Effect of Straw Management, Tillage and Cropping Sequence on Weed Population Dynamics in South-Eastern Highlands of Ethiopia

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Abstract

Four multi-factor crop management trials were initiated in 1992 in the south-eastern highlands of Ethiopia. Two of the trials were based on mechanised tillage, while two trials were based on the traditional ox-plow of Ethiopia. The trials examined the effects of alternative practices of crop residue management, tillage and cropping sequence on weed population dynamics. Partial removal or retention of stubble was followed by increase in the population density of some broadleaf weed species, while burning had the opposite effect. Burning of crop stubble also markedly reduced the total grass weed population as compared to the other straw management treatments. Broadleaf weed population were not affected by tillage practices in either the ox-plow or mechanised trials. Grass weeds, however, increased significantly in density under minimum or zero tillage. Amount of Broadleaf weeds did not vary markedly in response to cropping sequence, but most of the grass weed population decreased in the faba bean rotation.

Key words: Straw management, tillage, cropping sequence, weed population dynamics, South-Eastern Highlands
Running title: Effect of farming practices on weed population

Introduction

Weeds are a big threat to wheat production in Ethiopia, causing yield losses of up to 70% under specific conditions (Tanner and Giref 1991). Globally, they can cut wheat yields by 50% under heavy weed competition and sometimes depress to zero (Hanson et al. 1982). Weeds, in addition to their effects on wheat yield, play a significant role in harbouring insects, serving as alternate hosts to some diseases, and increasing the cost of production (Bahrendt and Hanf 1979).

Currently, in Ethiopia, weed control is one of the priority production constraints faced by wheat producers. In the south-eastern region, where small-scale wheat producers are predominant, problematic grass weeds, in particular, represent a serious threat to sustainable wheat production. Farmers' response to weed infestation consists of two approaches: hand weeding, which demands more time and labor, and chemical herbicides, primarily to control broadleaf weeds.

Despite these control efforts, Ethiopian wheat farmers have not succeeded in markedly reducing yield losses. Equally, if not more, important, the low availability and high cost of chemical herbicides aggravate yield losses due to weeds (Chilot et al. 1992). Thus, to optimise and sustain wheat yields in Ethiopia, it is important to study those aspects of crop husbandry which could minimise weed interference with the crop (Akobundu 1987), and encourage wheat growth by reducing weed competition (Triplett 1986). Such aspects may include stubble management, tillage practice and cropping sequence.

The effects of stubble management on weed infestation are diverse (Rasmussen et al. 1986). Some research results indicate that stubble burning affects the incidence of viable weed seeds in the soil, reducing the seed bank. Other reports draw attention to the role of stubble retention. Some studies stress the importance of stubble in releasing toxic (i.e., allelopathic) chemicals that hinder weed growth; these effects vary with weed species (Cheam 1986).

Tillage, in addition to establishing a fine-tilth seedbed, is often considered crucial for the control of weeds. Conventional tillage brings weed seeds to the surface where they can germinate and be desiccated by subsequent tillage passes (Akobundu 1987, Triplett 1986). However, reduced tillage often increases the density of some problematic weed species (Tanner and Giref 1991). Nonetheless, it has been reported that most alternate methods of weed control are more energy efficient than weed control by conventional tillage (Clements et al. 1996).

Crop rotation involves the use of different species as break crops to benefit the major crop, disturbing the environment and life cycle of weeds, and thereby reducing their competitive effect on the crop.

Modified cropping sequences may not eliminate interference by weeds, but can limit the build-up of weed populations and minimise shifts in species composition (Birhanu 1985). By growing a sequence of crops, it is possible to disrupt weed population due to differences in crop maturation, growth habit (i.e., reducing light infiltration), competitive ability, or allelopathic effects on weeds. The use of break crops of differing morphology can facilitate hand weeding and the use of strategic rotations, with different herbicides applied to each crop species, reduces the risk of developing herbicide-resistant weed biotypes (Higgs et al. 1990).

In Ethiopia, although some initial works have been conducted on the independent effects of tillage and cropping sequence on weed incidence in wheat (Asefa et al. 1992), no previous research examined the integrated effects of stubble management, tillage and cropping sequence. The current study examines the effects of these crop management practices on the population dynamics of several weed species in the highlands of south-eastern Ethiopia.

Materials and Methods

Experimental sites

Four crop management trials were initiated during 1992 at Kulumsa (8°02'N and 39°10'E) and Asasa (7°08'N and 39°13'E) research stations located in the south-eastern highlands of Ethiopia at respective altitudes of 2200 and 2360 m respectively. During the main crop growing season (i.e., June to November), long-term mean monthly minimum and maximum temperatures are 10.6 and 22.1 °C at Kulumsa and 6.7 and 22.7 °C at Asasa; mean precipitation during the main cropping season is 504 mm at Kulumsa and 472 mm at Asasa. Kulumsa has clay soil (an intergrade between a eutric Nitisol and a luvic Phaoezem) and Asasa clay loam soil (calcic Chernozem).

