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Full Length Research Paper

Comparison of the effects of different crop rotation systems on winter wheat and sunflower under rain-fed conditions

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The study was made to detect the most suitable crop rotation system(s) under rain-fed conditions of Southern Marmara Region, Turkey. In this study (1995-2001), two different crop rotation systems were carried out: winter wheat and sunflower as main crops experiments. Results were evaluated in terms of crop yielding ability, soil fertility and economic aspects. The sunflower-rapeseed-wheat, rapeseed-fodder pea + sunflower-wheat and rapeseed-common vetch + sunflower-wheat were found the most suitable rotation systems because of their various advantages in the first experiment in which wheat was used as main the crop. The highest sunflower seed yields were obtained from a fodder pea + sunflower-wheat-fodder pea + sunflower crop rotation system both in the first and second three year periods in which sunflower was used as main crop under rain-fed conditions. Economic analysis based on the second three-year results of the research showed that the highest mean net returns were obtained from the rapeseed-common vetch + sunflower-wheat and a fodder pea + sunflower-wheat-fodder pea + sunflower crop rotation systems under rain-fed conditions. These crop rotation systems were found the best crop rotation systems under rain-fed conditions of Southern Marmara region of Turkey. As a result, the rotation systems including common vetch and fodder peas as forage plants under rain-fed conditions gave economically the highest net profit.

Key words: Crop rotation, rain-fed conditions, winter wheat, sunflower.

INTRODUCTION

Crop rotation is one of the major cultural practices in the farming system. A well planned rotation reduces diseases, pests and weeds. In addition, it provides the advantages such as increasing the soil fertility deeply, utilizing various layers of the soil to the same extent and preventing erosion. Thus it improves the physical and chemical structure of soil and increases the productivity. It is noteworthy that different rotation systems in which legumes are involved are applied in countries with developed agriculture.

The feasibility of crop rotation system or systems recommended for a region is closely related to the profitability of the crops involved in this system. Therefore, the crop rotation systems planned in order to obtain production increment within a long period cannot meet the demands of the growers that give priority to their annual returns. That is why the suitable crop rotation systems cannot be widely used in poly cultured agricultural areas.

703.376 ha field area exists in the Southern Marmara Region of Turkey, which has a humid climate. About 18.5% of this area is allocated to wheat, and 8.2% is assigned to sunflower (TÜİK, 2006). These ratios indicate that binary cropping system consisting of wheat-sunflower is widely applied under rain-fed conditions of the region.

Binary crop rotation system consisting of wheat-sunflower is widely being applied in the region having suitable climatically conditions for poly cultured cultivation. Also many years are made compulsory to take the crop rotation system into consideration seriously and the present system made the soil infertile coupled with reduced profitability. Therefore, it is expected that the soil fertility and profitability will increase significantly by including alternative crops into the rotation.

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Table 1. The first 3 year (1995-1998) application plan for the crop rotation trials in which wheat was used as main crop.

Year	1.System	2.System	3.System	4.System
1	Wheat	Sunflower	Sunflower	Rapeseed
2	Sunflower	Chickpea	Rapeseed	Fodder peas + Sunflower
3	Wheat	Wheat	Wheat	Wheat

Legumes are of great importance in rotation, especially in rain-fed areas in which the fallow lands are intensive. Common vetch and winter lentil and chickpea are considered as the best rotation crops in the binary rotation systems with wheat (Kün et al., 1990). Rapeseed, an important oilseed crop which has an intensive root system, is also known as a good previous crop for numerous crops. The involvement of rapeseed crop in the rotation systems will play an important role in the improvement of production capacities of oil factories in the region, which are being utilized at 50% capacity, bringing together its economic benefits and to preserving the soil fertility. The successful inclusion of oilseed crops in cereal-based cropping systems has been shown to have positive agronomic and economic impacts. Genetic improvement in oilseed crop yields will continue to make them economically competitive with cereals (Johnston et al., 2002). Lafond et al. (1993), Dhuyvetter et al. (1996) and Zentner et al. (2002) explained that where oilseeds are adapted, their inclusion in rotation with cereals could increase net inversion return and reduce risk through improved production stability. In addition, it was emphasized by some researchers that the involvement of rapeseed crop in rotation systems led to an increase in wheat yield (Brandt et al., 1995; Heenan, 1995; Anderson et al., 1999). On the other hand, it was also reported by many researches (Calcagno et al., 1989; Heenan, 1995; Eser et al., 1998; Açıkgöz, 2001) that including the forage crops and legumes as a winter crop to rotation either for forage production or green manuring, i.e. growing two or three crops annually was a necessary practice for improving the soil fertility as well as for increasing the annual revenue. It will be possible to solve the productivity problems encountered in the region by applying crop rotation systems in which legumes are involved.

