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Impact of Different Soil Management Practices and Fertilizer Combinations on Yield and Quality of Chicken Pea (*Cicer arietinum* L.)

Pengaruh Teknik Pengelolaan Tanah yang Berbeda dan Kombinasi Pupuk terhadap Hasil dan Kualitas Kacang Arab (Cicer arietinum L.)

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ABSTRAK

Kegiatan pengelolaan tanah dan manajemen pemupukan secara signifikan mempengaruhi kinerja dan hasil tanaman. Studi kami bertujuan untuk mengevaluasi dampak dari berbagai teknik pengelolaan tanah dan integrasi pupuk organik dan kimia terhadap kinerja kuantitatif dan kualitatif kacang arab *(Cicer arietinum L.)*. Hasil mengungkapkan bahwa pengelolaan tanah dan sumber pupuk memiliki dampak yang signifikan terhadap jumlah polong per tanaman dan hasil biji. Jumlah polong tertinggi per tanaman diamati pada perlakuan pengolahan tanah konservasi dengan pupuk nitrogen 50% dan inokulasi mikoriza. Jumlah biji per polong dipengaruhi oleh sumber pupuk, dengan jumlah tertinggi diperoleh pada perlakuan tanpa pembenah tanah, pupuk nitrogen 100%, dan tanpa inokulasi mikoriza. Hasil bullir tertinggi pada perlakuan pengolahan tanah konservasi dengan pupuk nitrogen 50% dan inokulasi mikoriza. Hasilnya menyoroti bahwa pemupukan nitrogen optimal yang terintegrasi dengan mikoriza meningkatkan serapan hara dan meningkatkan komponen hasil. Studi ini menyoroti pentingnya pemupukan dan pengelolaan tanah dalam mengoptimalkan kinerja kacang arab. Efek positif dari pupuk nitrogen berimbang yang terintegrasi dengan inokulasi mikoriza dicatat pada sifat-sifat yang berhubungan dengan hasil. Temuan ini berkontribusi pada pengembangan praktik pertanian berkelanjutan yang mengurangi ketergantungan pada pupuk kimia dan meningkatkan produktivitas tanaman.

Kata Kunci:

sistem pertanian;

produktivitas tanaman;

mikoriza;

nutrisi;

potensi hasil.

Keywords:

agricultural systems;

crop productivity;

mycorrhizal;

nutrition;

yield potential.

ABSTRACT

Soil cultivation practices and fertilizer managements significantly influence crop performance and yield. Our study aimed to evaluate the impact of different soil management techniques and the integration of organic and chemical fertilizers on the quantitative and qualitative performance of chicken peas (Cicer arietinum L.). Our results revealed that soil management and fertilizer sources had a significant impact on the number of pods per plant and seed yield. The highest number of pods per plant was observed in the conservation tillage treatment with 50% nitrogen fertilizer and mycorrhizal inoculation. The number of seeds per pod was influenced by fertilizer sources, with the highest number obtained in the treatment without soil amendment, 100% nitrogen fertilizer, and no mycorrhizal inoculation. Grain yield was highest in the conservation tillage treatment with 50% nitrogen fertilizer and mycorrhizal inoculation. The results highlighted that optimal nitrogen fertilizer integrated with mycorrhizal improves nutrient uptake and increases yield components. This study highlights the importance of fertilizer and soil management in optimizing chicken pea performance. The positive effects of balanced nitrogen fertilizer integrated with mycorrhizal inoculation were recorded on yield-related traits. These findings contribute to the development of sustainable agricultural practices that reduce reliance on chemical fertilizers and enhance crop productivity.

INTRODUCTION

Soil cultivation plays an inseparable role in modern industrial agriculture. The primary objective of implementing soil cultivation is to create a favorable environment for seed germination, root system development, and soil structure enhancement, particularly in dry and semi-arid conditions (Abete et al., 2014). The process of tillage brought about significant transformations in the subsoil environment, decomposition of agricultural residues, and nutrient cycling in the soil (Sinha et al., 2009). Systems that avoid tillage exhibit different temperature patterns compared to tilled soil and often encounter higher surface compaction, resulting in inadequate drainage and ventilation, thus impeding the efficient exchange of gases between the soil and the atmosphere.

