Short Communication

Effect of Plowing Frequency and Weeding Methods on Weeds and Grain Yield of Wheat at Arsi Negelle, Ethiopia

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Abstract: The effect of repeated tillage and weed control methods on weed infestation and grain yield of wheat was evaluated at Arsi Negelle, southern Ethiopia, from 1993 to 1995 cropping seasons. Five tillage practices (zero, one, two, three and four times tillage) as main plot and four weed control methods (Duplosan sprayed at 2.5 l ha^{-1}, Duplosan plus one hand weeding at 30 days after emergence (DAE); one and two hand weeding at 30, and 30 and 60 DAE, respectively) as subplots were arranged in split plot design with three replications. Broadleaf weeds comprised 73% of the total weed population in the experimental plots. Effect of tillage and weed control was dependent on year. Increased frequency of tillage reduced weed infestation (r = -0.34**) and increased plant height (r = 0.42**), biomass (r = 0.51**) and grain (r = 0.43**) yields of wheat. Weed density in zero-till and three times plowing was 78 and 35%, respectively, more than four times. Weed density in plots treated with Duplosan alone and its combination with 1HW was 38.4 and 19.5% more, respectively, while it was 5.9% less with 1HW alone compared with 2HW. About 33 and 26% of the total variations in weed infestation were due to tillage and weed control methods, respectively. Grain yield reduction in zero-till and three times plowing was 59 and 21%, respectively, compared with four times' plowing. Twice weeding reduced weed population by 28% and increased wheat grain yield by 3.3% compared to Duplosan alone. Fifty five, 95 and 43% of the total variations in wheat grain yield in 1993, 1994, and 1995, respectively, were attributed to the regression. Frequent tillage reduced weed infestation and increased grain yield by 11 and 21.9%, respectively, compared to weed control. Generally, four times plowing significantly reduced weed infestation and increased wheat grain yield with considerable economic benefit.

Keywords: Herbicide; Repeated Plowing; Southern Ethiopia; Tillage; Weed Density; Wheat; Weed Infestation; Weed Population

1. Introduction

Bread wheat (*Triticum aestivum* L.) is one of the major crops in Arsi Negelle and Shashemene areas and covers 13.7% of the total cultivated area. Bread wheat covers about 19.29% of the total cereal areas in Oromia region with an average yield of 1957 kg ha^{-1} (CSA, 2010). Shortage of plowing oxen and labor constrain wheat production in these areas. A pair of oxen is needed to till the land, but many farmers own only a single ox and fail to prepare the land properly and timely. Often farmers practice two to three plowings before wheat sowing (Yohannes, 1982) and this increases infestation of both broad-leaf and grass weeds (personal comm., Regional Ministry of Agriculture, 1997) resulting in low productivity. Weed infestation, which is the result of poor land preparation and unavailability of labor to control weed on time, is one of the major constraints in wheat production. The report indicates that in Ethiopia weed competition reduced wheat yields by up to 36.4% (Rezene, 1989). Wheat grain yield ranges between 600 and 2500 kg ha^{-1} depending on weather conditions, crop management factors and soil type (Yohannes, 1982). Tillage is supplemented with the application of herbicide especially with, 2, 4-D 30 to 40 days after wheat emergence.

Tillage practices vary with the prevailing weather conditions and have an influence on soil moisture (Johnson *et al*., 1989; Kamwaga, 1990; Bonfil *et al.,* 1999). Where there is drought (moisture stress), no-till can produce better grain yield (Bonfil *et al*., 1999) resulting in yield increase by 18 to 75% in continuous wheat and 62 to 67% in wheat fallow rotation with no-till relative to conventional tillage in moisture stress areas**.** Aulakh and Gill (1988) observed that zero tillage, due to retention of crop residue, had more yields and lower bulk density than conventional tillage that had low yield due to higher soil bulk density and lower soil water availability to the crop. Zero tillage applied with straw mulch had more grains per spike and gave similar grain yield of wheat as compared to 6 to 8 plowings (Dhinam and Sharma, 1986 cited by Majid *et al*., 1988). The reason for better performance of zero till was due mainly to uniform placement of seeds, which resulted in better plant emergence and less weed infestation than the conventional tillage.

