DISCUSSION

The demonstration of the potential of *Desmodium* spp. in the control of the witchweed *S. hermonthica* has opened the possibility of new practical control methods commensurate with East African subsistence farming practices (Khan *et al.*, 2000). The use of *Desmodium* species in controlling parasitic witchweeds shows particular promise in mixed farming systems. This finding stimulated the further investigation into the mode of action, of which a number of possible mechanisms were considered: increasing the available nitrogen, offering shade or an allelopathic effect, all of which are known to give some control of witchweeds (Press and Gurney, 2000). In the field, nitrogen, shading and the combination of nitrogen and shading all significantly suppressed *S. hermonthica* emergence, but maximum *S. hermonthica* suppression was provided by *D. uncinatun* and the combined *D. uncinatum* and nitrogen treatment. Although there are benefits from nitrogen and shading on suppression of *S. hermonthica* and the growth of maize, the field data and the associated laboratory pot experiments clearly demonstrated an additional allelopathic effect associated with *D. uncinatum*. Investigation of the possible allelopathic mechanisms provided a clear demonstration that factors associated with *D. uncinatum* roots are responsible for suppression of *S. hermonthica* infestation. The demonstration that an allelopathic mechanism is involved in parasite suppression demands that the compounds released from *Desmodium* spp. be identified, and work is ongoing in this direction. This may give more exploitable leads, which are needed not only in subsistence agriculture but also to answer future world demands in agricultural production and in developing new approaches for molecular biology in weed control (Gressel, 2000).

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The contribution of zero tillage for the management of *Phalaris minor* in the Indian rice-wheat system

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ABSTRACT

The current epidemic of *Phalaris minor* in the rice-wheat system in northern India threatens wheat production across a large geographic area, affecting the livelihoods of millions of people. Development of resistance against the widely used herbicide isoproturon highlighted the vulnerability of the rice-wheat cropping system and the need for an integrated weed management strategy to reduce the ecological niche in which *P. minor* flourishes and ensure long-term sustainability of food production. Zero tillage may contribute to *P. minor* management as it gives, under northern Indian conditions, a reduction in grassy weed pressure. A field experiment was conducted to develop an understanding of the mechanism by which zero tillage affects the life cycle of *P. minor*. Results showed that zero tillage gives a reduction in emergence rate which cannot be solely attributed to differences in soil seed density or relative distribution of seeds through the soil profile. Variation in moisture levels and dormancy state between the two tillage systems are also likely to be involved in regulating *P. minor* emergence rate.

INTRODUCTION

The rice-wheat system on the fertile Indo-Gangetic plains is a highly productive cropping system taking a vital place in India's food grain production. The grassy weed *Phalaris minor* is, however, a major constraint for wheat production in winter, infesting more than 16 million ha of wheat in northern India. After germinating in multiple flushes, *P. minor* grows vigorously and shows prolific reproductive behaviour. Consequently, the weed is highly competitive with wheat and yield losses up to 50% due to *P. minor* are not uncommon (Singh *et al.*, 1999).

The problem of *P. minor* control dramatically worsened in the early 1990s when the weed developed resistance against the widely used herbicide isoproturon in areas of Haryana and Punjab. Three herbicides with alternative modes of action against *P. minor*, sulfosulfuron, fenoxaprop-P-ethyl and clodinafop-propargyl, have replaced isoproturon in the areas hit by resistance and as a result, weed control has improved. Since *P. minor* biotypes in Israel have developed resistance against the herbicide fenoxaprop-P-ethyl (Tal *et al.*, 1996) and isoproturon-resistant biotypes show cross resistance against diclofop-methyl (Malik & Singh, 1993), the chances of cross-resistance or the development of new resistance against one of the alternative herbicides should be taken seriously. Therefore, the introduction of new herbicides alone is not a long-term solution for the *P. minor* epidemic. Alternative weed control methods should be included to develop an integrated weed management strategy to tackle the driving variables behind the *P. minor* epidemic (Yaduraju, 1999).

Zero tillage: a rational approach?

Zero tillage is a soil cultivation technique that may assist in the development of an integrated weed management strategy. In areas outside India, studies have shown that tillage regime affects weed species composition and depth distribution of seeds in the soil (Yenish *et al.*, 1992; Clements *et al.*, 1996). Tillage regime also affects conditions for seed germination through changes in soil microenvironment due to differences in soil porosity, bulk density, soil surface conditions, pH and microbial activity (Lal *et al.*, 1994).

However, the effect of zero-till in winter crop wheat in northern India cannot be easily predicted from experience with zero-till in other areas due to the tillage operations associated with the summer rice cultivation. Initially, the strategy behind the introduction of zero-till in northern India was that farmers could save labour and soil cultivation costs and thereby, purchase more expensive, effective herbicides to control *P. minor*. Interestingly, three year's experience with zero till in the Indian rice-wheat system showed that it results in a decrease in grassy weed pressure, in particular *P. minor* (R K Malik, pers. comm.). This weed control effect is now an equally important motivation behind the rapid adoption of zero-till as savings in labour and cultivation costs.

The mechanisms behind the observed reduction in *P. minor* densities in fields under zero till are not well understood. One possible explanation is related to the sowing time of wheat. As farmers practising zero till avoid extensive soil cultivation operations, they manage to sow wheat one to two weeks earlier than conventional farmers. Early in the season, soil temperatures are above the optimum for *P. minor* germination, giving wheat one or two weeks extra time to establish before *P. minor* seedlings begin to emerge (Mehra & Gill, 1988; Chhokar & Malik, 1999).