In this research, it was aimed to determine more suitable crop rotation systems for wheat, as well as for sunflower under rain-fed conditions by comparing different rotation systems in which numerous crops are involved, with respect to increase crop yield and economic profitability.

MATERIALS AND METHODS

Trial site and characteristics

Field trials were carried out in the experimental areas of the Applied Research Centre for Agriculture, Uludag University, Bursa, Turkey (40° 11' N, 29° 04' W). Bursa province has a temperate climate. It is located in the Southern Marmara Region, with total annual rainfall of 713 mm and 14.6°C mean monthly temperature. Experimental field is 70 m above the sea level.

The mean temperatures recorded on monthly basic during the experimental years are parallel to the average of long-term period. The mean temperatures during the experimental years were recorded as 3.3 -10.2°C, 6.0-19.0°C and 21.8-27.0°C for the winter, spring and summer months, respectively. Monthly total precipitation values related to the experimental years show deviations from the average of long-term period. Total precipitation in 1997-1998 and 2000-2001 and long-term (1928-1996) winter periods were recorded as 282.7, 125.9 and 273.7 mm, respectively. Total precipitation related to the spring months of the experimental years and long-term period were determined as 237.1, 201.0 and 181.2 mm, respectively. Summer rains are limited and very erratic (DMİ, 2001).

Soil samples were analyzed in the laboratories of Bursa Rural Affairs, 17th Regional Directorate. According to the results of the soil analyses, it was determined that the soils of experimental field in which wheat and sunflower existed as the main crops were clay loam, slightly alkaline (pH is 7.0-7.5), medium in P (50-70 kg ha^{-1}) and rich in K (570-980 kg ha^{-1}), containing organic matter. There was no salinity problem in the soil of the experimental area.

Experimental design and plot size

Application plan of the trial in which wheat was considered as the main crop on yearly basis is given in Tables 1 and 2, and the plan for sunflower is presented in Tables 3 and 4.

In the trials, fodder peas was sown in autumn and harvested in the spring for forage production and thereafter sunflower was sown. Common vetch and sorghum were included into the trials for seed production in the second three years.

The experiments were designed in a randomized complete blocks with four replications. In the experiments, plot size was 62.4 m² (5.20x12.0 m).

Cultural practices, observations and statistical analysis

The plots sown of winter crops were prepared for sowing after being ploughed at a depth of 25-30 cm followed by disk-harrow and rake in September in all experimental years. Thinning was applied 15 days after emergence of sunflower seedlings and the plants were thinned when they were 15-20 cm height. All cultural practices such as weed control, pest and disease management were applied in the plants involved in trials, when necessary.

A few days before the harvest in wheat, the plants along a 1-m length of the interior rows of each plot in two replications were dug with roots for morphological measurements. In addition, all of the wheat plots were harvested for seed yield. Yield and yield components such as seed weight in a spike, harvest index, seed yield and 1000 seed weight were evaluated.

Measurement were made on agronomical and quality characters such as the head diameter, 1000 seed weight, oil yield, and seed yield in sunflower. Head diameter was determined in 20 plants randomly selected from the plots.

Table 2. The second 3 year (1998-2001) application plan for the crop rotation trials in which wheat was used as main crop.

