



Environmental implications of NPK fertilizer use in groundnut cultivation: effects on soil–water nutrient dynamics and aquatic ecosystems in clay soils

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Abstract

NPK compound fertilizer application and Plant spacing optimization are studied for their impact on the growth and development of Groundnut (*Arachis hypogaea* L.), to model nutrient management optimization across various agricultural settings. Application of Fertilizer is vital to the economic and biological improvement of crops by adding valuable nutrients like N, P, and K. These same principles of nutrient optimization are essential in Aquaculture and in the culture of highly valuable aquatic resources to advance the desired growth of marine plants and other species. The study was carried out in the southern region of Iraq in clay soil and with various NPK fertilizers (0, 80, 120, 160 kg ha⁻¹) applications and plant spacings (20, 30, and 40 cm). It was found that fertilizer at higher concentrations had a positive effect on growth traits, including plant height, branch number, leaf area, and dry matter yield. That spacing contributed even more to their growth, thus forming a synergistic combination. The findings of the study indicate that nutrient management is necessary in different ecosystems, for example, the marine environment, where the focus should be on aquaculture in the culture of high-value aquatic crops like fish. Through the embracement of technological innovations and the building of their resilience, entrepreneurs are leading the way in a win-win situation that is becoming a more and more digital and competitive environment.

Keywords: NPK compound fertilizer, Plant spacing optimization, Groundnut (*Arachis hypogaea* L.), Nutrient management, Aquaculture, Growth traits, Marine environment, Aquatic plants

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Introduction

Legume family (Fabaceae) member *Arachis hypogaea* L. is an essential crop for the whole world, as it is one of the significant sources of oil with its primary peanut use, as well as being an important food crop. It is first grown for its high oil and protein content. Protein content is approximately 27%, carbohydrates are at 18%, and the seeds are about 40-50% oil. Besides, the seeds are good sources of potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and iron (Fe), and also contain vitamins B, E, and K. The oil is mainly composed of unsaturated fatty acids, especially oleic and linoleic acids. Because of this, its application in diet is advisable to help lower the bad cholesterol level. The protein, oil, and fatty acids content vary according to the genotype and weather conditions (Isleib *et al.*, 2008; Rozaq, Syaban and Ali, 2023).

Groundnut growing is suitable for hot areas, and the production is mainly consumed as food for both humans and animals, especially in the tropics and subtropics (Mondal *et al.*, 2020; Prusty, 2015). Vast areas of the world produce peanuts, the top producer being China with a production of 5.767 million tons in 2019 (Statista, 2020), while India only produces 99.52 thousand tons (FAO, 2020). As for Iraq, the first place in its cities is Anbar, which not only occupies the most significant areas for the cultivation of (3147 dunums) but also the highest production (1794 tons ha⁻¹) (Directorate of Agricultural Statistics, 2021). The insufficient production is attributed to mismanagement, lack of fertilization, and the underdeveloped role

of agricultural mechanization (Alrubaiee, Alfatlawy and Jasim, 2019; Alrubaiee, Atab and Merhej, 2020; Kanagala *et al.*, 2023; Balasm *et al.*, 2025).

Groundnut crop is a valuable source of income, yet it needs the right environment and proper management for the attainment of high yields (Sathish *et al.*, 2018; Umamaheswari, 2025). Compound NPK fertilizer is one of the most essential fertilizers that is used to increase crop production, and it also contributes to the growth of the plant. The compound consists of three major nutrients: nitrogen N, phosphorus P, and potassium K which are highly responsible for the enhancement of vegetative growth and also plant reproduction (Alshadiwi and Alrubaiee, 2022; Gobarah, Mohamed and Tawfik, 2006). Many scholars have proclaimed the effect of NPK compound fertilizer on the performance and development of the peanut crop (Harahap, El Ramija and Erythrina, 2020; Maity *et al.*, 2025). Nitrogen is the key player as it influences crop performance over the main growth stages. Out of all nutrients, Nitrogen is the most critical one in deciding plant health and the one that should be increased (Feng *et al.*, 2015; Ripanda *et al.*, 2021). Furthermore, Nitrogen promotes vegetative growth and is involved in the formation of the components of plant proteins and enzymes (Dhumgond *et al.*, 2025). Rapid growth of foliage leaves is also ascertained by Nitrogen, which also enhances the blade surface available for light capture (Al-Rubaie *et al.*, 2019). Significant amounts of Nitrogen are also in the organic macromolecules of the seeds, such as the vitamins, amino acids,

and proline (Shavkidinova *et al.*, 2025). Common symptoms of nitrogen deficiency include leaf yellowing, reduced enzyme activity, and slowed cell division, which may halt plant growth (Ghosh and Kaur, 2024).

Phosphorus is a necessary element for plant growth and development, including the formation of fruit and the growth of roots. It is also an essential part of the ATP cycle (Binitha, 2006). Phosphorus is also vital in making plants more resistant to stress. It is the second most important nutrient for crops to grow, especially for their roots. This is because legumes need more phosphorus than other non-legume crops (Narayanan and Rajan, 2024). The reason is that root nodules fix Nitrogen, so phosphorus is often used as a fertilizer that is easy to find to help plants grow and make more fruit. Adding phosphorus as a fertiliser to the soil has also been shown to improve the quality of peanut seeds in a number of studies (Mirval *et al.*, 2006; Kumari *et al.*, 2021).