With the objective to improve the understanding of the mechanisms behind the observed reduction in *P. minor* populations in zero tillage, a field experiment was conducted to study the effects of conventional tillage and zero till on *P. minor* seed bank dynamics and weed emergence in the rice-wheat system.

MATERIALS AND METHODS

The experiment was conducted on sandy loam in the district of Fatehabad, Haryana State, India in 2000-2001. The experimental fields had been under rice-wheat for more than ten years and had no history of zero tillage. The soil contained a high natural seed bank of *P. minor*, which was sufficient for the experiment. A total area of 1.4 ha was equally divided over four replicate blocks. Treatments were arranged in a split-plot design. Each block was split into two subplots that were either conventionally tilled or under zero tillage. In each subplot, five measuring points were marked.

Soil samples were taken at depths of 0-2.5, 2.5-5, 5-10 and 10-20 cm on November 18 and 19, 2000. At each measuring point, five samples were taken with a soil auger which was 8.6 cm in diameter. In total, 25 samples were taken for each treatment. Seeds and organic matter were separated from the soil by washing through 2.4 mm wide sieves. Seeds, mixed with the remaining organic matter, were allowed to germinate in Petri dishes in an incubator at 15 ^{0}C and continuous light. The readily germinable fraction of the *P. minor* seeds in the soil samples was estimated by counting the number of emerged seedlings in the Petri dishes. The first counts were made after four weeks and seedlings were removed. Subsequently, samples were removed from the incubator, dried at room temperature for one week, mechanically kneaded, wetted again and placed back into the incubator. A second count was made eight weeks after sampling.

In the experimental field, wheat variety PBW343 was sown on November 20 and 21, 2000. *P. minor* seedling emergence was counted at 20 days after sowing for the first flush and at 45 days after sowing for the second flush (post-irrigation). Seedling emergence was assessed in two quadrats of 0.25 m^2 at each measuring point in the field.

RESULTS AND DISCUSSION

No significant difference in total numbers of seeds in the soil or the relative vertical distribution of seeds through the soil profile between the two tillage systems was found (Figure 1). Seeds were relatively equally distributed over the upper 10 cm of the soil for both tillage systems and few seeds were found below 10 cm depth. This is likely to be the result of the extensive tillage operations associated with the preceding rice cultivation, which equally distributed the seeds over the upper 10 cm of the soil, while below 10 cm the soil is left undisturbed. Also, under conventional tillage in wheat using local machinery, soil disturbance does not go beyond 10 cm depth.

Despite the fact that there was no difference between the two tillage systems in *P. minor* seed bank density and relative distribution of seeds through the soil profile, there was a significant effect of tillage system on numbers of emerged seedlings for the first and the second flush (ANOVA test F_{pr}=0.003 for 1st flush and 0.019 for 2nd flush) (Figure 2). This suggested that, besides temperature and depth of burial, other factors play an important role in regulating *P. minor* germination behaviour.

The differences in emergence rate of the first flush may be explained by variation in moisture distribution through the soil profile. It was observed in the experimental fields that under conventional tillage, soil cultivations result in a relatively equal distribution of soil moisture over the upper 10 cm soil at sowing time, while the lack of cultivations under zero till allows a crust to develop on the soil surface. This crust may discourage *P. minor* seeds in the upper layer to germinate and mechanically impedes seedling emergence from deeper layers.

After the first post-sowing irrigation, the crust in zero-till fields is wetted and moisture conditions in both tillage systems are expected to be similar. Nevertheless, also in the second flush there is a slight, though significant, difference in emergence rate between conventional tillage and zero-till (Figure 2b). This suggests that other factors, such as differences in soil chemical and physical properties, soil temperature and the lack of mechanical or light stimulation to break seed dormancy during ploughing, may also be involved in regulating *P. minor* germination behaviour.

Correlation coefficients between seedbank size and emerged seedling density for the two tillage systems varied between 0.17 and 0.59. These coefficients are comparable with those found in other studies aiming to establish a relationship between seed bank size and emerged seedlings (Cardina & Sparrow, 1996). Correlations of this strength are not sufficient to accurately predict weed seedling populations based on soil seed samples, indicating that other factors besides soil seed density and tillage system also determine seedling emergence. The percentage of seeds that emerged from the seedbank varied between 12 and 21 per flush, while emergence rate for both flushes was 27% for zero till and 39% for conventional tillage.

Linear regression models suggested that the emergence fraction remains constant at varying soil seed densities, thus the benefit of zero till in terms of reduction in numbers of emerged seedlings increases with higher soil seed densities. Crop yield benefit as a result of zero tillage depends on weed pressure after herbicide application during the second half of the growing season. Increasing herbicide inputs will diminish the difference in weed pressure between the two tillage systems.

In conclusion, for farmers who are unable to purchase effective herbicides and rely on alternative weed control methods, adoption of zero till may gain a substantial yield benefit, whereas for farmers using effective herbicides, the yield benefit as a result of zero till will be less. Extension efforts to increase the use of zero till should include knowledge on the mechanisms of how zero till affects *P. minor* populations, so farmers themselves can make the decision about whether the investments necessary for adoption are worthwhile.

