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ON-FARM EVALUATION OF AN ANIMAL-DRAWN IMPLEMENT DEVELOPED IN ETHIOPIA FOR ROW PLACEMENT OF WHEAT SEED AND BASAL FERTILISER

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ABSTRACT

Grass weeds are difficult to control by hand weeding in a broadcast wheat crop because several species are not easily distinguished from the crop at an early stage. Chemical weed control, on the other hand, can be highly effective, but is limited in Ethiopia by the unavailability and high cost of herbicides. Further, dependence on high efficacy herbicides to control grass weeds can result in weed species shifts and/or the development of resistant weed biotypes. Row sowing of wheat can facilitate hand and/or mechanical weeding by enabling farmers to identify grass weeds in the inter-row spaces. However, manual row seeding is extremely labour intensive and unacceptable to peasant farmers in Ethiopia. Row seeders developed elsewhere have not been accepted in Ethiopia because they were either too labour inefficient or ineffective in cloddy and rough fields. Therefore, a four-row seeder has been developed in Ethiopia with a new type of seed metering mechanism. Field tests have shown that the row seeder can work effectively in fields prepared by ox plough. The row seeder is labour efficient, requiring less than 25% of the time per unit area compared to the farmers' conventional practice of broadcasting seed and fertilizer and covering by ox plough. The seeder also facilitates placement of seed and fertilizer together in the row, enabling the crop to utilise fertiliser more effectively and limiting the nutrients available to weeds emerging between crop rows. In one season, use of the row seeder increased wheat grain yield by 28% in comparison to the conventional broadcasting. The row seeder used in conjunction with an inter-row weeder was the most profitable package tested on farmers' fields in 1995 and 1996, representing a sustainable production technology for peasant wheat farmers in Ethiopia.

Key Words: Animal traction, on-farm research, seeder, sowing, weed control, wheat

Resume

Les mauvaises herbes sont difficiles a controler par desherbage manuel dans un champ de ble seme a la volee, car plusieurs d'entre elles ne sont pas facilement differenciables de la culture a un stade precoce. Par contre, le desherbage chimique peut etre tres efficace. Neanmoins, il est restreint en Ethiopie par l'indisponibilite et le cout eleve des herbicides. De plus, dependre d'herbicides tres efficaces pour le controle des mauvaises herbes peut entrainer un changement dans la frequence des especes adventices et/ou le developpement de biotypes de mauvaises herbes resistants. Le semis en rangs du ble peut faciliter le desherbage manuel et/ou mecanique en permettant au cultivateur d'identifier les mauvaises herbes dans les espaces entre rangs. Cependant, le semis manuel en rangs est extremement laborieux et inacceptable par les paysans fermiers d'Ethiopie. Les semoirs a rangs mis au point ailleurs, n'ont pas ete adoptes en Ethiopie parce qu'ils etaient soit inefficaces au travail, soit ineffectifs dans les champs a mottes ou accidentes. Par consequent, un semoir a 4 rangs avec un nouveau type de mecanisme de comptage de graine, a ete mis au point en Ethiopie. Des essais au champ ont montre que ce semoir a rangs peut fonctionner efficacement dans des champs prepares a la charrue a boeufs. Le semoir a rangs travaille efficacement, necessite moins de 25% du temps par unite de terrain par rapport aux pratiques conventionnelles du cultivateur, qui consistent a semer a la volee, a fertiliser et a couvrir avec la charrue a boeuf. Le semoir facilite egalement la mise en place de la graine et de l'engrais ensemble dans le rang, permettant a la culture d'utiliser plus efficacement l'engrais et de restreindre les substances nutritives disponibles aux mauvaises herbes emergeant entre les rangs. L'utilisation du semoir a rangs durant une saison a augmente les rendements en grains du ble de 28% par rapport au semis a la volee conventionnel. Le semoir a rangs utilise conjointement a un sarcloir entre les rangs etait la strategie la plus avantageuse testee chez le cultivateur en 1995 et 1996, representant une technologie de production durable pour les paysans cerealiculteurs d'Ethiopie.

