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Effect of Crop Rotation Systems and Mineral Fertilization on Wheat Productivity and Improving Some Soil Properties Under Assiut Condition

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Abstract

A field experiment was conducted to detect the effects of crop rotation systems i.e. millet-fallow-wheat (S_1), millet-temporary clover-wheat (S_2) and cowpea-fallow-wheat (S_3) and levels of NPK fertilizers i.e. 100, 80 and 60% of the recommended doses of NPK fertilizers on wheat yield and some soil properties. The study carried out for two consecutive years from 2008-2010 on a calcareous soil at the experimental farm of Arab El-Awammer Research Station, Agriculture Research Center, Assuit, Egypt.

Results showed that all crop rotation under this study significantly reduced soil bulk density and increased soil EC, particularly S_3 rotation which decreased bulk density by 9.9 and 7.2% and increased EC by 12.0 and 1.7% when compared with S_1 and S_2, respectively. Soil organic mater, total N, available P and K in soil were significantly high by using S_3 rotation 47.3, 26.5, 107.0 and 34.2% higher compared with S_1 rotation, respectively.

Crop rotations, NPK fertilizers levels and its interactions significantly affected grain and biological yields of wheat as well as its grain nutrients content. Wheat plants cultivated after cowpea and fertilized with 100% of the recommended doses of NPK gave the highest values of grain and biological yields as well as NPK-uptakes by wheat grains, followed by wheat plants fertilized with 80% of the recommended doses of NPK under the same crop rotation.

Keywords: crop rotation, soil properties, mineral fertilization, wheat, yield.

Introduction

Crop rotations have a major impact on soil health, due to emerging soil ecological interactions and processes that occur with time. These include improving soil structural stability and nutrient use efficiency, increasing crop water use efficiency and soil organic matter levels, providing better weed control, and disrupting insect and disease life cycles (Carter et al., 2002, and Carter et al., 2003). Also, crop rotation systems increase yields and enhance nitrogen availability when nitrogen-fixing legumes were included (Galantini et al., 2000 and Miglierina et al., 2000). Crop rotation systems are more effective at reducing long-term

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yield variability than monoculture systems, and increase total soil C and N concentrations over time, which may further improve soil productivity (Varvel, 2000 and Kelley et al., 2003).

Fertilization is one of the most important practices in crop production for its influence on soil nutrients availability. Ishaq et al., (2002) and Mehdi et al., (2008) showed that a fertilizer application significantly increased soil P and K concentrations, and the concentrations of N, P, K and soil organic carbon (SOC) were greater in the plough layer than in the subsoil layer . Salem (2005) found that increasing nitrogen fertilizer levels from 72 and144 to 216 kg N ha^{-1} significantly increased grain and biological yields ha^{-1} of wheat. Abd-El-All (2007) found that the application of NPK fertilizers at levels of 80-15-50 kg fed^{-1} significantly increased grain and biological yields of wheat.

Sustainable agricultural systems require the maintenance and improvement of soil fertility. This is expressed in the following definition: Sustainable agriculture is a system which maintains the productive capacity of the land and its economic viability. It minimizes energy and resource use, as well as, optimizes the level of turnover and recycling of organic matter and nutrients. Sustainable land use is therefore a system which uses the land in a way that does not reduce its future productive capacity (Roberts, 1995).

The objective of this study was to examine impact of crop rotation systems and mineral NPK fertilization on the development of soil fertility and its productivity of wheat.

Materials and Methods

A field experiment was conducted for two consecutive years from 2008-2010 on a calcareous soil at the experimental farm of Arab El- Awammer Research Station, Agriculture Research Center, Assuit, Egypt. The investigation was expended to study the effects of wheat crop rotation with three crops of forage (millet, clover and cowpea) and NPK fertilization on sandy calcareous soil properties and wheat productivity. Data in Table (1) represent some physical and chemical properties of the experimental soil.

