POSTER SESSION 4D

BIOLOGY AND CONTROL OF WEEDS IN TROPICAL CROPS

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Poster Papers 4D-1 to 4D-7

Control of *Parthenium hysterophorus* in Tamil Nadu, India- a study on farmers' practices

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ABSTRACT

The present study was conducted in Tamil Nadu, India with a broad objective of identifying awareness and adoption behaviour of farmers with regard to newer methods of control of parthenium and to estimate the crop loss due to parthenium infestation. Parthenium was found in garden and rainfed lands and not in wet lands. None of the sample farmers were aware of herbicides for control of parthenium. Manual weeding twice was the normal practice. Crop loss due to heavy infestation was seen up to a maximum of 300 kg of seed cotton per ha. Extra weedings needed to control parthenium, costing $ 50 /ha. Health hazards like dermatitis, allergy, reddening of eyes etc., were reported in highly infested zones of the State due to partheinum pollen grains. Nowadays, agricultural labourers are reluctant to take up parthenium weeding and they demand additional wages when they do.

INTRODUCTION

Parthenium hysterophrus L, commonly known as carrot weed and congress grass in India, was first identified in 1956 in Pune. It has now spread throughout India infesting railway tracts, pastures, wastelands, roadsides and agricultural lands. Studies have shown that this weed poses severe health problems to not only human beings, but also animals, which include white cattle, black cattle and goats. Also, the weed is reported to reduce forage production up to 90 per cent, besides making the land less fertile (Vartak, 1968). The weed has been seen in crops like peanut, potato, cotton (Hosmani *et al.*, 1973) and in the case of tomato and finger millet the yield was reported to be reduced by 40 to 50 per cent (Lakshmi Rajan, 1973) due to decrease in the number of branches and tillers. Even in high altitude areas of India, under temperate climatic condition this weed was found to occur. In other words, parthenium is found in a variety of agroecological situations. The weed is highly drought resistant and is able to suppress other drought sensitive weeds.

In India, both chemical control of parthenium and manual control are advocated, besides, spraying salt solution to induce physiological drought. In spite of the efforts of the State and Central Governments, parthenium has continued to spread and grow quickly causing a serious problem to the farmers and to the production of food and commercial crops in the subcontinent. Hence, the present study was undertaken to identify the awareness and adoption behaviour of farmers with regard to newer methods of control of parthenium and to identify the crop loss, if any, due to parthenium infestation.

With this broad objective, the present study was undertaken with the following specific objectives:

i) to evaluate the awareness and adoption of newer techniques of controlling parthenium weed in Tamil Nadu, India ;
ii) to estimate the crop loss, if any, due to parthenium infestation ;
iii) to analyse health problems caused by parthenium ; and
iv) to understand the problems encountered in weeding parthenium in Tamil Nadu.

METHODOLOGY

Tamil Nadu, as a whole, was selected for the present study. Six districts were selected by stratified random sampling method. In other words, the State of Tamil Nadu was stratified into three regions based on the extent of parthenium infestation *viz.*, high, medium and low. In the highly infested group Vellore and Coimbatore districts were selected. Virudhunagar and Tiruchirapalli districts were selected from medium infested group, while Salem and Ramanathapuram were selected from low infested areas. From each district, one taluk was selected and from each taluk, two villages were selected using random sampling technique. Thus, 180 farmers were selected throughout the State using multi-stage random sampling method.

RESULTS AND DISCUSSION

Awareness and adoption of chemical weedicides

Almost all the farmers have reported parthenium infestation in both garden land and rainfed situations. 'Roundup 36%WSC'(glyphosate) and 'Atrataf 50% WP'(Atrazine) weedicides are recommended by concerned manufacturing firms as pre-emergence / post-emergence herbicides for control of parthenium. None of the selected farmers were aware of recommended herbicides. Since there is no awareness about herbicides, the question of adoption of the same does not arise. Spraying 20 per cent Sodium Chloride solution is one of the recommended practices by Agriculture Department to induce physiological drought in parthenium, which is reported to be followed by a section of farmers to eradicate the weed found in waste lands, roadside and other non-cultivable areas; However even this practice was not known to nearly 92 per cent of the farmers. The rest of the farmers who were aware of this practice adopted it in wastelands and fallow lands. This was found to be effective when spraying was undertaken before flowering in parthenium.

Farmers resorted to manual weeding two to four times, the mean expenditure on which varied from $ 33 in tomato to $ 121 per ha in cotton in garden lands and constituted 10.65 per cent to 28.32 per cent of the total variable cost of cultivation (Table 1). This shows the importance given by sample farmers to proper weeding and keeping the fields clean. Additional weedings were necessary in garden lands of Vellore and Coimbatore districts, which fall under highly infested zone of parthenium in the State. Additional manual weedings were undertaken in peanut, banana, tomato, sugarcane, cotton, corn and sorghum leading to an additional expenditure of $ 13 to $ 50 per ha (Table 2) where as chemical control costs only $ 32 per ha. Farmers did no resort to the same since they were not aware of specific herbicides for parthenium. The extra weedings were due to heavy infestation of parthenium in cropped lands. The details of additional cost incurred and number of farmers reported extra weeding are furnished in Table 2.In the highly infested zone, farmers have reported crop loss in peanut, corn, cotton and sorghum. Crop loss was reported to a maximum of 300 kg/ha as shown in Table 3.The economic importance of crop loss is shown by the price received by farmers at $ 0.5 per Kg of seed cotton and around $ 0.30 per kg of peanut pods.

Table 1. Average variable cost of cultivation for major crops in selected farms of Tamil Nadu

S.No	Crop name	No.of farmers	Cost of cultivation ($ /Ha)			Cost of weeding ($ /Ha)			% occupied by weeding
			Min	Max	Mean	Min	Max	Mean	
1	Banana	4	481	2038	911	63	313	128	14.05
2 (i)	Chillies (dry)	16	277	332	305	44	100	51	16.72
(ii)	Chillies (garden)	9	277	431	310	44	150	66	21.29
3 (i)	Cotton (dry)	31	119	540	301	31	150	62	20.60
(ii)	Cotton (garden)	27	222	759	552	31	188	121	21.92
4	Fodder Sorghum	15	76	140	108	-	-	-	0
5 (i)	Peanut (dry)	24	154	389	281	23	78	46	16.37
(ii)	Peanut (garden)	52	154	400	276	22	94	54	19.56
6	Corn	14	172	319	232	38	88	54	23.27
7 (i)	Paddy (wet)	16	169	211	193	13	25	23	11.91
(ii)	Paddy (garden)	17	149	262	215	13	47	40	18.60
(iii)	Paddy (Semi dry)	21	150	262	212	17	47	32	15.09
8	Sugarcane	5	688	931	774	63	131	85	10.98
9	Sorghum	8	153	194	173	38	56	49	28.32
10	Tomato	18	250	484	310	9	63	33	10.65

Table 2. Extra weedings undertaken to control parthenium in selected crops in Vellore and Coimbatore districts of Tamil Nadu

District	Crop	Extra weedings	Additional cost $ /Ha	No. of farmers reported	No. of farmers raised the crop
Vellore N=30	Peanut	1	19	12	25
	Banana	1	50	1	1
	Tomato	1	19	1	8
	Sugarcane	1	31	1	5
Coimbatore N=30	Cotton	1	31	8	
	Cotton	2	50	6	16
	Banana	2	31	3	3
	Corn	1	13	1	14
	Sorghum	1	19	4	8

N= Number of farmers interviewed

Table 3. Farmers perceptions of crop loss due to parthenium infestation in Vellore and Coimbatore districts, Tamil Nadu

(No. of farmers reported)

District	Crop	Quantity (Kg)						No. of farmers raised the crop
		1 – 50	51 – 100	101 - 150	151 - 200	201 - 250	251- 300	
Vellore	Peanut	5	1	-	-	-	-	25
Coimbatore	Corn	3	1	1	-	-	-	14
	Cotton	-	1	2	1	-	1	16
	Sorghum	-	1	-	-	-	-	8

Table 4. Farmers perceptions of health hazards due to parthenium infestation in Tamil Nadu

(No.of farmers reported)

Sl. No	District/Level of infection	Dermatitis	Reddening of eyes	Allergy	Fever	Head-ache	Eye sight	Swelling
1	Virudhunagar (Medium)	28 (93.33)	-	-	-	-	-	-
2	Vellore (High)	25 (83.33)	3 (10.00)	15 (50.00)	6 (20.00)	2 (6.66)	1 (3.33)	-
3	Ramanatha-puram (Low)	30 (100.00)	-	-	-	-	-	-
4	Salem (Low)	23 (76.66)	-	-	-	-	-	-
5	Trichirapalli (Medium)	21 (70.00)	-	-	-	-	-	-
6	Coimbatore (High)	29 (96.66)	11 (36.66)	17 (56.66)	-	1 (3.33)	-	4 (13.33)

Figures in parentheses indicate percentage to number of farmers in the district concerned.

Table 5. Farmers perception of problems encountered in the control of parthenium in Coimbatore and Vellore Districts of Tamil Nadu

	Vellore		Coimbatore	
	No. of farmers reported	%	No. of farmers reported	%
Labourers unwilling to weed	26	86.6	26	86.6
Feared by farmers	2	30.0	20	66.6
Increased labour cost	21	70.0	16	53.3

HEALTH HAZARDS AND PROBLEMS IN WEEDING PARTHENIUM

Health hazards due to parthenium infestation were reported throughout the study area. Dermatitis, which is caused by pollen grains of parthenium was reported by almost all the respondents. Other hazards like reddening of eyes, allergy, fever, headache and swelling were reported in Vellore and Coimbatore districts i.e. in the highly infested zone, as shown in Table 4.

Washing with soap, applying coconut oil and taking a bath immediately after weeding were found to be the major precautions followed by a large number of farmers to avoid health hazards after weeding parthenium. Because of the health hazards of parthenium, labourers are reluctant to weed infested land. This is the major problem reported by farmers in weeding parthenium in the highly infested zone (Table 5). Labourers also demand extra wages to weed parthenium, as reported by 53 to 70 per cent farmers.

RECOMMENDATIONS

i. Since none of the farmers reported awareness of herbicides available for parthenium control is now a priority to the farmers on the use of chemical weed control and the Agriculture Department has to train them in the use of herbicides.

ii. Herbicides for control of parthenium should be made available at cheaper rates so that all categories of farmers could adopt these without any difficulty, since manual weedings are undertaken by farmers themselves with their family members without any expenditure in nearly 30 per cent of the farms.

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Investigation of period threshold and critical period of weed competition in young tea

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ABSTRACT

An experiment was conducted to investigate the critical period of weed competition on clonal tea *Camellia sinensis* during the first six months after planting (MAP) at Low-Country station of the TRI, Ratnapura, Sri Lanka. Twelve treatments *i.e.* different periods of weed growth were replicated 3 times on plots planted with 10 nursery plants at a spacing of 1.2 m x 0.6 m. Five treatments *viz.* keeping the plots free of weeds were made for a period of 4, 8, 12, 16 and 20 weeks from planting. Another five treatments were left unweeded for the same periods after which time plots were kept weed-free until 24 WAP. Two treatments were maintained weed-free and unweeded throughout.

