Productivity and profitability of Wheat cropping system in southeastern Ethiopia

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Abstract

As demand for food is rising, yield is expected to double to feed the 9 billion people in 2050. However, climate change is posing a pressing threat to sustainable food production for the increasing population. Wheat is a strategic crop for food security, and increasing its productivity is vital to ensuring food sufficiency. The dominant cropping system in the southeast Ethiopian highlands is wheat monocropping, which is constrained by the prevalence of yield-reducing factors such as diseases, pests and weeds. We evaluated combinations of crop management options to determine system productivity and profitability for sustainable wheat production. The production factors included in the treatment combinations were tillage type, crop rotation, and weed management options; these factors were applied during alternating (2007, 2009 and 2011) seasons, followed by the main crop (wheat) in the next season (2008, 2010 and 2012). Analysis of variance was performed for yield, weed population and economic parameters and revealed the significant effects of the management factors on wheat yield, weed population density and system profitability. A greater yield was obtained from fallow-retention followed by dry tillage and faba bean rotation. The weed population density was lower in the faba bean and rape seed rotations. All the broad leaf weed species were less than 25%, except for the Galium species, and all the grassy weeds were less than 30%, except for Cyprus species, in both the faba bean and rape seed rotation systems. In addition, Bromus pectinatus and Avena fatua were effectively controlled by rape seed and faba bean rotation, respectively, in the bread wheat production system. Rape seed rotation was the most profitable weed management option for bread wheat production, with a net benefit of 44,559 Ethiopian Birr (ETB)/ha and a net marginal return of 790 ETB/ha, which ensures that farmers receive an additional return of 6.90 ETB from each 1 ETB invested in the rape seed-wheat production system.

1. Introduction

Rice (*Oryza sativa* L.), maize (*Zea mays* L.), and wheat (*Triticum aestivum* L.) provide approximately two-thirds of all energy in human diets, and the four major cropping systems in which these cereals are grown represent the foundation of the human food supply (Cassman, 1999). These cereals are essential for food security, especially in the developing world. Wheat is the most important staple crop in temperate zones, ranking first in total harvested area and third in total harvested area after maize and rice, and is known for adapting to a wide range of climate, elevation, and soil characteristics (Kizilgeci et al, 2021; Shewry & Hey, 2015; Zhao et al, 2019). Wheat plays a vital role in ensuring food and nutritional security as the most important cereal; 36% of the world's population consumes food, from which 20% of the calories and 55% of the carbohydrates are derived (El Sabagh et al, 2021). Ethiopia is one of the largest wheat producers in sub-Saharan Africa, ranking second after South Africa in terms of total wheat area coverage and the amount produced (Hei et al., 2017). Wheat ranks fourth after teff, maize and sorghum in area coverage and third after maize and teff in total production (Anteneh & Asrat, 2020). However, the average national wheat yield is low due to biotic and abiotic factors despite showing an increasing trend from 0.23 to 2.97 t/ha between 2013 and 2018 (CSA, 2018).

Crop production systems are facing challenges due to climate change and an increasing population (Abi Saab et al., 2019), and crop management requires significant investment to achieve environmentally friendly and ecologically sustainable yield and quality production. Wheat research has focused mainly on attaining high yields and neglecting yield stability; however, yield stability has become increasingly important in the face of climate change driven by agronomic factors, including crop rotation, integrated crop protection, soil tillage, fertilization and seeding density, in addition to environmental and genetic factors (Macholdt and Honermeier, 2017). Weeds are among the major yield reducing factors in cereal-dominated cropping systems because they compete for water, light and nutrient resources, thereby reducing yield potential. Cereal monocropping coupled with repeated applications of broadleaf herbicides has increased the density of problematic grass weeds (Birhanu, 1985; Tanner and Giref, 1991), whose widespread infestations are aggravated by increased usage of N fertilizers as well as noncompetitive semidwarf wheat varieties (Balyan et al., 1991; Tanner et al., 1993). With the wide use of combine harvesters, the ability of wild oat plants *(Avena fatua*) to remain in the soil without loss of viability for many years and their morphological similarity with cereal crops during the early growth stage are factors that increase the difficulty of developing control strategies. Weeds can be effectively controlled by increasing plant density, proper tillage, delayed planting, crop rotations, hand weeding, chemical control, and a combination of these factors. Several reports have indicated that higher crop density reduces yield loss due to severe infestation of cereals by wild oat species (Radford et al., 1980; Carlson and Hill, 1985; Martine et al., 1987; Torner et al, 1991; Scursoni et al., 1999). Raising the seed rate from 120 to 150 kg/ha was 27% more effective at reducing wild oat in Egypt (Hassanien, 1998), and increasing the seed rate from 63 to 135 kg/ha reduced the wild oat density by 35% in Canada (Friesen, 1973). A preliminary observation conducted at the Sinana station during 1998–2000 indicated greater grain yield and effective weed suppression as a result of a greater seed rate of 200 kg/ha. However, in other studies, increasing the seed rate had no impact on weed density, but the fresh biomass of weeds and the labour required for weed removal decreased with increasing seed rate (Amanuel Gorfu and Assefa Taa, 1992). It is common for farmers in Ethiopia to lose up to 40% of their crops because of weed infestations (Desta, 2000; Rezene, 2005). A wide range of 48–86% yield loss was also reported at a maximum weed density of 320 weed $^{plants/m2}$ across species (Taye et al, 1996; Rezene and Yohannes 2000). Hand weeding is a labour- and time-consuming task that takes up to 140 hr/ha because crops are normally not row-planted, making mechanical control difficult. Integrated weed management, which involves increasing the seeding rate, reducing the dose of herbicide and early application during the crop and weed growth stages followed by hand-weeding at later stages, has led to significant improvements in crop yield and sustainable weed management in major wheat-growing areas of southeastern Ethiopia (Deressa & Fana, 2010).

