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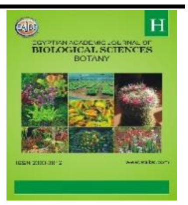

Biofortification of Productivity of Egyptian Cotton Variety Giza 94 through Split Application of Nitrogen Fertilizer and Phosphorus Sources

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Egyptian, cotton, N fertilizer, splitting, P, sources, yield, and its components.

ABSTRACT

Two field experiments were conducted at the Nubaria Agricultural Research Station in Giza, Egypt, located at 46 km southwest of Alexandria. The study aimed to evaluate the influences of splitting N fertilizer and different P sources on the seed cotton yield and its components of the Egyptian cotton cultivar Giza 94, a long-staple variety, during of 2021 and 2022 seasons. The experimental design was a split-plot design with four replications, where N splitting treatments (Twice, Thrice, and Four times) were assigned to the main plots, while the sub-main plots included sources of P fertilization (Super phosphate, Organic P, Phosphoric acid, and Phosphorien). The results indicated that growth and yield of Egyptian cotton were influenced by N splitting, P sources, and their interaction, particularly with three equal splits applied at 30, 45, and 60 days after sowingsowing (DAS). The first split occurred before the first irrigation (30 DAS), the second before the second irrigation (45 DAS), and the third before the third irrigation (60 DAS). The P application involved adding half a dose of Ca superphosphate during seedbed preparation, inoculating seeds with the biofertilizer Phosphorein at planting date, foliar application with 1.5 cm³ phosphoric acid per liter twice (after thinning and six days after the third irrigation at 66 DAS), and foliar application of 5 cm³ organic phosphorus (Pro Phos™ 0-20-0) per liter twice (at the squaring stage, 45 DAS, and flowering initiation, 80 DAS) in both seasons under Nubaria conditions.

INTRODUCTION

Cotton (*Gossypium* spp. L.) is a crucial natural fiber with a significant history and extensive applications, playing a vital role in global trade and manufacturing. Its influence on the world economy and textile industry remains strong today (Campbell *et al*., 2010).

Egyptian cotton (*Gossypium barbadense* L.) is a high-quality cotton recognized for its luxurious feel. It flourishes in the Nile River Valley, where ideal climate and soil conditions foster the growth of long-staple fibers. These longer fibers produce stronger, finer yarns, enabling the creation of exceptionally soft and durable fabrics. In 2019, the cultivated area for cotton was 238,10 feddan, with an average yield of 1281 kg/feddan and 8.13 kentar/feddan (FAO 2023).

Nitrogen (N) is essential for cotton production as it affects plant growth, fiber development, yield potential, and soil fertility. Effective N management is crucial for optimal cotton yields and the sustainability of cotton farming. Additionally, splitting N applications offers benefits such as improved efficiency, enhanced fiber quality, reduced environmental impact, better plant health, and encouraged flexibility in management. This practice promotes more sustainable and productive cotton cultivation (Khan *et al*., 2017;

Mugi-Ngenga *et al*., 2022). Additionally, Emara and Abdel-Aal (2017) and Abdel-Tawab *et al*. (2021) found that raising N levels correlated with greater plant height, more fruiting branches, increased bolls/plant, larger boll weights, higher seed indices, greater lint percentages, and higher seed cotton yields. In this trend, Said (2011) and (Nachimuthu *et al*., 2022) noted that splitting nitrogen fertilizer led to increases in No. of open bolls, boll weight, and seed yield of cotton /fed, likely due to decrease fertilizer leaching. Moreover, splitting N can help cotton plants meet their needs at different growth stages. The maximum bolls number/plant, weight of boll (g), and seed yield of cotton/fed were gotten with N split into four equal applications compared to three or two (Elhamamsey *et al*., 2016; Hamam and Abdullah, 2021). Also, El-Basuony (2009), Sattar *et al.* (2017) and Nachimuthu *et al*. (2022) observed the highest seed cotton yields with split nitrogen applications at each irrigation, while Farweez *et al*. (2020) observed that splitting N- fertilizer into 3 doses resulted in the highest values for growth, yield and quality traits in both seasons.