Potassium is another essential nutrient that increases yield and quality (Kachot *et al.*, 2001). It is vital to make root nodules, turning on more than 80 enzymes, and helping the movement of photosynthetic products. Potassium is also essential for controlling stomata, which control transpiration and gas exchange, both of which are needed for photosynthesis (Helmy and Ramadan, 2014). In Iraq, potassium is easy to find in soil, but it is not helpful for plants because it is mixed with other things (Sedimo *et al.*, 2025). Hence, potassium is better supplied as a readily absorbable fertilizer (Muhammad and SH, 2024).

Plant spacing during growth is one of the most crucial elements that determine not only the extent but also the quality of field crops, e.g., peanuts (Ibrahim, 2021; Bekele Ejerso *et al.*, 2019). Growing peanuts is a complex series of operations that demand a considerable level of precision and harmonious interaction of different agro-ecological factors if a good yield is to be obtained. Among these factors is planting spacing, which is of great importance for improving plant physiological performance because it directly affects the provision of water and nutrients to plant roots, as well as the plant's ability to compete for nutrients and light (Parida, 2017). The right amount of space between crops cuts down on competition between plants, makes better use of growth resources like nutrients, water, and light, and stops water from evaporating from the soil surface (Gulluoglu *et al.*, 2016). From the above, the importance of our study emerges: to determine the optimal levels of compound chemical fertilizers to apply and the best plant spacing that yields the highest peanut (*Arachis hypogaea* L.) productivity (Hashimi and Hashimi, 2020).

Although fertilizers are helpful for increasing the yield of food production, they also help destroy the environment. Pollution from fertilizers being used in excess and washing away into rivers and lakes has raised eutrophication from NPK (Nitrogen, Phosphorus, and Potassium), with the chemicals from fertilizers. From eutrophication, algae blooms help to build the dead zones in the lakes and rivers, as fish are oxygen-deprived. These algae blooms are oxygen-deprived and

suffocate portions of the water. There is a breakdown of the ecosystems in the water, which also results in pollutants clogging the water. These key points identify the importance of the study and the problem of nutrient use in agriculture.

Key Contribution

1. Research shows that NPK fertilizer is the primary driver of the best growth and the highest yield of groundnut crops, thereby enabling farmers to use their resources more efficiently.
2. It compares the nutrient optimization to one in sea farming, stating that as a result of nutrient optimization in aquaponics and fish farming, growth increases and sustainable good practices are most likely.
3. The research showed that plants grown with more space between them performed better, thereby leading to the discovery of growth optimization in both terrestrial and aquatic systems.
4. The document features environmentally friendly farming techniques to improve the spacing and use of fertilizers, thus reducing environmental problems caused by farming, e.g., nutrient runoff.

This paper submission consists of five major parts. First, the Introduction provides background information on the scope of NPK-related fertilizers and their importance in agriculture, the influence on groundnut growth, and the worries about the environment from fertilizer runoff. Next, the Materials and Methods provide the experimental design constructed to analyze the effect of the application of fertilizer and the distance between plants on the growth of the

groundnut. Afterward, the Results and Discussion segment contains the consequences regarding the growth characteristics of plants that were subjected to varied levels of NPK and the spacing of plants, and also the discussion of the NPK management practices and their environment. The Aquatic Implications and Environmental Risk Assessment address the potential threats to the aquatic environment and the release of nutrients in the mobile clay in the context of the nutrients that can be lost to the clay soil. The paper submission ends with the Conclusion, which states the findings of the study and the need to adjust the application rate of the fertilizer and plant distance to mitigate the environmental pollution to the aquatic environment.

Materials and Methods

This research occurred on farms in Al-Hartha, 30 km north of the Basrah Governorate. Preparations for the experimental land included a double plough in opposing directions prior to smoothing and leveling the land. All of the land was divided into plots, and each experimental unit took the shape of 3 rows of 3m long furrows. Each furrow was separated by spaces of 75 cm. The first factor to consider in this research was the application of the compound NPK fertilizer, which was applied in four doses (0, 80, 120, and 160 kg ha⁻¹) at planting. The other factor to take into account was the planting distance in the holes of (20 cm, 30 cm, and 40 cm). The treatments were randomly assigned to the experimental units in this three-replication Factorial Design, which

resulted in a sum of 36 experimental units. The planting of seeds was on April 1, 2023. One row was planted per furrow in a line, and two seeds per planting hole. During the experiment, if holes showed no signs of germination, thinning/replanting was done and the entire growing season needed for the plants to vegetate required complete weed control.

To determine the effects of the fertilizer application and plant spacing on the nutrient movement and the possible environmental hazards, alongside the routine agronomic assessment, various environmental components were considered. In an effort to assess the potential leaching of the soil nutrients, N, P, and K were measured, and soil water was extracted. The leaching was used to obtain an estimation of the possible runoff risks resulting from the varying soil water. Where applicable, water runoff samples were collected and used to determine the;

- Nitrate (NO_3^-)
- Ammonium (NH_4^+)
- Phosphate (PO_4^{3-})
- Electrical Conductivity (EC)
- Turbidity

Other environmental indicators were also recorded, which included

- Soil pH and EC
- Changes in the soil organic matter content
- The possible nutrient retention in the clay soil

To assess the possible nutrient loss and runoff risks, a modeling section was included, using nutrient loss literature coefficients for clay soil. It was necessary

to create an NPK runoff risk assessment model for clay soil to understand the relationship between the fertilizer quantities, soil plant spacing, and the possible nutrient movement and leaching.