Depending on the management, environment, and genotype, the seeding rate impacts wheat tillering, grain yield and protein; hence, achieving higher agronomic performance and better end-use quality requires optimizing and periodically reviewing management practices such as seeding rates (Haile et al., 2013). Wheat quality was not reduced at higher seeding rates, as protein content, kernel weight and test weight were unaffected; however, in other instances, the protein concentration decreased as seeding rates and yield increased (Haile et al., 2013). Conservation tillage and crop rotation are among the factors that enhance the productivity of cropping systems via N fixation by legumes, life cycle interruption of yield-reducing biotic factors, improvement of soil tilth, crop diversification and reduced soil erosion (Bogale & Fana, 2018). The southeastern highlands of Ethiopia are dominated by cereal monocropping, where wheat and barley are dominantly grown annually. This monocropping trend aggravated the prevalence of grassy weed species that resemble cereals in terms of their growth requirements, increasing the difficulty of weed control. Therefore, the objective of the present study was to evaluate major weed management options for wheat production and weed control.

2. Materials and Methods

2.1. Plant material and experimental site

Wheat was the main crop grown in the second, fourth and sixth years of the experiment. The bread wheat variety '*Sofumer'* was used as the main crop. The crop varieties released by the Sinana Agricultural Research Centre included the bread wheat variety '*Mada Walabu*', the faba bean variety '*Shallo*' and the rape seed cultivar '*Shaya*'. The experiment was conducted at three sites in the Sinana Agricultural Research Centre (SARC), which included the Selka and Hisu research stations.

2.2. Experimental setup

The treatments consisted of five factors at different levels, as shown in the following table (Table 1). The treatments were laid out in accordance with a randomized complete block design (RCBD) with three replications, which were conducted for six years from 2007–2012. The treatments were designed such that they were applied every other year (in 2007, 2009 and 2011), and the main crop (bread wheat) was planted during alternating years (in 2008, 2010 and 2012). The seeding rates for Mada Walabu, Shallo and Shaya were 150, 230 and 15 kg ha^{-1}, respectively. The tillage treatment was performed under wet and dry conditions. Dry tillage was applied during the off-season in March before the onset of rain, while wet tillage was performed after July to August. The fallow system included complete removal of the weeds that had grown on the plot and retention of the weeds. Stubble management consisted of burning and retaining wheat stubble. In the retention treatment, the stubble was chopped down and retained on the plots for incorporation into the soil. The weed control treatment included hand-weeding and chemical control by the herbicide Puma Super. The data collected were subjected to analysis of variance, and treatment means were separated using Fisher's least significant difference (LSD) test at a probability level of $P < 0.05$ with GenStat v15 software.

Table 1
Treatment arrangement

Treatment	precursor crop + treatment	Main crop
1	Wheat + Dry tillage	Wheat
2	Wheat + Wet tillage	Wheat
3	Fallow + Weed removal	Wheat
4	Fallow + Weed retention	Wheat
5	Wheat	Wheat
6	Faba bean	Wheat
7	Rape seed	Wheat
8	Wheat + Stubble burning	Wheat
9	Wheat + Stubble retention	Wheat
10	Wheat + Chemical treatment	Wheat
11	Wheat + hand weeding	Wheat

3. Results and Discussion

3.1. Yield and growth parameters

Analysis of variance revealed significant treatment effects on grain yield, biomass yield and other growth parameters (Table 1). Most of the treatments had similar effects on yield and growth parameters. The grain yield ranged from 3.02 t/ha in the wet tillage treatment to 3.74 t/ha in the fallow-weed removal treatment, for a difference of 0.72 t/ha. The highest biomass yield of 10.9 t/ha was obtained from the fallow plus weed retention treatment, whereas the lowest biomass yield of 8.1 t/ha was obtained from the wet tillage treatment. This combination has a biological yield advantage of 2.8 t/ha, which is an advantage of 25.7%. The thousand-kernel weight, harvest index and number of seeds per spike were not significantly affected by the treatment. These findings highlighted that agronomic factors such as tillage type, weed management options, and crop rotation indirectly affect economic and biological yields via indirect growth traits such as spike length, plant height and stand percentage but not by directly affecting yield components.

