a low probability of development of resistance to this class of herbicide. However, clomazone in its present formulation causes transient bleaching of the crop and sometimes damages non-target plants which limits its opportunities for use, but it may have potential at reduced doses in mixtures. Quinclorac was effective against all the *E. colona* accessions tested, but it should be used in an integrated programme because resistance to quinclorac has been reported in the weed *Digitaria ischaemum* (Ahrens, 1994).

Thiobencarb interferes with lipid synthesis, but its mode of action is not fully understood. It has a high use rate, but effectively controlled all the *E. colona* biotypes and is highly crop selective. It has been used for 27 years without any reports of resistance and has an important role to play in herbicide resistance management in rice.

The herbicide sequences and/or mixtures chosen will depend on weed spectrum, farming system, cost and availability. Additional herbicides require evaluation for control of herbicide resistant *E. colona* including butachlor, molinate and oxadiazon. The rice farmer has a relatively wide choice of modes of action for managing herbicide resistance in *E. colona*, but availability may be limited in some countries. In order to make the best use of available herbicides, information is required on survival of seeds from resistant plants in the seed bank. This will provide a quantitative basis for selecting the interval between repeat applications of herbicides with the same mode of action or Herbicide Resistance Action Committee classification (Jutsum & Graham, 1995).

Some mixtures, including propanil plus pendimethalin, are used successfully in the field but other. mixtures incorporating herbicides used in this study require evaluation to determine whether the combinations are additive, synergistic or antagonistic against weeds and rice.

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INTRODUCTION OF LOW VOLUME CDA SPRAYING FOR THE CONTROL OF INVASIVE WEEDS IN COLOMBIAN PASTURES

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ABSTRACT

Field work in Colombia has shown that the use of CDA for application of herbicides in pastures can result in control equivalent to the currently used high volume application systems. In order to promote the uptake of CDA technology, the specific economic and social conditions need to be identified. In Colombia, three levels are considered key : farm owners, often urban based who are interested in the economics of control; farm managers, who are concerned with management and supervision of spraying operations; and spray operators who need to be motivated and rewarded to adapt to the changing work patterns involved in the adoption of CDA spraying.

INTRODUCTION

In Colombia cattle rearing is a major industry. However, the nature of the climate is such that weed invasion is a significant limitation to pasture productivity. Current weed control methods are based on the application of high volumes, usually applied as a spot treatment. Equipment used in herbicide application includes knapsack sprayers, semi-stationary pumps with trailing hoses, and even motorised knapsack mistblowers. However, it is now recognised that these systems are inefficient and farm owners are beginning to investigate other systems of weed control, including "weed-wipe" and low volume controlled droplet application (CDA) systems. Compared to traditional high volume application systems, CDA offers considerable savings in the time required for application, largely resulting from the greatly reduced volumes of water that are used (Jollands *et al.*, 1983). The elimination of wasteful large droplets and a reduction in the driftable fraction are the main reasons for the increased efficiency of CDA (Bals, 1975)

The introduction of low volume CDA spraying is not simply a technological change. There are a number of non-technical barriers to the successful replacement of conventional systems with CDA. Some are due to the inherent nature of low volume CDA equipment - failure of the operator to see the spray and the tendency of the operators to spray to run-off. The higher concentrations of product used with CDA mean that the margin for error in application is lower than in traditional application systems, and so training and supervision of spray operators will need to be greater. This has implications in terms of management of spraying operations.

This paper discusses an approach designed to address the non-technical barriers through the use of a targeted training and information system designed to ensure that low volume CDA herbicide application is adopted readily by farm owners and spray operators. The paper is based on field trials undertaken in Colombia in 1996, and on interviews with spray operators, farm owners and technical staff.

MATERIALS AND METHODS

In order to establish confidence in the CDA system, and to investigate the current dosage recommendations, comparative field trials were undertaken to examine the effect of application volume and dosage on the control of a marker weed species in pasture. Product application rates were based on extrapolation from empirically derived field recommendations; this initially gave a product application rate of 2 l/ha. The weed species targeted was *Mimosa pudica*, a medium height plant with a spreading habit. The chemical used was 'Tordon 101' (DowElanco) (active ingredients 2-4D (240 g./l) and picloram (64g/l)), applied at a product application rate of 2 l/ha in Trial A and 4l/ha in Trial B.