Total plant dry weight of tea significantly decreased 6 MAP when plots were unweeded for 12 weeks or more compared with plots unweeded for 8 weeks or less. Tea dry weight increased significantly when plots were kept weed-free for 16 weeks or more compared with those kept weed-free for 8 weeks. Leaf area also decreased significantly when plots were unweeded for 16 weeks or more compared to those unweeded for 8 weeks. Therefore, the critical period for weed competition on young tea was between 8-16 WAP and the period threshold of competition was 12 WAP.

INTRODUCTION

Weeds in tea (*Camellia sinensis* (L) O. Kuntz). fields are more severe during crop establishment (new clearing) and following pruning due to the ground exposure until frame development is completed (Somaratne, 1988). It has been estimated that the yield loss due to weeds in high-grown young tea was 30% (Visser, 1961). The scenario of growth retardation due to weeds demonstrates that young tea is not sufficiently competitive to suppress weed growth at the early stages of phenological development (Prematilake, 1997). The maximum duration of weediness, which does not affect the growth of young tea, is stated to be two months (Wetttasinghe, 1971), but the critical period of competition during early establishment has not been investigated. An appraisal of the critical period for competition between tea and weeds during establishment of tea is of importance for selecting a time saving and low-cost weed management strategy for young tea lands. Critical periods of weed competition of perennial crops have been documented by many workers. Iremiran (1986) reported that weeding every 2-3 months is needed for oil palm seedlings raised in poly bags. Suryaningtyas and Terry (1993) reported a critical period of 4-6 weeks for weed competition on rubber seedlings.

The critical period may vary according to climatic and edaphic factors and clonal characteristics of tea. There have been no proper investigations on this aspect with reference to young tea. Hence the objective of the present investigation was to ascertain the critical period of weed competition during first six months of crop establishment at low elevation where weed infestation is pronounced.

MATERIALS AND METHODS

The field study was conducted from June-November '95 at the low-country station of the Tea Research Institute of Sri Lanka where the elevation is about 60 m above sea level and mean temperature is 28 °C. The soil is an Ultisol.

About 8 months old nursery plants of clone TRI 2025 were planted at a spacing of 1.2 m x 0.6 m. There were two rows, each having five plants in each plot. Tea inter-rows were mulched with "Mana" grass (*Cymbopogon confertiflorus)* soon after planting. Fertiliser, T-200 was applied (@15 g/plant/application) to a half circle about 15 cm away from the base of the plant at two-month intervals.

Treatments were continued for a six month period as given below. There were two systems of treatments. In system one plots were initially maintained weed-free by hand pulling for a period of 4, 8, 12, 16 and 20 weeks and thereafter weeds were allowed to grow until 24 WAP. In system two weeds were initially allowed to grow for periods of 4, 8, 12, 16, and 20 weeks after which time plots were maintained weed-free for the balance period of 24 WAP. In addition, two other treatments *i.e.* weed-free and weedy throughout were also assigned. Treatments were randomized in three replications in a randomized complete block design.

The plant height, thickness and leaf number per plant were measured from 6 randomly selected plants per plot three MAP. Weight of leaves, stem and roots and; leaf area per plant were recorded following uprooting of all plants 6 MAP.

RESULTS AND DISCUSSION

Plant growth:

At three months after planting leaf number per plant was significantly ($p<0.05$) reduced in treatments unweeded for a period of 12 week or where weeds were allowed to grow after 4 or 8 weeks (Table 1). Neither mean plant height nor collar thickness was significantly ($p>0.05$) affected by the presence or absence of weeds at this stage.

Total dry weight at 6 months from planting significantly decreased ($p<0.05$) when plots were not weeded for a period of 12 weeks or more compared with those plots which were unweeded for 8 weeks or less (Fig.1). However, leaf area was only decreased significantly when plots were not weeded for a period of 16 weeks or more compared to those unweeded for less than 8 weeks, whilst leaf area was comparable when plots were kept weedy for 8 to 12 weeks.

Table 1: Mean plant height, collar thickness and leaf number of tea at 3 months after planting as affected by different weeding treatments.

Treatment	Height (cm)		Plant Collar Thickness (mm)		Leaf Number/plant	
Duration	Weed	Weedy	Weed	Weedy	Weed	Weedy
4 weeks	34.52	33.36	4.06	3.93	11.3(1.07)*	13.0(1.14)
8 ,,	34.99	30.93	3.77	3.78	11.7(1.09)	11.3(1.09)
12 ,,	35.04	31.69	4.38	3.73	13.0(1.14)	8.0(0.95)
16 ,,	35.03	33.70	4.23	3.93	13.1(1.16)	9.0(0.99)
20 ,,	35.73	35.05	4.20	4.00	13.6(1.18)	8.7(0.97)
24 ,,	35.85	36.72	4.33	4.02	13.6(1.19)	8.7(0.98)
LSD (0.05)	ns		ns		(0.15)	

*- (Figures given in parenthesis are log (x+1) transformed values)

Conversely, total plant dry weight was increased significantly ($p<0.05$) when plots were kept weed-free for 20 weeks or more compared to those kept weed-free for 8 weeks or less. Similarly leaf area significantly increased when plots were kept weed-free for 16 weeks or more compared to those weed-free for 8 weeks. Weed-free period of 12 to 16 weeks resulted in a comparable plant growth.

The results also indicate that growth of tea in plots kept weed-free for 16 weeks either initially or later was comparable to the weed-free situation throughout.

Weed-free or unweeded duration did not affect root growth recorded at 6 MAP significantly ($p>0.05$), although root growth was poor when not weeded for 12-24 weeks from planting.

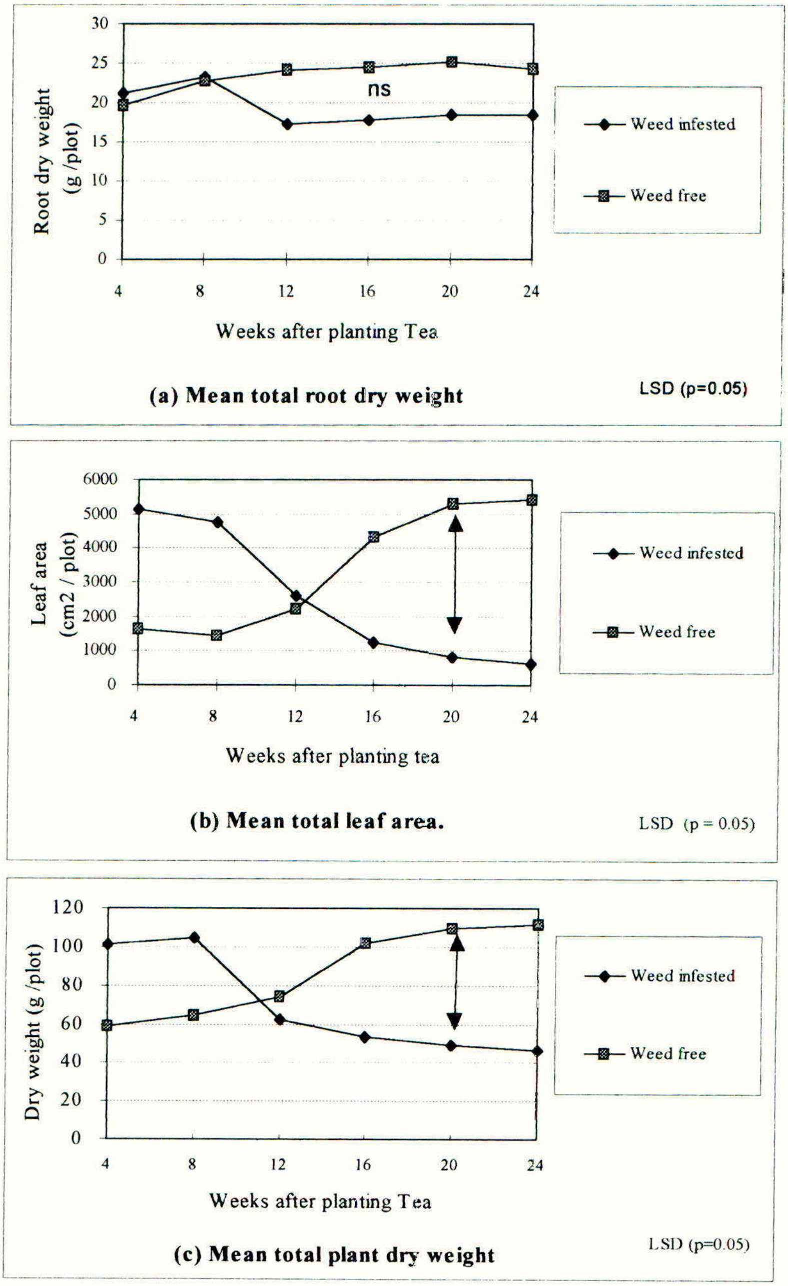

Fig.1: Effect of weed-free or weed-infested period on growth of young tea at 6 months after planting

The increased tea growth observed in plots infested with weeds for less than 8 to 12 weeks can be attributed to less weed competition due to low weed densities after mulching. In contrast, weed competition commenced when plots remained unweeded for more than 8 weeks and weed infestation for more than 12 weeks invariably retarded the growth of tea. Rapid growth and increased weed infestation as a consequence of mulch decomposition and manuring may have resulted in weed competition beyond 12 weeks. Prematilake (1997) reported elsewhere that more than 50 % of the grass mulch had decomposed by 12 weeks at the same location. Thus it was apparent that the period threshold of weed competition is 12 weeks from planting.

Results indicate that response of tea for weed competition was similar at the initial or late period of weed-free and weed-infested period beyond 16 weeks. It is also evident that weed control in young tea for 16 weeks was as effective as complete weeding for 24 WAP.

Similarly, plots infested with weeds for 16 weeks were as adversely affected as those weedy throughout for 24 weeks. Thus, it is clear that the critical period of weed competition is 8-16 WAP for the first 6 months of establishment. In Nigeria, Akobundu (1981) reported that the critical period of weed interference in white yam was between 8 and 16 WAP. Although data on the degree of weed infestation is not documented here, a high density of weeds was observed in plots unweeded for more than 12 weeks. This is attributed to the germination of seeds from the weed seedbank and also from new weed seeds produced in-situ. Under such condition tea plants were highly shaded by weeds species such as *Pennisetum polystachion* (L.) Schuit., *Mikania scandens* (L.) willd., *Hyptis suaveolence* Poit. and *Vernonia cinerea* (L.) Less. *etc*. Heavy shading by weeds reduced leaf growth and caused leaf senescence of tea.

These results indicate that weeding at 4-6 weeks intervals seem to be no more beneficial to young tea than leaving weeds for at least 8-10 weeks. In Nigeria, Iremiran (1986) also recommended that weeding at 2-3 months interval is more beneficial than weeding at monthly interval in a poly bag oil palm nursery. Similarly, Godfrey-Sam-Aggrey (1978) suggested that 45 days weeding interval could be used safely in place of 30 day intervals for cassava. At a practical level, the area underneath the tea rows must be weeded every two months to coincide with fertiliser application such a frequency also delays any possible early competition from weeds in young tea.