Table 1. Some physical and chemical properties of the experimental soil (0-60 cm depth)

Soil properties	Unit	Value *
Particle size distribution		
Sand	(%)	95.9
Silt	(%)	2.5
Clay	(%)	1.6
Texture grade		Sandy
Physical characters		
Saturation	% (w/w)	22.1
Field capacity	% (w/w)	10.2
Wilting point	% (w/w)	4.3
Bulk density	(g/cm^3)	1.70
Organic matter	(%)	0.15
$CaCO_3$	(%)	32.67
Chemical characters		
PH (1:1 suspension)		8.53
EC (1:1 extract)	$dS\ m^{-1}$	0.43
Total nitrogen	(%)	0.003
Available-P	($mg\ kg^{-1}$)	8.49
Available-K	($meq\ 100g^{-1}$ soil)	0.13

* Each value represents the mean of three replications

The experimental design was a split-plot design with four replicates; the plot size was 7x6 m. The cropping systems treatments were distributed in main plots, while the NPK fertilization programs were arranged randomly in sub-plots as follows:

A- Cropping systems (main plots):

1) Millet/fallow/wheat (S_1).
2) Millet/temporary clover (fahl)/wheat (S_2).
3) Cowpea/fallow/wheat (S_3).

B- Fertilization programs of wheat (sub main plots):

1) 100% recommended level of NPK (F_1).
2) 80% recommended level of NPK (F_2).
3) 60% recommended level of NPK (F_3).

Crop details:

- Millet

Millet seeds (*Pennisetum glaucum* L.) were sown by broadcasting at level of 20 kg fed^{-1} on 15 and 10 of April in 2008 and 2009, respectively. Ammonium nitrate level (33.5 % N) was added at level 80 kg N fed^{-1} in three equal levels, after 20 days from sowing, after 1st cut and 2nd cut. Single supper phosphate (15% P_2O_5) at a level of 30 kg P_2O_5 fed^{-1} and potassium sulfate (48% K_2O) at a level of 24 kg K_2O fed^{-1} was added to plots at sowing.

- Cowpea

Cowpea (*Vigna unguiculata* L) was planted at a level of 30 kg

fed^{-1}on 15 May in both growing seasons (2008 and 2009). The recommended dose of NPK fertilizers were 20-22.5-24 N-P_2O_5- K_2O kg fed^{-1}, respectively. Prior to sowing seeds inoculated was applied with the specific strain of nodule bacteria before planting.

- Clover

The clover (*Trifolium alexandrinum* L) seeds were sown at a level of 20 kg fed^{-1} just after millet harvest. Clover seeds were inoculated before seeding with Okadein for allowing nitrogen fixation. Before planting, phosphorous and potassium fertilizers were added in the form of single supper phosphate (15% P_2O_5) and potassium sulfate (48% K_2O), at levels of 30 and 24 kg of P_2O_5 and K_2O fed^{-1}, respectively. Nitrogen fertilizer (ammonium nitrate, 33.5% N) applied at the level of 15 kg $feddan^{-1}$ after germination.

- Wheat

Seeds were sown by broadcasting at a level of 60 kg fed^{-1} (*Triticum aestivum* L.). The date of sowing was 15^{th} and 22^{nd} November in 2008/2009 and 2009/2010, respectively. Nitrogen, phosphorous and potassium fertilizers were added in the form of ammonium nitrate (33.5% N), single supper phosphate (15% P_2O_5) and potassium sulfate (48% K_2O), at levels of 120, 30 and 24 kg of N, P_2O_5 and K_2O fed^{-1}, respectively. All PK and 1/3 N fertilizer were applied to wheat at sowing, while 1/3 N at one month after sowing and remaining 1/3 N at heading stage. Chelated Fe, Mn, Zn and boric acid in a liquid solution, containing 150, 150, 150 and 50 mg l^{-1} respectively, was used as a foliar spray at a level of 0.5 l $plot^{-1}$ (200 l fed^{-1}), and sprayed twice after 50 - 85 days from sowing.

At harvest, the wheat grain and biological yields (kg fed^{-1}) were recoded. Grains samples were wet digested (Parkinson and Allen, 1975) to determine nitrogen, phosphorus and potassium and multiplied by grain yield fed^{-1} to obtain the grain nutrients uptake according to A.O.A.C. (1980).

Soil sampling and analysis:

At the beginning of the study, soil mechanical analysis was carried out using pipette method according to Klute (1986). Soil bulk density was determined using the undisturbed soil cores according to Klute (1986). Carbonate content, soil organic mater, soil pH, electrical conductivity, total nitrogen, available P and K were determined according to Page (1982).