The application details (Table 1) were the same in both trials. Application of the conventional system was by Jacto Lever Operated Knapsack Sprayer (Jacto Ltda, Brazil); low volume application was by the Microfit Herbi (Micron Sprayers Ltd, UK). These formed two of the treatments. The third, for comparison, was an unsprayed control. Each treatment was replicated three times in each trial.

Table 1. Application details of field trials

Equipment	Volume Application Rate (l/ha)	Restrictor/ Nozzle	Flowrate (l/min)	Lane Separation (m)
Microfit Herbi	20	Yellow	0.15	1.2
Jacto LOK	260	8003	1.6	1

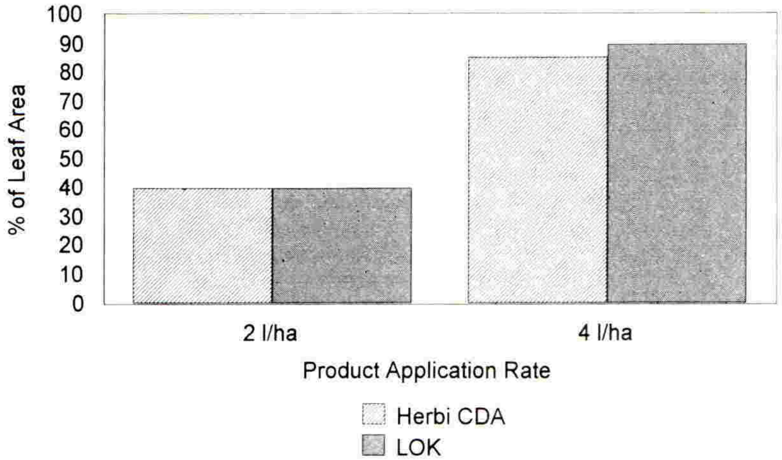
The trials were evaluated 17 days after application. The results were based on a visual observation of each plot, by two independent evaluators. Control was assessed as the proportion of the *M. pudica* leaf area showing necrosis. In addition, the proportion of plants showing symptoms was also assessed.

RESULTS OF FIELD TRIALS

The results of the trials are shown in Figure 1. The unsprayed plots showed no symptoms. It is clear from these results that there is no significant difference ($P>0.05$) in the levels of control achieved with traditional high volume systems and the low volume CDA technique. The high volume application did show slightly higher levels of control, but this is a reflection of the fact that there was some difficulty in maintaining even lane separation with the CDA system, leading to some plants being only partially sprayed.

The comparatively low level of control achieved at 2l/ha product application rate with both systems highlights an important problem with the current system of application. Dosage rates are given to spray operators as a concentration to be pre-mixed in 200 l containers. Observation indicated that the application volume being used in field practice was significantly higher than thought by farm owners and spray operators. This presumably

Figure 1 - Proportion of of Leaf Area Showing Symptoms



reflected the fact that the spray operators were spraying to well past run-off increasing the applied dose per plant.

LOW VOLUME SPRAYING - BARRIERS TO SUCCESSFUL INTRODUCTION

Farm size in the Colombian cattle zone varies depending on the use. Dairy farms are generally small, with an average size of about 20 ha. Farms dedicated to the production of cattle for meat are much larger, averaging 200 ha. Cattle are kept outside all year, but the pastures are rotated to allow for recovery of the grass and for control of weeds. Farms are usually managed by resident farm managers, although farm owners (usually urban based) take an active interest in the management of the farm. Spray operators are usually full time employees, although it is not unusual for short term staff to be employed at the times of highest labour demand.

The barriers to the introduction of low volume CDA spraying in Colombia can therefore be grouped into three categories: 1) those presented by the farm owners, usually based on the economics of spraying (both costs of spraying and the returns); 2) the farm managers - their concerns are both economic and the degree of management control and monitoring required of the spray operators; 3) the spray operators, who generally wish to complete the task with the minimum effort (but not necessarily the shortest time, as often they will then be required to do other tasks).