Phosphorus (P) is essential for cotton production, influencing seedling development, flowering, fruiting, energy transfer, fiber development, and soil fertility. Adequate P rates in the soil are critical for healthy cotton growth and maximizing yield potential. Phosphate fertilizer significantly impacts crop yield, addressing the greater phosphorus demand that often conflicts with soil P, particularly when other nutrients are suboptimal. While P is the 2nd most crucial nutrient for crop production after nitrogen, its global availability is limited. P application improves root structure by increasing root length, width, and diameter, thereby improving P uptake in plants (Parfitt *et al*., 2008; Ar 2009; Lynch 2011; Mai WenXuan *et al*., 2018). Consequently, P deficiency hampers cotton growth and reduces biomass accumulation, resulting in lower seed cotton yield (Singh *et al*., 2006). Increasing P rates boosts yield, reproductive biomass, and nutrients accumulation in cotton; however, the low P-sensitive cultivar Lu-54 shows a significant response to P application than the low phosphorus-tolerant variety (Iqbal *et al*., 2020).

Cotton yield response to applied P fertilizer varied with split N application ratio and timing, but not with N rates or water-run N strategies. Late N applications reduced lint yield and P response. Applying all N pre-plant with P improved lint yield of cotton by 37.2% (and seed yield by 32.5%) compared to applying P pre-plant and N in-crop. P application enhanced lint turnout by increasing lint production and reducing trash. These findings suggest that timely P fertilizer application combined with optimal early-season N promotes better agronomic efficiency. Distributing P throughout plant beds may improve P acquisition by cotton roots when more N is applied pre-plant than in-crop (Nachimuthu *et al*., 2022).

The main objective of this investigation was to examine the effects of different splitting strategies for N fertilizers, including the influence of P sources, on cotton production. Specifically, the study focused on the growth performance, earliness of maturation, yield, yield components, and the quality of fiber produced by the Giza 94 cotton cultivar under Nubaria conditions.

MATERIALS AND METHODS

Experiment Location:

Two field experiments were laid out at the Nubaria Agricultural Research Station, Agricultural Research Center (ARC) in Giza, Egypt, which is located 46 km Southwest of Alexandria at 30°45'N latitude and 29°30'E longitude, with an elevation of approximately 21 meters above sea level. This study aimed to evaluate the effects of splitting N and P sources, besides their interactions, on the seed cotton yield and its components of the Giza 94 Egyptian cotton cultivar (*Gossypium barbadense* L.) during the 2021 and 2022 growing seasons.

Egyptian clover (Barseem), *Trifolium alexandrinum* L. was the preceding crop for two seasons, harvested after two cuttings before ploughing. It is a preferred crop before summer plantings, particularly in newly reclaimed or calcareous soils in this region.

Soil Analyses:

Table 1, present the physical and chemical properties of soil from the Nubaria Agricultural Research Station, were described according to Chapman and Partt (1978). The initial physicochemical characteristics of the surface layer (0 - 60 cm) for both experimental seasons were determined and recorded in this table.

Table 1: Some physical and chemical properties of the experimental soil in both seasons.

Soil characteristics	Seasons	
Particle size distribution	2021	2022
Soil texture (%)	Sandy loam	
pH (1: 2.5 water suspension)	8.30	8.22
EC (dSm^{-1})	2.55	2.60
Organic matter (%)	0.30	0.27
Soluble Cations (meq/L.)		
Ca^{++}	7.60	7.50
Mg^{++}	5.20	4.85
Na^{+}	5.10	5.00
K^{+}	0.50	0.55
Soluble Anions (meq/L.)		
HCO_3^{-}	3.00	3.95
Cl^{-}	4.80	3.10
SO_4^{--}	10.30	10.20
O.M. (%)	0.82	0.83
Total $CaCO_3$ (%)	21.75	22.15
Available Mineral N (ppm)	19.80	19.90
K (mg/Kg)	88.00	90.00
Available P (ppm)	3.90	4.00

Experiment Set Up:

The experimental design utilized a split-plot design with four replications, assigning nitrogen (N) splitting treatments (Twice, Thrice, and Four times) to the main plots and different sources of phosphorus (P) fertilization (Super phosphate, Organic P, Phosphoric acid, and Phosphorien) to the sub-main plots.

1- Main plots: the N treatments at the rate of 80 kg/fed investigated as follows:

N1- Two equal splits serving as a control. The first split application was done before the first irrigation (at 30 days after planting ″DAS‶) and the second split before the 2nd irrigation (at 45 DAS).