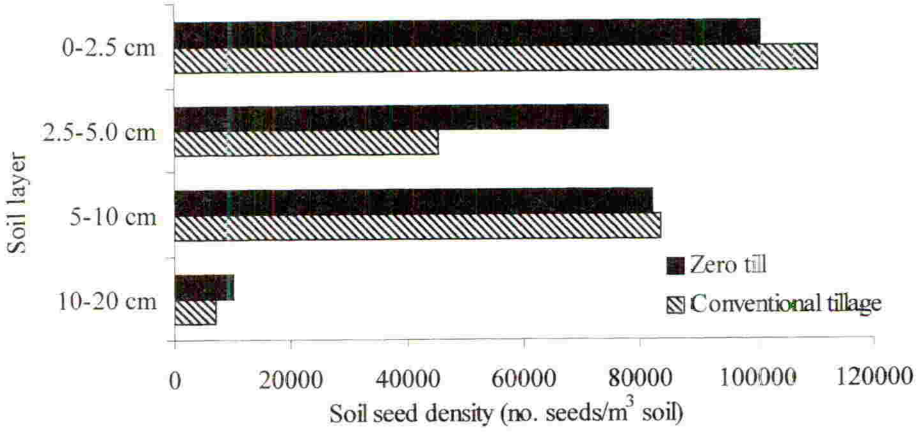

Figure 1: Vertical distribution of *Phalaris minor* seeds through the soil profile for conventional and zero tillage.

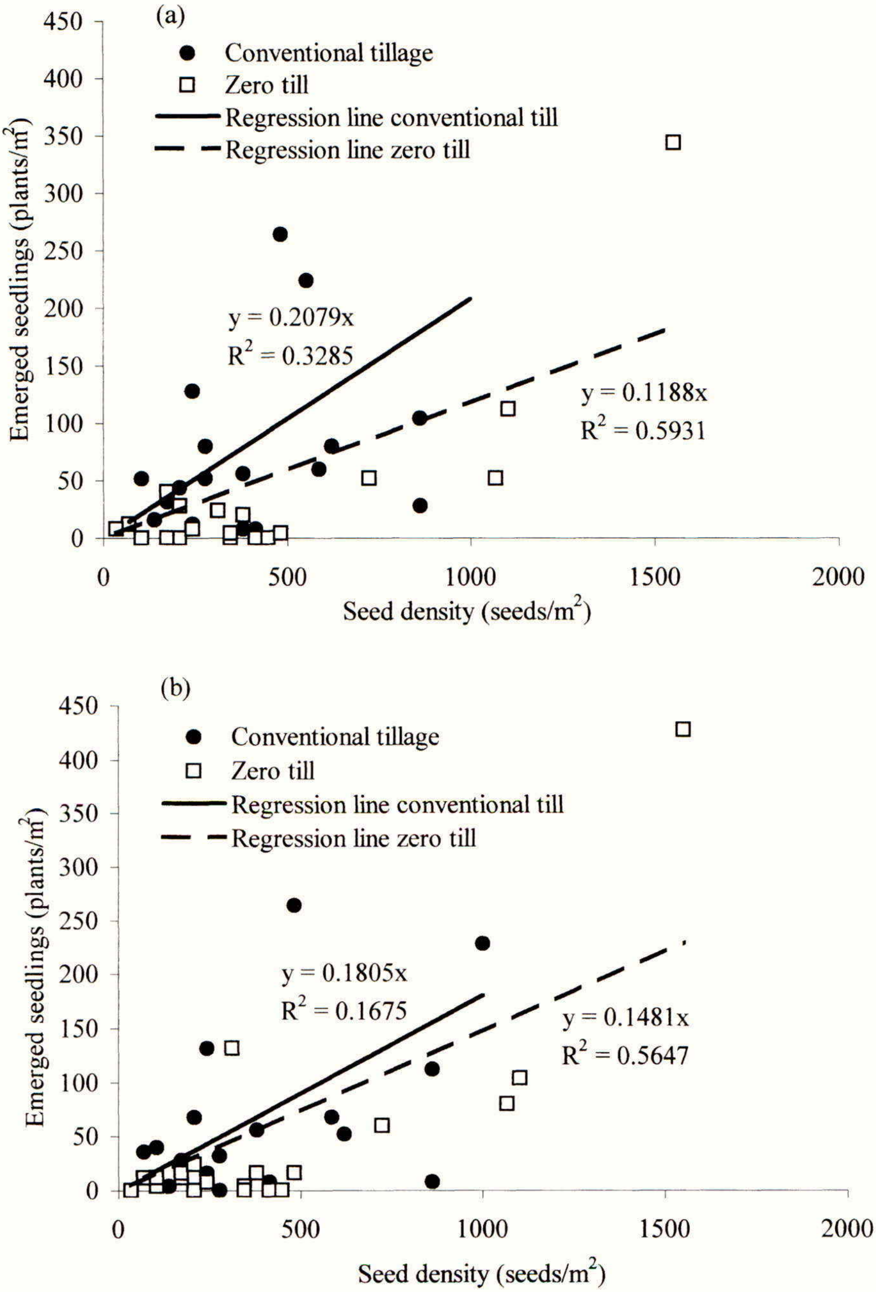

Figure 2: Relationships between soil seed density and emerged seedlings for *Phalaris minor* in wheat.
(a) First flush of germination
(b) Second flush of germination (post irrigation)

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Analysis of the constraints to adoption of herbicides by smallholder maize growers in Kenya and Uganda

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ABSTRACT

Evidence from on-farm participatory trials conducted in Kenya and Uganda indicate that herbicides can increase the net benefits to farmers, of cultivating maize, by up to 80 per cent. When this is combined with their ability to alleviate seasonal and gender-based labour constraints, their potential contribution to a more successful and economically sustainable farming system is substantial. Despite these potential benefits, a recent survey found that only 3 per cent of maize producing households in Kenya and Uganda were using herbicides as a means of weed control. Low adoption levels were found to be related to poverty, knowledge systems, poor access to credit and gender issues (particularly intrahousehold income flows).

