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Impact of plant density of pea intercropped with flax under different nitrogen fertilizer levels on crop productivity

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A field experiment was established to analyze the effect of different plant densities of pea (12.5, 25.0, 37.5 and 50.0% of the recommended plant density "RPD") intercropped with 100% flax under nitrogen fertilization levels (60, 85 and 110 kg N/ha) on yield of both crops, their competitive relationships and economic evaluation. A Split-plot design with three replications was used, where the main-plots were assigned to nitrogen fertilization levels and the sub-plots for intercropping patterns. Application of 85 kg N/ha significantly increased all studied characters of both crops. Sowing flax with pea with 12.5% from the RPD resulted in highest values of flax stem diameter, straw yield/ha, number of capsules/plant, seeds/plant, seed index and seed yield/ha. For pea higher values were also observed for number of leaves, branches and pods/plants, pod length and diameter, green pod weight and number of seeds/pod. The highest values of total green pods yield/ha of pea was produced when flax is sown with the RPD and pea with 37.5% RPD. It can be concluded that the maximum LER, RCC, total income and economic return were obtained from sowing flax with the RPD and pea with 37.5% RPD and fertilizing with 85 kg N/ha.

Keywords: Flax, pea, intercropping system, plant densities, nitrogen fertilizer levels, competitive relationships

INTRODUCTION

Flax (Linum usitatissimum L.) is one of the oldest cultivated crops to be widely grown for oil and fibers. Flax fibers from the stem of the plant are two to three times as strong as those of cotton and are naturally smooth and straight. Flax seeds are crushed to produce linseed oil and linseed meal. Linseed oil is a major ingredient in many fine paints, varnishes and stains that are used to preserve, protect and beautify wooden surfaces. Due to its high amounts of omega-3 fatty acid, flax cultivation and consumption is increasing as a healthy oil resource. In Egypt, the gap between the production and local consumption of flax increased, because it is difficult to increase flax area by replacing other major winter crops due to great competition among them. However, this gap could be minimized by increasing flax yield per unit area and by intercropping it with popular vegetable winter crops such as pea.

Pea (Pisum sativum L.) is a member of the Fabaceae family and is considered as a popular vegetable crop. It is protein rich and suited for animal feed as well as for human diet. Other positive effects of pea are the symbiotic nitrogen (N2) fixation as an ability to supply N for agriculture, recycling of N-rich crop residues and the break-crop effect in cereal rotations.

In Egypt, the agricultural intensification which includes crop rotation, relay intercropping and intercropping of major crops had become an urgent necessity to optimize the use of limited cultivated area and to maximize the monetary returns per unit area (Masri and Safina, 2015). Safina (2017) reported that land equivalent ratio (LER) ranged from 1.63 to 1.86 for intercropping flax with faba bean Giza-2 or Giza-843 varieties. Klimek-Kopyra et al. (2018) stated that intercropping pea with flax caused a significant increase in the number of seeds per pod and number of pods per plant. Abd-Rabboh et al. (2021) found that when sugar beet and flax were intercropped, the maximum sugar beet root production and economic return of both crops were achieved by sowing flax at 12.5% of the recommended seed rate after 21 or 35 days of sowing sugar beet at 100% of the recommended seed rate (second or third sowing date).