Table 1
Combined effect of weed management options on bread wheat growth and yield parameters.

Treatments	Stand count	Plant height	Seeds per spike	Spike length	TKW	Harvest index	Grain Yield	Biomass Yield
Dry tillage	172^{ab*}	100.9^{a-d}	41	9.62^{a}	43.0	37.3	3561.3^{ab}	9620^{a-c}
Wet tillage	161^{ab}	100.5^{a-d}	38	9.29^{a-c}	43.1	37.9	3018.4^{c}	8074^{c}
Fallow-removed	170^{ab}	104.4^{b-d}	41	9.53^{a-c}	42.1	35.5	3330.7^{a-c}	9905^{ab}
Fallow-retained	182^{ab}	104.9^{a}	39	9.40^{a-c}	41.9	37.1	3737.0^{a}	10273^{a}
Wheat monocrop	176^{ab}	101.6^{a-d}	40	9.56^{ab}	42.2	37.2	3431.8^{a-c}	9400^{a-c}
Faba bean rotated	184^{a}	103.9^{a-c}	40	9.63^{a}	43.5	34.8	3529.2^{a-c}	10863^{a}
Rape seed rotated	180^{ab}	102.5^{a-d}	40	9.21^{a-c}	42.3	36.2	3355.6^{a-c}	9462^{a-c}
Stubble burning	157^{ab}	100.2^{cd}	39	9.12^{c}	42.1	37.8	3494.9^{a-c}	9345^{a-c}
Stubble retention	162^{ab}	99.7^{d}	39	9.18^{bc}	43.3	38.3	3174.6^{bc}	8427^{bc}
Chemical	152^{b}	99.9^{cd}	40	9.40^{a-c}	43.5	35.4	3391.8^{a-c}	9810^{ab}
Hand weeding	165^{ab}	100.8^{b-d}	39	9.47^{a-c}	43.4	37.5	3112.7^{bc}	8536^{bc}
LSD	30.55	4.09	ns	0.44	ns	ns	511.55	1692.8
Mean	169.2	101.75	39.7	9.40	42.7	36.8	3376.2	9428.4
CV	19.18	4.27	10.1	4.97	4.85	11.1	16.09	19.06

*Means with the same letter are not significantly different; LSD = Fisher's least significant difference at probability $P \leq 0.05$ level; CV = coefficient of variation (%); TKW = 1000 kernel weight (g); ns = nonsignificant at the $P \leq 0.05$ probability level

The productivity of the weed management system was taken as the percentage increase in grain yield in the subsequent year due to the treatments applied in the preseason (Table 2). The percentage contribution to the increased yield of the main crop was calculated compared to the preseason yield of the crop influenced by the treatments. For the fallow treatments and the rotation crops, the relative percentage contribution of increased yield to the main crop was calculated based on the precursor yield of the wheat–wheat treatment. Fallowing with weed retention relatively increased the subsequent wheat yield by 19.5%. The wheat yield in the main season also increased by 18.8, 18.7 and 17.2% due to the chemical, dry tillage and stubble burning treatments applied following the wheat precursor in the mid-season (off-season), respectively. Hand weeding was not an effective weed control strategy because it contributed only 7.2% to the yield increase, likely because of the similarity of the grassy weed species to wheat, especially in the early growing stages when weeds severely damage the tillering capacity of the crop. Broad leaves are also aggressive in the early stages unless hand weeding starts early. Fallowing followed by removal of weed biomass and wet tillage also contributed less (7.6% and 9.8%, respectively) to the subsequent increase in wheat yield.

Table 2
Percentage of the main crop (wheat) yield increase due to the treatments

Treatment	Precursor crop + treatment (A)	Main crop (B)	Precursor yield kg/ha	Main crop yield kg/ha	Main crop yield (%)
1	Wheat + Dry tillage	Wheat	2905.1	3571.3	18.7
2	Wheat + Wet tillage	Wheat	2917.7	3233.4	9.8
3	Fallow + Weed removal	Wheat	0	3173.1	7.6
4	Fallow + Weed retention	Wheat	0	3639.2	19.5
5	Wheat	Wheat	2931.5	3504.2	16.3
6	Faba bean	Wheat	1618.2	3477.5	15.7
7	Rape seed	Wheat	1255.5	3383.3	13.4
8	Wheat + Stubble burning	Wheat	2882.5	3479.8	17.2
9	Wheat + Stubble retention	Wheat	2852.6	3299.8	13.6
10	Wheat + Chemical	Wheat	2725.2	3357.9	18.8
11	Wheat + hand weeding	Wheat	2928.1	3156.2	7.2