CONCLUSION

The critical period of weed competition in young tea for growth assessed 6 months after planting was observed to be 8-16 WAP and the maximum permitted period of weed competition on young tea fields is 12 WAP. However, it is appropriate to resort to a weeding method at 8 weeks intervals.

Further studies must be carried out on different clones with extended periods of weed competition during first two years after planting in order to recommend an economically viable policy of weeding for young tea.

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New weed management system in no till irrigated rice aiming to improve red rice control

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ABSTRACT

The low land areas cultivated for rice in Brazil extends to over one million hectares. About 30% of these areas are predominantly infested by red rice in such intensity that it is not economic to grow rice as a commercial crop. In 1984/85, Campos *et al.* (1986) developed adaptations to a no till system where, after soil preparation by primary tillage, it is irrigated in order to promote germination of the red rice seeds. When 30 - 40 cm high, red rice is sprayed with glyphosate at 1.62g a.i./ha and then the crop is planted. This system has been so successful in Brazil that several other rice producer countries have adopted the technique. This research suggests a new version for the system, which consists of several glyphosate applications with the red rice at earlier stages (5-10 cm). Periodic irrigation promotes germination of red rice by several flushes during 20 - 30 days and, application of glyphosate at 0.24 to 0.384 a.i./ha, 4 to 5 times, can control more red rice, reducing the soil seed bank considerably. This system allows reduced costs reduction for crop establishment and causes a lower environmental impact.

INTRODUCTION

In Brazil 3.3 million hectares are annually cultivated with rice producing about 8.5 - 9.5 million tons. More than one million ha is irrigated, concentrated mainly in the southern part of the country (Agrianual, 1998). The weeds that infest the crop, cause significant limitation to maximum yield, reduce final product quality and increase production costs. Among the major weeds, *Echinochloa* spp and *Oryza sativa* L. are the most serious (Menezes, 1991).

Brandão *et al.* (1982) listed 44 weed species present in irrigated rice. According to Holm *et al.* (1977), the four major weeds in rice are: *E. crusgalli, Fimbrimbistylis miliacea, Cyperus ferax* and *Aeschynomene rudis* L, besides red-rice. Because of its vigor and rusticity, high reproductive input, continuous ripening, and dormancy, red-rice is the worst weed in irrigated rice. So this weed is difficult to be managed and can cause significant damage to the crop (Leite, 1988). Contamination of rice grain by red rice reduces the value of the crop (Gonçalves, 1986).

In Brazil there are extensive areas where rice can not be cultivated economically because the infestation of red-rice in the soil seed bank is so high. Lately the use of varieties imported from Philippines has increased the problem because growers are not using preventive methods of red-rice control (Menezes, 1991). The no till system that has been used in soybean was also tested in rice (Lovato, 1982). However the experience has not been very successful, partly due to poor profitability of the pasture-rice crop rotation. During 1980-1985, Campos et al. (1986), proposed a conventional system of minimum tillage for rice, which combined the advantage of no till, with the reduction in soil preparation and the possibility of controlling red-rice. The principle is to cultivate the soil and then irrigating it, to break the dormancy of the seeds. Then, 30 to 40 days later, red-rice seedlings are sprayed with glyphosate at 1.68 to 1.92 kg a.i./ha and after that rice is seeded. This system has resulted in an excellent control of red-rice. The objective of this research was to propose a new method of pre-planting red rice management, with several irrigations and herbicide application at low rates.

METHOD

The traditional method of no till used by growers in Brazil is summarized schematically in Figure 1. The proposed new system (Figure 2) consists of early irrigation of the field (end of winter) in order to promote red-rice germination. When the seedlings are emerged, about 15 days after irrigation, glyphosate is applied at 0.384kg a.i./ha, and if broadleaf weeds are also a problem the area is sprayed in mixture with 2,4-D at 0.36kg a.i./ha. One week later, when the plants are dead, another irrigation/emergence/spraying is followed, but glyphosate is reduced to 0.24-0.288 kg a.i./ha, and the process is repeated once or twice. The aim of this process is to promote maximum germination of red-rice.

RESULTS

The results at field level, showed equal or even better control of red-rice with the new system, when compared to the traditional. On the other hand there is an increase in the costs, by the higher number of herbicide application, but the lower rates of glyphosate and the possibility of non application of the post emergence herbicide after crop establishment may represent a lower environmental impact of the herbicides. Yields were not significantly different, since red rice was included in the productivity measurement (data not shown). The major problem of red rice presence in the final grain yield is the post-harvest processing that damage the grains, reducing the commercial value. The new proposed system reduced the infestation of red rice and consequently lower infestation of the disease Bruzone, resulting in a lower fungicide application. Glyphosate lower rates were sprayed in the new proposed system and so reduced cost and environmental impact.

CONCLUSIONS

The modified system with 3 or 4 applications of glyphosate at low rates is feasible for rice production in Brazil. The use of multiple irrigation of the area that is going to be cultivated for rice allows a reduction in the soil seed bank. With lower red-rice seed bank, it is possible to obtain an excellent control by spraying the crop with only a pre-emergence herbicide, reducing the need for herbicide, as is required in the conventional system. This lower use of herbicide in rice will contribute to reduce environmental impact of rice cultivation in Brazil.

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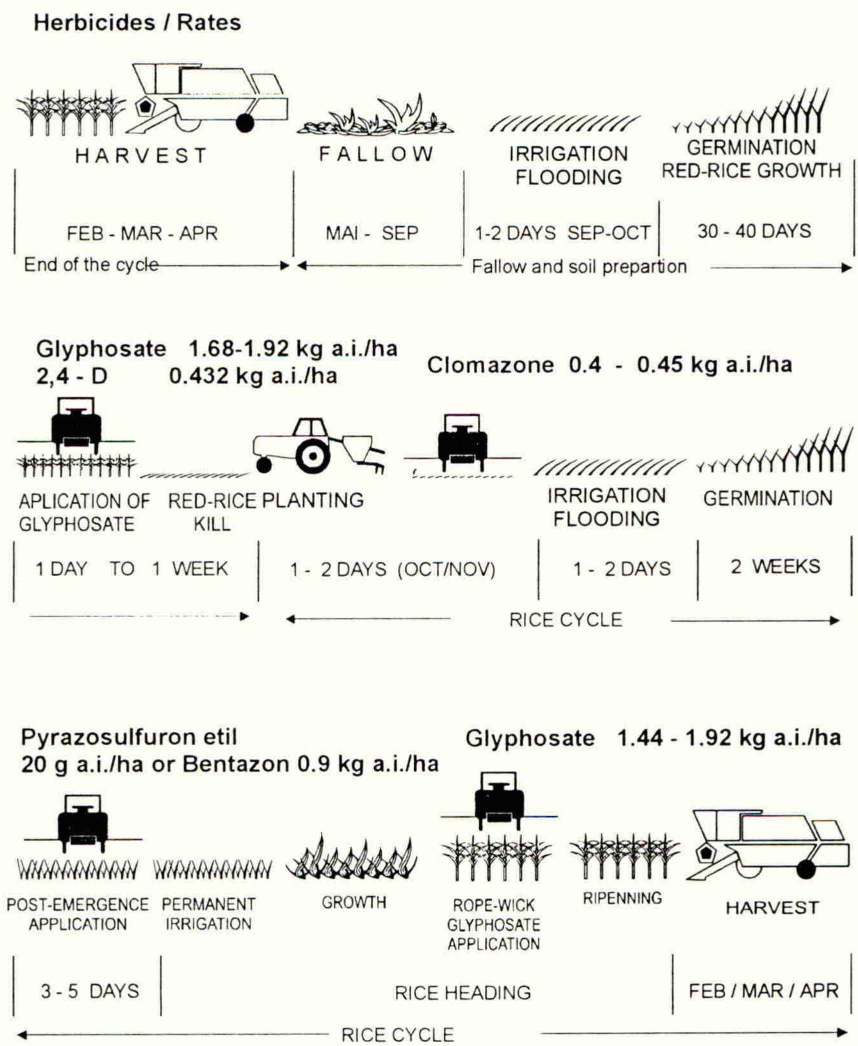
No Till in Rice for Red Rice Control - Traditional



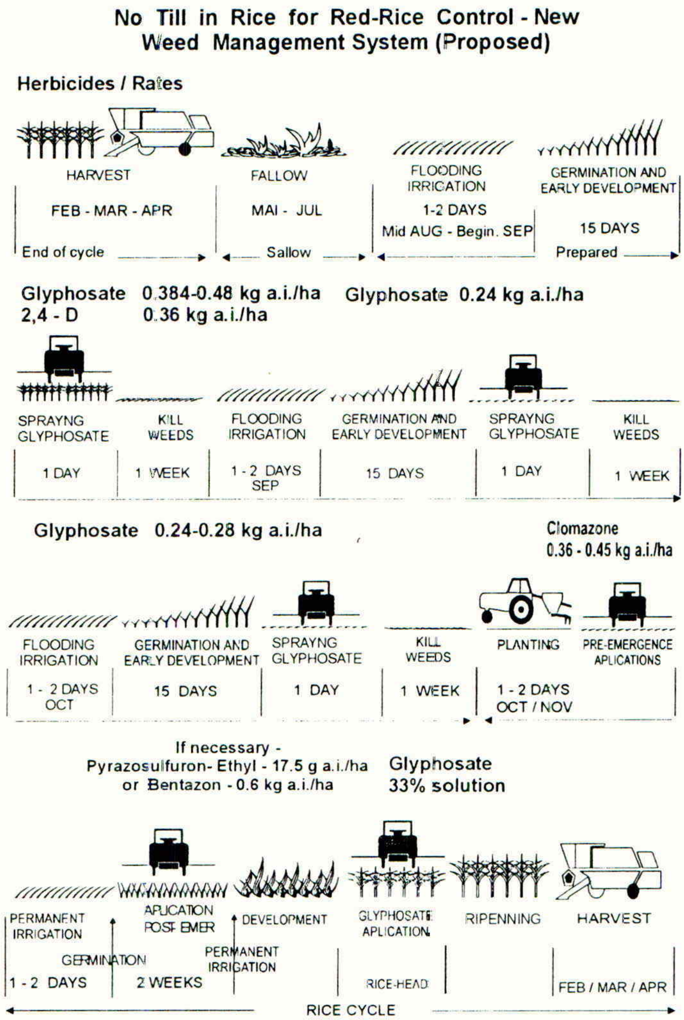


Figure 2. New red rice management proposed

Control of *Cyperus rotundus* on Vertisols and vertic clays in Ghana

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ABSTRACT

Field trials on Vertisols in Ghana showed that 1.8 kg a.e./ha glyphosate reduced tuber populations of *Cyperus rotundus* L. by 95% after being applied at the beginning of four cropping seasons during 1997 and 1998. Yields of maize grown during the major seasons of these years were significantly increased by use of the herbicide treatment. Camber beds (4.8 m-wide raised beds) appear to increase crop growth in typical wet seasons, compared to flat seed beds, but not in seasons that are much drier than average. The combination of camber beds for land drainage and glyphosate for controlling *C. rotundus* and other weeds is appropriate technology for small scale farmers in the Accra Plains of Ghana.