Farm Owners

The primary concern of farm owners is in the economics of weed control. Assuming that the cost of chemical remains the same irrespective of the system of application and the degree of control is similar, then the costs to the farm owner are :

1) Capital cost of re-equipping
2) Costs of application - including labour and direct costs (primarily batteries for CDA equipment)

The cost of re-equipping involves not only purchasing new equipment, but the decision to discard old equipment. The savings in costs of application must compensate for this investment. The major saving in low volume application are related to reduced water use. Calculations show that the savings in labour can be as much as 50% even with the water source as little as 1 minute away from the spraying site. The effect of the impact of the savings on labour depends upon the unit cost of labour. However, it is also the case that the reduction in labour requirement for spraying operations frees up labour to undertake other on farm-tasks, increasing productivity of labour. The degree of importance attached to this will vary from farm to farm, but can be of major significance, particularly as farms intensify and seek to maximise labour productivity.

The capital cost of the CDA sprayer is equivalent to 15 days labour cost, based on 1996 prices. The operational cost increases the daily cost of using the sprayer by 15% (labour and batteries, but without depreciation), which will be set against the savings in labour. Therefore, the cost of the CDA sprayer could be recovered in one year on a farm undertaking 31 days spraying with traditional high volume equipment.

Farm Managers

Farm managers are concerned with the management and supervision of spraying operations. They need to be convinced that the additional supervision and training required in the use of CDA will be rewarded with a proportionate increase in labour utilisation. The additional supervision is largely to ensure correct application, and also to make sure that potential labour savings are realised. In the case of small scale operations, it will be the farm manager himself undertaking this supervisory role, at least in the early stages. In situations where larger scale operations are being undertaken, this role will be taken by a spray supervisor. However, whoever is undertaking this role will need to be trained to understand the use of this technology.

One of the disadvantages of switching to CDA spraying is that it may be difficult to recruit casual labourers for spraying who are competent in the use of this technology. This may mean that time has to be expended on training casual labourers who may only be employed for a very short time. This naturally has time and cost implications for farm managers.

Spray Operators

The key to the successful introduction of low volume spraying is the acceptance and proper use by spray operators. From an operator point of view, the use of low volume spraying has four drawbacks. Firstly, the area that they will be required to spray per day is significantly higher, and it therefore may be perceived to be harder work. Secondly, by completing the spraying task earlier, they may be required to undertake other on-farm tasks. Thirdly, the use of CDA means that the number of tank re-fillings is less than with traditional high volume systems and the opportunity for rest periods taken during re-filling is reduced. These are important areas to address, and may require a restructuring of the system of remuneration to operators. The fourth problem is the difficulty of seeing the spray produced by the machine, and the consequent inability to see significant deposit on the target weeds. This has two implications - firstly the operator may not have confidence that the target has received sufficient deposit, and secondly and as a result of this there is a tendency to overdose This can only be addressed by the use of a "field school" approach. On a small scale, operators are encouraged to spray defined areas with different rates (defined as number of seconds per plant for spot treatment). Spray operators are asked to evaluate the levels of control achieved after various time intervals. This system allows the spray operators to develop confidence in CDA on a small scale.

CONCLUSIONS

Field trials in Colombia in 1996 have shown that low volume controlled droplet application of herbicides gives control equivalent to conventional systems of application. Despite the advantages of low volume spraying in terms of reduced labour requirement and more speedy application (thus freeing labour for other tasks), the uptake of this technology is hindered by non-technical barriers. It is only by the identification of the barriers at each level in the application chain that appropriate training and information can be provided. It is clear that the information and training requirements at each level are different, and need to be designed with this in mind.

In the Colombian context, the introduction of CDA technology can be best achieved through the use of the existing network of pesticide distributors, who are able to promote CDA technology as a tool for farm owners to increase productivity. Thus the pesticide distributors are able to present to farm owners packages of technology, training and chemical for the control of weeds in pasture areas.

The introduction of low volume CDA spraying serves as an interesting model for the introduction of improved application technology in a developing country, indicating that not only the technological, but the social and economic context into which technology is introduced needs to be understood. To be successful, the concerns of all involved need to be addressed through the provision of appropriate information and training.