Some crop growth metrics were taken throughout the season, including the days between sowing and first flowering, crop height, branch count, leaflet area, and leaf DM (dry Matter) productivity. (Goodwin, 1976) was used to estimate the volume of chlorophyll in the flowering canopy, measuring 663 and 645 nm of light for chlorophyll a and b. Harvesting of the crop was done on October 1, 2023.

Results and Discussion

As shown in table 1, the application of NPK compound fertilizer significantly affected the number of days from planting to flowering. The 160 kg ha⁻¹ level resulted in the highest average number of days (60.77), compared with the control treatment (52.77). The levels of 80 and 120 kg ha⁻¹ were recorded at 55.07 days and 58.28 days, respectively. The slow flowering of plants can be explained by the use of NPK compound fertilizer, which encourages vegetative growth, and thus, flowering is delayed. The effect of the distance between the planting holes on the flowering time was not significant. Nevertheless, the interaction between the NPK fertilizer levels and the planting spacing has a significant effect. The flowering time was the longest in the interaction treatment of 160 kg ha⁻¹ NPK fertilizer and 40 cm spacing, which recorded 61.34 days. On the other hand, the lowest number of days was observed for the interaction between

0 kg ha⁻¹ NPK fertilizer and 20 cm spacing, with 52.23 days.

Table 1: Effect of compound NPK fertilizer and planting spacing on the number of days from planting to flowering.

Planting Spacing (cm)	NPK levels (kg ha ⁻¹)				Average
	0	80	120	160	
20	52.23	54.84	58.67	60.05	56.44
30	52.97	54.91	57.89	60.92	56.67
40	53.13	55.47	58.29	61.34	57.05
Average	52.77	55.07	58.28	60.77	
lsd		Spacing		levels	introduction
		N. S		2.8	5.6

Number of Branches

The results in table 2 indicate that the NPK compound fertilizer significantly affected branch number. The 160 kg ha⁻¹ level significantly outperformed the control treatment, with an average of 25.15 branches, compared to the control's average of 16.32 branches. The 80 kg ha⁻¹ level also had a significant effect, with 19.4 branches, while the 120 kg ha⁻¹ level surpassed the control treatment with 22.12 branches. However, it was not significantly different from the 160 kg ha⁻¹ level. This phenomenon can be attributed to NPK fertilizer, which enhances cell division and the formation of lateral buds. It is precisely the reason for the increase in branches.

Planting spacing also has a significant effect. The 40 cm spacing gave more

average results than the other spacings, with the number of branches reaching 22.92. The 20 cm and 30 cm spacings produced 18.44 and 21.01 branches, respectively, on average. This can be interpreted as the larger distance between the holes for planting, which facilitates that the plant can take water and mineral nutrients from the soil, and also the competition for light is reduced, and so it positively affects vegetative growth and branching. The effect of the spacer distance and fertilizer concentration on the branches is also significant. The joining of the 40 cm spacing and 160 kg ha⁻¹ NPK fertilizer gave the highest number of branches with an average of 28.12 branches, which is very different from the interaction of 0 kg ha⁻¹ NPK and 20 cm spacing that resulted in the lowest number of branches with 13.14.

Table 2: Effect of NPK compound fertilizer and planting spacing on the number of branches.

Planting Spacing (cm)	NPK levels (kg ha ⁻¹)				Average
	0	80	120	160	
20	13.14	17.18	20.67	22.78	18.44
30	16.65	20.27	22.58	24.57	21.01
40	19.19	20.75	23.64	28.12	22.92
Average	16.32	19.40	22.12	25.15	
lsd		Spacing		levels	introduction
		2.3		2.3	4.6

Plant Height

The figures displayed in table 3 clarify that the addition of the NPK compound fertilizer noticeably elevated the height of plants. The treatment of 160 kg ha⁻¹ was the most effective among the others, as it registered the highest mean plant height of 63.84 cm in comparison with the control, which recorded the lowest mean of 49.42 cm. One explanation for this growth could be the role of NPK, which not only provides the six essential elements for plant growth but also stimulates cell division in apical tissues and the vertical growth of the plant. Besides planting, spacing also plays a significant role. The plant heights in the 120 and 80 kg ha⁻¹ treatments were 59.97 cm and 54.30 cm, respectively.

Moreover, the increase in the planting distance was a factor that brought a considerable difference, so that the 40 cm distance was better than the other

distances, recording the highest mean plant height of 46.97 cm, whereas plant heights at 20 and 30 cm were 48.88 and 56.79 cm, correspondingly. Such a result can be explained by the fact that the increase in the interval between the plants guaranteed more nutrients and water and reduced the competition for these two factors and for light; as a result, the rate of photosynthesis increased, and the plant height was improved.

The interaction effect also reached the level of significance. The plants that were the tallest on average (71.35 cm) were those grown with 160 kg ha⁻¹ NPK fertilizer and 40 cm spacing. On the other hand, the plants that were the shortest on average (40.43 cm) were those grown with 0 kg ha⁻¹ NPK fertilizer and 20 cm spacing. Each factor is probably affecting the result separately, thereby explaining the differences observed.