INTRODUCTION

Weeds are a major obstacle to crop production in sub-Saharan Africa. Traditional weed control is very labour intensive because it is done almost totally by hand. Herbicides, as part of an overall crop management strategy, can reduce this labour requirement and generally improve yields over more traditional methods. Most resource-poor farming households in East Africa face an effective labour constraint, which is seasonal and gender-based. This constraint affects the timeliness of weed control practices, particularly during initial crop growth stages, reducing yields and providing secondary hosts for insect pests. This paper is principally concerned with analysing factors limiting adoption levels.

MATERIALS AND METHODS

Most of the evidence presented in this paper was collected from a survey of 240 farmers conducted across the maize growing areas of Kenya and Uganda in 1999/2000. Sampling methods combined formal and informal methods to generate a representative survey of farmers stratified by wealth. There was purposeful sampling at the first stage (i.e. selection of maize growing areas) followed by random sampling through administrative layers until village level was reached in each growing area (six villages per area). Following this, a participatory wealth ranking exercise was conducted in each village, with households then selected at random from each wealth stratum with a probability of selection proportionate to stratum size (or proportion of total households in that stratum).

Additional evidence, on economic returns to herbicide use, was generated by on-farm participatory trials conducted in Embu, Kenya involving 30 farmers over one growing season.

RESULTS

Herbicide usage patterns

The survey evidence based, on 240 households across Kenya and Uganda, indicates that herbicides are only used by 3 per cent of households for weed control; hand weeding predominates, and no instances of herbicide use were found in Uganda. As a result of this small (positive) number, it is difficult to establish statistically the determinants of herbicide use (using a binary logistic model). However, it appears that the small number of farmers who use herbicides are generally better educated, cultivate more land, sell a higher proportion of their maize, and send a higher proportion of their children to school (Overfield, 2001).

Low herbicide usage in developing countries is often regarded as a function of knowledge deficiencies. Evidence from this study indicates that about half of all households are aware of herbicides – meaning they can identify a product, explain what it does and know its potential benefits. This indicates not only substantial gaps in basic awareness but also very low adoption among the proportion of the population that are aware of herbicides.

Factors influencing adoption levels

The adoption gap (or difference between awareness and actual adoption) has a number of explanations, most of which are founded in poverty, temporal cash flow issues and the undervaluing of the opportunity cost of labour. Low levels of adoption are also related to a lack of knowledge for many households – itself a function of the agricultural knowledge information system (AKIS) in these areas.

Household incomes and poverty

The factor with greatest influence would appear to be household income levels and the poverty they imply. Annual household *per capita* incomes are in the region of £50 (equivalent to Kenya Shillings 5,500 and Uganda Shillings 120,000) leaving little room for the introduction of new expenditure items into household budgets. The contribution of maize to household cash incomes is also relatively small, making up a significant proportion of farm income (over 40 per cent) but a much smaller proportion of total household income (22 per cent). The value of household sales is in the region of £105 (KSh 11,550) in Kenya and £65 (Ush 156,000) in Uganda, generating relatively small amounts of cash against which to invest.

Access to credit and sprayers

Low household incomes would not form such a binding constraint if households had access to both credit and the sprayers that are required to apply herbicides. The majority of households (70 per cent) do not have access to credit, with this proportion falling to less than 10 per cent in Uganda. Access to Sprayers, at 42 per cent (across both countries), is greater than credit but most households still do not have access to a sprayer (even on a shared basis), providing a double hurdle for many farmers to overcome. Sprayers cost in the region of £70 (an up front payment) in most rural areas in Uganda and Kenya – which is most (or all in the case of Uganda) of the income earned from maize in one year. Add to this the cost of applying herbicide of approximately £30 per season for the 'average' sized farm (see next paragraph) and the prospects for uptake, without provision for credit, do not appear optimistic.

Temporal cash flow issues

Household budget constraints are further compounded by temporal cash flow concerns and household spending priorities. Education (school fees) is what most households spend most of their income (after food) and this is the expenditure area with the highest priority. This creates temporal concerns because school fees are due at exactly the same time that herbicides would be required (September and January) and there is simply not enough available income to pay for both at this time. Herbicides could ease this temporal constraint by reducing expenditure on labour but require up front payments for both the herbicides and the sprayer. Labour payments, however, are generally on a day by day basis (and often in kind). Compounding this still further is that herbicides are generally only available in large packages (generally 5 litre containers) but 'average' farmers require less than 1 litre per season (at an approximate cost of £6 as opposed to £30). In some areas, the appropriate herbicides for maize (particularly for intercropping systems) are also not available.

Intrahousehold issues and the opportunity cost of labour

Weeding activities are not evenly distributed within the household, with the majority of the burden falling on women and, to a lesser extent, children. Women generally have the responsibility for making decisions on weeding and carrying out the activity, but not for maize selling which is a male preserve and indicates male control of this income flow. There is a more gender-balanced picture for farm incomes in Kenya (36 per cent male derived) compared to Uganda (72 per cent male derived). In terms of herbicide adoption, the important issue is that the major beneficiaries of the reduced labour burden would be women, but they have much more limited access to the funds that would be required for purchasing herbicides compared to men. Men, on the other hand, may 'undervalue' the opportunity cost of women's labour time when making investment and expenditure decisions such as those concerning herbicides.