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CATCH-CROPPING WITH SUDAN GRASS - AN OPTION FOR STRIGA CONTROL IN SUBSISTENCE AGRICULTURE

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ABSTRACT

Sudan grass was intercropped into maize as a *Striga* catch-crop and up-rooted after 30 or 50 days. It stimulated the germination of high numbers of *Striga* seeds. However, no immediate effect of a single Sudan grass catch-crop on *Striga* populations in the following growth period was detected. Competition with Sudan grass for 50 days reduced maize yields considerably while 30 days did not affect yield. Inorganic fertiliser generally increased maize yields but high N rates (100 kg ha^{-1}) rarely resulted in superior maize performance due to *Striga* competition and drought. A combined food-crop catch-crop system seems feasible under low-input conditions but the management of Sudan grass in intercropping systems and its direct effect on *Striga* infestation and the *Striga* seed bank in the soil needs further investigation.

INTRODUCTION

Striga hermonthica or witchweed is a parasitic weed which attacks maize, sorghum and other staple cereal crops. It has become an increasing problem to smallholder subsistence farmers in sub-Saharan Africa and represents the largest single biological barrier to food production in the region (Sauerborn, 1991). Catch-cropping *Striga* refers to an agronomic technique in which a crop, which stimulates a high percentage of the parasite seeds to germinate, is grown in an infested field for several weeks until the parasite has attached to its roots at which stage it is up-rooted to destroy the weed. This has been used to control *S. asiatica* in maize in Zimbabwe (Timson, 1929; 1945) and *S. hermonthica* in sorghum in Sudan (Last, 1961). Here, Sudan grass (*Sorghum sudanense*) as the catch-crop achieved reductions in *Striga* infestation of up to 66 %. In parts of Ethiopia, Eritrea and Sudan farmers first plant sorghum or maize at high densities and then, after attachment of *Striga,* thin the crop to standard densities, to reduce *Striga* infestation.

However, catch-cropping has rarely been used by small scale farmers because the technique is not well known or understood and holds serious disadvantages if not adapted to the specific cropping system. Under rain-fed conditions, for example, the farmer can lose a complete growing season because rainfall might not be enough to sustain a food crop planted after the catch-crop. Also there are extra costs for labour and (catch-crop) seed. The objective of recent work in Kenya was to develop a catch-cropping system appropriate for small-scale farmers, i.e. to combine the advantages of the catch-cropping technique with the farmers' requirements for a staple food source. Maize was inter- and relay-cropped with Sudan grass (SG) at different fertility levels to investigate the effect on *Striga* germination and the competition between the food and catch crops.

MATERIALS AND METHODS

Trials were planted at four sites during the long rainy season (March to August) 1996 and the short rainy season (September to January) 1996/97. The locations were the National Sugar Research Center (NSRC - 0°02' S, 34°48' E; 1240 m elevation) at Kibos, Kisumu district, the Alupe Research Sub-Station (ARSS - 0°29' N, 34°08' E; 1190 m elevation) at Alupe, Busia district, and two farmers' fields in the vicinity of the ARSS. The vetro-eutic planosol soil at NSRC is moderately well drained with a sandy loam texture. At the ARSS the soils are ferro-orthic Acrisols with a sandy clay texture which are shallow to moderately deep and well drained. Precipitation is generally higher and more reliable at the ARSS than at the NSRC. However, because of the lighter, shallower and better drained soils at Alupe plants may become water stressed after a relatively dry spells. The experimental design was a three factorial randomised complete block with three replications on-station and two replications on-farm. Plots consisted of five rows each 5.0 m long with 0.75 m between rows. Within row spacing was 0.5 m with two maize plants per hill to provide 53,000 plants/ha. Maize hybrid 511, with a growth period of 120 days was used in all experiments. Plots were kept weed free throughout the growth season by hoe and hand weeding except for *Striga*. Rice and Sudan grass (SG) were used as catch-crops in the long rainy season trials. In the short rains rice was substituted by relay planting of SG, i.e. SG was sown either simultaneously or two weeks after the maize crop. The catch-crop was planted in strips between the maize rows with a seed rate of 250 kg ha^{-1}, up-rooted 30 or 50 days after planting and left on the field to rot. Four fertility levels were established by applying 0, 50 or 100 kg of inorganic N ha^{-1} in split applications or 10 t ha^{-1} cow manure at planting. *Striga* plants were counted in three centre rows per plot at two week intervals from emergence of the parasite until a few weeks before harvest when *Striga* numbers began to decline. Maize yields were obtained from the three centre rows and were converted to 12 % moisture content. Yield data was subjected to analysis of variance. *Striga* counts were transformed to logarithm and the data of the on-farm sites were combined according to the methods described by Neeley *et al.* (1991) prior to analysis.