INTRODUCTION

It is estimated that 308 million ha of the earth's surface are composed of Vertisols (Coulombe *et al.*, 1996), including 90 million ha in Africa (Willcocks, 1989) with 180,000 ha in Ghana (Ahenkorah, 1967). Vertisols are montmorillonitic clays, representing valuable resources as they hold more water and are generally more fertile than the sandy soils that cover much of Africa. They are, however, difficult to manage as they are hard and cloddy when dry and very sticky when wet. These properties of Vertisols mean that the windows of opportunity for land preparation, sowing and early weeding are small. Vertisols are hard to cultivate when dry and too sticky for tractor operations and limit human access when wet. However, since these montmorillonitic clays shrink when dry and expand when wet, they are self-loosening. Hence, their physical properties make these soils ideally suited to reduced systems of tillage as there is little need to loosen them by mechanical tillage to grow crops.

Options for managing Vertisols in Ghana were explored during a three year project during 1992-95 which showed that raised land forms gave superior crop yields to those obtained on traditional flat beds (Ahenkorah, 1995). Camber beds, 4.8 m wide and 0.3 m high, were the most successful land form studied, increasing crop yields by 90% compared with flat beds. An unwelcome observation was that camber beds supported high populations of *Cyperus rotundus* L. and *Imperata cylindrica* (L.) Raeuschel which can seriously reduce the benefits of the improved land form.

Cyperus rotundus, reputedly the worst weed in the world (Holm *et al.*, 1977), is widespread in West Africa (Akobundu & Agyakwa, 1987). It reduces crop yields, causing losses, for example, of up to 89% in vegetables (Williams & Warren, 1975). Cultivation can be effective for controlling *C. rotundus* by exposing the perennating organs (tubers) to desiccation or by exhausting the food reserves. This is not practical on Vertisols because of the difficulties in cultivating the soil, especially when dry. Glyphosate is one of the few herbicides that controls *C. rotundus*; applied post-emergence at the flowering stage, glyphosate is taken up by actively growing shoots and translocated to the tubers. Dose rates of 2.0 kg a.e./ha are usually recommended. Glyphosate has a low mammalian toxicity (oral LD_{50} for rats = 5,600 mg/kg) and is inactivated on contact with soil, making it relatively safe for use by farmers in developing countries.

Over 67% of farmers in the Accra Plains of Ghana use tractors (usually hired) for land preparation and 30.5% use herbicides (Kwadzo, 1995). Labour takes up between 50 and 80% of the production costs. These farmers have adopted improved technologies in the past, so there is a reasonable probability that they will use herbicides and camber beds if cost/benefits are good and risks are low. Against this background, a three-year project was implemented to test glyphosate for the control of *C. rotundus* on Vertisols in the Accra Plains. Some aspects of the project are presented in this paper.

METHODS AND MATERIALS

A trial site on Vertisol was prepared at the Agricultural Research Station Kpong, Ghana (6°08'N, 0°05'E), a location where annual rainfall averages 1,200 mm distributed between a major season (March to July, approx. 800 mm) and a minor season (September to December, approx. 400 mm). Project research on this site commenced during the minor season of 1996 for an intended duration of 3-4 years. This paper reports on the results of research during the major seasons of 1997 and 1998.

Land forms and weed management treatments were studied for their effects on maize and weeds in a multi-factorial trial. For the purpose of this paper, only two main plot treatments are addressed, i.e. weed management (glyphosate and hand weeding), each containing two split plots (flat beds and raised camber beds). Treatments were kept to the same plots for the duration of the experiment. Other factors studied were tillage method (conventional and minimum) and the effects of residual herbicides but the results of this work will be reported elsewhere.

Site preparation started in late 1996 when an area of long-term fallow land infested with a variety of small shrubs, annual weeds and a high density of *C. rotundus* was mechanically slashed to ground level. In mid-March, a disc plough was used to prepare flat seedbeds, the standard land form used by farmers in the area. Camber beds were formed by repeated passes of a polydisc plough to make a raised profile 4.8 m wide and 40 cm high from the trough to the top of the bed. After a few weeks, the camber beds settled to a height of approximately 30 cm. The site was divided into six blocks containing randomised main plots measuring 38.4 m x 20 m. Each main plot was divided into two split plots, one consisting four camber beds in an area of 19.2 m x 20 m, the other consisting of a flat bed of the same size. Weeds were allowed to grow and glyphosate at 1.8 kg a.e./ha was applied with a knapsack sprayer to actively growing *C. rotundus*. No rain fell within eight hours of the glyphosate application. Maize, the first crop on the experimental site, was then sown. Hand weeding with hoes was done when necessary on all treatments. When hoeing proved impossible on the wet Vertisol, weeds were slashed to ground level with a cutlass. In subsequent seasons, the flat plots were prepared by disc ploughing and harrowing whilst the camber beds were cultivated with a polydisc. Cowpeas were grown in the minor season of 1997, followed by maize and cowpeas in the major season and minor season of 1998, respectively. Cowpea data are excluded from this paper.

Maize var. *Obatanpa* was sown 40 cm apart in rows 80 cm wide. Rows were oriented along the camber beds. Crop growth and yield parameters were measured in six rows, 5 m long, within eight harvested areas of 4.8 m x 5 m in each main plot. These were positioned between the top of one camber bed and the top of the adjacent bed. This enabled the effects of planting position across soil profiles to be determined. Rows 4 and 9 were on the tops of adjacent camber beds, rows 5 and 8 on the sides and rows 6 and 7 in the trough between the raised beds. In 1997, cobs were not shelled so grain yield was estimated by multiplying cob yield by a factor of 0.631. In 1998, actual grain yields were recorded.

Tuber densities of *C. rotundus* were evaluated in November 1998 using eight 20 cm x 100 cm quadrats per main plot. Quadrats were randomly placed on flat beds but only on the tops of the camber beds where growth of *C. rotundus* was greatest. Soil was excavated to a depth of 30 cm in each quadrat and removed from the site before tubers were extracted by washing with water. ANOVAR was done on square root transformed data.

RESULTS

Growth of *C. rotundus* was greater on the top of camber beds than on flat plots, and considerably greater on hand-weeded treatments than on glyphosate treatments. This is shown for tuber densities in 1998 (Table 1).

Table 1. Mean tuber densities of *C. rotundus* ($\sqrt{}$tubers/0.2 m^2). Figures in parenthesis are back transformed

Method of weed control	Camber bed	Flat bed
Hand weed	12.05 (145.2)	10.97 (120.3)
Glyphosate	2.83 (8.0)	1.87 (3.5)
LSD (P = 0.05):		
Different land forms and weed control	2.26	
Weed control for same land form	2.22	
Land form for same weed control	1.21	

Tuber densities are significantly greater ($P<0.01$) on hand weeded plots than on glyphosate treatments. Overall, tuber densities are greater on camber beds than on flat beds ($P = 0.043$) but individual differences between land forms in Table 1 are not quite significant.

In 1997, maize yields on the top and side of camber beds (positions 4, 5, 8 and 9) were significantly greater ($P<0.05$) than on flat beds, whilst yields in the trough (positions 5 and 6) were significantly less ($P<0.01$) than on flat beds (Fig. 1). Comparing land forms overall, the increase in yield from camber beds is not quite significantly different ($P = 0.08$) from that of flat beds (Table 2).

In 1998, maize yields on flat beds were significantly greater ($P<0.05$) than on the side and trough of camber beds (positions 5, 6, 7 and 8) but not significantly different from the top of

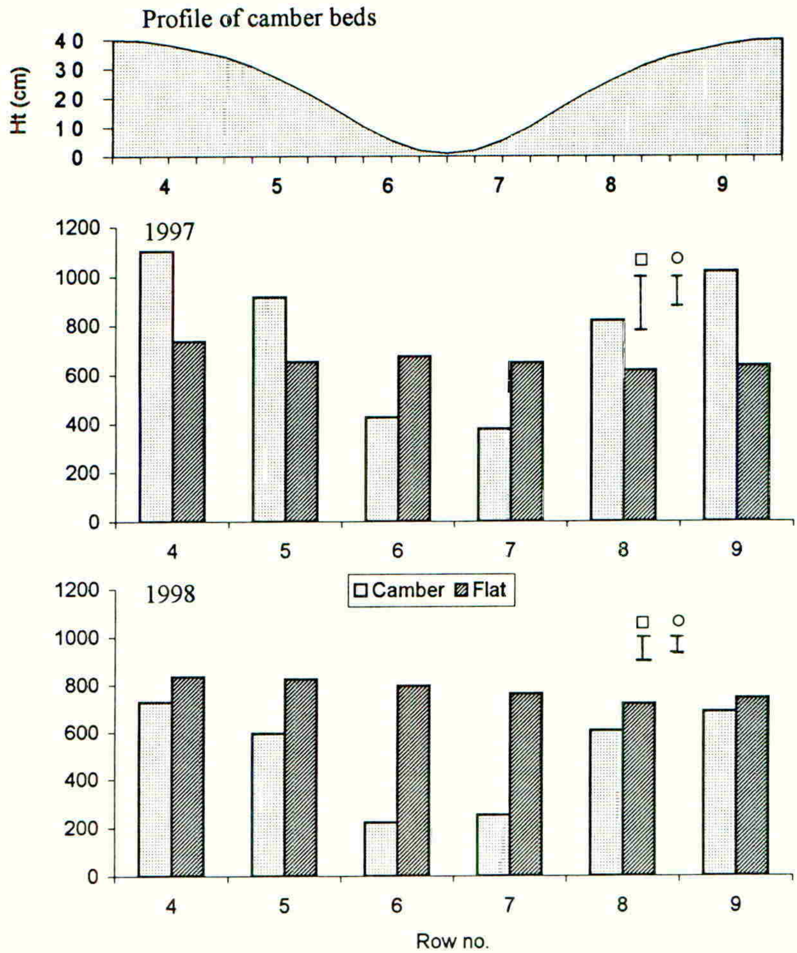

Fig. 1. Camber bed land form showing positions of crop rows 4-9 (vertical scale exaggerated x2); 1997 and 1998 maize grain yields (g/5m row). LSD (P = 0.05) bars: □ between land forms, ○ between row position for a given land form.

Table 2. Maize grain yields (t/ha) with glyphosate and hand weeding on two land forms

Method of weed control	1997		1998	
	Camber	Flat	Camber	Flat
Hand weed	1.48	1.31	0.50	0.83
Glyphosate	2.73	2.32	1.54	2.46
LSD (P = 0.05):				
Different land forms and weed control	0.56		0.42	
Weed control for same land form	0.52		0.39	
Land form for same weed control	0.37		0.27	

camber beds (positions 4 and 9) (Fig. 1). Overall, yields on flat beds were significantly greater ($P<0.0001$) than on camber beds (Table 2).

In 1997 and 1998, maize yields were significantly ($P<0.001$) higher on glyphosate treatments than on the hand-weeded plots (Table 2).

DISCUSSION

Crop yields on this trial were comparable to those obtained by local farmers for maize. The best yields on glyphosate-treated camber beds were 2.73 t/ha (equivalent to 11 bags/ac where a bag weighs 100 kg) in 1997 and 1.54 t/ha (6.2 bags/ac) in the drier 1998. Though much lower than research station yields in Ghana of 18 bags/ac cited by GGDP (undated), they are greater than those generally achieved by farmers on Vertisols near Kpong where typical yields are 0.5 – 1.0 t/ha (Kwadzo, 1995). The lower yield of 1998 reflects the very low rainfall (62% of average) during that season.