Evidence from the survey indicates that women have significantly less formal education than men (a gap of approximately two years, on average), which may reduce agricultural productivity and the adoption of new technologies. This is particularly critical at these levels of education because statistical evidence indicates that it is post elementary or primary schooling that has the greatest influence on the adoption of new techniques and crop varieties (Azhar, 1991). Formal education over four years begins to assert a positive influence; four years or less was found to be statistically insignificant. However, the impact of education on agricultural productivity is complex and beyond the scope of this paper.

Agricultural knowledge and information system (AKIS)

The survey evidence has indicated a significant knowledge shortfall with regard to herbicides. In this context it is important to know from where farmers are obtaining information regarding agricultural practices and of the biases that may operate within this system. Based on a large Kenyan study, Hassan (1998) concluded that the major constraint to the adoption of improved varieties and pest control methods was lack of information, particularly in the lowland tropics. In this same study, the major barrier to increased adoption of fertiliser was found to be its high cost (a similar situation to that of herbicides where the costs are even higher). There was also little variation in the factors that influenced the uptake, or non-adoption, of recommended maize production practices, whether these were improved varieties, fertiliser use or pest control strategies.

In this study, farmers where found to have multiple sources of information, and different information sources for different topics (varying by gender and age). The two primary sources of information were extension services, other farmers (including neighbours and parents) – both of these being of equal importance. Other significant sources of information included stockists (particularly for agro-chemicals), NGOs (particularly in Uganda) and CBOs. These results are in line with previous studies in Kenya and Uganda [Hassan, 1998; Mulhall & Garforth, 1997 (cited in Overfield & Lamboll, 2000)] indicating that many parts of the AKIS need to be targeted in the promotion of herbicides.

Economic returns to herbicide investment

The combination of reduced competition from weeds (and, hence, increased yields) and reduced production costs gives the net benefits presented in Figure 1. This shows that herbicides produce net benefits that are between 55 and 82 per cent higher compared to farmers' normal practice in this area. These clearly indicate that herbicides can have a highly positive impact on the net benefits accruing to farmers for two main reasons. The first concerns the factors underlying yield increases – more effective weed control during the critical period of crop growth and competition (particularly where there are seasonal labour shortages). The alleviation of this constraint by herbicides contributed to yield increases of over 30 per cent for both maize and beans and consequent increases in the value of production (and hence to net benefits). The second reason concerns the overall reduction in production costs associated with herbicides caused by a massive reduction in the labour required for weeding, from 39.2 to 1.3 person days per hectare (equivalent based on plots of 500 square metres). These should be regarded as initial indications as they relate to one season and one area – results from three areas and three seasons should be available by the completion of research in 2002. In addition, they overstate the level of benefits because they do not take into account the additional labour costs that would be associated with increased yields (harvesting and processing), the costs of a sprayer or the true herbicide cost to farmers.

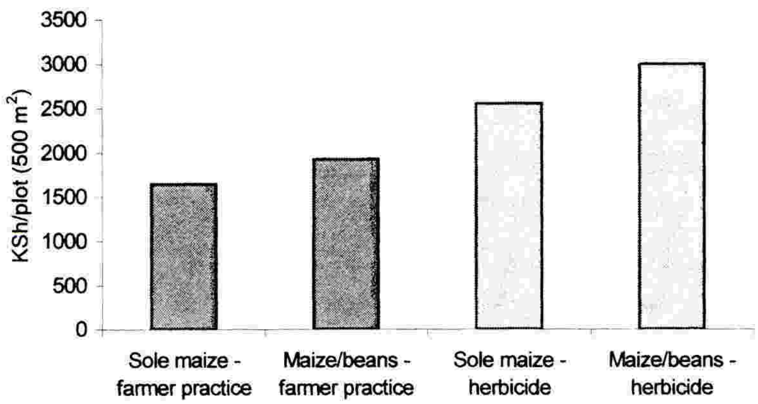

Figure 1. Net benefits of farmer practice and herbicide for weed control in sole maize and maize intercropped with beans.

The cost of using a sprayer could be as high as £10 per season (assuming they last five years and there are two seasons per year). However, some households already own or can borrow sprayers that can be used on a number of crops. A more reliable estimate of sprayer costs may indicate the net benefits to maize (of herbicide use) would be reduced by £2-3 per plot, which represents about 15 per cent in the net gain due to herbicides. Labour costs would also contribute to further reductions in the improvement of net benefits – but these are expected to be relatively small (a fraction of the 30 per cent yield and production increase), still leaving substantial benefits to be gained by farmers. Net benefits were also calculated using the actual amount of herbicide used; currently farmers would have to buy a 5 litre tin (costing around £30) when a 1 litre tin would be more appropriate (and cost around £6). This would also reduce the size of potential net benefits. The exact herbicide price facing smallholders is difficult to estimate at the 'farm gate' given the small market; prices are based on those currently prevailing in urban/peri-urban areas, which is the best guide.