In fact, minimum tillage can cost less since the power and time requirement is minimal (Dawelbeit and Salih, 1994). In addition, minimum tillage allows earlier sowing**,** reduces soil erosion and there can be less potential for pesticide contamination of surface water (Brecke and Shilling, 1996). On the other hand, Kamwaga (1990) found no significant yield variation between conventional and reduced tillage over a two year period at various locations because of uniform distribution of rainfall. He also noted higher grain yield of wheat in minimum tillage

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under erratic rainfall. Similarly, Bordovsky *et al.* (1998) reported that under rainfed condition, both reduced and conventional tillage produced equal yields of wheat in Texas. According to Macharia *et al.* (1997), tillage frequency conducted for three consecutive seasons showed no significant variation on wheat yield. As reported by Assefa *et al.* (2000), nitrogen content and N uptake of wheat straw increased under conventional (four times plowing) compared with minimum tillage (one time plow).

Repeated tillage stimulates weed seed germination before the final tillage leading to reduced seed bank and weed infestation (Johnson *et al.*, 1989). Reports of ICARDA (1984), Dorado *et al.* (1998), and Thompson and Whitney (1998) showed that weed density was higher in no-till plots than in repeatedly plowed plots. Assefa *et al.* (2000) investigated that one time plowing (minimum tillage) reduced wheat seedling density at emergence while four times plowing (conventional) increased straw and grain N uptake. The density of some weeds (*Bromus pectinnatus* and *Galinsoga parviflora)* was also reported to increase under minimum tillage (Assefa *et al.*, 2000). In contrary, despite application of residue to both, reduced tillage had lower grain yield of wheat relative to the conventional tillage due mainly to decreased plant populations caused by poor seed-to-soil contact during sowing (Bordovsky *et al.*, 1998). Repeated tillage reduced weed infestation by more than 50% compared with zero tillage (ICARDA, 1984). Others reported that zero tillage reduced weed competition and produced higher grain yield (Brecke and Shilling, 1996). Chemical weed control, tillage, and hand weeding, and integrated weed management are of the many alternatives available for weed control. Hand weeding and chemicals are effective to control weeds (ICARDA, 1984). Availability of labor on time is a problem during weeding due to overlapping of farm activities and is costly. Availability, costliness, efficacy, and its effect on human health are problems to consider using herbicides. However, herbicide is commonly used by some farmers of Arsi Negelle for the control of wheat weeds. On the other hand, because of few plowings/passes due to shortage of oxen, control of weeds was minimal thus competing and reducing grain yield of wheat. The overall objective of this study was, therefore, to investigate the effect of season, repeated tillage and weed control methods on weed infestation and grain yield of wheat.

2. Materials and Methods

2.1. Site Description

The study was conducted at Arsi Negelle, Ethiopia for three consecutive years, 1993-95. It is located at an altitude of 1960 m.a.s.l. Mean annual rainfall of of Arsi Negelle district varies between 800 and 1400 mm while the soil type of the experimental area is sandy loam. Wheat is the major cereal crop widely grown in and around Arsi Negelle and Shashemene areas.

2.2. Experimental Description

The treatments were: plowing frequencies (zero, one, two, three, and four times plowing at an interval of 15 days for the repeated plowings) as main plots, and weed control methods (post-emergence herbicide Duplosan (D2.5) at the rate of 2.5 l ha^{-1} applied after 5-leaf stage of wheat; Duplosan (2.5 l ha^{-1}) plus one time hand weeding (1HW) at 30 days after emergence (DAE); one time hand weeding at 30 DAE and two times hand weeding (2HW) at 30 and 60 DAE, which is recommended) as subplot were arranged in split plot design with three replications. The subplot size was 15 rows of 0.2 m row spacing and 5 m length. Glyphosate (round up) herbicide at the rate of 4.5 l ha^{-1} (recommended) was applied on zero-till plots 15 to 20 days before sowing since no-till plot is not plowed, which is commonly used in zero-till plots. The seed rate of Dashen wheat variety was 125 kg ha^{-1} and was drilled in furrows using hoes and Diammonium phosphate (DAP) fertilizer at the rate of 18/46 N/P_2O_5 kg ha^{-1}, respectively, was side banded at sowing. The land was tilled with traditional oxen-drawn plow. The crop was sown on 22 July 1993 and 1994, and 4 August 1995.