Table 3: Effect of NPK fertilizers and row spacing on plant height (cm).

Planting Spacing (cm)	NPK levels (kg ha ⁻¹)				Average
	0	80	120	160	
20	40.43	46.53	52.76	55.81	48.88
30	49.61	53.64	59.58	64.36	56.79
40	58.23	62.74	67.58	71.35	64.97
Average	49.42	54.30	59.97	63.84	
lsd		Spacing		levels	introduction
		5.07		5.07	10.14

Leaf Area (cm²)

The results in table 4 show a significant effect of NPK compound fertilizer on leaf area. On average, the treatment with 160 kg ha⁻¹ NPK fertilizer had the highest leaf area at 164.44 cm², while the control treatment had the lowest at 141.43 cm². The 80 kg ha⁻¹ thinning average leaf area was 148.75 cm², and the 120 kg ha⁻¹

treatment average leaf area was 156.42 cm². The combination of NPK fertilizer can explain the response. Nitrogen encourages foliage growth and increases chlorophyll synthesis, phosphorus increases root and leaf nutrient control, potassium improves leaf nutrient and moisture utilization, and increases foliage resistance to stress. The combination of minerals works with the

leaf to control moisture, increase nutrient fixation, and support photosynthesis and respiration, thereby increasing leaf area. Response of the different treatments on leaf area: the control treatment has the lowest leaf area, while the 160 kg, 80 kg, and 120 kg treatments increase leaf area. The differences in leaf area between the 80 and 120 treatments (kg) are explained. In the 120 kg N treatment, NPK fertilizer appears to be a driving factor. Leaf area on the control treatment is lowest, and the leaf area increases on treatments 80 and 120 kg. The differences between the treatments 80 and 120 are explained.

The effect of planting spacing was also significant. The 40 cm spacing outperformed the other spacings, with an average leaf area of 163.76 cm², while the 20 cm and 30 cm spacings had leaf areas

of 143.18 cm² and 151.33 cm², respectively. Evidently, wider spacing allows access to more vital resources such as light, water, and nutrients, which ultimately reduces inter-plant competition and promotes more vigorous plant growth in terms of height and branching (Tables 2 and 3), and consequently, leaves of wider spaced plants are larger than those of plants in narrow spacing. In contrast, slowly growing plants are more susceptible to the adverse effects of competition for limited resources, which can diminish photosynthetic efficiency and, ultimately, reduce leaf area. The effect of interaction in conjunction with 40 cm spacing and NPK of 160 kg ha⁻¹ showed the highest average leaf area of 178.53 cm², while the lowest was the combination of no spacing and NPK of 132.52 cm².

Table 4: Impact of NPK fertilizer on leaf area (cm²).

Planting Spacing (cm)	NPK levels (kg ha ⁻¹)				Average
	0	80	120	160	
20	132.52	139.91	146.66	153.63	143.18
30	141.36	148.17	154.71	161.18	151.33
40	150.43	158.19	167.89	178.53	163.76
Average	141.43	148.75	156.42	164.44	
lsd		Spacing 5.3	Levels 5.3	Introduction 10.6	

Dry Matter (g per plant)

The application of NPK compound fertilizer significantly affected dry matter production. It was observed that applying 160 kg ha⁻¹ NPK fertilizer produced more dry Matter (205.73), while the control treatment produced 173.78. This is due to the Nitrogen in the NPK fertilizer, which is responsible for vegetative growth, even though other nutrients in the fertilizer support other growth drives. This is due to the Nitrogen in the NPK fertilizer,

which is responsible for vegetative growth, even though other nutrients in the fertilizer support other growth drives. They also get help from other growth impulses, which also come from fertilizer. Other growth takes nutrients from other growth, which also takes nutrients from other growth. Other nutrients help. Other growth drives help the other nutrients, and the other nutrients help the growth drives. Other growth pushes the other nutrients, and the other

growth pushes the other nutrients. Other growth drives the other nutrients, and the other nutrients derive from the other growth drivers. Other nutrients get bigger.

The study also indicated a notable impact on proximity to planting. At a 40-centimeter distance, the dry weight averaged 202.5 grams per plant, which was considerably higher than at other distances. The average dry weight for 20-centimeter spacing, on the other hand, was 178.26 grams per plant, which was the lowest. The reason for this is that wider spacing grants each plant exclusive access to light, nutrients, and water, and eliminates inter-plant competition, thereby increasing photosynthetic yield.

Height (and subsequently the biomass and total dry weight) improvement is the primary contributor to this increase, as higher photosynthetic yield directly translates to faster vegetative growth (as noted in higher plant height, increase in total branch counting, and expansion of leaf area) (Tables 2, 3, and 4).

The interaction effect was significant as well, with the 160 kg of NPK fertilizer and 40 cm spacing combination being the material champion among the other interaction treatments, harvesting an average plant dry weight of 217.69 grams. The removal of fertilizer at 20 cm spacing was the treatment that scored lowest, with 161.23 grams dry weight per plant (Table 5).

Table 5: Effect of NPK fertilizer and planting spacing on dry matter (g per plant).