A = the precursor crop and the related treatments performed in the off-season before the main crop is sown in the main season, B = the main crop (wheat), which is the target variable

3.2. Weed population density

The weed data showed that the most prevalent weeds among the broadleaf weed species were *Galium, Anagalis* and *Chenopodium species* (Figs. 1, 3 and 4). The prevalence of the weed *gallium species* was 37% in the chemical treatment, 35% in the stubble retention treatment, 30% in the wet tillage treatment, and 25% each in the dry tillage, wheat—wheat, stubble burning and hand-weeding treatments. The percentage of all the broad-leaf weed species was lower than 20% in the faba bean precursor treatment. From a broad leaf management point of view, the faba bean rotation is the best option among the treatments for determining the severity of broad leaf weeds in wheat. Dry tillage, stubble burning, and hand-weeding can also be alternative options for reducing broadleaf weed species by up to 25%. Both fallow-removal and fallow-retention reduced the broadleaf weed species by less than 20%, except for *Carygola species*, which constituted 35% of the total weed species in both fallow systems. On the other hand, *Cyprus species* were the most abundant among the grassy weeds (Table 2), where the highest population was observed in the faba bean rotation (93%). *The abundance of Chlorella species* was lower in the fallow removal (33%) and chemical (38%) treatments. Dry tillage and stubble retention were strongly associated with the highest population of *Avena* species (25% and 19%, respectively), whereas the lowest population was observed in the faba bean rotation and wheat monocrop. Moreover, burning stubble and wheat monocropping were related to greater populations (18% and 17%, respectively) of *Bromus pectinatus*, while the lowest population was found in the rape seed rotation.

Among all the weed species grown, broadleaf weeds constituted more than 70% of the total weed population in the experimental plots. The highest yield obtained by the faba bean rotation was also associated with the lower population of all the weeds except for *Cyprus species*. This finding agrees with certain findings that grain legumes sown in rotation will enhance soil fertility and reduce the incidence of weeds, diseases and pests (Lopez-Belido et al., 2005). *Avena fatua* and *Bromus pectinatus* were at lower densities in the faba bean rotation, while the population of *Cyprus species* was greater. These findings showed that the faba bean rotation decreased the abundance of *Avena* and *Bromus species*, while the effect of the *Cyprus species* was nonsignificant and counterbalanced by that of the legume through improvements in soil fertility. A reduction in yield was observed under wet tillage, fallow-retention and hand-weeding, apparently due to the increase in the grassy weed population of 20% and above.

3.3. Economic analysis

The economic analysis was based on the procedures of the CIMMYT (CIMMYT, 1988). Partial budget and marginal analyses were performed for the weed management options, and the decision to select the most profitable treatment was made based on the highest net benefit and the marginal return above the minimum acceptable value for the farmers (Table 3). The profitability of bread wheat production evaluated against weed management interventions was analysed by taking the price at the local market for wheat at 8 kg/m2, for faba bean at 15 kg/m2 and for rape seed at 20 kg/m2 for Ethiopian Birr (ETB). Wheat seeds per quintal were purchased at a price of 1,200 ETB, faba bean at 1,500 and rape seed at 2,000 ETB. The grain yields of both the precursor and main crops were adjusted to 10% according to the CIMMYT procedure. The gross field benefit was calculated based on the sum of the precursor and main crop yields in the two seasons.

The fallow system appears to be the least costly and least profitable production system. The highest net benefit of 44,559 ETB was obtained from the total return of the rape seed rotation in the first season and the main crop in the next season. The faba bean rotation is the most profitable enterprise, but it is also associated with the highest cost of production. Dry tillage is also a profitable option, but the cost of production and off-season activity are likely unattractive to farmers. Hand weeding is profitable but costly, and the unavailability of labour is the major concern for farmers when choosing this technique for wheat production.

Table 3
Partial budget analysis based on the mean values of the weed management treatments.

Treatments	Yield A (kg/ha)	Yield B (kg/ha)	Adjusted Yield A (kg/ha)	Adjusted Yield B (kg/ha)	Total GFB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)
Dry tillage	2905.1	3571.3	2614.59	3214.17	46,630	3,625	43,005
Wet tillage	2917.7	3233.4	2625.93	2910.06	44,288	3,600	40,688
Fallow-removed	0	3173.1	0	2855.79	2,846	2,100	20,746
Fallow-retained	0	3639.2	0	3275.28	26,202	1,800	24,402
Wheat monocrop	2931.5	3504.2	2638.35	3153.78	46,337	3,620	42,717
Faba bean rotated	1618.2	3477.5	1456.38	3129.75	46,884	5,550	41,334
Rape seed rotated	1255.5	3383.3	1129.95	3044.97	46,959	2,400	44,559
Stubble burning	2882.5	3479.8	2594.25	3131.82	45,809	3,625	42,184
Stubble retention	2852.6	3299.8	2567.34	2969.82	44,297	3,650	40,647
Chemical	2725.2	3357.9	2452.68	3022.11	43,798	2,000	41,798
Hand weeding	2928.1	3156.2	2635.29	2840.58	43,807	4,500	39,307