Nitrogen (N) is one of the most important nutrients, which limits the yield of any crop, if not applied in proper amount, as it is needed for fast growth of plants and to get high productivity per unit area. Nitrogen plays an important role in all plant metabolic processes and is a major constituent of plants, especially in living tissues formation. Nitrogen is also an integral part of proteins, phytochromes, coenzymes, chlorophyll and nucleic acids (Marschner, 1995). All the biochemical processes occurring in plants are mainly managed by nitrogen and its associated compounds, which make it essential for the growth and development. In this regard, El-Nagdy et al. (2010) reported that fertilizing flax plants with 45 kg N/fed (feddan = 4200 m2) resulted the highest seed and straw yields. Dervisevic et al. (2014) reported that the optimal nitrogen rate for fiber flax was obtained with 30 kg N/ha. Abdel-Galil et al. (2015) indicated that the highest mineral N fertilizer rate (178.5 kg N/ha) had the highest flax plant height, technical length, number of capsules/plant, number of seeds/capsule, 1000-seed weight, seed yields/ plant, ha, straw and fiber yields/ha. Conversely, flax seed oil content was decreased by increasing mineral N fertilizer rates. El-Borhamy (2015) observed that nitrogen levels from 30 to 60 kg/fed significantly increased straw yield/plant, straw yield/fed, fiber length, fruiting zone length and number of capsules/plant. Adding 45 kg N/fed resulted in the highest values of seed yield and its components. El-Gedwy (2018) showed that flax traits under study were significantly increased by increasing nitrogen fertilizer rates from untreated up to 60 kg N/fed. He added that no significant differences between soil fertilized by 45 and 60 kg N/fad on all flax traits under study. Abdel-Kader et al. (2019) indicated that fertilized flax Giza12 variety with nitrogen at the rate of 45 kg N/fed at El-Gemmeiza location yielded the highest values of seed index, seed yield/plant, seed yield and oil yield per feddan. Brunsek et al. (2022) stated that morphological and textile-technological properties of flax achieved higher values where it was not necessary to add more than 30 kg N/ha. Therefore, it is necessary to apply the suitable rate of nitrogen as a favorable factor for increasing growth and productivity of flax intercropped with pea.

Plant densities are critical practice for determining the productivity of crops, where adjusting planting density is an important tool to optimize crop growth and maximize productivity. Plant density also influences crop environment and help to improve disease avoidance, thus adjusting plant density is an important tool to optimize crop growth and the time required for canopy closure and to achieve maximum productivity. In this concern, Abul-Soud et al. (2014) indicated that the highest vegetative growth characteristics were recorded with 50 cm row distance and 30 cm plant distance. The highest yield of peas was recorded by plant distance of 30 cm. Byan et al. (2015) recommended a plant density between 30 and 40 plants m-2, which increased plant length, number of leaves and fresh weight plant-1, as well as total chlorophyll, green pod characters (length, diameter, weight and number of seeds pod-1), while the increase of total green pods of pea was obtained by 80 plant m-2. Sibhatu et al. (2016) showed that the high plant population per unit area had negative relationship with plants growth, yield and its quality due to the competition between the plants for moisture, light and nutrients. Fekry and El-Shatoury (2017) showed that sowing Master B cultivar with plant density of 40 plant m-2 had the best plant growth and higher quality of the green pods, whereas the density 60 plant m-2 had the highest total green pod yield in winter green pea. Ahmed et al. (2019) reported that sowing pea with the spacing of 15 cm significantly increased plant length, total weight and weight of 100 grains, followed by 5 cm, while planting distance of 25 cm showed lowest values of these parameters. Krizmanic et al. (2020) demonstrated that planting pea at different plant densities significantly modifies yield, plant height and number of pods/plant.

Therefore, this study was performed to 1) study the effect of different plant densities of pea intercropped with flax under nitrogen fertilization levels on productivity of both flax and pea, 2) saving areas for planting pea, 3) maximizing the use of land area and 4) increasing the economic return under the environmental conditions of Northern Delta of Egypt.

MATERIALS AND METHODS

A two year field experiment was carried out at the Experimental Station Farm, Faculty of Agriculture, Kafr El-Sheikh University, Egypt, during 2020/2021 and 2021/2022 seasons to study the effect of different plant densities of pea (Master-B cultivar) intercropped with flax (Sakha-5 cultivar) under nitrogen fertilization levels of 60, 85 and 110 kg N/ha on yield and its components of both crops as well as on their competitive relationships and economic evaluation.

Treatments and experimental design

The field experiment design as a split-plot with three replications with the main-plots assigned to three nitrogen fertilizer levels (60, 85 and 110 kg N/ha) of both flax intercropped with pea. The nitrogen fertilizer in the form of ammonium nitrate (33.5 % N) was applied in two equal rates just before the first and the second irrigations.

The sub-plots were assigned to four plant densities of pea intercropped with flax, where flax was sown as the main crop with the recommended plant density with hill spacing of 140 cm and pea sown on both sides of the hills with plant distances of 90, 45, 36 and 30 cm (3-4 seeds/hill), which the resulting densities of 12.5, 25.0, 37.5 and 50.0 % of the recommended plant density of pea.