An iron rod quadrat size of 25 cm length by 25 cm width was used for weed count. A mean of weed population count from four throws in each plot was recorded and weeds were identified as grass and broadleaf weeds. Data on weed types and population m^{-2} (1993 and 1994), plant height (1993-1995), spike length (1994 and 1995), grains per spike (1993), thousand kernel weight (1993-1995), biomass (1994 and 1995) and grain (1993-1995) yields were recorded. Log transformation was used for weed count. Duncan's Multiple Range Test was used to differentiate treatment means (Gomez and Gomez, 1983). Combined analysis over years was carried after test of homogeneity. Multiple regression model was used to predict yield response to frequency of tillage and simple Pearson's correlation coefficient analysis was performed. Economic analysis was carried out using the procedure of CIMMYT (1988).

3. Results and Discussion

3.1. Rainfall

Rainfall was adequate in 1993 and 1994, but moisture shortage was high in 1995 cropping season with intermittent shortages of rainfall beginning at sowing, which has seriously affected the crop (Table 1). Amount and distribution of rainfall in the first two years was better and resulted in relatively better crop performance and biomass and grain yields. Total amount of rainfall in 1995 compared with the long-term was 18.4% less. Thus, the rainfall in 1995 was so short that wheat development stages (vegetative growth, grain filling) were significantly affected and resulted in low biomass and grain yields. Despite shortage of rain in 1995, plots plowed three and four times had relatively better growth, and biomass and grain yields, possibly due to conservation of soil moisture through crop canopy cover which had better seedling establishment and growth, and reduced weed competition.

Table 1. Amount of rainfall (mm) during the growing season of wheat at Arsi Negelle.

Month	Year			Long-term
	1993	1994	1995	1994-2002
July	116.1 (-9.2%)	134.7 (+5.3%)	83.7 (-34.5%)	127.8
August	124.6 (-1.0%)	163.0 (+32.1%)	93.7 (-24.1%)	123.4
September	134.1 (-9.4%)	192.1 (-29.8%)	136.0 (-8.1%)	148.0
October	112.1 (+67.3%)	99.1 (+47.9%)	67.0 (0.0%)	67.0
Total	486.9 (+4.4%)	588.9 (+26.3%)	380.4 (-18.4%)	466.2

Note: Number in parenthesis is percent of rain over the long-term; The negative numbers show shortage of rain relative to the long-term

3.2. Weed Type and Infestation Level

The prominent weed species recorded during the study were broad leaf and grass weeds, broadleaf being dominant (Table 2) covering 73% of the total weeds in the experimental plots during 1993 season (Table 3). Significant variation in broad-leaf and grass weeds was not observed among tillage practices but weed control methods showed significant variation. Grass weed was low in one and two weedings compared with Duplosan alone or its combinatation with one hand weeding. On the other hand, application of Duplosan together with one hand weeding significantly reduced broad-leaf weeds by 47.9, 66.8 and 49% when compared with the application of Duplosan alone, hand weeding once and twice, respectively.

There was a significant effect of season, tillage, and interaction of season with tillage and weed control methods on most parameters measured (Table 4). There was no interaction effect of frequency of tillage and weed control methods on most parameters except spike length. The result of combined analysis showed significant ($P \leq 0.05$) variation in weed density due to tillage, interaction of season with tillage and weed control methods. Effect of tillage on weed was dependent on seasonal rainfall in which tillage responded differently to the different years (Table 5). Four times plowing consistently reduced weed population in both years while no-till and two times tillage had more weeds in 1994 than 1993 because of variation in years. Weed population in plots plowed four times was significantly 25 and 57% less compared with no-till in 1993 and 1994, respectively. Weed density in three plowings was 21.7 and 51.2% more than plowing four times in the respective years. It shows that effect of tillage on weed infestation was variable from one year to the other because of variation in rainfall amount and distribution.