Camber beds have a significant effect on crop growth and yield. Raising the seedbed prevents damage by flooding which commonly occurs on these Vertisols. This was evident in the major season of 1997 when the water shedding capacity of camber beds reduced soil saturation and improved the yield of maize. However, in the much drier than average year of 1998, water shedding proved to be a disadvantage and maize yields were reduced as a result of drought stress. In typical years, however, camber beds are beneficial (Ahenkorah, 1995). Crop yields on the tops and sides of the camber beds were much higher than in the trough. This is attributed to moisture distribution (good drainage on the top and side; poor drainage in the trough). However, soil fertility might also influence these results as, during camber bed formation, fertile top soil is placed on top of the bed, leaving less fertile soil in the trough. As approximately one third of a 4.8 m camber bed is in the wet and/or low fertility trough, there could be merit in having a wider camber bed to reduce the proportion of land in the poor location. Indeed, companion trials have indicated that camber beds of 10 m width can give higher yields than the narrower beds.

The impact of glyphosate on *C. rotundus* densities was evident in all four cropping seasons. The reduction in tuber densities was over 95% by November 1998, demonstrating the feasibility of using glyphosate for the management of this weed. However, a result of this magnitude is not unexpected; glyphosate is widely used in some countries for the management of *C. rotundus* and other perennial weeds. Zandstra *et al.*, (1974) showed that tuber populations of *C. rotundus* could be reduced by 92% with three applications of glyphosate and a reduction of 86% after four applications was obtained by Charles (1995). However, *C. rotundus* has the capacity to regenerate rapidly from low populations of tubers; Zandstra *et al.* (1974) observed a 5-fold increase in the residual tuber population after six weeks. By November 1998, our plots had been treated four times with glyphosate, always as overall applications. Under more practical management regimes, spot treatments of glyphosate would be applied after one or two overall applications, particularly on tops of camber beds where the greatest populations of *C. rotundus* occur.

Glyphosate did more than control *C. rotundus*. Annual grasses and broadleaved weeds were considerably reduced, necessitating one hand weeding instead of two on untreated plots. Economic analyses of the costs and benefits of the treatments in maize were very favourable for glyphosate, even though yields were not optimal. Early indications from on-farm trials confirm the economic benefits of glyphosate and camber beds compared with the traditional practice of hand weeding on flat beds. More importantly, farmers are very pleased with the results and have expressed a desire to manage their crops with this technology.

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The potential of low volume herbicide application in developing agriculture

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ABSTRACT

The removal of weeds by hand is a laborious and time consuming task and a major constraint to the development of small-scale agriculture in many developing countries. One solution to these problems in West Africa has been the introduction of low volume spray application of herbicides, particularly with CDA (Controlled Droplet Application) sprayers. The successful introduction of chemical weed control requires farmer training and support. Recent experience in Northern Cameroon has demonstrated how extension services in place for cotton development can be utilised to improve cultivation of both cash and food crops through the introduction of appropriate application technologies.

INTRODUCTION

The development of appropriate weed control methods within small-scale agriculture in developing countries is an issue of increasing significance. Traditional methods of cultural control through hand weeding, ploughing in or burning are often inappropriate due to a lack of available labour or time. In many developing countries, urbanisation is progressing rapidly and also with more children, who traditionally help out on the farm, now attending school this has led to labour shortages at certain critical periods of the year. Chemical weed control is therefore of increasing importance to reduce the time and effort involved in hand weeding but also to conserve soils from erosion through no tillage programmes. The constraints of water availability in many semi-arid countries and the need for manual application methods, however, demands that spray equipment is simple, easy and safe to operate and favours low volume techniques which reduce the time and effort required for application. This paper discusses the development of low volume herbicide application techniques in maize, sorghum, cotton and vegetable crops in West Africa with particular reference to the wide scale introduction of spinning disc CDA (Controlled Droplet Application) technology as well as low volume application with lever operated knapsack sprayers.

WEED CONTROL PROBLEMS

Cotton is the major cash crop in West Africa, grown on over 2.08 million hectares in the francophone countries south of the Sahel. For many small-scale farmers' cotton is a major source of income and for the region itself an important source of foreign exchange earnings. Food crops such as maize, sorghum, rice and vegetables are also grown, however, these crops are generally only traded locally and there are few support infrastructures established to assist farmers with their cultivation. With the exception of ploughing and occasionally threshing, mechanisation of these essentially subsistence farms is difficult due to low income levels and small farm sizes. Weed competition for both food and cash crops represents one of the major biological constraints to increasing production in developing countries and it is estimated to contribute to 25% yield reduction in humid and sub-humid climates (CFDT 1999).

Traditional weed control methods have relied almost exclusively on hand weeding, ploughing, burning or fallow crop rotation. Hand weeding is extremely labour intensive and it can take around 40 hours to weed each hectare of crop. This represents some 20-50% of labour requirement during the growing season. (Parker and Fryer, 1975). In practice the farmer often has to abandon part of the area sown to crops, as weeds cannot be controlled.

Table 1. Average labour requirement for various farm operations in Nigeria (days/ha). (After Akobundu, 1980)

Operation	Savannah	Forest reservation
clearing	7	13
planting	33	13
weeding	189	256
harvesting	57	44

Matin (1990) identified that the amount of time spent weeding maize and sorghum crops meant that often the planting of cotton was delayed. Furthermore, losses incurred as a consequence of late weeding in cotton resulted in a significant yield loss typically 15 –30 kg yield loss per day from average yields of around 1 tonne/ha.

THE DEVELOPMENT OF CHEMICAL WEED CONTROL

During the last 30 years or so chemical weed control with herbicides has become extremely important in subsistence farming in West Africa. Early attempts to introduce chemical weed control did encounter a number of problems. The high initial cost of herbicides and the relatively low value of many food crops often precluded their use. Other problems were poor farmer knowledge of which herbicides to use, poor timing of application especially for pre-emergence herbicides, unavailability of herbicides in farmer pack sizes and lack of extension services to support the introduction of herbicides (Akobundu, 1980). Often herbicide use has been most successful in cotton or rice growing areas where support infrastructures and extension services were well established and the value of the produce encouraged private sector development.

In the cotton sector herbicide treatments are often required at least once and sometimes twice to each field. Conventional application techniques for weed control used high volume applications typically 200-300 l/ha applied with a lever operated knapsack sprayer. Manual collection of large quantities of water often meant spraying could take upwards of 8-10 hours for each hectare, and often water supplies are poor at the start of the rains as water levels in bore holes are low. This encouraged the development of low volume application techniques, particularly the introduction of CDA hand sprayers, which reduced the need to collect and carry large volumes of water to the fields. Despite the early difficulties in introducing weed control for subsistence farming, the economic advantages over traditional hand weeding is clear and Labrada (1994) argues that improving weed management practises in small scale farms is essential to improve productivity.

HERBICIDE APPLICATION WITH KNAPSACK SPRAYERS

Matthews (1993) has identified a number of requirements of spray application techniques for weed control at the small-scale farmer level when using lever operated knapsack sprayers. These fall into two areas, those which essentially address safety features and those concerned with efficacy of weed control. With the introduction of new sprayer standards e.g. BS7411 and FAO guidelines (1998) for knapsack sprayers a number of desirable features have been identified. These include minimising tank and surface residues, using secure and comfortable straps, security of lance, trigger valves and hose connections, appropriate filters, large filling apertures and mechanical durability of the sprayer in general. The adoption of such standards, particularly when equipment is centrally purchased or countries impose minimum standards upon application equipment through registration procedures, will assist in improving sprayers from a safety perspective.

Concerning biological efficacy, knapsack sprayers need to be used with appropriate nozzles. Currently, the majority of low cost sprayers are only provided with a single cone nozzle. To apply herbicides efficiently nozzle tips need to minimise spray onto non-target areas or adjacent crops. Generally a fan type spray pattern is required so a fan or deflector nozzle should be used. Soil applied residual herbicides can be sprayed with large droplets (typically 300-400μm VMD – Volume Median Diameter). This type of spray is also suitable for systemic products where the herbicide is redistributed within the plant. Alternatively the air inclusion nozzle may be more appropriate. For contact herbicides a smaller droplet size is preferred, typically in the 200-300μm range to ensure good biological efficacy, hence standard flat fan nozzles may be used in this instance.

The width of spray band is also important as operators often wish to spray either a large area typically up to 2m with a fan spray pattern when using soil applied or total herbicides, or narrow width, say 20-30cm in diameter, along the bands or ridges. The spraying of ridges is not widely practised but as a technique this avoids applying herbicide to the total surface area and obviously will save costs considerably, up to 70%. Farmers are able to hoe the inter-row through traditional methods as it is easier to do when no crop is present

The need to carry large volumes of water is perhaps the most pressing issue when using knapsack sprayers. Recently in West Africa, techniques have been developed to apply herbicide at 60-80 l/ha using low volume deflector nozzle tips. This can save considerable time in carrying and fetching water. Certainly the trend is towards lower volumes. One other problem frequently encountered is the inconsistency in sprayer output due to variations in pumping rate between different operators and during spraying. Operators frequently apply more at the start of spraying as their pumping rate is higher. As fatigue sets in the output declines so large differences in application rate can occur. The fitting of a spray regulating valve to control pressure, ideally with a maximum and minimum setting, is essential and a number of products are now available in the market place.

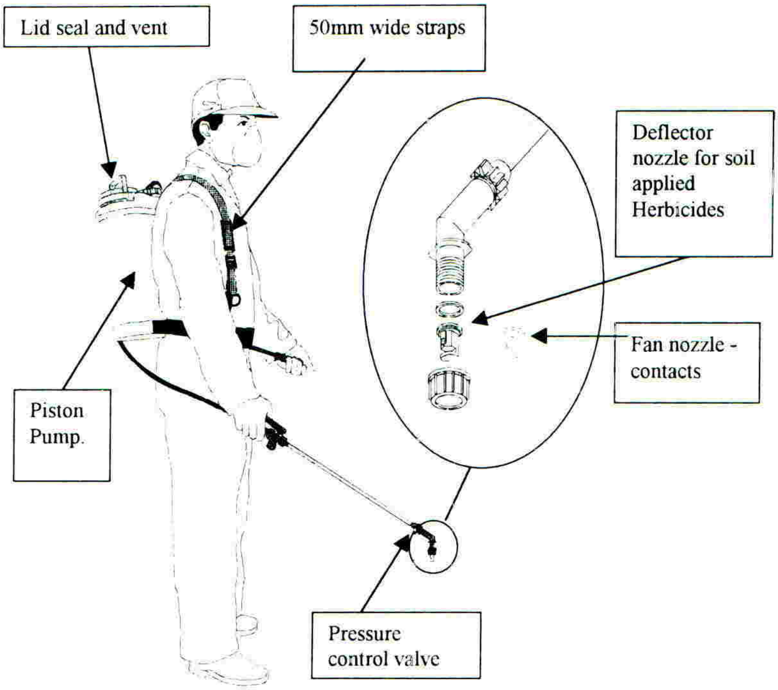

Figure 1. Knapsack sprayer requirements for low volume herbicide treatments

LOW VOLUME CDA SPINNING DISC SPRAYERS

Bals (1975) first described the introduction of a hand-held spinning disc sprayer for the application of herbicides at volume rates as low as 10-20 l/ha. Such systems work on the principle of Controlled Droplet Application (CDA) where relatively uniform spray droplets are produced by a rotating disc powered from torch batteries. This overcame a major constraint by minimising water requirements and in conjunction with a major agrochemical company the system was successfully introduced into small holder cotton with the chemical delivered initially, in a 5 litre container, ready to use, to treat 0.25 hectare. Uniform drop sizes of around 250µm are produced and the atomiser head is held behind the operator to improve safety and avoid walking through the spray or treated area (Thornhill *et al*, 1995). CDA sprayers were used mainly for pre-emergent herbicides such as atrazine, in maize. Recently with the introduction of newer selective herbicide products these can now be used for post emergence. Operators typically walk at 1.5 m/sec treating a band of around 1m and can treat 1 hectare of surface in around 2 hours. The 'Handy' sprayer is the most widely used CDA herbicide sprayer in West Africa and has recently been updated. The system now features a redesigned 5 litre bottle for closed transfer of product, improved sealing mechanism for the bottle support and aluminium battery case for reliable electrical operation. The disc speed is electronically controlled to deliver consistent drop sizes of 250µm irrespective of the condition of the batteries. Typically four batteries last for around 30 hours or 15 hectares spraying. Wijewardene (1980) reported 5-10 times improvements in farmer productivity through the introduction of low volume CDA hand sprayers without the need to use tractors.