At the end of the experimental plots, surface soil samples (0-20 cm) for each rotation were collected, air dried, ground to pass through 2 mm sieve and then analyzed for electric conductivity ($EC_{1:1}$), soil $pH_{1:1}$, organic matter, total nitrogen, available-P and K. Meanwhile, Soil bulk density was determined using the undisturbed soil cores.

The MSTAT-C (Version 2.10) computer program written by Freed et al. (1987) was used to perform all the analysis of variance and to compare for significant differences among treatment means, using the LSD at $p = 0.05$ as outlined by Steel and Torrie (1982).

Result and Discussion

Some physical and chemical properties

Soil bulk density, soil pH and EC as affected by the three rotations i.e. millet-fallow-wheat (S_1), millet-temporary clover-wheat (S_2) and cowpea-fallow-wheat (S_3) under different levels of NPK fertilization treatments are presented in Figures (1, 2 and 3). The results indicated that bulk density was decreased, particularly with S_3 crop rotation (cowpea-fallow-wheat), compared with other cropping systems treatments. However, the decreasing in soil bulk density was 9.9 and 7.2% compared with millet-fallow-wheat (S_1) and millet-temporary clover-wheat (S_2) treatments, respectively. The lower soil bulk density in this sequence was likely associated with improved soil physical conditions. Inclusion of cover crops, such as the cowpea or clover planted in the 2-yr crop sequences may improve the formation of soil aggregates which reflected in lowering the soil bulk density, increased aggregate stability, and more rapid infiltration levels. In contrast, crop sequences coming out of millet-fallow-wheat (S_1) may have possessed a higher proportion of micro aggregates, causing a decrease in inter aggregate porosity and a proportional increase in soil bulk density. Similar results were reported by (Liebig et al., 2002 and Moghaddam et al., 2011).

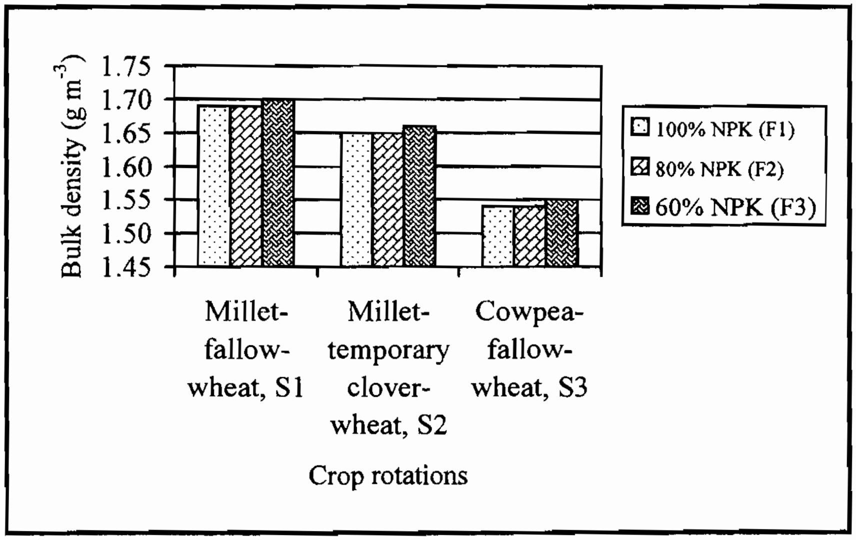

Fig.1. Effect of crop rotations and application of NPK-fertilizer levels on soil bulk density at the end of the experiment.