Trial design. Two trials: one mechanised and one ox-plow were located at each of Kulumsa and Asasa. The mechanised trial consisted of 12 treatments comprising the complete factorial combination of: (a) three levels of post-harvest straw management (SM)—straw burning (BURN), partial straw removal (50%) (PARM), and complete retention of straw (RET); (b) two levels of tillage—zero tillage (ZT) and conventional tillage (CT) at Kulumsa, and minimum tillage (MT) and CT at Asasa, and; (c) two levels of cropping sequence (CS)—continuous wheat and one year of faba bean (*Vicia faba*) followed by two years of wheat.

The ox-plow trial consisted of eight treatments comprising the complete factorial combination of: (a) two levels of post-harvest SM—straw burning and partial removal (50%); (b) two levels of tillage—MT and CT, and; (c) two levels of CS—continuous wheat and one year of faba bean followed by two years of wheat.

For each trial, all treatments were laid out in a split-split-plot arrangement in a randomised completed block design with three replications. SM treatments were initiated in main plots of 20 x 20 m, tillage in sub-plots of 10 x 20 m, and CS in sub-sub-plots of 5 x 20 m in 1992. All treatments were applied to permanent plots maintained over the trial duration.

Crop management practices. In the mechanised trials, conventional tillage consisted of one pass with a tractor-drawn disc plow followed by two passes with a disc harrow during the "short rains" fallow period in order to maximise weed control. At Kulumsa, a tractor-drawn "Aitchison Seedmatic 3000" zero-till drill was used to sow seed plus basal fertiliser for the CT and ZT treatments. However, in the mechanised trial at Asasa, one pass with a disk harrow was used to incorporate broadcast seed and fertiliser for the MT and CT treatments.

In the ox-plow trials, CT consisted of four plowings prior to sowing (i.e., similar to farmers' practice); for MT, one pass was done to incorporate the broadcast seed and fertilizer.

For the MT and ZT treatments, chemical fallow was substituted for tillage during the "short rains" period each year; glyphosate was applied at 720 g/ha active ingredient (a.i.) as required during the "short rains" season to prevent weeds from attaining a height of 20 cm with a maximum of two applications per season.

Partial straw removal simulated grazing by removing 50% of post-harvest crop stubble. Thus, approximately 500 kg/ha of stubble remained on the soil surface at sowing time. Straw burning was carried out during late January each year before the "short rains" began. Plots with complete straw retention were left undisturbed until spraying or tillage operations began; more than 2 t/ha of stubble remained on the soil surface at sowing time.

Zone-specific recommended levels for the non-experimental crop management factors were adopted for bread wheat and faba bean during the trial period. Over the trial period (1992 to 2000), sowing dates ranged from June 11 to 19 at Asasa and from June 26 to July 7 at Kulumsa. As per the initial trial plan, the best recommended crop cultivars were utilised each season. This was particularly important for bread wheat since some cultivars succumbed to new races of foliar rust pathogens (*Puccinia* spp.) during the course of the trial. Thus, over the trial duration, the bread wheat cultivars Enkoy (1992–93), Mitike (1994), and Qubsa (1995–2000) were sown at seed rate of 150 kg/ ha. From 1992 to 1994, bread wheat received a basal N application of 41 kg/ha at Kulumsa and 18 kg/ha at Asasa. From 1995 to 2000, newly-recommended fertilizer rates were implemented, and bread wheat received a basal N application of 82 kg/ha at Kulumsa and 41 kg/ha at Asasa. During 1992, 1995, and 1998, faba bean cultivar CS20DK was sown at seed rate of 200 kg/ha and basal N was applied to it at rate of 18 kg/ha at both Kulumsa and Asasa. Both crops received a basal application of 20 kg P/ha each year. Due to the risk of damage by spray drift, hand weeding was done to control weeds during 1992, 1995, and 1998 when both wheat and faba bean were sown. During 1993, 1994, 1996, 1997, 1999 and 2000, when all plots were sown to wheat, weed control entailed a post-emergence spray application of a tank mix of 0.069 kg a.i./hafenoxaprop-P-ethyl + 0.175 kg a.i./ha fluroxypyr + 3.0kga.i./haMCPA.

Weed assessment: Weed count data (no/m^2) were collected each year at each location 30–35 days after crop emergence and prior to the first hand weeding or herbicide application. Four counts of 0.25 m^2 each using metal quadrats were taken from each plot, resulting in a total sample area of 1 m^2. All weeds within the quadrat were uprooted and separated into the different species and counted. Depending on weather conditions and weed populations, grass weed panicle of the major grass weed species were counted at maturity of wheat.

Statistical analysis: The weed count data were transformed using a square root transformation of actual data (i.e., SQRT [weed count /m^2 + 0.5]) to satisfy the assumptions of normality of distribution and homogeneous variances. The adjustment constant of 0.5 was used for count data to compensate for the 0 values (i.e., when a weed species is absent from a given plot). The transformed weed density data were subjected to analysis of variance separately for each trials. For the significant factor interaction, interaction means were separated by the LSD test at $P = 0.05$.

Results

The effects of the studied crop management factors on density of weed seedling varied with location due to soil and climatic differences and weed species. The results from the mechanised and ox-plow trials, on total broadleaf weed (TBW) and total grass weed (TGW) population densities were summarised in Tables 1–3). All the means presented in the text and tables in this section are detransformed from the ANOVA means.