Year	1.System	2.System	3.System	4.System
1	Wheat	Sunflower	Sunflower	Rapeseed
2	Sunflower	Chickpea	Lentil	Vetch + Sunflower
3	Wheat	Wheat	Wheat	Wheat

Table 3. The first 3 year (1995-1998) application plan for the crop rotation trials in which sunflower was used as main crop.

Year	1.System	2.System	3.System	4.System
1	Wheat	Rapeseed	Fodder peas + Sunflower	Wheat
2	Chickpea	Chickpea	Wheat	Vetch
3	Sunflower	Sunflower	Fodder peas + Sunflower	Sunflower

Table 4. The second 3 year (1998-2001) application plan for the crop rotation trials in which sunflower was used as main crop.

Year	1.System	2.System	3.System	4.System
1	Wheat	Sunflower	Fodder peas + Sunflower	Wheat
2	Chickpea	Lentil	Wheat	Sorghum
3	Sunflower	Sunflower	Fodder peas + Sunflower	Sunflower

All the data were subjected to analysis of variance using MSTAT-C (version 2.1, Michigan State University, 1991) and MINITAB (University of Texas at Austin) software. The significance of crop rotation systems were determined at the 0.05 and 0.01 probability levels, by the F-test. The F-protected least significant difference (LSD) was calculated at the 0.05 probability level according to Steel and Torrie (1980).

RESULTS AND DISCUSSION

First experiment with wheat as main crop

Southern Marmara Region which has contributed greatly on the agricultural production of Turkey is a suitable region for many field crops, because of its ecological and climatically characteristics. However, a conscious rotation system in these areas is not generally applied. The current situation has resulted in important reduction at the soil fertility for many years. The study was made to detect the most suitable rotation system (s) under rain-fed conditions in Southern Marmara Region.

Mean values related to the yield and yield components of wheat in the 3rd year of the first 3-year trial are given in Table 5.

Harvest index, 1000 kernel weight and grain yield traits were significantly affected by the rotation systems in the study. The highest mean values for these traits were obtained from Sunflower-Rapeseed-Wheat rotation system (3rd system), while the other systems gave statistically lower mean values.

In the second 3-year trial, nor yield neither yield components were statistically affected by crop rotation systems (Table 6). However, the crop rotation systems containing different crops, especially legumes, such as sunflower-chickpea-wheat or rapeseed-common vetch-sunflower-wheat are thought to be more convenient as an alternative to the conventional crop rotation system (wheat-sunflower-wheat) which is widely used under rain-fed conditions, due to their various advantages.

When the first and the second 3-year results are examined together especially in terms of grain yield, it can be seen that crop rotation systems, sunflower-rapeseed-wheat, rapeseed-fodder pea-sunflower-wheat and rapeseed-common vetch+ sunflower- wheat gave better results compared with the conventional crop rotation system (wheat-sunflower-wheat) for rain-fed conditions (4340 and 4220 kg ha^{-1} for these rotation systems in the first 3-years-experiment and 3686 kg ha^{-1} in the second 3-years-experiment). The same crop rotation systems gave 28.4 and 24.8% higher grain yield in wheat, respectively compared to conventional crop rotation system (wheat-sunflower-wheat). Inclusion of legumes in the crop rotation is generally desirable (Heenan, 1995; Eser et al., 1998), especially chickpea- a crop preferred in the rotation systems because of its many advantages, as in the other legumes (Calcagno et al., 1989; Fouqeroux et al., 1989; Avçin et al., 1992). However, it was observed that sufficient nodule formation could not be achieved in the 2nd rotation system of the first 3 year-trial, since no bacteria inoculation was done for the seed or soil. Hence the efficiency expected from chickpea

Table 5. Mean values related to the yield and yield components of wheat in the first 3 Years (1995-1998) - trial in which wheat was the main crop.