RESULTS

Rice did not establish well and as farmers were very reluctant to up-root this crop once established it was not used in subsequent short rain experiments. On the long rains grain yields were higher than in the short rains because of favourable climatic conditions. *Striga* numbers were likewise considerably higher ranging from 10 to 150 plants m^{-2} (data not shown). Nevertheless maize yields responded similarly to treatments applied in both growing seasons; only the data of the short rainy season is presented here.

Table 1. Grain yields in t ha^{-1} of maize Hybrid 511 grown with different fertiliser rates, in pure stands (control) or intercropped with Sudan grass at three locations in western Kenya

Location	Kibos									
Time of planting	SG[a] simultaneous					SG relayed				
Fertiliser rates	0 N	50 N	100 N	manure	Average	0 N	50 N	100 N	manure	Average
Time of uprooting										
30 d	0.8	1.7	1.6	0.8	1.2	1.0	1.4	1.3	1.0	1.2
50 d	0.2	0.3	0.6	0.1	0.3	0.4	1.2	1.3	0.9	1.0
No catch crop	1.1	1.2	1.8	1.1	1.3	1.1	1.2	1.8	1.1	1.3
Average	0.8	1.1	1.3	0.7	1.0	0.9	1.2	1.5	1.0	1.2
Fertiliser rate / Planting time x Uprooting time: SE = 0.195; 46 DF; $p < 0.01$										
Location	Alupe									
Time of planting	SG simultaneous					SG relayed				
Fertiliser rates	0 N	50 N	100 N	manure	Average	0 N	50 N	100 N	manure	Average
Time of uprooting										
30 d	1.8	2.4	3.0	2.4	2.4	1.7	2.8	3.1	2.0	2.4
50 d	1.7	2.4	3.3	1.6	2.3	2.0	2.6	2.9	1.8	2.4
No catch crop	2.1	2.3	2.5	2.0	2.3	2.1	2.3	2.5	2.0	2.3
Average	1.9	2.4	2.9	2.0	2.3	1.9	2.6	2.8	1.9	2.4
Fertiliser rate: SE = 0.581; 46 DF; $p < 0.01$										
Location	On-farm									
Time of planting	SG simultaneous					SG relayed				
Fertiliser rates	0 N	50 N	100 N	manure	Average	0 N	50 N	100 N	manure	Average
Time of uprooting										
30 d	0.8	2.1	1.2	1.3	1.3	1.2	1.5	1.6	1.1	1.4
50 d	0.4	1.1	2.0	0.5	1.0	0.4	1.2	1.4	0.7	0.9
No catch crop	1.3	1.8	2.4	1.3	1.7	1.3	1.8	2.4	1.3	1.7
Average	0.8	1.7	1.9	1.0	1.4	1.0	1.5	1.5	1.0	1.3
Fertiliser rate / Uprooting time: SE = 0.345; 69 DF; $p < 0.01$										

[a]SG = Sudan grass; [b] = factors not mentioned were not significant at 0.05 level