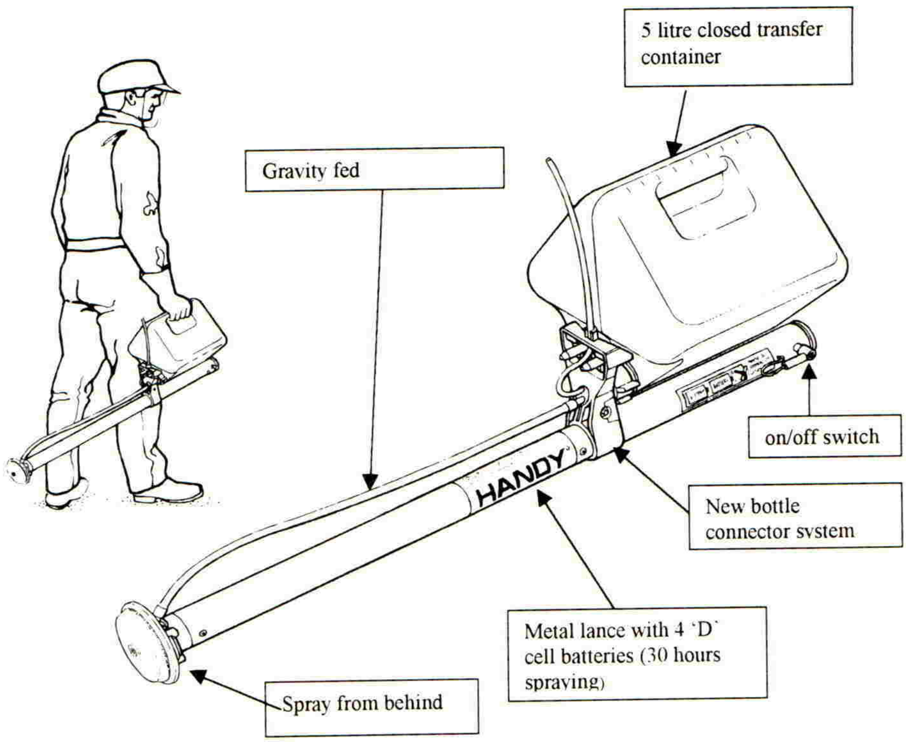

Figure 2. Low volume CDA spinning disc sprayer

DISCUSSION

Many small-scale farmers have been reluctant to invest in the purchase of herbicides, as they do not know if there will be sufficient rain for their crops. Furthermore governments have been hesitant to promote herbicide use in part to avoid import costs. Nevertheless with the continuing migration of people to towns and cities, there is an increasing lack of labour at the critical period of crop establishment. Hoeing and hand weeding is a tedious backbreaking task which often has to be repeated. To overcome such problems, an extensive programme of weed control has been recently introduced in Northern Cameroon by the national cotton organisation, Sodecoton who have an established extension network for farmers. By 1995 over 40,000 hectares of cotton and 15,000 hectares of maize were treated using low volume techniques, predominantly CDA hand sprayers (Matin and Gaudard 1997). Chemical weed control in cotton fields was estimated to have saved 12 man-days labour/ha of crop, a saving of 50% over the costs of hand weeding. Estimates of the increase in cotton yield were 240-600 kg/ha and 500-600 kg/ha for maize seed. A holistic approach to small farmer crop management was adopted and training, information and recommendations developed at the village level for all crops, maize, sorghum, groundnuts, cowpea, rice and cotton together with farmer credit schemes which are essential to support chemical weed control programmes. It is estimated that 80% of all pesticides available in developing countries are used on cash crops and only some 5% are available for use on food crops. Farmers who use pesticides mainly use insecticides but herbicide usage is now increasing markedly (CFDT, 1999). Studies by Johnson (1995) indicated that 80% of rice farmers in Côte d'Ivoire acknowledged they would increase the area under cultivation if weeds were less of a problem.

CONCLUSIONS

The development of low volume herbicide application for small-scale agriculture has been successful in overcoming constraints on labour availability by replacing hand weeding. Low volume techniques make spray application faster and are often more accurate than conventional techniques. Correct sprayer type and safety issues need to be considered in equipment choice. Examples from West Africa have demonstrated that infrastructures that exist to support cotton production can be extended to provide support for all crops. Utilising such extension services in place for cash crops may be the most appropriate method to ensure technology transfer.

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Weed management in semi-arid agriculture: application of a soil moisture competition model

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ABSTRACT

Weed water uptake is a key competitive factor in semi-arid, low-input farming. Smallholder farmers in Zimbabwe have long recognized the need for good weed control, both during the cropping and the dry season, as timely tillage restricts weed growth and transpiration losses. However, access to draught animal power (DAP) determines a farmer's ability to winter plough and to carry out timely planting and weeding operations.

Unfortunately, computer simulation studies to date have often failed to relate crop responses to management restrictions and weed competition. A weed management and water competition routine was developed, to simulate the effect of weed management on crop performance. This routine was incorporated in the PARCHED-THIRST crop growth model and calibrated with results from a 2-year weeding trial.

The effects of weed competition on crop performance were assessed over a 30-year simulation period, for four levels of access to DAP and labour. The results demonstrate how sub-optimal crop management affects weed competition and crop production. The timely access to sufficient DAP and labour is particularly crucial during planting operations, as a delay in planting can severely reduce crop performance.

INTRODUCTION

Weed competition for soil moisture is a key competitive factor in semi-arid, low-input farming (Twomlow *et al.*, 1997). Smallholder farmers in semi-arid Zimbabwe have long recognized the need for good weed control. Winter ploughing at the start of the dry season, prevents the depletion of the moisture that is stored in the soil profile, and thus improves the soil moisture conditions during crop emergence and establishment (Willatt, 1967). Timely land preparation and weeding operations restrict weed growth and transpiration losses during the growing season.

However, access to labour and draught animal power (DAP) determines a farmer's ability to winter plough and to carry out timely land preparation and weeding operations (Ellis-Jones and Mudhara, 1994). Chatizwa *et al.* (1998) distinguished three broad categories of farmers, based on their wealth and the recources available to them. Riches *et al.* (1998) subsequently summarized how these categories related to farm size, land quality, access to labour, DAP and off-farm income (*e.g.* remittances from family members). These studies demonstrated how livelihoods affect farmers' options for proper land preparation and weed control, and importantly, how they can restrict the opportunities for the uptake of soil and water conservation practices.

If research and dissemination efforts, that deal with improved farming practices, are to address the issues that restrict the production potential of smallholder farmers, it is of great importance to consider the constraints and opportunities that result from their livelihoods. Yet, quantitative computer simulation studies often fail to address how crop performance relates to restrictions in management options, and how management affects weed competition for limited water resources. These relations are crucial, if the quantitative nature of computer simulations is to be used to its full advantage, in the drive towards improved cropping practices for smallholder farmers.

MATERIAL AND METHODS

A simple computer routine was developed to simulate the effects of weed management and weed competition on crop performance. In this routine, water competition between the simulated crop and weeds takes place solely via the reduction of the soil water potential, as a result of water extraction. More detailed approaches exist, but these were deemed to be too elaborate for the purposes of this study.

Weed growth and water uptake routine

The weed growth and water uptake routine was derived from the results of a field trial, which quantified the water use of weeds, and which described how weed growth was restricted by soil physical constraints such as the soil moisture status (Van Der Meer *et al.*, 1998). The weed growth routine as it is presented in this paper, describes weed growth with three main parameters, the maximum weed transpiration rate (T_{max}), the maximum rate of root front advancement, and the maximum rooting depth. Water extraction from each soil layer is calculated as the product of T_{max} and several scaling factors f_x ($f_x \in [0,1]$), which introduce the effects on weed transpiration of the soil water potential, weed development stage, crop competition for light, and the depth of extraction. A detailed description of the weed growth routine is given in Van Der Meer (1999).

Weed management

Weed management in this model, takes place during tillage and weeding operations. It is assumed that all weeds are mechanically controlled during ploughing and weeding operations. This assumption means, that differences in weeding efficiencies, which are caused by the use of different ploughing and weeding techniques, are not addressed. However, when farmers consider the use of different weeding techniques, the pivotal factors are often the accessibility to DAP, and the differences in labour input between techniques (Scoones *et al.*, 1996). Despite this limitation, the simple weed management assumption that is used, allows the weed growth routine to simulate the agronomic effects of timing and frequency of weeding in greater detail, and with a greater relevance to the socio-economic context.

Calibration and validation

The model was calibrated and validated using data which were collected at the Makoholi Experimental Station (MES), Masvingo Province, Zimbabwe. The climate is semi-arid and characterised by a unimodal wet season from October to March. The 30-year average seasonal rainfall at the MES is 583 mm, but this ranges from 260 to 1150 mm (Bruneau & Twomlow, 1999), as a result of the high inter- and intra-seasonal variability of the rainfall. The data were collected over two seasons. The 1991-92 season received below average rainfall (270 mm) while the 1992-93 season was above average (773 mm). The soils at the MES are fast draining, infertile, medium to coarse grained sandy soils, and are classified as a Ferralic Arenosol (FAO). With depth, clay content gradually increases from 2.5% to 3.5-6% (Twomlow 1994). Gravel layers, that obstruct the rooting depth, occur at depths which vary between 1500 - 300 mm.

The weed growth and management routine was incorporated into the PARCHED-THIRST crop growth model, which was designed to simulate crop growth in a multi-challenging, semi-arid environment (Young & Gowing, 1996).