Main-plots

N fertilizer levels of 60, 85 and 110 kg N/ha.

Sub-plots

Intercropping pattern of pea with flax as follows:

1- (100% flax + 12.5% pea) by planting pea on both sides of terrace at 90 cm apart and leaving 2 plants/hill.

2- (100% flax + 25% pea) by planting pea on both sides of terrace at 45 cm apart and leaving 2 plants/hill.

3- (100% flax + 37.5% pea) by planting pea on both sides of terrace at 36 cm apart and leaving 2 plants/hill.

4- (100% flax + 50% pea) by planting pea on both sides of terrace at 30 cm apart and leaving 2 plants/hill.

Pure stands of flax and pea as recommended are also part of the experiment.

Each experimental basic unit (sub-plot) included three hills, each of 1.4 m width and 3.6 m length, with an area of 15.1 m2. The preceding summer crop was rice (Oryza sativa L.) in the first and second seasons.

Soil sampling and analysis

The soil of the experimental field was characterized as clayey-saline soil, where samples were randomly taken from the soil surface (0 - 30 cm) during soil preparation in both seasons. Then particle size distribution and chemical analyses were measured using methods described by Page et al. (1982) (Table 1).

Agricultural practices

The experimental field was well prepared through three ploughings, compaction and then divided into the experimental units with dimensions previously mentioned. Normal calcium superphosphate fertilizer (15.5 % P_2O_5) as a source of phosphorus was applied as one dose for all sub-plots during soil preparation, at the rate of 240 kg/ha.

Flax was sown at recommended seeding rate (140 kg seeds/ha) by using dry sowing method on top of the terraces, 140 cm width, on 31st October and 2nd November in the first and second seasons, respectively. For pea, seeds were inoculated with N-fixing bacteria (Rhizobium leguminosarum) and intercropped with flax by sowing in hills (3-4 seeds/hill) by using dry sowing method on both sides of the terraces, 90, 45, 36 and 30 cm apart, and thinned after 30 days from sowing flax and leaving 2 plants/hill, which resulted in 12.5, 25.0, 37.5 and 50.0 % of the recommended plant density of pea. In addition to the solo cultivation of both flax and pea was carried out according to the recommendations. Potassium sulphate (48 % K_2O) at the rate of 120 kg/ha was applied for experimental sub-plots before the second irrigation. The other agricultural practices for flax and pea in intercropping or solo cultivation as recommended for each crop.

Harvesting was done for flax on 14th and 22 April and for peas on 10 and 12 January in the first and second seasons for each crop, respectively.

The studied characters

Flax characters

At harvest, ten plants of flax were pulled out manually from each sub-plot to determine technical length (cm), stem diameter (mm), straw yield/ha (ton), fruiting zone length (cm), number of capsules/plant, number of seeds/plant, seed index (g) and seed yield/ha (kg). Straw and seed yields/ha were recorded from the whole sub-plot area basis.

Peas characters

At harvest, samples of 10 plants were randomly taken from each sub-plot to determine number of leaves/plant, number of branches/plant, number of pods/plants, pod length and diameter (cm), green pod weight (g), number of seeds/pod and total green pods yield (kg/ha).

Competitive relationships

• Land equivalent ratio (LER) was determined according to the following formula described by Willey and Rao (1980):

Where: Yaa and Ybb were yields of pure stand of crop, a (flax) and b (pea), respectively. Yab is mixture yield of a crop and Yba is mixture yield b crop.

• Aggressivity (Ag) was calculated according to Mc-Gillchrist (1965) as the following formula:

For crop (a),

and for crop (b),

Where:

Aab = Aggressively value for the component a (flax).

Aba = Aggressively value for the component b (pea).

Yab is intercrop yield of flax, Zab is percentage of the area occupied by pea.

• Relative crowding coefficient (RCC) or K was calculated according to De-Wit (1960) as follows:

Where:

a is flax and b is pea, respectively. Zab is percentage of the area occupied by flax and Zba is percentage of the area occupied by pea.

