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Growth and yield of linseed (*Linum usitatissimum* L.) enhanced through adding organic and inorganic fertilizers.

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ABSTRACT

This study aims to the impacts of organic manures and NPK fertilizers on the growth of plants, lyield, and yield components during the winter growing season of 2023-2024 at the Gardarasha Field, College of Agricultural Engineering Sciences, Salahaddin University-Erbil. A factorial randomized complete block design (RCBD) was used to evaluate the single and combined effects of three levels of manure (0, 10, and 20 t ha^{-1}) and NPK (0, 50, and 100 kg ha^{-1}). The results showed that moderate manure treatment (10 t ha^{-1}) combined with 50 kg ha^{-1} NPK significantly boosted growth parameters, including plant height, stem diameter, and technical stem length, while maximizing yield components such as total fresh yield (131.53 g) and seed yield (35.70 g). Additionally, both above yield parameters were significantly improvised when organic manure was added at the rate of 10 kg ha^{-1} (101.18 and 25.72 g), respectively, while it was dropped to (74.21 and 16.36 g), respectively when NPK was added at the rate of (100 kg ha^{-1}). This combination lowers environmental hazards and production costs, promoting sustainable and productive flax agriculture. The compost analysis shows a carbon content of 21.04% and a nitrogen content of 1.05%, for a C/N ratio of approximately 20:1, which is optimum for compost maturity and nutrient release. This balance improves soil fertility and nutrient uptake, promoting plant development.

KEYWORDS: Flax; Plant nutrition; Manure and synthetic fertilizers; Improve productivity.

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تحسين نمو وانتاجية الكتان (*Linum usitatissimum* L.) بإضافة الأسمدة العضوية وغير العضوية

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الملخص

نُفّذ البحث في حقل كرداشة، كلية علوم الهندسة الزراعية، جامعة صلاح الدين - أربيل، خلال موسم النمو الشتوي 2023-2024، لدراسة تأثير الأسمدة العضوية وأسمدة **NPK** على نمو نبات الكتان وإنتاجيته ومكوناته، بهدف تحقيق توازن بين الأسمدة العضوية والكيماوية لتحسين إنتاجية الكتان وتعزيز الاستدامة الزراعية. تم استخدام تصميم القطاعات العشوائية الكاملة **(RCBD)** لتقييم التأثيرات الفردية والمشتركة لثلاثة مستويات من السماد العضوي (0، 10، و20 طن/هكتار) وسماد **NPK** (0، 50، و100 كجم/هكتار). أظهرت النتائج أن المعاملة المتوسطة بالسماد العضوي (10 طن/هكتار) مع 50 كجم/هكتار من **NPK** عززت بشكل ملحوظ معايير النمو، بما في ذلك ارتفاع النبات وقطر الساق وطول الساق التقني، بالإضافة إلى تحسين مكونات الإنتاج مثل إجمالي الغلة الطازجة (131.53 جم) وإنتاج البذور (35.70 جم). علاوة على ذلك، تحسنت هذه القيم بشكل ملحوظ عند إضافة السماد العضوي بمعدل 10 كجم/هكتار، حيث بلغت (101.18 و25.72 جم) على التوالي، بينما انخفضت إلى (74.21 و16.36 جم) على التوالي عند إضافة سماد **NPK** بمعدل 100 كجم/هكتار. هذا المزيج يقلل من المخاطر البيئية وتكاليف الإنتاج، مما يعزز الزراعة المستدامة والمنتجة لنبات الكتان. يُظهر تحليل السماد محتوى كربون بنسبة 21.04% ومحتوى نيتروجين بنسبة 1.05%، بنسبة كربون/نيتروجين تبلغ تقريبًا 20:1، وهي النسبة المثالية لنضج السماد وإطلاق العناصر الغذائية. يعمل هذا التوازن على تحسين خصوبة التربة وامتصاص العناصر الغذائية، مما يعزز نمو النبات.

الكلمات المفتاحية: الكتان؛ تغذية النبات؛ السماد الطبيعي والأسمدة الصناعية؛ تحسين الإنتاجية.