Mots Cles: Ble, desherbage, recherche en exploitation, semis, semoir, traction animale

INTRODUCTION

Grass weeds represent a serious constraint to sustainable bread wheat (*Triticum aestivum*) production in Ethiopia. Since several grass weed species resemble the wheat crop during early growth stages, Ethiopian peasant farmers experience difficulty in removing grass weeds from broadcast wheat crops by hand weeding (i.e., the normal practice in Ethiopia) sufficiently early to reduce yield losses (Amanuel *et al*., 1992a). Wheat yield losses due to grass weeds can be considerable (Tanner *et al*., 1993b), and sometimes total crop failure can occur.

The principal problematic grass weed species encountered in peasant farmers' wheat fields in Ethiopia are *Avena abyssinica*, *A. fatua*, *Bromus pectinatus*, *Lolium temulentum*, *Phalaris paradoxa* and *Setaria pumila* (Taye *et al*., 1996a). With the exception of *B. pectinatus*, herbicidal control of all of these grass weeds can be economically feasible in the peasant farming sector of Ethiopia (Tanner *et al*., 1993b); density-dependent economic thresholds have been determined for most species (Taye *et al*., 1996b). However, concerns have been raised in various scientific fora in Ethiopia regarding the long-term implications of reliance on herbicidal weed control. Shifts in weed species composition and density have been observed in farmers' fields as a result of herbicide application: *B. pectinatus* opportunistically increases in density where broad spectrum grass herbicides such as fenoxaprop-P-ethyl have controlled the previously dominant grass weed species (Amanuel *et al*., 1992a). Although not yet observed in Ethiopia, frequent application of high efficacy herbicides is known to increase the risk of developing resistant biotypes within weed species previously controlled (Gorddard *et al*., 1996). Furthermore, imported grass herbicides are expensive in Ethiopia, representing a high cash investment by the individual farmer and a drain on the foreign exchange reserves of the country, and are often limited in availability throughout the countryside.

Integrated weed management (IWM) research, focusing on the beneficial effects of modified crop management on weed interference with crop yield, can facilitate the development of more sustainable cropping systems (Swanton and Murphy, 1996). In general, alternative methods of weed control (e.g., reduced herbicide and tillage inputs) have been found to be more energy efficient than conventional weed control practices (e.g., broadcast application of herbicides at recommended rates) (Clements *et al*., 1995). Aspects of IWM relevant to wheat cropping systems include: 1) inherent differences in the ability of wheat cultivars to compete with grass weeds (Tanner *et al*., 1995); 2) the effects of wheat seed rate and relative time of crop emergence on competitive yield losses due to grass weeds (Blackshaw, 1993; Khan *et al*., 1996); and 3) the effects of fertiliser rates (Tanner *et al*., 1993a) and placement (Cochran *et al*., 1990) on grass weed competitiveness with wheat.

One additional crop management intervention proposed to facilitate the control of grass weeds in peasants' wheat fields in Ethiopia is row sowing (vs. the traditional practice of broadcasting seed and fertiliser): weeds emerging in the inter-row space could be more readily controlled either by hand pulling or by using a mechanical weeder. The limitation to row sowing wheat by hand in Ethiopia is the high labour and time requirement (Melesse *et al*., 1996).

Animal-drawn row seeders originating from various developing countries have not been effective when tested under Ethiopian conditions primarily because, like tractor-drawn row planters, ground wheels drive the seed metering mechanism: the ground wheels fail to rotate effectively in the cloddy fields of small-scale farmers (i.e., prepared using traditional ox ploughs). On the other hand, the funnel type of hand-metered seed drill has not been accepted because it requires a high level of skill for metering seeds, level land to ensure equal distribution of seeds among rows, and a second operation to apply fertiliser (Abiye Astatike, ILRI, personal communication). A simple, hand-pushed, single-row seeder for wheat developed in Madagascar was found to be labour-inefficient, and was rejected by Ethiopian farmers despite good technical performance in terms of the resultant wheat crop (Amanuel *et al*., 1992b).