N2- Three equal splits (at 30, 45 and 60 DAS). The first split application was done before the 1st irrigation (at 30 DAS), the second split before the 2nd irrigation (at 45 DAS) and the third split before the 3rd irrigation (at 60 DAS).

N3- Four equal splits (at 30, 45, 60 and 75 DAS). The first split application was done before the 1st irrigation (at 30 DAS), the second split before the 2^{nd} irrigation (at 45 DAS), the third split before the 3rd irrigation (at 60 DAS) and the fourth split before the 4^{th} irrigation (at 75 DAS).

Ammonium nitrate (33.5% N) was applied as a form of nitrogen fertilizer at the rate of 80 kg N/fed based on the treatments described.

2- Sub plot: the treatments of phosphorus (P) sources:

P1- Add calcium superphosphate (SP),15.5% P2O5 at the recommended rate of 22.5 kg P2O5 /fed. It was incorporated during seed bed preparation (serving as a control).

P2- Foliar application with 1.5 cm3 phosphoric acid H3PO4 [85%], (PA)/L twice [after thinning and six days after the third irrigation (at 66 DAS)].
P3- Foliar application with 5 cm3 organic phosphorus (OP) in the form of Pro Phos™ 0- 20- 0/L twice [after thinning and six days after the third irrigation (at 66 DAS)].
P4- Seeds inoculation with 400 g bio-fertilizer (Phosphorein)/20 kg seeds per feddan at planting (Bio-P). After planting, the irrigation immediately done.
P5- Combination of P sources: add half dose of Ca superphosphate during seed bed preparation + inoculated seeds with biofertilizer (Phosphorein) at planting + foliar application with 1.5 cm3 phosphoric acid/L twice [after thinning and six days after the third irrigation (at 66 DAS)] + foliar application with 5 cm^3 organic phosphorus [Pro Phos™ 0- 20- 0]/L twice [at the squaring stage (45 DAS) and flowering initiation (80 DAS)].

Fertilizers application:

Organic phosphorus (Ferticell® Pro Phos™ 0-20-0), derived from Rock Phosphate (20% P_2O_5), was used as a foliar application. This mineral-sourced, liquid phosphorus fertilizer is appropriate for organic use and designed to supply phosphorus in an easily mineralizable form. It utilizes micronization technology and algae extract to enhance nutrient availability for plant growth and productivity. Foliar application was conducted with phosphoric acid and Pro Phos™ 0-20-0 utilizing a hand-operated sprayer, applying 200 litters per feddan. Both the upper and lower leaf surfaces were thoroughly wetted, with Tween™ 20 (0.5%) used as a wetting agent. The study utilized a bio-fertilizer called Phosphorein, a commercial multi-strain phosphorus-dissolving bacterium. Inoculation cotton seeds of Phosphorein at the rate of 400 g Phosphorein per 20 kg seeds/feddan, using a sticking agent (5% Arabic gum) right before planting. The seeds were planted in dry soil then subsequently irrigated.

Experiment Area:

Each sub-plot, measuring 16.25 m^2 in both seasons, comprised 5 ridges spaced 0.65 m apart and 5 m long, with 25 cm between hills. Giza 94, an Egyptian long staple cotton cultivar, was planted at the rate of 30 kg/fed on May 15 and May 22 in the 2021 and 2022 seasons, respectively.

Irrigation and Hoeing:

Regular agricultural practices were maintained according to the recommendations of the commercial production of the West Nubaria region such as before the 2^{nd} irrigation, plants were thinned to two healthy seedlings per hill. Hand hoeing occurred three times during the two seasons prior to the first, second, and third irrigations. Standard pest and weed control practices were implemented throughout the two growing seasons. Cotton plants received irrigation every 15 days during the growing season, starting with the first irrigation (Mohayat) 21 days after planting. Before the second irrigation, 24 kg of potassium fertilizer (K_2O) was applied in the form of potassium sulfate (48%). Other regular agricultural practices for the West Nubaria region were maintained throughout the two growing seasons.

The Studied Characteristics*:*

Seed cotton yield was hand-harvested on September 22 to October 9 in the first season, and on September 28 to October 15 in the second season. The study examined several factors: number of fruiting branches/plant, seed cotton yield per fed (kentar), open boll number/plant, seed cotton yield/plant (g), boll weight (g), plant height (cm), and number of vegetative branches/plant (Kentar = 157.5 kg).