INTRODUCTION

Flax (*Linum usitatissimum* L.) belongs to the genus Linum and the family Linaceae. It is a major industrial crop grown to produce dry oil from seeds and fiber from stems. It is the world's third largest fiber crop and one of the five major oil crops; flax seeds contain 30-45% oil (Mueller et al., 2010). The average productivity of flax per unit area in Iraq is very low, and it is only at the research level, so it is necessary to expand the sowing of this crop and increase its yield per unit of area through some agricultural operations, including the use of organic manure and fertilizers, particularly macronutrients such as NPK fertilizer.

Manures are organic substances formed by decomposition of plant and animal wastes that are environmentally friendly, inexpensive, and can promote plant growth, increase crop yield, bring significant economic benefits, and generally improve soil physical, chemical, and biological properties (Meghwal & Kent, 2022).Several studies have found that adding organic manure at the optimum doses significantly improves growth metrics. For example, applying 10 t/ha of organic manure enhanced plant height by 15.3% and seed yield by 20.5% over untreated plots (Makenova et al., 2024).

NPK fertilizer is an inorganic fertilizer that plays an important role in the process of plant nutritional balance. It is regarded one of the most effective agronomic measures to boost flax growth, yield, and quality (Al-obady & Shaker, 2022). According to research, applying NPK at a rate of 50 kg/ha increased stem diameter and total biomass, however larger dosages (100 kg/ha) decreased seed yield due to nutrient imbalances (Mohammed et al., 2023).

When used together, organic and inorganic fertilizers complement one another. Organic fertilizers reduce the negative effects of inorganic fertilizers, such as nutrient leaching and soil deterioration, by increasing nutrient retention and soil organic matter content. This combination optimizes balanced nutrient delivery, enhances plant growth, and boosts yields sustainably. In addition, the integration reduces the dependency on synthetic fertilizers, which helps lower production costs and minimizes environmental hazards such as chemical runoff, greenhouse gas emissions, and groundwater contamination (Kumar et al., 2022). The combination of 10 t/ha of organic manure and 50 kg/ha of NPK significantly improved total fresh yield and seed output as compared to single applications (Mohamed et al., 2020). Furthermore, such combinations maximize nutrient uptake, increase soil fertility, and reduce environmental concerns such greenhouse gas emissions, nutrient runoff, and groundwater contamination (Al-Enzy et al., 2024) .

Taking into consideration the beneficial aspect of integrated fertilizers, an experiment will be conducted to study the response of growth and yield of linseed towards the single and combined effect of NPK doses and organic manures.

MATERIALS AND METHODS

1. Description of Study Site

The field experiment will be carried out during winter growing season 2023-2024 at Gardarasha Field, College of Agricultural Engineering Sciences, Salahaddin University-Erbil (8 km southwest / 36.101.16" North; 44.009.25" East, and 415 meters above sea level).The region's climate is described as semi-arid. Representative air – dried soil sample was taken for field at the depth (0-30cm), then sieved with 2mm mesh and analyzed for some physical and chemical properties.

Some chemical and physical properties of the field soil of Grdarasha.

Soil properties		**Soil component**
Particle	Sand	384.75
size distribution (g kg^{-1})	Slit	515.00
	Clay	100.25
Texture Class		Silty clay loam
pH		7.53
Electrical Conductivity (EC) ds m^{-1}		0.38
Organic Matter (%)		0.91
Bulk density (Mg m^{-3})		1.45
Total Nitrogen (N) ppm		89.17
Total Phosphor (P) ppm		5.36
Total Potassium (K) ppm		64.10

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2. Cultural Practices

Twenty-seven treatments were established in three replications. Each treatment will be applied $1m^2$ plots (1m×1m) (Figure 1). The variety of flax that will be used is Brazowe, Poland cultivar. Seeds will be planted in a row, each plot will consist of 9 rows, the space between the rows is 8 cm, and the seed rate is 5 g/m^2 (Salih *et al*., 2021). The field experiment was designed in Factorial Randomized Complete Block Design (RCBD) with two factors. The first factor was organic manure (M) consisted of sheep manure and goat manure which was added at three levels; M1= 0 control (without adding any organic and inorganic fertilizers), M2= 10 t ha^{-1} and M3= 20 t ha^{-1}. The second factor were different levels of NPK 13-2-44 fertilizer (F) which was added at three levels in two splits, with sowing and two months after sowing (Salih *et al*., 2019); F1=0 control, F2=50 k g ha^{-1} (25 k g ha^{-1} was applied with sowing and 25 k g ha^{-1} two months after sowing), and F3=100 k g ha^{-1} (50 k g ha^{-1} was applied with sowing and 50 k g ha^{-1} two months after sowing).