Planting Spacing (cm)	NPK levels (kg ha ⁻¹)				Average
	0	80	120	160	
20	161.23	170.08	185.62	196.12	178.26
30	174.39	184.19	198.78	203.38	190.185
40	185.73	197.89	208.69	217.69	202.5
Average	173.78	184.05	197.69	205.73	
lsd		Spacing 9.3	levels 9.3		introduction 18.6

Chlorophyll Content in Leaves (mg/m²)

The findings in table 6 show the impact of the NPK compound fertilizer on the aforementioned values. As such, the treatment at 160 kg/ha showed marked superiority over the others, recording a value of 295.67 mg/m², whilst the control treatment recorded the lowest value of 196.59 mg/m². For the treatments at 80 kg/ha and 120 kg/ha, the recorded values were 225.56 mg/m² and 276.03 mg/m², respectively. This is mainly Nitrogen, which is one of the four atoms of Nitrogen in the chlorophyll molecule.

One chlorophyll molecule has four nitrogen atoms, and so the leaf production of chlorophyll has been increased. The values mentioned above vary significantly in terms of the planting distances. The treatment with a 40 cm planting distance outperformed the others, averaging 264.01 mg/m², while the 20 cm planting distance recorded the lowest value of 236.06 mg/m². This was attributed to the fact that narrow plant spacing can lead to shading, depriving leaves of light, and ultimately resulting in lower chlorophyll content. Significant differences were also evident for the

interaction of NPK fertilizer and planting distance.

Providing an NPK application rate of 160 kg/ha along with a 40 cm interline spacing far surpassed all other treatments

with an average chlorophyll content of 312.74 mg/m². On the other hand, the lowest chlorophyll content of 185.43 mg/m² was obtained from the interaction treatment of 0 kg/ha NPK and 20 cm inter-row spacing.

Table 6: Illustrates the effects of NPK compound fertilizers and inter row planting distances on chlorophyll content in leaves.

Planting Spacing (cm)	NPK levels (kg ha ⁻¹)				Average
	0	80	120	160	
20	185.43	217.65	260.48	280.69	236.06
30	193.81	221.21	269.72	293.60	244.58
40	210.53	234.83	297.89	312.74	264.01
Average	196.59	225.56	276.03	295.67	
lsd		Spacing		levels	introduction
		15.12		15.12	30.24

Impact of Fertilization and Plant Spacing on Nutrient Runoff and Aquatic Ecosystems

Table 7 shows the application of NPK fertilizer at even more exaggerated levels of 120 and 160 kg ha⁻¹ was recognized to considerably heighten the levels of nitrates, phosphates, and ammonium that run off. Hence, the nearby water systems were at a much higher risk of eutrophication. When looked at together, the highest treatment levels, 160 kg ha⁻¹, were even more prone to the poorer outcomes that could result in algal blooms, dead zones, and fish kills. Conversely, the control treatment group, and also that of the lower fertilization levels of 80 kg ha⁻¹, had runoff water that was much more nutrient-poor, indicating a significantly lower risk of eutrophication. However, even at these

lower levels of fertilization, while it could be deemed marginal, there were subsisting levels of nitrates and phosphates that had been detected, and which could be considered to contribute a not insignificant amount to cumulative nutrient loading, at least at the ecosystem level. Plant spacing was also critical; wider spacing at 40 cm significantly reduced nutrient runoff due to better root development and nutrient uptake, while closer spacing of 20 cm increased runoff due to more root competition for water and due to more nutrients being contained in the runoff. There being more residual nutrients in the soil was a potential result of the more fertilization, mainly when rainfall occurred, and it could be established that phosphates and nitrates, which were likely to cause more eutrophication, were more mobile in the soil system.

Table 7: Comparison of fertilization levels and spacing on runoff risk and aquatic ecosystem impact.

Fertilizer Level (kg ha⁻¹)	Runoff Risk	Spacing (cm)	Impact on Aquatic Ecosystems	Soil Nutrient Residuals (N, P, K)
0 (Control)	Low	20	Minimal risk; no added nutrients	Minimal residuals, natural soil content
80	Moderate	30	Moderate risk; slight nutrient runoff	Moderate residuals
120	High	40	Increased risk of eutrophication, potential for algal blooms	Higher residuals, potential for leaching
160	Very High	50	Very high risk; significant potential for fish mortality and plant degradation	Maximum residuals, high nutrient mobility

Effect of NPK Fertilizer Levels and Plant Spacing on Plant Height of Groundnut

Figure 1 shows the line graph looks at the effect of differing tiers of NPK fertilizer (0 kg/ha, 80 kg/ha, 120 kg/ha, and 160 kg/ha) on the growth (height) of Groundnut (*Arachis hypogaea*) at three different plant spacing intervals (20 cm, 30 cm, and 40 cm). Overall, the graph shows an appreciation for NPK fertilizer and the corresponding growth of the organism across all spacing treatments (except 0 kg/ha). On average, the maximum plant growth/height was observed at 40 cm spacing, at or near the highest fertilizer level of 160 kg/ha.