Economic evaluations

Gross return from each treatments was calculated in Egyptian Pound (LE), and then converted to U.S. Dollar (USD) as stated by the Egyptian Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Agricultural Statistics, where market price of flax straw was 222.9 and 163.8 USD/ton straw, flax seed was 0.76 and 0.82 USD/kg and pea green pods were 0.30 and 0.27 USD/kg in 2020/2021 and 2021/2022 seasons, respectively.

Statistical analysis

The obtained data were statistically analyzed according to the technique of analysis of variance (ANOVA) for the split-plot design as published by Gomez and Gomez (1984) using “MSTAT-C” software package. Least significant of difference (LSD) method was used to test the differences among treatment means at 5 % level of probability as described by Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Flax characters

Effect of N fertilizer levels

Nitrogen fertilization levels (60, 85 and 110 kg N/ha) on both flax intercropped with pea showed significant effect on all studied characters of flax intercropped with pea i.e. technical length, stem diameter, straw yield/ha, fruiting zone length, number of capsules/plant, number of seeds/plant, seed index and seed yield/ha in both growing seasons (Tables 2 and 3). Application of 85 kg N/ha significantly increased all studied characters of flax intercropped with pea and resulted in the highest values of these characters in both seasons. However, application of 110 kg N/ha came in the second rank after application of 85 kg N/ha concerning its effect on all studied characters of flax intercropped with pea without significant differences on straw and seed yields/ha in both seasons. On the other hand, application of 60 kg N/ha gave the lowest values of all studied characters of flax intercropped with pea in both seasons. These results might be due to the low soil content of available nitrogen (Table 1), since nitrogen plays an important role in all metabolic plant, where it is the main component and major constituent of plants especially in living tissues formation besides being an integral part of proteins, phytochromes, coenzymes, chlorophyll and nucleic acids. Therefore, all the biochemical processes occurring in plants are mainly managed by nitrogen and its associated compounds, which make it essential for growth and development. However, increasing nitrogen to more than recommended leads to a decrease in yield as a result of the lodging of some plants (Marschner, 1995). These results are compatible with those found by El-Nagdy et al. (2010), Abdel-Galil et al. (2015), El-Borhamy (2015), El-Gedwy (2018) and Abdel-Kader et al. (2019).

Effect of pea intercropping patterns with flax

The studied plant densities of pea (12.5, 25.0, 37.5 and 50.0 % of the recommended plant density) intercropped with flax exhibited significant effects on technical length, stem diameter, straw yield/ha, fruiting zone length, number of capsules/plant, number of seeds/plant and seed yield/ha and insignificant effects on seed index of flax intercropped with pea in both seasons (Tables 2 and 3). Sowing flax with the recommended plant density (140 kg seeds/ha) in the intercropping system with pea using 12.5% of recommended plant density resulted in the highest values of flax stem diameter, straw yield/ha, number of capsules/plant, number of seeds/plant, seed index and seed yield/ha, and the lowest values of flax technical length and fruiting zone length during the two winter seasons of 2020/2021 and 2021/2022. These results may be due to reduced competition among adjacent plants, which led to an increase in the amount of solar radiations intercepted by flax plants, as well as increment aeration and light distribution among flax plants, which led to increased photosynthetic activities and dry matter accumulation per individual flax plants, and therefore increasing straw and seed yields/ha. At the same time, we observed a decrease in technical length and fruiting zone length. However, sowing flax with the recommended plant density in the intercropping system with pea, using 50.0 % recommended plant density, produced the highest values of flax technical length and fruiting zone length and the lowest values of flax stem diameter, straw yield/ha, number of capsules/plant, number of seeds/plant, seed index and seed yield/ha in the two growing seasons. These results may be due to the high competition between adjacent plants at higher plant density of pea (50.0 % from the recommended plant density) for light, water and nutrients, which led to decrease photosynthetic activities and production of less dry matter in different plant organs of individual plants. These results are partially compatible with those from Sibhatu et al. (2016) who showed that high plant population per unit area had adverse effect on plants growth, yield and its quality due to the competition between the plants for their needs of moisture, light and nutrients.