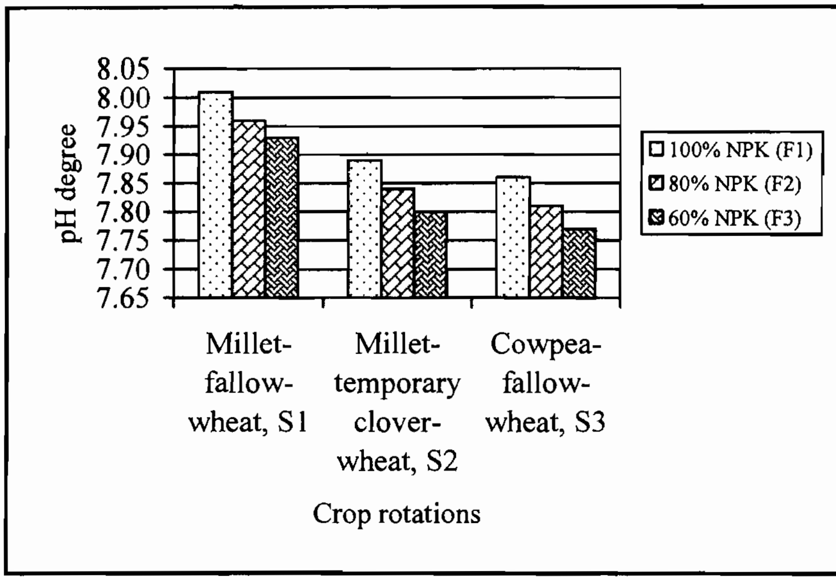

Fig.2. Effect of crop rotations and application of NPK-fertilizer levels on soil pH at the end of the experiment.

The studied cropping systems had no significant effects on final soil pH. Soil pH was insignificantly lower at soil surface layer in cowpea–fallow-wheat (S_3) and millet–temporary clover-wheat (S_2) rotations treatments compared with millet–fallow-wheat (S_1) treatment.

The main effects of NPK fertilizer levels and its interaction effects with cropping systems had no significant effect on both soil bulk density and pH.

At the end of the experiment the crop rotations treatments caused an increase in soil EC, particularly, cowpea-fallow-wheat system (S_3) which increased EC by 12.2 and 1.7% compared with millet-fallow-wheat (S_1) and millet-temporary clover-wheat (S_2), respectively.

Electrical soil conductivity (EC) was significant increased with increasing the levels of NPK-fertilizers treatments, particularly the 100% of the recommended level of NPK (F_1).

The interactions of crop rotations and NPK fertilizer levels were significantly affect the soil EC. Plots planted with cowpea-fallow-wheat rotation (S_3) and fertilized with 100% of the recommended level of NPK (F_1) gave the maximum soil EC followed by that fertilized with 80% recommended level of NPK (F_2) under the same crop rotation (S_3). The reason might be that more biomass was produced in the cowpea-fallow-wheat rotation fertilized with 100% of the recommended level of NPK-fertilizer (F_1), resulting in more soil organic matter than other treatments when crop harvested, roots left over in the field decayed and during this decaying process, they excrete organic acids and nutrients consequently increases EC values.

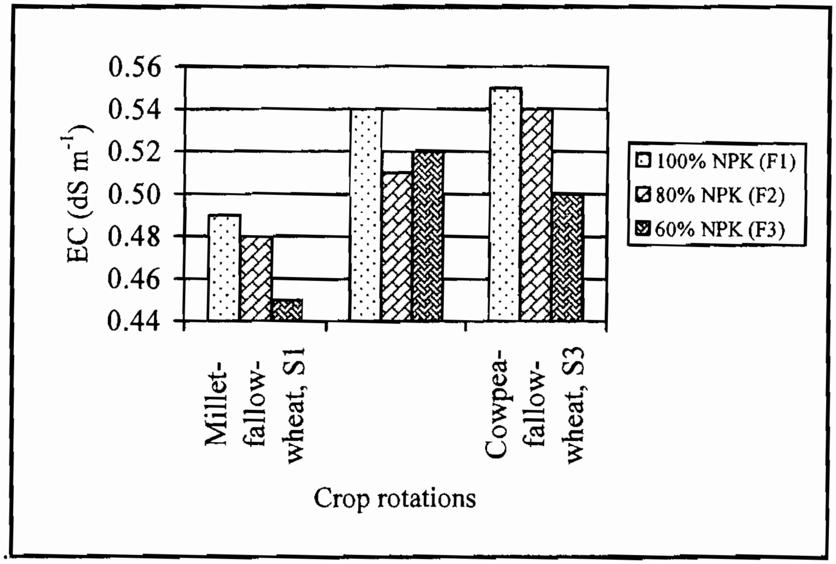

Fig.3. Effect of crop rotations and the application of NPK-fertilizer levels on soil electric conductivity (EC) at the end of the experiment.