Straw management: TBW seedling density was affected by stubble management in the Kulumsa mechanised trial during 1997, 1998 and 1999 (Table 1). In 1997 and 1998, complete retention of crop stubble (RET) of crop stubble resulted in more total broadleaf weed density than to partial removal of crop stubble (PARM) and burning of crop stubble (BURN), respectively; in 1999, TBW density was equal for RET and PARM and both were significantly greater than BURN. In the Asasa mechanised trial, a significant effect of stubble management on TBW was observed during 1996 and 1999; in both years, TBW values for PARM and RET were equal and greater than TBW values for BURN (Table 1).

In the Asasa ox-plow trial, a significant effect of stubble management on TBW was observed during 1995; 1997 and 2000; in 1995, TBW was greater for BURN than for the PARM treatment, but, in 1997 and 2000, TBW was denser on PARM than on BURN (Table 1). The ox-plow trial at Kulumsa didn't exhibit a significant effect of SM on total broadleaf density in any year (Table 1).

TGW seedling density was significantly affected by SM in the Kulumsa mechanised trial during 1995 and 2000, in the Asasa mechanised trial during 1998 and 2000, in the Kulumsa ox-plow trial during 1996 and 1997, and in the Asasa ox-plow trial during 1995, 1998 and 2000 (Table 1). With only one exception, density of TGW was significantly low for the BURN treatment in each trial in which a significant effect of SM was observed.

In the Asasa mechanised trial during 1998, the TGW density for the BURN treatment was lower than for RET, while PARM was intermediate and equal to the other two treatments.

Guizotia scabra seedling density was significantly affected by the SM treatments during 1995 in the Kulumsa mechanised trial and during 1997 in the Kulumsa ox-plow trial. In 1995 density of *G. scabra* was the lowest for PARM, but the highest for RET; in 1997, PARM reduced the density of *G. scabra* relative to BURN (Table 2). Thus, the effects of SM on *G. scabra* density were consistent across the two trials.

SM affected *Amaranthus hybridus* seedling density in the two trials at Asasa during 1997 (Table 3). In both trials, the BURN treatment resulted in the lowest *A. hybridus* density. However, in the mechanised trial, the PARM treatment resulted in intermediate *A. hybridus* density and equal to the other two treatments. Density of the weed was the highest for RET.

Seedling density *of Setaria pumila* was significantly affected by SM in the Kulumsa mechanised trial during 1995, in the Asasa mechanised trial during 1995 and 1997, and in the Kulumsa ox-plow trial during 1996 (Table 4). In each trial, density of *S. pumila* was higher on the PARM treatment than on the other two treatments.

Bromus pectinatus seedling density was significantly affected by SM in the Kulumsa mechanised trial during 1999 and 2000, in the Asasa mechanised trial during 1997, 1998 and 2000, in the Kulumsa ox-plow trial during 1999 and 2000, and in the Asasa ox-plow trial during 1994, 1997 and 2000 (Table 5). In each trial, the BURN treatment resulted in the lowest *B. pectinatus* density in wheat, reflecting a consistent effect of stubble burning in reducing the seedling density of *B. pectinatus*. In the Kulumsa mechanised trial during 2000, the retention treatment exhibited the highest weed density, while the Asasa mechanised trial during the same year exhibited a higher density for PARM than for RET (Table 5).

Tillage: Of the three crop management factors, tillage exerted the most pronounced effect on weed seedling density. TBW seedling density was significantly affected by tillage in the Kulumsa mechanised trial during 1994 and 1999, in the Asasa mechanised trial during 1994, 1996, 1997, 1998 and 2000, in the Kulumsa ox-plow trial during 1994, 1998, and 1999, and in the ox-plow trial at Asasa during 1993, 1997, 1999 and 2000 (Table 6). CT resulted in the highest TBW density only in the Kulumsa ox-plow trial during 1998. In the Asasa mechanised and ox-plow trials, CT markedly increased TBW density in eight trials, while MT increased TBW density in only the Asasa ox-plow trial during 1999. TGW seedling density was affected by tillage in the mechanised trial at Kulumsa during 1995, 1996, 1999 and 2000; in the mechanised trial at Asasa during 1998 and 2000; and in the ox-plow trial at Kulumsa during 1996 and 1997 (Table 6). However, the ox-plow trial at Asasa failed to exhibit a significant effect of tillage on TGW density in any year (Table 6).

G. scabra density was affected by tillage in the Kulumsa mechanised trial during 2000, in the Asasa mechanised trial during 1999, and in the ox-plow trials at Kulumsa and Asasa during 2000 (Table 2). In the Kulumsa mechanised and Asasa ox-plow trials, CT resulted in a higher *G. scabra* density than ZT/MT. In the mechanised trial at Asasa and the ox-plow trial at Kulumsa, MT resulted increased *G. scabra* density more than under conventional tillage. Thus, the effect of tillage on *G. scabra* density was not consistent across.

Tillage significantly affected the seedling density of *Amaranthus hybridus* in the Asasa mechanised trial during 1994, 1996, 1997 and 2000; in the Kulumsa mechanised trial during 1999; and in the Asasa ox-plow trial during 1997 (Table 3).