3. Data Collection

Treatments were evaluated over winter growing season 2023-2024. Five plants were randomly selected from each treatment plot's middle two rows. The data were collected for Plant height (cm), Number of main branches $plant^{-1}$, Number of lateral branches $plant^{-1}$, Number of capsules $plant^{-1}$, Number of seeds $capsule^{-1}$, Capsules weight (g $plant^{-1}$), Stem diameter (mm), 1000 seed weight (g), Biological yield (t ha^{-1}), Seed yield (t ha^{-1}), and Harvest index (%).

4. Data Analysis

Growth, yield and its components were analyzed. The analysis of variance (ANOVA) of the data was performed using IBM SPSS statistical software program version (20) as well as Duncan's test. Differences were considered statistically significant with a p-value of 0.05.

RESULTS AND DISCUSSION

Table 1 shows the single effects of manure and NPK application on plant growth parameters such as plant height, stem diameter, technical stem length, fruit zone length, number of branches $plant^{-1}$, number of fruit bunches $plant^{-1}$, and number of capsules $plant^{-1}$. M2 (10 t ha^{-1}) manure had the highest overall performance, with significantly larger fruit zone length, number of fruit bunches $plant^{-1}$, and number of capsules $plant^{-1}$ compared to M1 (control) and M3 (20 t ha^{-1}). While, M3 increased technical stem length, it decreased reproductive growth, implying that excessive manure may shift resources toward vegetative growth at the expense of productivity. Higher NPK application levels (F3: 100 kg ha^{-1}) enhanced technical stem length and number of capsules $plant^{-1}$, but decreased fruit zone length, indicating potential imbalances with excessive fertilizer use. Moderate NPK application (F2: 50 kg ha^{-1}) improved the balance between vegetative and reproductive growth. These findings highlight the importance of adjusting manure and NPK rates to achieve balanced growth and yield. Manure improves soil fertility and long-term health, whereas NPK enhances nutrient availability. Moderate levels of manure (M2) and NPK (F2 or F3) appear to be the most effective. Future research should examine the combined impacts of organic and inorganic fertilizers to improve crop productivity and sustainability. Kiran *et al.* (2022) revealed similar results, demonstrating that combining NPK with organic manures greatly increases growth and yield, underlining the benefits of integrated nutrient management in sustainable agriculture.

Table 1. Single effect of manure and NPK application on growth parameters

Manure	Growth parameters						
	HP (cm)	**SD (cm)**	**TSL (cm)**	**FL (cm)**	**NBP**	**NFBP**	**NCP**
M1	75.24^a	4.23^a	45.16^b	29.22^a	4.98^a	32.49^b	195.90^b
M2	75.13^a	4.08^a	45.63^b	30.24^a	5.07^a	38.98^a	205.52^a
M3	76.27^a	4.27^a	48.69^a	26.17^b	4.82^a	38.58^a	181.01^c
NPK							
F1	75.18^a	4.10^a	45.07^b	29.02^a	5.16^a	37.17^a	193.98^b

F2	75.93a	4.24a	47.22a	28.89a	4.60a	34.73b	182.63c
F3	75.53a	4.29a	47.19a	27.72a	5.11a	38.14a	205.89a

M1= 0 (control), M2= 10 t ha^{-1}, M3= 20 t ha^{-1}, F1= 0 (control), F2= 50 kg ha^{-1}, F3= 100 kg ha^{-1}, HP= plant height, SD= stem diameter, TSL= technical stem length, FL= fruit zone length, NBP= number of brunches $plant^{-1}$, NFBP= number of fruit brunches $plant^{-1}$, NCP= number of capsules $plant^{-1}$, *Means followed by the different letter within a column are significant at (p ≤0.05).