Yields were highest at Alupe while at Kibos a pronounced drought from November 96 to January 97 affected grain output adversely (Table 1). The on-farm sites had notably higher *Striga* infection rates which reduced overall productivity compared to Alupe (Table 2 & 3). Fertiliser rates showed no interactions with time of planting or time of up-rooting of the SG. Application of 50 kg N ha^{-1} always increased grain yields compared to the 0 N treatments except for the control with maize in sole stand and for simultaneous planting of maize and SG with late up-rooting at Kibos. Doubling the N rate to 100 kg ha^{-1} produced consistently higher yields at Alupe only, where the response was almost linear, although absolute increments were rather low. At Kibos the higher N rate did not increase yields compared to 50 kg N ha^{-1}, except for sole maize where the 50 N rate had no effect on crop yield at all. The on-farm experiments showed a mixed response to increasing fertiliser rates. While the sole maize, and maize with simultaneously planted and late up-rooted SG had higher yields with higher N rates, returns were similar for both treatments where SG was relay planted. There was no clear trend for maize with simultaneously planted and early up-rooted SG, because grain yield for the higher N rate was very low due to a high *Striga* number of 45 plants m^{-2}. Manure use did not improve maize yields. A clear interaction effect on maize yield between time of planting and time of up-rooting SG was only observed at Kibos. Yields were very low when SG was planted simultaneously with maize and up-rooted late. Competition from the catch-crop, *Striga* infection and a late season drought contributed to this poor performance. When SG was relayed and up-rooted at 50 d, yields of the fertilised plots (including manure) were similar to where SG was up-rooted at 30 d, with the non-fertilised treatment yielding considerably less. In the on-farm experiments maize yields of the simultaneously and relay planted treatments were clearly reduced when SG was up-rooted after 50 d. However, high fertiliser application reversed that trend partially. Controls without SG produced highest yields, followed by treatments with maize and early up-rooted SG and maize with late up-rooted SG.

Treatments imposed during the long rains did not affect *Striga* emergence in the short rains. This may reflect the generally lower infection levels of the short rains which were up to 70% less than recorded during the long rains. At Kibos and Alupe *Striga* emergence in maize was of similar magnitude with 4 to 17 (with a SE of ± 0.88) emerged plants m^{-2} 89 days after planting (DAP). Infection rates of the on-farm experiments were higher and reached up to 45 (standard error ± 4.0) plants m^{-2}. *Striga* emerged on maize by 35 DAP at the on-farm sites and by 50 days at Kibos. SG proved to be a good host as *Striga* not only emerged by 28 DAP with up to 260 plants m^{-2}. At Alupe and on-farm, fertiliser application did not affect *Striga* (Table 2; data for Alupe not shown). At the first *Striga* count maize controls and treatments with maize and simultaneous planting of SG had less *Striga* infection than where SG was relay planted. At the later count *Striga* numbers in controls had increased and were similar to the late up-rooted treatments but still lower than for the early up-rooted ones. At Kibos 100 kg N ha^{-1} reduced *Striga* significantly in treatments with SG as compared to the control for both counts. Manure application resulted in a contrary effect, i.e. SG treatments had clearly higher *Striga* numbers than the control.

Table 2. *Striga* plants m^{-2} at two dates following use of catch-cropping with Sudan grass in maize at two on-farm sites. Counts presented for means of planting time and up-rooting treatments averaged over four fertility levels

	Striga count 60 DAP[a]						*Striga* count 74 DAP					
Time of Planting	simul[b]	trans[c]	relay	trans	Aver[d]	trans	simul	trans	relay	trans	Aver	trans
Uprooting at												
30 d	15.1	1.6	22.6	1.9	18.9	1.8	32.5	2.0	44.3	2.3	38.4	2.2
50 d	16.2	1.6	24.2	2.2	20.2	2.0	20.2	2.1	22.3	2.0	21.3	2.0
No catch crop	8.4	1.3	8.4	1.3	8.4	1.2	27.1	1.8	27.1	1.8	27.1	1.8
Average	13.2	1.5	18.4	1.8	15.8	1.7	26.7	1.9	31.3	2.0	28.9	2.0
	SE = 0.16; 69 DF; p = 0.05						SE = 0.18; 69 DF; p = 0.01					

[a]DAP = days after planting; [b]simul. = simultaneous; [c]trans. = log transformed means; [d]Aver. = average

Table 3. *Striga* plants m^{-2} at two dates following use of catch-cropping with Sudan grass in maize at Kibos. Counts presented for means of fertiliser rates x up-rooting time averaged over two planting times