One of the emerging topics in sustainable agriculture is the management of soil resources, examining soil organisms and the beneficial symbiotic relationships among ecosystem components in food chains and vital cycles (Herridge et al., 2008; Köpke & Nemecek, 2010; Oomah et al., 2011). Both in natural and agricultural ecosystems, there exists a mutually beneficial connection between plants and soil microorganisms, which significantly influences soil structure, biological cycles, nutrient chemistry, plant growth, and their adaptability to changing environments (Xiao et al., 2018; Xu et al., 2019). Over the past half-century, the combination of technology and innovation has been developed to manage the negative impact of synthetic fertilizer on land ecosystems to identify the limitations of sustainability and optimize agricultural systems (Mirbakhsh, 2023), so biological fertilizers, such as natural inputs, humic acid, or appropriate use of nano-fertilizer can serve as complements or substitutes for chemical fertilizers in sustainable farming practices (Mejias et al., 2021; Mirbakhsh and Zahed., 2023; Sharma et al., 2022). Researchers have found that mycorrhizal fungi contribute to increased corn yield and components. These fungi possess abundant hyphae that colonize plant roots, enhancing root mass and facilitating the uptake of phosphorus and water, thereby promoting yield components (Mouradi et al., 2018). They are friendly user, especially under environmental stress including salinity or drought that retarded plant growth and yield, negatively impact gene expression, and became the most distributing problem in the world (Ma et al., 2020; Mirbakhsh & Sedeh, 2022; Olfati et al., 2012). The use of mycorrhizal fungi can trigger the activity of antioxidant enzymes that have a key role in enhancing tolerance and protecting plants against oxidative reactions (Mirbakhsh & Sedeh, 2022; Rahdari et al., 2012).

Mycorrhizal fungi rely on carbohydrates provided by plants for their nutritional needs. It appears that once the symbiotic relationship with the plant is established, these fungi obtain necessary nutrients from the host plant while simultaneously promoting the development of the plant's root system through mycelium branching. Additionally, they produce an enzyme called phosphatase that helps make non-absorbable soil phosphorus accessible to the plant. This mechanism partially fulfills the plant's phosphorus requirements, particularly when soil phosphorus levels are low (Taheri & Fathi, 2016). Consequently, the provision of phosphorus to the plant leads to an increase in grain yield. The symbiosis between wheat and mycorrhizal fungi enhances the utilization of non-absorbable soil phosphorus by the fungal hyphae, potentially resulting in higher grain weight and quantity per ear (Ardakani et al., 2006).

Researchers found the highest grain yield and crop productivity under the no-tillage system with residue left over. This was attributed to the increased weight of a thousand seeds due to improved moisture retention in the soil. Additionally, the researchers noted that the performance of soybeans did not significantly differ between conventional and conservation tillage methods. However, wheat and maize yields were lower in conservation tillage methods compared to the conventional method, showing a reduction of around 10-14%. This decrease was attributed to a decline in soil nitrate levels in the conservation tillage system, as increasing nitrogen through fertilizer application did not result in performance differences between conventional and conservation tillage methods (Alvarez & Steinbach, 2009).

Recognizing the significance of attaining sustainable agricultural approaches, which aim to minimize the reliance on chemical fertilizers and reduce the time interval required for soil preparation after harvesting the previous crop (wheat) in the region, conducting a study on the mutual chemical influence becomes essential (Chiremba et al., 2018; Mattila et al., 2018; Shi et al., 2018).

We found chicken pea as a key model species in our study to determine the impact of various soil management methods and integration of organic and chemical fertilizers as different practices on legume quality and product. Chicken pea beans are one of the most important legume plants in winter and one of the main sources of protein for human and animal nutrition (Dawood et al., 2019). Chicken pea (*Cicer arietinum* L.*)* is now grown worldwide on 2.67 million ha in the year 2020. The total world production of chicken peas is 5.67 million tons.