Soil fertility properties

The status of soil fertility i.e. OM content, total N, availability of P and K under the three rotations treatments i.e. millet-fallow-wheat (S_1), millet-temporary-clover (S_2) and cowpea-fallow-wheat (S_3) are presented in Figures (4, 5, 6 and 7). Results revealed that crop rotation significantly affect OM, total N, available P and K in soil. The maximum values of these characters were recorded in cowpea-fallow-wheat rotation (S_3) which increased by 47.3, 26.5, 107.0 and 34.2% higher than that obtained by millet-fallow-wheat rotation (S_1), respectively. This might be attributed to more N_2 fixation and/or N and P released from organic matter decomposition as well as subsequently incorporated into microbial biomass. These findings are in line with Cox et al., (2003) and Martini et al., (2004).

All previous characters showed significant increase with increasing NPK-fertilizer levels except OM. The highest values of total N, available P and K found in the plots treated with 100% of the recommended dose of NPK fertilizers treatment (F_1). Meanwhile, OM was recoded the maximum value with 80% of the recommended level of NPK fertilizers treatment. These results are in line with those obtained by Kumbhar et al., (2007) and Wei et al., (2010) who reported that application of NPK fertilizers at levels of 150-75-75 kg N, P_2O_5 and K_2O ha^{-1} resulted in OM, N and P accumulation in the soil.

It was further noted that the interaction between crop rotations and the fertilizers application treatments was insignificantly affected the previous characters except OM.

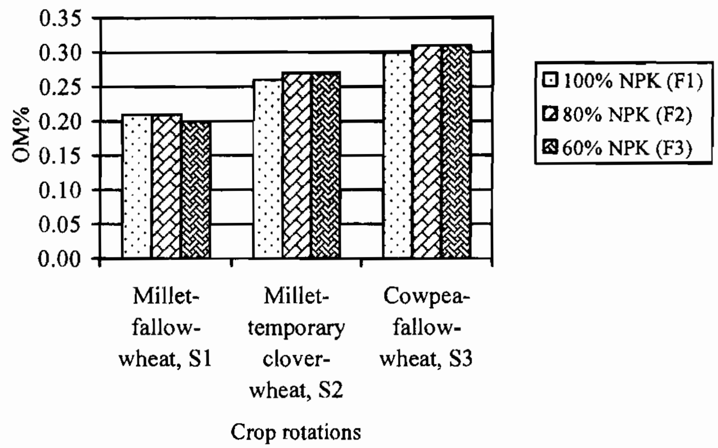

Fig.4. Effect of crop rotations and the application of NPK fertilizer levels on soil organic matter (OM) at the end of the experiment.

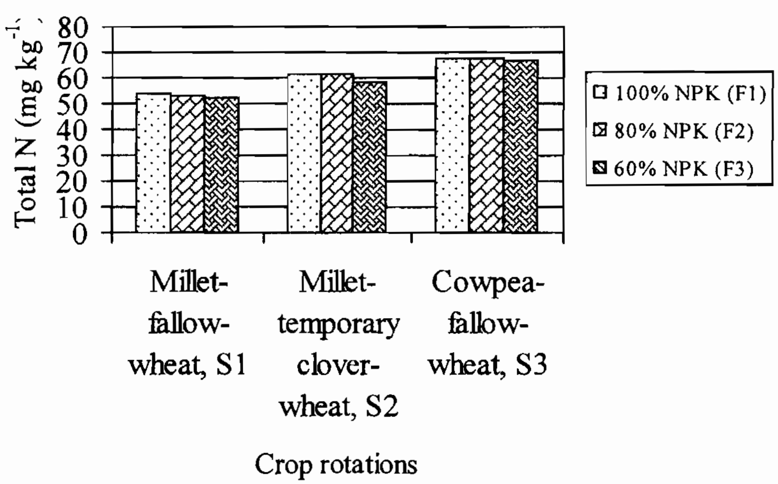

Fig.5. Effect of crop rotations and the application of NPK fertilizer levels on Total N in soil at the end of the experiment.