CONCLUSIONS

Evidence from the on-farm participatory trials indicate that herbicides can increase the net benefits of maize cultivation to farmers by up to 80 per cent. When this is combined with their ability to alleviate seasonal and gender-based labour constraints, their potential contribution to a more successful and economically sustainable farming system is clear. There are potential negative employment effects and further information on this issue needs to be collected. Herbicides will benefit farmers economically, but is clear that households do not just farm, and hiring out labour is often an important element of household livelihood strategies. It is the exact balance between these that will determine the overall level of net benefit to rural communities. There are other potential costs relating to health (particularly of spray operators) and the environment that could occur due to inappropriate use of herbicides. However, it is very unlikely that there will be substantial further adoption of herbicides in these farming and livelihood systems in the near future due to a combination of poverty, poor access to credit, household spending priorities (particularly the role of school fees), seasonal/temporal cash flow issues and knowledge deficits.

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Evaluation of animal-drawn weeders for smallholder maize production in Zimbabwe

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ABSTRACT

To improve weed management at the smallholder level, a plethora of animal-drawn weeding equipment is now available, with very little technical information available to the farmer on their performance. This paper presents the draught characteristics of a range of weeders, commonly used in southern Africa. Comparable results were obtained in terms of weeding efficiency for the ox-drawn cultivators, but the light three-tined cultivator had a lower work rate and was more difficult to control on heavier soils than the traditional five-tined cultivators. In sandy soils the ducks foot tines performed better than the reversible tines in terms of yield responses, and *vice versa* for the heavier clay loam soils. The single animal-drawn tool-bar had the second lowest weeding efficiency and required the most supplemental hand weeding. In terms of yield responses and returns to hours spent weeding, post-emergent ridge weeding out-performed all of the other weeding treatments. The results help explain the reasons why many farmers are unwilling to use the traditional five-tine weeders currently available.

INTRODUCTION

The greatest demands for mechanical energy in smallholder crop production operations are for land preparation and weed control; either or both of these can limit the output of a smallholder farmer (O'Neill, 1998) and "bottlenecks" can occur. For land preparation, the limit is due primarily to the intensity of the energy demand, whilst for weed control, the duration of the demand is likely to be more restricting (Rogan & O'Neill, 1993). The maximum rate of working (i.e. power developed) that may be expected of a smallholder is around 40 watts over a 6-hour working day (Dibbits, 1993) and this energy (totalling around 0.9 MJ) would be applied rather inefficiently through the use of simple hand tools, typically hoes of various designs (e.g. see Anon, 1992). Although weeding is associated with a lower power demand than land preparation, the time available may be inadequate to complete the task. This contributes to the drudgery of long hours of weeding, a burden borne mainly by women who must accommodate weeding within their schedule of domestic tasks. Chatizwa (1997) has investigated the use of hoes for weeding in Zimbabwe. He concluded from studies using female subjects that, of four designs, the garden hoe was the best overall tool in terms of work rate and effort, but that the *badza*, the local traditional tool, had the highest weeding efficiency.

To improve weed management, a plethora of animal-drawn weeding equipment is now available, with limited technical information available to farmers and extension agents on their performance (e.g. Kwiligwa *et al.*, 1994; Mbanje & O'Neill, 1997). This paper presents the performance results of a range of weeders and weeding practices, that are common in southern Africa.

METHODS AND MATERIALS

Site location

Field experiments were conducted at Domboshawa Training Centre (DTC) and the Institute of Agricultural Engineering (IAE), Mashonaland East, in northern Zimbabwe during the 2000/2001 cropping season. The climate at each site is characterised by a unimodal rainy season from October/November to March, when most of the rain falls as sporadic 'heavy' convectional storms, followed by a long dry season from April to May. The 15-year seasonal average rainfall is 478 mm (1982-1996) at DTC, with a range of 260 to 1150 mm, similar to rainfall patterns at IAE. Table 1 shows the rainfall for 2000/2001.

Table 1. Rainfall distribution (mm) at DTC and IAE for the 2000/2001 season

Site	October	November	December	January	February	March	Total
DTC	1	57	272	91	301	309	1031
IAE	56	64	271	71	332	320	1114

The soils at DTC are deep, coarse-grained granitic sands (82% sand, 13% silt, 5% clay) with a plant-available water capacity of less than 12% by volume, which means that crops grown on these soils are prone to drought, as any excess water quickly drains below the plant rooting zone (Vogel, 1994). These are typical soils that are found in most smallholder farming areas of Zimbabwe. Dependent on the availability and condition of draught animals and implements, they are normally cultivated annually to a depth of 80 to180 mm (Koza *et al.*, 2000). The second site, IAE, has deep red clay loams (>60% clay), typical of much of Zimbabwe's commercial agricultural land (Elwell, 1986).