Interaction effect

The technical length, straw yield/ha, fruiting zone length, number of capsules/plant, number of seeds/plant and seed yield/ha of flax intercropped with pea were significantly affected by the interaction between nitrogen fertilization levels and different plant densities of pea intercropped with flax in both seasons (Tables 2 and 3). In contrast, stem diameter and seed index of flax intercropped with pea showed insignificant effect due to the interaction between nitrogen fertilization levels and different plant densities of pea intercropped with flax in both seasons. The highest values of flax straw yield/ha, number of capsules/plant, number of seeds/plant and seed yield/ha were obtained from sowing flax with the recommended plant density in the intercropping system with pea with 12.5 % of the recommended plant density and fertilizing them with 85 kg N/ha. However, sowing flax with the recommended plant density in the intercropping system with pea with 50.0% of the recommended plant density and fertilizing them with 85 kg N/ha produced the highest values of flax technical length and fruiting zone length in both seasons. However, the lowest values of flax straw yield/ha, number of capsules/plant, number of seeds/plant, and seed yield/ha were recorded when sowing flax with the recommended plant density in the intercropping system with pea with 50.0% of the recommended plant density and fertilizing them with 60 kg N/ha in both seasons. On the other hand, sowing flax with the recommended plant density in the intercropping system with pea using 12.5% of the recommended plant density and fertilizing them with 60 kg N/ha produced the lowest values of flax technical length and fruiting zone length in both seasons.

Pea green pods yield and its components

Effect of N fertilizer levels

The studied nitrogen fertilization levels (60, 85 and 110 kg N/ha) proved significant effect on number of leaves/plant, number of branches/plant, number of pods/plants, pod length and diameter, green pod weight, number of seeds/pod and total green pods yield/ha of pea intercropped with flax in both growing seasons (Tables 4 and 5). Fertilizing both flax and pea in the studied intercropping system with the medium nitrogen level (85 kg N/ha) resulted in the highest values of number of leaves/plant, number of branches/plant, number of pods/plants, pod length and diameter, green pod weight, number of seeds/pod and total green pods yield/ha of pea intercropped with flax, followed by fertilizing with 110 kg N/ha in both seasons. On the other side, fertilizing the intercropped flax and pea with the lowest nitrogen level (60 kg N/ha) gave the lowest values of number of leaves/plant, number of branches/plant, number of pods/plants, pod length and diameter, green pod weight, number of seeds/pod and total green pods yield/ha of pea intercropped with flax in both seasons. These results might be due to the role of nitrogen as one of the major elements for plant nutrition and it increases the vegetative cover for plant and forms strong plants. Moreover, nitrogen encourages plant to uptake other elements, activating all the biochemical processes occurring in plants, therefore nitrogen is essential element for the growth and development of plants (Marschner, 1995). These results are partially compatible with those found by Abdel-Kader et al. (2019) and Brunsek et al. (2022).

Effect of pea intercropping patterns with flax

Studied plant densities of pea (12.5, 25.0, 37.5 and 50.0 % of the recommended plant density) intercropped with flax showed significant effects on number of leaves/plant, number of branches/plant, number of pods/plants, pod length and diameter, green pod weight, number of seeds/pod and total green pods yield/ha of pea intercropped with flax in both seasons (Tables 4 and 5). Intercropping pea with flax by sowing flax with the recommended plant density (140 kg seeds/ha) and sowing pea with 12.5% of the recommended plant density attained the highest values of number of leaves/plant, number of branches/plant, number of pods/plants, pod length and diameter, green pod weight and number of seeds/pod and lowest values of total green pods yield/ha of pea intercropped with flax during the two winter seasons of 2020/2021 and 2021/2022. However, intercropping pea with flax by sowing flax with the recommended plant density and sowing pea with 25.0 % of the recommended plant density ranked second after the lowest plant density and followed by sowing flax with the recommended plant density and sowing pea with 37.5 % of the recommended plant density concerning its effect on pea green pods yield and its components in both seasons. The highest plant density of pea (sowing flax with the recommended plant density and sowing pea with 50.0 % of the recommended plant density) gave the lowest values of number of leaves/plant, number of branches/plant, number of pods/plants, pod length and diameter, green pod weight and number of seeds/pod and second best values of total green pods yield/ha of pea intercropped with flax in the two growing seasons. However, the highest values of total green pods yield/ha of pea intercropped with flax were produced when flax is sown with the recommended plant density and pea sown with 37.5 % from the recommended plant density in both seasons. Such effects of plant density of pea intercropped with flax might have been due to low plant density of pea intercropped on both sides of flax terraces leading to reduced competition and mutual shading among pea plants and flax plants, which affects the growth, yields and its components of both flax and pea. These results are in accordance with those established by Abul-Soud et al. (2014), Byan et al. (2015), Fekry and El-Shatoury (2017), Ahmed et al. (2019) and Krizmanic et al. (2020).