*Yield A = yield of the precursor treatment; yield B = yield of the main crop (wheat); adjusted yields denote the yield adjusted to 10%; GFD = gross field benefit; TVC = total variable cost; NB = net benefit

The marginal rate of return was calculated as the ratio of the change in total net benefit to the change in total variable cost. The decision for the profitable option is made based on the marginal rate of return, which is immediately above the minimum acceptable value, which is 100% in most farmers. The final recommended technology is identified by changing from one technology to the next until the minimum marginal rate of return is reached. The highest residual (R), the difference between the net benefit and the total variable cost, is taken to cross-check the decision for the selected profitable treatment. The fallow-retained, chemical option, and rapeseed rotation treatments were selected for the final recommendation (Table 4). Fallowing followed by retention of the weed biomass has rendered a minimum net benefit of 24,402 ETB per hectare and a minimum cost of production of 1,800 ETB per hectare. The next option was chemical treatment, which had a net benefit of 41,798 ETB per hectare and a cost of 2,000 ETB per hectare. The highest net benefit of 44,559 ETB per hectare was obtained from the combined return of wheat yield in the second year and rape seed yield in the first year. The marginal analysis indicated that changing from a fallow system with retention of weed biomass to a chemical control option resulted in a marginal rate of return of 8,798%, signifying a return of 87.98 ETB from this investment. A shift from chemical options to rape seed rotation produced a marginal rate of return (MRR) of 790%. We stop here and recommend rape seed rotation in the wheat production system as a profitable weed management option, with every ETB investment producing a return of 6.90%. The decision to recommend rape seed rotation in the first season followed by bread wheat rotation in the next season as an economically feasible weed management option for sustainable bread wheat productivity and profitability was cross-checked against the residual that produced the highest value from the rape seed rotation, complementing the decision made using the MRR.

Table 4
Marginal analysis and final net return of the recommended management options

Treatments	Yield A (kg/ha)	Yield B (kg/ha)	Adjusted Yield A (kg/ha)	Adjusted Yield B (kg/ha)	Total GFB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)	R	MRR (%)
Fallow-retained	0	3639.2	0	3275.28	26,202	1,800	24,402	22,602	8,798
Chemical	2725.2	3357.9	2452.68	3022.11	43,798	2,000	41,798	39,798	790
Rape seed rotated	1255.5	3383.3	1129.95	3044.97	46,959	2,400	44,559	42,159	

Yield A = precursor yield, Yield B = main crop yield, GFB = gross field benefit, TVC = total variable cost, NB = net benefit, R = residual (NB-TVC), MRR = marginal rate of return (ΔNB/ΔTVC)

4. Conclusion

Fallowing and weed biomass retention produced the highest main crop yield, while dry tillage and faba bean rotation also produced similar yields. Fallow-retention also contributed the highest 20% to the increase in subsequent yield of wheat in the main season, whereas the contributions of dry tillage and faba bean rotation were 15.7% and 18.7%, respectively. A study of the weed population revealed that more than 70% of the weeds were broad-leaf weeds. Among the broad leaf weeds, *Galium spurium*, *Anagalis species* and *Chenopodium species* are the dominant plant types. The total grassy weed population density was less than 30%. However, among the grassy weeds, Cyprus species were the most common weed species, with a maximum density of 93% observed in the faba bean rotation and lowest densities of 33% and 38% observed in the fallow-removal and chemical treatments, respectively. The best option for controlling broad leaf weeds in wheat is faba bean and rape seed rotation, whereas the recommended management for controlling *Cyprus* is fallowing land followed by weed removal. Chemical treatment with Puma Super or any other effective herbicide can also serve as a management option to reduce the size of the *Cyprus* weed population. In areas where *Avena* species are problematic for bread wheat production, the faba bean rotation is the best option, while in areas severely constrained by the prevalence of *Bromus pectinatus*, rape seed rotation is the best treatment for bread wheat production. From the perspective of weed population density, the overall weed population can be significantly reduced by faba bean rotation, rape seed rotation and chemical control. Dry tillage also had a significant effect on all the weed species except Avena species. *Avena fatua* can stay in the seed bank for many years without breaking dormancy; hence, when the land is tilled in dry conditions, it is exposed to direct sunlight, which helps it break dormancy. This process enables the seeds to germinate during the main season.