	Striga count 75 DAP[a]							
Fertiliser rates	0 N	trans.	50 N	trans.	100 N	trans.	manure	trans.
Uprooting at								
30 d	6.3	1.6	6.4	1.6	3.1	1.3	7.8	1.8
50 d	13.7	1.7	8.9	1.9	7.3	1.8	8.7	1.0
No catch crop	7.2	1.7	9.8	1.9	9.9	1.3	4.1	1.2
	SE = 0.18; 46 DF; p = 0.05							
	Striga count 89 DAP							
Fertiliser rates	0 N	trans.	50 N	trans.	100 N	trans.	manure	trans.
Uprooting at								
30 d	4.6	1.6	6.4	1.8	4.3	1.6	8.0	1.8
50 d	11.2	1.8	7.3	1.8	5.4	1.6	8.2	1.7
No catch crop	9.6	1.8	7.8	1.8	11.3	2.0	4.4	1.3
	SE = 0.10; 46 DF; p = 0.05							

[a] DAP = days after planting; [b]trans. = log transformed means

DISCUSSION

Last (1961) reported that a single SG catch-crop reduced *Striga* infestation by 66 %. In our trials SG had no immediate effect on *Striga* populations was observed although the catch-crop was planted for two consecutive seasonss and considerably higher SG seed rates than the 45 kg ha^{-1} used by Last (1961) were applied. This can either be attributed to a masking effect of the climatic conditions prevailing during the short rainy season or to the fact that strip planting of SG in maize is less effective than broadcasting. However, *Striga* emerged first at all sites in SG, probably because the seed is planted shallowly and therefore stimulates *Striga* seeds in the uppermost soil layers to germinate. *Striga* counts of up to 260 plants m^2 in SG demonstrated that it is a potent stimulant producer but strip planting may require longer to reduce the density of *Striga* in soil than planting of a sole catch-crop. Relay planting of SG by resulted in significanttly higher *Striga* infection in maize at Alupe and on-farm. The higher *Striga* infection did not result in lower maize yields, as the negative effects of the increased number of parasites were compensated by the less severe competition stress between the two crops due to later planting of the SG. Also at Kibos fertiliser applications of 100 kg N ha^{-1} or manure affected *Striga* populations in SG treatments versus the controls, but failed to produce an effect on maize yields, indicating that other stresses were more potent and masked the effects of different *Striga* infection rates in maize.

Prolonged competition between maize and SG due to late up-rooting of the catch-crop severely affected grain yields. The catch-crop reduced maize yield on-farm significantly, irrespective of planting time. Inorganic fertiliser applications improved yields, balancing the negative effects, but 0 N and manure gave almost no returns. At Kibos late up-rooting resulted in almost complete crop failure for all simultaneously planted treatments while relay planting produced average yields only if maize was fertilised. Probably the severe drought at the end of the growing season at this location and the early and prolonged competition stress of SG combined, caused the low grain yields. Alupe with the more favourable climatic conditions was the only location where maize yields were not affected by the catch-crop.

Maize yields were maintained when SG was uprooted after 30 days (except where 100 N was used on-farm) which implies that competition between the crops during this period is not severe. Spatial separation of the crops and complementary use of nutrients and water, for a certain period of time might reduce competition while an association for a longer time increases competition and yield loss. Nevertheless, if the duration of the stresses is similar, staggered planting of the catch-crop favours maize growth, but also *Striga* attachment. Hence in heavily infested fields the catch-crop should be planted simultaneously while under moderate infestations relay planting might be advisable. Fertiliser application increased yields at all experimental sites. However, a rate of 100 kg N ha^{-1} rarely produced higher grain yields than 50 kg N ha^{-1} even where yield levels were generally low. Also manure did not improve yields compared to non-fertilised treatments, although a positive long-term effect on soil fertility can be anticipated.

Although high numbers of *Striga* emerged on SG inter- or relay-cropped into maize the parasite population was not reduced by a single cycle of catch-cropping. A complementary food-crop catch-crop system seems feasible however as competition is limited if SG is uprooted at 30 days. In that period SG produces 2 to 3 t ha^{-1} biomass of valuable fodder. Application of low rates of fertiliser may be necessary to counter effects competition on crop performance where fertility is low. The management of SG intercropped in maize and its direct effect on *Striga* infestation and *Striga* seed bank needs further investigation in order to develop a practical system, which can be adopted by farmers.

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