Interaction effect

The interaction between nitrogen fertilization levels and different plant densities of pea displayed significant effect on number of leaves/plant, number of pods/plants, green pod weight, number of seeds/pod and total green pods yield/ha of pea intercropped with flax in both seasons (Tables 4 and 5). Data showed that the highest number of leaves/plant, number of pods/plants, green pod weight and number of seeds/pod of pea intercropped with flax resulted from sowing flax with the recommended plant density in the intercropping system with pea with 12.5% of the recommended plant density and fertilizing them with 85 kg N/ha, followed by sowing flax with the recommended plant density with pea using 25.0 % of the recommended plant density and fertilizing them with 85 kg N/ha in both seasons. However, the highest values of total green pods yield/ha of pea intercropped with flax produced when flax is sown with the recommended plant density and pea with 37.5 % of the recommended plant density and fertilizing them with 85 kg N/ha and the lowest values of total green pods yield/ha of pea intercropped with flax produced when flax is sown with the recommended plant density and pea sown with 12.5 % of the recommended plant density and fertilizing them with 60 kg N/ha in both seasons. Sowing flax with the recommended plant density in the intercropping system with pea using 50.0 % of the recommended plant density and fertilizing them with 60 kg N/ha recorded the lowest highest number of leaves/plant, number of pods/plants, green pod weight and number of seeds/pod of pea intercropped with flax in both seasons.

Competitive relationships and yield advantages

The highest values of competitive relationships i.e. land equivalent ratio “LER” (1.33 and 1.31) and relative crowding coefficient “RCC” (13.3 and 5.50) as presented in Table 6 were obtained from sowing flax with the recommended plant density and pea with 37.5 % of the recommended plant density and fertilizing them with 85 kg N/ha in the first and second seasons, respectively. On the other hand, flax was the dominated crop in 3 and 2 treatments in the first and second seasons, respectively. Concerning the Aggressivity (Ag), the highest value for flax (+0.13 and +0.05) and the lowest value for pea (- 0.13 and -0.05) resulted from sowing flax with the recommended plant density and sowing pea with 50.0 % of the recommended plant density and fertilizing them with 85 kg N/ha in the first and second seasons, respectively. Data revealed that pea was the dominant crop in 9 out of 12 treatments in the first season, and 10 out of 12 treatments in the second season.

Economic evaluations

Concerning the economic evaluation of the interaction between nitrogen fertilization levels and different plant densities of pea intercropped with flax during the two winter seasons of 2020/21 and 2021/22, the data (Table 7) show that the highest values of actual flax straw yield/ha (1514 and 1078 USD), actual flax seed yield/ha (1171 and 1222 USD) intercropped with pea were obtained from sowing flax with the recommended plant density in the intercropping system with pea using 12.5 % of the recommended plant density and fertilizing them with 85 kg N/ha in the first and second seasons, respectively. However, the highest values of actual pea green pods yield/ha (812 and 809 USD) intercropped with flax, total income (3470 and 2993 USD), net return (1822 and 1580 USD) and the increase in total income (+22.7 and +22.6) of both flax and pea crops were obtained from sowing flax with the recommended plant density and sowing pea with 37.5 % of the recommended plant density and fertilizing them with 85 kg N/ha in the first and second seasons, respectively (Table 7). The second best interaction treatment for net return was flax sown with the recommended plant density and pea sown with 25.0 % from the recommended plant density and fertilizing them with 85 kg N/ha in both seasons.

CONCLUSION

It could be concluded that to obtain the best land usage and total income for farmers from intercropping pea with flax is given by intercropping pea with 37.5 % of its recommended density with flax et 100% recommended density with 85 kg N/ha in the Egyptian Northern Delta.

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