Linking Table 2 data to the compost analysis table improves understanding of nutrient content and the impact of the carbon-to-nitrogen (C/N) ratio on plant growth. The compost analysis reveals a carbon content of 21.04% and a nitrogen content of 1.05%, resulting in a C/N ratio of around 20:1, which is ideal for compost maturity and nutrient release. This balance increases soil fertility and nutrient uptake, which promotes plant growth, as shown in Table 2, where plant height reached 77.20 cm (M3F3) and stem diameter was 4.52 cm (M1F3). The presence of 1.05% nitrogen encourages vegetative growth, resulting in more branches per plant (5.33 in M3F1), whereas 0.47% phosphorus supports root and flower development, resulting in the most capsules per plant (229.97 in M1F3). Potassium (1.03%) improves fruit quality, which correlating with a greater number of fruit bunches per plant (46.27 in M3F1).Furthermore, micronutrients such as iron (179.09 ppm) and manganese (326.21 ppm) improve photosynthesis, promoting optimal vegetative development in M3F3, whereas boron (120.5 ppm) and zinc (155.04 ppm) promote flowering and fruit set, resulting in higher fruit bunch numbers in M3F1. The results show that combining compost with NPK fertilizer greatly increases plant output, although excessive fertilization may have a negative impact on reproductive growth, as seen in Table 2, where high nutrient levels inhibited capsule formation. The compost's C/N ratio promotes effective decomposition, improving soil structure and nutrient availability, resulting in higher crop yields.

Table 2. Effects of interaction between manure and NPK on growth parameters

Treatments	**Growth parameters**						
	HP (cm)	**SD (cm)**	**TSL (cm)**	**FL (cm)**	**NBP**	**NFBP**	**NCP**
M1F1	74.33a	4.08a	43.73c	27.60bc	5.07a	28.13d	184.80d
M1F2	75.73a	4.10a	44.60bc	30.60ab	4.73a	32.07c	172.93d
M1F3	75.67a	4.52a	47.13ab	29.47bc	5.13a	37.27b	229.97a
M2F1	75.67a	3.75a	44.20c	33.27a	5.07a	37.10b	188.07cd
M2F2	76.00a	4.40a	47.13ab	30.53ab	5.13a	39.87b	226.77a
M2F3	73.73a	4.08a	45.57bc	26.93cd	5.00a	39.97b	201.93bc
M3F1	75.53a	4.31a	47.27ab	26.20cd	5.33a	46.27a	209.07b
M3F2	76.07a	4.23a	49.93a	25.53d	3.93a	32.27c	148.20e

M3F3	77.20[a]	4.26[a]	48.87[a]	26.77[cd]	5.20[a]	37.20[b]	185.77[d]

HP= plant height, SD= stem diameter, TSL= technical stem length, FL= fruit zone length, NBP= number of brunches plant^{-1}, NFBP= number of fruit brunches plant^{-1}, NCP= number of capsules plant^{-1}, *Means followed by the different letter within a column are significant at (p ≤0.05).