The data show an unequivocal trend: wider spacing (40 cm) promotes the growth of all plants across all fertilizer rates, indicating that, although groundnuts need a fair spacing to prevent

resource competition, closer spacing actually adversely affects groundnut height. At a closer spacing of 20 cm, overall plant height was negatively influenced by the lower fertilizer rates, thus suggesting that a closer spacing may, in fact, be harmful to overall growth as it increases the competition for growth-limiting nutrients.

The interaction plot here shows the effect of the fertilizer rate (amount) and the spacing between plants on Groundnut growth. The findings indicate that determining the proper fertilizer rate and the correct spacing between plants is essential. Someone may apply these findings to other crops and to aquatic environments as well, where, similarly, provision of nutrients and spacing are vital for healthy growth.

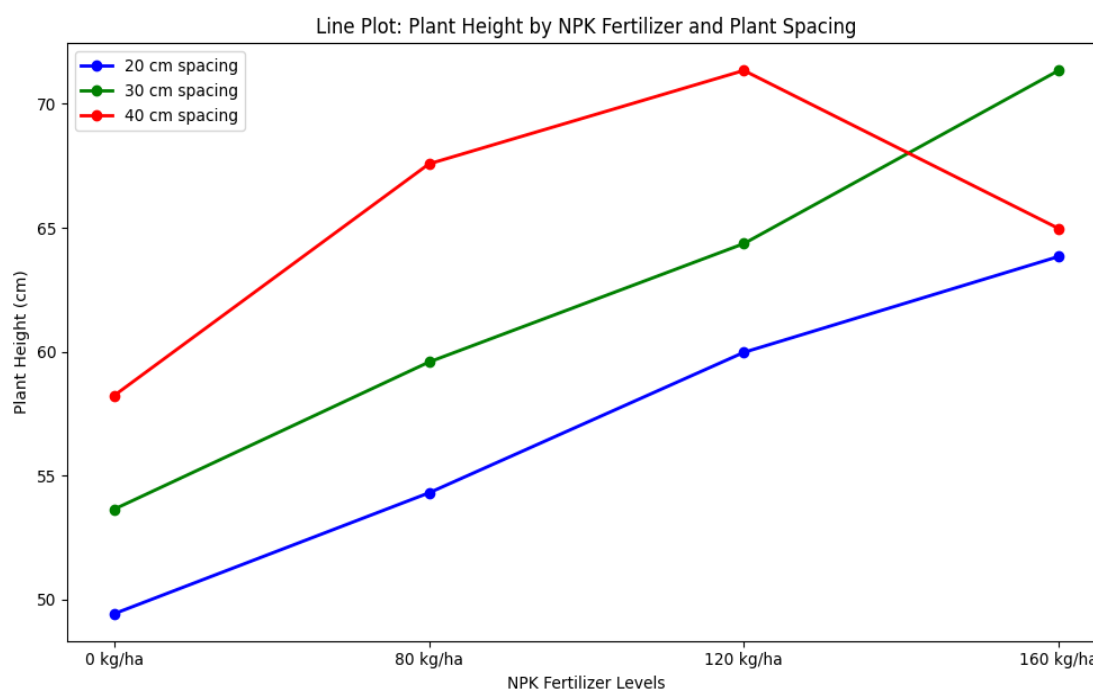


Figure 1: Interaction of NPK fertilizer levels and plant spacing on plant height of groundnut.

Effect of NPK Fertilizer Levels and Plant Spacing on Plant Height

The provided heat map in figure 2 shows the integration of height measurements (in centimeters) across different plant spacings (20 cm, 30 cm, and 40 cm) and fertilizer levels (0 kg/ha to 160 kg/ha). Each color indicates the height of the plant(s), with the lightest of colors indicating the plant(s) are shorter and the darker shades of color indicating the inverse of that. There is a tendency to suggest that, across all spacing categories, plant height increases with increasing fertilizer levels.

The combination of 40 cm spacing and 120 kg/ha or 160 kg/ha corresponds with an increased peak height of 71 cm, compared to all others. This is a sign that with increased fertilizer application, there

is an enhancement of the resources, light, nutrients, and water that are available to the plants vertically. The shortest plant height was recorded at the 20 cm spacing, which gradually increased with the fertilizer levels, as there was apparently increased competition for nutrients/water in the soil.

The heat map visualizes the interaction between fertilizer spacing and application and the resulting plant height increase, thus giving a broader perception of the integration of distance and height. It sketches out the optimal situations required to achieve the most significant plant height, therefore serving as a detailed guide on how to co-adjust nutrient management and plant spatial distribution on the site for maximal plant height growth efficiency.