Therefore, a new type of animal-drawn four-row seeder without ground wheels was developed at the Agricultural Implement Research and Improvement Centre (AIRIC) at the Nazret Research Center of the Institute of Agricultural Research of Ethiopia. The "AIRIC Row Seeder for Wheat" (Fig. 1) was evaluated on farmers' fields during 1995 and 1996 in co-operation with the National Wheat Research Team of Ethiopia and the CIMMYT/CIDA East African Cereals Programme. In this implement, seeds are metered by hand-oscillation of a lever in cycles corresponding to the footsteps of the operator. The seeder has been calibrated to release a predetermined amount of seed and fertiliser in every stroke and distribute the mixture uniformly among four rows, spaced at 25 cm apart, and along the distance covered by a single pace of the operator. The amount of seed and fertiliser released in each stroke is based on the recommended seed rate of 150 kg ha^-1 for row-sown wheat in Ethiopia, and a basal fertiliser application of 100 kg ha^-1 of diammonium phosphate (DAP). Additional nitrogen can be supplied as required in a top-dressing of urea fertiliser.

The objective of this study was to assess the performance of the row seeder on representative farmers' fields prior to recommending the technology for extension to small-scale wheat producers in Ethiopia.

MATERIALS AND METHODS

The "AIRIC Row Seeder for Wheat" was tested on five farmers' fields in Gonde and Itheya woredas of Arsi zone in southeastern Ethiopia during the 1995 cropping season. The five selected farm sites, having clay soils, were clustered within a radius of approximately 20 km from the Kulumsa Research Centre (8 degrees 02'N, 39 degrees 10'E, 2200 m a.s.l.). Farmers were initially identified by Kulumsa researchers in 1994 on the basis of visual observation of a high density of grass weeds on their farms. Selected farmers agreed to host the on-farm trial in the subsequent season; compensation in the form of grain was promised for any perceived loss of revenue as a result of hosting the trial.

At each site, a total of six treatments (Table 1), consisting of logical combinations of seeding methods (i.e., row seeding or broadcasting) with weed control methods (hand weeding, a push row-weeder, or 2,4-D alone or in combination with fenoxaprop-P-ethyl), were superimposed on fields ploughed according to the host farmers' preferences and practices. The farmers' preferred sowing dates were used for trial establishment. Each of the six treatments were applied to plots measuring 5 m x 30 m. Two replications were located at each site, and the treatments were laid out in an RCBD. Seed of the bread wheat cultivar Pavon was sown at the rates recommended by the Kulumsa Research Centre: 150 kg ha^-1 for row-sown wheat and 175 kg ha^-1 for broadcast wheat. The zone-specific nutrient rate of 82 kg N and 46 kg P2O5 ha^-1 was applied to each treatment: 18 N and 46 P2O5 was applied basally in the form of DAP and 64 kg N ha^-1 was broadcast as urea at the time of hand weeding.

In 1996, the trial was conducted on five selected farm sites clustered within a radius of approxi-mately 10 km from the Asasa research sub-station (7 degrees 08'N, 39 degrees 13'E, 2360 m a.s.l.) in Arsi zone. This area was selected for the 1996 trials since grass weeds, particularly B. pectinatus, had caused total crop failure in some farmers' fields in 1995 (Mohammed Hassena, IAR, personal communication), and there are currently no herbicides capable of controlling this weed species available in Ethiopia. Soils on the selected farms were clay loams. Individual host farmers were preselected during the 1995 cropping season.

In 1996, treatments were modified to reflect observed limitations in the 1995 trials. At each site, three treatments (Table 2) were superimposed on fields ploughed according to the host farmers' practices, and the sowing dates used were selected by the host farmers. All plots sown by the row seeder were harrowed once using a blade harrow attachment (also developed by the third author) on the row seeder frame immediately prior to seeding; this pre-seeding operation eliminated newly emerged weed seedlings on the "stale" seedbed (cf. the conventional practice in which the post-seeding pass with the ox plough to incorporate seed and fertiliser destroys such seedlings). Plot dimensions, layout and seed rates were the same as in the 1995 trials. In 1996, however, the newly released bread wheat cultivar Kubsa (= HAR 1685) was used as was a zone-specific nutrient rate of 41 kg N and 46 kg P2O5 ha^-1 (i.e., with 18 N and 46 kg P2O5 as basal application).