Statistical Analysis*:*

All data that were collected during the study underwent a thorough analysis of variance, following the methodologies established by Gomez and Gomez (1984). This detailed statistical analysis was carried out utilizing the analysis of variance technique, which was facilitated through the CoStat computer software package, specifically version 6.311, (2005). To ensure accurate comparisons among the treatment means, the least significant differences (LSD) at a significance level of 0.05 were employed as part of the statistical evaluation process. This approach allowed for a robust examination of the varying treatment effects, providing clarity in the results acquired from the analysis.

RESULTS AND DISCUSSION

Table 2, shows the results of nitrogen fertilizer splitting, various phosphorus fertilizer sources, and their interaction on plant height (cm), number of vegetative branches/plant, open boll number/plant, seed cotton yield/plant (g), boll weight (g), and seed cotton yield/fed (kentar) during the 2021 and 2022 cropping seasons.

The results indicate that N fertilizer splitting significantly affected plant height only in the first season. However, in both seasons, splitting nitrogen significantly influenced the open boll number/plant, seed cotton yield/plant, and overall seed cotton yield. There was no significant differences on the number of vegetative branches/plant and boll weight as affected by N splitting. Applying nitrogen fertilizer in four splits resulted in the tallest plants, while three splits yielded the greatest open boll number/plant, seed yield/plant, and seed yield/fed across both seasons. These findings align with Arain *et al.* (2001), who noted that split nitrogen applications enhanced boll weight, bolls number/plant, and seed cotton yield. Similarly, Soomro *et al.* (2001) found that nitrogen fertilizer applied at different times significantly affected seed cotton yield and boll count. Anjum *et al.* (2007) reported that split N increased total bolls and boll weight (g), although seed cotton yield remained unchanged. Raju *et al.* (2008) found that 3 splits produced 15% more seed cotton yield than two splits, while Hallikeri *et al.* (2010) indicated that increasing split numbers did not affect yield. Jat and Nanwal (2013) observed insignificant effects of N splitting on boll weight, consistent with findings from El-Basuony (2009), Elhamamsey *et al.* (2016), Sattar *et al.* (2017), Hamam and Abdullah (2021), and Farweez *et al*. (2020).

Regarding P fertilizer sources, the results showed significant impacts on all studied characteristics except the number of vegetative branches/plant in both seasons. The maximum values for plant height, open boll number/plant, seed cotton yield (g)/plant, boll weight (g), and seed cotton yield/fed (kentar) were recorded with the combination of all P sources (P5), which included half a dose of calcium superphosphate during seed bed preparation, inoculated seeds with biofertilizer (Phosphorein) at planting, and two foliar applications of phosphoric acid and organic phosphorus at specified growth stages. Dohary *et al.* (2004) noted that P deficiency adversely affects the growth of flower buds in cotton, while Ahmad *et al.* (2020) reported that P addition significantly improved cotton yield metrics. Ali *et al.* (2020) indicated that reduced phosphorus availability decreased boll weight and size, while Iqbal *et al*. (2020) recorded the similar results.

Concerning the interaction between N splitting and phosphorus sources, (**Fig.s 1 to 12),** demonstrate significant effects on all tested characteristics in both seasons. The tallest cotton plants were recorded with the combination (N2 + P2), followed by (N3 + P5). The highest number of vegetative branches was recorded with (N3 + P4), while the greatest open bolls number, seed yield/plant, boll weight, and seed cotton yield/fed were obtained with (N2 + P5), which involved three equal splits of nitrogen fertilizer and the specified phosphorus combination.

Overall, there has been limited research on how N and P fertilizers interact to influence cotton lint and seed yield in high-yielding modern cotton cultivars. Liu *et al*. (2021) reported that optimal applications of P and potassium can mitigate the effects of reduced nitrogen on cotton yield, while Tewolde *et al.* (2021) highlighted the importance of balancing nitrogen fertilization when using P-based amendments.

Table 2: Effect of number of N fertilizer applications and sources of P on cotton growth and productivity during seasons 2021 and 2022.