Economic analysis revealed fallow-retention, chemical treatment, and rape seed rotation to be economically feasible weed management options in bread wheat production systems. This shows the real scenario in which farmers fallow their land for the purpose of enhancing fertility to avoid deterioration during continuous farming. However, fallowing has become a difficult option due to the increasing family size and the shrinking of the land held by each household because of population pressure. The continuous use of chemicals for controlling weeds, fertilizers for increasing yield and pesticides for controlling diseases and insects has recently become common undertakings for food security and income reasons. The highest net benefit and marginal rate of return were obtained from the combined return of wheat in the main season and rape seed in the first season. The highest net benefit was 44,559 ETB/ha, with a marginal rate of return of 790%. The change from the fallow-retention system to chemical control produced a marginal rate of return of 8,798%. Although the marginal rate of return was highest when the switch of technology choice was made from the fallow-retention system, the marginal rate of return of 790% obtained from the combined return of wheat in the main season followed by the rape seed rotation in the first season was chosen for user recommendation. This is because farmers continue to invest until the switch from one technology to the other comes near the minimum acceptable marginal rate of return. An acceptable marginal return of 790% was attained from the combined rape seed treatment in the first year, followed by the wheat treatment in the next season. Therefore, the best technique for successful weed management and sustainable productivity and profitability of wheat in the highlands of Bale is rape seed rotation in the first year, followed by wheat rotation in the next season. Hence, this technology is recommended for obtaining a net benefit of 44,559 ETB per hectare, and the expenditure of one birr in the combined rape seed rotation in the first season and wheat in the next season will result in an additional 6.90 ETB.

Declarations

Conflict of interest

The authors claim no potential conflicts of interest.

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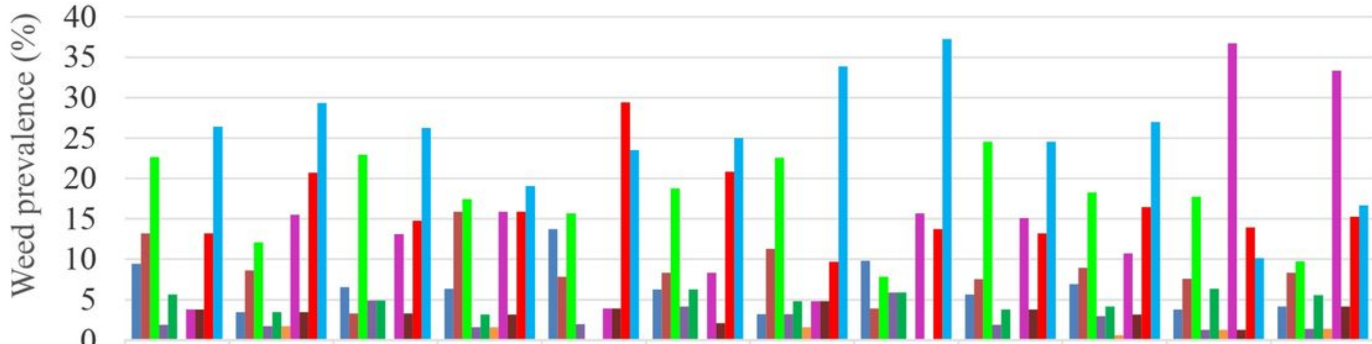
Figures



	Dry tillage	Wet tillage	Wheat monocrop	Faba bean rotated	Rape seed rotated	Burning stubble	Stubble retained	Chemical	Hand weeding	Mean	Fallow-removed	Fallow-retained
Guizotia	9	3	7	6	14	6	3	10	6	7	4	4
Amaranth.	13	9	3	16	8	8	11	4	8	9	8	8
Chenopod.	23	12	23	17	16	19	23	8	25	18	18	10
Scoreprus sp	2	2	5	2	2	4	3	6	2	3	1	1
Lucaus sp.	6	3	5	3	0	6	5	6	4	4	6	6
Raphanus	0	2	0	2	0	0	2	0	0	1	1	1
Carygola	4	16	13	16	4	8	5	16	15	11	37	33
Medicago	4	3	3	3	4	2	5	0	4	3	1	4
Anagalis	13	21	15	16	29	21	10	14	13	16	14	15
Galium	26	29	26	19	24	25	34	37	25	27	10	17