Seedling density of *Setaria pumila* was significantly affected by tillage in the Kulumsa mechanised trial during 1995; in the Asasa mechanised trial during 1995, 1996 and 1997; and in the ox-plow trials at Kulumsa and Asasa during 2000 (Table 4). In the Asasa mechanised and ox-plow trials, seedling density of *Setaria pumila* significantly increased under CT more than under MT, but, in the Kulumsa trials, the population density of *S. pumila* increased under ZT/MT (Table 4). Thus, the effect of tillage practice on *S. pumila* density was site-specific, perhaps dependent on prevailing soil and weather conditions.

Seedling density of *Bromus pectinatus* was significantly affected by tillage in the Kulumsa mechanised trial during 1999 and 2000; and in the Asasa mechanised trial during 1996, 1998 and 2000 (Table 5). In all the five instances of significance, seedling density of *B. pectinatus* increased more under ZT/MT than under conventional tillage.

Cropping sequence: TBW seedling density was significantly affected by CS in the Kulumsa mechanised trial during 1993 and in the Asasa mechanised trial during 1996, 1999 and 2000 (Table 7). In each instance of significance, the faba bean rotation resulted significantly increased TBW density than did the continuous wheat treatment. The ox-plow trials at both sites failed to exhibit a significant effect of CS on TBW density. In the mechanised trials, most of the broadleaf weed species had high density under the legume-wheat crop rotation, implying that the residual N after the legume harvest enhanced the vigor of the broadleaf weed species. TGW seedling density was significantly affected by CS in the Kulumsa mechanised trial during 1997 and 2000; in the Asasa mechanised trial during 1996 and 2000; in the Kulumsa ox-plow trial during 1996 and 1997; and in the Asasa ox-plow trial during 1996.

Seedling density of *G. scabra* was significantly affected by CS in the mechanised trial at Kulumsa during 1993 and in the ox-plow trial at Kulumsa during 1993 and 1999 (Table 2). During 1993, in both trials, the faba bean rotation resulted in higher *G. scabra* density than did continious wheat (CW). In the ox-plow trial at Kulumsa during 1999, *G. scabra* density was significantly higher in CW than in the faba bean rotation (Table 2). The mechanised and ox-plow trials at Asasa did not exhibit a significant effect of CS on *G. scabra* density in any year .

CS significantly affected the seedling density of *Amaranthus hybridus* in the mechanised trial at Asasa during 1993 and 1996; and in the ox-plow trials at Asasa during 1996 and 1997 (Table 3). In the Asasa mechanised trial during 1993 and the Asasa ox-plow trial during 1997 density of *A. hybridus* significantly increased under CW. In both trials at Asasa during 1996, density of *A. hybridus* markedly increased under the faba bean rotation more than under CW (Table 3). In the mechanised and ox-plow trials at Kulumsa, cropping sequence had no significant effect on *A. hybridus* density in any season throughout the trial period (Table 3). These results suggest that the effect of cropping sequence on *A. hybridus* density varies markedly with location and season.

CS significantly affected seedling density of *Setaria pumila* in the mechanised trial at Asasa and in the ox-plow trial at Kulumsa during 1996 and 1999 (Table 4). In the Asasa mechanised trial during 1996 and 1999 and in the Kulumsa ox-plow trial during 1996, population density of *S. pumila* significantly increased under CW. In the Kulumsa ox-plow trial during 1999, density of *S. pumila* in wheat markedly increased under the faba bean rotation. CS significantly affected seedling density of

B. pectinatus in the Asasa mechanised trial during 1996 and 2000; in the Kulumsa ox-plow trial during 1999; and in the Asasa ox-plow trial during 1994, 1996 and 1997 (Table 5).

Discussion

SM exhibited a relatively consistent effect on TBW and TGW seedling density across the trials and seasons. Burning of crop stubble reduced weed seedling populations more than did the other two treatments; complete stubble retention tended to increase weed densities to the greatest extent. In three of the four instances of a significant SM effect, the BURN treatment resulted in the lowest seedling density of *S. pumila*. However, in the Asasa mechanised trial during 1995, the BURN treatment resulted in intermediate and equal *S. pumila* density to the other two treatments. Thus, SM reflected a relatively consistent effect on *S. pumila* density.

In most cases, TBW density was significantly higher under ZT/MT in the Kulumsa mechanised and ox-plow trials in Ethiopia. Tanner and Giref (1991) reported a higher density of *Guizotia scabra, Plantago lanceolata* and *Galium spurium* under reduced tillage. In each instance of significance, ZT/MT markedly increased TGW density, reflecting a consistent effect of reduced tillage in increasing TGW density more than under conventional tillage. Kamwaga (1990) indicated a higher density of grass weeds under minimum tillage in wet conditions. Overall density of weed seedling increased under minimum or zero tillage more than under the conventional tillage practice. Elsewhere, weed populations have been observed to build up rapidly under zero or minimum tillage (Arshad *et al.*, 1994), necessitating the use of increasingly sophisticated post-emergence weed management practices. Clements *et al.* (1996) and Giref *et al.* (1992) have reported that some broadleaf weed species germinate at reduced frequency under zero tillage.

The effect of tillage treatment on the population density of grass weed species was consistent in both mechanised trials at Kulumsa and Asasa. CT significantly reduced seedling density of the weed. Repeated tillage brings weed seeds to the surface and exposes them to desiccation, on one hand buries seeds deep in the soil, creating unsuitable conditions for germination and growth, reducing the density of some weeds on the other (Akobundu 1987, Wilson and Cussans 1985). Tillage had no effect on *B. pectinatus* density in the two ox-plow trials.