Traits / Treatments	Plant height (cm)		No. of vegetative branches plant^{-1}		No. of open bolls plant^{-1}		Seed cotton yield/plant (g)		Boll weight (g)		Seed cotton yield fed^{-1} (kentar)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
A-Number of N fertilizer application (Splitting):												
N1.Twice	159.80	145.80	1.87	0.19	9.47	10.20	22.37	24.01	2.32	2.35	5.59	6.00
N2.Thrice	160.00	146.00	1.89	0.19	9.70	11.88	24.04	29.01	2.40	2.44	6.01	7.25
N3.Four times	160.73	146.73	1.92	0.19	8.95	11.66	21.22	27.58	2.28	2.36	5.31	6.90
LSD at 5%	1.42	NS	NS	NS	0.22	0.60	2.76	0.69	NS	NS	0.69	0.17
B- Sources of P fertilizer												
P1-Super phosphate	159.67	145.67	1.96	0.20	8.19	10.52	16.41	24.05	1.99	2.29	4.10	6.01
P2- Organic P	162.00	148.00	1.87	0.19	10.44	11.42	27.61	28.07	2.65	2.46	6.90	7.02
P3-Phosphoric acid	160.11	146.11	1.78	0.18	9.47	11.53	21.53	26.73	2.26	2.32	5.38	6.68
P4-Phosphorien	158.78	144.78	2.02	0.20	7.18	10.16	13.21	23.01	1.84	2.27	3.30	5.75
P5-(P1+ P2+ P3+ P4)	160.33	146.33	1.84	0.18	11.58	12.60	33.95	32.47	2.94	2.58	8.49	8.12
LSD at 5%	0.97	0.97	NS	NS	0.42	0.44	1.83	0.62	0.15	0.06	0.46	0.15
Interaction:												
LSD at 5%	*	*	*	*	*	*	*	*	*	*	*	*

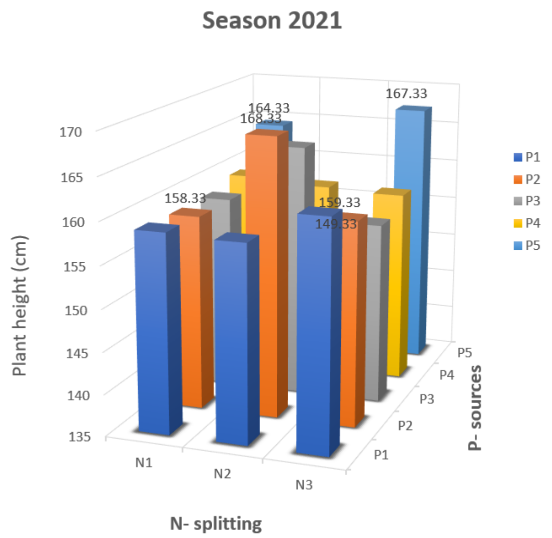

Fig. 1. Interaction between number of N fertilizer applications and sources of P on plant height of cotton in 2021 season

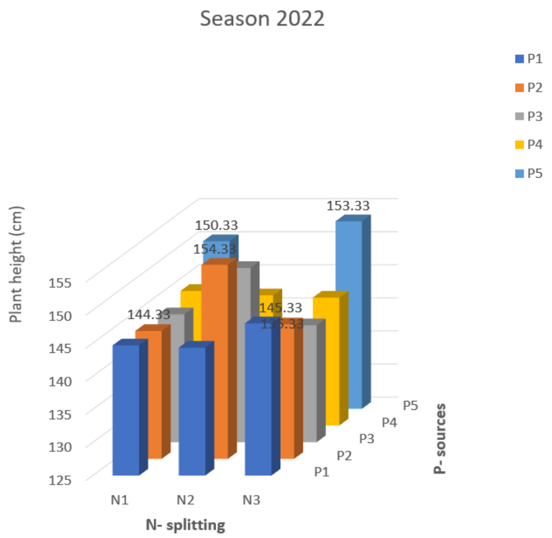

Fig. 2. Interaction between number of N fertilizer applications and sources of P on plant height of cotton in 2022 season

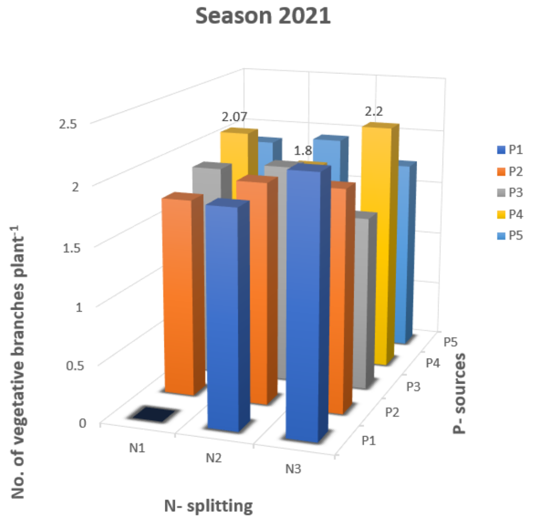

Fig. 3. Interaction between number of N fertilizer applications and sources of P on number of vegetative branches/plant in 2021 season