MATERIAL AND METHODS

Experimental design

In order to evaluate the effects of different soil management techniques and the integration of organic and chemical fertilizers on the quantitative and qualitative performance of chicken peas, a split-plot experiment was conducted based on a randomized complete block design with four replications in late spring of 2018 in the farms of Sari, Mazandaran, Iran. The experimental site was located at a latitude of 33° and 47 minutes north, a longitude of 46° and 36 minutes east, and an elevation of 975 meters above sea level. The experimental factors included soil management at three levels (no soil management, conservation soil management, and conventional soil management) in the main plots and fertilizer at four levels (50% mycorrhizal inoculation + nitrogen, no mycorrhizal inoculation + 50% nitrogen, 100% mycorrhizal inoculation + nitrogen, and no mycorrhizal inoculation + 100% nitrogen) in the sub-plots. To determine the soil characteristics prior to conducting the experiment, sampling was carried out from a depth of zero to 30 centimeters, and the properties of the soil were tested. The results of soil sample analysis at the experimental site are shown in Table 1.

Soil preparation

In conventional soil management, for preparation, after plowing the land, deep plowing (-25 to 20 centimeters) was performed using a moldboard plow, followed by two cross-discs with a depth of 10-15 centimeters to break up the clods and finally, the land was leveled using a leveling device.

Table 1. Physiological and chemical properties of the experimental field.

Depth (cm)	Soil texture	pH	EC	Organic carbon (%)	Available N	Available phosphorus	Available K
0 – 30	Silt – loam	6.9	0.98	1.5	13.05	12	131.2

In conservation tillage, a combined tillage machine was used for land preparation, which entered the ground only once. After land preparation, the seedbed was formed using a row cutter for seed sowing. In the treatment without tillage, a direct seeding machine was used, which sowed the seeds into the soil using a direct seed drill without tilling the soil.

Plant preparation

Geographically, Sangihe Islands Regency is located at 20 4'13" - 40 44' 22" North latitude and 1250 9' 28.

In this experiment, the seeds of chicken peas were obtained from the Agricultural Research Center of Babolsar, Mazandaran, Province, Iran, and used for planting. Mycorrhizal fertilizer (Glomus mosseae species obtained from Ferdowsi University of Mashhad) was used as a mixture of spores, soil, and separated root fragments as an inoculant at the time of planting. During seed sowing, 50 grams of mycorrhizal fungus, including roots, soil, and spores, were used (each gram of fungal sample contains about 300 viable spores).

Nitrogen fertilizer was also applied at the recommended rate of 100 kilograms per hectare from urea as a source, and it was evenly distributed in each plot before planting. Each plot consisted of 6 rows, 3 meters in length, with a row spacing of 50 centimeters, plant spacing within the row of 15 centimeters, planting depth of 4 centimeters, and a distance of 2 meters between the replications. One row was left unplanted between the plots with a distance of 50 centimeters.

The dimensions of each subplot were selected as 3x3 meters. Care was taken to ensure that irrigation water did not mix between the plots and replications. The planting operation was carried out on July 21st and the first irrigation was immediately performed. In the treatment without tillage, irrigation was done using the plot-wise method, while in the conservation and conventional tillage treatments, the irrigation was done accordingly.

Weather conditions and harvesting were carried out. In order to determine the yield and yield components of the seeds, at the physiological maturity stage where over 95% of the pods were matured, one square meter area was selected from the middle of each plot by excluding the side rows and 50 centimeters from the beginning and end of each plot as margin effects. The soil was carefully separated from this area by hand and then transferred to the laboratory.

Simultaneously with harvesting, 10 plants were selected separately from each plot, and the number of pods per plant, number of seeds per pod, weight of seeds per plant, and weight of 100 seeds were measured. The Kjeldahl method (Jackson, 1964) was used to determine the protein percentage

Statistical analysis

Statistical analysis of the data was performed using SAS 9.1 statistical software, and for comparing the means of the desired traits, the LSD test at a significance level of 0.05 was utilized.