Systems*	Seed weight/spike (g)	Harvest index (%)	1000 kernel weight (g)	Grain yield (kg ha^{-1})
1.System(W-S-W)	0.81 c	28.0 b	36.0 b	3380 c
2.System (S-C-W)	0.81 c	29.0 b	35.8 b	3670 bc
3.System (S-R-W)	1.04 a	36.0 a	41.9 a	4340 a
4.System (R-F.P+S-W)	0.92 b	34.0 a	37.5 b	4220 ab
LSD (5 %)	0.14	5.4	5.6	65.6

*W, Winter wheat; S, sunflower; C, chickpea; R, rapeseed; FP, fodder peas.
Means of the same column followed by the same letter is not significantly different at 0.05 level using LSD test.

Table 6. Mean values related to the yield and yield components of wheat second 3 years (1998-2001) - trial in which wheat was the main crop.

Systems*	Seed weight/spike (g)	Harvest index (%)	1000 kernel weight (g)	Grain yield (kg ha^{-1})
1.System (W-S-W)	1.65	22.9	43.7	3726
2.System (S-C-W)	1.78	22.1	45.7	3926
3.System (S-L-W)	1.82	18.0	45.9	3418
4.System (R-V+S-W)	1.72	22.2	45.8	3686
LSD (5 %)	NS	NS	NS	NS

*W, Winter wheat; S, sunflower; C, chickpea; R, Rrapeseed; V, common vetch; L, lentil.

could not be obtained completely. Our results are in agreement with those of Ghaffari (2002) who reported that wheat grain yields were not significantly different in rotation with chickpea, sunflower and fallow. Also, in a previous study, Lopez-Bellido et al. (2000) found that yield decreased in the following crop rotation sequence: wheat-faba bean > wheat-fallow > wheat-sunflower > wheat chickpea > continious wheat. Lopez-Bellido et al. (2001) reported that the effect of chickpea rotation on wheat yield was clearly smaller than that of faba bean rotation, and generally similar to that of sunflower rotation.

Oilseed crops have economical importance beside their contribution to oil production. Several early studies with rapeseed reported that especially rapeseed as a previous crop increased the yield of wheat (Heenan, 1995). For instance, Heenan (1995) stated that there were 84 and 86% increase in wheat yield when fodder peas and rapeseed were used as previous crop, respectively. These results are similar to the yield increase obtained in the 3rd crop rotation system (sunflower-rapeseed-wheat) in our study at the first 3-years.

It was likely that the relatively low wheat yields in our trials were due to the deficiency and uneven of rainfall. Studies made in the region with different wheat cultivars indicated that the grain yield varied between 3650 and 6090 kg ha^{-1} (Doğan and Yürür, 1997). These studies suggest that the addition of rapeseed and a legume crop to the system in arid and semi arid regions applied binary crop rotation systems consisting of wheat-sunflower-wheat would be beneficial. On the other hand, rapeseed is harvested 2-2.5 months earlier compared with sunflower harvest. When it is considered that the oil factories are operated at low capacity during summer period due to the shortage of raw material, it may be seen that the only crop that will increase this capacity is the rapeseed. Moreover, rapeseed is a good previous crop that can lead an increase in wheat yield. It is clear that rapeseed should be included in rotation systems due to these advantages.

Second experiment with sunflower as main crop

As seen in Tables 7 and 8, in the experiment consisting of sunflower as main crop, six-year results revealed that the highest mean values in seed yield (2510 kg ha^{-1}) and oil yield (1112 kg ha^{-1}) were obtained from the 3rd system (fodder pea + sunflower-wheat-fodder pea + sunflower). In addition, the rotation systems consisting of legume crops such as chickpea and lentil as previous crops are also suitable for sunflower. Muresan (1972) stated that sunflower gave the highest yield when sown after legume crops. As can be seen from this study, the efficiency of legume green manure crops in the crop rotation systems is rather strong. However, the yield increase caused by green manure crops on the subsequent crop is reduced when the only stubble and roots of plants are incorporated into the soil. Caporali and Campiglia (1993) reported that increase of 86% was obtained in the yield of sunflower, by mixing all parts of the green manure crops into the soil, while increase of 58% was resulted in the yield by mixing the only stubble or roots of these plants

Table 7. Mean values related to the yield and yield components of sunflower in the first 3 years (1995-1998) - trial in which sunflower was the main crop.