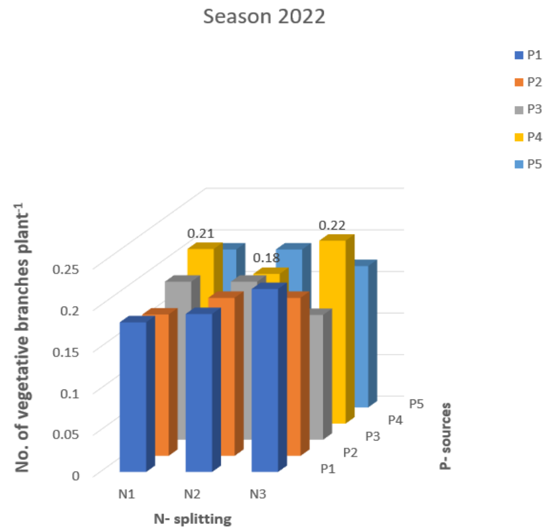

Fig. 4. Interaction between number of N fertilizer applications and sources of P on number of vegetative branches/plant in 2022 season

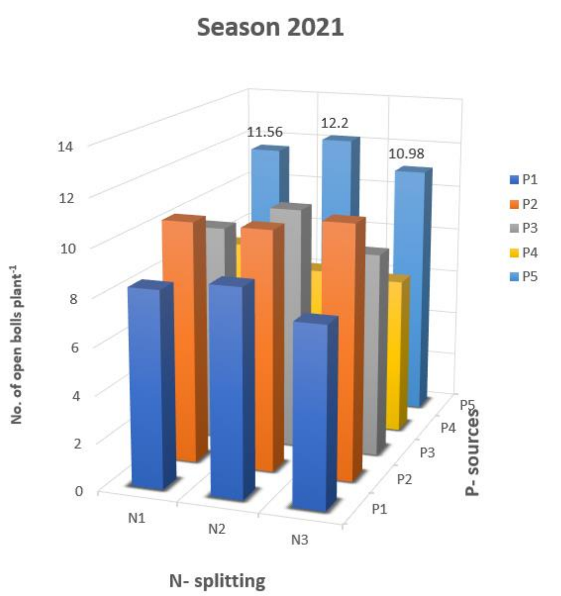

Fig. 5. Interaction between number of N fertilizer applications and sources of P open boll number/plant in 2021 season

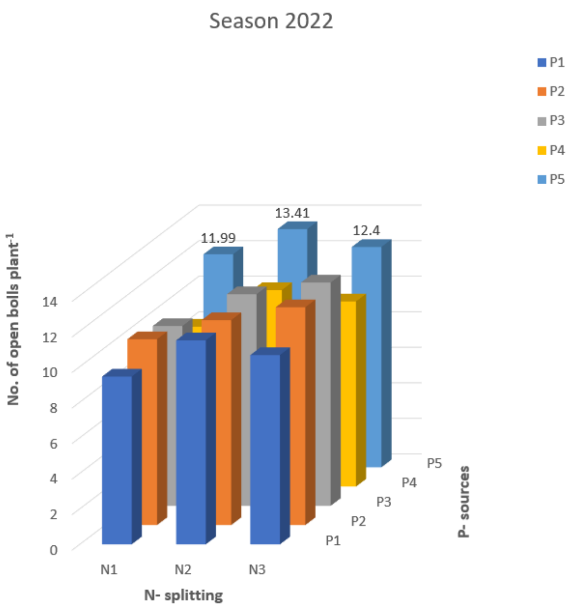

Fig. 6. Interaction between number of N fertilizer applications and sources of P on open bolls/plant in 2022 season