RESULT AND DISCUSSION

The number of pods per plant

The results of this study indicate a significant effect of soil management and fertilizer sources on the number of pods per plant (Table 2). The highest number of pods per plant was obtained in the treatment of conservation tillage with 50% nitrogen fertilizer along with seed inoculation with mycorrhiza, with a value of 74.47 pods per plant. This value was higher than the treatment without soil management, along with 100% nitrogen fertilizer and without mycorrhiza inoculation, which had 69.36 pods per plant (Table 3). Conservation tillage, in combination with the use of mycorrhiza and optimal nitrogen fertilizer application, promotes plant vigor, does not disturb the soil structure, and provides conditions for increased nutrient uptake. This has resulted in an increased number of pods per plant in the chicken pea crop. The alignment with the findings of the current study was observed, indicating a significant main effect of soil management, a significant main effect of urea fertilizer, and a significant interaction effect between soil management and urea fertilizer on the number of pods per chicken pea plant (Cheragi & Pezeshkpour, 2013).

Number of seeds per pod

According to the results of the analysis of variance, the effect of fertilizer sources and the interaction effect of fertilizer sources and soil amendment on the number of pods per plant was significant (at a significance level of 1%). However, the main effect of soil amendment was not significant (Table 2). The highest number of seeds per pod was obtained in the treatment without soil amendment, along with the use of 100% nitrogen fertilizer and without mycorrhizal inoculation, with a value of 31.10 seeds per pod. This value was higher than the condition without soil amendment, along with the use of 50% nitrogen fertilizer and without mycorrhizal inoculation, which resulted in 4.94 seeds per pod (Table 3).

Table 2. Analysis of variance of tillage and nutrition effect on chicken pea traits

Source of variance (SOV)	df	Number of pods per plant	Number of seeds per pod	100 seeds weight	Seed yield	Biologic yield	Seed yield	Protein yield	Protein function
Replication	3	14.21	5.150	0.126	133.8	115007.3**	0.0042	0.115	5.34
Tillage (T)	2	32.93*	0.563	0.009	444.6*	225700.6**	0.0141	0.436	8.69
Error	6	4.98	0.765	0.216	76.0	5276.9	0.079	3.512	10.97
Tillage Fertilizer (F)	3	96.82**	12.393*	1.510**	606.6**	1408307.1**	0.1892	7.534*	49.05**
T × F	6	42.82*	13.950**	0.181	1562.5**	37369.8**	0.518	20.07**	63.09**
Error	27	9.66	1.603	0.201	110.8	48981.9	0.0457	1.745	5.05

*and** significant at 0.05 and 0.01 respectively.

Table 3. Comparison interaction of tillage and mycorrhizal on chicken pea traits.

Tillage	Fertilizer resource	Pod/ plant	Seed/pod	Biological yield (Kg/ha)	Nitrogen %	Seed yield (Kg/ha)	Protein %	Protein Yield (Kg/ha)
Zero tillage	No mycorrhizal+ 100% nitrogen	36.69^{d}	10.31^{a}	1696.9^{e}	3.10^{a}	1073.57^{ef}	19.37^{a}	20.79^{abc}
	No mycorrhizal+ 50% nitrogen	43.21^{abc}	4.94^{e}	2365.7^{bc}	2.39^{d}	1396.25^{ab}	14.92^{d}	20.81^{abc}
Conversion	No mycorrhizal+ 100% nitrogen	37.36^{d}	7.50^{bcd}	1720.9^{cde}	2.29^{d}	1187.45^{cde}	14.34^{d}	17.18^{cde}
	No mycorrhizal+ 50% nitrogen	45.0^{abc}	8.0^{abcd}	2865.9^{a}	2.66^{bcd}	1127.45^{def}	16.63^{bcd}	18.74^{cd}
Conventional	No mycorrhizal+ 100% nitrogen	37.75^{abc}	5.63^{de}	1943.9^{cde}	2.3^{d}	1243.9^{cde}	14.35^{d}	18.55^{cd}
	No mycorrhizal+ 50% nitrogen	43.21^{abc}	6.94^{bcde}	1953.3^{cde}	2.29^{d}	1953.3^{cde}	14.31^{d}	13.33^{e}