Frequency of tillage was negatively correlated with weed infestation ($r = -0.34^{**}$). Weed population due to tillage was reduced by 20 and 26% in comparison with no-till in 1993 and 1994 seasons, respectively. Repeated tillage, before the final tillage, might stimulate weed seed germination and would reduce the seed bank and subsequent weed densities (Akobundu, 1987; Johnson *et al*., 1989). The finding at ICARDA (1984) shows that repeated tillage compared to no-till reduced weed infestation by 50%. Dorado *et al.* (1998) and Thompson and Whitney (1998) reported low weed population in repeated tillage. Others (Assefa *et al*., 2000) also reported reduced weed density (*Bromus pectinnatus* and *Galinsoga parviflora*) under minimum tillage (one time plow). Wallace and Bellinder (1989) also noted high redroot pigweed (*Amarnhus hybridus* L.) in reduced tillage compared with more plowings. On the other hand, Brecke and Shilling (1996) observed more weed biomass of sicklepod (*Senna obtusifolia* L.) in conventional tillage (45%).

Table 2. Weed species identified at Arsi Negelle during the experimental seasons (1993-1995).

Weed species
Broad leaf weeds
Plantago lanceolata
Galinsoga parviflora
Bidens pilosa
Commelina benghalensis
Nicandra physalodes
Guizotia scabra
Anagalis arvensis
Grassy weeds
Eragrostis spp
Couch grass

Table 3. Effect of weed control methods on grass and broad leaf weeds (No. m^{-2}) at Arsi Negelle in 1993.

Tillage frequency (No.) and weed control method	Weed types by density	
	Grass weeds	Broad leaf
Tillage frequency*		
Zero tillage	37.9	179.2
One time tillage	54.2	129.2
Two times tillage	55.8	129.2
Three times tillage	90.0	163.3
Four times tillage	32.0	129.2
Weed control method*		
Duplosan: 2.5 l ha^{-1}	67.0ab	142.0ab
Duplosan +hand weeding once	73.0a	74.0b
Hand weeding once	25.0c	223.0a
Hand weeding twice	51.0bc	145.0ab

**Means within a column of the same factor followed by the same letter are not significantly different at P > 0.05*

Weed infestation was not significantly affected by the interaction effect of tillage by weed control methods. Significant interaction effect of year and weed control methods observed implies that mainly seasonal rainfall affected the effect of weed control due to variable rainfall pattern and thus responded differently to the different years. In 1994, weed infestation in plots weeded twice was significantly low by 52.5% compared with plots treated

with Duplosan alone (Table 5). However, weed density was significantly high (39.6% more) in 1993 compared with 1994 in plots treated with weeding twice. Weed density over seasons was 38 and 19% more in plots treated with Duplosan alone and its combination with one hand weeding, respectively, compared with those hand-weeded twice. The finding indicates that hand weeding twice will benefit the crop for better growth and yield due to reduced weed competition for moisture and soil nutrients. According to ICARDA report (1984), twice hand weeding significantly reduced weed infestation and was better than chemical weed control. Similarly, Chugunov *et al.* (1988) reported that two hand weedings reduced weed infestation and gave higher grain yield of wheat.

The regression equation indicates that 59% of the total variations in weed infestation/density were attributed to the model:

$$Y = 482.9\text{-}43.6T\text{-}63.7Wc \ (R^2 = 0.59^{**}),$$

where Y-weed infestation/density, T-tillage frequency, and Wc-weed control method. Of these 32.6 and 26.4% of the variations were due to frequency of tillage and weed control method, respectively.

Table 4. Effect of tillage frequency, weed control and season on the different parameters of wheat in Arsi Negelle, Ethiopia.