Figure 1

Percentage of broad-leafed weeds

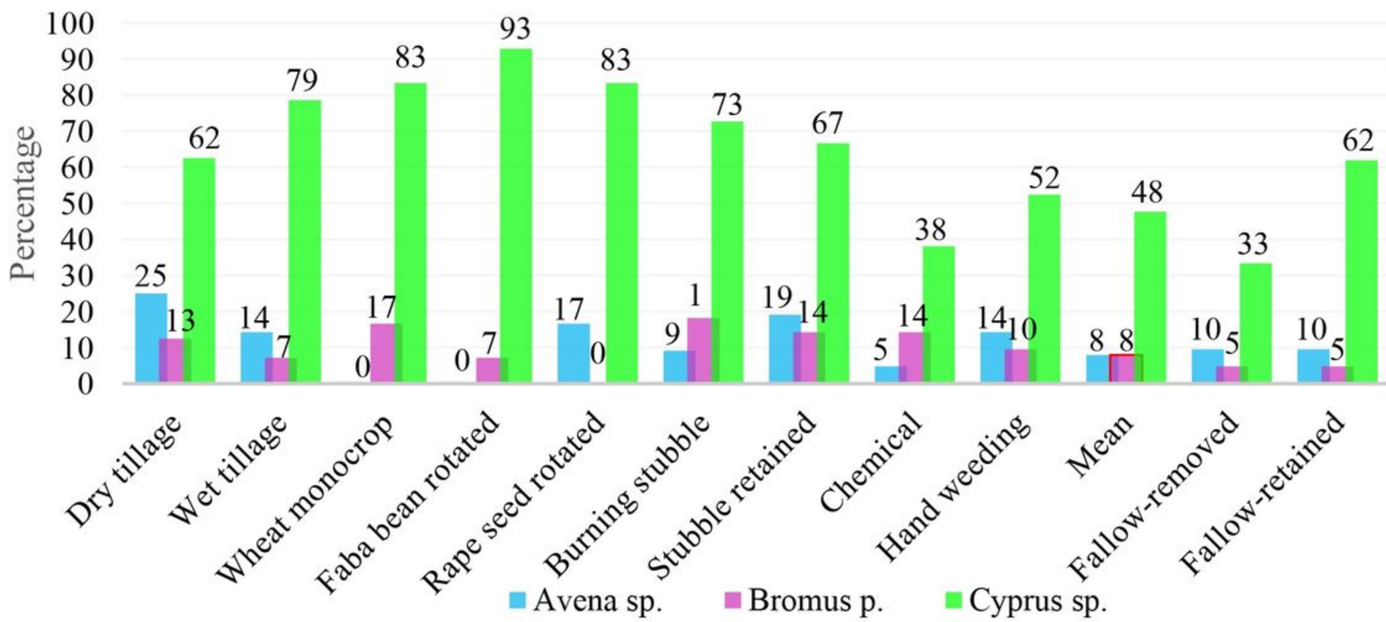


Figure 2

Percentage of grassy weeds

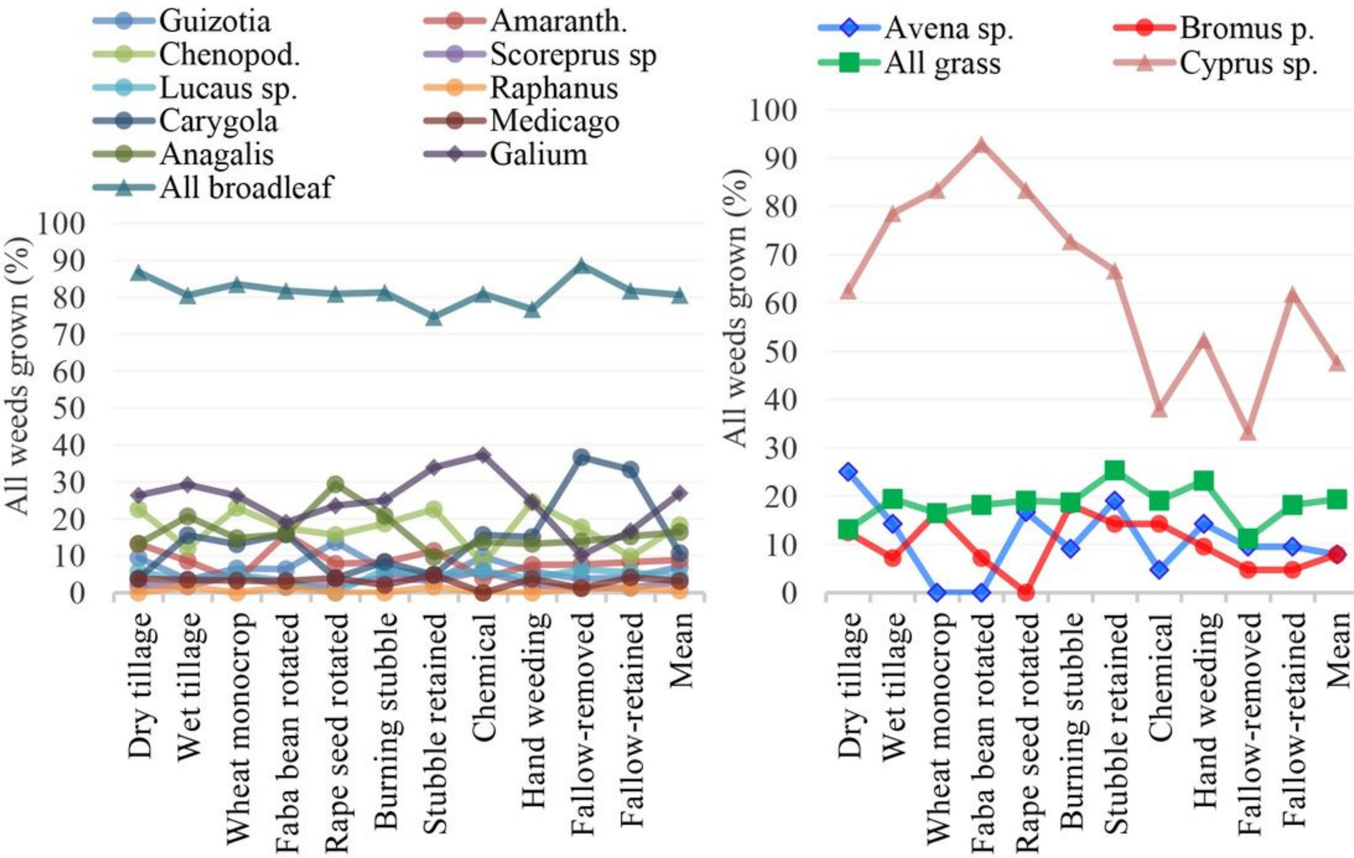


Figure 3

