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STRIGA HERMONTHICA SURVEYS IN WESTERN KENYA

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ABSTRACT

Data were collated on the distribution, severity and spread of *Striga hermonthica* within eleven districts of western Kenya. Information was also obtained on cereal production systems and the farmers' perceptions of the *Striga* problem. Digitised maps of the *S. hermonthica* infested areas were prodused and overlaid with data on farming systems to show correlations with *Striga* .incidence The overriding conclusion was that *S. hermonthica* is an ever increasing threat to crop production in the majority of the region. *S. hermonthica* infestation levels were found to be rising. However, the severity of *S. hermonthica* infestation is decreasing in a few localised areas. Some farmers are able to control *S. hermonthica* to a satisfactory level and sustainable cereal yields are harvested. In some localised areas there appeared to be a natural decline in *S. hermonthica,* which could not be explained. *S. hermonthica* is still spreading, both within the generalised zones of *S. hermonthica* infestation and also beyond present boundaries. It is predicted that *S. hermonthica* has the capability of spreading over the highland areas, which presently act as the boundary of *S. hermonthica* infestation, into areas of central Kenya. Whilst many farmers associated the incidence of *Striga* with less fertile soils, the majority were unaware of its habit.

INTRODUCTION

Striga hermonthica is a serious constraint to cereal production at altitudes below approximately 1,600 metres above sea level (a.s.l.) in western Kenya. Local research into a range of potential agronomic control methods is being undertaken (Odhiambo & Ransom, 1993), and so surveys were used to define current limits to infestation and investigate controls currently used by farmers, in order to plan future research. In addition, any recommended control strategies need to make use of local farmer knowledge, as this information can provide us with, at the very least, a partial insight into the local environment (Bonitatibus, 1991).

This research randomly surveys 367 farms in eleven districts of western Kenya where *Striga hermonthica* had previously been reported to local agricultural offices. Whilst the zones of *Striga* infestation were being established, other information on the major weeds of the region was also recorded.

The specific objectives of the survey were:

i) To record the infestation levels of *S. hermonthica* at precise latitudes and longitudes on randomly selected farms.
ii) To record field observations of *S. hermonthica*, taking plant counts (per square metre).
iii) To collate data on local cereal production in order to give some insight into the factors affecting the distribution and spread of *S. hermonthica*.

iv) To obtain information on the farmers' perceptions of the *Striga* plant, and try to establish how they are attempting to overcome this problem.

v) To establish which weeds other than *S. hermonthica* are a major problem.

vi) To obtain other relevant information on *S. hermonthica* which could be of use by researchers in the future.

Survey methods

The survey area extended from the shores of Lake Victoria to both the Tanzanian and Ugandan borders and then eastwards to the foothills of the Kenyan highlands.

A standard format, style and strategy was used for each survey. Local Agricultural Officers assisted in planning and conducting the surveys, so improving data reliability.

Farmers were surveyed throughout three wet seasons (approximately 1.5 years), each survey season commencing when the first *S. hermonthica* flowers were seen, and ending at harvest time. Surveys lasted just under one hour per farm, allowing six to eight surveys per day. A Global Positioning System (GPS), "Garmin II", was used to record precise survey positions.

All accumulated data, either from the survey forms or downloaded from the GPS, was entered into a database ("dBase iv"), from which basic information and statistics were extracted and analysed using standard procedures. Further to this initial analysis, Geographical Information Systems (GIS) software was used to produce digitised maps of the *S. hermonthica* infested areas. These maps were then overlaid with the farming systems data to illustrate possible correlations of *S. hermonthica* incidence and the farmer's crop production practices.

RESULTS

Farming systems

The data confirmed that maize is by far the most preferred cereal crop grown by farmers. However, as sorghum is grown by 88.6% of farmers it is also of vital importance in the farming system. Likewise finger millet, although not produced in large quantities, is planted by over 40% of all the farmers questioned and often plays a vital role in many diets, especially those of infants.

The majority of the farmers in the middle-upland zones (approximately 1,400 - 2,200 metres a.s.l.) plant the hybrid maize varieties of the H6 series, whereas the farmers of the lower zones (< 1,400 metres a.s.l.) prefer to plant local landraces.

Intercropping of legumes was practised by the majority of farmers (96.2%), planting at least one legume, though reports on the effects of intercropping on overall yields were mixed.

The application of inorganic fertilisers (such as triple super phosphate, di-ammonium phosphate, calcium ammonium nitrate and urea) on cereal crops was only practised by farmers in the more productive middle-upland areas. It appeared least fertiliser was applied in areas of high *Striga* infestation and greatest amounts in the boundary areas of *Striga* infestation.

The most preferred (or available) crop nutrition was farmyard manure (FYM) as 63.8% farmers claimed to apply this, even if in small amounts, whereas almost half this number, 31.6% applied inorganic fertiliser. In addition to this, most of the divisional extension staff were of the opinion that even where inorganic fertilisers were applied, the rates used were well below those recommended. Just over a quarter of all farmers did not use any type of fertiliser at all.

Only around 37% farmers practised fallowing, with fallow periods of only for one to two years, with cropping periods of more than two years between fallows. The majority of farmers indicated that the use or length of fallows had decreased over the past decade.

Incidence of *S. hermonthica* (and other weeds)

Striga hermonthica was the most serious weed reported by farmers (72.5%), followed by *Digitaria abyssinica* (66.0%), *Commelina benghalensis* (31.5%) and *Bidens pilosa* (29.4%).

The survey also attempted to establish how long the farmers had experienced *S. hermonthica* infestation on their land, whether it was increasing or decreasing and, if so, for what reasons. Almost half (47.8%) of the farmers surveyed had known *Striga* to be on their land for over 50 years. *S. hermonthica* is still spreading into new areas. Over 22% farmers with *Striga* said that it had arrived within the last 10 years, and nearly two thirds of these said that it has only been seen within the past five years. In three districts (Kisumu, Siaya and Busia), and parts of four other districts (Vihiga, Kakamega, Kisii and Bungoma) *S. hermonthica* has been in evidence for many decades. However, in parts of some districts (Vihiga, Kericho, Kisii, Homa-Bay and Bungoma) *S. hermonthica* appears to have arrived only in the last few years. Even within the districts which have had high *Striga* infestations for over 30 years or more there are still reports of some farmers having only seen *Striga* appear within the last decade.

It seems likely that *S. hermonthica* is not only still spreading into new areas but is also increasing in severity in areas already infested as over half (53.1%) of all the farmers reported that *S. hermonthica* was still increasing. In all districts over one third of the farmers reported that *S. hermonthica* was increasing in severity, whilst in the three districts where *Striga* has been established the longest (Kisumu, Siaya and Busia) 71.7% of farmers reported an increase in *S. hermonthica* infestation levels. This was also the case in parts of two other districts (Kisii and Kericho) where *S. hermonthica* has only appeared more recently. There are indications that *Striga* is increasing in parts of neighbouring districts (Nandi, Nyamira, Homa-bay and Migori).

Striga is now decreasing on the land of 21% of farmers surveyed, and over half (56.6%) of farmers with *S. hermonthica* infestation in Kakamega District reported Striga to have decreased. Though percentages of surveyed farmers were lower, *Striga* was also reported to be decreasing in Vihiga and Bungoma and even parts of Siaya and Busia District. When asked why this might be so the majority of these farmers (65%) replied that this was due to the application of FYM, or the use of handpulling or a combination of both methods. Table 1 summarises these responses. Just over 22% farmers, mainly on the periphery of the *S. hermonthica* infested areas, had not yet encountered *Striga* in their land.

Table 1: Reasons given for the decrease in *S. hermonthica* infestation levels, where found to be decreasing.

Reason	% Farmers *
FYM and/or organic fertiliser	31.3
Continued handpulling	27.3
FYM with handpulling	6.5
Other	3.9
Unknown/don't know	10.4
Unrecorded	20.6

* As % of those reporting a decrease in *Striga* infestation

The maximum *Striga* count recorded was 297 plants per square metre in Usigu Division, Siaya, and the second largest was 287 plants per square metre in Nyando Division, Kisumu. The highest altitude where *Striga hermonthica* was found to be present was at 1,800 metres (approximately) in Chemase Location, Aldai Division, Nandi District.

S. hermonthica incidence and farming practices

Statistical analyses were run to test for correlations between the incidence of *S. hermonthica* and specific farming practices, but due to the problem of variability between surveyed areas the resulting data were shown to be unreliable. Observations on the incidence of *S. hermonthica* and farmers' perceptions were believed to be more consistent and allowed for local variation.

Farmers' perceptions and knowledge of *Striga*

Farmers were asked a series of questions on their knowledge of the control of *Striga*. Particular emphasis was placed on identifing possible modes of spread for the *Striga* seed. Their responses are shown in Table 2 below. However, subsequent studies on *Striga* seed dispersal, Berner *et al* (1995), show that the neither wind or cow dung are efficint methods for the spread of *Striga* seed.

Table 2: Farmers suggestions for the modes of *Striga* spread

Mode of spread	% All Farmers
Wind and/or water (erosion)	16.4
Livestock and/or FYM	5.2
Poor *Striga* disposal	4.6
Cultivation (ploughs/hoes)	7.4
Natural spread/not pulled	4.1
Other	3.8
Unknown/don't know	58.5

The most common method used in attempting to control *Striga* is handpulling, said to be used by almost half of all farmers questioned. The application of FYM is undertaken by 27.2% farmers as a common practice. Some 31.3% know no methods of *Striga* control.

Handpulling of *Striga* plants is believed to be a traditional control method, originating from pre-colonial times (Connelly, 1988). When farmers were asked if they specifically handpulled *Striga* (as opposed to just normal weeding) almost two thirds (65.2%) said that they did. However, after further questioning it appeared that only 40.7% used pulling as a method of control. Furthermore, on trying to find out exactly when the *Striga* was pulled it became clear that very few farmers (12.3%) were actually pulling the plants before they flowered (flowering being a more identifiable stage of plant development for farmers than the seed formation stage). Most farmers say that they place the pulled plants on the road which, in colonial times, was a method enforced by law to ensure that handpulling was carried out. It is possible that this response was influenced by this fact.

Varieties and Landraces

Farmers believe Hybrid maize to be more susceptible to *Striga* than the local, open pollinated varieties, although only one of those, a yellow maize known as "Nyamula" in the local language (Kijaluo), was consistently reported as being less prone to *Striga*. Overall, farmers recognise that sorghum is generally more tolerant to *Striga* attack than maize and within the group of local sorghum the tall, red type (known as "Uchuti" in Kijaluo) and the short, white type (known as "Andiwo" in Kijaluo) are considered to be better at withstanding *Striga* than the other landraces. 12% farmers reported seeing *S. hermonthica* on plants other than cereal crops, usually on grasses.

Farmers associated high *Striga* incidence with less fertile areas of the farm (over 30% farmers), and some connections were also made to the dry areas with light soils. Some farmers associated *Striga* with the most frequently cultivated land which may also relate to low soil fertility or to a lack of soil structure. However, a large proportion of farmers either did not notice any differences in *Striga* infestation levels, or could not suggest any reasons why possible variation may occur.

Prediction of possible *Striga* spread

It was speculated that *S. hermonthica* may be able to invade other areas of Kenya, with similar climatic conditions as western Kenya, though this has not yet been proven through research. Now that the boundaries of the *Striga* infested zones have been defined, it was thought possible that the climatic data of this area could be used to predict future spread of *Striga* to new, climatically similar regions.

Owing to time and data limitations GIS software could not be used to overlay the survey data fields with climatic data. However, limited rainfall data were available on CD Rom (Climate Research Unit, 1992) and temperature data were obtained the Kenya Meteorological Department. The data were used to compare the climates of the various regions.

From the rainfall data alone it was difficult to compare different regions, owing to the wide range of rainfall values in areas where *Striga* is presently found (maximum 1377.2 to 3265.0 mm/annum and minimum 144.5 to 1713.6 mm/annum). However, once the temperature data are included, two regions have values that fall within the same range of temperatures as *Striga* infested areas (maximum 29.6 to 31.5 °C and minimum 12.8 to 16.1 °C). Both of these regions are in Central Province and lie North East (Sagana and Tebere) and South East (Makindu and Kampi) of Nairobi.

CONCLUSIONS

Striga hermonthica is not only spreading to areas that were previously uninfested, but it is also increasing in its severity in many areas already infested. *Striga hermonthica* is still only a problem in a few divisions of the districts which border the *Striga* infested areas. Though there is evidence that *Striga* infestation is not severe on all farms within these districts, it is spreading into new areas, and increasing in its severity in others. There is evidence that in a few divisions of three districts the level of *Striga* infestation is receding. The exact reasons for this decrease in *Striga* severity are still unclear. Some local landraces of maize, and especially sorghum, show signs of *Striga* tolerance. *Striga hermonthica* has not been extensively seen on alternative host plants, so it is unlikely that an alternative host is directly responsible for increasing the levels of the *Striga* infestation. *Striga hermonthica* is being controlled by a few knowledgeable and capable farmers demonstrating that *Striga* control (though not eradication) is possible, even now. The farmers' knowledge of *Striga* is poor, restricting their ability to control this complex weed. It is highly possible that *Striga hermonthica* is capable of parasitising cereal crops in some localised areas of Central District where climatic conditions could be favourable.

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DISTRIBUTION AND INFESTATION OF *STRIGA* SPECIES IN SHINYANGA REGION OF TANZANIA AND EVALUATION OF CONTROL METHODS

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ABSTRACT

A survey in 56 maize and 26 sorghum fields was carried out during February-March 1994 in order to collect data on the *Striga* distribution and infestation in Shinyanga Region of Tanzania. *Striga hermonthica* and *Striga asiatica* were observed in 51 % and 24 % of all fields inspected, respectively. In total, *Striga* was found in 59 % of the maize and 65 % of the sorghum fields with infection rates of the plant stands ranging mainly from 2.5 to 50 %. Other *Striga* species determined were *S. passargei* and *S. densiflora*, both of lesser economic importance. In addition, 140 farmers were interviewed to determine their indigenous farming practices and the possible impact of them on *Striga* populations. All farmers interviewed were very familiar with the increasing problem of *Striga* in cereals. Only one third of them knew its form of propagation. Although the parasitic nature of *Striga* was unknown, many farmers had observed deleterious effects on their crops due to the presence of the weed. Of the proposed *Striga* control measures, rotation with trap crops such as cotton (96 % of the farmers surveyed), the use of fertilizer in the form of cow manure (82 %) and regular hand-pulling (54 %) were most likely to be adopted in the future by the farmers. Farm inputs such as mineral fertilizers and herbicides were neither available nor affordable for the farmers and therefore hardly considered as feasible options.

INTRODUCTION

The semi-parasitic weeds of the genus *Striga* (Scrophulariaceae), are widely distributed in the savannah regions of Africa. *S. hermonthica* and *S. asiatica* parasitize cereals such as maize, sorghum and millet. Only *S. gesnerioides* attacks dicotyledons, mainly cowpea and tobacco. Following Sauerborn (1991), 21 million ha of arable land in Africa are infested by *Striga* with an approximate yield loss of 4,1 million metric tons of grain crops per year causing income deficits of about 2,9 billions of US $.

In the past, several control strategies against *Striga* were examined and evaluated. In general, most of the common *Striga* control methods should be applied over years and in combination including regular hand-pulling of *Striga* shoots in the flowering stage to avoid re-infestation. Otherwise no sustainable decrease of the seed bank in the soil and consequently, no sufficient decline of *Striga* infestation is guaranteed. However, it is essential to assess the willingness of the farmers concerned to implement appropriate control methods to serve as a basis for adequate recommendations for further extension work. Moreover, the farmers need a solid appreciation of the *Striga* biology and of its life cycle in particular to understand the rationale for applied control measures to ensure they are effective in the long run. Investigations by Shaxson *et al.* (1993) in Malawi showed the effects of applying control methods without knowing the biology of the parasite. Farmers pulled *Striga* regularly but left the weeded plants between the crop rows. Consequently, the soil was re-infested as well as the farmers disillusioned to continue with this strategy. In order to determine the occurrence of *Striga* species as well as the indigenous farming practices, the applied control methods and the farmers' knowledge in view of their possible impacts on *Striga* population, a field survey and questionnaire were carried out in Shinyanga Region of Tanzania 1994.

MATERIALS AND METHODS

The *Striga* survey was conducted around 30 villages randomly selected throughout Shinyanga Region in February-March 1994, including the five districts of Bariadi, Maswa, Meatu, Shinyanga and Kahama. In total, 56 maize and 26 sorghum fields were investigated according to their importance as stable crops. Preference was also given to fields where crops had already reached the reproductive stage in order to include late emerged *Striga* plants. The fields were crossed in a zigzag line by sampling 20 plant stands per field. According to Wetzel (1984), after every 15 steps the plant stand next to the right foot was examined for the occurrence of *Striga* species and the *Striga* infection rate (number of *Striga* plants per plant stand).

In addition, 4 to 5 farmers were interviewed in each village, in total, 128 male (91 %) and 12 female (9 %) farmers. The questionnaire comprised open and closed questions on the farming system, general plant protection problems and in particular on the *Striga* situation. The applicability of the questionnaire was pretested and adjusted. Moreover, several control measures were proposed and explained to the farmers in order to evaluate their acceptability as well as their feasibility in particular for small scale farming. To make the farmers aware of the necessity of these measures, e.g. regular hand-pulling, also the *Striga* biology, i.e. its life cycle was clarified to them.

RESULTS AND DISCUSSION

Striga infestation and distribution

S. hermonthica was distributed in 51 % of the 82 fields inspected, particularly on vertisols ('black cotton soils') in the northern and eastern part of the region (Bariadi, Maswa, Meatu and northern Shinyanga District) (Table 1). In comparison to *S. hermonthica*, *S. asiatica* was represented in 24 % of the fields visited, predominantly on sandy soils in the south west of Shinyanga Region (Kahama and southern Shinyanga District). Moreover, 16 % of the fields surveyed were infested with *S. hermonthica* and *S. asiatica*, which are included in the 51 % and 24 % of the *Striga* infestation mentioned above, respectively. Correspondingly, *S. hermonthica* is reported to emerge on light as well as on heavy soils (Doggett, 1965; Ogborn, 1987). On the other hand, *S. asiatica* is generally found on lighter soils but not on heavy clay (Nelson, 1958; Doggett, 1965).

The highest proportion of infested fields (79 %) and one of the maximum mean plant infections (22.5 %) was found in Kahama District. This was neither related to high population density, land use intensity nor rainfall or soil conditions as found by Vogt *et al*. (1991). However, it should be taken into consideration that the cropping season 1993/94 was unusual dry and therefore, the inspection of the fields does not reflect the normal situation. Consequently, the field survey indicates merely an overview and should be done for several seasons to be more representative. In total, *Striga* was found in over 61 % of all fields sampled, i.e. 59 % of maize and 65 % of sorghum fields were infested by *Striga* with infection rates ranging mainly from 2.5 to 50 % (Table 2). On average, 14 % of the maize stands and 19 % of the sorghum stands were attacked. No infestation by *Striga* was observed in bulrush millet (*Pennisetum typhoides*) during the survey period, although *S. hermonthica* was seen in millet later in the season.

In the driest area in the east of the region (Meatu District), the rare *S. passargei* was seen on maize (2 % of all fields surveyed). *S. passargei* does not appear to be of economic importance for the region and is occasionally found in Africa (Parker & Riches, 1993). *S. densiflora* was seen parasitizing maize and wild grasses such as bermuda grass (*Cynodon dactylon*) and crowfoot grass (*Dactyloctenium aegypticum*). The flowers of *S. densiflora* are white and look very similar to *S. asiatica*. According to Parker & Riches (1993), this species is only found in India and Arabia. However, the occurrence of *S. densiflora* in Tanzania has been confirmed, based on the number of calyx ribs as reliable means of distinguishing the species.

Table 1. *Striga* infestation and infection in different districts of the Shinyanga Region, Tanzania 1994

District	**Bariadi**	**Maswa**	**Meatu**	**Shinyanga**	**Kahama**	**Total**
Number of fields surveyed	26	16	8	16	16	**82**
Proportion of infested fields (%)	46	54	61	69	79	**61**
Proportion of fields infested with						
S. hermonthica (%)	46	50	50	69	43	**51**
S. asiatica (%)	0	6	13	31	73	**24**
S. hermonthica and *S. asiatica* (%)	0	0	13	31	36	**16**
S. passargei (%)	0	0	13	0	0	**2**
Mean plant infection (%)	7.7 (2.6)[1]	23.3 (7.4)[1]	10.7 (6.0)[1]	15.5 (4.6)[1]	22.5 (5.5)[1]	**15.9** (2.3)[1]
Min. (%)	0	0	0	0	0	**0**
Max. (%)	45	75	50	60	85	**85**

[1]SE

Table 2. *Striga* infestation and infection classes determined by sampling 20 plant stands in 82 fields surveyed, Shinyanga Region, Tanzania 1994

Infection class	Total fields surveyed		Maize fields		Sorghum fields	
(%)	Absolute	**Relative %**	Absolute	**Relative %**	Absolute	**Relative %**
0	32	**39**	23	**41**	9	**35**
2.5-10	17	**21**	11	**20**	6	**23**
11-20	9	**11**	6	**11**	3	**11**
21-50	18	**22**	13	**23**	5	**20**
51-75	5	**6**	2	**3**	3	**11**
76-100	1	**1**	1	**2**	0	**0**
All fields in total	82	**100**	56	**100**	26	**100**
Proportion of infested fields	50	**61**	33	**59**	17	**65**
Mean plant infection of all fields surveyed		**15.9** (2.3)[1]		**14.4** (2.7)[1]		**18.8** (4.5)[1]
Mean plant infection of infested fields		**26.1** (3.0)[1]		**24.8** (3.6)[1]		**28.7** (5.4)[1]

[1]SE

Knowledge and control methods on subsistence level concerning *Striga*

The main cultivated crops in Shinyanga Region are cotton as the most important cash crop, and maize, sorghum, paddy rice, cassava, sweet potato, groundnut and other pulses for home consumption in particular, as well as for marketing. Various production systems are used, however, subsistence farms with average land size of 5 ha predominate. The main problems identified by the farmers were drought, pests, weeds and diseases. For cereal production, *Striga* was the most frequently mentioned constraint besides stalkborers (*Busseola fusca*, *Sesamia calamistis* and *Chilo partellus*).

All farmers interviewed were very familiar with the *Striga* problem in cereals. Most of the farmers (82 %) reported that their fields are infested by the parasite and three quarters regard *Striga* as an increasing problem over the last years. According to the field survey, farmers indicated that maize (63 %) and sorghum (95 %) are highly infested. Millet seems to be attacked less by *Striga* in Tanzania, which corresponds to observations by Doggett (1965), and is assumed to be due to different *Striga* strains. Some farmers even considered millet as a plant which lowers the degree of infestation.

More than one third of the respondents (37 %) were aware that *Striga* propagates by seeds. The rest either guessed that propagation was by the development of new roots (6 %) or had no idea (57 %). Although the parasitic nature of *Striga* was unknown to the farmers, many had observed deleterious effects on their crops such as stunted growth, yellowing of leaves and a lower yield due to the presence of the weed. They estimated crop losses of about 60 % to 80 % because of *Striga*. In some fields such crop losses can occur, but in general, they are obviously overestimated by the farmers. However, Sauerborn (1991) calculated average yield losses of 24 % from six West African countries. Contrary to expectations, some farmers indicated that *Striga* occurs on sweet potato, cassava, cotton and legumes, too. Apparently, these observations derived from mixed cropping systems with cereals and point out the low knowledge of the farmers about the *Striga* biology and its host specificity.

The common control methods practised by the farmers to combat *Striga* were weeding (98 %), changing crop sequence, mainly by cultivating cotton (63 %), and fallow periods of two years on average (56 %). One quarter applied fertilizer in the form of cow manure to lower the level of *Striga* infestation. However, the weeding was done twice or thrice four to eight weeks after sowing and obviously, not with special regard to *Striga*. Moreover, 36 % of the farmers left the weeded *Striga* plants between the crop rows, where the parasite is still able to produce seeds and re-infects the soil. Nevertheless, 55 % of the persons asked collected *Striga* at the edge of the fields. Only 9 % burned the weeded plants.

Of the proposed *Striga* control strategies, rotation with trap crops such as cotton (96 %), the use of fertilizer in the form of cow manure (82 %) and regular hand-pulling (54 %) were most widely thought to be feasible by the farmers (Figure 1). Trap crops such as cotton and several legumes (groundnut, cowpea and chickpea) stimulate the germination of *Striga* seeds, but cannot be infected. Thus, they reduce the number of *Striga* seeds in the soil (Wilson-Jones, 1953; Sprich, 1994). *Striga* is well adapted to poor and exhausted soils. Application of organic manure or mineral fertilizer leads to an improvement of soil fertility and crop growth and helps to reduce the infestation of the weed (Ogborn, 1987; Sherif & Parker, 1986). However, in some areas of the Shinyanga Region the available organic matter from cattle is either not sufficient to allow an application on the entire farm land or it is used for fuel.

Regular hand-pulling every 2-3 weeks from the beginning of *Striga* flowering lowers the *Striga* infestation in the long run. In addition, weeding after harvest is supposed to prevent the flowering and seed production of *Striga* which occurs on ratooning sorghum or other host plants such as wild grasses. Actually, regular hand-pulling (thought to be practical by 54 % of the farmers surveyed) and weeding after harvest (15 % of the farmers) were only considered as options if the field size was small, or if the infestation level was low. Otherwise, these tasks would be too labour-intensive and time-consuming for the household members.

Catch cropping is used to deplete the *Striga* seed bank in the soil and is reported to be a very effective method for *Striga* control (Sprich, 1994). High susceptible varieties of sorghum or millet are densely sown in order to induce *Striga* seed germination but are harvested or ploughed into the soil before *Striga* flowers and develops seeds. Although the early harvested sorghum can be used as fodder for animals, this strategy was not regarded as a feasible measure by 60 % of the farmers because it would be a waste of time and seed material. One third had no opinion to this proposal. Further, transplanting of sorghum from seedbed to the field leads to a decrease of *Striga* infection. Sorghum roots performed before transplanting were more resistant to *Striga* attack than young roots (Dawoud, personal communication). One quarter of the farmers were interested in adopting this control method whereas one third judged the transplanting of sorghum too labour-intensive.