Systems*	Head diameter (cm)	1000 seed weight (g)	Seed yield (kg ha^1)	Oil yield (kg ha^{-1})
1.System (W-C-S)	16.4	49.8	2339 b	959 ab
2.System (R-C-S)	16.2	51.5	2263 b	931 b
3.System(F.P.+S-W-F.P.+S)	16.4	51.0	2510 a	1016 a
4.System (W-V-S)	15.6	48.8	2097 c	851 c
LSD(5 %)	NS	NS	141	65

*W, Winter wheat; S, sunflower; C, chickpea; R, rapeseed; F.P, fodder peas; V, common vetch.

Table 8. Mean values related to the yield and yield components of sunflower in the second 3 years (1998-2001) - trial in which sunflower was the main crop.

Systems*	Head diameter (cm)	1000 seed weight (g)	Seed yield (kg ha^1)	Oil yield (kg ha^{-1})
1.System(W-C-S)	17.6	51.4	2332 a	1102 a
2.System(R-L-S)	16.7	51.1	2224 a	1073 a
3.System(F.P.+S-W-F.P.+S)	17.1	48.6	2260 a	1112 a
4.SystemW-Sor.-S)	16.2	51.2	2084 b	1001 b
LSD (5 %)	NS	NS	129	70

*W, Winter wheat; S, sunflower; C, chickpea; R, rapeseed; L, lentil; Sor, sorghum; F.P, fodder peas

into the soil. The results of these researchers were similar to our findings which revealed that the sunflower sowed after the fodder pea gave high seed yield. The same researchers reported that the sunflower sowed after alfalfa-again a legume crop-(4 years) gave 60% higher yield compared with sunflower subjected to sunflower-wheat-wheat-maize rotation, and that the number of seeds per head and 1000 seed weight increased significantly (Campiglia and Caporali, 1994). In our study, it was observed that common vetch did not form nodules in the soils of the experimental area, although it is a legume crop. Furthermore, common vetch was harvested for seeds and the stem residues were not left on the soil. Therefore soil improving effect of common vetch was not observed.

Six-year results of the study revealed that fodder pea + sunflower-wheat-fodder pea + sunflower were superior crop rotation system for sunflower. Crop rotation systems including fodder pea as a winter intercrop and lentil or chickpea as a previous crop gave 6.7 - 19.7% higher seed yield in sunflower compared to rotation systems consisting of common vetch or sorghum crops. Reddy and Sudhakara Babu (2003) reported that the higher sunflower seed equivalent yield was obtained with groundnut and sorghum as sequence crops. In a previous study, it was found that the maize–potato–sunflower, maize–mustard–sunflower, cowpea–toria–sunflower and rice–sunflower rotations had significantly higher sunflower seed yield equivalents (201, 17, 15 and 4% higher, respectively) than the rice–wheat rotation (Pahl, 2003).

Economical evaluation of crop rotation systems

Absolute returns were determined for each crop rotation system, using the valid input prices of the crops involved in each one of the rotation systems and the crop prices paid to the farmers in the experimental years (Table 9). It was revealed that the crop rotation system consisting of rapeseed-common vetch + sunflower-wheat in the trial in which wheat was the main crop under rain-fed conditions and the rotation system consisting of fodder pea + sunflower-wheat-fodder pea + sunflower in the 2nd trial in which sunflower was the main crop were more advantageous compared with the other crop rotation systems, having net profits of \$474 and \$482 ha^{-1} year-1, respectively.

Absolute returns were determined for each crop rotation system, using the valid input prices of the crops involved in each one of the rotation systems and the crop prices paid to the farmers in the experimental years. The net profit values was determined by subtracting the production costs (excluding the land rent and active capital interest) related to production activities from the gross production value found by giving price to the yield values belonging to the products obtained from the three-year trials (Rehber and Çetin, 1998).

It was revealed that the crop rotation system consisting of rapeseed-common vetch + sunflower-wheat in the trial in which wheat was the main crop under rain-fed conditions and the rotation system consisting of fodder pea + sunflower-wheat-fodder pea + sunflower in the 2nd trial in which sunflower was the main crop were more ad-

Table 9. Absolute returns of crop rotation systems ($ ha^{-1} $year^{-1}$).