Density of *A. hybridus* consistently increased under CT than ZT/MT. However, in the Kulumsa ox-plow trial, tillage treatment showed no effect on *A. hybridus* density in any year (Table 3). In a previous study, Gireg *et* al. 1992, indicated that Amaranthus spp. exhibited poor germination on zero till plots, and *Guizotia scabra, Galinsoga parviflora* and *Galium spurium* also occurred at lower densities under zero tillage compared to CT.

In the six instances of significance, continuous wheat significantly resulted in more TGW seedling density than did the legume-wheat rotation. Thus, rotation of wheat with faba bean is a promising means of reducing grass weed densities in wheat. Grass weed species build up in continuous wheat production systems (Heenan *et al.* 1990). The population density of *B. pectinatus* in wheat increased under CW (Table 5), reflecting a higher infestation of the weed in continuous wheat production systems. Herbicidal control of other grass weeds by the application of fenoxaprop-p-ethyl might have contributed to the increase in numbers of this weed species since the chemical does not control *Bromus* species.

Conclusions

Weed species responded differentially to the crop management factors included in the current study. Partial removal or retention of stubble tended to increase the density of some broadleaf weed species, whereas, the burn treatment reduced weed density. Total grass weed density showed a consistent pattern across trials: burning crop stubble markedly reduced the weed population more than did the other SM treatments. The effects of tillage also varied with weed species and location. Broadleaf weeds did not exhibit a consistent response to tillage in nither the ox-plow nor mechanised trials. Grass weeds, however, markedly increased in density under MT or ZT. Broadleaf weeds did not vary markedly in response to CS, but most grass weeds decreased in the faba bean rotation.

The density of *Bromus pectinatus* could be reduced by occasional burning of crop stubble, by conventional tillage, and by adopting crop rotation with faba bean. Since no herbicide is currently available to effectively control this problematic weed species in Ethiopia, care must be taken to avoid inducing a weed population shift towards *B. pectinatus* (i.e., by practicing continuous wheat production under reduced tillage with stubble retention).

Table 1. Effects of straw management on total broadleaf and total grass weed population density

	1993	1994	1995		1996		1997		1998		1999		2000	
	TBW	TBW	TBW	TGW	TBW	TGW	TBW	TGW	TBW	TGW	TBW	TGW	TBW	TGW
Kulumsa														
Mechanized Burn	135	62.9	58.8	11.9B	20.6	2.56	48AB	2.31	21.9B	1.32	107B	47	49	92B
Removal	110	73.1	41.5	39.2A	22.1	2.25	40B	3.50	22.5AB	3.68	188A	58	33	128AB
Retention	139	60.1	7.42	27.9A	27.1	1.67	51A	5.38	38.3A	5.15	207A	69	59	160A
Prob	NS	NS	NS	**	NS	NS	†	NS	†	NS	*	NS	NS	*
Kulumsa Burn	136	91.5	49.6	14.8	23.9	4.32B	64.3	2.37B	42.9	3.92	188	6.74	56	61
Ox-plow Removal	125	79.6	36.8	16.3	24.7	69.3A	78.5	3.31A	73.9	5.71	184	4.19	56	95
Prob	NS	NS	NS	NS	NS	**	NS	†	NS	NS	NS	NS	NS	NS
Asasa Burn	62.4	34.8	66.7	101.2	33.3B	7.84	82.2	16.6	72.0	27B	43B	30	40	53C
Mechanized Removal	57.8	49.0	49.7	151.0	69.7A	19.7	96.4	30.1	100	90AB	66A	36	53	368A
Retention	88.9	57.8	56.7	98.0	67.7A	20.3	96.4	44.9	108	104A	70A	48	63	261B
Prob	NS	NS	NS	NS	†	NS	NS	NS	NS	†	*	NS	NS	**
Asasa Burn	66.3	24.8	20.7A	92B	26.3	25.8	39.5B	21.3	38.6	16.7B	37	18	15B	86B
Ox-plow Removal	59.8	24.8	8.6B	557A	40.0	15.0	65.1A	29.3	63.4	70.0A	47	27	24A	327A
Prob	NS		*	*	NS	NS	†	NS	NS	**	NS	NS	**	**

†, *, **, *** Statistically significant at $0.05 < P < 0.1$, $0.01 < P < 0.05$, $0.001 < P < 0.01$, and $P < 0.001$, respectively.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

All values detransformed from ANOVA means [i.e., based on SQRT (weed count/m^2 + 0.5)]. Probability levels and LSD groupings determined from ANOVA on transformed data.