Percentage of grassy weed population: a) broad leaf species; b) grassy weed species

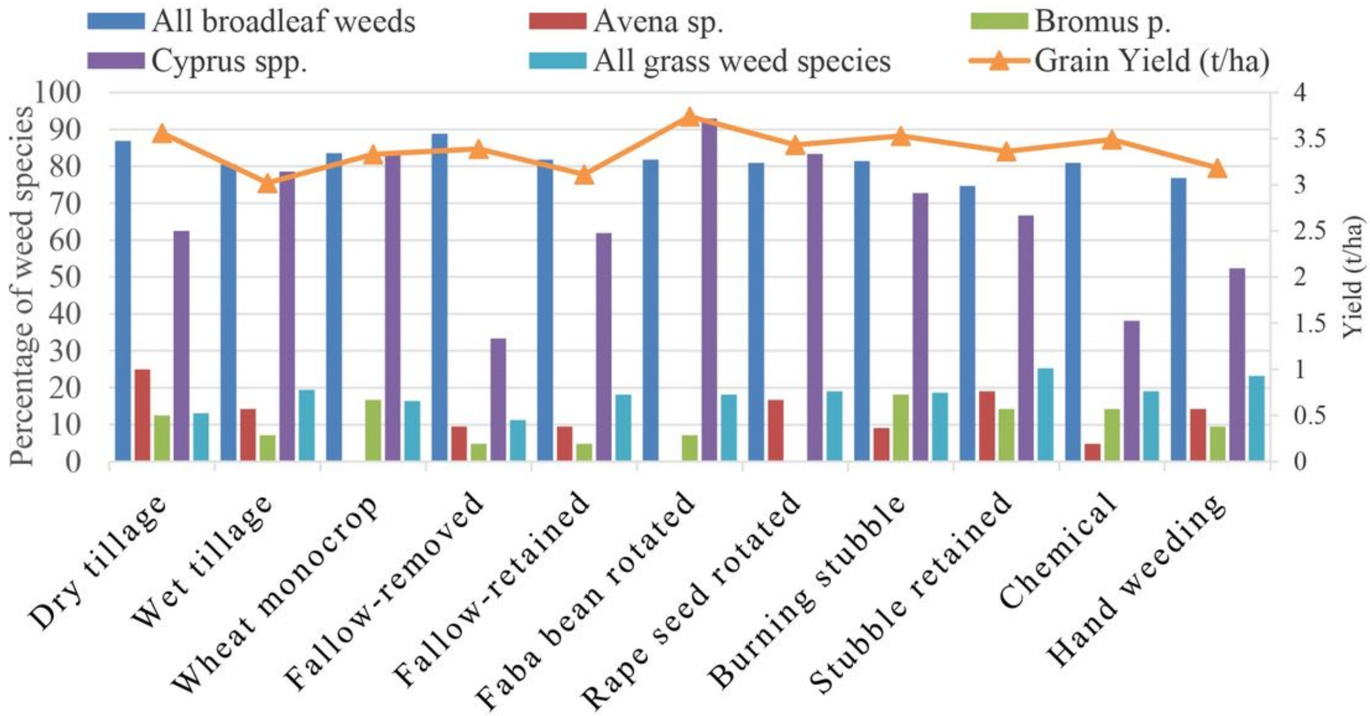


Figure 4

Percentage of weeds and grain yield