Parameter	Y/S	T	W	Y*T	Y*W	T*W
Plant height (cm)	**	**	ns	**	ns	ns
Spike length (No.)	**	**	ns	**	ns	ns
Seed weight (g)	**	ns	ns	**	ns	ns
Grain yield (kg)	**	**	ns	**	**	ns
Biomass yield (kg)	**	**	ns	**	ns	ns
Weed density (No.)	ns	**	**	**	**	-

*Y/S = Year/Season; T = Tillage frequency; W = Weed control; and interaction of Y*T, Y*W, T*W and Y*T*W; ** = Significant at P ≤ 0.01; ns = Not Significant at P > 0.05*

Table 5. Combined effect of year with tillage frequency and weed control on weed density (No. m^{-2}) (combined over years), Arsi Negelle.

Tillage frequency (no.) and weed control method	Year	
	1993	1994
Tillage frequency*		
Zero tillage	215abc	300a
One time tillage	172bc	287a
Two times tillage	162cd	275ab
Three times tillage	196abc	194cd
Four times tillage	161cd	128d
Weed control method*		
Duplosan: 2.5 l ha^{-1}	188bc	324a
Duplosan +hand weeding once	144c	297ab
Hand weeding once	178bc	170bc
Hand weeding twice	215ab	154c

**Means within a column of the same factor followed by the same letter are not significantly different at P > 0.05*

3.3. Wheat Plant Height

Wheat plant height was significantly (P ≤ 0.05) affected by season, tillage frequency, and season combined with tillage and weed control methods. Plant height was affected by the different tillage practices in the seasons (Table 6). Plant height in plots with four times plowing was not different from three times plowing in 1993 and 1995 seasons; however, four times plowing increased plant height by 12.7 cm in 1994 (compared with three times plowing) and by 41.4 cm (compared with zero tillage). In all years plowing four times increased plant height compared with other tillage treatments while no-till and plowing one time had the lowest plant height. The overall trend, averaged across seasons, showed that increase in tillage frequency was accompanied by increase in wheat plant height and the increase over the other tillage practices varied between 6.8 cm and 25.6 cm. In contrary, Tolera *et al.* (2009) found increased plant height from minimum tillage (no-till) over years.

Weed control methods also performed differently across years; however, plant height was not significantly affected by the interaction effect of tillage by weed control methods. Hand weeding twice resulted in significantly shorter plant heights in all years compared with other weed control methods although it had no significant variation in some years. Four times plowing reduced weed infestation and improved vegetative growths of wheat, which might be attributed to better soil tilth, soil moisture conservation, and reduced soil evaporation through better ground cover.

3.4. Spike Length, Grains Spike^{-1} and Thousand Kernel Weight

There was a significant ($P \leq 0.05$) variation in spike length due to year, tillage frequency and interaction of year with tillage. Frequency of plowing showed significant variation in spike length at different years. In both years the trend showed an increase in spike length as frequency of plowing increased (Table 7). In 1994 four times plowing significantly increased spike length but not significantly variable from three times plowing. Spike length in plots plowed four times was 57.8, 36.5 and 10.9% more compared with no-till, one and two times plowing, respectively. A similar trend was also observed in 1995 although it was significantly low compared with the other year. This was due to variation in amount and distribution of rainfall from one year to the other. But the report of Tolera *et al* (2009) showed significant increase in spike length from minimum tillage (applied with round-up before three weeks) compared with conventional tillage (five times plow with oxen drawn maresha) only for one year while the other year did not show.

Year and its interaction with frequency of tillage significantly affected kernel weight of wheat. However, kernel weight was not affected by the interaction effect of tillage and weed control methods (Table 7). There was an increase in thousand seed weight in two, three and four times plowing in 1994 compared with no-till and one time plowing. However, low seed weight was observed in plots plowed four times in 1993 and 1995 season which was related to the rainfall of each year. This finding disagrees with the observation of Aulakh and Gill (1988) and Tolera *et al* (2009) who reported no significant variation among tillage practices.

Though there was a one year data on grains per spike, the trend showed that repeated tillage significantly increased the number of grains per spike (Table 7). There was an increase in grains per spike as frequency of tillage increased in spite of the non-significant variation between three and four times plowing. Grains per spike were 104 and 34% greater with four plowings than those with no till and two times plowing, respectively. Similarly, Assefa *et al.* (2000) found significant increase in grains per spike in conventional tillage than minimum tillage in one out of the five seasons.