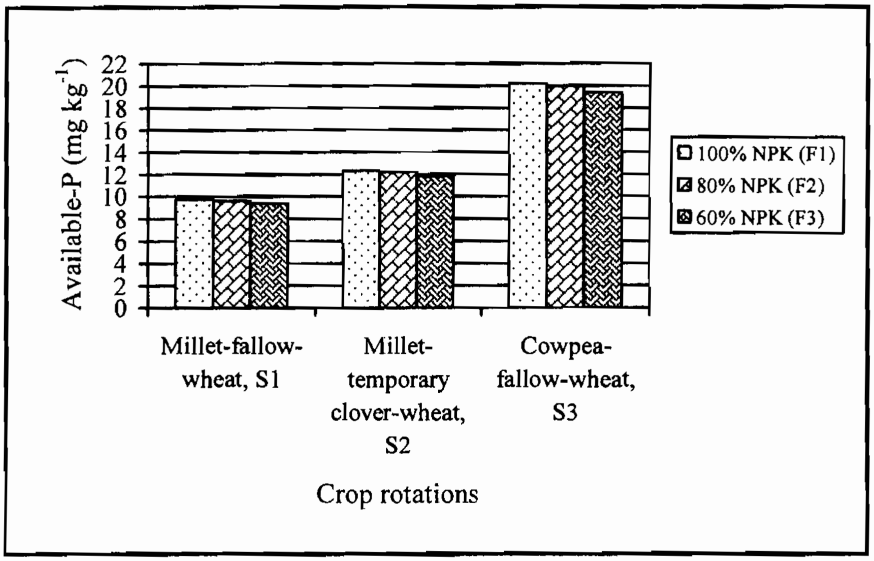

Fig.6. Effect of crop rotations and the application of NPK fertilizer levels on soil available-P at the end of the experiment.

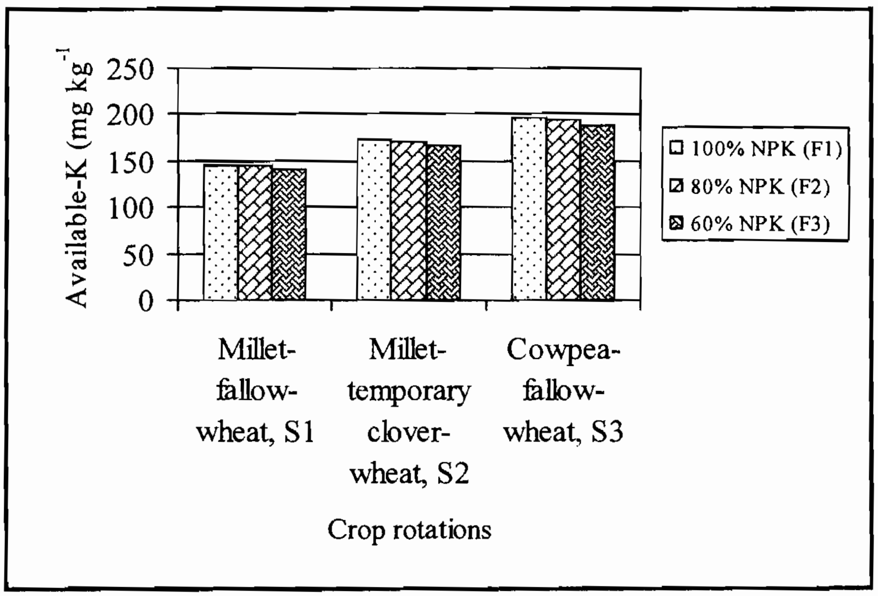

Fig.7. Effect of crop rotations and the application of NPK-fertilizer levels on soil available-K at the end of the experiment.

Wheat productivity

Statistical analysis of data in Table, (2) revealed that the differences among grain and biological yields of the three crop rotations were significant. The higher grain and biological yields were produced by cowpea-fallow-wheat crop rotation (S_3). Grain and biological yields were increased in this crop rotation by 55.4 & 56.0% in the first season and by 66.7 & 60.9 % in the second season over millet-fallow-wheat crop rotation (S_1), respectively. Meanwhile, millet-temporary clover-wheat crop rotation (S_2) caused increases in grain and biological yields by 23.7 & 24.0% and 28.6 & 26.1 in both two seasons over millet-fallow-wheat crop rotation (S_1), respectively. The higher grain and biological yields of wheat after cowpea or temporary clover may be due to the biologically fixed N in the legume root nodules (Ahmad et al., 2010) which increased the total N content in soil as compared to millet-fallow-wheat crop rotation (S_1). Moreover, the less competition of existed weeds in the crop rotation of temporary clover before wheat. Similar results were also reported by Moghaddam et al., (2011) that the involvement of a rapeseed crop in a rotation system led to an increased wheat yield.