The results in table 3 shows that both manure and NPK applications have a significant impact on yield and its components, emphasizing the need of nutrient balance. M2 (10 t ha^{-1}) had the highest yield (101.18 g), slightly higher than M1 (100.78 g), whereas M3 (20 t ha^{-1}) had the lowest yield (54.01 g). F2 (50 kg ha^{-1}) achieved the highest total fresh yield plant^{-1} (94.88 g) across NPK treatments, outperforming F1 (86.88 g) and F3 (74.21 g). These findings indicate that moderate manure application (M2) was slightly more effective than NPK (F2) in improving total fresh yield plant^{-1}. In terms of the number of seed capsules^{-1}, manure treatments indicated M2 to be the most effective (8.64), while M1 was the least effective (7.88). Similarly, among NPK treatments, F2 had the greatest number of seed capsules^{-1} (8.37), followed by F1 (8.28), while F3 (8.01) had the lowest. These results show that both manure and NPK improve number of seed capsules^{-1}, though M2 and F2 performed similarly. In regard to total seed yield, M2 (25.72 g) again outperformed M3 (16.48 g). NPK treatments revealed that F2 was the most effective (24.72 g), while F3 produced the least (16.36 g). M1 (79.53 g) had the maximum biological yield, while M3 (39.14 g) showed a significant decrease, showing that excessive manure application (M3) lowered biomass output. The NPK treatment F2 (69.56 g) exceeded F1 (66.47 g) and F3 (58.01 g). In addition, M3 had the greatest harvest index (48.07%), followed by M2 (33.20%) and M1 (28.52%). Among NPK treatments, F1 had the highest harvest index (46.52%), followed by F2 (35.29%), and F3 (27.98%). These findings suggest that excessive application of manure or NPK can affect the balance of vegetative and reproductive growth, lowering total yields. In general, moderate amounts of manure (M2) and NPK (F2) were the most effective at increasing yield and its components. Manure (M2) beat NPK (F2) in terms of total fresh yield, number of seed capsules-1, and total seed yield, implying that manure provides a more sustainable nutrient release over time. Organic manure improves soil structure, provides a consistent supply of nutrients, which could be reason for its improved performance in some metrics, these results are in the agreement with previously results of Silveira et al. (2020) and Sood et al., (2020).

However, NPK (F2) performed comparably, in particular, total seed yield and biological yield, most likely due to the readily available nutrients in inorganic fertilizers, particularly nitrogen, which promotes vegetative and reproductive growth. This shows that, while manure has a modest advantage in terms of sustainability and soil health, NPK fertilizers can also play an important role in increasing yield components, especially in the coming years. Cocozza *et al.* (2021) reached similar observations, emphasizing the synergistic benefits of integrated nutrient management on crop output and soil health. These findings highlight the potential advantages of combining moderate amounts of organic manure with NPK fertilizers to maximize their complimentary effects. Excessive application of manure (M3) or NPK (F3) reduces returns, emphasizing the importance of balanced nutrient management for crop growth.

Table 3. Single effect of manure and NPK application on yield and its components

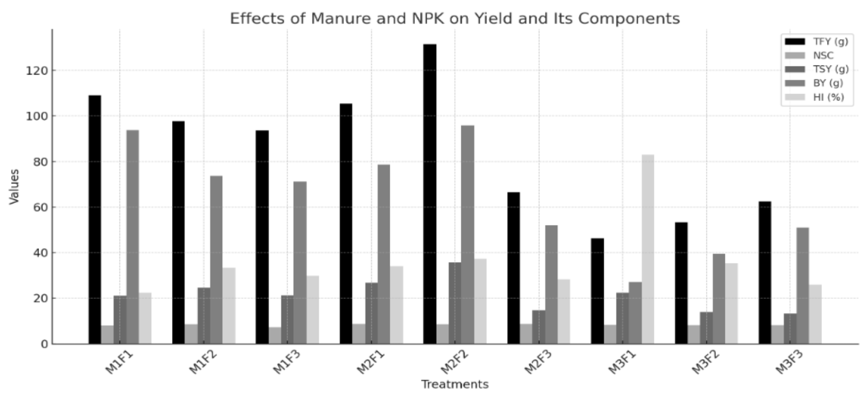
Manure	**Yield and its components**				
	TFY (g)	**NSC**	**TSY (g)**	**BY(g)**	**HI (%)**
M1	100.78^{a}	7.88^{a}	22.27^{b}	79.53^{a}	28.52^{c}
M2	101.18^{a}	8.64^{a}	25.72^{a}	75.46^{b}	33.20^{b}
M3	54.01^{b}	8.13^{a}	16.48^{c}	39.14^{c}	48.07^{a}
NPK					
F1	86.88^{b}	8.28^{a}	23.39^{a}	66.47^{b}	46.52^{a}
F2	94.88^{a}	8.37^{a}	24.72^{a}	69.56^{a}	35.29^{b}
F3	74.21^{c}	8.01^{a}	16.36^{b}	58.01^{c}	27.98^{c}

M1= 0 (control), M2= 10 t ha^{-1}, M3= 20 t ha^{-1}, F1= 0 (control), F2= 50 kg ha^{-1}, F3= 100 kg ha^{-1}, TFY= total fresh yield plant^{-1}, NSC= number of seeds capsules^{-1}, TSY= total seed yield, BY= biological yield, HI= harvest index, *Means followed by the different letter within a column are significant at ($p \leq 0.05$).