Furthermore, in the interaction effect of a conventional soil amendment system using 50% nitrogen fertilizer and mycorrhizal inoculation, there were 10 seeds per pod (Table 3). The response of the number of seeds per pod under the same conditions of soil amendment and without mycorrhizal inoculation only showed the highest value with an increase in nitrogen consumption to 100%. This indicates that the number of seeds per pod is visually responsive to nitrogen availability, and a decrease in nitrogen consumption leads to a decrease in this trait due to a reduction in photosynthesis and the production of photosynthetic materials. In the investigation of other levels, it is observed that in conventional soil amendment with a 50% reduction in nitrogen, but with the use of mycorrhizal inoculation, this nitrogen deficiency is compensated to a great extent due to the increased root capacity of the chicken pea in nutrient uptake. Our results are aligned with the same study on wheat that recorded the impact of fertilizer and soil management on the number of seeds in wheat, and a similar study on barley (Malecka & Blecharczyk, 2008; Sepidehdam & Ramroudi, 2016).

Seed function

The results of the analysis of variance showed that the effects of experimental factors (fertilizer sources and soil amendment) and the interaction effect of fertilizer sources and soil amendment were statistically significant in terms of grain yield (at a significance level of 1%) (Table 2). The highest grain yield was obtained in the treatment of protective soil amendment along with the use of 50% nitrogen fertilizer and seed inoculation with mycorrhizae, with a yield of 1510.03 kilograms per hectare. However, in the conventional soil amendment treatment with the use of 50% nitrogen fertilizer and without mycorrhizal inoculation, the grain yield was 934.1 kilograms per hectare (Table 3). It appears that under protective soil amendment conditions, with reduced soil disturbance, the conditions for mycorrhizal activity in the plant root zone have improved. Additionally, the optimal application of nitrogen fertilizer has influenced the yield components, leading to an increase in the final yield of chicken peas. Researchers have reported that the main effect of soil amendment and the interaction effect of soil amendment and chemical fertilizer on chicken pea grain yield was significant. The use of chemical fertilizer resulted in an increased grain yield. This could possibly be due to the direct effect of nitrogen on leaf area index, plant shading, and consequently an increase in received radiation, which enhances photosynthetic capacity and ultimately increases plant yield (Karami Chame et al., 2016; Rial-Lovera et al., 2016; Sepidehdam & Ramroudi, 2016).

Biological performance

Based on the results of this experiment, in addition to the effects of experimental treatments (fertilizer sources and soil type), the interactive effect of fertilizer sources in soil type was also statistically significant in terms of biological performance (at a significance level of 1%). The interactive effect of fertilizer sources and soil type had a significant impact on biological performance. The highest biological performance was observed in the treatment with protective soil management, accompanied using 100% nitrogen fertilizer and seed inoculation with mycorrhiza, yielding 1510 kilograms per hectare. In contrast, in the absence of soil management, with the use of 100% nitrogen fertilizer and without mycorrhiza inoculation, the biological performance was 934 kilograms per hectare (Table 3).

Nitrogen content

The analysis of variance indicated that only the main effect of fertilizer sources and the interactive effect of fertilizer sources and soil type had a significant impact on grain nitrogen content (at a significance level of 1%). However, the effect of soil type on this trait was not significant (Table 2). The comparison of means showed that the highest grain nitrogen content was observed in the treatment without soil management, accompanied using 100% nitrogen fertilizer and without seed inoculation with mycorrhiza, with a content of 3.01%. This value was higher than the conventional soil management with the use of 50% nitrogen fertilizer and without mycorrhiza inoculation, which yielded a content of 2.29% (Table 3). It seems that increasing the amount of chemical nitrogen fertilizer resulted in an increase in grain nitrogen content, which can be attributed to the availability of nitrogen for the plant. Other researchers have also reported the significant interactive effect of soil type and chemical fertilizer on grain nitrogen content (Avian Petrody et al., 2011; Rial-Lovera et al., 2016; Wasaya et al., 2017).