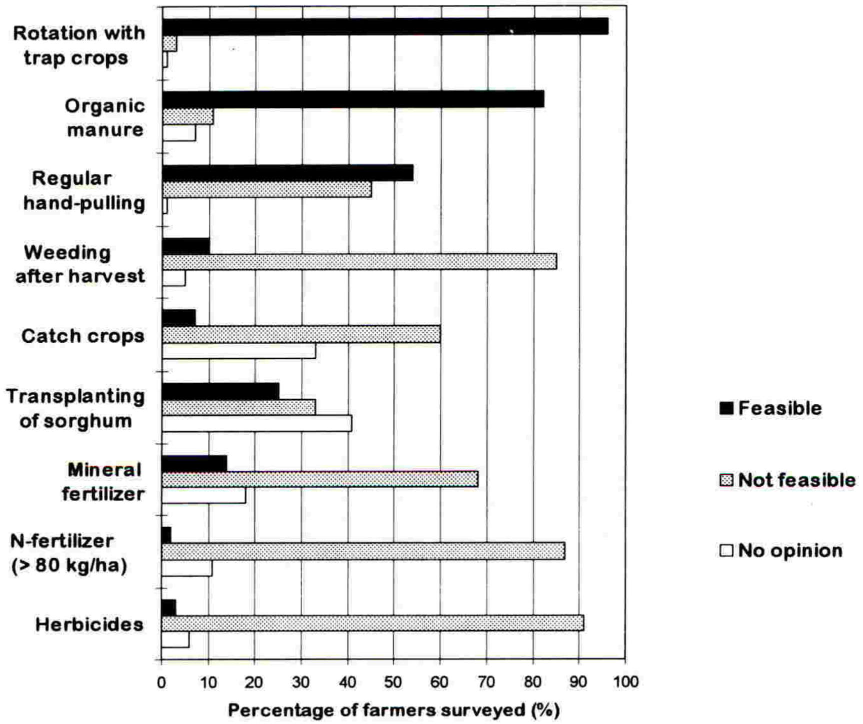

Figure 1. Interest of 140 farmers surveyed in adopting *Striga* control methods in the future, Shinyanga Region, Tanzania 1994

A well-balanced provision of nutrients lowers the damage and yield loss of the crop caused by parasitic weeds (Sherif & Parker, 1986). However, mineral fertilizers were generally neither available nor affordable for the smallholders and therefore not regarded as a feasible control strategy by 68 % of the farmers. Only 14 % were interested in adopting the use of such farm input in the future. Most farmers (87 %) rejected the idea of nitrogen fertilizer application for the same reasons. Field trials as well as greenhouse trials showed that high dosages of nitrogen in particular have an inhibiting effect on *Striga* seed germination and the development of *Striga* (Last, 1960; Kroschel, 1989; Bebawi *et al.*, 1991).

The post-emergence herbicide 2,4-D is effectively used in corn for *Striga* control in the U.S.A. (Shaw *et al.*, 1962). Nevertheless, it is not recommended in areas cultivating dicotyledons such as cotton or legumes in intercropping systems with cereals (Parker & Riches, 1993). However, 2,4-D is neither applicable nor available in Shinyanga Region in general. Moreover, management of *Striga* with farm inputs, e. g. herbicides, requires adequate farm income, a good market situation and a great deal of background knowledge by the farmers. Considering these issues, 91 % of the farmers could not afford chemicals in sufficient quantities. Additionally, all farmers surveyed did not obtain satisfactory information and advice from the extension service how to apply control strategies to combat *Striga* effectively.

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THE SOCIO-ECONOMICS OF WEED CONTROL ON SMALLHOLDER FARMS IN UGANDA

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ABSTRACT

Weed management is inextricably linked to social and economic factors. In order that research is appropriate, it is essential for weed scientists to understand the factors that influence farmers in their choice of weed management strategy. During a research planning exercise, a survey was conducted of weeds and the socio-economics of weed control on smallholder farms in three districts of Uganda. The majority of respondents used manual methods of land preparation and weeding, making labour the main resource. Labour shortages for weeding are widespread and the period of labour shortage tends also to be the time when farmers are most short of food and cash, thus restricting the use of herbicides or hired labour. There is a strong gender dimension to weed management; in some areas, women grow food and men cash crops; in others, weeding is exclusively a female task, but men control household expenditure. Such factors are of considerable importance in determining the uptake of new technologies that require cash investment and it is important that they are taken into account by those planning and conducting research to improve weed management on smallholder farms.

INTRODUCTION

When farmers have access only to manual labour or animal draught, weed control is the most labour-demanding pre-harvest crop protection activity, often requiring 45% - 60% of total pre-harvest labour (Akobundu, 1987). Timely and efficient weeding depends on the availability of sufficient weeding resources, and Parker & Fryer (1975) estimated that late weeding as a result of labour shortage often causes yield losses of up to 25%.

Farmer decision making when choosing a weed control strategy is influenced by factors such as risk and the opportunity cost of labour as well as the total availability of weeding resources. Shaxson *et al.* (1993) note that while farmers face risk in the form of crop loss, they also face risk by undertaking an uneconomic activity where the investment is not reflected in increased output. The deployment of labour invariably has an opportunity cost and a farmer must weigh up the potential costs and benefits of different activities when deciding how best to allocate family or hired labour. Baker (1987) observed in Botswana that male labour for weeding is often short due to competition from waged employment. In Mali, while farmers place a high value on early weeding, they often weed late. The reasons for this include absolute labour shortages in a household, the need to seek wage labour to overcome seasonal food shortages, limited access to draught animals among poorer families, and the cultivation of large areas as a drought management strategy (Webb, 1993; Sharp, 1992).

Shaxson *et al.* (1993) note that weeding recommendations for farmers have changed little with changing agricultural systems and tend to be based on technical considerations such as the critical period for weed competition. However, the examples above illustrate how smallholder farmers may be restricted in their ability to adopt recommendations by a range of socio-economic constraints. When initiating research to develop improved weed management recommendations, in order that the recommendations are appropriate and have a chance of being adopted by farmers, it is important that these constraints are taken into account.

With this in mind, in April and May 1993, a survey was conducted of weed problems and the socio-economics of weed control on smallholder farms in Uganda. The objective was to provide information on which the newly established National Agricultural Research Organisation could plan a programme of research in improved methods of weed management for smallholder farmers. Uganda suffers a range of agricultural problems, many resulting from the decades of social unrest and economic crises since the early 1970's, during which time agricultural research virtually ceased and Uganda lost much of its technical expertise.

METHODS

Three districts (Kabale, Soroti and Mubende) were selected for survey to provide a range of ethnic groups and agro-ecological zones. Kabale is a highland area in the south west where production of cash and food crops is intensive. People are mainly from the Bakiga and Banyaruanda tribes and population pressure is high. Land shortage is increasingly causing land fragmentation, reduced fallowing, declining soil fertility, soil erosion and increasing pest problems. The main crops are beans, sweet potato, sorghum, maize, potato, finger millet, wheat and horticultural crops. Mubende District is in central Uganda. Farmers in eastern Mubende are more progressive than in the west and with better access to markets, but this area has seen the development of a severe labour shortage in recent years. The Baganda are the main ethnic group and the main crops are cassava, sweet potato, maize, beans, groundnut, banana, coffee and potato. Soroti is in the north east where soils are poor and both soil fertility and rainfall progressively decrease towards the north. Most people are Iteso and the main crops are finger millet, sorghum, maize, cowpea, soya, sesame, sweet potato, groundnut and rice. Cattle are traditionally important as a source of food, capital and animal traction in Soroti but in the 1980's most cattle were lost to raiders from the Karamoja. A period of political instability followed which caused long and short term migration from the countryside and these factors combined have had a major impact on farming practices and livelihoods.

In each district, two representative sub-counties were selected for survey and within each two villages were selected at random from the electoral register. Transect lines were taken across the villages, and households interviewed *en route*. In total, 80 farmers were interviewed (45 women and 35 men) and 49 households represented. In order to take into account the gender element in weed management, men and women were interviewed separately and women were interviewed by a female research team. The survey was conducted by means of semi-structured interviews to give a degree of flexibility, allowing the emphasis of the interview to be influenced by the farmers and unanticipated issues to be explored. The interviews sought to obtain a broad picture of the farming system so that weed management practices and problems could be seen in the context of the system. The following key topics were covered:

(a) farm size and number of plots and parcels
(b) land tenure system
(c) household size and composition
(d) crops and cropping systems
(e) perceived production constraints
(f) availability and allocation of labour and cash
(g) perceived weed control problems
(h) weed management practices

RESULTS AND CONCLUSIONS

Problem weeds

Perennial weeds including *Digitaria abyssinica, Cyperus rotundus, C. esculentus, Cynodon nlemfuensis* and *Imperata cylindrica* were perceived by farmers to be a major problem in all 3 districts. *I. cylindrica* was more frequent in Soroti and said to be increasing since the loss of animal traction and subsequent decrease in ploughing. In Mubende and Kabale, *D. abyssinica* was particularly serious and cited as a problem by 70% and 50% of farmers respectively and ranked as the most serious weed by 61% and 31%. A heavy infestation produces a dense mat of rhizomes so that land preparation and weeding require hard digging and sifting of the soil. Several farmers noted that this weed increases the cost, labour and time required for weed control and can decrease the value of land. Given its competitiveness and the poor control achieved by manual weeding, it undoubtedly also causes yield loss.

Several annual broad leaved species were also of widespread importance and, despite considerable climatic, edaphic and management differences between districts, the most troublesome weeds were common throughout including *Bidens pilosa, Galinsoga parviflora* and *Commelina* spp. (mainly *C. benghalensis*). In the colder climate of Kabale, *Galium spurium* was also important. In Soroti, *Striga* spp. were cited as a major weed in cereals by 46% of farmers and the incidence is said to be increasing due to a decline in fallowing.

Weed control

In all districts, weeding and land preparation were almost exclusively by manual methods. Even farmers in Soroti, who previously relied heavily on animal traction, now use predominantly manual control. A large proportion of farmers, particularly women, had not heard of herbicides (28%, 17% and 76% in Kabale, Soroti and Mubende respectively) and less had any experience of using them (2.5% of respondents), though most had knowledge or experience of other crop protection chemicals. The use of herbicides tended to be confined to total weed control using glyphosate or paraquat in cash crops (particularly banana).

In most crops, farmers' perceptions of the optimum timing for weeding were consistent with recommended practices. The exception was groundnut, where almost all farmers endorsed a first weeding at flowering and a second at seed set, a practice which is likely to result in yield loss due to early competition and damage to developing pegs (Webb, 1995). Despite an awareness of the importance of early weeding, farmers often fail to complete weeding within what they consider to be the best time (64% of those questioned in Kabale, 85% in Soroti and 76% in Mubende). The reasons for this were various and included labour shortages, labour bottlenecks at weeding time, sickness and prioritisation of crops. High value crops (e.g. beans, potato) were weeded first, and crops sensitive to weed competition (e.g. finger millet) received earlier and more frequent weeding than less sensitive crops (e.g. peas, sweet potato).

Mulching was widely used for weed control in banana and horticultural crops. Crop rotations were also used in weed management: in very weedy fields farmers often sowed sweet potato or cassava, as the former can suppress weeds and the latter withstands weed competition. Fallowing has traditionally been used in weed management, but is now declining in all 3 districts. In Kabale, the scarcity of land and increasing population pressure are forcing fallow periods to become shorter or omitted entirely. In Mubende and Soroti, land is not limiting but a lack of resources for opening land under long term fallow is resulting in a tendency to cultivate continuously on a small portion of the available area. In addition to worsening perennial weed problems, this practice is causing a decline in soil fertility.

Labour and cash constraints

Labour shortage was a major problem in all 3 districts. In Kabale, despite high population density and small farm size, labour was short at certain times. This was due to bottlenecks at periods of peak demand, but also due in part to the limited involvement of men in agriculture; women do most farm work, but their input is restricted by other domestic responsibilities. Health is also important, several women noting that crop management can be neglected during pregnancy, with tasks requiring hard physical work (such as weeding) particularly affected. In Soroti and Mubende, the labour shortage was severe. In Soroti this is the result of political instability and migration, compounded by the loss of animal traction. In Mubende it is the result of migration to urban centres, loss of life during the wars, and ill health.

With the current reliance on manual methods, labour is the main resource for land preparation and weeding, and periods of peak labour demand and shortage coincide with these activities. Most additional (non-family) labour is hired at this time, particularly in Kabale and Soroti where annual crops predominate. In Mubende, the greater proportion of perennial crops means that labour is less seasonal. In all districts, respondents were generally not able to hire as much additional labour as they need because the period of labour shortage tends also to be the time when households are most short of food and cash. This was most evident in Mubende, where proximity to urban centres means that the price of labour is particularly high.

Gender issues

The gender division of labour varied considerably between the ethnic groups of the 3 districts. In Kabale women provide most agricultural labour and are responsible for all weeding; labour inputs from men vary between households but are generally small and directed at cash crops. In Mubende, women do a greater proportion of weeding but men assist with land preparation. Again there is a tendency for men to have a greater involvement in cash crops, particularly perennial crops, and women are responsible for annual food crops. In Soroti, men provide more agricultural labour than women, and there is little division of task according to gender.

Ten of 17 women interviewed in Kabale were employed in casual, off-farm agricultural labour. The majority belonged to women's groups and were hired principally for land preparation and weeding. The cash generated by this activity can be an important component of household income, particularly among poorer families.

Access to information on non-traditional farming practices appeared greater among male than female farmers. For example, only 24% of women interviewed had ever heard of herbicides, compared with 62% of men. Women also have limited access to cash. In Kabale, though women do most agricultural work, they often have little access to income from crop sales; they take decisions on agronomic practices, but have limited powers to control cash investment in crop production. In Mubende, women are generally responsible for decision making in their own (mainly subsistence) crops and control any income from these, while men take responsibility and receive income from the cash crops. In Soroti, decision making and control of expenditure is shared or lies mainly with the husband.

Implications for weed management

The high labour demand for land preparation and weeding, coupled with the shortage of labour and cash at critical times, has a considerable impact. The timeliness of activities such as planting and weeding is affected, and can reduce crop yield. Of 40 farmers questioned, 87% considered that they currently lose yield to weeds, mainly due to late or inadequate weeding. In Soroti and Mubende, the labour shortage is also affecting the ability of farmers to clear land under long term fallow which, as noted, is leading to continuous cultivation of a reduced area. The high labour demand is increased by the presence of perennial weeds such as *D. abyssinica*, and there appears to be a vicious circle where worsening weed problems cause and are exacerbated by labour shortages. In some areas of Soroti and Mubende, the labour constraint on weeding limits the area cultivated, farmers tending to plant as much as they think they will be able to weed. Where this is the case, weeds can be considered as the main constraint on agricultural production.

Given the constraints of labour and capital, the options for improved weed management are few. Herbicides could offer a potential alternative for some farmers. Complex patterns of crop rotation and intercropping limit the use of residual compounds and spraying within the crop, but the prevalence of perennial weeds and current shortage of labour for opening land could make the use of non-selective herbicides, such as glyphosate, an attractive option for land preparation. Herbicides are most likely to be appropriate where the cost (and therefore opportunity cost) of labour is high, where men are doing some or all of the weed related activities, and where the crops are primarily cash crops. For the most resource poor farmers, however, there is no immediate possibility for herbicide use and there is a need to focus on weed management techniques which do not require increased labour or cash investment. Potential options include the selection of more competitive crop varieties, and the use of cover crops for suppression of perennial weeds in managed fallows.

That weeding is often a female gendered task has important implications for weed management. The generally limited access that women have to cash is likely to have considerable influence in determining the uptake of new weed control technologies that require cash investment. Currently, the survey found cash expenditure on weeding (in the form of labour hire) to be rare where women were responsible for weed control (Kabale) or in crops which were the responsibility of women (annual food crops). Uptake of new technologies is also likely to be affected by the apparently limited access of rural women to information. Changes in weeding technology may in some cases have a negative impact on women. In Kabale for example, the introduction of labour saving weed control practices would be detrimental to resource poor women for whom off-farm weeding is an important source of income.

The survey results illustrate that weed problems affect the allocation of labour, crop management, crop yield and costs of production. They also have a social cost, demanding considerable time and hard labour, a burden which is often borne by women. The ability of farmers to modify weeding practices, particularly where this requires cash investment, is limited by a range of social and economic factors which vary between district and ethnic group. In order that research is appropriate, it is essential for these factors to be taken into account by those planning and conducting research in Uganda to improve weed management on smallholder farms.

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IMPERATA CYLINDRICA IN SMALLHOLDER RUBBER-BASED FARMING SYSTEMS IN INDONESIA

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ABSTRACT

Imperata cylindrica is a major problem weed for smallholder rubber producers in Indonesia, as it is difficult to clear, very competitive with young rubber trees and highly combustible in the dry season. Research by the authors shows that the severity of the problems that it poses varies significantly from one farming system to another. There is also considerable variation in the nature of the control measures used. In some areas most smallholders rely entirely on manual control; but in the Batumarta transmigration area nearly all of them use glyphosate, although in ways that differ from recommended practice.

INTRODUCTION

Nature of the problem

For many smallholder rubber producers in Indonesia and other S.E. Asian countries *Imperata cylindrica* constitutes a problem at two points in the rubber production system (Figure 1): first, at the stage of clearing *Imperata* grassland for productive use; second, between the harvest of the last intercrop and canopy closure. The majority of farmers usually plant rubber and an intercrop at about the same time. The area planted with rubber is intercropped for 1 or 2 years, the duration of intercropping often being limited by low and declining soil fertility. During this period farmers regularly weed, and there is relatively little *Imperata* present. It is after intercropping that the immature rubber plantation is prone to invasion by *Imperata* and other weeds.

The duration of the period to canopy closure varies, depending on the type of rubber planting material used and the level of inputs and maintenance. Canopy closure may occur 5-6 years after planting in a well-kept clonal rubber plantation, and after 10-12 years in a seedling rubber plantation in which there has been little weeding or fertiliser application.

Opening *Imperata*-infested land Vast areas of land in S.E. Asia are infested with sheet *Imperata*. This land could in principle be used for agricultural production or forestry. One of the reasons why it is not used for these purposes is the high cost of effectively removing the *Imperata*. Some rhizome fragments are inevitably left in the soil, which means that the *Imperata* can rapidly regrow and establish itself again. For these reasons, smallholders tend to prefer opening forest land if they have that option.

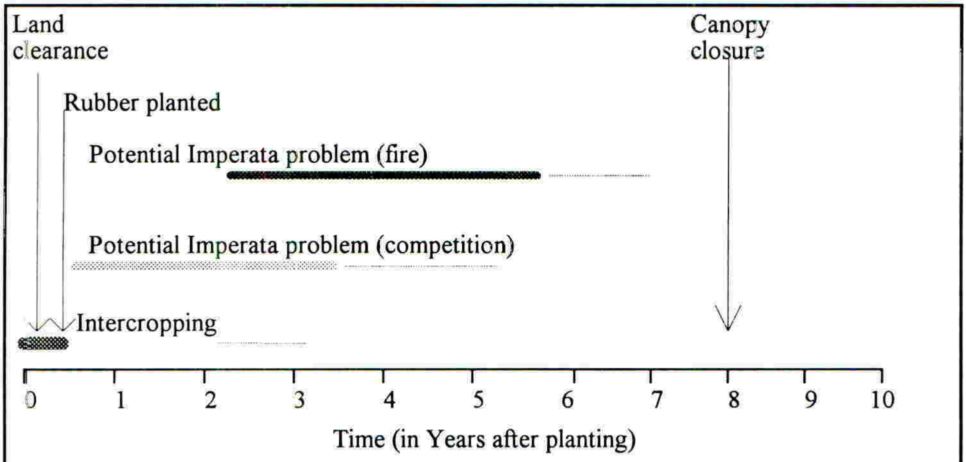

Figure 1: The periods in the first 10 years of a smallholder rubber plantation when Imperata is likely to be a problem.

The thickness of the horizontal lines reflects the severity of the problem.

Imperata in immature rubber Informal interviews held by the authors with smallholders in various parts of South Sumatra have identified *Imperata* as one of the main problems they face in immature rubber (Gunawan *et al*, 1994). There are two dimensions to the problem. First, it is well-known that *Imperata* competition can have a severe retarding effect on rubber trees during the first few years after planting (Anon, 1938). Second, if *Imperata* becomes established in a block of immature rubber fire can be a serious risk during the dry season, when the *Imperata* becomes a potential source of fuel. The probability of fire affecting a block depends very much, however, on the characteristics of a given location (Gunawan *et al*, 1995).

Potential control methods

There are several possible control methods, each of which needs to be considered in relation to the three main phases of rubber-based agroforestry systems, ie land opening, intercropping and post-intercropping. (For a more detailed discussion of these and other control methods see Terry *et al*, 1995.)

Manual In the past, *Imperata*-infested land was often opened by burning the *Imperata* at the start of the dry season and digging it over. This dessicates the rhizomes by exposing them to the sun. The process is repeated until they can be knocked loose (Terry *et al*, 1995). The farmer then plants his crop before the *Imperata* has had time to re-establish itself. Manual control in immature rubber involves slashing the *Imperata* and/or hoeing.

Herbicides To rehabilitate an area of *Imperata* grassland, the recommended practice is to burn or slash the *Imperata* and 20 days or so later to apply glyphosate at 1.8 kg a.i./ha: this should then be followed by spot spraying any remaining *Imperata* at about 0.36 kg a.i./ha (Terry *et al*, 1995). The recommended practice for herbicide use in the post-intercropping phase is essentially the same, except that the amount of glyphosate applied per ha should be reduced *pro rata* if the *Imperata* coverage is not 100 percent (D Laycock, pers. comm.).

Legume cover crops The basic control technology adopted by rubber (and oil palm) estates involves a combination of herbicides and perennial legume cover crops. Herbicides are used to clear the land of *Imperata*; and the legume cover crop is then planted and establishes itself before the *Imperata* is able to regrow. Its competitive effect on rubber is less than that of *Imperata*, and it tends to be less of a fire problem. Hardly any Indonesian smallholders have adopted this system: they prefer to plant intercrops that will provide food or cash.

Draft animal power Ploughing using animal traction is a very effective way of opening *Imperata*-infested land. It is not widely practised in Indonesia, however, although it is used by some farmers, both for opening land and during the first year or so of intercropping.

SURVEY METHODS

This paper draws on the experience of an ongoing adaptive research project on The Management of *Imperata cylindrica* in Smallholder Farming Systems. The project is funded by the UK's Overseas Development Administration, and implemented by the Natural Resources Institute, in collaboration with the Indonesian Rubber Research Institute (IRRI). It is based at IRRI's research station in South Sumatra, and is seeking to adapt to smallholders' situations the findings of previous research conducted on the research station.

To gain a better understanding of how the glyphosate technology developed on the research station could be adapted to smallholders' needs, a programme of on-farm research was established in various locations in South Sumatra. The programme monitors on a fortnightly basis farmers' actual control methods, their efficacy and their rationale: the information presented here has been collected through that research programme, and various surveys conducted by the project. As the on-farm research only began in October 1994, the information presented is preliminary. The project enters a second phase in October 1995, the start of the next agricultural season, which will involve the establishment of on-farm trials.

SURVEY RESULTS AND DISCUSSION

Smallholders' Farming Systems and Control Methods

Until now, smallholders have relied primarily on manual methods to control *Imperata*. However, these require large amounts of labour, particularly given *Imperata*'s propensity for rapid regrowth. Consequently, *Imperata* control is often neglected by smallholders. There is a gradual shift from manual control to herbicides taking place, principally glyphosate ('Roundup'). This may reflect growing pressures to adopt labour-saving technologies as the opportunity cost of labour rises and as people's incomes grow.

Increased herbicide use is also being encouraged by the fact that as land becomes scarcer, particularly forest land, there is a greater need to open *Imperata*-infested land rather than abandon it.

The types of control methods vary considerably; and to understand the variations it is essential to consider them in the context of the farming system and the socioeconomic characteristics of the farmers. Some of the main farming systems identified by the project in South Sumatra, and their associated control methods, will now be described.

Four rubber-based smallholder farming systems and their control methods

1. The jungle rubber system This is the traditional and most widespread smallholder system, in which farmers use a modified slash and burn system to clear existing primary or secondary forest or old rubber plantations. Seedling rubber, which is low-yielding, is planted into the burnt residue, and initially intercropped with upland rice, a subsistence crop. Farmers allow the secondary forest to grow amongst the rubber trees, and trees with a food or economic value (fruit or timber) are encouraged.

Sheet *Imperata* is rarely found in areas where this system predominates, and Imperata is less of a problem in immature rubber in this farming system than it is in areas and farming systems where sheet *Imperata* is present. (For possible reasons for this see Bagnall-Oakeley *et al*, 1995). Farmers' approach to *Imperata* control in immature rubber is essentially one of prevention, i.e. abandoning intercropping after one season.

2. Low input plantation system In this system smallholders plant their rubber, which may be seedling or clonal, with similar spacings to those used by estates. Their intercrop is usually upland rice, which is again essentially a subsistence crop. External inputs are used sparingly. There are many villages in the Musi Banyuasin region where this system can be found, and *Imperata* tends to be widespread in both uncultivated and cultivated plots of land. Use of glyphosate is rare: manual control is dominant.

3. High input, multiple cash crop farming systems These systems differ from the above-mentioned ones in that the intercrops are primarily cash crops, such as chilli (*Capsicum longum*), which can be highly profitable. These smallholders, in the Musi Banyuasin region, often regard chilli as their most important crop (Anwar & Conroy, 1993). 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 and inorganic fertilisers.

Sheet *Imperata* is widespread. To open such land for chilli production, the area is normally hand cultivated twice, the second cultivation serving as a weeding. The planting beds are progressively developed throughout the growing season, which also serves as a weeding since the rhizomes are removed. Farmers prefer manual labour to herbicides: the land has to be dug over anyway, so spraying is regarded as unnecessary. *Imperata* is a serious problem at the post-intercropping stage, but for a shorter period of time, as canopy closure is quick. The wealthier farmers are more likely to use herbicide-based technologies at this stage, but some still use manual control. This farming system shows that where substantial profits can be made from a short-term cash crop there is an increased incentive for farmers to open *Imperata*-infested land, although this kind of system is only possible in areas with good acccess to markets, usually near large cities.

4. Transmigration systems The system described here is found in the Batumarta transmigration area of South Sumatra. The transmigration project cleared large areas of forest, and gave each family from Java a house and 3.5-5 ha of land, including 1 ha of mature rubber. Subsequently, farmers have been planting their own (clonal) rubber. Rubber is regarded as the most important crop (Anwar & Conroy, 1993).

Sheet *Imperata* is probably more prevalent in these systems than in any other, mainly because the land was cleared by the transmigration authorities well before the farmers arrived, enabling sheet *Imperata* to establish itself before farmers had planted any crops. *Imperata* is generally the most serious weed in immature rubber. The use of herbicides is more widespread (almost 100%) in this system than any other: details are given in the next section.

Farmers' herbicide control practices in a transmigration area

This section looks in some detail at the herbicide control methods used by farmers in the Batumarta transmigration area. It came as a surprise to the project staff to discover through a survey that virtually all of these farmers were already using glyphosate. These transmigrants will generally have had no previous experience of growing rubber themselves, but were exposed to the plantation system when they arrived in Batumarta. Thus, their widespread adoption of herbicides could be due to them being more receptive to adopting an "estate"-like system than indigenous farmers who have previously used the jungle rubber system.

Constraints Both capital and labour constraints affect whether and how farmers control *Imperata*. Many of these smallholders face a capital constraint that results in them applying less herbicide than they would like to apply and less than is recommended. There is also a labour constraint. Only a few of the poorest herbicide users follow the recommended practice of slashing before spraying. The vast majority regard slashing as requiring too much labour, and spray instead.

Opening land A substantial proportion of farmers in the area are using glyphosate for opening land that is infested with sheet *Imperata* or a mixture of *Imperata* and scrub. Almost all farmers burn the area first, as recommended. Sixty percent apply glyphosate at less than the recommended 1.8 kg a.i./ha.

Intercropping and post-intercropping practices During the post-intercropping phase there is a tremendous degree of heterogeneity in the control measures used. Furthermore, no one sequence appears to be significantly more effective than others. The application method appears to be determined primarily by the amount of *Imperata* present at the time when the farmer sprays, but also what the farmer can afford. For example, if *Imperata* cover is > 75%, about two-thirds of farmers blanket spray and about one-third strip spray, the latter group largely consisting of poorer farmers. At intermediate levels of *Imperata* cover strip spraying is the norm, and at low levels spot applications are often made.