The model was calibrated with soil moisture and agronomic measurements, from a bare weed free treatment, a bare unweeded treatment, and a maize planted treatment that was kept free of weeds (Twomlow, *unpublished data*). With these treatments, it was possible to perform separate calibrations of the soil hydraulic behaviour, and the water uptake characteristics of the simulated crop and weeds. The drying out of the soil profile over the dry season was simulated accurately, which enabled the simulation of the water conservation effects of winter ploughing (Van Der Meer, 1999).

The model was validated using the results of a weeding trial, that investigated the effect of different weeding regimes on the soil water balance, and on the performance of a maize crop (Twomlow *et al*,. 1997). The model over-predicted the production of stover on average by 1.0 $ton.ha^{-1}$, but the correlation of the simulated dry matter production with the measured data was good (r=0.95). It was observed that the harvest index of the measured data was greater than 0.50, which implies that the stover production may have been higher than the figures indicate. The model captured the inter-annual variability of yield production well (r=0.97). Crop failure during extremely unfavourable conditions was not predicted, although the corresponding yields were typically < 0.38 $t.ha^{-1}$. The effects of the weeding treatments on the simulated yield and dry matter produced adequate correlations with the measured data (r >0.83).

Simulation of management scenarios

Four management scenarios were defined, based on farmer decision trees that were described by Chatizwa *et al.* (1998). The scenarios relate to the farmers' access to draught animal power and labour, which results from their financial and social position. This access defines whether a farmer is able to winter plough, to plant at the optimal planting date, and to control weeds efficiently during the growing season. The scenarios are outlined in Table 1. The four scenarios were simulated over 30 growing seasons, starting with the 1967-68 season. Daily rainfall data were available for the entire 30-year period, while daily data on minimum / maximum temperature, rainfall, and sunshine hours was only available for the period 1991-1998. The weather generator in PARCHED-THIRST was used to add a 30-year daily weather data set to the existing rainfall data. The 30-year simulation results of the four scenarios were compared using the median, and the average, of the crop yield, and the annual weed and crop transpiration. The upper and lower quartiles were used to indicate the variability of the data, because we could not assume a normal distribution of the 30-year crop performance.

Table 1. Typical crop management scenarios available to farmers with different resources at their disposal. Winter ploughing takes place 21 days after the simulation indicates crop maturity. The four scenarios represent decreasing levels of weed control.

Farmer Category	**Winter Ploughing**	**Planting**	**Weeding** (weeks after emergence)	**Reference in Text**
Well-Resourced	Yes	Timely	2+6	WP 2+6
Medium Resourced	No	Timely	2+6	nWP 2+6
Poorly Resourced I	No	Timely	4	nWP 4
Poorly Resourced II	No	Late (21 days)	4	nWP 4 LP

RESULTS AND DISCUSSION

The results of the 30-year simulation runs are presented in Figures *1-4*. Each scenario produced a wide range in maize yields, indicated by the values at the upper and lower quartile. This range results from the large inter-annual variability of the rainfall distribution, which has a marked effect on the conditions for crop growth.

Figure *1* demonstrates how winter ploughing affects the soil water content at the start of the growing season. In the absence of winter ploughing (*nWP 2+6*), weeds typically transpired 10 mm of soil moisture over the dry season, which reduced the soil water content at the start of the growing season by 1.6%. The model results however did not indicate that this made a substantial impact on crop performance. On soils with a higher moisture holding capacity than the sandy soils at Makoholi Experimental Station, weeds will be capable of extracting more water from the soil profile (Willatt, 1967), and thus weed control by winter ploughing will have a greater impact on the soil water status at the start of the growing season.

Yield effects of the four scenarios are presented in Figure *3*. The difference in yields between the treatments *nWP 2+6* and *nWP 4* show the effects of the application of two weedings rather than one weeding operation. This effect appeared to be strongest during seasons with above average rainfall, and thus higher yields. Although the reductions in crop transpiration between these two treatments were limited (Figure *2*), the predicted yields at the upper quartile showed a marked decrease from 1.85 to 1.44 $ton.ha^{-1}$. It was argued that because a well developed crop has a higher potential transpiration rate, it will be more susceptible to within-season drought spells. The increased rate of depletion of the soil profile, due to weed competition for soil moisture, is likely to increase the detrimental effects of intra-seasonal drought spells on crop production.

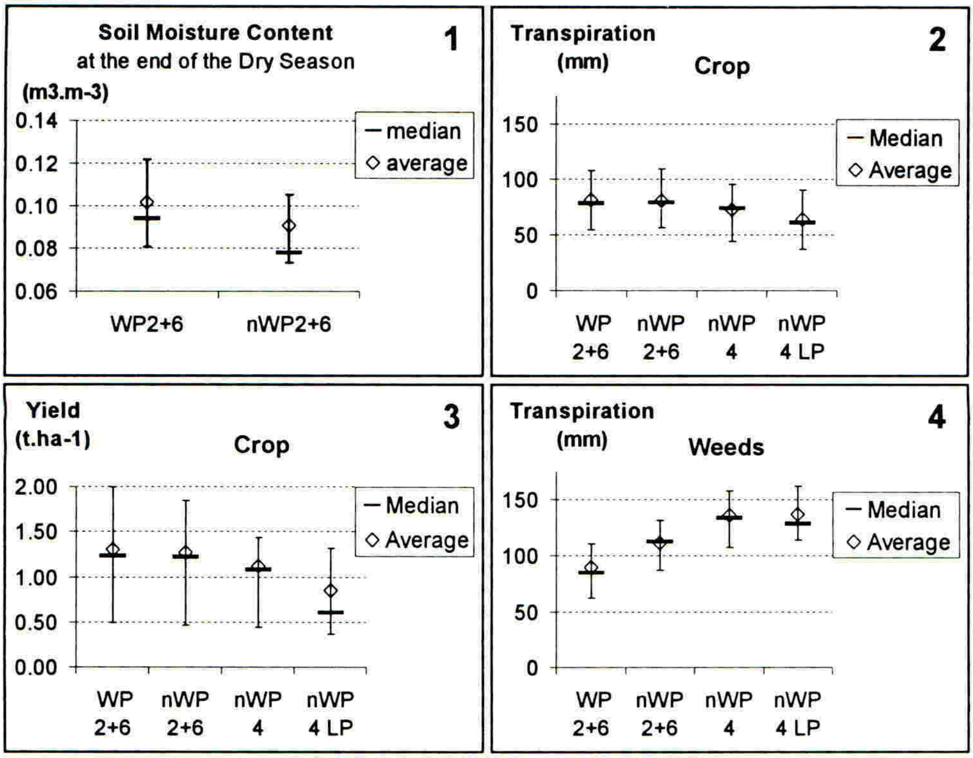

Figure 1. 30-year simulation results of the soil moisture content at the end of the dry season, for treatments with and without winter ploughing (respectively *WP 2+6* and *nWP2+6*). Error bars indicate the lower and upper quartiles.

Figures 2-4. 30-year simulation results of respectively crop transpiration, simulated yield, and weed transpiration, for four farming scenarios with different levels of weed control and land preparation practices. Error bars indicate the lower and upper quartiles.

While winter ploughing and weeding frequency did affect crop performance, the most pronounced reductions in crop yields were found to be the result of the delay in planting (treatment *nWP 4 LP*, Figure *2*). The effect of the planting delay on annual weed transpiration was limited, but as crop establishment took place under sub-optimal conditions, crop development was badly affected. Furthermore, maturity was reached later in the season, and this increased the risk of experiencing an intra-seasonal drought. Weed control was limited as a result of the single weeding, and the additional water extraction by weeds further decreased the soil water availability to crops during such dry spells, leading to the simulated yield reductions.

CONCLUSIONS

This modelling study shows how different farming scenarios, which are based on farmers' livelihoods, affect the agricultural productivity that they can achieve. The study demonstrates how the competition by weeds for soil water resources has a strong impact on the availability of water to crops, and how this competition exacerbates the detrimental effects of an erratic rainfall distribution. The timely access to adequate draught animal power and labour is particularly crucial during the planting operations, as a delay in planting can severely reduce crop performance.

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Semi-arid maize yield responses to conservation tillage and weeding

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ABSTRACT

The major problems associated with conservation tillage approaches currently promoted to the smallholder farmer in sub-Saharan Africa are weed control and crop establishment. To date little work has been carried out to assess the interaction of different conservation tillage options with different weeding regimes on maize yield and soil water regimes. To redress this situation on-station trials were carried out on a semi-arid sandy soil in Zimbabwe.

Results from three very different seasons showed that soil water regimes and crop yields were strongly influenced by both the conservation tillage option and the timing and frequency of weeding. In terms of crop water use efficiency and grain yield, a combination of weeding carried out at two and six weeks after crop emergence performed the best, whilst a single weeding four weeks after crop emergence was the worst of the weeding regimes. Where tied ridges were used, if weed control was inadequate, i.e. a single weeding four weeks after crop establishment, crop yields were significantly reduced, when compared to simple open plough furrow planting techniques that were weeded using the mouldboard plough with the body attached.

INTRODUCTION

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 essential and not only reduces competition for nutrients and light between the crop and the weed, but also influences the availability of water in the soil profile (Cooper and Gregory, 1987). Recent studies in Zimbabwe have confirmed the benefits of timely weed control and its impact on maize (Riches *et al.*, 1997; Twomlow *et al.*, 1997).

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 after crop emergence caused the greatest reduction in yields. Unfortunately, little work has been carried out to assess the interaction of different weeding regimes with conservation tillage approaches currently promoted to smallholder farmers on maize yield and soil water regimes (Vogel, 1994; Dhliwayo *et al.*, 1995; Muza *et al.*, 1996).

In this study we describe the responses of a maize crop to different conservation tillage options with two different weeding regimes on a semi-arid sandy soil.

MATERIALS AND METHODS

Trials were conducted at Makoholi Experimental Station (MES), Masvingo; in Natural Region IV of Zimbabwe (19°50'S 30°47'E, elevation 1204 m) during the 1994/95, 1995/96 and 1996/97 cropping seasons. Rainfall follows a unimodal pattern from October/November to March, when most of the rain falls as sporadic 'heavy' convectional storms, followed by a long dry season from April to May. The 15-year seasonal mean rainfall is 491 mm (1982-1997), with a range of 260 to 1150 mm.

Table 1. Rainfall distribution (mm) at Makoholi for 1994/95, 1995/96 and 1996/97 crop seasons compared to 15 year (1982-1997) mean

Season	October	November	December	January	February	March	Total
1994/95	126	10	248	80	65	53	582
1995/96	20	57	180	499	87	14	857
1996/97	0	138	187	281	60	81	747
15 yr- mean	36	58	117	144	98	38	491

The soil at MES is a deep coarse-grained granitic sand with a plant available water capacity of less than 6.2 % by volume, which means that crops grown on these soils are prone to drought, as any excess water quickly drains below the plant rooting zone (Twomlow and Bruneau, 1998). These are typical of soils used by Zimbabwe's subsistence farmers, and if properly managed, represents a large and valuable resource (330 Mha) in sub-Saharan Africa.