TBW = Total broadleaf weed; TGW = Total grass weed

Table 2. Effects of crop management treatments on *Guizotia scabra* seedling density

	KuMec93	KuMec95	KuMec00	AsMec99	KuOx93	KuOx97	KuOx99	KuOx00	AsOx00
Straw management									
Burn	7.68	0.78AB	2.68	4.21	7.79	1.01A	4.73	4.42	2.36
Remove	6.11	0.54B	1.66	2.21	9.05	0.67B	6.85	4.84	2.28
Retain	9.49	2.19A	0.53	2.17	---	---	---	---	---
Prob.	NS	P<0.1	NS	NS	NS	*	NS	NS	NS
Tillage									
Conventional	8.56	0.89	2.47A	1.99B	9.68	0.69	6.20	2.63B	3.46A
Zero/Minimum	6.95	1.30	0.78B	3.73A	7.23	0.99	5.31	7.12A	1.75B
Prob.	NS	NS	**	P<0.1	NS	NS	NS	*	P<0.1
Cropping sequence									
Faba bean rotation	16.5A	---	1.08	3.82	12.6A	0.89	4.38B	5.26	0.62
Continuous wheat	4.52B	---	2.02	1.92	6.47B	0.75	7.28A	4.03	2.88
Prob.	***	---	NS	NS	*	NS	*	NS	NS
Mean	7.74	1.11	1.52	2.80	8.38	0.83	5.75	4.65	2.56
C.V.(%)	29.7	28.5	41.3	48.5	37.7	62.0	18.7	44.3	29.3

*, **, *** Statistically significant at $0.01 < P < 0.05$, $0.001 < P < 0.01$, and $P < 0.001$, respectively.

KuMec = Kulumsa mechanized; KuOx = Kulumsa oxen plow; AsMec = Asasa mechanized;
AsOx = Asasa oxen.

All values detransformed from ANOVA means [i.e., based on SQRT (weed count/m^2 + 0.5)]. Probability levels and LSD groupings determined from ANOVA on transformed data.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 3. Effects of crop management treatments on *Amaranthus hybridus* seedling density

	KuMec99	AsMec93	AsMec94	AsMec96	AsMec97	AsMec00	AsOx96	AsOx97
Straw management								
Burn	1.23	9.42	2.74	173.7	13.6B	1.57	8.5	10.9B
Remove	0.80	4.42	2.39	323.5	20.4AB	3.38	63.5	15.4A
Retain	1.24	9.55	2.74	547.1	28.9A	3.82	---	---
Prob.	NS	NS	NS	NS	P<0.1	NS	NS	P<0.1
Tillage								
Conventional	1.96A	10.0	3.91A	728.5A	31.0A	5.26A	31.6	19.4A
Zero/Minimum	0.40B	5.50	1.75B	80.5B	10.7B	1.59B	27.9	7.85B
Prob.	*	NS	*	*	*	*	NS	*
Cropping sequence								
Faba bean rotation	1.36	5.65B	3.11	483.5A	24.1	3.62	48.5A	10.5B
Continuous wheat	0.83	10.2A	2.74	224.5B	17.1	2.15	15.5B	15.9A
Prob.	NS	P<0.1	NS	*	NS	NS	*	*
Mean	1.08	7.62	2.74	330.7	20.5	2.85	29.8	13.0
C.V.(%)	46.9	30.9	32.6	62.2	32.8	39.5	57.4	18.1

* = Statistically significant at $0.01 < P < 0.05$

KuMec = Kulumsa mechanized; AsMec = Asasa mechanized; AsOx = Asasa oxen.

All values detransformed from ANOVA means [i.e., based on SQRT (weed count/m^2 + 0.5)]. Probability levels and LSD groupings determined from ANOVA on transformed data.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test

Table 4. Effects of crop management treatments on *Setaria pumila* seedling density

	KuMec95	AsMec95	AsMec96	AsMec97	AsMec99	KuOx96	KuOx99	KuOx00	AsOx00
Straw management									
Burn	10.6C	12.2AB	2.74	7.17B	10.1	1.52B	0.74	9.35	2.03
Remove	33.7A	24.1A	2.39	11.3A	7.92	17.6A	1.60	3.62	2.81
Retain	23.8B	9.55B	3.11	7.34B	9.27	---	---	----	----
Prob.	***	P<0.1	NS	*	NS	P<0.1	NS	NS	NS
Tillage									
Conventional	9.42B	24.7A	4.79A	12.7A	10.6	2.29	1.65	3.82B	4.16A
Zero/Minimum	38.9A	7.23B	1.46B	4.61B	7.92	15.5	0.64	9.04A	1.06B
Prob.	***	P<0.1	*	*	NS	NS	NS	*	*
Cropping sequence									
Faba bean rotation	---	---	1.19B	8.80	3.31B	0.67B	2.16A	7.28	1.57
Continuous wheat	---	---	4.79A	7.62	17.9A	20.5A	0.36B	5.26	3.38
Prob.	---	---	**	NS	***	*	*	NS	NS
Mean	21.6	14.8	2.75	8.20	9.29	7.51	1.14	6.20	2.42
C.V.(%)	23.1	61.4	55.0	54.3	45.1	103.4	50.9	56.7	45.1

*, **, *** Statistically significant at $0.01 < P < 0.05$, $0.001 < P < 0.01$, and $P < 0.001$, respectively.
KuMec = Kulumsa mechanized; KuOx = Kulumsa oxen plow; AsMec = Asasa mechanized; AsOx = Asasa oxen.
All values detransformed from ANOVA means [i.e., based on SQRT (weed count/m^2 + 0.5)]. Probability levels and LSD groupings determined from ANOVA on transformed data.
Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 5. Effects of crop management treatments on *Bromus pectinatus* seedling density