Seasonality in applications There are two peak periods during the year for herbicide applications: October/November and May/June. The former is the beginning of the rainy season. The farmers' rationale for spraying then is probably as follows: (i) the *Imperata* is starting to grow vigorously again after a lull during the dry season (June-September), hence uptake of glyphosate will be high and its effectiveness will be maximised; and (ii) this is when they plant their annual crops, and they want to facilitate their survival and establishment. The rationale for the May/June peak of spraying activity may be related to the fact that this is the start of the dry season when *Imperata* becomes a fire risk.

Non-recommended practices Farmers' practices often differ from those recommended. They tend to: use lower dose rates, and inappropriate sprayer nozzles; do not mark out the area to be sprayed (although the rubber planting stations may serve as markers to some extent); and do not calibrate their sprayers. Most farmers use insecticide nozzles: few of them own polyjet nozzles and many have never seen one.

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ASPECTS OF CULTURAL CONTROL OF SPEARGRASS (IMPERATA CYLINDRICA VAR. AFRICANA)

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ABSTRACT

An experiment was conducted in 1992 and 1993 to investigate the effects of some cultural practices on the growth of speargrass (*Imperata cylindrica*) and its effects on the yields of maize and cowpea. Cultivation suppressed speargrass infestation and increased crop yield whereas the difference between slash and burn was non-significant. During 1992, burn + hoe-tillage reduced speargrass infestation by 63 and 23 % relative to burn + no-tillage in the first and second cropping seasons and increased maize yield by 449 % and cowpea by 38 % respectively. In the first season, burn + hoe-tillage resulted in greater maize yield than burn + plough and no-tillage treatments. During the second season, cowpea yield was greater following hoe-tillage than all slashed and no-tillage treatments. In 1993, mean maize yield was significantly lower in burn + hoe-tillage plots than in other plots, but in the second season, yield of cowpea in burn + hoe-tillage was only significantly different from the twice ploughed plot which was the lowest yielding treatment. In 1992 and 1993, frequent weeding significantly increased maize yield in the first season, but had no residual effect on cowpea yield in the second season. In the first season of 1992, increasing weeding frequency from two to five weedings significantly increased maize yield only in burn + plough and hoe-tillage plots. In 1993 first season, weeding at 2, 4, 6 and 8 weeks after planting (WAP) was as good as weeding at 2, 4, 6, 8 and 10 WAP and both weeding regimes resulted in significantly better maize yield than 2 + 8 and 4 + 8 weeding regimes.

INTRODUCTION

Speargrass is a tropical and warm temperate perennial noxious weed with an extensive rhizome system. It is a fire climax species (Ivens, 1975; Aweto, 1987; Afolayan, 1988; Brook, 1989). Thus frequent bush-fires in the savanna ecosystems is the major factor in maintaining its site occupancy in the region. In addition, relatively high competitive ability of speargrass facilitates its existence as pure stands in what were once prime arable fields (Eussen & Wirjahardja, 1973). However, in order to suppress speargrass, resource-poor farmers burn and cultivate speargrass-infested lands They use hand-held hoes, whereas large scale farmers resort to disk-ploughing in response to current economic recession which has rendered herbicides unaffordable. Research into control of speargrass has largely been based on var. *major* in south-east Asia and the southern states of the USA. Little information exists for var. *africana* (Ivens, 1975) which affects the lives of over 400 million people in sub-Saharan Africa (Akobundu, 1991). Therefore, there is a need to explore management practices that require low inputs that would suit resource-poor farmers of sub-Saharan Africa. Considering the current weed management practices of farmers in the study area, this research was undertaken to evaluate the effects of their control strategy on the competitive ability of speargrass in a traditional cropping system.

MATERIALS AND METHODS

The experimental field located in the derived savanna zone near Ibadan, Nigeria was of an alfisol soil. Rainfall in this location has a bimodal distribution. The first rainy season with total precipitation of about 560 mm begins in April and ends in August, whereas the second rainy season with about 200 mm total precipitation starts early in October and ceases in November. The field was previously in speargrass fallow for 3 years having been abandoned to this weed which infested the land uniformly. The experiment was conducted in 1992 and 1993 using a split plot in a randomised complete block design with 4 replicates. In 1992 the main plots measured 6 m x 8 m and were divided into two to form sub plots of 4 m x 6 m. Main plots were separated by 6 m wide alley ways which served as treatment plots in 1993. The main plot treatments in 1992 were slash + no-tillage, slash + plough, slash + hoe-tillage, burn + no-tillage, burn + plough and burn + hoe-tillage. The sub plot treatments were weeding at 4 + 8 and at 2 + 4 + 6 + 8 + 10 WAP maize. In 1993 main plots measured 6 m x 16 m, and were divided into 4 subplots. Main plot treatments in 1993 were burn + plough once, burn + plough twice, burn + hoe-tillage and plough twice. The subplot treatments were weeding at 2 + 8, 4 + 8, 2 + 4 + 6 + 8 and 2 + 4 + 6 + 8 + 10 WAP maize. Slashing and burning in plots to be cultivated were done in the first week of April and first ploughing in plough twice treatments followed one day after slashing and burning. Second ploughing in plough twice treatments, plough once treatment, hoe-tillage and slashing in no-tillage plot was done a day before planting in first week of May.

In the first season, maize var. TZSR-W was planted at a density of 40,000 plants ha^{-1} and 45 kg ha^{-1} of 15-15-15 NPK fertiliser was broadcast a day after planting. At 6 WAP, maize was side-dressed with urea to provide total nitrogen of 60 kg ha^{-1}. In the second season, cowpea var. TVX 3236 was planted at a density of 53,333 plants ha^{-1}. It was sown after slashing speargrass, but without tillage or fertiliser and blanket weeding was done every fortnight. In 1992 and 1993, 4 ml of insecticide 'Sherpa plus' and 'Karate' respectively were mixed in l litre of water and sprayed on cowpea. In 1992, insecticide was applied four times at fortnightly intervals, but only twice in 1993. Data was collected within a net plot area of 32 m^2 and maize was harvested at 18 WAP, whereas cowpea was harvested at 11 WAP. Maize yield was determined at 12 % moisture content. At crop harvest, speargrass density was determined and shoots were clipped within two unweeded areas of 0.5 x 1 m each. Thereafter rhizomes within this area were excavated to 30 cm soil depth. Dry weight of the shoots and fresh rhizomes were determined after oven-drying at 80 °C for 48 h.

RESULTS

Response of speargrass to cultivation

In 1992, cultivation significantly reduced infestation of speargrass in the first season, but there was no significant difference between methods of cultivation. However, in the second season, infestation in hoe-tillage plots remained significantly lower than infestation in other plots. At the time of maize harvest in the first season of 1992, speargrass infestation was lower by 42 and 44 % 18 weeks after ploughing and hoe-tilling respectively in slashed plots compared with no-tillage. Also, in relation to no-tillage treatment, infestation of speargrass in burnt plots was 31 % less after ploughing and 63 % less after hoe-tillage. In the first season, shoot and rhizome biomass of speargrass in hoe-tillage plots were significantly lower than in other plots except in burn + plough and slash + plough plots when shoot and rhizome biomass respectively were assessed. However, there were no significant differences in the second season. Although density of speargrass in hoe-tillage plots remained significantly less than other treatments in the second season, the non significant differences in shoot and rhizome biomass in this season confirms that cultivation systems in the first season did not persist in the second cropping season of 1992 (Table 1).

Table 1. Effects of cultivation systems in the first season on speargrass density (no.m^{-2}) and biomass (g m^{-2}) in unweeded plot at harvest in the first and second seasons (1992).

	Shoot density		Shoot biomass		Rhizome biomass	
Season	first	second	first	second	first	second
Cultivation systems						
Slash + no-tillage	376	107	1418.2	128.1	2538.0	658.0
Slash + plough	219	133	1112.1	153.8	1273.8	662.0
Slash + hoe-tillage	211	79	576.4	138.3	1323.9	530.4
Burn + no-tillage	417	112	1577.6	136.2	2579.8	610.0
Burn + plough	286	114	852.5	125.4	1629.7	665.0
Burn + hoe-tillage	154	82	481.9	108.4	984.6	449.7
LSD (P=0.05)	110	50	622.7	NS	1165.3	NS

In the first season of 1993, cultivation systems did not affect speargrass density nor rhizome biomass. However, highest shoot biomass ensued from burn + hoe-tillage plot, but it was only significantly different from burn + plough once. Although there was no significant difference in shoot and rhizome biomass of speargrass in the second season, speargrass density was significantly lower in burn + plough once and plough twice plots than in other plots. Given that growth of speargrass was lesser in burn + plough once plot in both seasons, this treatment probably suppressed speargrass more than the other treatments in 1993 (Table 2).

Table 2. Effects of cultivation systems in the first season on speargrass density (no.m^{-2}) and biomass (g m^{-2}) in unweeded plot at harvest in the first and second seasons (1993)

Season	Shoot density first	Shoot density second	Shoot biomass first	Shoot biomass second	Rhizome biomass first	Rhizome biomass second
Cultivation systems						
Burn + plough once	135	32	355.2	44.2	710.5	99.0
Burn + plough twice	167	39	499.0	61.0	775.3	93.4
Burn + hoe-tillage	180	55	575.5	75.6	741.0	127.9
Plough twice	166	34	571.0	48.1	615.2	120.3
LSD (P=0.05)	NS	20	216.7	NS	NS	NS

Crop yield response

In 1992, maize yield was about 4 - 6 times greater in cultivated than in uncultivated plots probably in response to significant suppression of speargrass by cultivation. Highest yield was obtained from burn + hoe-tillage plot which was significantly different from all treatments except slash + plough and slash + hoe-tillage. Since maize yield had a similar trend to speargrass biomass, it implies that the latter rather than shoot density affected maize yield. Weeding five times resulted in significantly higher maize yield than weeding twice. Nonetheless, increasing weeding frequency from twice to five times did not significantly increase yield of maize in no-tillage plots (Table 3).

Table 3. Influence of first season cultivation systems and weeding on yield (Kg ha^{-1}) of first season maize and second season cowpea in 1992.

	Weeding regime (WAP) in maize 4+8	Weeding regime (WAP) in maize 2+4+6+8+10	Mean yield of maize	Mean yield of cowpea
Cultivation systems				
Slash + no-tillage	218.8	312.5	265.6	729.2
Slash + plough	1437.5	1640.6	1539.1	701.4
Slash + hoe-tillage	1281.3	1812.5	1546.9	736.1
Burn + no-tillage	359.4	218.8	289.1	631.9
Burn + plough	859.4	1609.4	1234.4	791.7
Burn + hoe-tillage	1375.0	1796.9	1585.9	875.0
Mean	921.9	1231.8		
LSD (P=0.05)	---------- 132.9 ----------		230.1	125.0
LSD (P=0.05) for subplot means within same main plot maize				325.4

In the second season of 1992, yield of cowpea was least in burn + no-tillage plots, but it was not significantly different from slashed plots. Greatest cowpea yield was observed in burn + hoe-tillage, but was not significantly greater than yield in burn + plough plot. Weeding regimes in the first cropping season did not significantly affect yield of cowpea in the second season (Table 3).

In the first season of 1993, burn + hoe-tillage led to the lowest maize yield which was significantly different from only plough twice treatment. Since there was no significant difference between treatments when density and rhizome biomass of speargrass was assessed, lowest maize yield in burn + hoe-tillage plot may have been caused by matching highest speargrass shoot biomass observed in this plot. However, yield in plough twice plot was not significantly higher than in burn + plough once and burn + plough twice plots. Four and five weedings resulted in significantly higher yields than two weedings (Table 4). In the second season of 1993, ploughing twice resulted in least cowpea yield, albeit only significantly different from the maximum yield obtained for burn + plough once. The significantly higher cowpea yield in the latter than in the former may be due to lower density of speargrass in the same plot in the second season. Weeding regimes in the first season did not affect cowpea yield in the second season (Table 4).

Table 4. Influence of cultivation systems and weeding in the first season on yield (Kg ha^{-2}) of maize in the first season and cowpea in the second season of 1993.

	Weeding regimes (WAP) in maize				Mean yield of maize	Mean yield of cowpea
	2+8	4+8	2+4+6+8	2+4+6+8+10		
Cultivation systems						
Burn+plough once	1890.6	2281.3	2437.5	2203.1	2203.1	271.9
Burn+plough twice	2000.0	2296.9	2468.8	2125.0	2222.7	231.2
Burn+hoe- tillage	1375.0	1359.4	2250.0	2562.5	1886.7	229.2
Plough twice	2140.6	2187.5	3015.6	2500.0	2460.9	143.7
Mean	1851.6	2031.2	2543.0	2347.7		
LSD (P=0.05)	---------- 348.3 ----------				348.3	104.2

DISCUSSION

Slashing and burning had similar effects on speargrass and crop yield and combination of these treatments with cultivation greatly suppressed speargrass and increased crop yield compared to the no-tillage situation. In 1992, hoe-tillage in burnt plot consistently resulted in highest crop yield. It increased crop yield by 449 and 38 % in the first and second seasons respectively indicating that this treatment was probably the most sustainable cultivation system. However, burn + hoe-tillage was not the best treatment in 1993 probably because rhizomes were not desiccated at the soil surface as in 1992. In the first season of 1993, maize yield in ploughed plots was identical, but plough twice in unburnt plot resulted in significantly lowest cowpea yield in the second season.

Therefore, it appears that plough once or twice in burnt plot were better cultivation systems in 1993.Burn + plough twice which is the management practice of farmers in the study area yielded 2.2 t ha^{-1} of grain in this trial as compared with 0.6 t ha^{-1} obtained from farmers' fields. Given that implements used for cultivation in this experiment are identical to those used by farmers, poorer yields in farmers' fields may be attributed to weeding once whenever convenient which is farmers' present practice. Since there was no significant difference between ploughing once or twice in burnt plots, it implies that the latter is not cost-effective and farmers may need to give serious thought to the trade-off involved in using their scarce economic resources to intensify weeding and reduce cultivation. In 1992 and 1993, cowpea yield in the second season was unaffected by weeding regimes in the first season indicating that weeding had no residual effect. Although frequent weeding increased crop yield in the first season, maize yield in uncultivated plots was not significantly improved by increasing weeding frequency from two to five. This emphasised the importance of cultivation in speargrass-infested lands. However, four or five weedings was better than 2 weedings in cultivated plots. Weeding at 2, 4, 6, 8 and 10 WAP was beneficial. Nonetheless, the last weeding at 10 WAP appeared unnecessary given that weeding at 2-weekly intervals until 8 WAP resulted in an identical crop yield. Density and biomass of speargrass in 1992 and 1993 were lower in the second than in the first season probably because of the re-positioning of sampling area to adjacent sites that were weeded in the first season and at the beginning of the second cropping season. Also it may be attributed to lesser rainfall in the second season as the dry season approached. Growth of speargrass was less vigorous in 1993 than 1992 because alley ways which were constantly slashed in 1992 were used for 1993 experiment resulting in higher maize yield in 1993 than in 1992. However, cowpea yield was higher in the latter than the former due to four applications of insecticide compared to two applications in 1993.

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THE CONTROL OF *IMPERATA CYLINDRICA* WITH TANK-MIXTURES OF IMAZAPYR AND GLYPHOSATE

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ABSTRACT

Imazapyr herbicide was tested at reduced doses in tank-mix combination with glyphosate for the control of *Imperata cylindrica* in rubber plantations. These two herbicides were applied alone or in combinations at doses of 0.125-0.75 kg a.e. ha^{-1} and 0.36-1.80 kg a.e. ha^{-1}, respectively. Single application of imazapyr at 0.75 kg a.e. ha^{-1} was effective in controlling *I. cylindrica* and suppressing germinating broadleaf weeds. In mixtures with 0.36 kg a.e. ha^{-1} glyphosate, imazapyr was effective at reduced doses of 0.25 and 0.50 kg a.e. ha^{-1}, thereby minimising the adverse effect of herbicide residues in soil.

INTRODUCTION

Imperata cylindrica is a serious weed of rubber plantations in Indonesia reducing rubber growth and delaying the tapping time by up to three years (PT. Perkebunan X, 1981). Herbicides giving good control of *I. cylindrica* include imazapyr and glyphosate. Both are translocated herbicides, each inhibiting the syntheses of a different range of amino acids. Whereas the two herbicides have a similar behaviour in plants, imazapyr at 1.0 kg a.e. ha^{-1} is more effective than glyphosate at 2.16 kg a.e. ha^{-1} in controlling *I. cylindrica* (Faiz & Faiz, 1989). Imazapyr also provides pre-emergence control of germinating weeds, but this residual activity in the soil has often resulted in adverse effects on succeeding crops such as upland rice (Cox and Johnson, 1989).

Suryaningtyas (1990) showed that improved control of *Cyperus rotundus* was possible with mixtures of glyphosate with imazapyr at reduced rates, thereby minimizing the adverse after-effect of herbicide residues in soil. This experiment was conducted to investigate the effects of comparable mixtures on *I. cylindrica*.

MATERIALS AND METHODS

A field experiment was done at Sembawa Research Institute in South Sumatra, Indonesia during the dry season from May to August 1994. The site was in an *I. cylindrica* area between rows of 1.5-year-old rubber trees planted at a spacing of 7 m x 3 m. The *I.*

cylindrica cover about 1.3 m high was fairly uniform, accounting for 75% - 90% of the total vegetation. Also present were the broadleaf species *Melastoma malabathrichum* and *Chromolaena odorata*. These shrubby plants were cut to ground level before herbicide treatment in order that spraying would be easier.

Imazapyr (Assault 250 A) and glyphosate (Roundup) were each applied at 5 doses (including 0) either alone or as tank-mixtures. Herbicides were sprayed in 500 l ha^{-1} of clean water using a Solo knapsack sprayer fitted with a red 'Polijet' nozzle at 15 psi. Each plot measured 6 m x 4 m with a minimum border of 1 m between the plots. The experimental design was three replicates of a randomized complete block with a factorial arrangement of the herbicide doses.

Visual assessments were made of percentage cover of green shoots of *I. cylindrica* on the whole plot at 16 weeks after treatment (WAT), by two independent observers. At the same time, shoot number of *I. cylindrica* and weeds other than *I. cylindrica* were counted from three randomly placed quadrats of 0.5 m x 0.5 m in each plot.

Analyses of variance were performed on the data. Additionally, the percentage cover of green shoots of *I. cylindrica* was graphically analyzed using a non-linear regression technique. Assuming independent action of imazapyr and glyphosate in mixtures, the simple similar action model (Finney, 1971) was used to predict weed response which could have been expected from the herbicide dose mixtures. This expresses imazapyr doses as equivalent doses of glyphosate:

$$Y = C / (1 + (G + A\ I/\exp(ED_{50}))^{B})$$

where Y is the percentage cover of green shoots of *I. cylindrica*; C is the control response; G is the dose of glyphosate; I is the dose of imazapyr; A is the equivalent dose of imazapyr to glyphosate; ED_{50} is the log dose of glyphosate causing 50% reduction in weed response and B is the steepness of the sigmoid curve around its point of infection. The difference between the actual and predicted means weed responses were then compared with zero using the t-test at 5% probability. When the difference is above the (+) t x SEM (standard error of means) or below the (-) t x SEM lines, the mixture is antagonistic or synergistic, respectively. If the mean lies between the two lines, the mixture is additive (Figure 1).

RESULTS AND DISCUSSION

Percentage green shoots of *I. cylindrica*

Imazapyr, applied alone, at 0.75 kg a.e. ha^{-1} effectively controlled *I. cylindrica* (percentage cover 43%) but did not at the lower doses. However, when used in mixtures with glyphosate, imazapyr, even at low doses, was more effective against *I. cylindrica* due to synergistic interactions.

The best fit additive model obtained from regression analyses of percentage cover of green shoots at 16 WAT on different doses of herbicide mixtures which were expressed as the equivalent dose of glyphosate (Table 1), is presented in Figure 1. There was significant lack of fit, indicating interaction between the chemicals. The dose-response curve with the parameter estimates of ED_{50} = - 0.57, A = 0.75, B = 2.45 and C = 78.8, gave the predicted weed responses that are also presented in Figure 1.

Synergistic actions were noticed from the mixtures of imazapyr either at 0.25 or 0.50 kg a.e. ha^{-1} and glyphosate at 0.36 kg a.e. ha^{-1}. Imazapyr at 0.25 kg a.e. ha^{-1} and glyphosate at 0.36 kg a.e. ha^{-1}, each applied alone, did not effectively control *I. cylindrica*; the percentage cover of green shoots already accounted for 73% and 67% of the total ground cover, respectively. When used in a mixture at these doses, the percentage cover was considerably reduced to 30%, which was 64% lower than that on the untreated control. A better synergistic activity was shown by the combination of imazapyr at 0.50 kg a.e. ha^{-1} and glyphosate at 0.36 kg a.e. ha^{-1} which could maintain the percentage cover at the low level of 15%. This percentage was much lower compared with either 60% or 67% which were obtained when imazapyr or glyphosate were applied alone at these doses, 0.50 and 0.36 kg a.e. ha^{-1}, respectively.

Additive interactions of imazapyr and glyphosate were observed at the other dose combinations, all of which (except 0.125 kg a.e. ha^{-1} imazapyr + 0.36 kg a.e. ha^{-1} glyphosate) satisfactorily controlled *I. cylindrica* with the percentage cover not more than 30%. The mixtures of 0.125-0.75 kg a.e. ha^{-1} imazapyr and 1.80 kg a.e. ha^{-1} glyphosate gave a percentage cover of less than 5%.

Shoot number of *I. cylindrica* and weeds other than *I. cylindrica*

Imazapyr at 0.75 kg a.e. ha^{-1} and glyphosate at 1.80 kg a.e. ha^{-1}, in isolation, were both effective in suppressing weed regrowth, with the mean number of *I. cylindrica* shoots being 26.1 for imazapyr at 0.75 kg a.e. ha^{-1} in isolation (57% lower than on the untreated control), and 11.4 for glyphosate at 1.80 kg a.e. ha^{-1} in isolation (81% lower than the untreated control). (The standard error of both percentage reductions is 12.0 on 48 df).

Imazapyr was better than glyphosate in preventing or reducing germination of broadleaf-weed seeds. Plots treated with imazapyr at 0.75 kg a.e. ha^{-1} had the lowest density (1.8 /0.25 m^2) of weed (other than *I. cylindrica*) seedlings, i.e mostly broadleaf species and only partially of grasses. In contrast, plots treated with glyphosate, even at the highest dose of 1.80 kg a.e. ha^{-1}, showed a substantial increase in seedlings other than *I. cylindrica* (5.11/0.25 m^2) which was significantly higher than 1.4/0.25 m^2 on the untreated control treatment. These results are in agreement with the findings by Mohamad & Hock (1990) who compared imazapyr with several other herbicides for the control of *I. cylindrica* in Malaysia.

In general, results from this experiment indicated that imazapyr was more effective against *I. cylindrica* in tank-mixtures with glyphosate than applied alone. Assessments of percentage green shoots showed that synergistic interactions occurred when imazapyr either at 0.25 or 0.50 kg a.e. ha^{-1} was mixed with glyphosate at 0.36 kg a.e. ha^{-1}. At these dose combinations, the percentage cover of green shoots was maintained to less than 30% for up to 16 weeks. Therefore, these findings may have a practical application in that while providing an acceptable level of *I. cylindrica* control, imazapyr can be used at reduced doses in mixtures with glyphosate, thereby reducing the risk of its phytotoxic after-effect on crops planted after herbicide use. In addition, the mixtures also suppressed the newly germinating broadleaf weeds that were not controlled by glyphosate alone. However, the total cost for *I. cylindrica* control using these herbicide mixtures remain to be taken into consideration, especially compared with the use of glyphosate alone.

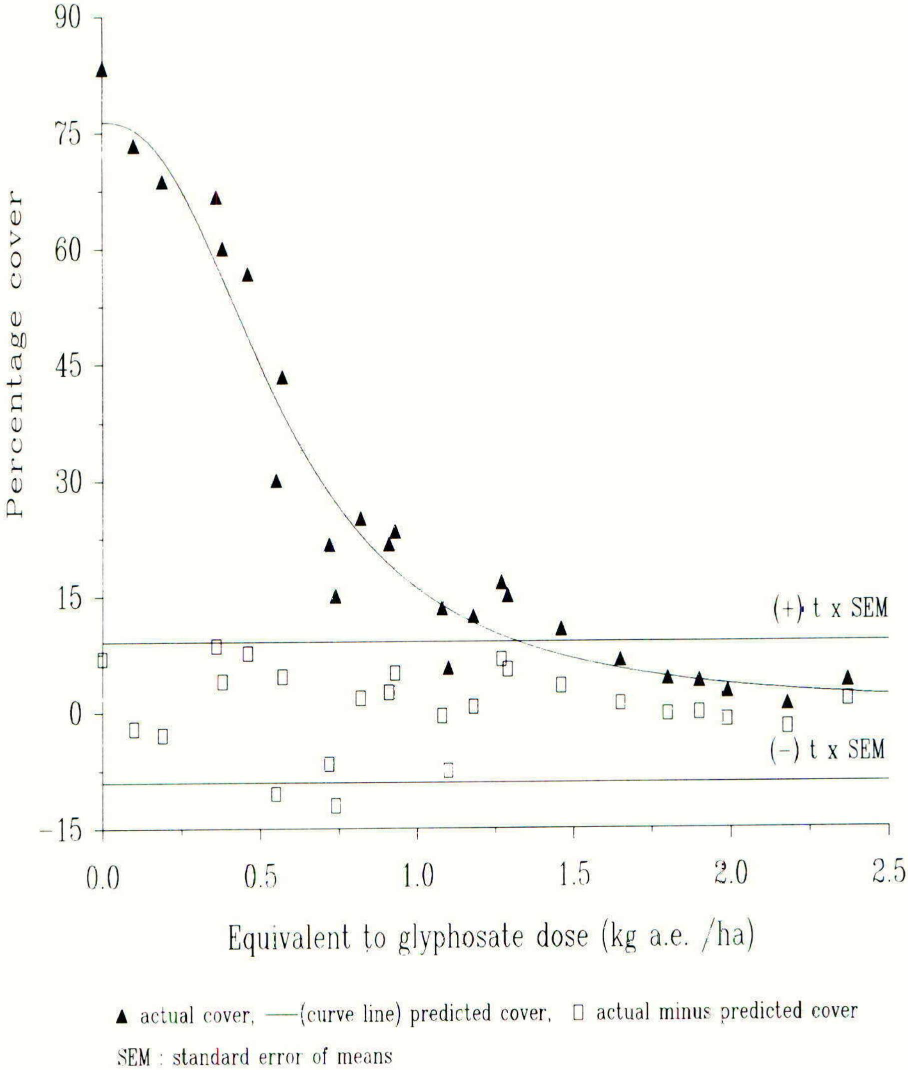

Figure 1. Percentage cover of green shoots of *I. cylindrica* 16 weeks after treatment with imazapyr and glyphosate mixtures.

Table 1. The predicted equivalent to a single dose of glyphosate of imazapyr and glyphosate mixtures for the percentage green cover of *I. cylindrica* shoots 16 weeks after treatment.