Table 6. Interaction effect of season with frequency of tillage and weed control methods on plant height of wheat (combined over years), Arsi Negelle.

	Plant height (cm)		
Tillage frequency*	1993	1994	1995
Zero tillage	99.8b	58.5f	63.1ef
One time tillage	100.3b	60.1f	59.1f
Two times tillage	108.0ab	73.4de	66.8ef
Three times tillage	108.2ab	87.2c	80.6cd
Four times tillage	115.5a	99.9b	81.0cd
CV (%) = 7.15; SE (±) (Season x tillage) = 3.37			
Weed control method*			
Duplosan: 2.5 l ha^{-1}	104.5ab	74.0cd	75.1cd
Duplosan + hand weeding once	108.6a	78.0c	68.1e
Hand weeding once	109.5a	76.5c	69.2de
Hand weeding twice	102.7b	74.9cd	68.0e
CV (%) = 7.15; SE (±)(Season x weed control) = 1.90			

** Interaction means within a column and row in each factor (tillage or weed control) followed by the same letter are not significantly different at P > 0.05*

Table 7. Combined effect of season and frequency of tillage on spike length, thousand seed weight and grain spike^{-1} (combined over years).

	Spike length (cm)*		Thousand seed weight (g)*			Grain spike^{-1}*
Tillage frequency	1994	1995	1993	1994	1995	1994
Zero tillage	4.5e	4.9de	46.7c-f	46.9c-f	41.5fg	13.5c
One time tillage	5.2de	4.6e	49.5bcd	48.6cde	43.6ef	18.3bc
Two times tillage	6.4bc	5.1de	44.0ef	51.1abc	46.0c-f	20.6bc
Three times tillage	6.9ab	5.4d	45.6def	54.9a	33.6h	24.5ab
Four times tillage	7.1a	5.6cd	41.6fg	53.9ab	37.6gh	27.6a
CV (%) = 10.78; SE (±)(Season x tillage) = 0.23			CV (%) = 15.04; SE (±)(Season x tillage) = 1.57			

**Means within a column and row in each trait (spike length, seed weight and grain spike^{-1}) followed by the same letter are not significantly different at P > 0.05*

3.5. Grain Yield

Significant ($P \leq 0.05$) variation in grain yield due to year, tillage, and interaction of year with tillage and weed control methods was observed. Interaction effect of tillage by weed control methods had no significant effect on grain yield of wheat. The trend showed an increase in grain yield of wheat as frequency of tillage increased (Table 8). Although tillage effect was variable from one year to the other, it showed that plowing four times gave significantly ($P \leq 0.05$) higher yield than the other tillage treatments in the first two years (1993 and 1994). Grain yield was affected positively and linearly by frequency of tillage in the experimental years. In 1993, increase in grain yield due to four times plowing was 33 and 16% over the two and three times plowing, respectively, while the respective increase in 1994 was 146 and 51%. The response of grain yield to four times tillage was variable with years as indicated in the result due to variation in amount and distribution of rainfall. The high wheat yield obtained from frequent plowing might be due to better root growth (Jongdee, 1994), less weed infestation and better seedling establishment (Assefa *et al*., 2000), which indirectly increased grains per spike and biomass yield. According to Austin *et al.* (1998), yields of wheat and barley were strongly dependent on seasonal rainfall.

The low yield in reduced tillage (zero-till, one and two plowings) was due to high weed infestation and probably low seedling emergence, which is consistent with the work of Wallace and Bellinder (1989) who noted 16 and 22% reduction in plant stand and tuber yield of potato, respectively. Similarly, Dhinam and Sharma (1986) cited by Majid *et al.* (1988) showed six times plowing gave more grain yield of wheat than five and no-till. Getinet (1988) also noted higher grain yield of wheat from four times plowing either in red or dark grey soil. Kreuz (1993) reported low seedling density, number of spikes m^{-2}, and straw and biomass yields in zero-till. The low grain yield of wheat in zero-till was due to high weed infestation and probably low crop establishment, which is in line with the findings of Thompson and Whitney (1998) and Assefa *et al.* (2000) who reported low grain yield with no-till plots. The finding of Antapa and Mariki (2000) indicated significantly high grain yield of wheat from conventional tillage while zero-till produced the lowest. In contrary, Tolera *et al* (2009) reported significantly high grain yield of wheat from minimum tillage (no-till plots) compared with conventional tillage (plowing five times with oxen drawn maresha).