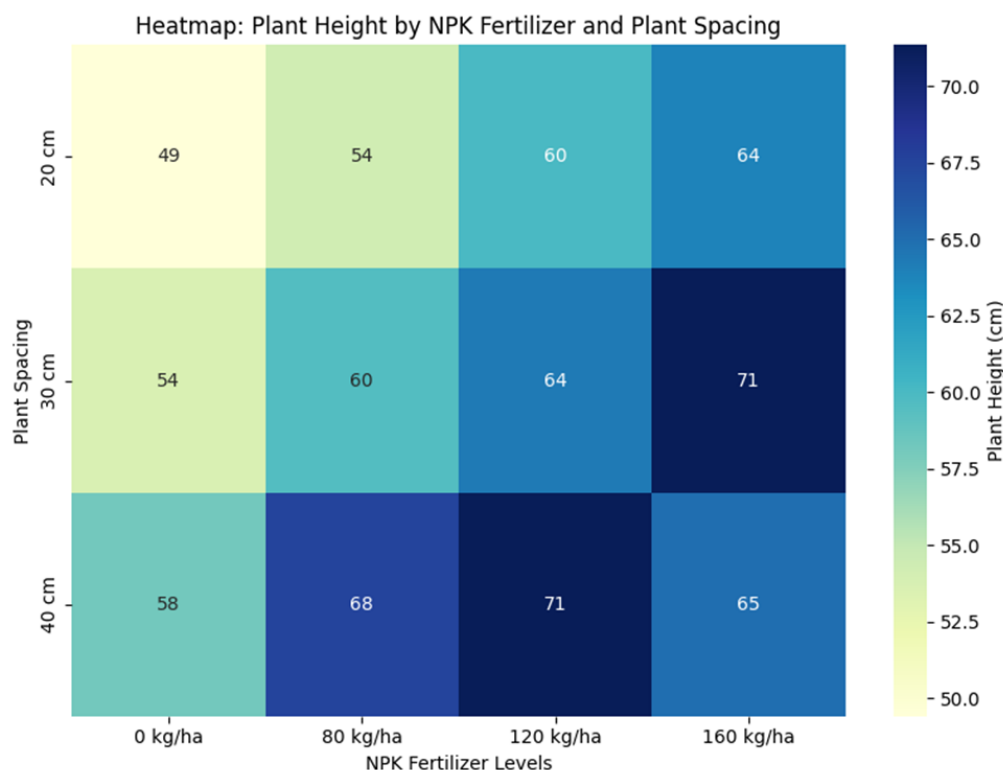


Figure 2: Heatmap showing the interaction effect of NPK fertilizer levels and plant spacing on plant height of groundnut.

Research Data Description

The data file Groundnut_RowSpacing_FertilizerLevels_UASD_2001_2002 contains information about the experimental plots of the Kharif 2001 season that were carried out in the field with great diligence at the Main Research Station, University of Agricultural Sciences, Dharwad, India, according to the research of Appanna S. Jambale (2002). The research is "an investigation into the influence of different row-spacings and fertilizer levels on the growth, yield, nutrient uptake, and economics of Groundnut (*Arachis hypogaea* L.)" genotype. Crop and fertilizer variants were replicated thrice in rainfed conditions. The experiment used a split-plot factorial design with three genotypes (GPBD-4, TGLPS-3, and JL-24), 2 row

spacings (30×10 cm and 45×10 cm), and two fertilizer levels (25:75:25 and 37.5:112.5:37.5 kg N:P₂O₅:K₂O ha⁻¹).

The observational data span from the growth data (including plant height, branch density, leaf area index, and dry mass; nodulation) through data on yield and yield parameters (pod, kernel and haulm yields; 100 kernel weight, shelling percent and harvest index) and quality data (oil and protein content) as well as nutrient (N, P, K) recovery and economic data (cost of cultivation, gross/net income, and benefit-cost ratio) all in conjunction with the environmental data (rainfall, temperature, relative humidity, and soil nutrient data). Thus, the data set allows us to quantitatively assess genotype responses to groundnut cultivation agronomy and characterize data achieved through modelling,

fertilizer and spacing optimization, and yield comparisons.

Experimental Parameters and Variables

The measured multiple parameters with the aim of assessing the effects of varying NPK compound fertilizers and plant spacing on the growth of the Groundnut. The parameters measured were, days to flowering which shows the growth duration of the Groundnut to the flowering stage; plant height (cm) which shows the overall vertical growth of the plant from the ground to the top; number of branches per plant which shows the vegetative vigor and the branching ability of the plant; leaf area (cm²) which shows the location of all the leaves that can influence photosynthesis of the plant; dry matter per plant (g) which shows the amount of all the plant's biomass the plant accumulated and after the plant was killed (dried) due to the loss of photosynthesis; and chlorophyll (mg/m²) which shows scanty (low) photosynthesis consequent to poor health of the plant and the low leaf chlorophyll. These parameters demonstrate the vegetative and photosynthetic response of the Groundnut to the varied concentration and spacing of fertilizers and the treated clay soil.

Comparative Analysis of Three Groundnut Genotypes with Respect to Yield, Nutritional Content, and Cost-Effectiveness

The grouped figures demonstrate how the three Pede beans GPBD-4, TGLPS-3,

and JL-24 all demonstrate variable levels of podule and kernel yield, nutrition assimilation, vegetative development, and profitability. Figure 3 most clearly shows how GPBD-4 has the most podules and kernels, TGLPS-3 and JL-24, in that order, podules and kernels, underscoring GPBD-4's superiority. Figure 4 shows oil and protein contents, where all three pods were the same, showing that all three had the same nutrition. Figure 5 shows how GPBD-4 assimilated the most Nitrogen (N), phosphorus (P), and potassium (K), showing that it assimilated the most nutrients and that GPBD-4 was better, of the three, assimilative of nutrients. Figure 6 shows revenue collection and the Benefit to Cost ratio, where GPBD-4 has the most revenues and, in the ratio, the most profit, showing that GPBD-4 was, of all branches, the most profitable. Figure 7 describes growth in the period and GPBD-4's vegetative period and, when compared to TGLPS-3 and JL-24, shows a historical record of GPBD-4's prominence.