Herbicide dose (kg a.e. ha^{-1})	Equivalent to a single dose of glyphosate (kg a.e. ha^{-1})	Percentage cover
Untreated control	-	83.3
Imazapyr		
0.125	0.10	73.3
0.25	0.19	72.7
0.50	0.38	60.0
0.75	0.57	43.3
Glyphosate		
0.36	0.36	66.7
0.72	0.72	21.7
1.08	1.08	13.3
1.80	1.80	4.3
Imazapyr+glyphosate		
0.125 + 0.36	0.46	56.7
0.25 + 0.36	0.55	30.0
0.50 + 0.36	0.74	15.0
0.75 + 0.36	0.93	23.3
0.125 + 0.72	0.82	25.0
0.25 + 0.72	0.91	21.7
0.50 + 0.72	1.10	5.7
0.75 + 0.72	1.29	15.0
0.125 + 1.08	1.18	12.3
0.25 + 1.08	1.27	16.7
0.50 + 1.08	1.46	10.7
0.75 + 1.08	1.65	6.7
0.125 + 1.80	1.90	4.0
0.25 + 1.80	1.99	2.7
0.50 + 1.80	2.18	1.0
0.75 + 1.80	2.37	4.0
SEM (48 d.f.)	-	6.71

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THE INFLUENCE OF WEEDS IN THE NATURAL CONTROL OF UPLAND RICE INSECT PESTS IN COTE D'IVOIRE.

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ABSTRACT

There is considerable evidence that weeds, in addition to competing directly with crops, provide shelter and other resources for both insect pests and their natural enemies. Since natural enemies are crucial to control of insect pests in rice, it is important that weed management strategies should conserve their populations. Results of research on the effects of weed and weed residue management strategies on predatory arthropods in the forest and derived savanna zones in Cote d'Ivoire are described. On-farm surveys of weed, insect pest and natural enemy populations of farmers fields demonstrated that length of prior fallow and proportions of grass and broadleaved weeds influenced insect pests and some groups of natural enemies. Experiments at Bouaké demonstrated that weeding upland rice between 28 and 63 DAE increased spider populations and gave rice yields equivalent to those in a standard herbicide treatment, although there was no apparent effect of weeding regimes on insect pests. Different weed trash management regimes also affected predatory arthropod populations.

INTRODUCTION

Most rice produced in West Africa is grown by small-holders in upland systems (Johnson & Adesina, 1993) where pests are major constraints to production. Yield losses to weeds in upland rice vary between 44% and 100%, (Akobundu, 1987) and insect pests reduce yields by up to 40% in the absence of protection (Heinrichs, 1992a). Pesticides are rarely used in peasant rice production in West Africa but demand for intensified production has led to research on control of weeds and insect pests. In South-East Asia, where plant hoppers are major rice pests, Cheng & Zhu (1994) showed they could become serious pests in rice following over-use of insecticides that are toxic to spiders. In West Africa, where stem borers and gall midges are important (Heinrichs, 1992b), the impact of generalist predators on insect pests has not been studied. Traditional methods of weed control result in severe weed infestation but insect pest populations in farmers' fields are generally fairly low, suggesting that natural enemies may effectively suppress pests.

Surveys conducted by WARDA in several countries and studies in Nigeria (Emosairue & Usua, 1994) showed that spiders, ants, assassin bugs and lady beetles are abundant in upland rice in West Africa. Altieri *et al.*, (1977) and William (1981) suggested that the presence of weeds increased activity of predators in some crops by providing shelter, modifying crop microclimates and altering crop background to enhance predator colonization. However, Litsinger (1984), reported that weedy rice fields often had higher populations of insect pests. This paper reports on weed composition and activity and abundance of generalist predators and insect pests in upland rice in the forest and derived savanna zones in Cote d'Ivoire, as well as the effects of weed control and trash management on insect pests and their natural enemies in research station experiments.

MATERIALS AND METHODS

Studies were undertaken in major rice-producing areas at Gagnoa (humid forest zone) and Touba (derived-savanna zone) and on-station experiments at Bouaké. Gagnoa has bi-modal rainfall with average annual rainfall of 1490 mm, while Touba has mono-modal rainfall with 1405 mm per annum. Surveys were conducted in eight farmers' fields in the Gagnoa area and in 10 fields in the Touba area, from January to October 1994. Fields with different fallow periods preceding cultivation were sampled at seedling, tillering, booting and milk grain stages of the crop. Activity of ground-living predators was determined from six pitfall traps/field and their populations from six 0.25 m^2 quadrats/field on each sampling occasion. Predators and pests in the canopy were sampled with sweep nets (200 sweeps per field). Weed species and rice/weed biomass ratios were determined from six 0.25 m^2 quadrats per field.

Experiments were carried out at Bouaké on the effects of different weeding regimes and weed trash management on insect pests and predators in upland rice. In the first experiment, seven levels of weed infestation were compared. The weeding regimes (Table 1) included a herbicide treatment, 'Ronstar' (oxadiazon, 1 kg a.i. ha^{-1}) at planting and 'Garil' (triclopyr, 0.3 kg a.i. + propanil, 1.44 kg a.i. ha^{-1}) at 25 DAE. Weed biomass per unit area, density and activity levels of predators and insect pests were estimated from two 0.25 m^2 quadrats and two pitfall traps per plot on each sampling occasion. Number of spider webs and stem borer damage were counted and grain yields (g/m^{-2}), were determined at harvest.

In the second experiment, effects of different weed trash placement on beneficial arthropods and pest insects were investigated. The field was weeded twice at 35 DAE and 65 DAE and after each weeding, the trash was arranged in four treatments; a) trash evenly distributed across the plots b) trash placed in piles within the plots c) trash placed in strips in inter-rows and d) trash removed from the plots. Data on predator populations, activity and pest numbers at seedling, tillering, booting and milk grain stages and grain yield at harvest were collected, using the same methods as in the previous experiment.

RESULTS

At Gagnoa the broad-leaved *Chromolaena odorata* was dominant, while *Rottboellia cochinchinensis*, *Eleusine indica* and *Paspalum scrobiculutum*, were common grasses. At Touba, the dominant grasses were *Imperata cylindrica*, *Pennisetum polystachyum*, *Hackelochloa granularis* and *Andropogon* spp. Spiders and ants accounted for 84% of all predators found during the survey. Other groups of predators included carabids,

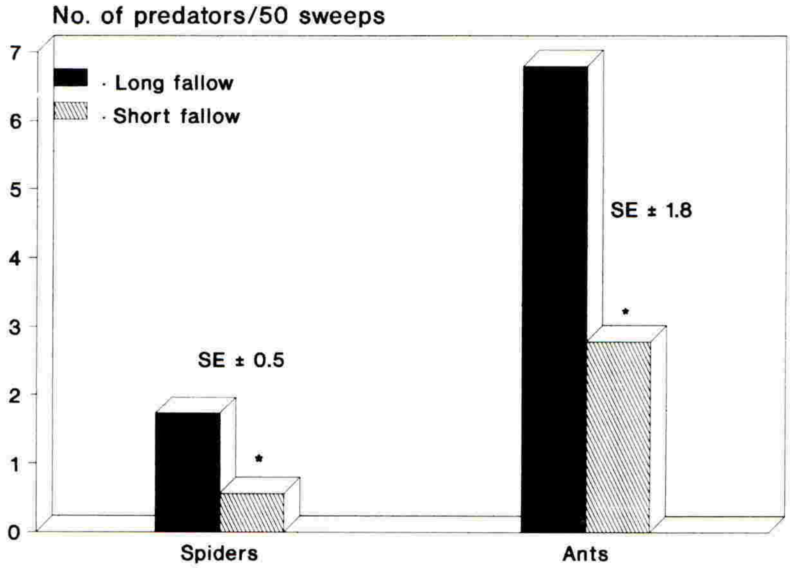

Figure 1. Effect of fallow on spiders and ant populations in upland rice canopy; Savanna zone, 1994.

cicindelids, reduviids and gelastocorids. Spider activity at Gagnoa was positively correlated with proportion of grasses in the fields (r = 0.55, n = 24), but there was no correlation for ants. At Touba, spider activity differed significantly between farms, but activity was not significantly correlated with proportion of weeds, as was the case in the forest zone. Differences between farms in ground-active spider and ant numbers were not significant in either zone. At Touba, ground activity of predatory beetles was correlated with proportion of broad-leaved weeds in the rice (r = 0.82, n = 30). There were no significant differences between farms in rice canopy fauna.

Ground spider activity was significantly higher in long fallow farms in both zones. At Gagnoa, there was no effect of fallow length on canopy predators, but in the savanna zone, spider and ant populations in the canopy were both significantly higher in long fallow farms (Fig. 1). Here, leaf beetles *(Chaetocnema* spp.), the most common insect pests, were significantly more abundant in long fallow fields.

In the weeding regime experiment, *Euclasta condylotricha*, *Imperata cylindrica, Pennisetum polystachion* and *Spermacoce stachydea* were the principal weeds. Weed proportions in the herbicide treated plots were similar to those in plots weeded from 28 - 63 DAE and significantly lower than those in plots weeded earlier in the crop cycle (Table 1). Ground spider activity was significantly greater in plots weeded from 28 - 63 DAE than in the herbicide treated plots but ant activity was not affected by weeding regimes. Although the unweeded plots had the highest density of spiders, they did not differ significantly from those in plots weeded from 28 - 63 DAE (Table 1). Ant populations and activity were not affected by weeding and populations of other predators were unaffected by weeding regimes. Spider web density in the canopy was significantly greater in all plots weeded earlier than 42 DAE than in those weeded from 42 - 63 DAE or in herbicide treated plots. Yield differences between weeding regimes were highly significant and yields were negatively correlated with the proportion of weeds in the crop (r = -0.99, n = 14). Plots weeded from 28 - 63 DAE yielded the same amount as the herbicide treated plots, while unweeded plots gave almost no yield (Table 1).

Table 1. Effect of weeding regimes on weed ratio, spider activity, spider populations, webs and yield in upland rice.

Weeding period (DAE)	None	0-21	14-35	28-49	42-63	0-100	Herbi-cide	sed
Weed %	85	51	42	17	24	1	23	6
Spiders/trap	11.3	12.6	11.6	15.4	15.3	11.4	9.9	1.8
Spiders/m^2	43.7	29.3	25.5	39.7	37.7	35.7	22.3	5.5
Spider webs/m^2	13.4	11.7	12.8	11.8	7.1	11.3	9.3	1.2
Yield g/m^2	34	190	203	285	262	339	267	29

In the trash management experiment, spider activity was significantly higher when trash was placed in strips between rows or scattered evenly across plots than in other treatments. However, spider populations were significantly greater when trash was piled or placed in strips than in other treatments. The lowest populations and activity were on the trash-free plots (Table 2). Ant activity and populations were not affected significantly by trash placement. Likewise, pest numbers and rice yields were unaffected by trash placement.

Table 2. Effect of trash placement following weeding on activity and density of spiders in upland rice.[1]

Trash placement	Even	Piles	Strips	Free	lsd(5%)
Spiders per trap	3.8	2.8	3.9	2.5	0.7
Spiders per m^2	19	37	30	13	8

[1] Data are average figures for all four growth stages.

DISCUSSION

Sampling intensity in the on-farm surveys was relatively low and lack of response of some predators to preceding fallow length and proportions of different weed categories may reflect small sample sizes. The survey is being repeated in 1995 with larger samples from each field to check the results from the preliminary studies described here.

The effects of weeding treatments on predator populations and activity did not appear to follow any clearly defined trend across treatments except that the herbicide treated plots had the lowest populations and activity. However, spider populations and activity, were significantly higher in the plots weeded between 28 and 63 DAE than in the herbicide treated plots though there was no difference in yields between these treatments. Early weed control resulted in higher weed infestation at the reproductive stage of the crop which apparently favoured web-building spiders. The number of spider webs in the crop at the grain stage were significantly correlated with surface area of broadleaf weeds ($r = 0.54$, $n = 14$).

Trash placement clearly had significant effects on ground-active spider populations and on activity levels. Clark *et al.*, (1993), reported that the abundance of some generalist predators, was proportional to the amount of ground cover (mulch). Trash piles may have supported large numbers of detritivore prey (Stinner & House, 1990) and/or provided a preferred micro-habitat (Laub & Luna, 1992) for spiders. If spiders foraged principally within the piles rather than in the plots in general, numbers in pitfall traps may be reduced. The lack of effects of trash placement on ant populations or activity was possibly due to their subterranean nesting habits.

Although there were no effects of trash management methods on either pest populations or crop yield, it is not yet clear whether this holds in all circumstances. In 1994 the first rice crop followed a long fallow and weed growth was relatively sparse on these plots and the amount of residues available correspondingly low. The experiments will be repeated in 1995 on the same plot, where weed density is expected to be higher. Trash would be imported as and when necessary, with the hope of clearly defining the effect of weeds and weed residue on the predators and pests.

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THE DEVELOPMENT OF RICE VARIETIES COMPETITIVE WITH WEEDS.

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ABSTRACT

Rice farmers in West Africa largely rely on hand-weeding as the main weed control method. Due to the limited availability of labour, weeding of the crop is often delayed or inadequate, and crop losses due to weeds are severe. Rice varieties which are able to tolerate or compete strongly with weeds would make a significant contribution to productivity and yield stability on farmers' fields. Research was conducted to identify rice varieties which can compete with weeds and to determine the characteristics of the rice plant which contribute to competitiveness with weeds.

Two field experiments are described. In the first, a range of rice varieties, including traditional and improved *Oryza sativa*, and *O. glaberrima* were grown under low input conditions, where weed growth was only partially controlled. In the second experiment, rice varieties with differing plant types were exposed to different levels of weed management.

In the experiments, differences between rice varieties in their competitiveness with weeds were apparent, with substantial differences in the weed biomass between varieties. Weed biomass at harvest was lower on plots of those rice varieties developing a large number of tillers, high leaf area indices and good root growth. There were differences between varieties in the extent to which weed competition depressed grain yield. Varieties of *O. glaberrima* appeared to be particularly competitive with weeds.

INTRODUCTION

Weeds are one of the major constraints to upland rice production in West Africa. In a survey of 3 ecological zones in the Côte d'Ivoire, all rice growers reported weeds as major pests (Johnson & Adesina, 1993). Farmers rely on cultural methods of control such as fallow periods between crops, hand weeding and tillage. Only 2% of farmers rely solely on the use of herbicides. Weed problems in traditional shifting cultivation become more serious as fallow periods are reduced due to the increased demand for land (Heinrichs *et al.*, 1995). Yield losses caused by uncontrolled weed growth in upland rice in West Africa are in the range of 48 to 100% (Akobundu & Fagade, 1978).

In Asia, tall traditional rice varieties are generally considered to be more competitive with weeds than shorter, modern rice varieties (Moody, 1979). Merlier & Deat (1978) reported that in West Africa there were substantial differences in the response of different rice varieties to weeds, with certain varieties being less affected by competition than others. Koffi (1980) reported that *O. glaberrima*, the original cultivated rice of West Africa, could compensate for weed competition in the early stages of growth, by producing late tillers after the crop had been weeded.

Competitive ability, is the ability of a plant to reduce the growth of other plants in the proximity. The availability of rice varieties to compete with, or to tolerate, weeds, would make a substantial contribution to a weed management strategies for resource poor farmers. With the objective of developing such varieties, studies were conducted to determine if differences in the competitiveness with weeds existed within rice varieties grown in West Africa, and to identify those traits related to competitiveness. It was intended that this information would be used to guide plant breeders. The selections of rice varieties to be tested, included modern and traditional *Oryza sativa*, and *O. glaberrima*.

METHODS AND MATERIALS

In the first experiment (1993), twenty promising varieties were evaluated for their ability to suppress or tolerate weeds under low input conditions intended to approximate to those found on farmers' fields. A complete randomized block design, with 4 replications was used; all plots were hand weeded at 18 and 42 Days After Seeding (DAS). Land was prepared by shallow hand cultivation and the rice sown in lines 25 cm apart; urea was applied (18 kg N/ha) at 21 DAS.

In the second experiment (1994), twelve *O. sativa* and *O. glaberrima* lines were selected to form a range of distinctly different plant types in terms of plant height, tillering capacity and leaf type. The varieties were grown in factorial combination with two levels of weeding: weed free, and hand weeded once at 43 DAS. The design was a complete randomized block, with 3 replications. Phosphate was applied (20 kg P/ha), after ploughing; urea was applied (14 kg N/ha) 43 DAS. The rice was sown in hills 25 cm apart, with seedlings thinned to two plants shortly after emergence.

The information collected on crop development comprised, tiller number, leaf area, height and, in experiment 2, root growth. Root samples were taken using a 10 cm diameter auger, to a depth of 20 cm, and the washed roots were measured with a Delta-T Area Meter (Voorhees *et al.*, 1980). Weeds were sampled during the vegetative stage of the rice and at harvest.

RESULTS

Most of the *O. glaberrima* and improved *O. sativa* varieties are of intermediate-stature, with plant height varying between 90 and 110 cm, while traditional *O. sativa* varieties, like M 22 and LAC 23, tend to be tall statured.

The predominant weeds in experiment 1 were *Ageratum conyzoides* and *Euphorbia heterophylla*. There were no significant differences in weed biomass between varieties at 18 DAS, though at harvest, differences were significant, with biomass ranging between 495 and 1507 kg/ha (Table 1). The *O. glaberrima* varieties, CG 14 and CG 20, had the lowest weed weights at harvest, followed by the traditional *O. sativa* varieties, M 22 and YS 236. The improved *O. sativa* varieties such as WAB 56-50, WAB 56-104 and WAB 32-80 had the highest weed biomass. The varieties with lower weed biomass were those that showed rapid vegetative growth (seedling vigor), had a large number of tillers, had droopy lower leaves within 20-40 days, and established a high leaf area index by 50 DAS. Weed biomass at harvest was negatively correlated with leaf area index at 50 DAS (r= - 0.292, n= 80) and tiller number at 48 DAS (r = -0.290). There was no significant correlation between rice plant height and weed biomass.

Table 1. Weed biomass, crop growth, and grain yield, Côte d'Ivoire, 1993.

Varieties	Leaf area index	Weed biomass (kg/ha)		Tiller $/m^2$	Height (cm)	Grain yield (kg/ha)
	50 DAS	18 DAS	Harvest	48 DAS	Harvest	
WAB 56-50	0.97	304	1507	248	100	2044
WAB 56-104	0.95	300	1485	276	94	2309
WAB 56-125	0.99	229	966	215	95	2300
WAB 32-80	0.97	342	1486	235	107	1417
WAB 181-18	0.63	257	1270	182	89	2104
WAB 96-1-1	0.97	267	931	211	110	1357
WAB 99-1-1	0.60	277	1362	126	93	2081
ITA 257	0.67	196	978	182	89	1314
ITA 301	0.97	278	1005	223	92	1907
IRAT 144	1.28	330	1090	190	98	2400
IDSA 76	0.90	316	1275	146	88	1227
CG 14*	1.73	217	495	402	107	1427
CG 20*	1.35	213	683	363	100	1931
YS 236	1.23	311	819	296	107	1114
SP 4	0.90	273	995	254	119	1941
IDSA 10	1.00	356	1000	167	94	1760
LAC 23	0.96	416	1024	189	115	631
M 22	1.34	198	774	280	112	654
IGUAPE	0.89	253	1162	189	101	1281
IDSA 6	0.89	295	1074	312	83	1400
SE	±0.112	±56.7	±198.8	±24.9	±6.7	±312.6

* = Oryza glaberrima

There was no correlation between weed weight at harvest and grain yield, suggesting that the two hand weedings resulted in insufficient weed pressure to substantially affect yield, or that other factors had greater influence. Grain yield ranged from 631 kg/ha from the traditional variety, LAC 23, to 2400 Kg/ha for the modern variety, IRAT 144. The varieties yielding above 2000 kg/ha were all improved varieties of intermediate stature, such as IRAT 144, WAB 56-104, and WAB 181-18. This suggests that these were well adapted to the low input conditions in the experiment.

In the second experiment, *Brachiaria lata*, *Trianthema portulacastrum*, *A. conyzoides*, *Cyperus rotundus*, and *Oldenlandia corymbosa* were the predominant weeds. Weed biomass at 43 DAS did not significantly differ between varieties (Table 2). However, at maturity, the differences were significant, with a range from 948 kg/ha in IG 10 to 3732 kg/ha in WAB 56-104. Three *O. glaberrima* varieties, IG 10, ACC 102257, and CG 14 and the traditional *O. sativa* variety, YS 236, had high leaf area indices at 49 DAS and tiller numbers at 36 DAS, but low weed biomass.

Table 2. Weed biomass, crop growth, and grain yield, Côte d'Ivoire, 1994.

Varieties	Weed biomass (kg/ha)		Tiller/ m^2	Leaf area index	Root τ length cm/hill	Grain yield (kg/ha)	
	43 DAS	Harvest	36 DAS	49 DAS	49 DAS		
	W	W				W	C
CG 14*	1327	1956	97.6	1.2	429	1208	2032
SP 8	1810	2707	62.4	0.9	252	962	2694
WAB 56-50	1759	2513	65.6	0.6	323	586	2924
Digba Youho	1763	2670	91.2	0.8	327	1194	2688
G 5	1451	1931	57.6	0.6	260	998	2343
YS 236	1516	1471	80.0	1.1	362	1242	2619
ACC 102257*	1503	1815	128.0	1.2	426	1539	2504
WAB 99-1-1	1511	3010	68.8	0.7	313	727	3174
WAB 96-1-1	1700	2662	65.6	0.8	330	1130	3465
WAB 56-104	1851	3732	62.4	0.6	202	152	2527
IG 10*	1277	948	134.4	1.6	688	2061	2179
ITA 257	1527	2527	48.0	0.7	246	907	2132
SE	±253.3	±378.5	±9.28	±0.11	±48.7	± 206.4	

* = Oryza glaberrima; W = weedy; C = clean weeded
τ = cm for 1571 cm^3 of earth

There were significant correlations between the growth of rice plants in the vegetative stages and weed biomass at harvest, including tiller number (r = - 0.59, n=36), leaf area indices (r = - 0.53), and root length (r = - 0.68). Rice plant height was not significantly correlated with weed biomass.

On average, yields with a single hand-weeding were 57% lower than those on plots which were regularly weeded. However, there were interactions (P<0.003) between variety and weed control, with yield of IG 10 being reduced by only 5%, while WAB 56 104 was reduced by 95%. Analysis across varieties and replicates showed that grain yield on the weedy plots, expressed as a proportion of yield on the clean weeded plots, was negatively correlated with weed weight at rice maturity (r= - 0.57, n=36), and positively correlated with root length at 49 DAS (r= 0.77), tiller number (r= 0.75) and leaf area indices (r= 0.69) at 49 DAS. A number of the improved varieties, such as WAB 56-104 and WAB 56-50, which produced relatively good yields in experiment one, despite weed competition, produced poor yields in the second experiment where they were exposed to severe weed competition.

DISCUSSION

The rice varieties tested differed substantially in their ability to suppress weed growth. There were approximately three-fold differences in the weed biomass at harvest between the least and the most competitive lines. *O. glaberrima* varieties in particular, appeared to be very competitive with weeds. These varieties were characterized by vigorous early growth, high tillering and rapid leaf area development. The early establishment of a closed crop canopy limits the growth of weeds and the late germination of weed seeds. The negative correlation of crop leaf area index during the vegetative phase and weed biomass at harvest found in these experiments is in agreement with the results reported by Garrity *et al*, 1992. However, they concluded that rice plant height was the factor most closely related to low weed biomass, while in our studies there was no significant correlation between plant height and weed biomass. In our experiments, there was negative correlation between weed biomass at harvest and tiller number during the vegetative stages, though others have suggested that tiller number is not necessarily an important factor in determining competitiveness with weeds (Kawano *et al*., 1974).

Perera *et al.*, (1992) suggested that root competition may be more important than shoot competition, particularly in the early stages of the crop. The results of our study indicate that root development may be a factor related to differences in weed competitiveness of rice varieties. The root development of IG 10, an *O. glaberrima*, was particularly extensive. Further studies are required on root development patterns, growth rate and possibly on allelopathy, to determine the importance of below-ground competition with weeds.

The ability of some of the improved varieties to produce good yields despite weed competition, and the lack of correlation between weed biomass and grain yield in experiment 1, suggests that some tolerance to weed competition may exist. Further studies are required to determine if there is a relationship between competitiveness with weeds and tolerance to weed competition.

These studies indicate that *O. glaberrima* may be a valuable source of those characteristics which impart competitive ability with weeds. In further research, the extent to which this ability has been transferred to progenies of *O. sativa* x *O. glaberrima* will be examined.

The development of varieties with ability to compete successfully with weeds would significantly enhance rice yield stability under extensive, low-input conditions common in West Africa. To determine an "optimum plant type" for conditions of poor weed control, future studies will focus on the major morphological characteristics that determine weed competitiveness and the extent to which yield potential may be sacrificed by the incorporation of weed competitiveness.

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OCCURRENCE OF PROPANIL RESISTANCE IN *ECHINOCHLOA COLONA* IN CENTRAL AMERICA

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ABSTRACT

Main rice growing areas in Central America were surveyed for propanil resistance in junglerice (*Echinochloa colona*). Seed was collected in Costa Rica, El Salvador, Guatemala, Nicaragua and Panama and bioassays were carried out at CATIE, Costa Rica. Selected *E. colona* populations were sprayed with propanil at increasing rates up to 22.4 kg/ha under screenhouse conditions to determine dose response and calculating GR_{50} values. Populations varied widely in their response to propanil, some being up to 70 times more resistant to the herbicide than the control (susceptible) population, depending on local growing conditions and herbicide selection pressure. Propanil resistance is fairly common in *E. colona* in Central America.

INTRODUCTION

The annual grass junglerice (*Echinochloa colona*) is a principal weed of rice throughout the tropics. Propanil, a relatively inexpensive, contact, post-emergence herbicide, has been traditionally used to control this weed. However, continued reliance on this herbicide led to the evolution of resistance. In Latin America, propanil resistance has been confirmed in Costa Rica and Colombia (Garro *et al.*, 1991, Fischer *et al.*, 1993).

Propanil resistance also occurred in the related species barnyardgrass (*E. crus-galli*) in Greece (Giannopolitis & Vassiliou, 1989) and Arkansas, USA (Smith *et al.*, 1992). The loss of this control option due to resistance in the weed flora has serious implications to farmers who depend on chemical weed control. The potential also exists for *Echinochloa spp*. to evolve resistance to alternative herbicides used in rice such as the case of a population of *E. colona* already resistant to propanil which was found to be resistant to the grass-herbicide fenoxaprop-ethyl in rice fields in Costa Rica (Caseley *et al.*, 1995).

The biochemical and physiological mechanism of resistance has been identified as an increased capability of *E. colona* to metabolize propanil in the same manner rice avoids phytotoxic damage (Leah *et al.*, 1994, 1995).

The existence, extent and severity of herbicide resistance is largely ignored in Latin America. Even in rice, where farmers now begin to recognize resistance as a problem, no specific actions are being taken by most growers to deal with or prevent the build up of resistance.

The objective of the bioassay studies reported here was to survey the extent of propanil resistance in *E. colona* populations in the main rice producing areas of Central America.