I. Trial (Main Crop: Wheat)								
Year	I. System		II. System		III. System		VI. System	
	Crop	Return	Crop	Return	Crop	Return	Crop	Return
1	W	355	S	356	S	333	R	231
2	S	326	C	438	L	265	V+S	798
3	W	365	W	356	W	362	W	393
Means		349		385		350		474

*W, Wheat; S, sunflower; C, chickpea; L, lentil; R, rapeseed; V, common vetch.

II. Trial (main crop: sunflower)								
Year	I. System		II. System		III. System		VI. System	
	Crop	return	Crop	return	Crop	return	Crop	return
1	W	385	R	233	F.P.+S	695	W	463
2	C	482	L	293	W	436	Sor.	79
3	S	532	S	507	F.P.+S	313	S	475
Means		466		344		482		339

*W, Wheat; S, sunflower; C, chickpea; L, lentil; R, rapeseed; F.P, fodder peas; Sor, sorghum.

vantageous compared with the other crop rotation systems. The superiority of these rotation systems was due to high prices of product belonging to fodder pea and common vetch grown for forage production in these rotations. On the other hand, 1st rotation system (wheat-chickpea-sunflower) of the trials consisting of sunflower as main crop was also profit rotation because chickpea was a cash crop in agricultural marketing. Differences in net return were affected by crops in rotation, weather conditions, and crop prices. In similar studies, the highest net income was obtained from the rice-potato-sunflower sequence (Jaiswal et al., 1993) and sunflower-groundnut rotation (Reddy and Sudhakara Babu, 2003). In addition, Nel and Loubser (2004) reported that drybean and soybean improved net returns and reduced risk while sunflower was the most effective in reducing risk with little effect on the net return. Previous studies in the Great Plain indicated that where oilseeds are adapted, their inclusion in rotation with cereals could increase net return and reduce risk through improved production stability (Lafond et al., 1993; Dhuyvetter et al., 1996).

Conclusion

This investigation was aimed to determine the most suitable crop rotation systems consisting of wheat and sunflower as the main crop under rain-fed conditions. The best crop rotation systems were determined with respect to crop productivity, soil fertility and economical returns for rain-fed conditions. There was significant difference between the crop rotation systems in terms of the wheat yield in the first 3-year-trial in which wheat was the main crop under rain-fed conditions. Nevertheless, it was concluded that the 3rd system (sunflower-rapeseed-wheat) and the 4th system (rapeseed-fodder pea + sunflower-wheat) were more suitable according to the results of the first 3-year trials, and the 4th system (rapeseed-common vetch+sunflower-wheat) rotation system was more suitable according to the second 3-year trials, considering various advantages although there was not a statistically significant difference in grain yield.

The highest seed and oil yields were obtained from the 3rd (fodder pea + sunflower-wheat-fodder pea +sunflower) rotation system in the first 3-year-trial in which sunflower was used as the main crop, and from the 1st (wheat-chickpea-sunflower), 2nd (rapeseed-lentil-sunflower) and the 3rd (fodder pea + sunflower-wheat-fodder pea + sunflower) systems according to the results of the second 3-year trials.

Economical analyses revealed that the crop rotation system consisting of Rapeseed-Common vetch + Sunflower-Wheat in the trial in which wheat was the main crop and the rotation system consisting of Fodder pea + Sunflower-Wheat-Fodder pea + Sunflower in the 2nd trial in which sunflower was the main crop were more advantageous than the other systems with the net profits of $474 and $482 ha^{-1} year-1, respectively.

When the productivity and profitablities of wheat and sunflower were evaluated as the main product under rain-fed conditions, the crop rotation systems consisting of rapeseed-fodder pea + sunflower-wheat and rapeseed-common vetch + sunflower-wheat and fodder pea + sunflower-wheat- fodder pea + sunflower were determined to be more advantageous, according to the results of 6 years.

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