The experiment involved four commercially-available types of ox-drawn cultivators, fitted with different arrangements of reversible and ducks foot tines (Figures 1 and 2). These were (i) the standard BS41 five tined cultivator (Figure 3), (ii) the BS221 cultivator with hilling blades (Figure 4), (iii) the Zimplow light weight cultivator with three tines, and (iv) a single

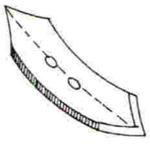

Fig. 1. Reversible tine

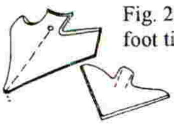

Fig. 2. Ducks foot tine

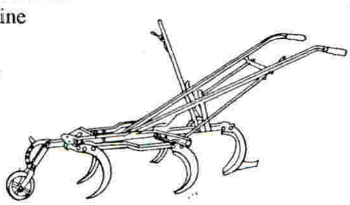

Fig. 3. BS41 five tined cultivator

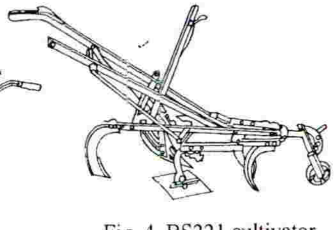

Fig. 4. BS221 cultivator with hilling blades

animal-drawn tool bar with a 0.3 m wide ducks foot sweep. Weeding with these implements was compared with the traditional farmers' practices of overall hand hoe weeding, weeding with the plough-share (mouldboard removed) and an improved practice of post emergent ridge weeding using the plough with the mouldboard attached (Riches *et al.*, 1997). Full details of the different weeding treatments, including tine arrangements, are given in Table 2.

Table 2. Details of the different weeding treatments, including tine arrangements

Treatments	Description
BS2212R2H1D	Standard BS221 with hilling blades, 2 reversible tines and a single ducks foot tine
BS2213D2H	Standard BS221 with hilling blades and three ducks foot tines
BS415R	Standard BS41 with 5 reversible tines
BS414R1D	Standard BS41 with 4 reversible tines and single ducks foot tine
BS415D	Standard BS41 with 5 ducks foot tines
ZLW2R1D	Light weight 3 legged tine with 2 reversible tines and single ducks foot tine
ZLW3D	Light weight 3 legged tine with 3 ducks foot tines
CTB	Contil single animal drawn tool bar with sweep tine attached
SHARE	Standard VS8 plough with mouldboard removed, share only
MB	Standard VS8 plough with mouldboard attached
Hand	Traditional overall hand weeding with hand hoe (badza or jembe)

The trial was laid out in a fully randomized design; each plot was 10 m wide by 25 m long and replicated three times at each site. The site was uniformly spring ploughed using a standard ox-drawn plough. Maize hybrid SC513 test crop was planted in 0.9 m rows at both sites during the third week of December 2000, and thinned to an in-row spacing of 0.3 m after crop emergence. The crop was top-dressed with 56 kg/ha N (150 kg ammonium nitrate) in a split application at six and ten weeks after planting. No basal fertiliser was applied, in accordance with smallholder farmer majority practice. Weeding operations were planned to be undertaken at two and six weeks after emergence, with supplemental hand weeding within the crop row undertaken after each animal-drawn weeding operation.

During each weeding operation, the depths and widths of soil disturbance for each weeder were recorded (four measurements per plot), as were draught forces (eight measurements per run for a total of eight runs per plot). Effective working time per run, turning time and total time spent on each plot were measured, from which work rates and draught power characteristics were calculated. Crop records included maize plant population at harvest, grain yield at 12% moisture content, and the number of barren plants to check if there was any serious crop damage during the weeding operations. Estimates of weed biomass cover were made on a whole plot basis prior to and after the first weeding, and at harvest. Data were analysed by conventional ANOVA for the design and comparisons of means by t-test at the 0.05 level of probability.

RESULTS AND DISCUSSION

The above average rainfalls (Table 1) experienced at both sites in February and March meant that it was possible to carry out only a single weeding operation during the second week of January 2001. The most common weeds at both sites were *Cynodon dactylon*, *Richardia scabra*, *Galinsoga parviflora*, *Commelina benghalensis* and *Eleusine indica*. *C. dactylon* was particularly prevalent on the sandy loam and caused numerous stoppages at weeding, as the rhizomes collected around the implements and reduced their performance.

Table 3 summarises the key draught characteristics of the different animal-drawn weeding treatments and the labour inputs required for both the animal-drawn and supplemental hand weeding operations. Although the lowest draught forces were measured for the CTB, significantly lower (*P<0.001*) than any of the other animal drawn implements, its work rate was very similar to the commercially available three and five tined cultivators. However, its weeding efficiency was the second worst after the BS2213D2H (Figure 5), necessitating the greatest amount of supplemental hand weeding (Table 3), and resulted in significantly lower (*P<0.001*) yields than either of the plough-based systems (Table 4). Despite the significant differences in draught characteristics, all of the implements tested were well within the draught power capabilities of communal oxen (Koza *et al.* 2000).

Table 3. Draught performance characteristics, effective field capacities and labour inputs for the 11 different weeding systems (treatments) at DTC and IAE

Treatments/sites	Draught, kN		Work rate oxen h/ha		Hand weeding h/ha	
	DTC	IAE	DTC	IAE	DTC	IAE
BS2212R2H1D	0.74	0.90	5.5	3.3	86.0	63.5
BS2213D2H	0.80	0.84	5.2	4.6	93.9	68.1
BS415R	0.85	1.03	5.4	3.3	92.2	57.5
BS414R1D	1.00	0.88	5.9	3.3	86.4	62.2
BS415D	0.77	0.89	5.2	3.3	78.0	72.1
ZLW2R1D	0.56	0.47	5.5	4.2	87.7	56.2
ZLW3D	0.65	0.56	6.1	4.2	90.8	72.8
CTB	0.14	0.34	5.9	3.8	98.3	76.1
SHARE	0.80	0.62	10.7	7.5	83.8	49.6
MB	0.91	0.59	11.7	7.9	81.1	47.6
Hand	n.d	n.d	n.d	n.d	175.5	158.1
SED	0.090	0.027	0.336	0.757	7.510	18.970