MATERIALS AND METHODS

Collection of *E. colona* seed

E. colona seed samples were collected in the principal rice-growing areas in Panama, Costa Rica, Nicaragua, El Salvador and Guatemala. Fully mature seed was harvested by hand and taken to CATIE, Turrialba, Costa Rica, where they were coded and stored at room temperature until planting. Recent herbicide use history of sampled rice fields was obtained when it was possible.

Bioassays

Seeds were soaked in tap water for 24 hours with at least two water changes before they were placed in petri dishes containing filter paper (Whatman No. 2) moistened with water for germination at room temperature. Four seedlings (one-leaf growth stage) were transplanted in plastic pots with 260 g of soil supplemented with 2 g of 10-30-10 fertilizer and placed in a greenhouse with reduced light conditions. After this adaptation period, plants were transferred to a fully-exposed screenhouse until they reached the three-leaf stage.

One day before the application, plants were thinned to three per pot and sorted in a complete randomized block design with four replications. Propanil (Stam M4 AC 48% EC, Rohm and Hass) was applied at increasing doses (0, 0.35, 0.7, 1.4, 2.8, 5.6, 11.2 and 22.4 kg/ha) to individual pots in a spray booth (R & D Sprayers, Opelousas, Louisiana, USA) equipped with a Teejet 8001VS nozzle at 2.06 Bars, delivering 200 l/ha. Plants remained in the screenhouse for two more weeks until harvesting. Propanil phytotoxicity on *E. colona* was assessed visually at 8 and 15 days after treatment (DAT) and by harvesting the aerial part of the plants at 15 DAT to determine both fresh and dry weights. Two weeks after initial harvesting, clipped plants that resprouted were counted and weighted. Results shown in this paper are based only on fresh weight determinations.

GR_{50} (propanil rate required to reduce fresh weight by 50%) values were calculated for each *E. colona* population from regression equations. The resistance index (RI) was calculated as the ratio of the GR_{50} of the selected population over the GR_{50} of the most susceptible one (P2).

RESULTS AND DISCUSSION

Response to propanil varied considerably among *E. colona* populations from Central American countries and even within the same rice-growing region (Table 1). In general, there seems to be a relation between the rice-production history and the resistance level; however, some of the weed management practices at specific farms apparently have delayed resistance evolution even after many years of rice monoculture.

For example, susceptible populations from El Salvador were found at small farms (less than 3 ha) where agronomic practices are performed using family labor; fields are planted only once a year and hand weeding is practiced up to three times per crop cycle. Evidently, hand weeding decreases the selection pressure imposed by propanil in these fields.

The highest resistance levels were found in Nicaragua. In the Granada (Malacatoya) area, farms are bigger, with long history of rice production and usually planted twice a year since there is irrigation available. Propanil has been used for more than 25 years and farm size does not allow for hand weeding. Susceptible populations from Nicaragua were those from farms where soil is puddled and the water table from irrigation helps in controlling weed seedlings. If propanil is used, it is commonly tank mixed with other herbicides.

Additionally, in recent years some growers have shifted to the use of systemic grass killers such as fenoxaprop-ethyl.

Table 1. Response of selected *E. colona* biotypes from Central America to propanil.

Code	Country	Province or Department	Years of	Cycles/ rice[1]	GR_{50} year	RI[2]
CR39	Costa Rica	Guanacaste	NA	2	0.25	1.25
CR14	Costa Rica	Puntarenas	0	0	0.73	3.65
CR29	Costa Rica	Puntarenas	NA	1	1.16	5.80
CR5	Costa Rica	Puntarenas	15	1	1.55	7.75
CR16	Costa Rica	Puntarenas	NA	1	7.92	39.60
ES35	El Salvador	Ahuachapán	NA	NA	0.20	1.00
ES9	El Salvador	La Libertad	1	1	0.30	1.50
ES18	El Salvador	Sonsonate	15	1	0.35	1.75
ES3	El Salvador	Ahuachapán	15	1	0.50	2.50
ES8	El Salvador	La Libertad	5	1	0.69	3.45
ES6	El Salvador	La Libertad	2	1	0.70	3.50
ES7	El Salvador	Sonsonate	15	1	0.70	3.50
ES4	El Salvador	Chalatenango	10	1	1.50	7.50
ES5	El Salvador	Ahuachapán	15	1	1.50	7.50
ES28	El Salvador	Ahuachapán	26	1	2.80	14.00
ES30	El Salvador	La Libertad	NA	NA	8.68	43.40
G2	Guatemala	Chiquimula	25	1	0.33	1.65
G5	Guatemala	Chiquimula	25	1	0.42	2.10
G5	Guatemala	Chiquimula	25	1	0.42	2.10
G6	Guatemala	Chiquimula	NA	1	0.45	2.25
G1	Guatemala	Chiquimula	40	1	1.13	5.65
G3	Guatemala	Chiquimula	6	1	1.85	9.25
N21	Nicaragua	Matagalpa	0	0	0.24	1.20
N14	Nicaragua	Matagalpa	NA	2	0.45	2.25
N8	Nicaragua	Boaco	NA	2	0.47	2.35
N17	Nicaragua	Matagalpa	NA	2	0.85	4.25
N15	Nicaragua	Matagalpa	NA	2	1.70	8.50
N19	Nicaragua	Matagalpa	NA	NA	1.80	9.00
N10	Nicaragua	Boaco	NA	2	1.90	9.50
N7	Nicaragua	Granada	8	2	3.20	16.00
N5	Nicaragua	Granada	20	2	3.60	18.00
N1	Nicaragua	Granada	NA	2	3.62	18.10
N2	Nicaragua	Granada	5	2	3.62	18.10
N4	Nicaragua	Boaco	NA	2	4.25	21.25
N25	Nicaragua	Matagalpa	20	2	5.20	26.00
N3	Nicaragua	Granada	10	2	8.14	40.70
N12	Nicaragua	Granada	NA	2	8.14	40.70
N28	Nicaragua	Matagalpa	NA	2	9.58	47.90
N13	Nicaragua	Granada	NA	2	14.07	70.35
N11	Nicaragua	Managua	NA	NA	14.23	71.15
P2	Panamá	Coclé	NA	2	0.20	1.00
P6	Panamá	Herrera	16	2	5.40	27.00

[1] NA: Information not available, 0= Area not cultivate (field edge)
[2] RI: Resistance index

Most of the *E. colona* populations from Guatemala are still fairly susceptible. Farmers in the Chiquimula area, where seed was collected, resemble those small growers from El Salvador, since they supplement chemical weed control with hand weeding.

The situation in Costa Rica was partially documented previously (Garro *et al.*, 1991). Only a few populations are included in this study, with varying degrees of resistance but it is well known that propanil resistance is very common in dryland-rice producing areas (Valverde, B. E., unpublished).

Only two populations from Panama are included. P2 from Penonomé was collected at a field edge and was used as a control for calculating the resistance indices; P6 from Chitré exhibited a high resistance level.

Results presented here indicate that propanil resistance is common among *E. colona* populations in the main rice growing areas in Central America and that differing degrees of resistance occur depending on local growing conditions and herbicide selection pressure.

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INTERACTION BETWEEN A COVER CROP (*MUCUNA* SP.), A WEED (*ROTTBOELLIA COCHINCHINENSIS*) AND A CROP (MAIZE)

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ABSTRACT

A field experiment was conducted in the seasonally arid area of NW Costa Rica to study the interaction between the cover crop *Mucuna* sp., itchgrass (*Rottboellia cochinchinensis*) and maize. *Mucuna* was planted between maize rows at 0, 50 000 and 80 000 plants/ha. Four densities of itchgrass were achieved by applying 0.12, 0.25, 0.50 and 1.50 kg pendimethalin/ha. Total itchgrass control was achieved with the highest rate of pendimethalin plus handweeding. At the end of the growing season, in the absence of *Mucuna*, itchgrass above-ground biomass was 0, 525, 665, and 1016 g/m^2 with increasing densities. *Mucuna*, regardless of its density, reduced itchgrass biomass between 75 and 95%. Conversely, no definite effect of itchgrass on *Mucuna* biomass was observed. All treatments reduced maize grain yield compared to the control (without interference from either species). Considered individually, the cover crop and the weed reduced grain yield up to 40%. The convenience of associating *Mucuna* with maize for itchgrass control should be evaluated rigorously considering yield penalties, non-herbicidal benefits of the cover crop and cost of alternative treatments.

INTRODUCTION

Itchgrass (*Rottboellia cochinchinensis*) is one of the most troublesome weeds in Central America. Itchgrass is widespread in Costa Rica, especially in the Pacific and Atlantic regions where it is a major weed in maize, beans, dryland rice, sorghum and sugarcane (Herrera, 1989).

In the seasonally arid area of the Pacific Northwest of Costa Rica, itchgrass causes major crop losses and costs of controling it may limit planting areas for small and medium-size farmers (Rojas *et al.*, 1993b). Under these conditions, the critical period of competition in maize varies between 20 and 60 days after crop planting, depending on the season and itchgrass density, and yield reductions of 45 to 64% have been recorded when left unchecked (Rojas *et al.*, 1993a).

Itchgrass infestation in maize can be reduced by in-crop use of selective herbicides, chemical control during the fallow period and zero tillage (Rojas *et al.*, 1993b). Cover crops also can supress itchgrass when planted in association with maize or during the fallow period. Of several species evaluated, velvetbean (*Mucuna* sp.) was shown to be the best adapted and exhibited the highest ground cover and itchgrass suppression without causing yield losses (De la Cruz *et al.*, 1994).

Research is being conducted to study the competitive effects of both itchgrass and velvetbean on maize yield. In this paper, results from a first experiment on the effect of velvetbean in the presence of increasing densities of itchgrass on maize yields are presented.

MATERIALS AND METHODS

The experiment was established at the University of Costa Rica Regional Centre in Santa Cruz, Guanacaste, Costa Rica, on land which was naturally infested by itchgrass. Maize (cv Diamantes) was planted manually on 23-08-94 at 1.0 by 0.4 m spacing to achieve a density of 50 000 plants/ha. Velvetbean was planted a week later (31-08-94) between maize rows at two spacings (0.40 and 0.25 m) to obtain densities of 50 000 and 80 000 plants/ha. At maize planting, 225 kg/ha of 10-30-10 fertilizer was applied together with 8 kg/ha chlorpyrifos, supplemented with a 136 kg/ha application of ammonium nitrate 21 days after planting (DAP).

To obtain four itchgrass densities, a tank mixture of pendimethalin (0.12, 0.25, 0.50 or 1.50 kg/ha) plus 0.40 kg/ha paraquat were applied one DAP by a portable CO_2-operated sprayer equipped with four TeeJet SS8003 flat fan nozzles delivering 250 l/ha. Itchgrass plants that escaped the highest rate of pendimethalin were pulled by hand to achieve the zero density.

Treatments were arranged in a four by three factorial in a complete randomized block design with four replications. Factors were four densities of itchgrass (zero, low, medium and high) and three velvetbean densities (0, 50 000 and 80 000 plants/ha). Experimental plots were 20 m^2 with a sampling unit of four rows of maize for a total of 13.5 m^2. Additionally, four quadrats (0.40 x 0.40 m) were randomly marked, two within the maize row and two between maize rows (where velvetbean had been planted), for determining itchgrass densities. Number of itchgrass plants in each quadrat were counted weekly beginning two weeks after planting (WAP) until the eighth week. A week before maize harvest, a 1.0 m^2 sample was harvested to determine velvetbean and itchgrass fresh weight. Maize was harvested in the sampling unit on 13-12-94 and dried to 12% moisture content.

RESULTS AND DISCUSSION

At two WAP, itchgrass densities averaged 0, 11, 24, and 28 plants/m^2 within the maize row and 0, 11, 22 and 23 plants/m^2 between maize rows, corresponding to the zero, low, medium and high densities, respectively. The medium and high densities were equivalent throughout sampling dates, except at the last two dates (7 and 8 WAP) between the maize rows where velvetbean suppressed itchgrass (Fig. 1). Regardless of treatments, itchgrass densities increased up to five WAP (Fig. 1), indicating differential germination and emergence, up to a maximum of 70 plants/m^2 within the maize rows (data not shown). Similar observations were made in experiments by Rojas *et al.* (1993), at the same experimental area, where they found increases in itchgrass densities 45 DAP compared to 15 DAP, regardless of in-crop herbicide use.

At the end of the cropping season, above-ground itchgrass biomass (fresh weight) had substantially decreased in plots where velvetbean had been planted (Table 1). Increasing the velvetbean density from 50 000 to 80 000 plants/ha further slightly reduced itchgrass biomass. Velvetbean suppressed itchgrass biomass between 75 and 95%, being more effective at lower itchgrass densities. On the other hand, itchgrass density did not affect velvetbean biomass nor were differences found between the two actual velvetbean densities (Table 1). Thus, it appears that velvetbean could have a higher competitive ability than itchgrass when growing together, which explains the efficacy of this cover crop in the integrated management of this weed.

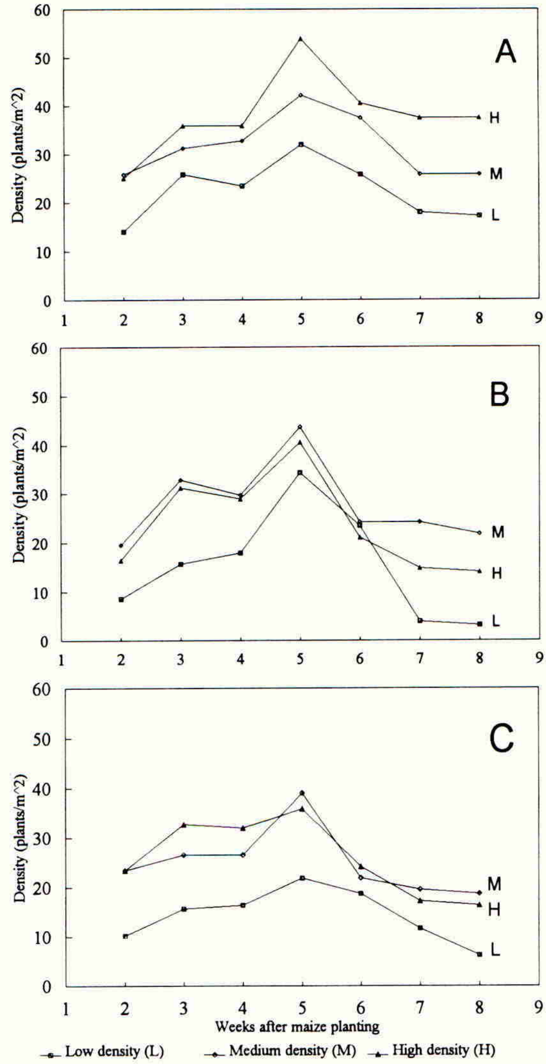

FIGURE 1. Number of itchgrass plants between maize rows at different densities in the absence of velvetbean (A) and with velvetbean at 50 000 plants/ha (B) or 80 000 plants/ha (C).

The presence of velvetbean or itchgrass, regardless of density, reduced maize grain yield up to 39%. There was no significant interaction between velvetbean and itchgrass densities on maize yield. In previous experiments, at the same location and with similar velvetbean densities, velvetbean suppression of itchgrass improved maize yield (De la Cruz *et al.*, 1994). In the present experiment velvetbean was not allowed to invade the maize row but proximity among plants was enough for interference to occur. The most likely resource for which maize and both velvetbean and itchgrass competed was water since rainfall was unusually low during the cropping season. Based on these results, it is important to further characterize the interaction between the three species to better define the role of velvetbean in integrated management of itchgrass in maize, considering yield penalties, non-herbicidal benefits of the cover crop and cost of alternative treatments.

TABLE 1. Effect of velvetbean and itchgrass densities on velvetbean and itchgrass biomass at the end of the cropping cycle and maize grain yield.

Treatments	Fresh weight (g/m^2) Itchgrass	Velvetbean	Maize yield (kg/ha)
Without velvetbean	(552)[1]	(0)	(3424)
Without itchgrass	0	0	4189
Low itchgrass density	526	0	3167
Medium itchgrass density	665	0	3359
High itchgrass density	1016	0	2981
Velvetbean at 50 000 plants/ha	(111)	(419)	(2809)
Without itchgrass	0	362	3100
Low itchgrass density	26	607	2809
Medium itchgrass density	160	436	2667
High itchgrass density	256	269	2659
Velvetbean at 80 000 plants/ha	(60)	(425)	(2823)
Without itchgrass	0	470	3081
Low itchgrass density	48	280	2570
Medium itchgrass density	54	484	2741
High itchgrass density	139	466	2900
$LSD_{0.01}$ within velvetbean densities	317	-	-
$LSD_{0.01}$ among velvetbean densities	-	155	541

[1] Averages across itchgrass densities in parenthesis.

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INTEGRATED CONTROL OF *CYNODON DACTYLON* IN COMMUNAL AREAS OF ZIMBABWE

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ABSTRACT

Cynodon dactylon is a major weed problem in the communal farming areas of Zimbabwe. Its widespread occurrence is associated with shallow primary cultivations with an animal drawn plough. Combinations of glyphosate applications with post-harvest and pre-plant tillage by plough have been tested at on-farm sites in two contrasting cropping environments. Initial results suggest that excellent *Cynodon* control can be achieved by a single application of glyphosate post-harvest or prior to spring tillage. Opportunities for reducing herbicide dose while maintaining weed control and improving maize productivity, by appropriate timing of tillage, are demonstrated.

INTRODUCTION

Cynodon dactylon is a creeping perennial grass that spreads by seed, stolons and rhizomes. Overwintering, achieved through stolons and rhizomes, allows the weed to establish early in the growing season and achieve a competitive advantage over annual crops. *C. dactylon* is a common weed in smallholder farming areas of Zimbabwe. Difficulties in controlling this species have been reported for both marginal (Thomas, 1970) and high rainfall areas (Chivinge, 1988). For example, it has been observed in Zvimba Communal Area, that for every g m^2 of *Cynodon* dry weight there was a 15kg ha^{-1} decrease in maize yield (Agronomy Institute, 1989).

C. dactylon is difficult to control under smallholder farming conditions. Land preparation by mouldboard ploughing and mechanical weed control tend to cut stolons and rhizomes into fragments, which easily re-establish if conditions are suitable. However, it has been shown that if the rhizomes are exposed on the soil surface for up to six hours the desiccation that occurs can reduce re-establishment (Agronomy Institute, 1992). Tillage practices which bring the rhizomes to the soil surface have therefore a potential to control *C. dactylon*. Two passes with a mouldboard plough between the onset of spring rains and planting suppressed *C. dactylon* regrowth for four years in trials in Botswana (Phillips, 1993).

The post-emergence herbicide glyphosate can be used to control *C. dactylon* (Hicks & Jordon, 1984). Unfortunately, the high cost of glyphosate has, to date, discouraged communal farmers from using it. There is, therefore, a need to evaluate the effects of reduced rates of the herbicide for control *C. dactylon* under smallholder farming conditions. The objective of this study is to investigate the integration of chemical control using glyphosate with tillage in an attempt to develop a cost effective *Cynodon* management system for smallholders.

MATERIALS AND METHODS

Trials were established on six farms in both Zvimba Communal Area (750 - 1000 mm annual rainfall) and Gutu Communal Area (450-650 mm annual rainfall) during the 1994/95 season on sandy soils severely infested with *C. dactylon*. The treatments were: glyphosate at 2.2 kg a.e. ha^{-1} applied post-harvest followed by winter (dry season) and spring ploughing (FGWPSP), glyphosate at 1.1 kg post-harvest, winter and spring ploughing (HGWPSP), winter ploughing and spring ploughing (WPSP), glyphosate at 2.2 kg in spring followed by spring ploughing (FGSP), double spring ploughing (DSP) and spring ploughing only (SP). Rain in late May stimulated *Cynodon* growth so post-harvest herbicide applications were made at the end of the month and mid-June at Zvimba and Gutu respectively. Winter ploughing followed four days later. Following rain in October, spring herbicide applications were made in mid-November. The subsequent spring ploughing followed four days later at Zvimba but not until the second week in December at Gutu. The second plough pass of the DSP treatments was carried out at planting. The treatments were replicated twice per farmer and arranged in a randomised complete block design. All ploughing, to 10-15 cm deep, was done with ox-drawn single furrow mouldboard ploughs owned by participating farmers. Glyphosate was applied by knapsack sprayer.

Maize cultivar R201 was planted at two seeds per station in furrows opened by a mouldboard plough, at a spacing of 90 cm x 30 cm, in plots measuring 10 m x 5.4 m. The maize seeds were covered using feet. Maize planting was done on 23 November 1994 and 12 to 14 December 1994 at Zvimba and Gutu, respectively. Fertiliser, 24kg N, 42kg P, and 28kg K ha^{-1}, was applied at planting and crops were side dressed twice with 35kg N ha^{-1}. Maize grain yield, *C. dactylon* dry weights and soil moisture content were recorded. The maize was harvested in plots measuring 6 m x 3,6 m. *C. dactylon* shoots were clipped at the soil surface in quadrats measuring 60 cm x 45 cm, at five randomly selected positions per plot. Sampling was done prior to first and second weeding, both undertaken by ox-drawn cultivator at 3 and 7 weeks following emergence, and at harvest. The harvested material was oven dried and weighed. Soil moisture was determined grammetrically at two weekly intervals. Data were subjected to analysis of variance.

RESULTS AND DISCUSSION

Cynodon control and maize yield

Rainfall during the 1994/95 season, (Table 1), was below average at both sites resulting in lower than normal yields. Analysis of *C. dactylon* above ground biomass showed no treatment by farm interaction for any sampling date at Zvimba, so mean data for all six sites is shown in Table 2.

Table 1: Rainfall (mm) for Zvimba and Gutu Communal areas for 1994/1995 crop season

	October	November	December	January	February	March	Total
Zvimba	60	34	154	99	55	0	402
Gutu	46	21	135	52	41	0	295

Glyphosate at 2.2 kg a.e ha^{-1} applied either post-harvest, followed by winter and spring ploughing, or in early spring, prior to a single spring ploughing resulted in significant reductions in *C. dactylon* regrowth (P >0.01) at harvest and considerably higher maize yields (P > 0.01) compared to a single spring ploughing. A lower rate of glyphosate (1.1 kg) used in combination with winter and spring ploughing also suppressed *C. dactylon* regrowth and produced a higher yield than double or single ploughing treatments. Two plough passes in the spring resulted in some reduction in *Cynodon* biomass by harvest but no increase in maize yield compared to single spring ploughing.

Table 2. The effect of herbicide and ploughing treatments on *C. dactylon* regrowth (g m^2 dry weight) at 18, 51 days after emergence and harvest, and on maize grain yield at Zvimba Communal Area. Means of data for 6 sites.

	Cynodon dactylon dry weights at:			
Treatment	18 Days	51 Days	Harvest	Maize Yield kg ha^{-1}
FGWPSP	10.1	8.1	11.9	1289
HGWPSP	26.9	17.5	12.6	1018
WPSP	44.8	24.0	20.2	874
FGSP	8.8	5.7	7.6	1146
DSP	34.6	23.5	19.1	785
SP	45.7	29.8	26.0	865
s.e.	6.8***	3.4***	4.6**	105***

*** P > 0.001, ** P > 0.01

At Gutu there was a significant treatment by farm interaction for *C. dactylon* biomass at two sampling dates; data for 25 days following planting is shown in Table 3. With the exception of farm 2, where *C. dactylon* infestation was considerably more severe than elsewhere, greatest weed suppression followed either double spring ploughing or application of the full rate of glyphosate used in combination with a single spring ploughing. Data for subsequent sampling dates (not presented) showed similar trends. Less regrowth of *Cynodon* followed the pre-plant application of glyphosate in the spring than where the same dose rate had been used following the previous maize harvest. The poorer activity of the post-harvest treatment may have been related to a delay between the last rain of the season and spraying when active weed growth and hence translocation of glyphosate may have been reduced. At two sites the combination of winter and spring ploughing resulted in as good control of *Cynodon* as post-harvest herbicide application followed by ploughing. Although spring application of herbicide or double spring ploughing may delay planting, particularly if the onset of the rainy season is delayed, both treatments resulted in nearly double the maize yield produced from the traditional practice of planting following a single plough pass.

Table 3. The effect of herbicide and ploughing treatments on *C. dactylon* dry weights (g m^2) at six sites at Gutu communal Area on 7/01/95 and mean maize grain yields.

Farm/ treatment	1	2	3	4	5	6	Mean	Mean Yield kg ha^{-1}
FGWPSP	28.3	74.1	21.2	14.8	9.6	8.1	26.0	822
HGWPSP	27.6	105.2	21.2	48.9	6.3	7.9	36.2	1084
WPSP	51.4	96.7	31.3	18.2	6.2	1.5	34.2	852
FGSP	0.00	103.0	0.00	13.0	0.00	0.0	19.3	1182
DSP	1.6	118.9	1.5	19.3	1.3	1.2	24.0	1032
SP	31.7	253.7	13.8	22.6	11.0	4.8	56.3	663
s.e. Farm		10.4***				s.e. yield		142***
s.e. Treatment		10.4*						
s.e. Farm Treatment		25.4**						

*** P>0.001 ** P>0.01 * P>0.05

Soil moisture

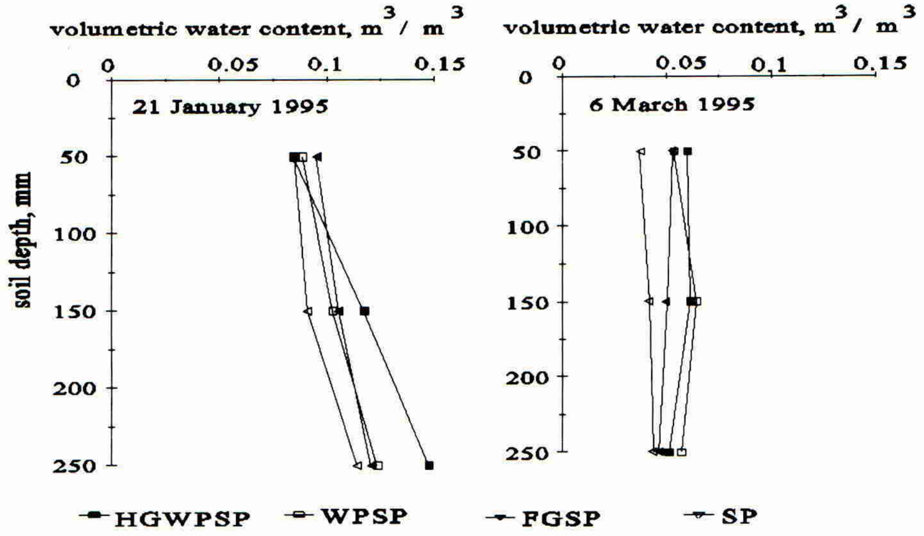

Figure 1 Variation in volumetric water content with soil depth following four *C. dactylon* control practices at Zvimba on 21 January (59 days) and 6 March 1995 (103 days after planting).

Figure 1 summarises the effects of *C. dactylon* control on soil water content for two occasions in Zvimba Communal Area. At the first sampling on 21 January 1995 the single spring ploughed (SP) treatment was significantly ($P < 0.05$) drier than the other treatments that had been either sprayed with glyphosate or winter and spring ploughed. However, by the second sampling on 6 March 1995 both single spring ploughed treatments (FGSP and SP) were drier ($P < 0.1$) than the plots that had received both winter and spring ploughing (HGWSP and WPSP). This suggests that mechanical disturbance achieved by double ploughing can have a beneficial effect on soil water contents throughout the season. The lower water contents recorded on the SP treatment coincided with higher levels of *C. dactylon* infestations and lower crop yields, as is shown in Tables 2 and 3. Although, the unsprayed winter and spring ploughed plots (WPSP) retained a similar amount of water as those treated with glyphosate, the mechanical action of ploughing alone did not give the same efficacy of *C. dactylon* control. Consequently, the WPSP plots had similar levels of *C. dactylon* infestations and crop yields as observed on the single ploughed treatment.