Table 4. Analyzing compost composition, including key nutrient percentages and the carbon-to-nitrogen (C/N) ratio

Elements	**Amount**
Nitrogen (%)	1.05
Phosphorous (%)	0.47
Potassium (%)	1.03
Carbon (%)	21.04
Iron (Ppm)	179.09
Boron (Ppm)	120.5
Zinc (Ppm)	155.04
Sulphur (Ppm)	1.50
Manganese (Ppm)	326.21
Magnesium (%)	0.33
Organic mater (%)	53.26

The results in Figure 1 show that the interaction of manure and NPK has a significant impact on yield and its components. M2F2 (10 t ha^{-1} manure + 50 kg ha^{-1} NPK) had the highest total fresh yield of 131.53 g, indicating a synergistic effect of moderate levels of manure and NPK. M3F1 (20 t ha^{-1} manure + 0 kg ha^{-1} NPK) had the lowest total seed yield of 46.23 g, indicating that excessive manure application without NPK reduces yield. M2F2 had the highest total seed yield of 35.70 g, whereas M3F3 had the lowest total seed yield of 13.20 g (20 t ha^{-1} manure + 100 kg ha^{-1} NPK), suggesting that using too much fertilizer can reduce seed yield. M2F1 and M2F3 had the most number of seed capsules (8.70 each of them), but M1F3 had the fewest (7.20), these results are supported by Gupta et al, (2017) and Kaushal et al, (2019). Biological yield followed a similar pattern, with M2F2 reaching the highest Biological yield (95.83 g), followed by M1F1 (93.73 g), and M3F1 having the lowest Biological yield (27.07 g), underlining the necessity of balanced fertilizer use for biomass development. Interestingly, the harvest index was highest in M3F1 (83.03%), indicating a greater allocation of resources toward seed production under stress situations produced by excessive manure and minimal NPK, whereas the lowest harvest index was seen in M1F1 (22.44%). These findings illustrate the importance of balanced nutrient management. M2F2 consistently showed the highest values across TFY, NSC, TSY, and BY, indicating that a moderate application of manure (10 t ha^{-1}) mixed with NPK (50 kg ha^{-1}) is the most successful treatment. This combination most likely supplied a good nutrition supply by combining slow-release nutrients from manure with easily available nutrients from NPK. These results are supported by previously work done by Li et al. (2023). Excessive manure application (M3) was less successful, especially when combined with low or no NPK, most likely due to nutrient imbalances or inadequate decomposition, which reduced nutrient availability. NPK alone (M1F2) performed well, but it was outperformed by the combination of manure and NPK, which increases soil structure, long-term nutrient availability. These findings highlight the complimentary effects of manure and NPK in increasing crop productivity. Overuse of either manure (M3) or NPK (F3) reduced yield components, emphasizing the importance of precision nutrient management. Overall, M2F2 proved to be the most successful treatment, illustrating the advantages of combining moderate quantities of manure with NPK for long-term crop production. These findings are consistent with those of Kiran *et al.* (2022) who found significant enhancements in growth and yield characteristics in turnip (*Brassica rapa* L.) after applying organic manures and NPK.



TFY= total fresh yield $plant^{-1}$, NSC= number of seeds $capsules^{-1}$, TSY= total seed yield, BY= biological yield, HI= harvest index

Figure 1. Effects of interaction between manure and NPK on yield and its components.

CONCLUSION:

This study emphasizes the crucial role of balanced nutrient management in enhancing the growth of plants and productivity. Moderate manure application and proper NPK levels proved to be the most effective treatment, improving key growth parameters and maximizing yield. Organic manure contributes to improving soil structure and promoting long-term soil health, whilst NPK fertilizers provide the nutrients required for rapid plant growth and higher yields. By combining these two approaches productivity increased, while the negative environmental impacts of synthetic fertilizers were reduced, leading to more sustainable and cost-effective flax cultivation. These findings highlight the benefits of utilizing organic and chemical fertilizers for optimal agricultural results.

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