The trial was maintained on the same site for three years. After an overall winter ploughing in May/June of each year with a single- furrow, ox-drawn mouldboard, the trial site was laid out in a criss cross plot design with four conservation tillage techniques as main plot factors and weeding regime as the cross plot factor, replicated eight times. Conservation tillage techniques under investigation were: A)open plough furrow planting (OPFP) ; crop planted in open furrows created by a single pass of the mouldboard plough at 0.9 m spacing, B) crop planted as in A) plus a mid season ridge (OPFP+MR); ridges formed by weeding with a mouldboard and cross tying ridges at a 2.0 m interval to prevent water movement, C) Tied Ridge and D) Tied Furrow; constructed in September of each season at 0.9 m intervals with an initial amplitude of 0.13 m and cross ties every 2.0 m. Weed control was carried out by hand on tillage treatments A, C and D and with the mouldboard plough for tillage treatment B at either I) two and six weeks after crop emergence; or II) at four weeks after crop emergence. Maize hybrid SC501 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 7 December 1994, 13 December 1995 and 29 November 1996 . Fertilizer, 12 kg N, 21 kg P, and 14kg K per 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 maize grain yield was determined and adjusted to 12.5% moisture content. Total weed biomass was recorded at harvest from quadrats 0.5 by 0.5 m at five random positions in each plot. Weed and crop data was subjected to an analysis of variance and treatment comparisons were made using paired t-tests *($P<0.05$)*.

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 1994. Measurements were made within the crop row on three replicates of each tillage/weeding combination at 100 mm depth intervals to a maximum depth 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 and comparisons were made using paired t-tests ($P<0.05$). Total seasonal water use for each tillage by weeding regime 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:

$$\text{WUE (kg/ha/mm)} = \text{crop biomass (kg/ha)} / \text{water use (mm)}.$$

RESULTS AND DISCUSSION

As is shown in Table 1, total rainfall, and its seasonal distribution at MES varied considerably over the cropping seasons, having dramatic effects on crop yield responses (Table 2) to the different tillage and weeding regimes and the *in situ* variations in average seasonal soil water contents with depth (Figure 1).

Although maize yields varied considerably with seasonal rainfall there were no overall interactions observed between conservation tillage technique and weeding regime (Table 2). Some of this lack of interaction may be attributed to the late plantings in December of 1994 and 1995, that caused the crop to experience drought stress shortly after germination, and the above average rainfalls in 1996/97 that led to water logging.

Table 2. Maize grain yield (kg/ha), total crop water use (mm/ha) and water use efficiency (WUE, kg/mm) in response to tillage and time of weeding at Makoholi.

	1994/95			1995/96			1996/97		
Tillage	Grain	Crop water use	WUE	Grain	Crop water use	WUE	Grain	Crop water use	WUE
OPFP	1,282	294	4.4	707	331	2.1	2,435	307	7.9
OPFP+MR	1,471	297	5.0	1,073	335	3.2	1,981	290	6.8
Tied ridge	1,280	290	4.4	495	332	1.5	3,429	312	11.0
Tied Furrow	1,234	304	4.1	302	335	0.9	2,577	300	8.6
s.e.d#	158.6	4.4*	0.947	82.9***	5.5	0.44***	259.7***	15.0	1.29*
Weeding Regime - weeks									
4	1,165	299	3.9	466	328	1.4	2,604	303	8.6
2+6	1,468	293	5.0	823	338	2.4	2,608	302	8.6
s.e.d	112.1**	3.1	0.669	58.6***	3.92*	0.32***	183.6	10.6	0.91

Significant treatment effects * $P<0.05$; ** $P<0.01$; *** $P<0.001$

In 1994 the trial was initially planted in early November to try and utilize the above average rainfalls that occurred in the October. Unfortunately the lack of rain in November severely reduced crop establishment and caused the trial to be replanted on 13 December 1994. Even at this early stage the detrimental effects of pre-plant ridges on crop establishment could be easily

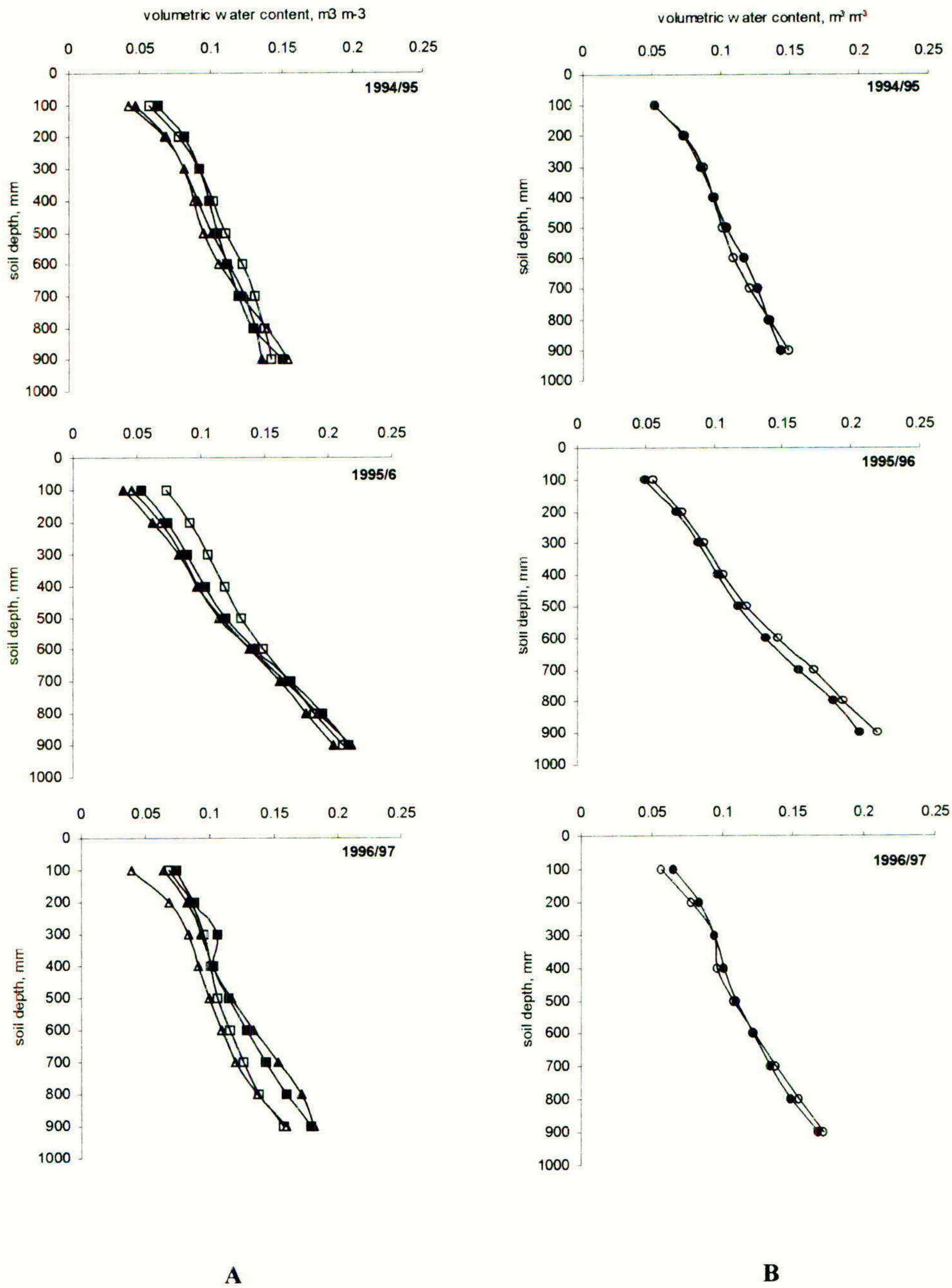

Figure 1. Variation in average volumetric water content for A) four different tillage regimes at Makoholi over three seasons (■ Open Plough Furrow Planted; □ Open Plough Furrow Planted plus Mid Season Ridge; △ Tied Ridge; ▲ Tied Ridge) and B) two different weeding regimes. • 4 week weeding; ○ 2+6 week weeding

seen, with fewer than 2000 plants per ha on the ridges, compared to 5000 to 10000 plants on the other treatments. The fact that plants established on a ridge top have a tendency to suffer from drought is a frequently observed phenomenon, as pre-plant ridges tend to drain more readily and result in drier soil profiles (Twomlow and Bruneau, 1998). This is shown in Figure 1 for this soil, where the tied ridge treatment is the driest of the conservation tillage treatments, in contrast to OPFP+MR, which was the wettest. Consequently, in the first two seasons the OPFP+MR yielded the highest (Table 1) and tied ridges or furrow the least. This was in contrast to the last year of the trial which experienced above average rainfall, 747 mm, evenly distributed throughout the season and resulted in very good yields. In fact, tied ridges, in contrast to the previous two seasons, significantly (*$P<0.001$*) out yielded all other treatments by at least 1000 kg/ha, by virtue of its improved drainage and reduced water-logging (Figure 1).

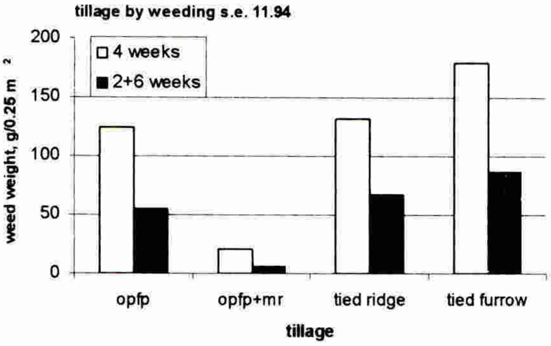

Figure 2: Weed dry weights (g/m^2) at harvest for the different conservation tillage and weeding regimes combinations in 1995/96.

Statistical analysis of mean weed biomass determined at harvest showed a significant interaction between conservation tillage method and weeding regime for each of the three seasons, as is shown in Figure 2 for 1995/96 data. Weeding at 2+6 weeks had a significant impact on crop yield in the first two seasons, and a significant impact on crop water use and WUE in the 1995/96 season (Table 2). As is shown in Figure 1 (B), the 2+6 weeded plots were significantly wetter than the 4 week weeding plots at depth, particularly for the 1995/96 season, and caused yield increases of 26 % in the first season and 75% in the second. This was in contrast to the last season, when weeding had no significant effects on crop yield, crop water use (Table 2) or variation in soil water content (Figure 1). Irrespective of weeding frequency, a combination of open plough furrow planting followed by mid season ridging had a significant impact on the level of weed infestation, when compared to the other treatments (Figure2) and significantly (*$P<0.001$*) reduced the incidence of *Eleusine indica* (unpublished data).

CONCLUSIONS

Results from three very different seasons showed that soil water regimes and crop yields were strongly influenced by both the conservation tillage option and the timing and frequency of weeding. In terms of crop water use efficiency and grain yield, a combination of weeding carried out two and six weeks after crop emergence performed the best, whilst a single weeding four weeks after crop emergence was the worst of the weeding regimes. Where conventional conservation measures such as tied ridges were used, if weed control was inadequate, i.e. a single weeding four weeks after crop establishment, crop yields were significantly reduced, when compared to simple open plough furrow planting techniques that were weeded using the mouldboard plough with the body attached. Previous work has shown that mid season ridge weeding with a plough conserves not only soil and water, but also labour and draught animal power (Riches *et al.*, 1995), two resources frequently in short supply on subsistence farms in sub-Saharan Africa.

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