The following agronomic parameters were measured in each trial plot: wheat and weed seedling densities at 25-30 days after emergence (DAE) (i.e., before weed control measures were imposed), wheat plant height, days to crop heading, wheat spikes m^-2 at maturity, wheat grain yield, biomass yield, and thousand kernel weight (TKW). Using these measured crop parameters, harvest index (HI), grains spike^-1 and grains m^-2 were calculated. In 1996, total grass inflorescences m^-2 were measured at crop maturity.

Labour data were recorded for all operations, including use of the blade harrow (in 1996 only), row seeding, broadcasting seed and fertiliser and covering with the local ox plough, hand weeding, row weeding, and spraying herbicide.

Farmers' assessments of the row seeder technology were solicited and recorded, including those of the host farmers plus neighbouring farmers who observed field operations during the cropping season.

The annual service cost (C) of the small-scale implements used in the trials were based on the following formula (Spencer *et al*., 1979):

C = rV/[1 - (1+r)-n]

where r = interest rate (assumed in this analysis to be 12% per year)

n = the number of years of effective use (assumed to be 5 years)
V = acquisition cost (estimated as 790 Ethiopian Birr (EB) for the row seeder and 150 EB for the row weeder) [6.6 EB = 1 US$ in March, 1997].

On the basis of preliminary observations of operating efficiency, it was estimated that the row seeder could service 6 ha y^{-1}, while the row weeder could service 2 ha y^{-1}; thus, the per ha annual cost of the two implements was 36.53 and 20.81 EB ha^{-1}, respectively.

Other costs/prices incorporated in the economic analysis were as follows: opportunity cost of labour: 4.50 EB work-day^{-1}, cost of fenoxaprop-P-ethyl: 330 EB ha^{-1}, cost of 2,4-D: 46 EB ha^{-1}, cost of sprayer rental: 4 EB ha^{-1} (excluding labour), field price of wheat grain: 1.05 EB kg^{-1} [also used for farmers' (own) seed price] and, field price of wheat straw: 0.03 EB kg^{-1} (assumed 60% recovery and economic disposal of straw)

Using the data for labour, input costs and output prices, the treatments were analysed according to the partial budget methodology developed by CIMMYT (1988).

RESULTS AND DISCUSSION

For the 1995 row seeder trial in Gonde/Itheya zone, four on-farm sites were successfully maintained throughout the season and harvested, but the fifth site was eliminated due to damage by grazing livestock. In 1996, all five on-farm sites in Asasa zone were harvested.

Agronomic results. In the 1995 trials, the treatment main effect (with 5 d.f.) was significant for days to heading, plant height, spike density, and grass weed seedling density (Table 3). However, partitioning the treatment effect into single degree of freedom (orthogonal) contrasts revealed that row seeding (vs. broadcasting) had a significant effect on the same four parameters plus biomass yield and harvest index. It is notable that there was no treatment effect upon early wheat seedling density (mean = 206 m^{-2}) despite the use of differential seed rates for the two seeding methods (i.e., 150 kg ha^{-1} for row seeder vs. 175 kg ha^{-1} for broadcasting).

Row seeding in contrast to broadcasting increased wheat plant height (91.9 vs. 89.0 cm), the number of wheat spikes m^{-2} at maturity (507 vs. 438), the number of days to heading for the crop (66.9 vs. 66.1), and wheat biomass yield (9271 vs. 8480 kg ha^{-1}); harvest index decreased in row seeded plots (34.1 vs. 36.3%), resulting in the relatively uniform wheat grain yield across treatments (i.e., 3188 kg ha^{-1} for row seeder vs. 3082 kg ha^{-1} for broadcasting, $P > 0.1$).