Protein content

According to the obtained results, the main effect of experimental treatments, fertilizer sources, and the interactive effect of fertilizer sources in soil management had a significant impact on grain protein content (at a significance level of 1%). However, the effect of soil management was not significant (Table 2). The highest grain protein content was observed in the treatment without soil management, accompanied using 100% nitrogen fertilizer and without seed inoculation with mycorrhiza, with a content of 19.37%. This value was higher than the conventional soil management with the use of 50% nitrogen fertilizer and without mycorrhiza inoculation, which yielded a content of 14.31% (Table 3). Increasing the amount of grain nitrogen had a direct relationship with the protein content because nitrogen is the main component of protein, and usually, under conditions of increased nitrogen input to the soil, the grain protein content increases. Researchers investigating corn have reported the significant effects of nitrogen fertilizer, soil management, and their interaction on grain protein percentage (Khorramian et al., 2015; Rial-Lovera et al., 2016; Wasaya et al., 2017).

Protein function

According to the obtained results from this experiment, only the main effect of experimental treatments, fertilizer sources, and the interactive effect of fertilizer sources in soil management had a significant impact on grain protein yield (at a significance level of 1%). However, the main effect of soil management was not significant (Table 2). In comparison, the average protein yield in the conventional soil management treatment with 50% nitrogen fertilizer and mycorrhiza inoculation was 24.99 kilograms per hectare, which was higher than the yield in the conventional soil management alone. The protein yield in conventional soil management with 50% nitrogen fertilizer and without mycorrhiza inoculation was 13.33 kilograms per hectare (Table 3). It appears that in conventional soil management, protein yield increases with the use of nitrogen. Protein yield is an indicator that results from the multiplication of grain protein content and grain yield, indicating that mycorrhiza usage improves growth and reproductive conditions in chicken pea plants. Researchers have shown in their study on maize that the effect of chemical nitrogen fertilizer, soil management, and their interaction has a significant impact on protein yield (Khorramian et al., 2015; Rial-Lovera et al., 2016; Wasaya et al., 2017).

CONCLUSION

In conclusion, the results of this study provide valuable insights into the effects of soil management and fertilizer sources on multiple aspects of chicken pea crop performance. The findings emphasize the potential of conservation tillage, mycorrhiza inoculation, and optimal nitrogen fertilizer application to enhance plant vigor, nutrient uptake, and overall yield. The combination of these practices resulted in increased numbers of pods per plant, indicating improved reproductive capacity. Moreover, nitrogen availability played a crucial role in determining the number of seeds per pod, with higher values observed when nitrogen fertilizer was applied at optimal levels.

The study also demonstrated the benefits of protective soil amendment, along with proper nitrogen fertilizer application and mycorrhiza inoculation, in achieving higher grain yield and overall biological performance. These practices, which minimized soil disturbance and enhanced mycorrhizal activity, contributed to improved nutrient uptake and growth of chicken pea plants.

Furthermore, the research highlighted the direct relationship between nitrogen fertilizer application and grain nitrogen content, as nitrogen is a fundamental component of protein. The increase in grain nitrogen content under higher nitrogen input reflects the availability of nitrogen for protein synthesis. Similarly, the protein content of the grains was positively influenced by nitrogen availability, with higher values observed under optimal nitrogen fertilizer application.

Importantly, the study demonstrated that the combination of nitrogen fertilizer, soil management, and mycorrhiza inoculation had a significant impact on protein yield. This finding underscores the importance of considering multiple factors in crop management strategies to optimize protein production in chicken pea crops.

Overall, these findings contribute to the existing body of knowledge on sustainable agricultural practices and highlight the significance of integrated approaches that incorporate soil management, fertilizer application, and the utilization of beneficial microorganisms. By implementing such strategies, farmers and agricultural practitioners can enhance crop performance, improve yield, and optimize protein content in chicken pea crops, ultimately supporting sustainable and efficient agricultural systems.

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