CONCLUSION

For sandveld soils in a below average rainfall year a combination of tillage and herbicide, in this instance glyphosate, gave the best efficacy of *C. dactylon* control and increased maize grain yields by between 20 and 50% over single spring ploughing. The use of glyphosate sprayed at 2.2kg a.e ha^{-1} on to *Cynodon* regrowth following the onset of the spring rains combined with a single ploughing, the common tillage practice used by the majority of smallholders in Zimbabwe, resulted in the most consistent weed suppression of treatments compared. A reduced rate of herbicide applied post-harvest also appears to have the potential to increase maize productivity. In addition to good *Cynodon* control, the two plough passes following post-harvest herbicide use may also result in higher levels of moisture in the soil profile. Double spring ploughing, a cheaper but more labour intensive option, resulted in *Cynodon* suppression and maize yields comparable with glyphosate treatments at Gutu but performed poorly at Zvimba. Further trials are being undertaken to determine the conditions under which tillage treatments result in effective *Cynodon* suppression. Monitoring of *Cynodon* regrowth and maize yields in the season following the use of glyphosate or double ploughing will now be undertaken to determine the residual effect of and the full cost and benefits of *Cynodon* management options under smallholder conditions.

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THE EFFECTS OF WEEDING METHODS AND WATER CONSERVATION ON WEED POPULATIONS IN DRYLAND MAIZE

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ABSTRACT

Weed pressure was measured in monocropped maize (*Zea mays*) over four seasons (1991/92 - 1994/95) on two sites at Makoholi Experiment Station in the semi-arid region of Zimbabwe. Water conservation and weeding systems involved flat and pot-holed land; hand-hoeing, hand-push weeding, ox-cultivation and ox-ploughing at two and six weeks after crop emergence. Results showed that weed biomass in 1991/92 and 1992/93 were significantly ($P < 0.05$) less than the 1993/94 and 1994/95 seasons. With the exception of the 1991/92 drought year, the length of time a site had been cultivated strongly influenced weed biomass. The older C.P.U. site had significantly ($P < 0.001$) lower weed densities than the younger Drewton Site. *Richardia scabra* was the dominant weed at both sites, with a biomass significantly ($P < 0.001$) more than either *Eleusine indica* or *Hibiscus meeusei*, irrespective of the season or weeding regime. The lowest weed weights were recorded on hand-hoed plots at both sites. The pot hole technique did not have any affect on weed biomass and only caused a significant ($P < 0.01$) increase in grain yields at the Drewton site during the 1991/92 drought.

INTRODUCTION

Excessive weed growth is one of the most important single factors limiting crop production on smallholder farms within the communal areas of Zimbabwe (Chivinge, 1984). This is due to the fact that weed germination is strongly influenced by the tillage and weeding practices currently used by small holders. Numerous studies have shown that shallow tillage at monthly intervals after planting, can, either increase or decrease the emergence of some weeds and at the same time, have no effect on others (e.g. Ogg & Dawson, 1984; Egley & Williams 1990). For efficient weed control methods to be developed it is important to understand how different weed species react to different combinations of tillage and weeding.

Identification of weed control as the limiting factor in the adoption of reduced or conservation tillage systems has been well documented (Douglas, 1992; Roberts & Potter, 1990). Acceptance of these systems might be possible if the weed problem can be reduced through weed control practices that decrease dominant weed species. The use of pot-holes, 0.5 m wide shallow pits created between crop rows, has been investigated as a water conservation measure with encouraging results in Zimbabwe (Mashavira *et al*, 1995). The objective of this study was to determine the effectiveness of different weeding methods used in combination with potholes on sandy soils, typical of Zimabwe's communal areas.

MATERIALS AND METHODS

The study was conducted at Makoholi Experiment Station, Masvingo; in Natural Region IV of Zimbabwe (1204 m above sea level, 30°47'E, 19°50'S); at two sites, Crop Production Unit (C.P.U.) and Drewton from 1991/92 to 1994/95 season. C.P.U. is an old land that was opened for cropping in 1969/70 season. Since then, it has been cropped continuously with subsistence food crops such as maize and groundnuts. Primary tillage has been by a tractor mounted disc plough and weeding by hand-hoe. In contrast, Drewton is relatively new land, that has been continuously cropped since it was opened in the 1982/83 season, primary tillage has been by ox-drawn mouldboard plough and weeding by a combination of ox-cultivator and hand-hoeing. Consequently, the depth of tillage at the two sites, and hence the potential weed seed populations tend to be different. Annual rainfall at both sites varied during the period of the trials from 150 to 700 mm. Table 1 summaries the actual rainfall received at the wetter Drewton site. Both sites have infertile medium grained sandy soils derived from granitic rock.

TABLE 1. Seasonal rainfall characteristics' Makoholi Experimental Station 1991 to 1995

Month	1991/92	1992/93	1993/94	1994/95
Drewton Site				
November	51.9	92.4	148.8	10.3
December	35.1	268.4	214.3	248.3
January	115.2	107.9	138.7	80.2
February	5.5	201.4	77.9	64.5
March	51.7	28.5	8.0	52.8
April	1.4	3.7	2.0	12.3
Total	260.8	702.3	589.7	468.4

Maize hybrid R201 was used as a test crop. A basal fertilizer of 150 kg/ha compound 'D' (8N:14P205:7K20:6.5S) was applied at planting and a top-dressing of 150 kg/ha ammonium nitrate (34.5%N) was applied as a split dressing at four and eight weeks after crop emergence. A split-plot design with weeding methods as the main plot and conservation tillage method as subplot, replicated four times, was used. The gross plot area was six rows at 0.90m apart and 10.0m long (54.0m^2). Treatments consisted of four weed control methods: a) hand-hoe; b) a hand-push weeder; c) ox-cultivator; d) ox-plough with mouldboard (breast) removed, used in combination with two water conservation techniques: 1) flat: traditional ploughing with a 300 mm wide mouldboard plough and planting in 0.9 m rows and 2) pot-holes into traditionally ploughed land: pits approximately 0.5 m wide and 0.15 m deep at 1.0 m intervals created with the hand-hoe between the crop rows at planting. Weed control was carried out at two and six weeks after crop emergence and pot holes were remade as required after each weeding. Before each weeding, weeds from five quadrats (0.90m x 0.60m) sampled per plot, were separated by species dried and weighed. Weed and crop data were subjected to an analysis of variance for each site and season. Treatment comparisons were made using Fisher's Protected LSD ($P < 0.05$).

RESULTS

Over the four seasons of testing, weeding method, water conservation and their interaction only had a significant ($P < 0.01$) influence on maize grain yields at the Drewton site during the 1991/92 drought, when a total crop failure was recorded the C.P.U. site. For the other three seasons a similar pattern of yield response was seen at each site, with the Drewton site yielding consistently higher grain yields than the older C.P.U. site (Table 2). Yields obtained following the diferent weeding and water conservation treatments were not significantly different.

TABLE 2. Maize yield response to method of weeding and water conservation techniques

	Drewton Site, kg/ha @ 12.5%m.c.				C.P.U., kg/ha @ 12.5% m.c.			
Treatment	91/92	92/93	93/94	94/95	91/92	92/93	93/94	94/95
hand-hoe	0	2040	2263	1643	280	4453	2643	1579
push-weeder	0	1866	2479	1435	106	4281	2632	1377
ox-cultivator	0	2188	2971	1570	134.0	3767	2248	1532
ox-plough	0	2098	2754	1538	134.0	3913	2330	1474
weeding s.e.	0	76.5	212.1	145.5	22.4**	295.3	446.4	140.5
flat	0	2033	2664	1619	114	4183	2432	1559
pothole	0	2052	2622	1511	182**	3834	2172	1458
tillage s.e.	0	44.2	180.2	84.0	12.9	170.5	257.7	81.1

During the first two seasons of the trial labour requirements for the four weeding methods were significantly ($P < 0.05$) different (Dhliwayo *et al.*, 1993). At both sites' mechanical weeding with the ox-cultivator allowed a considerable reduction in labour required for weeding. Typically times required to weed one ha with this implement averaged 7.5 hours, compared with 24.5 hours for the ox-plough, 49 hours with the push weeder and 57 hours by hand-hoe. Needless to say, labour requirements varied considerably between sites and seasons in response to previous management strategies and rainfall.

Figure 1 summarises the variation in mean weed weights between seasons and sites. Weed biomass in 1991/92 and 1992/93 were significantly ($P < 0.05$) less than the 1993/94 and 1994/95

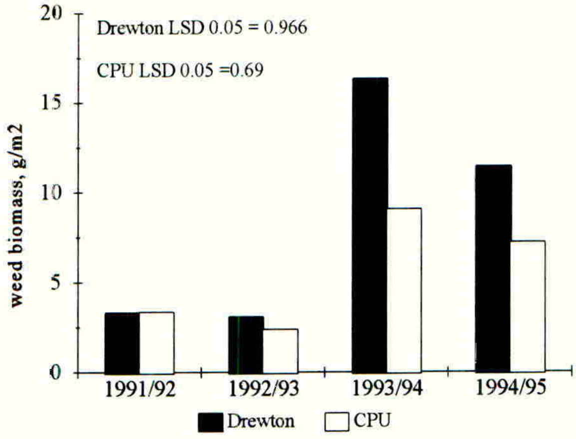

Figure 1. Variation in total weed biomass between seasons and sites (means of all assessments)

seasons. These differences can be attributed to the drought conditions experienced in 1991/92 (Table 1) and a carry over effect into the following season. As is shown in Figure 2, with the exception of the 1991/92 drought year, the length of time a site has been cultivated strongly influenced weed weights. The older C.P.U. site had significantly ($P < 0.001$) lower weed biomass than the younger Drewton site. An analysis of season and treatment effects on weed species revealed that at both sites, the lowest weed weights were recorded on the hand-hoed plots (Figure 3). *R. scabra* was the dominant weed with significantly greater ($P < 0.001$) weed biomasses than either *E. indica* or *H. meeusei*, irrespective of season or time of weeding. Similar patterns of species response to weed control method were recorded at the C.P.U. site over the experimental period, with biomasses (mean of all assessments) for each species as follows, *R. scabra* 5.2 g/m^2, *E. indica* 0.25 g/m^2 and *H. meeusei* 0.13 g/m^2. As is shown in Figure 4, water conservation technique had no significant effect on weed biomass production over the period of the study.

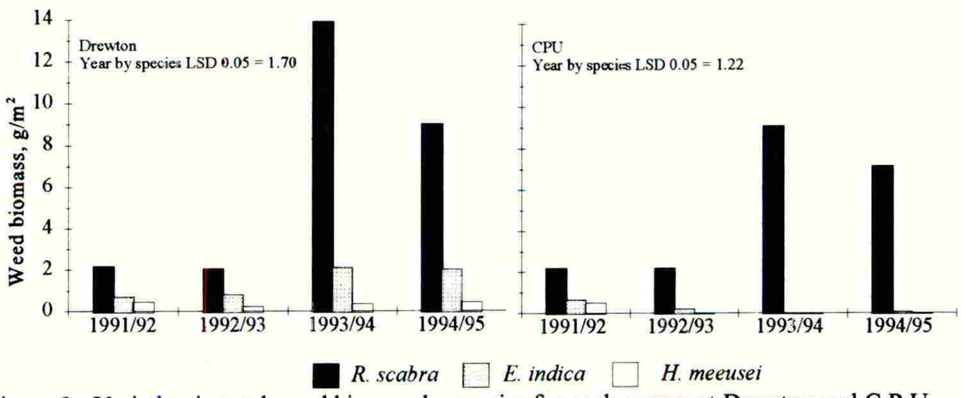

Figure 2. Variation in total weed biomass by species for each season at Drewton and C.P.U. sites (mean of all treatments and assessments)

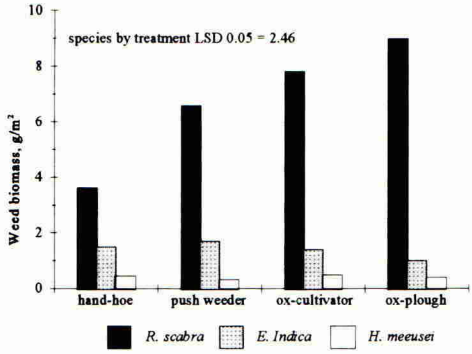

Figure 3. Weed species response to weed control treatment at the Drewton site, weed biomass by species for the experimental period (mean of all assessments)

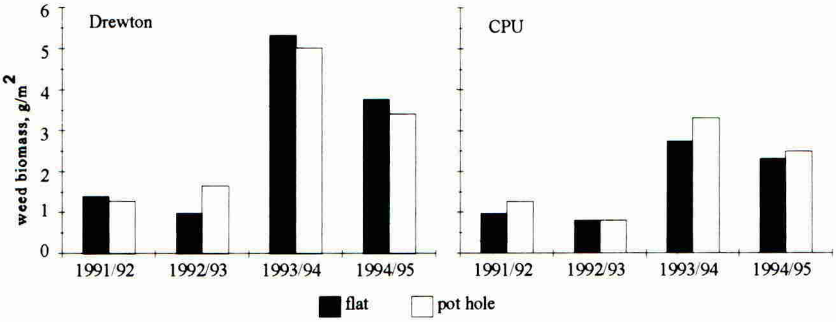

Figure 4. Total weed biomass response to water conservation technique at Drewton and C.P.U sites (means of all assessments)

DISCUSSION

The extreme rainfall patterns experienced over the four seasons of this study had a greater influence on maize yield response at both sites, than did either the methods of weed control or water conservation technique. Only during the drought of 1991/92 was a significant grain yield response to water conservation technique observed, and then only at the Drewton site. In fact, the high rainfalls that were experienced in subsequent seasons had a greater effect on grain yields, than either weed control or water conservation technique. This lack of maize yield response, in all but the driest of seasons, can be attributed to the low water holding capacity of these sandy soils (Twomlow, 1994) and confirmed the findings of previous work carried out on similar soils and environments (e.g. Shumba *et al.* 1993). These results suggest that for very sandy soils new crop husbandry practices cannot be evaluated solely by crop yield, but also require detailed observations of labour to allow a full cost benefit analysis to be carried out.

The use of pot-holes, designed to increase the amount of water available to the crop, did not lead to an increased weed burden. Significantly lower weed weights were recorded on hand-hoed plots for all weed species. This could be due to efficient weed control by this weeding method, particularly within the crop row, as reported by Mabasa (1992); or because the other weed control methods have the effect of leaving a rough soil surface which enhances moisture retention (Ellis-Jones *et al* 1993), thereby encouraging more weed seedling emergence as reported by Roberts and Potter (1990). Hand hoeing has a high labour demand; inter-row weeding using a cultivator or plough allows timely weeding with a significant reduction in labour use (Ellis-Jones *et al*, 1993).

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LOSS OF WEED SEEDS FROM THE SOIL SURFACE OVER WINTER IN BOTSWANA

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ABSTRACT

Seed of 11 common arable weeds was attached to sticky tape fixed on cards, and either left over winter on the soil surface or buried at 15 cm. The numbers of surface seeds were counted weekly for 15-19 weeks. After the observation period buried seed was recovered. All seeds remaining were assessed for damage. A germination test was then performed on surviving intact seeds. Losses due to predation by vertebrates and invertebrates varied between species and were generally greater for seeds left on the surface than for those buried, and for soft coated seeds compared with hard coated seeds. However there was more damage to buried seeds. The germination percentage of five species was increased if the seed was left on the surface rather than buried. The implications for weed management are discussed.

INTRODUCTION

The majority of land farmed traditionally in Botswana is not ploughed until at least the first spring rainfall and more usually not before planting in November to January (Anon, 1990). Weed seed shed during the previous cropping season has therefore lain on the soil surface for at least six months before being ploughed under. During this time losses to vertebrate and invertebrate predators could be considerable. In addition, the seeds will be exposed to bright sunlight and large diurnal fluctuations in temperature. This exposure may affect the subsequent germination of the seeds when in favourable soil conditions. Winter ploughing, which is recommended and has agronomic advantages, places seeds in dry soil at between 10 and 20 cm below the surface. If this confers advantages in seed survival, then the technique may have implications for weed management. The study was designed to measure losses of seed from the surface and at plough depth, and the germination potential of surviving seeds. The species selected are all common arable weeds of Botswana (Phillips, 1992), and their seeds vary in size and type of seed coat.

MATERIALS AND METHODS

The study was conducted during the dry seasons (May to September) of 1990 and 1991. In the first year five species were compared and in the second year six further species were studied. All were broad-leaved plants apart from one grass (Table 1). The seed was collected in the season prior to use except that of *D. ferox* which had been stored in the lab for one year.

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Twenty-five seeds of each species were placed on the sticky side of a piece of masking tape approximately 4 x 5 cm. This in turn was stapled on to a piece of card 10 x 15 cm. Six replicates were made of each card which were then placed in a field in which cowpeas had been grown the previous season. The cards were anchored to the ground with soil and a light dusting of soil was spread over the tape to prevent insects being trapped on the sticky surface. Wire mesh and naphthalene balls were used to exclude predators from one card which acted as a control. Another five sets of cards were prepared and carefully buried at a depth of 15 cm.

Table 1. Weed species and seed description.

1. *Acrotome inflata* - small angular, hard coat.
2. *Datura ferox* (large thorn apple) - large, hard coat.
3. *Hibiscus meeusei* (wild stockrose) - medium, hard coat.
4. *Ipomoea obscura* (morning glory) - large, hard coat.
5. *Sesbania bispinosa* (sesban) - large, hard coat.
6. *Acanthospermum hispidum* (upright starbur) - medium size, soft hooked coat.
7. *Amaranthus thunbergii* (pig weed) - small, soft coat.
8. *Cucumis myriocarpus* (wild striped cucumber) - large, soft coat.
9. *Hermbstaedtia odorata* - small, soft coat.
10. *Sesamum alatum* (wild sesamum) - small, soft coat.
11. *Urochloa mosambicensis* - (bush veld herringbone grass) small, soft coat.

The cards were placed in position during May or June and counts were made weekly for 15-19 weeks of seed numbers on the surface cards. At the end of this period, the buried cards were recovered and the seeds counted. Some seeds may have been lost during this difficult process. Remaining seeds on all cards were assessed for damage and intact seed used for a germination test. Twenty-five seeds, or as many as were available, were placed on moist filter paper in a petri dish and incubated at 30°C for 9 hours and 20°C for 15 hours in the dark, until they had germinated or started to decompose. Tests were made on lab stored seed of the same species.

In one year, maximum and minimum soil surface temperatures and the daily soil temperatures at 10 and 30 cm were recorded.

RESULTS

None of the seeds on the control cards was lost so all losses from the surface cards can be attributed to predation. The one possible exception was *A. hispidum* seed which has hooks and did not adhere so well to the tape, so seeds could have been blown away. The losses of seeds from the surface cards over the observation period are presented in Figures 1 and 2.

In the first year there were clear differences between species in the numbers of seeds lost and the rate of loss. The small soft seeds of *A. thunbergii* disappeared rapidly at first and then at a more steady rate, while those of *A. hispidum* initially went more slowly, then after 15 weeks the rate increased. In contrast the hard coated *H. meeusei, I. obscura* and *D. ferox* seeds were hardly touched.

In the second season the small seeds of *H. odorata*, similar to those *A. thunbergii*, did not get

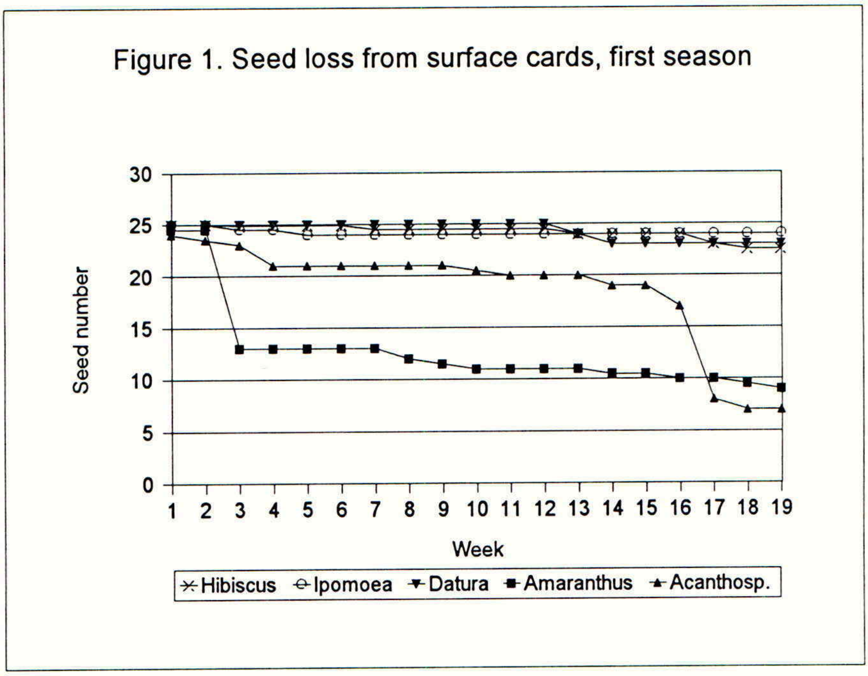
Figure 1. Seed loss from surface cards, first season
Seed number
Week
Hibiscus
Ipomoea
Datura
Amaranthus
Acanthosp.

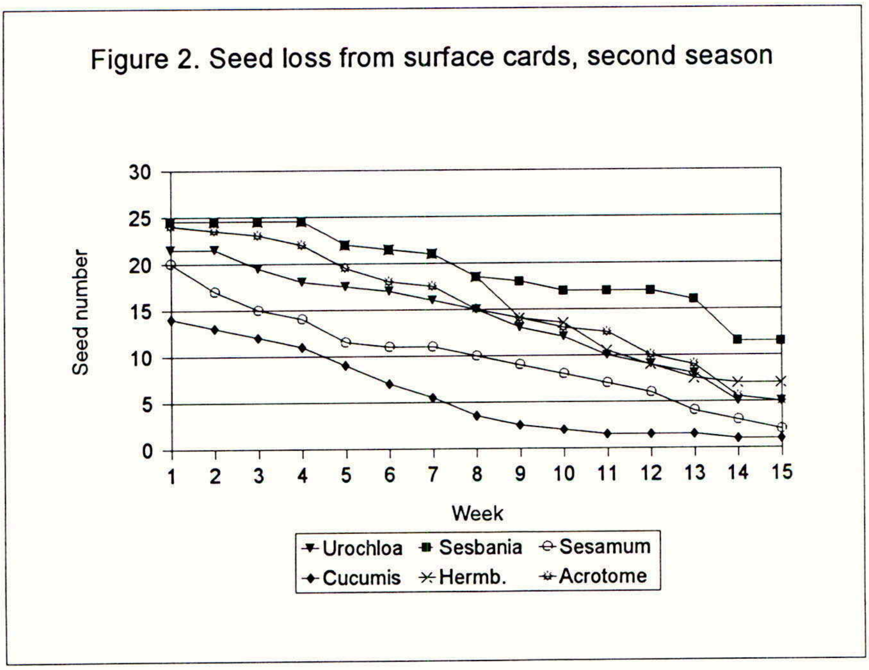
Figure 2. Seed loss from surface cards, second season
Seed number
Week
Urochloa
Sesbania
Sesamum
Cucumis
Hermb.
Acrotome

taken until after 4 weeks when a steady decline began. *S. bispinosa* was the least attractive species, despite it probably being a nutritious seed. In contrast, the soft seeds of *C. myriocarpus* and *S. alatum* almost completely disappeared over a period of 15 weeks. Seed of the other two species was taken at a similar rate with 80% lost during the experiment.

The percentages of seeds lost from the buried and surface cards at the end of the observation period, and the percentages of remaining seeds damaged are given in Table 2.

Table 2. Percentage of seeds lost and damaged following exposure on the soil surface or burial at 15 cm in the field during the dry season.

Species	Buried % Lost	Buried % Dam.	Surface % Lost	Surface % Dam.
A. inflata	19	7	80	15
D. ferox	21	13	8	0
H. meeusei	6	0	10	0
I. obscura	46	59	4	10
S. bispinosa	31	0	54	0
A. hispidum	54	41	72	0
A. thunbergii	38	1	64	0
C. myriocarpus	31	46	96	0
H. odorata	22	0	72	9
S. alatum	58	40	92	14
U. mosambicensis	36	22	80	36

Losses of hard coated seeds of *I. obscura*, and to a lesser extent *D. ferox*, were greater when they were buried than when left on the surface, but were still less than 50%. Very few *H. meeusei* seeds were lost from either position. In contrast losses of *A. inflata* and *S. bispinosa* seeds were greater from the surface than the buried cards, with 80 and 54% lost respectively. Apart from buried *I. obscura* seed, few hard seeds suffered much damage.

Losses of soft coated seeds were greater from the surface cards, with the large majority of surface seed of most species being taken. Most of what remained was intact, except for about one third of *U. mosambicensis* seeds which were damaged. Losses of buried soft seeds varied from over half of *A. hispidum* and *S. alatum* seeds, and nearly half the survivors damaged, to 22% of *H. odorata* seeds, with none of the remaining seeds damaged.

Some interesting differences were noted in the results of the germination tests, which are given in Table 3. Most of the *A. hispidum* seeds had lost their hooks, but were otherwise intact. With the exception of *A. thunbergii*, there was very little germination of buried seed. Most buried seed behaved similarly to stored seed. An exception was seed of *U. mosambicensis*, only 4% of which germinated compared with 50% of stored seed. Most of the surface seed of

A. hispidum and *A. thunbergii* germinated, as did 24% of *H. meeusei* and 33% of *C. myriocarpus* seed. Only a small proportion of the seeds of *D. ferox* and *A. inflata* from the surface cards germinated, and none of the seed of the other five species. Only stored seed of *U. mosambicensis* and *A. thunbergii* had significant germination percentages.

Table 3. Germination (%) of seed following exposure on the soil surface, burial at 15 cm in the field or storage in the lab for 15-19 weeks.

	Source		
Species	Surface	Buried	Stored
A. inflata	18	0	15
D. ferox	12	0	8
H. meeusei	24	0	0
I. obscura	0	8	4
S. bispinosa	0	0	0
A. hispidum	88	4.5	0
A. thunbergii	92	75	32
C. myriocarpus	33	0	9
H. odorata	0	0	0
S. alatum	0	0	0
U. mosambicensis	0	4	50

There was considerable diurnal variation in soil surface temperature of up to 50°C. In one 24 h period the temperature went from -4° to 33°C. In contrast the 10 cm soil temperature rarely dropped below 10°C and only reached a maximum of 30°C . In addition, seeds on the surface were exposed to bright sunlight for most of the daylight hours.