The density of grass weed seedlings identified prior to the application of weed control was greater (detransformed means = 11.0 vs. 4.5 m^{-2}) in row seeded vs. broadcast plots, presumably reflecting the relative ease of identifying grass seedlings in a row seeded wheat crop. It should be emphasised that the mean density of grass weed seedlings, primarily Avena fatua, counted in this trial (actual mean = 10.3 seedlings m^{-2}) was relatively low in comparison to prior on-farm studies conducted in Ethiopia (Amanuel *et al*., 1992a), despite the deliberate pre-selection of infested farm sites in 1994. Further, this weed density is below the economic threshold density reported by Taye *et al*. (1996b) for A. abyssinica in Ethiopia (i.e., ca. 17.3). Thus, it was decided to conduct the 1996 trials near Asasa in southern Arsi zone where problematic densities of grass weeds, particularly the herbicide-resistant *Bromus pectinatus*, are more frequently encountered on farmers' fields.

In the 1996 trials, the treatment main effect (with 2 d.f.) significantly affected the following wheat parameters: days to crop heading, biomass and grain yield, and the number of spikes and grains m^{-2} (Table 4). As in the 1995 trials, mean wheat seedling density (284 m^{-2}) was not affected by seeding method; thus, row seeding effectively allowed farmers to save 25 kg ha^{-1} of wheat seed by facilitating uniform depth of seed placement and seedling emergence.

Row seeding vs. broadcasting decreased the number of days to crop heading (69.8 vs. 70.8), and increased the number of wheat spikes m^{-2} at maturity (479 vs. 354), biomass yield (8609 vs. 6568 kg ha^{-1}), and the number of wheat grains m^{-2} (13517 vs. 10537).

In the combined analysis of variance for wheat grain yield in 1996, F values indicated that the effects of treatment ($P < 0.001$) and treatment by location (T x L) interaction ($P < 0.01$) were both significant, but the mean square for treatment was seven times the magnitude of the mean square for T x L. Assuming location to be a random factor, the treatment F value with 2 and 8 d.f. (i.e., testing the T/[T x L] ratio) was 7.077 (P=0.017). The significant T x L interaction in 1996 arose from inconsistent relative rankings of T2 and T3 (i.e., row seeder with 2,4-D vs. row weeder for weed control). At one site, T1 = T2 = T3, but at four sites, T1 was significantly < T2 and T3. However, at the latter four sites, T2 = T3 at two, T2 < T3 at one, and T3 < T2 at one site. Thus, on the basis of treatment means across the five sites [T1 (3230 kg ha^{-1}) < T2 (4103 kg ha^{-1}) = T3 (4181 kg ha^{-1})], it appears that the row seeder increased wheat grain yield by 912 kg ha^{-1} or 28% cf. the broadcast seeded treatment. There was no consistent difference associated with the use of the row weeder vs. 2,4-D application on the row seeded plots.

The mean grass weed seedling density (actual mean = 20.2 m^-2) was almost twice the density recorded in the 1995 trials. Consistent with the 1995 results, the recorded grass seedling density was greater (P < 0.1) in the row seeded (detransformed means = 23.7 vs. 13.3 m^-2) vs. broadcast plots prior to the first weed control intervention, reflecting the ease of identifying grass seedlings in the row seeded wheat crop. However, at maturity of the wheat crop, there were no differences (P > 0.1) in the density of grass weed inflorescences (actual mean = 69.2 m^-2) among treatments, although there was a tendency for grass density to be lower (P=0.13) in the row weeder treatment (actual mean = 60.5 m^-2) vs. the two treatments receiving 2,4-D + supplementary hand weeding (actual mean = 73.5 m^-2).

Labour data. In the 1995 trial, the row seeder markedly improved the efficiency of labour required to sow wheat, using only 22% of the time per unit area compared to the farmers' conventional practice (Table 5). Surprisingly, the reduction in labour required for hand weeding as a result of row seeding was not as great as could logically be expected (i.e., comparing T1 and T4); nonetheless, the use of the inter-row weeder markedly reduced hand weeding labour (i.e., comparing T2 and T4). The total labour required for all operations varying among the six treatments ranged from a low of 1.28 work-days ha^-1 (for T3 = row seeder + complete chemical weed control) to the maximum of 22.08 (for T4 = broadcast + hand weeding). Although labour for harvesting the wheat crop was not included in the economic analysis, it also appeared that row seeding marginally reduced this aspect by 9% (4.25 for broadcast vs. 3.79 work-days ha^-1 for row seeded wheat).