Effect of weed control methods was variable from one year to the other. Grain yield from application of Duplosan alone and its combination with one hand weeding was not significantly different from two hand weedings in 1993. On the other hand, grain yield of bread wheat in two hand weedings in 1994 was 27.4 and 14.8% more than yields obtained from plots treated with Duplosan alone and its combination with one hand weeding, respectively (Table 8). Grain yield response to weed control methods showed a decrease from one year to the other, which was dependent mainly on the rainfall of each year. Twice hand weeding was effective in controlling weed infestation and increased wheat grain yield, which is in accordance with the finding of ICARDA (1984) and Chugunov *et al.* (1988) who showed twice hand weeding was most effective in reducing weed infestation and increasing wheat grain yield.

Grain yield had a significant and positive association with tillage ($r = 0.43^{**}$), plant height ($r = 0.89^{**}$) and seeds per plant ($r = 0.24^{*}$). In this study, 55, 95 and 43% of the total variations in grain yield were explained by the regression equation during 1993, 1994 and 1995, respectively (Table 9). The equation points that grain yield and effect of tillage on grain yield were dictated by the rainfall during the crop growing season when low moisture resulted in decline in yield.

It appeared that repeated tillage created conducive environment for better plant establishment, growth and production because of reduced weed competition and possibly better root growth, while reduced tillage (no-till, one and two times weeding) had lower plant height, biomass and grain yields, but higher weed infestation. This study indicated that repeated tillage reduced weed competition for moisture, which probably was important in the 1994 and 1995 resulting in improved yield and yield-related characters of wheat. Besides reducing weed competition repeated tillage probably helped in situ soil moisture conservation (through its canopy cover because of better root and vegetative growth) in which wheat crop utilized the moisture for better growth and grain yield. This was reflected by the positive response of plant height, spike length, grains $spike^{-1}$, and biomass yield to repeated plowing. Four times' plowing might probably have resulted in better seedling emergence and thus more yields because of reduced weed competition for moisture and soil nutrients and presumably in situ moisture conservation.

Table 8. Interaction effect of year with tillage frequency and weed control methods on grain yield of wheat (combined over years), Arsi Negelle.

Tillage frequency (no.) and weed control method	Grain yield (kg ha^{-1})		
	1993	1994	1995
Tillage frequency*			
Zero tillage	1923.0d	623.1f	276.9f
One time tillage	2369.1c	500.0f	253.8f
Two times tillage	2530.7c	1184.6e	261.5f
Three times tillage	2899.9b	1930.7d	553.8f
Four times tillage	3369.1a	2915.3b	553.8f
Weed control method*			
Duplosan: 2.5 l ha^{-1}	2830.7a	1261.5d	361.5e
Duplosan + hand weeding once	2646.0a	1399.9cd	415.4e
Hand weeding once	2384.5b	1453.8cd	361.5e
Hand weeding twice	2607.6ab	1607.6c	384.6e
CV (%) 7.15			
SE (±)(Season x weed control) 1.90;			

* *Interaction means within a column and row in each factor (tillage or weed control) followed by the same letter are not significantly different at P > 0.05*

Table 9. Multiple regression analysis of tillage by weed control methods experiment on grain yield (kg ha^{-1}).

Year/Season	Regression equation	R^2
1993	Y = 1882.1 + 315.0 T	0.55**
1994	Y = 591.5 T + 99.9 W	0.95**
1995	Y = 184.4 + 84.5 T	0.43**

*T = Tillage frequency; Y = Yield (kg ha^{-1}); W = Weed control method; and S = Season; ** = Significantly different at P > 0.01*