	KuMec99	KuMec00	AsMec96	AsMec97	AsMec98	AsMec00	KuOx99	KuOx00	AsOx94	AsOx96	AsOx97	AsOx00
Straw management												
Burn	0.00B	5.95C	1.35	2.36B	3.38B	14.2C	1.86B	12.7B	48.2B	16.2	6.47B	77.1B
Remove	2.41AB	21.1B	10.3	12.9A	50.5A	324.5A	9.27A	45.1A	147.9A	203.9	15.4A	323.5A
Retain	4.15A	66.2A	11.3	16.3A	57.7A	216.8B	—	—	—	—	—	—
Prob.	P<0.1	**	NS	*	*	**	**	***	*	NS	*	P<0.1
Tillage												
Conventional	0.15B	7.45B	2.89B	4.08	14.7B	60.5B	4.93	28.6	80.7	86.5	7.85	184.5
Zero/Minimum	4.53A	66.2A	12.0A	17.2	52.4A	271.8A	4.93	24.5	102.6	81.9	13.5	173.7
Prob.	*	**	*	NS	*	***	NS	NS	NS	NS	NS	NS
Cropping sequence												
Faba bean rotation	1.05	7.70	3.26B	7.85	—	73.5B	1.03B	21.1	57.9B	30.6B	6.42B	127.2
Continuous wheat	2.75	44.5	11.4A	11.5	—	247.0A	11.2A	32.4	103.5A	163.3A	36.1A	239.8
Prob.	NS	NS	**	NS	—	*	**	NS	*	*	P<0.1	NS
Mean	1.82	29.6	6.26	9.55	30.7	148.3	4.93	26.5	91.3	84.3	10.5	179.5
C.V.(%)	102.9	75.5	43.0	70.9	49.7	39.5	40.3	28.0	22.3	60.9	44.8	44.2

*, **, *** Statistically significant at $0.01 < P < 0.05$, $0.001 < P < 0.01$, and $P < 0.001$, respectively.

KuMec = Kulumsa mechanized; KuOx = Kulumsa oxen plow; AsMec = Asasa mechanized; AsOx = Asasa oxen.

All values detransformed from ANOVA means [i.e., based on SQRT (weed count/m^2 + 0.5)]. Probability levels and LSD groupings determined from ANOVA on transformed data.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

Table 6. Tillage effects on total broadleaf and total grass weeds population density

	1993	1994	1995		1996		1997		1998		1999		2000	
	TBW	TBW	TBW	TGW	TBW	TGW	TBW	TGW	TBW	TGW	TBW	TGW	TBW	TGW
Kulumsa Mechanized CT	128	52.6B	55.9	11.5B	24.0	2.89B	44.3	3.27	1.04	2.10	90.3B	54B	50	67B
ZT	130	79.2A	47.3	43.6A	26.0	6.76A	49.8	7.04	1.12	1.08	260A	95A	43	196A
Prob	NS	†	NS	**	NS	***	NS	NS	NS	NS	**	*	NS	**
Kulumsa CT	119	69.6B	49.4	12.1	21.1	17.3B	67.2	1.66B	58.4A	734	11.5B	8.64	42.8	79.6
Ox-plow MT	118	102A	48.5	19.4	22.5	39.0A	75.7	4.38A	30.8B	2.78	210A	2.86	71.9	74.6
Prob	NS	*	NS	NS	NS	**	NS	*	*	NS	†	NS	NS	NS
Asasa CT	73.1	68.9A	62.3	106	85A	13.6	118A	27.6	30.0A	43B	56.3	36.2	70A	90B
Mechanized MT	65.1	29.2B	52.9	126	42B	17.2	58B	30.5	13.4B	102A	63.0	39.2	36B	317A
Prob	NS	†	NS	NS	***	NS	*	NS	*	**	NS	NS	**	**
Asasa CT	74.1A	18.3	15.5	10.6	27.9	9.80	61.9A	29.9	50.6	45.4	37.9B	21.2	24A	189
Ox-plow MT	52.7B	21.7	12.3	16.6	38.4	10.3	42.1B	20.8	49.7	38.8	43.3A	23.7	18B	175
Prob	*	NS	NS	NS	NS	NS	**	NS	NS	NS	†	NS	†	NS

†, *, **, *** Statistically significant at $0.05 < P < 0.1$, $0.01 < P < 0.05$, $0.001 < P < 0.01$, and $P < 0.001$, respectively.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

All values detransformed from ANOVA means [i.e., based on SQRT (weed count/m^2 + 0.5)]. Probability levels and LSD groupings determined from ANOVA on transformed data.