In 1996, the row seeder operation was preceded by one pass with a blade harrow attachment to ensure a flatter seedbed and to dislodge newly-emerged weed seedlings. Thus, the total time required for row seeding (i.e., the sum of 0.54 work-days ha^-1 for the blade harrow and 0.81 work-days ha^-1 for the row seeder) represented 38% of the time required for conventional sowing by broadcasting. Labour requirements for hand weeding, row weeding and herbicide application were similar to the values measured in 1995. Total labour requirements ranged from 15.66 (T2) to 26.66 work-days ha^-1 (T3).

Economic analyses. The results of the net benefit and marginal rate of return (MRR) analyses are presented in Table 6 and Table 7, respectively.

In the MRR analysis of the 1995 trials (Table 7), the highest cost treatments, T5 and T3, were dominated by the next highest cost treatment, T2; that is to say, T3 and T5 cost more than T2, but produced a lower return (net benefit) to the farmer. Thus, treatments in which complete chemical weed control (i.e., fenoxaprop-P-ethyl + 2,4-D) substituted for more labour-intensive weed control technologies were not profitable, particularly considering the relatively low density of grass weeds encountered at the trial sites in 1995.

The lowest cost production package (T6 = broadcast + 2,4-D) was outperformed by three other treatments: T1, T4 and T2 in order of increasing variable costs. Each of these treatments resulted in an MRR (i.e., relative to the next lowest cost treatment) greatly in excess of the minimum acceptable MRR of 100%. The most profitable treatment was T2 (= row seeder + row weeder + supplementary hand weeding), incurring 35.59 EB ha^-1 in additional variable costs relative to T6 and realising an increase of 418.27 EB ha^-1 in net benefit (= 1175% rate of return on the investment).

In the MRR analysis of the 1996 trials, the broadcast treatment (T1) was dominated by the lowest cost treatment T2 (i.e., T1 cost more and returned less revenue than T2). The most profitable treatment T3 (= row seeder + row weeder + supplementary hand weeding) incurred 20.31 EB ha^-1 additional variable costs relative to T2 (= row seeder + 2,4-D + supplementary hand weeding) and increased net benefit by 64.26 EB ha^-1 (= 316% rate of return on the investment).

Farmers' assessments. Farmers responded favourably in their comments on the performance and utility of the row seeder. They observed that wheat in the row seeded plots was superior to the broadcast crop in terms of stand establishment and plant vigour, particularly in the 1996 trials in Asasa zone, and attributed this to uniform distribution of the seed, enhanced emergence of wheat seedlings, and the placement of basal fertiliser in crop rows, thus enabling wheat to utilise the fertiliser more effectively while depriving weeds in the inter-row spaces of nutrients. They noted that the row seeder worked effectively in rough and cloddy fields, applying a uniform rate of seed and fertiliser. Hand weeding was reported to be easier in row seeded vs. broadcast wheat, and it was also possible to use the row weeder (having a 17 cm wide blade) between the rows. However, farmers expressed a concern that use of the row weeder might be limited on heavier clay soils, particularly when the soils are saturated.

CONCLUSIONS

On the basis of an on-farm evaluation conducted over two cropping seasons, it appears that the "AIRIC Row Seeder for Wheat" in conjunction with an inter-row weeder represents a sustainable technology for peasant wheat production in Ethiopia. The row seeder established a uniform wheat stand, using 25 kg ha^-1 less seed than the standard farmers' practice of broadcasting, increased the efficiency of labour for sowing, and increased wheat grain yield by 28% in the second year of testing. The nonherbicidal crop management package of the row seeder combined with a row weeder reduces the need to apply high efficacy herbicides, such as fenoxaprop-P-ethyl, for grass weed control, minimising the investment by farmers and the nation in expensive imported herbicides.

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