Table 2. Effect of crop rotations and the application of NPK-fertilizer levels on grain and biological yields as well as grain nutrients uptakes of wheat during 2008-2009 and 2009-2010 seasons

Cropping system	Fertilizer level	Grain yield (kg fed^{-1})		Biological yield (kg fed^{-1})		N uptake (kg fed^{-1})		P uptake (kg fed^{-1})		K uptake (kg fed^{-1})	
		2008/09	2009/10	2008/09	2009/10	2008/09	2009/10	2008/09	2009/10	2008/09	2009/10
S1	F1	1526.35	1545.68	3127.38	3438.78	29.02	29.52	3.37	3.44	12.87	13.10
	F2	1314.08	1294.35	2688.18	2920.03	23.48	22.96	2.67	2.61	10.39	10.16
	F3	1068.93	1003.90	2180.88	2320.28	17.08	15.38	1.87	1.65	7.52	6.76
Mean		1303.12	1281.31	2665.48	2893.03	23.19	22.62	2.64	2.57	10.26	10.01
S2	F1	1978.83	2081.25	4063.73	4543.60	40.83	43.50	4.87	5.20	18.17	19.36
	F2	1542.23	1564.50	3160.28	3477.65	29.44	30.02	3.43	3.50	13.06	13.32
	F3	1316.38	1297.05	2692.90	2925.60	23.54	23.04	2.68	2.62	10.41	10.19
Mean		1612.48	1647.60	3305.64	3648.95	31.27	32.19	3.66	3.77	13.88	14.29
S3	F1	2202.20	2345.48	4525.93	5088.33	46.66	50.40	5.60	6.08	20.78	22.45
	F2	2033.78	2146.28	4177.40	4677.65	42.26	45.20	5.05	5.42	18.81	20.13
	F3	1839.23	1916.08	3774.83	4202.95	37.18	39.19	4.41	4.66	16.53	17.43
Mean		2025.07	2135.95	4159.39	4656.31	42.03	44.93	5.02	5.39	18.71	20.00
F1		1902.46	1990.80	3905.68	4356.90	38.84	41.14	4.61	4.91	17.27	18.30
F2		1630.03	1668.38	3341.95	3691.78	31.73	32.73	3.72	3.84	14.09	14.54
F3		1408.18	1405.68	2882.87	3149.61	25.93	25.87	2.99	2.98	11.49	11.46
LSD at 0.05 for S		38.42	45.48	88.68	104.58	1.00	1.19	0.13	0.15	0.45	0.53
LSD at 0.05 for F		30.36	35.93	61.26	72.31	0.79	0.94	0.10	0.12	0.36	0.42
LSD at 0.05 for SxF		52.59	62.24	106.11	125.25	1.37	1.63	0.17	0.21	0.62	0.73

A. Cropping systems (main plots): (S_1). Millet/fallow/wheat, (S_2). Millet/temporary clover (fahl)/wheat and (S_3). Cow-pea/fallow/wheat.

B. Fertilization programs of wheat (sub main plots): (F_1). 100% recommended level of NPK, (F_2). 80% recommended level of NPK and (F_3). 60% recommended level of NPK.

Grain and biological yields were significantly affected by the application of NPK-fertilizers levels. Application of 100% of the recommended level of NPK-fertilizers treatment (F_1) gave higher grain and biological yields. On the contrary, the minimum grain and biological yields were recorded with 60% of the recommended dose of NPK-fertilizers treatment (F_3) in both seasons. This might be due to the well utilization of NPK fertilizers in metabolism and meristimic activity and its vital role in plant life and its contribution in increasing the grain yield. This is substantiated by the results reported by El-Gizawy (2009) and Katkar et al. (2011).

Data presented in Table (2) revealed that the different interactions between crop rotations and the application of NPK-fertilizers levels had significant effect on grain and biological yields. Wheat plants cultivated after cowpea and fertilized with 100% of the recommended level of NPK-fertilizers (F_1) gave the maximum grain and biological yields followed by wheat plants fertilized with 80% of the recommended level of NPK-fertilizers treatment (F_2) under the same crop rotation. The lowest grain and biological yields were achieved at the end of the rotation period in wheat following cowpea and consume of 60% of the recommended dose of NPK-fertilizers treatment (F_3).