n.d. – no data collected from overall hand-weeded plots

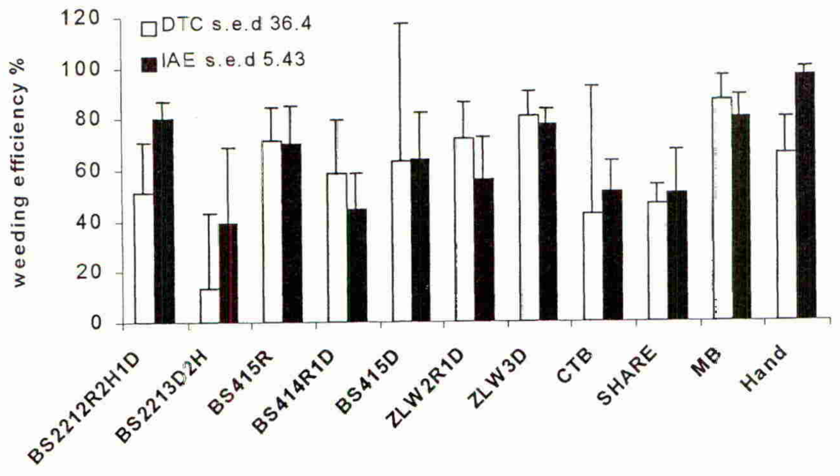

Figure 5. Weeding efficiencies for the 11 weeding treatments at DTC and IAE

Table 4. Maize yields, labour requirements[#] and returns on labour for 11 different weeding treatments at DTC and IAE

	Grain yield kg/ha		Barren plants/ha		Total weeding time h/ha		Returns on labour kg/h	
Treatments/sites	DTC	IAE	DTC	IAE	DTC	IAE	DTC	IAE
BS2212R2H1D	484.0	1146.4	6208	450	96.9	70.2	5.0	16.3
BS2213D2H	582.4	1375.2	6750	475	104.4	77.3	5.6	17.8
BS415R	377.0	1548.2	5521	400	103.1	64.2	3.7	24.1
BS414R1D	836.8	1217.4	3292	300	98.2	68.8	8.5	17.7
BS415D	770.7	1049.4	6146	125	88.4	78.8	8.7	13.3
ZLW2R1D	815.7	1501.8	4063	1000	98.7	64.6	8.3	23.3
ZLW3D	1519.8	990.2	-250*	775	103.0	81.1	14.8	12.2
CTB	636.1	974.7	-1771	-450	110.1	83.6	5.8	11.7
SHARE	1566.2	1502.4	-1750	-525	105.3	64.6	14.9	23.3
MB	1618.6	1598.7	104	2375	104.4	63.5	15.5	25.2
Hand	1034.9	1183.8	3646	475	175.5	158.1	5.9	7.5
SED	36.3	311.1	4343	1469	6.96	8.17	1.30	1.78

Total weeding time = oxen work rate (Table 3) x 2 people + hand weeding (Table 3)

* Negative values occur when plants have more than one cob, hence no. of cobs > no. of plants

Table 4 presents criteria that are important to farmers, although the importance of the returns on labour may be influenced by the availability of family labour (cf. hired). Yields are variable, particularly at DTC, but may not be representative of a typical year because of the heavy rainfall improving water availability in the sandy soils. The BS415R and ZLW3D give contrasting performances in terms of yield, with the former being associated with a (relatively) low yield at DTC and a high yield at IAE, whereas the latter has the opposite association. However, both these implements gave relatively high weeding efficiencies at both sites (Fig 5), which imply an interaction between the tine arrangements used and the soil types. It would appear that in sandy soils, when the reversible tines are replaced by the ducks foot tines on the traditional five-tined cultivator (BS415D) and the light-weight three-tined cultivator (ZLW3D), yield responses are significantly ($P<0.001$) greater, although the number of barren plants may increase (Table 4). The opposite occurred on the heavier clay loam soil. This was different from the responses of the BS221 cultivator, which, as purchased (i.e. BS2212R2H1D), had significantly ($P<0.001$) higher weeding efficiencies on both soils with reversible tines (Fig 5), than when they were replaced with ducks foot tines (BS2213D2H), but the latter set up gave the higher yields and better returns to overall weeding labour (Table 4). Of all of the weeding treatments, the CTB consistently performed the worst (Table 4), a reflection of its poor weeding efficiencies (Fig 5). Without discriminating between sites, the plough-based practices gave the best overall crop response. Because of the higher yields, the best returns to weeding labour are also associated with the plough-based practices.

CONCLUSIONS

The results for two different soil types, albeit for a wetter than average season, help clarify some of the reasons why many farmers are unwilling to use the traditional five-tine weeders currently available, even after they have purchased them (Chatizwa and Ellis-Jones, 1997). In terms of weeding efficiencies, the light three-tined cultivator was very similar to the traditional five-tined cultivator but it had a lower work rate and was more difficult to control on the heavier soils, particularly when the reversible tines had been replaced with the ducks foot type. For heavier soils, farmers should use the reversible tines that are sold with most cultivators, whilst, on lighter sandy soils, farmers would be wise to use the ducks foot tines. However, for farmers who do not own a cultivator and draught animals are not a constraint, post emergent-ridge weeding with the mouldboard plough should be actively encouraged, as it not only gives good weed control, but also enhances crop yields. These may be further enhanced by tying the subsequent ridges to conserve moisture (Riches *et al.*, 1997).

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