DISCUSSION

Seeds lying on the soil surface are exposed to more variable and extreme environmental conditions than buried seeds, as well as to predation. In studies of the fate of *Avena fatua* (wild oat) seeds in the UK, Wilson (1972) concluded that the main factor ensuring the higher survival of buried seeds was protection from environmental factors. Caged seeds on the surface declined in number and viability at a similar rate to uncaged seeds. In this study environmental factors may have affected viability, though it was not possible to determine if the seeds that did not germinate were non-viable or dormant. Environmental conditions on the soil surface may have caused the increased germination of surface seeds of some species.

Predation of surface seeds was probably by vertebrates and invertebrates. Predators appear to have been selective, avoiding the hard coated seeds. Insects were seen on the cards and bird and rodent droppings were found nearby. The long dry season without soil disturbance may favour invertebrates. Brust and House (1989) found more weed seeds were lost in a soyabean crop in the US established by zero tillage than by conventional tillage, possibly due to less disturbance of invertebrate predators. Losses varied with seed size and larger seeds were more likely to be consumed by rodents and birds and smaller seeds by arthropods.

Cultivation and depth of burial have been shown to influence seed germination of some common weeds of Zimbabwe (Schwerzel and Thomas, 1979; Schwerzel, 1976). One species they tested was *A. hispidum*. They found that the seed lost viability within three years when buried. Seed of *D. ferox* is known to be dormant at harvest and in studies in South America, Soriano *et al.* (1971) found that dormancy was lost more rapidly when the seed was buried than when on the surface or stored dry, though this process takes several years. The seed used in this experiment was still young and mostly dormant, so few seeds germinated, irrespective of where they were placed. Deep burial adversely affects the emergence of many weed species but not all (Schwerzel, 1976).

Losses of soft coated seed were greater from the surface than from the buried cards, and in most cases progressed steadily during the dry season. The greater survival of buried seed was offset by more damage and less likelihood of germination, though this could be due to dormancy rather than loss of viability. Losses of hard coated *D. ferox* and *H. meeusei* seed were low whether left on the surface or buried, nor did they suffer much damage. *I. obscura* seed suffered more loss and more damage when buried. *H. meeusei* and *A. hispidum* may be adapted to a regime of exposure on the surface during the dry season before germinating in moist soil. If the emerging seedlings can be destroyed before planting or prevented from competing with the crop, this could be an effective way of reducing the seed bank. If seedlings are not removed, yield loss from weed competition is likely. On balance, winter ploughing does not appear to conflict with the management of these common annual weeds, and can increase yield and control the perennial grass *Cynodon dactylon* (Phillips, 1993).

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ASSESSING THE POTENTIAL OF HEAD SMUT AS A BIOLOGICAL CONTROL AGENT OF *ROTTBOELLIA COCHINCHINENSIS* USING A SIMPLE MODEL

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ABSTRACT

Modelling techniques offer a rigorous approach to the selection of biological control agents against weeds. They can help to determine both the characteristics required by potential control agents, and how such agents might interact with other methods of weed control. In this paper we describe a model *of Rottboellia cochinchinensis* population dynamics which explores the potential of the head smut *Sporisorium ophiuri* to suppress *R. cochinchinensis* populations. An attempt was made to capture the essential features of the weed-smut interaction but include as little extraneous detail as possible. Analysis of the model indicated that three attributes of the pathogen: spore production rate, infection efficiency and rate of loss of spore viability, were of equal importance in determining pathogen efficacy. A significant feature of the model was that both seed production and smut spore production were dependent upon weed density. This assumption gave rise to a stable weed-pathogen interaction: an important attribute for sustainable control.

INTRODUCTION

Rottboellia cochinchinensis is an increasingly serious weed in the humid tropics, especially in maize, sorghum, rice and sugar cane. The ability of single plants to produce thousands of seeds over one season and the ineffectiveness of herbicides used in maize, combined with a tendency to grow maize on the same land year after year, have resulted in an increasing prevalence of *R. cochinchinensis* (Fisher *et al.*, 1985).

A model was developed which represents the interaction between a plant and a fungal pathogen as a continuous process on a large scale (e.g. district or region). The model is appropriate for plant-pathogen interactions where the healthy and infected plants compete for resources, and a plant, once infected, produces only propagules of the pathogen and no seed. Examples of such pathogens are the monocyclic head smuts which infect the host as a germinating seed. Infected plants grow relatively normally but the seedhead becomes a mass of smut spores. The head smut *Sporisorium ophiuri* has been suggested as a potential biological control agent for *R. cochinchinensis* (Ellison, 1993). We attempt to parametrise the model for the particular case of *R. cochinchinensis* control and determine some of the conditions which are prerequisites for successful implementation.

THE MODEL

Four variables are considered in the model. They are the size of the populations of: healthy weeds, smutted weeds, viable smut spores in the soil, and seeds in the soil. The crop is not included since it is replanted every season by the farmer. The flow chart (Fig. 1) indicates the processes which take place in the model. Four equations define the model; they specify the rates of change of the four variables (Equations 1-4 in Appendix). The model incorporates the following assumptions: 1. The healthy *Rottboellia* population produces seed at a rate proportional to its abundance but constrained to a maximum total weed abundance *i.e.* healthy plus smutted plants; 2. Smutted and healthy plants are assumed to have an equal impact on the density dependent decline in seed production, i.e. they are of equal competitive ability; 3. Healthy plants become smutted at a rate dependent upon their own abundance, and the abundance of smut spores; 4. Healthy and smutted plants have the same death rate, i.e. they are destroyed annually when the crop they inhabit is harvested; 5. Smutted *Rottboellia* produce viable smut spores at a rate proportional to their abundance but constrained to a maximum abundance by the total *Rottboellia* density; 6. Smut spores lose viability at a constant rate; 7. Seeds in the soil seed-bank lose viability at a constant rate; 8. A constant proportion of seeds germinate. The model does not include the effects of continuous growth of *Rottboellia* plants on headlands, or in fallow fields, although this could easily be included by reducing the death rate.

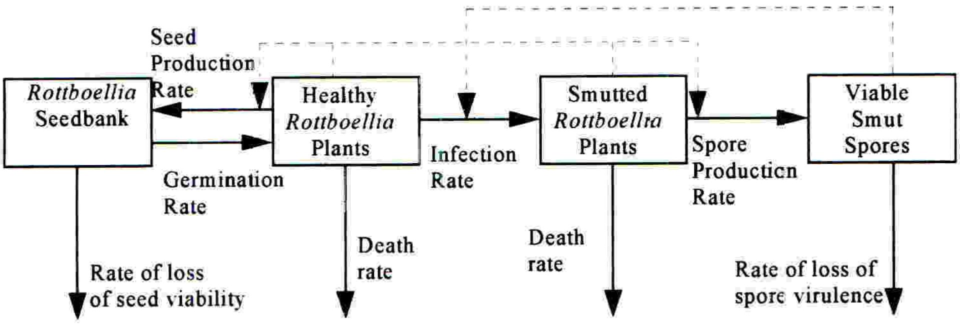

Figure 1. The *Rottboellia*/smut model. Boxes indicate densities of *Rottboellia* plants or viable seeds and viable smut spores. Solid arrows indicate flows between life stages. Dashed arrows indicate that smut spores are necessary for infection, and that total *Rottboellia* density influences the spore and seed production rates.

Initial parameter values for the *Rottboellia* component are derived from the literature (Thomas & Allison, 1975; Thomas, 1970; Fisher *et al.*, 1975); from field observations (R Reeder, Unpublished); and from analyses of all these data (M Smith, Unpublished). Deriving parameter values for the smut component is considerably more difficult. Ellison (1993) describes the smut life cycle, observations on the infection rate obtained from different teliospore concentrations, and initial observations on relative competitiveness of smutted plants. Mwijage (1994) provides an estimate of teliospores produced per whip. No information was available for spore mortality rate so the parameter is initially given the same value as the mortality rate of *Rottboellia* seeds.

Conditions for successful biocontrol

The model was used to define the conditions (in terms of ranges of parameter values) for which acceptable outcomes occur. As a first step, an expression was derived for each of the variables for the situation where the system was at a steady state (the critical points, Appendix). An analysis of these equilibrium values was used as an indication of the likely long-term outcome of the biological control intervention. Numerical analysis of the model using simulations was also used because the behaviour of the system before it reaches a steady state is also important.

Three sets of critical points exist (Appendix) corresponding to three possible outcomes in the weed smut interaction as we model it: (1) the smut does not become established and dies out (also the situation before smut is applied to the system); (2) the weed and smut are able to co-exist; (3) the smut destroys the weed population then itself dies out (reinvasion by the weed from elsewhere may then occur, so eradication may not be sustainable). The second outcome is the one desired for successful biological control, but clearly it is also necessary that the smut suppresses the weed population to a useful degree (e.g. Fig. 2).

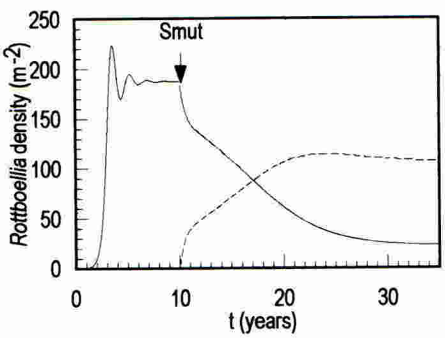

Figure 2. Simulation using the initial parameter values and a small, initial seed bank. The vertical arrow indicates the addition of smut to the system. Solid and dashed lines show the variation in density of healthy and smutted *Rottboellia* plants, respectively, with time. In this case, the total equilibrium density of *Rottboellia* with smut in the system was 128 m^{-2}, compared to 188m^{-2} without.

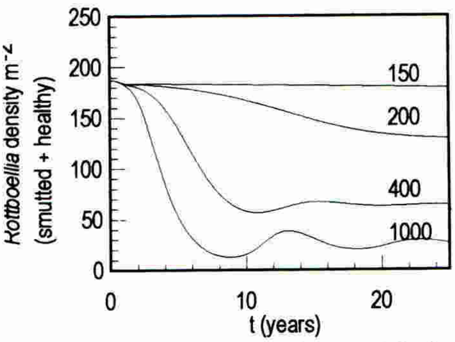

Figure 3. Behaviour of the model for different values of spore production rate (No x 10^{-6} /smutted plant/ year). The initial *Rottboellia* plant and seed bank densities were those predicted at equilibrium with no weed control.

The expression (Equation 5) is the equilibrium density of healthy *Rottboellia* (X^*) derived for outcome (2) where the smut does not establish or was never present. A number of conclusions can be drawn directly from the position of the various parameters in the expression. Weed density, in the absence of smut, is proportional to the carrying capacity parameter (k). Decreasing the ratios of weed fecundity (r) to death rate (b), and seed germination rate (g) to seed mortality rate (m) decrease equilibrium weed density. These conclusions are reasonable, if unsurprising, but it is useful to contrast this situation with the one in which smut is present.

The equations for the equilibrium densities of infected and uninfected *Rottboellia* when both co-exist were complex, but summing to give the total weed density (Equation 6) simplified them considerably. It can be concluded directly from Equation 6 that the three key attributes of the pathogen: spore production rate (*s*), infection efficiency (*p*) and rate of loss of spore viability (*c*), were all of equal importance in determining pathogen efficacy, i.e. total *Rottboellia* density was proportional to spore death rate, and inversely proportional to infection rate and to spore production rate. Of the parameters relating to the attributes of the weed, germination rate (*g*) occurred in both the numerator and denominator of Equation 6. The impact of germination rate was therefore more complex. However, simple proportionality existed with respect to seed production rate (*r*), and inverse proportionality with respect to loss of viability (***m***). It is important to note that neither ***k*** nor ***b*** appeared in Equation 6. The existence of density dependence had a major effect on the extent of population fluctuation after introduction of the pathogen. The very stable behaviour of the present model is illustrated in Fig. 3.

The long-term impact of other weed management options and their interaction with biocontrol was investigated by examining the relative sensitivity of Equations 5 and 6 to changes in parameter values. For example, hand-weeding might be represented by an increase in weed death rate (b). For the situation without biocontrol (Equation 5), weeding clearly reduces *Rottboellia* abundance. For the situation with biocontrol (Equation 6), weeding has no impact on *Rottboellia* abundance. Biocontrol is therefore antagonistic to control options which affect weed death rate because their impact is nullified. Table 1 summarises the impact of interactions with various management options, as represented by changes in specific parameters. Management practices which reduce germination rate would be highly effective in conjunction with biocontrol. Other management practices are unlikely to be effective unless they are selective e.g. reducing seed production but not spore production.

Weeding appears to be ineffective in conjunction with biocontrol, but a more sophisticated treatment with selective weeding could be investigated. In practice weeding often misses *Rottboellia* plants within maize rows, but these would be prevented from setting seed by the smut.

Table 1. Summary of the interaction of various *Rottboellia* management practices with biocontrol

Parameter reduced	Management practice simulated	Interaction with biocontrol
r & *s* by similar proportions	more competitive crop, cover crop, earlier removal of *Rottboellia*	antagonistic; no benefit over biocontrol alone
r or 1/*s*	selective practices	synergistic
1/*b*	weeding, herbicide	antagonistic; no benefit over biocontrol alone
g	cover crop, low tillage	synergistic
1/***m***	?	neutral/synergistic; slight benefit over biocontrol alone, but model is insensitive to increases in ***m***
k	?	antagonistic; no benefit over smut alone, smut is eliminated at low ***k***

DISCUSSION

Analysis of the model revealed that there may be a simple trade off between spore production rate, infection rate, and spore longevity. Effective biocontrol agents may be selected which have a lower infection rate if this is compensated for by higher spore production or longevity. Long-term effectiveness of biocontrol was considerably improved if used in conjunction with methods which reduce *Rottboellia* germination rate, or selectively attack unsmutted *Rottboellia*. Other methods, according to the model, had little long term benefit over biocontrol alone. The issue of effective weed control in an individual crop in a particular season is not considered here. Clearly, methods such as hand weeding can have short-term local impact. The equilibria of this system are very stable. This stability arises from the density dependent processes incorporated in both the smut and weed dynamics. The dual density dependence is also responsible for the simplicity of Equation 6. When, for example, it was assumed that seed production but not spore production was density dependent, a more complicated expression involving both k and b, resulted instead. The implications will be considered elsewhere.

Two major simplifications arise from representation of the system using differential equations: *Rottboellia* population growth and the smut infection are effectively considered as continuous processes. This makes no sense for individual fields but may be reasonable provided that the model is considered as representing processes on a sufficiently large spatial scale. The assumption that smutted and unsmutted weeds are of identical competitive ability may also be questioned. Differences could be easily incorporated however by replacing Y with aY in Equations 3 & 4, where a is a competition coefficient of smutted relative to unsmutted plants.

Searches of the literature revealed little application of modelling approaches to weed biological control. This paper illustrates the ease with which simple analytical models can be used to investigate weed biological control problems.

ACKNOWLEDGEMENTS

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APPENDIX. MODEL EQUATIONS AND THE CRITICAL POINTS.

Table 2. Initial parameter values used in the model

Symbol	Meaning	Units	Values
X	Healthy weed population	No m^{-2}	
Y	Smutted weed population	No m^{-2}	
U	Viable seeds in seed bank	No m^{-2}	
Z	Viable smut spores in soil	No x 10^{-6} m^{-2}	
r	Maximum weed fecundity	Seeds incorporated into seed bank/ plant/ year	80
k	Weed density at which fecundity drops to zero	No m^{-2}	200
p	Infection rate	Proportion of plants infected x 10^6/ spore/ year	$5x10^{-4}$
b	Weed death rate	Proportion/year	1
s	Maximum production rate of viable spores	No x 10^{-6} incorporated into soil/smutted plant/ year	200
c	Spore mortality rate	Proportion/year	0.8
g	Seed germination rate	Proportion/year	0.2
m	Seed mortality rate	Proportion/year	0.8

Equations

$$\frac{dX}{dt} = gU - pZX - bX \quad \text{Eq.1}$$

$$\frac{dY}{dt} = pZX - bY \quad \text{Eq.2}$$

$$\frac{dZ}{dt} = sY(1 - \frac{X+Y}{k}) - cZ \quad \text{Eq.3}$$

$$\frac{dU}{dt} = rX(1 - \frac{Y+X}{k}) - (g+m)U \quad \text{Eq.4}$$

Critical Points (Obtained by simple substitution, with equations 1-4 equal to zero.)

(1) Smut dies out $X^* = k(1 - \frac{b(g+m)}{gr})$ Eq.5; $U^* = \frac{bX^*}{g}$; $Y^* = 0$; $Z^* = 0$

(2) Weed and smut co-exist $X^* = \frac{bck(g+m)}{kps(g+m) - cgr}$; $Y^* = k - X^* - \frac{kps(g+m) - cgr}{ps(g+m)}$;

$$X^* + Y^* = \frac{cgr}{ps(g+m)} \quad \text{Eq.6;}$$

$U^* = \frac{bcr}{ps(g+m)}$; $Z^* = \frac{kps(g+m) - cgr}{cp(g+m)} - \frac{(kps(g+m) - cgr)^2}{cp^2ks(g+m)^2} - \frac{b}{p}$

(3) Both die out $X^* = 0$; $Y^* = 0$; $U^* = 0$; $Z^* = 0$

RESPONSE OF HERBICIDE RESISTANT PHALARIS MINOR TO PRE-AND POST-EMERGENCE HERBICIDES, HERBICIDE MIXTURES AND ADJUVANTS

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ABSTRACT

Reports of the development of resistance in Phalaris minor to isoproturon in India were confirmed using pot experiments. Resistance was more evident following post-em. as compared to pre-em. application of isoproturon. Two resistant (Amin and Lalodha) and one susceptible (Pusa) populations were exposed to pendimethalin, metribuzin, atrazine, diuron and oxyfluorfen applied pre-em. either singly or in combination with isoproturon. All treatments except those involving diuron were highly effective in controlling all the populations of P. minor. There was no evidence of cross resistance to pendimethalin in populations resistant to isoproturon. Of the post-em. herbicides tralkoxydim gave adequate control of resistant P. minor. Diclofop-methyl was not effective at the doses tried (0.4 and 0.6 kg/ha.). Isoproturon +tralkoxydim (0.50+0.20 kg/ha.) did better control than other mixtures. Adjuvant 'Agral' at 0.3 or 0.5% conc. significantly enhanced the activity of isoproturon against the resistant population Lalodha.

INTRODUCTION

A rice-wheat rotation is wide spread on the north-western plains of India. Introduction of high yielding and input-responsive dwarf wheat cultivars in the late 1960's has led to the dominance of little seed canary grass (Phalaris minor) which by middle of 70's posed a great threat to wheat cultivation in this area. Several herbicides, mainly phenyl-ureas such as chlortoluron, isoproturon, metoxuron and methabenzthiazuron were introduced in the late 1970's to control this growing menace (Gill et al.,1979). Isoproturon was widely adopted and has become an important component of weed control in wheat giving satisfactory control of a wide range of weeds including P. minor under varied agro-ecological conditions. However poor performance against P.minor has recently been noticed. The first report of the development of resistance was in Haryana state (Malik et al., 1992). which was found to be more prevalent in the rice-wheat system, where isoproturon has been in continuous use for over 10-12 years (Malik & Singh, 1993). Yaduraju et al., 1995) confirmed the development of resistance in populations collected from Haryana. In this paper, the response of populations of P.minor collected mainly from areas in Haryana state to some pre- and post-em. herbicides, herbicide mixtures and adjuvants is reported.

MATERIALS AND METHODS

A series of pot experiments were conducted during 1994-95 winter season in an outdoor net house, where mean min. and max temperatures were 8.7 and 22.9 ^{0}C during the experimental period. The P. minor seeds used were collected during 1993-94 crop season from different places where resistance to isoproturon was suspected. After preliminary screening (data not reported) it was found that populations from Amin and Lalodha were resistant and Pusa was susceptible which were used in subsequent experiments. Pre-germinated seeds (at 20 ^{0}C for 4 days) were planted at 1 cm deep in plastic pots (10cm inner diameter) containing sandy loam soil and 5 seedlings/pot were maintained after emergence. However, in experiment on pre-em. activity of herbicides, 10 seeds were planted in each pot and the desired dose of herbicides was diluted in water and applied as soil drench at 5 ml/pot, immediately after sowing. In all other experiments, the herbicide treatments were applied at the desired dosage levels in 500 l/ha water using a Knapsack hand operated sprayer when P.minor plants were at 3-4 leaf stage. The pots were watered from above as and when required. The adjuvants,'LI-700'(organo-silicone compound) and 'Agral'(nonylphenol IOEO(ethyloxidide)) were applied at 0.1, 0.3 or 0.5% concn, whereas, 'Codicide' (rapeseed oil) was applied at doses equivalent to doses of isoproturon. Above ground plants fresh weights were assessed at 15-25 days after treatment(DAT). In all experiments the treatments and untreated controls were replicated 3 times.

Petri dish experiment

A petri dish experiment was conducted to study the germination and early seedling development of Amin, Lalodha and Pusa seed stocks when exposed to a range of concentrations of pendimethalin. Twenty five seeds were placed in each 10 cm petri dish containing two Whatman No. 1 filter papers and 8 ml of pendimethalin solution at 0, 0.25, 0.50 1.0, 2.0 or 4.0 mg/l were added. The dishes were placed in a controlled environment cabinet maintained at 20^{o} C with 14 hours light. Each treatment was replicated 3 times. The lengths of the radicle and primary shoot were recorded from 10 representative germinated seeds at 10 DAT. The effective dose for reducing the lengths of shoot and root to 50 % of the untreated (ED_{50}) was calculated as per standard procedure. The ED_{50} values for shoot inhibition were abnormally low and hence only the values for root inhibition are reported.

RESULTS

Pre-em. application of herbicides

All herbicides except diuron and isoproturon applied singly or in mixtures resulted in complete kill of all three populations of P. minor(Table 1). While all the populations appeared equally sensitive to doses of diuron, Amin and Lalodha were more tolerant to isoproturon than Pusa. Similarly combinations of isoproturon and diuron were more effective on Pusa than on the other populations. Wheat was less susceptible to all the herbicide treatments than P.minor.

Table 1. Effect of pre-em. herbicides on foliage fresh weight (as % of control) of P. minor populations and wheat at 25 DAT. Data subjected to arcsin transformation.

Herbicide	Dose (kg/ha)	P.minor populations Amin	Lalodha	Pusa	Wheat
Atrazine	0.25	0	0	0	37.1
Atrazine	0.50	0	0	0	38.0
Diuron	0.25	35.8	21.7	27.3	54.3
Diuron	0.50	25.2	2.4	20.2	49.1
Isoproturon	0.50	48.9	31.4	4.3	NT
Isoproturon	0.75	43.1	25.0	0	40.2
Isoproturon	1.50	31.7	7.3	0	31.2
Metribuzin	0.20	0	0	0	67.6
Metribuzin	0.40	0	0	0	22.2
Oxyfluorfen	0.125	0	0	0	41.9
Oxyfluorfen	0.250	0	0	0	43.1
Pendimethalin	0.75	0	0	0	56.1
Pendimethalin	1.50	0	0	0	51.6
Isoproturon + atrazine	0.75 +0.25	0	0	0	46.9
Isoproturon + diuron	0.75 +0.25	26.3	10.1	0	37.0
Isoproturon + metribuzin	0.75 +0.20	0	0	0	29.1
Isoproturon + oxyfluorfen	0.75 +0.125	0	0	0	33.8
Isoproturon + pendimethalin	0.75 +0.75	0	0	0	52.0
Untreated control		90.0 (0.545)*	90.0 (0.945)	90.0 (0.690)	90.0 (2.51)
SED		5.6	3.2	2.4	5.4

* Foliage fresh weight in g/pot. NT- Not tested

Effect of post-em. herbicide mixtures

Of the herbicide mixtures tried, only isoproturon + bifenox and isoproturon + tralkoxydim gave significantly lower fresh weights of herbicide resistant P. minor than the untreated control (Table 2). Single application of isoproturon or tralkoxydim also reduced the P. minor fresh weight significantly. None of the treatments, however was significantly superior to isoproturon. Tralkoxydim at 0.30 kg/ha was the best treatment with about 60 % reduction in growth.

Table 2. Response of *P.minor* (Lalodha) at 17 DAT to herbicide mixtures applied post-emergence.

	Dose (Kg/ha)	Plant ht. (cm)	Fresh wt. (g/pot)
Isoproturon + 2,4-D *	0.75+ 0.187	27.9	3.68
Isoproturon + bifenox *	0.75+ 0.375	32.6	3.28
Isoproturon + diflufenican*	0.75+ 0.075	30.2	3.80
Isoproturon + difenzoquat*	0.375+0.375	25.8	3.78
Isoproturon + 2,4-D	0.75+ 0.237	23.4	3.81
Isoproturon + naproanilide	0.75+ 0.237	30.4	4.45
Isoproturon + tralkoxydim	0.50+ 0.20	15.8	2.72
Isoproturon + diclofopmethyl	0.50+ 0.30	28.4	3.90
Isoproturon	0.750	25.5	2.89
Tralkoxydim	0.30	18.1	1.92
Diclofop-methyl	0.60	22.5	3.98
Untreated control	-	27.9	4.89
LSD at 5%			1.23

* Ready-mix formulations, rest are tank mixes.

Effect of adjuvants

Isoproturon at 0.75 kg/ha with 'Agral' at 0.1, 0.3 or 0.5 % reduced the foliage fresh weight significantly over isoproturon alone(Table 3). At 1.50 kg/ha, there were further reductions in fresh weight but the differences were not statistically significant. Isoproturon with surfactant 'LI-700' or 'Codicide' did not have any additional advantage over isoproturon alone. 'Agral' alone at 0.3 % reduced the fresh weight significantly as compared to untreated control.

Table 3. Effect of adjuvants on the foliage fresh weight (g/pot) of herbicide-resistant *P .minor* (Lalodha) at 20 DAT.

Adjuvant	Concn.	Isoproturon (kg/ha) 0	0.75	1.50
No adjuvant	-	4.50	3.40	1.46
'LI-700'	0.1%	4.64	2.27	2.40
'LI-700'	0.3%	4.27	3.17	1.08
'LI-700'	0.5%	4.22	2.50	2.32
'Agral'	0.1%	4.02	2.20	1.45
'Agral'	0.3%	3.97	0.52	0.44
'Agral'	0.5%	3.05	0.61	0.62
'Codicide'		4.00**	3.51*	1.88*
LSD (at 5%)		1.35		

* The concentration was equivalent to isoproturon dose in kg/ha
** Mean of 'Codicide' at 0.75 and 1.50 kg/ha.

Cross resistance to pendimethalin

The response of Amin, Lalodha and Pusa to pendimethalin was similar(Table 4). However the computed ED_{50} values showed that Lalodha recorded higher values (0.357 mg/l) than either Amin (0.136 mg/l) or Pusa (0.106 mg/l).

Table 4. Effect of pendimethalin on radicle length (mm) of P.minor populations at 10 DAT.