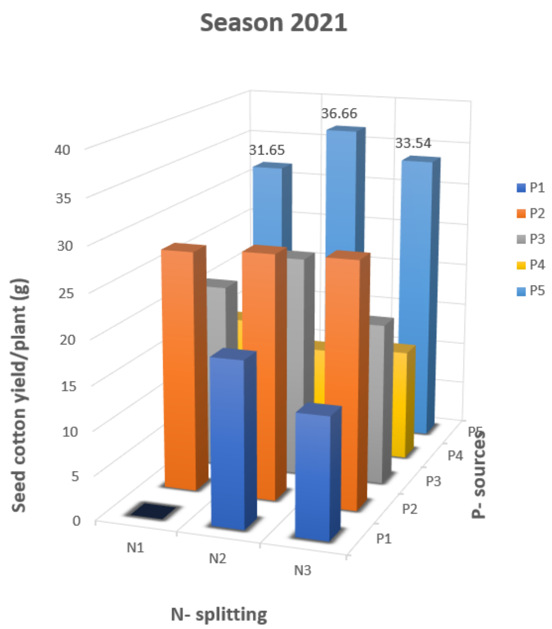

Fig. 7. Interaction between number of N fertilizer applications and sources of P on seed cotton yield/plant of Egyptian cotton in 2021 season

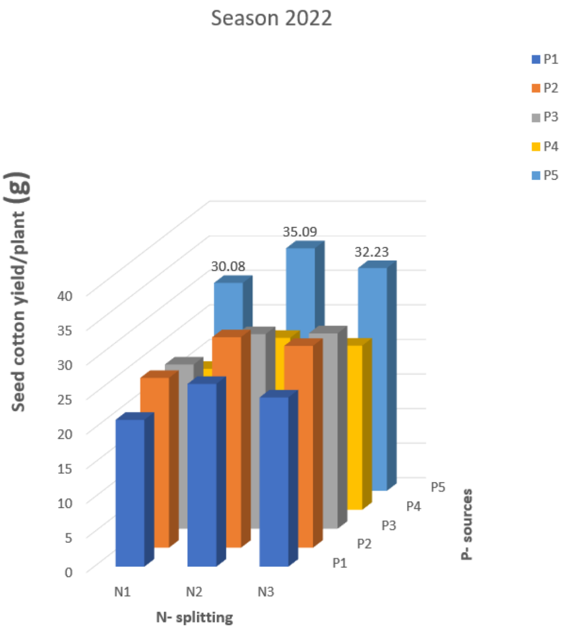

Fig. 8. Interaction between number of N fertilizer applications and sources of P on seed cotton yield/plant of Egyptian cotton in 2022 season

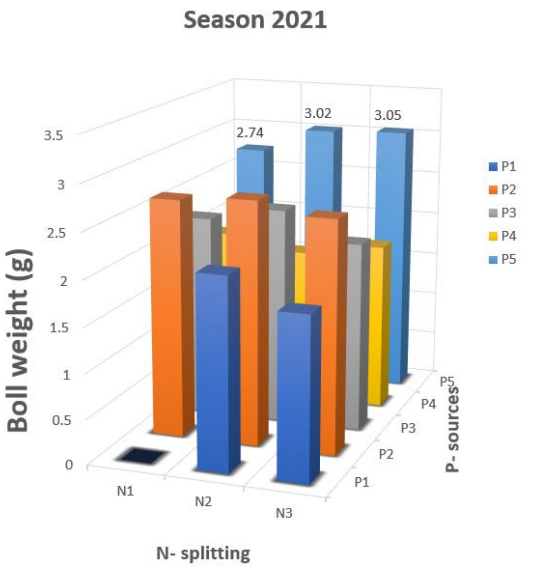

Fig. 9. Interaction between number of N fertilizer applications and sources of P on boll weight of Egyptian cotton in 2021 season

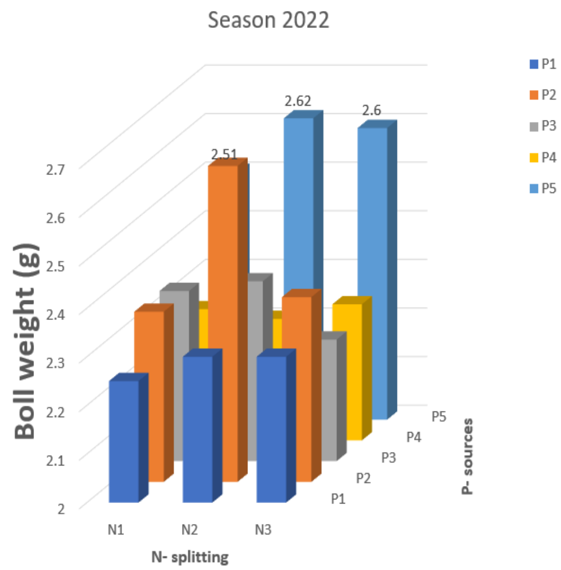

Fig. 10. Interaction between number of N fertilizer applications and sources of P on boll weight of Egyptian cotton in 2022 season