3.6. Biomass Yield

Biomass yield was significantly ($P \leq 0.05$) affected by season, tillage frequency and interaction of season and tillage. However, biomass yield was not affected by the interaction effect of tillage by weed control method. Biomass depended on the interaction between tillage and year in which the 1994 season resulted in greater biomass yield (Table 10). In 1994 the biomass in four times plowing was significantly higher than the other tillage practices while significant difference was not observed between three and four times plowing in 1995. The biomass in four times plowing was 48.8% higher in 1994 than that obtained from three times plowing whereas the difference in 1995 was only 18.2% which was attributed to variation in rainfall. When averaged across years, there was an increase in biomass yield as frequency of tillage increased from one to four times plowing that varied between 1227 kg ha^{-1} (one time plowing) and 6199.8kg ha^{-1} (four times plowing). Wallace and Bellinder (1989) found decreased potato stand by 16% due to reduced tillage when averaged over seasons, and reported a 22% reduction in potato yield in reduced tillage compared with yields in conventionally tilled plots. The findings of Thompson and Whitney (1998) also noted poor crop stands in no-till plots, which imply reduction in biomass yield.

3.7. Economic Analysis

An increase in net benefit was achieved through frequent plowing. For every birr the farmer invests in plowing the crop land four times, the farmer in turn gets a marginal rate of return (MRR) of 1120%. It means that the farmer can benefit 11.2 birr for every birr he invests in plowing four times (Table 11). Similar results were also obtained in the sensitivity analysis. Even if the cost of tillage and selling price of the crop changes, the farmer can still get a MRR of 914 and 790% for every birr the farmer expends in plowing the land four times, respectively. But the finding of Tolera *et al.* (2009) showed higher net return from minimum tillage compared with conventional which was plowed four times.

Table 10. Interaction effect of season and plowing frequency on biomass yield (kg ha^{-1}) (combined over years).

	Biomass yield (kg ha^{-1})	
Tillage frequency	1994	1995
Zero tillage	1869.2def	1038.4f
One time tillage	1453.9ef	1000.0f
Two times tillage	3253.7c	1300.0ef
Three times tillage	6415.1b	2415.3cde
Four times tillage	9545.8a	2853.7cd
CV (%) = 22.13; SE (±)(Season x tillage) = 323.1		

[*] *Interaction means within a column and row followed by the same letter are not significantly different at P > 0.05*

Table 11. Marginal rate of return (MRR) and sensitivity analysis of tillage frequency by weed control methods, 1993-1995, Arsi Negelle.

Marginal rate of return (MRR)			
Tillage frequency	Total cost (Birr ha^{-1})	Net benefit (Birr ha^{-1})	MRR (%)
Sensitivity analysis assuming one pass tillage at 100 Birr ha^{-1} and wheat field price (current) 2.8 Birr kg^{-1}			
One time tillage	100	2525.8	-
Two times tillage	200	3143.2	614
Three times tillage	300	4222.6	1080
Four times tillage	400	5339.7	1120
Sensitivity analysis assuming one pass tillage at 120 Birr ha^{-1} and wheat field price (current) 2.8 Birr kg^{-1}			
One time tillage	120	2505.8	-
Two times tillage	240	3103.2	498
Three times tillage	360	4162.6	883
Four times tillage	480	5259.7	914
Sensitivity analysis assuming one pass tillage at 100 Birr ha^{-1} and wheat field price (current) 2 Birr kg^{-1}			
One time tillage	100	1775.6	-
Two times tillage	200	2188.0	412
Three times tillage	300	2910.0	722
Four times tillage	400	3699.8	790

4. Conclusions

Effects of tillage and weed control methods were dependent on seasonal rainfall as it was indicated in the result of this study. Plowing four times reduced weed infestation and increased plant height, spike length, grains spike^{-1} and biomass and grain yields of wheat. Poor crop performance was observed in reduced tillage that finally resulted in low yield. On the other hand, two times weeding significantly reduced weed infestation compared with Duplosan alone or its combination with one hand weeding. The finding revealed that effect of repeated tillage was more than the weed control methods, and the benefit obtained from tillage in reducing weed infestation, and increasing plant height and grain yield was higher than the effect of weed control. Overall, plowing four times is beneficial to farmers due to reduced weed infestation and increased grain yields of wheat, reduced costs for weeding and herbicide as it minimizes the use of labor and herbicide.

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