TBW = Total broadleaf weed; TGW = Total grass weed

Table 7. Cropping sequence effects on total broadleaf and total grass weeds population density

	1993	1994	1996		1997		1999		2000	
	TBW	TBW	TBW	TGW	TBW	TGW	TBW	TGW	TBW	TGW
Kulumsa										
Mechanized FB	146A	64	27.0	3.40	43.9	2.40B	186	54	49.9	94B
CW	114B	60	23.0	6.25	19.6	5.15A	144	62	43.3	157A
Prob	*	NS	NS	NS	NS	*	NS	NS	NS	*
Kulumsa FB	120A	77.6	26.7	16.6B	27.2	2.68B	211	5.54	64	73
Ox-plow CW	96B	97.4	21.9	40.1A	27.8	3.13A	163	5.59	50	81
Prob	P<0.1	NS	NS	***	NS	*	NS	NS	NS	NS
Asasa FB	70.3	81A	74.9A	8.52B	85	2.56	68A	34.3	61A	104B
Mechanized CW	68.9	65B	49.3B	24.2A	85	2.25	52B	41.3	42.B	292A
Prob	NS	**	*	***	NS	NS	*	NS	*	*
Asasa FB	67.6	21.9	37.1	6.5B	54.8	22.6	40.3	18	22	131
Ox-plow CW	71.9	20.7	29.1	13.6A	47.5	27.8	43.0	23	15	243
Prob	NS	NS	NS	*	NS	NS	NS	NS	NS	NS

†, *, **, *** Statistically significant at $0.05 < P < 0.1$, $0.01 < P < 0.05$, $0.001 < P < 0.01$, and $P < 0.001$, respectively.

Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test (or 10% level where indicated by the probability).

All values detransformed from ANOVA means [i.e., based on SQRT (weed count/m^2 + 0.5)]. Probability levels and LSD groupings determined from ANOVA on transformed data.

TBW = Total broadleaf weed; TGW = Total grass weed

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References

Akobundu IO. 1987. *Weed science in the Tropics: Principles and practices.* John Wiley and Sons, London. Pp. 71–78.

Arshad KL MA, Gill KL and GR Coy 1994. Wheat yields and weed population influenced by three tillage systems on a clay soil in temperate continental climate. Soil Tillage Res. 28, 227–238

Asefa Taa, DG Tanner and Amanuel Gorfu. 1992. The effect of tillage practice on bread wheat in three different cropping sequences in Ethiopia. In: Tanner DG and W Mwamgi (eds.). *The Seventh Regional Wheat Workshop For Eastern, Central, and Southern Africa.* Pp. 376–386, CIMMYT Nakuru, Kenya.

Bahrendt S and H Hanf 1979. Grass weeds in the world agriculture. BSAF.Actiengesellschaft, Ludwighaten.

Birhanu Kinfe. 1985. Progress of weed management in wheat production in Ethiopia. Pp. 95–102. In: *Regional Wheat Workshop for Eastern, Central and Southern Africa and the Indian Ocean,* Njoro, Kenya. Sept. 2-5, 1985. CINNYT, Nairobi.

Cheam AH. 1986. Patterns of chabge in seed dormancy and persistence of *Bromus diandros* Roth (great brome) in the field. *Australian Journal of Agriculture Researches.* 32, 471–481

Clements DR, DL Benoit SD Murphy and CJ Swanton. 1996. Tillage effects on weed seed return and seedbank composition. Weed Science. 44, 314–322.

Chilot Yirga, Hailu Beyene, Lema Zewde and DG Tanner 1992. Farming systems of Kulumsa area. In: Franzel S and Van H Houten (eds.) Research with farmers: Lesson from Ethiopia. IAR and CABI, Wollingford, U.K.

Giref Sahile, DG Tanner and Lema Zewdie. 1992. A study of weed emergence patterns in the bread wheat producing agroecological zones of southeastern Ethiopia. Pp 503–509. In: Tanner DG and W Mwangi (eds.). *The Seventh Regional Wheat Workshop for Eastern, Central and Southern Africa.* CIMMYT Nakuru, Kenya.

Hanson H, N Borlaug and RG Anderson 1982. Wheat in the Third World. Pp. 130–132. Westview Press. Inc. Boulder, Colorado.

Heenan DP, AC Taylor and AR Leys 1990. The influence of tillage, stubble management and crop rotation on the persistence of great brome (*Bromus diandrus* Roth). *Australian Journal of Exp. Agriculture*. 30: 227–230

Higgs R.L Arthur, A.E Peterson and WH Paulson 1990. Crop rotations: Sustainable and profitable. *Journal of Soil and Water Conservation* 45, 68–70.

Kamwaga N J 1990. Grain yield as influenced by different tillage systems in Kenya. Pp 133–139. In: Tanner DG M. van Ginkel and W. Mwamgi (eds.). *The Sixth Regional Wheat Workshop for Eastern, Centeral and Southern Africa.* CIMMYT, Mexico, D.F.

Rasumssen PE, RW Rickmanl and CL Douglas 1986. Air and soil emperature during spring burning of standing wheat stubble. *Agronomy Journal* 78, 261–263.

Tanner DG and Giref Sahile. 1991. Weed control conducted on wheat in Ethiopia. Pp. 235–275. In: Hailu Gebre-mariam, DG Tanner and Mengistu Hulluka (eds.). Wheat research in Ethiopia: A Historical perspective. IAR/CIMMYT, Addis Ababa, Ethiopia.

Triplett GB. 1986. Crop management practices for surface tillage systems. Pp. 149 180. ***In***: Sprague MA and GB Triplet (eds.). No tillage and surface tillage agriculture. The Tillage Revolution. John Wiley and Sons; New York.

Wilson BJ and GW Cussans GW. 1985. A study of population dynamics of *Avena fatua* L. as influenced by straw burning, seed shedding and cultivations. Weed Research. 15, 249–258.