	Pendimethalin (mg/l)						ED_{50} (mg\l)
	0	0.25	0.50	1.00	2.00	4.00	
Amin	53.1	27.0	9.3	7.2	5.4	4.3	0.136
Lalodha	40.7	29.1	10.3	9.1	5.0	4.8	0.357
Pusa	44.5	20.3	7.3	7.1	3.3	3.3	0.106
SED	1.8	1.6	0.8	0.6	1.0	0.6	

DISCUSSION

The results obtained in this paper confirm the findings already made with respect to the development of resistance in P. minor to isoproturon (Malik & Singh,1993; Malik et al., 1992; Yaduraju et al., 1995). Populations from Amin and Lalodha showed high levels of resistance. The ED_{50} of isoproturon in these were at least 4-6 times higher than the susceptible population Pusa. The susceptibility of herbicide resistant P.minor to several pre-em. herbicides provides an alternative control strategy although except for pendimethalin, the field selectivity of other herbicides in wheat is questionable. Pendimethalin may not be an effective alternative,however, as field performance against P. minor was found to be inconsistent (Malik & Singh, 1993). Its effect on Avena ludoviciana- another major grass weed in wheat was also poor (Yaduraju and Ahuja, 1993). It is worth testing combination of some of these pre-em. herbicides in field at low doses with isoproturon as wheat posses better tolerance to some of these herbicides . Post-em. application of combinations of herbicides as ready-mix or tank-mix was not promising (Table 2), except for tralkoxydim applied either singly or in combination with isoproturon. The ability of tralkoxydim to control P.minor and A. ludoviciana has been well documented (Yaduraju et al.,1992; Malik & Singh, 1993) but its narrow spectrum of weed control is a matter of concern. The performance of diclofop-methyl was found poor in the present studies probably because of lower dosages tried, as satisfactory control of P.minor has been reported at 1-2kg/ha by Malik & Singh (1993) in areas where isoproturon had failed. However, Clarke & Moss (1991) discourage the use of members of aryloxyphenoxypropionate and cyclohexanedione groups due to the potential risk of rapid development of resistance in grasses to these herbicides.

Amongst the adjuvants, 'Agral' at concentrations of 0.3 or 0.5% gave on an average about 90% weed control when applied with isoproturon at 0.75 kg/ha as against 25% with herbicide alone. Further trials with this surfactant are however, necessary to confirm its suitability for field use in wheat.

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THE EFFECT OF SILWET L-77 OR FENOXAPROP-P-ETHYL ON THE EFFICACY OF ISOPROTURON APPLIED TO ISOPROTURON RESISTANT *PHALARIS MINOR*

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ABSTRACT

The continuous use of isoproturon for more than a decade has resulted in the evolution of resistant biotypes of *Phalaris minor* in India. The biotypes vary greatly in the extent of resistance and are a serious threat to the efficiency of wheat production in the affected areas. The use of surfactants and mixtures of herbicides with different modes of action has been postulated to delay the onset of resistance and to enhance herbicide activity; the lower dose rates possible would be desirable from both economic and environmental view points. In this paper the results of studies conducted under controlled growth conditions using isoproturon and fenoxaprop-P-ethyl, either alone or with the non-ionic surfactant ('Silwet L-77', 0.05%) and/or as a tank mixture (1:1 ratio) are presented. Experiments were repeated twice using wheat and susceptible (S), pristine (PR) and resistant (R) biotypes of *P. minor*. Addition of surfactant to isoproturon greatly enhanced its activity against PR (PR-1) and S (H-2) biotypes of *Phalaris*, but had little effect on the R (KR-1) biotype; wheat was damaged at higher doses. The addition of surfactant had no significant effect on the activity of fenoxaprop-P-methyl. The tank mixture of isoproturon and fenoxaprop-P-ethyl was more effective than application of either alone but the effect was more pronounced on the S as compared to R biotypes, but can be used to control the R biotype effectively. The results require confirmation under field conditions.

INTRODUCTION

Phalaris minor (Littleseed canarygrass), a dominant grass weed of wheat in India, has evolved resistance to isoproturon due to high selection pressure exerted by the use of a single herbicide over the last 10-15 years in a rice-wheat cropping sequence (Singh *et al.*,1993, 1995a, 1995b; Malik and Singh, 1993, 1994, 1995). The R biotypes require >10 times higher dose for the same level of control compared to the S biotypes (Singh *et al.*,1995a). Wheat is not tolerant to these high dose rates. Preliminary evaluation of a range of graminicides indicated no cross-resistance with dinitroanilines, triazines, aryloxyphenoxypropionates (except perhaps with diclofop-methyl), cyclohexanediones and chloroacetamides. Fenoxaprop-P-ethyl was one of the most effective graminicides, providing very good control of R and S biotypes, though with some crop injury at higher dose rates (Singh *et al.*; 1995a). A biotype of *P. minor* from Israel has also been reported to be highly resistant to fenoxaprop+S with an R/S ratio of 75.0 (Zarka and Rubin, 1995).

Several strategies have been postulated to maximise herbicide efficiency and delay or prevent the evolution of resistance; these include the use of herbicide rotations and mixtures (Gressel 1990, 1991; Gressel and Segel, 1990; Wrubel and Gressel, 1994). The use of herbicide mixtures is increasing and changing rapidly with the addition of new compounds. Herbicide use has evolved from very high rates of single herbicides to low rates of three, four, and five-way mixtures with one or two adjuvants incorporated which vary according to weed spectrum and environmental conditions (Green 1989). The judicious use of lower herbicide rates, tank mixed with surfactant or other herbicides, coupled with intelligent agronomy has enhanced the activity and increased the spectrum of weed kill without reducing crop yields (Singh and Malik, 1989). Such approaches enable savings in herbicide costs and are regarded as environmentally friendly. Heterologous mixtures of herbicides which act at different sites have many desirable effects. For a mixture to be effective in preventing resistance it should at least be able to act on the same weed spectrum, have a similar persistence level, different target sites and mode of degradation and preferably exert negative cross-resistance (Wrubel and Gressel, 1994). Ideally, it is desirable to select herbicide combinations that have synergistic effects on weeds or antagonistic effects on crops (Zhang *et al.*, 1995). Not all herbicides mixtures can be classified as such (Gressel, 1991) since, generally, interactions between herbicides have been found to be more frequently antagonistic than synergistic (Zhang et al., 1995). The present experiments were conducted to evaluate the effect of i) the non ionic surfactant 'Silwet L-77' (0.05%) tank mixed with isoproturon or fenoxaprop-P-ethyl and ii) the effect of a combination of isoproturon and fenoxaprop-P-methyl against R, S and PR biotypes of *P. minor* and on wheat.

MATERIALS AND METHODS

Pot experiments were conducted during 1994 and 1995 under controlled environmental conditions at Strathclyde University, Glasgow. Seeds of a range of *P. minor* biotypes had been collected from Haryana State, India during 1991, 1992 and 1994; these included the test biotypes H-2 (S), KR-1 (R) and PR-1 (PR). The KR-1 was collected from farmers fields where isoproturon had been continuously used for 12-15 years, with diminishing efficiency of control. H-2 was collected from research plots within Haryana Agricultural University, Hisar where herbicides and crops are rotated continuously and PR-1, a wild type, was collected from fields with no history of herbicide use. Plants were raised in John Innes No. 2 compost in a greenhouse (22±3^{0}C and 15±3^{0}C day and night temp., respectively) in 9 cm polystyrene pots. The pots were thinned one week after emergence to maintain 6-7 plants. In order to have the same growth stage at spraying, wheat (cv. WH-147) was sown 7-10 days after *P. minor*.

Plants were sprayed with isoproturon ('Sabre', 55.3% SC) or fenoxaprop-P-ethyl ('Cheetah Super' 5.5% EW) at 0, 0125, 0.25, 0.50, 1.0, 2.0 and 4.0 kg a.i./ha alone or in tank mixture with 'Silwet L-77' (an organosilicone surfactant) at 0.05%. A tank mixture (1:1 ratio) of isoproturon and fenoxaprop-P-ethyl was also compared at 0.0625+0.0625, 0.125+0.125, 0.25+0.25, 0.50+0.50, 1.0+1.0 and 2.0+2.0 kg a.i./ha with a treatment of 'Silwet L-77' (0.05%.) alone. Plants were sprayed at the 2-3 true leaf stage of wheat and *Phalaris* species using a motorised track sprayer fitted with a flat fan even spray nozzle ('Lurmark') at 270 kPa pressure using 400 litres water/ha. After spraying pots were arranged in a completely randomised block design with three replicates in a growth room (24±3/18±3^{0}C day/night temp. and 80/60 RH) with a photoperiod of 14 h by fluorescent lamp (6,000 lux intensity). Plants were watered as necessary. Treatments were assessed visually and mortality of crop and weeds was recorded on a 0-100 scale (0=no effect and 100=complete mortality) at harvest, 21 days after treatment. Fresh and dry weights of 5 plants per pot were recorded and a single plant of each biotype for each dose replicates was subjected to membrane leakage bioassay (Fletcher and Drexler, 1980). The membrane leakage depicts the enhanced leakage of ions from plant cells as a result of herbicidal damage. The cell conductivity or membrane leakage is derived as:

$$Percent\ membrane\ leakage = \frac{[ion]\ before\ boiling - [ion]\ water}{[ion]\ after\ boiling - [ion]\ water}\ x\ 100$$

The experiment was repeated at least twice except with the PR-1 biotype as there was no difference between susceptible and pristine biotypes. The results for dry weight were expressed as percent of controls. The percent data for dry weight, visual mortality and membrane leakage results were transformed to arcsins and analysed using analysis of variance. The interaction tables showing the combined effects of all doses against species are presented. Results for the average fresh weight/plant were plotted in graphs.

RESULTS

Effect on fresh and dry weight

Significant reductions in the fresh weight of the S biotype of *P. minor* were recorded with isoproturon at 0.50 kg a.i/ha and above, but it had no effect on the KR-1 biotype except at 4.0 kg a.i./ha (Figure 1). Wheat was damaged at concentrations above 2.0 kg a.i./ha. Surfactant incorporation greatly enhanced the reduction in fresh weight compared with isoproturon alone both in *P. minor* (S) and wheat but KR-1 was relatively unaffected. Fenoxaprop-P-ethyl was quite effective on both S and R biotypes but no difference was observed with the addition of surfactant (Figure 2). The mixture of isoproturon and fenoxaprop-P-ethyl greatly reduced the fresh weight of all biotypes of *P. minor*; the reduction in fresh weight of wheat was also increased significantly with the mixture compared with single applications (Figure 3).

The addition of surfactant to isoproturon significantly reduced the dry weight of H-2 and PR-1 biotypes of *P. minor* and wheat but not KR-1 (Table 1). Significantly lower dry weights were recorded with the mixture of isoproturon and fenoxaprop-P-ethyl of all the biotypes compared with isoproturon, the effect being more pronounced on the H-2 and PR-1 than KR-1. The dry weight of wheat was little affected except in case of isoproturon tank mixed with surfactant.

Table 1. Effect of isoproturon, alone or in mixture with Silwet L-77 or fenoxaprop-P-ethyl on the dry weight of *P. minor* biotypes and wheat at 21 days following application (arcsin transformed values)

	Dry weight reduction (% of control)				
Species	IPU	IPU +S	FNP	FNP+S	IPU+FNP
H-2	50.92	37.53	52.59	51.70	41.72
KR-1	80.99	74.61	56.37	54.40	53.23
PR-1	58.40	36.95	47.78	48.45	43.63
Wheat	63.68	55.05	65.06	62.92	62.82
LSD at 5%			7.27		

IPU=isoproturon, IPU+S=isoproturon+surfactant, FNP=fenoxaprop-P-ethyl

Effect on membrane leakage

The addition of 'Silwet L-77' to isoproturon greatly increased ion leakage in the PR-1 and H-2 biotypes but not in KR-1 (Table 3). The effect was similar in all biotypes with fenoxaprop-p-ethyl with or without surfactant. The mixture of isoproturon and fenoxaprop-P-ethyl increased membrane damage compared to fenoxaprop-P-ethyl in H-2 and PR-1 but not in KR-1. The higher values in case of wheat with all herbicidal treatments were due to its greater foliage weight as the values were 4-5 times more in control treatments compared to *P. minor* biotypes.

Table 2. Effect of isoproturon, alone or in mixture with Silwet L-77 or fenoxaprop-P-ethyl on membrane leakage of *P. minor* biotypes and wheat at 21 days following application (arcsin transformed values).

	% Membrane leakage				
Species	IPU	IPU +S	FNP	FNP+S	IPU+FNP
H-2	35.01	44.61	24.54	25.33	42.90
KR-1	11.42	10.65	27.74	29.38	29.07
PR-1	26.74	41.35	28.77	30.83	39.46
Wheat	31.35	39.17	26.82	31.11	33.15
LSD at 5%			10.56		

IPU=isoproturon, IPU+S=isoproturon+surfactant, FNP=fenoxaprop-P-ethyl

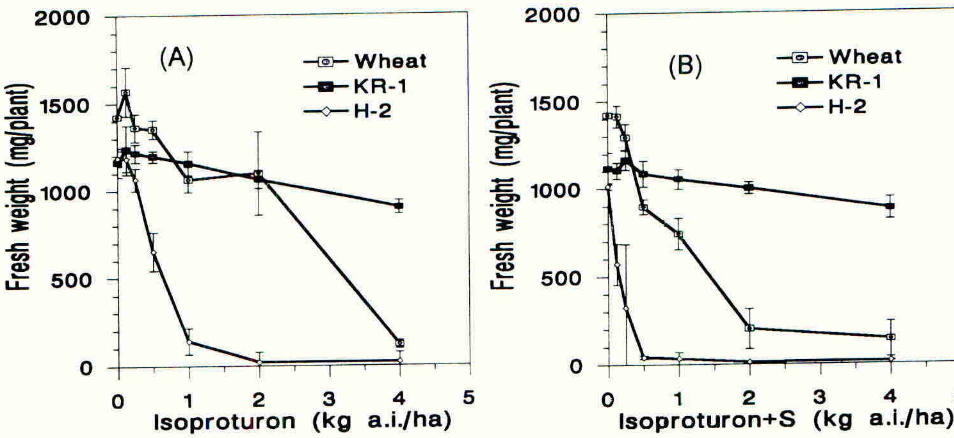

Figure 1. Effect isoproturon alone (A), plus surfactant (B) on fresh weight of different species 21 days following application at the 2-3 leaf stage (bars indicates S.D.)

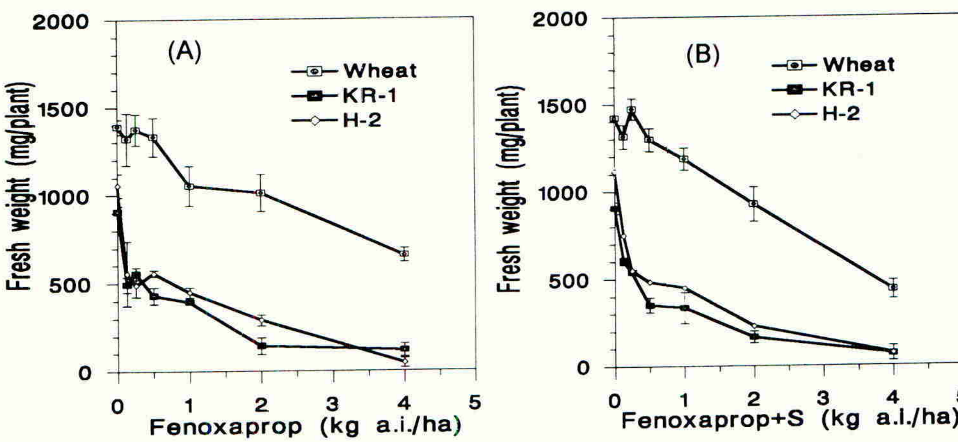

Figure 2. Effect of fenoxaprop alone (A) plus surfactant (B) on fresh weight of different species 21 days following application at the 2-3 leaf stage (bars indicates S.D)

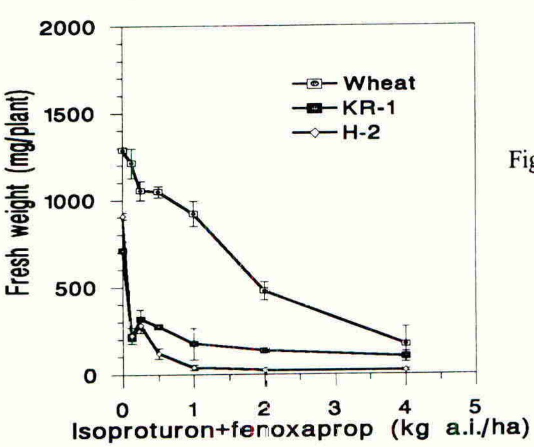

Figure 3. Effect of mixture of isoproturon and fenoxaprop on fresh weight of different species at 21 days following application at the 2-3 leaf stage (bars indicates S.D.)

Visual mortality

Visual mortality was significantly increased with the addition of 'Silwet L-77' to isoproturon in the case of the H-2 and PR-1 biotypes but not with KR-1 (Table 3). The effect of fenoxaprop-P-ethyl alone or with surfactant was similar in all biotypes, whereas tank mixture of isoproturon and fenoxaprop-P-ethyl provided significantly higher mortality in H-2 and PR-1 biotypes but the effect of mixture was less with KR-1 biotype.

Table 3. Effect of isoproturon, alone or in mixture with Silwet L-77 or fenoxaprop-P-ethyl on visual mortality of *P. minor* biotypes and wheat (arcsin transformed values).

	% visual mortality				
Species	IPU	IPU +S	FNP	FNP+S	IPU+FNP
H-2	34.70	58.39	41.62	38.31	56.42
KR-1	0.88	0.88	37.15	39.53	45.32
PR-1	33.92	62.55	37.83	39.65	56.48
Wheat	11.07	25.51	5.27	6.84	16.36
LSD at 5%			8.97		

IPU=isoproturon, IPU+S=isoproturon+surfactant, FNP=fenoxaprop-P-ethyl

DISCUSSION

The activity of isoproturon was greatly enhanced by addition of 'Silwet L-77' (0.05%) against susceptible (H-2), pristine (PR-1) biotypes of *P. minor* and wheat as was evident from all of the parameters recorded; the resistant biotype (KR-1) however, was not affected by isoproturon with or without surfactant. Surfactant treatment alone had no adverse effect on either species (data not shown). Wheat was significantly damaged by addition of surfactant to isoproturon at higher doses but KR-1 was more tolerant than the crop. The higher degree of resistance to isoproturon in the KR-1 biotype appears to be due to greater detoxification of the herbicide as no target site alteration has been recorded (Singh *et al.*, 1995b). Enhanced detoxification of chlorotoluron by resistant biotypes of *Alopecurus myosuroides* and *Lolium rigidum* has been reported (Moss 1990; Burnet *et al.*, 1993).

Fenoxaprop-P-ethyl significantly controlled R and S biotypes of *P. minor* and was relatively safe to wheat. The selectivity in wheat to fenoxaprop-P-ethyl seems to be due to greater metabolism by conjugation with glutathion s-transferase which is further converted to more polar metabolites (Tal *et al.*, 1993). It has been shown that the amounts of glutathion and cystein are higher in tolerant wheat than susceptible grass weeds (Tal *et al.*, 1995). The mixture of isoproturon and fenoxaprop-P-ethyl was not found to greatly improve control of the isoproturon resistant KR-1 biotype, though both have different target sites. It may possibly be used as a temporary control measure since the activity of mixture is greater than the application of either alone; in the worst affected areas where isoproturon has been de-registered, the mixture may provide an acceptable control. However, it requires further investigation under field conditions before a general recommendation can be made for use by farmers.

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STRATEGY FOR WEED CONTROL IN CITRUS ROWS AND INTER-ROWS WITH THE USE OF FULL AND REDUCED DOSES OF HERBICIDE

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ABSTRACT

Chemical weed control in citrus is normally limited to the tree rows, while mechanical cultivation is used in the inter-rows. The present work discusses the possibility of using glyphosate and sulphosate at full recommended dose for application to the rows, and replacing mechanical cultivation by the application of reduced doses of the same products between the rows. For the control of more difficult weeds, such as *P. maximum* and *D. insularis*, the application of total dose (recommended) in the inter-rows was studied. The results show that the integrated system permitted a good level of control and that it can reduce application costs, besides presenting the advantage of eliminating or reducing mechanical cultivation.

INTRODUCTION

Chemical weed control in citrus is normal practice in many producing regions in the world (Lange *et al*., 1975). Today, as a consequence of the scarce and costly manual labor in Brazil, new methods of weed control are necessary to solve the problem for the citrus producer. (Marcondes *et al*., 1987). Blanco & Oliveira (1978) explain that the critical period for competition is from August to November or from December to March. However, the best period to control weeds is from December to March (due to the rainy season and also because of the good development of weeds); there are no losses due to competition, and there is a decrease both of annual grasses and annual and perennial dicots, effects that do not occur to full extent when the control is made during the other seasons. According to Andersen (1966), the soil should be covered during the rainy season and must remain free of weeds during the dry season. For that reason, chemical control is recommended only in the bands of 4.0 m width along the rows, while the inter-rows are slashed during the rainy season (rainfall of 1250 to 1500 mm per year, being 70 to 80% during this period) to reduce erosion and ploughed when it is safe to do so during the dry season. This method results in a good level of weed control and is also economically viable.

This work aimed to compare the efficacy of sulphosate and glyphosate herbicides applied in the rows and reduced doses of these, or paraquat+diuron, or mechanical cultivation applied to the inter-rows.

Traditional tillage systems

Until recent years, citrus producers used manual cultivation in the rows and mechanical cultivation between rows. The application of the recommended dose (total dose of glyphosate or paraquat of 2.0 l/ha) is made by tractor sprayer equipped with a protected side bar covering a band of 2.0 m width; in the round trip it covers the two bands along the citrus rows. The central band - inter-row - is controlled through mechanical cultivation requiring from one to three passes of the tractor (depending on its cutting width).

Durigan (1985) proposed the hipothesis that the excessive mechanical control, by cutting the roots (resulting in waste of energy to form them again) and the lack of an hibernal period (resting period and reorganisation of the cycle) would be the main cause for the short useful life of the plants that constitute our orchards. Besides, the mechanical cultivation can expose the plants to the occurrence of *Phytophothora gummosi*, an important fungal disease attacking citrus.

Integrated system

Foloni (1988) proposed a specific type of equipment that permitted the application of differentiated doses of glyphosate in the rows and inter-rows of the crop, replacing or reducing mechanical operations in the inter-rows. Basically, the system permitted the application of full dose in the rows and reduced dose in the inter-rows. This system presents an economical advantage just considering the direct costs, without considering the costs involved in equipment, repair, etc. The purpose of this work was to integrate glyphosate, sulphosate and paraquat+diuron into the system.

MATERIALS AND METHODS

The trial was conducted in São Paulo State, the biggest citrus producing region in Brazil; the variety was Valência, planted in 1989, at a spacing of 4.0 x 8.0 m. Soil type is Haplorthox, with organic matter 1.7% and pH 5.8. The experimental design was randomised blocks with 4 replicates, each plot containing 10 plants. Treatments (Table 1) were made at delayed post-emergence, with a band of 2.0 m on each side of the citrus row and another of approximately 4.0 m in the inter-rows.

Table 1. Tested treatments in citrus rows and inter-rows

	Row		Inter-row	
N° of treatment	Product	Dose kg a.i./ha	Product	Dose kg a.i./ha
1	Sulphosate	0.96	Mechanical cultivation	-
2	Glyphosate	0.96	Mechanical cultivation	-
3	Sulphosate	0.96	Sulphosate	0.36
4	Glyphosate	0.96	Glyphosate	0.36
5	Sulphosate	0.96	Paraquat+diuron	0.40+0.20
6	Glyphosate	0.96	Paraquat+diuron	0.40+0.20

Weed infestation

Weeds infesting the experimental area were divided into two communities: those infesting citrus rows (first figure) and those infesting the inter-rows (second figure): *Cenchrus echinatus* (25%, 20%); *Digitaria horizontalis* (20%, 5%); *Digitaria insularis*

(2%, 0), *Panicum maximum* (3%, 15%), *Commelina benghalensis* (10%, 5%), *Brachiaria decumbens* (15%, 40%), *Portulaca oleracea* (3%, 1%), *Amaranthus viridis* (2%, 0), *Sida cordifolia* (15%, 5%), *Bidens pilosa* (5%, 3%), from 26 to 75 cm tall.

Application and evaluations

The herbicides were applied in December, 1994, through CO_2 sprayer operating at a pressure of 2.78 bar, equipped with 4 Spraying Systems nozzles XR 110.03, at the rate of 185 l/ha. Evaluations were made by visual scoring at 15, 30 and 45 DAT (days after treatment). Zero equals no control, 100% total death.

RESULTS AND DISCUSSION

The results are sumarized in Tables 2 and 3. The control data for the three main weeds occurring in the rows are shown in Table 2 and inter-rows in Table 3.

Table 2. Percentage control observed at 15, 30 and 45 DAT in the rows.

Treat ments	% of control *Cenchrus*			*Digitaria*			*Commelina*		
(DAT)	15	30	45	15	30	45	15	30	45
1	100.0	100.0	90.0	98.7	98.7	85.0	60.0	52.5	45.0
2	100.0	100.0	90.0	98.7	98.7	83.7	60.0	50.0	42.5
3	100.0	100.0	95.0	100.0	100.0	85.0	65.0	53.7	35.0
4	100.0	100.0	95.0	100.0	100.0	85.0	65.0	55.0	30.0
5	100.0	100.0	95.0	100.0	100.0	82.5	65.0	50.0	30.0
6	99.5	98.7	85.0	100.0	100.0	82.5	60.0	50.0	30.0
F	1.0 NS	1.0 NS	2.4 **	0.80 NS	0.80 NS	0.50 NS	1.08 NS	2.43 NS	3.79 *
CV%	0.41	1.02	1.82	0.29	1.45	4.15	8.43	5.45	19.69
DMS	0.918	2.296	3.750	0.649	3.247	7.844	11.858	6.358	15.687

In general, sulphosate and glyphosate herbicides resulted in a good level of control of *C. echinatus*, *D. horizontalis*, *B. decumbens* and *S. cordifolia*, but in insufficient control for *C. benghalensis* in the rows.

Reduced doses of sulphosate and glyphosate provided good control of *C. echinatus*, *B. decumbens* and *P. maximum*, which were present between the rows, when compared to mechanical cultivation, allowing a longer period of time between mechanical cultivations.

Inter-row application of a formulation mixture of paraquat+diuron gave an excellent level of control of the weeds, especially *P. maximum*.

Table 3. Percentage control observed at 15, 30 and 45 DAT in the inter-rows.

Treat ments	% of control								
	Cenchrus			*Brachiaria*			*Panicum*		
(DAT)	15	30	45	15	30	45	15	30	45
1	60.0	40.0	30.0	75.0	57.5	30.0	50.0	10.0	0.0
2	60.0	40.0	30.0	75.0	55.0	35.0	50.0	10.0	0.0
3	80.0	65.0	50.0	81.2	70.0	60.0	62.5	47.5	27.5
4	85.0	65.0	42.5	96.2	70.0	50.0	62.5	47.5	27.5
5	100.0	100.0	60.0	100.0	100.0	85.0	100.0	90.0	90.0
6	100.0	100.0	60.0	100.0	100.0	85.0	100.0	90.0	90.0
F	66.69 **	261.6 **	48.7 **	37.04 **	77.0 **	58.3 **	408.2 **	461.4 **	816.8 **
CV%	5.46	4.88	8.61	4.55	6.05	10.85	3.19	6.78	7.370
DMS	9.922	7.50	8.79	8.992	10.269	14.03	5.136	7.50	6.49

The results show the possibility of using herbicides in the rows (at full dose) and in inter-rows (at reduced or full dose, depending on the weed) resulting in a good level of control; less mechanical cultivations are required depending on the adaptation of the existing equipment, reducing the costs involved in the treatment.

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