N, P and K uptakes

Crop rotations significantly influenced the N, P and K uptakes over the entire study period, being significantly lower in the presence of millet-fallow-wheat (S_1) treatment than in other two crop rotations with lower grain yield (Table, 2). Diversity and quality of crop residues in the legume-wheat crop rotations could be responsible for higher N, P and K uptakes compared to millet-fallow-wheat system (S_1). Though less in residue input to soils than wheat and millet, below ground residues of cowpea and clover have been reported to support more microbial population which influences the concentrations of nutrients released in the rhizosphere for plant uptake (Yusuf et al., 2009)

Also, the increasing levels of NPK-fertilizers treatments from 60 to 100% of the recommended doses increased N, P and K uptakes for both two seasons, particularly in the second season under the application of NPK-fertilizers at levels of 120-30-24 kg fed^{-1} (F_1) respectively.

This study provides strong evidence that rotation systems can enhance wheat nutrition through improving nutrients availability and microbiological activities which lead to an increase of N, P and K uptake by wheat plants.

Conclusions:

The highest grain and biological yields of wheat plants as well as soil fertility (OM, N, P and K) were obtained by wheat plants cultivated after cowpea and fertilized with 100% of the recommended dose of NPK-fertilizers treatment.

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تأثير أنظمة للدورات الزراعية والتسميد المعدنى على إنتاجية القمح وتحسين بعض خواص التربة تحت ظروف أسيوط

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أجريت تجربة حقلية للسنوات المتتالية من 2008–2010 على التربة الجيرية في المزرعة التجريبية للبحوث الزراعية بمحطة عرب العوامر، مركز البحوث الزراعية ، أسيوط، مصر. لدراسة تأثير ثلاثة دورات زراعية لمحاصيل العلف (دورة الدخن ثم البور ثم القمح (S_1) ودورة الدخن ثم البرسيم الفحل ثم القمح (S_2) ، ودورة لوبيا العلف ثم البور ثم القمح (S_3) ، تحت ثلاث معدلات من أسمدة الـــ NPK (100 و 80 و 60 ٪ من الجرعة الموصى بها لكل سماد) على خصائص التربة الرملية الجيرية وإنتاجية القمح.

أظهرت النتائج أن كل الدورات الزراعية تحت الدراسة أدت إلى انخفاض معنوي في كثافة التربة وزيادة في قيم التوصيل الكهربائية للتربة (EC) فـــي مـــستخلص التربة بنسبة 1:1. خاصة الدورة الزراعية الثالثة (S_3) والتى ادت إلى انخفـــاض الكثافة الظاهرية في الطبقة السطحية (0–20 سم) بنسبة 9.9 و 7.2 ٪ وكذلك إلى زيادة EC بنسبة 12.0 و 1.7 ٪ مقارنة بالدورة الزراعية الأولى (S_1) والثانية (S_2) على التوالي.

وقد أظهرت النتائج ايضا أن محتـــوى التربـــة مـــن المـــادة العـــضوية (OM) والنيتروجين الكلى (N) والفوسفور (P) والبوتاسيوم (K) الميسرين فـــي التربـــة السطحية (0–20 سم) تأثرت معنويا بالدورات الزراعية المدروسة وكذلك بزيادة المعدلآت السمادية خاصة الدورة الزراعية الثالثة (S_3)حيث ســجلت اعلـــى قـــيم لمحتوى التربة من الصفات السابقة بمقـــدار 47.3، 26.5، 34.2 ٪ و 107.0٪ مقارنة بالدورة الزراعية الأولى (S_1) على التوالي. علاوة علي مـــا ســـبق فـــان الدورات الزراعية ومعدلات التسميد بالـــNPK والتفاعل بينهما أثـــرت معنويـــا على محصول الحبوب والمحصول البيولوجي للقمح وعلى امتصاص كـــل مـــن النيتروجين والفسفور والبوتاسيوم فى حبوب القمح.

مما سبق أوضحت النتائج أن أفضل المعاملات هى تسميد نباتات القمح بالمعـــدل الموصى به من أسمدة الـــ NPK والمنزرعة بعد لوبيا العلف حيث أنها أعطـــت أعلى قيم لكل من محصول الحبوب والمحصول البيولوجي والكمية الممتصة مـــن العناصر بواسطة حبوب القمح تليها النباتات المسمدة بمعدل 80٪ من NPK تحت نفس الدورة الزراعية.