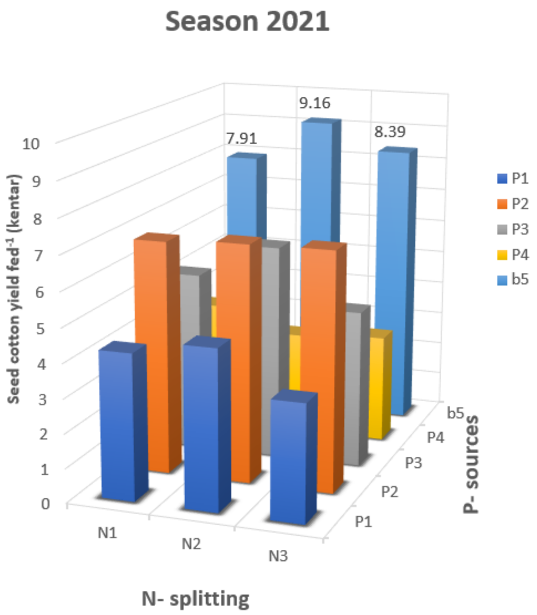

Fig. 11. Interaction between number of N fertilizer applications and sources of P on seed cotton yield of cotton in 2021 season.

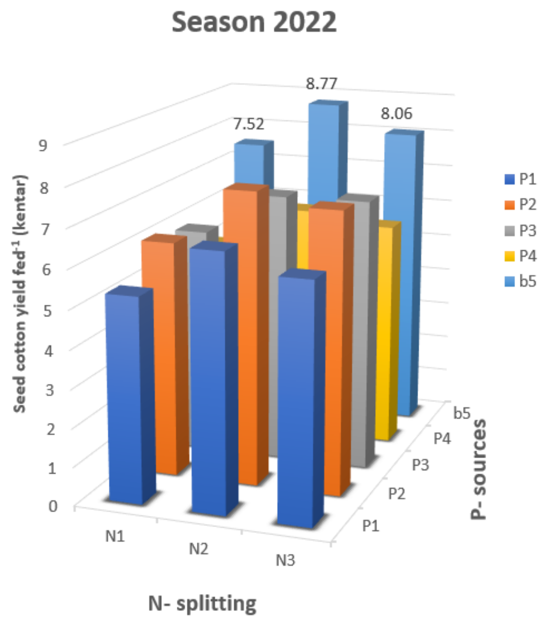

Fig. 12. Interaction between number of N fertilizer applications and sources of P on seed cotton yield of cotton in 2022 season.

Conclusion:

Cotton growth and yield were influenced by the N splitting fertiliser, P sources fertilization and their combination. The use of (N2 + P5)= (Three equal splits (at 30, 45, and 60 DAS) produced the greatest value of growth and yield characteristics. Before the 1st irrigation, the 1st split application was applied at 30 DAS; before the 2nd irrigation, the 2nd split was applied at 45 DAS; and before the 3rd irrigation, the 3rd split was applied at 60 DAS. P sources were combined as follows: half a dosage of calcium superphosphate was added while preparing the seed bed; seeds were injected with phosphorein biofertilizer during planting; and 1.5 cm3 phosphoric acid/L was sprayed twice on the leaves [after thinning and six days after the third watering (at 66 DAS)]. + twice applying 5 cm3 of organic phosphorus [Pro Phos™ 0-20-0]/L to the leaves [at the squaring stage (45 DAS) and the start of blooming (80 DAS)] in both seasons while living in Nubaria.

Declarations:

Ethical Approval: No plant, animal model(s) or human subjects were recruited directly for the current study. Consequently, no ethical considerations are necessary.

Conflict of interest: The authors declare no conflict of interest.

Authors Contributions: I hereby verify that all authors mentioned on the title page have made substantial contributions to the conception and design of the study, have thoroughly reviewed the manuscript, confirm the accuracy and authenticity of the data and its interpretation, and consent to its submission.

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Availability of Data and Materials: All datasets analysed and described during the present study are available from the corresponding author upon reasonable request.

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