Finally, figure 8 makes a comparison visualization between oil composition and pod yields, finding a positive correlation where the most oil-rich genotype had the highest pod yields. Overall, the results obtained display that GPBD-4 demonstrated superior productivity, nutrient use efficiency, and economic returns in comparison to the other genotypes, thus designating GPBD-4 as the most beneficial cultivar in the experimental evaluation.

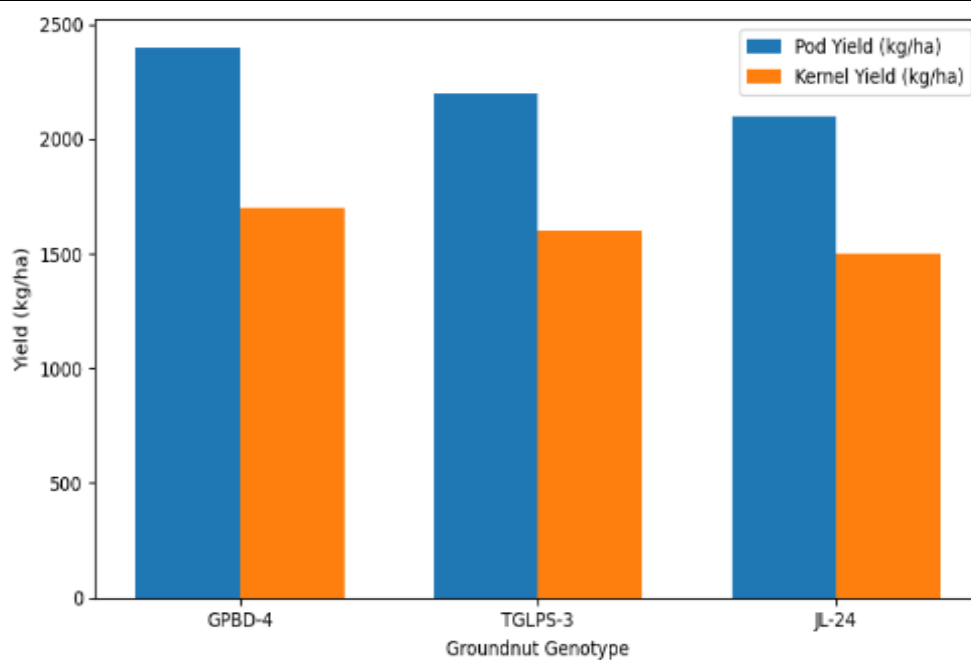


Figure 3: Effect of genotype on pod and kernel yield of groundnut.

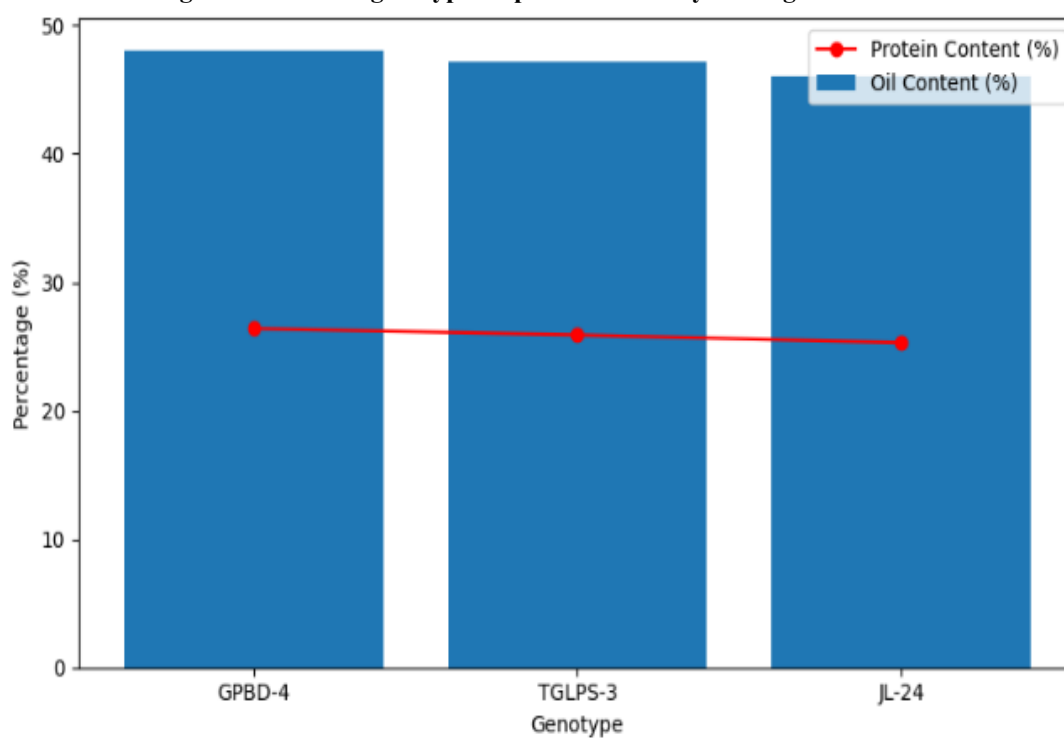


Figure 4: Oil and protein content of groundnut genotypes.

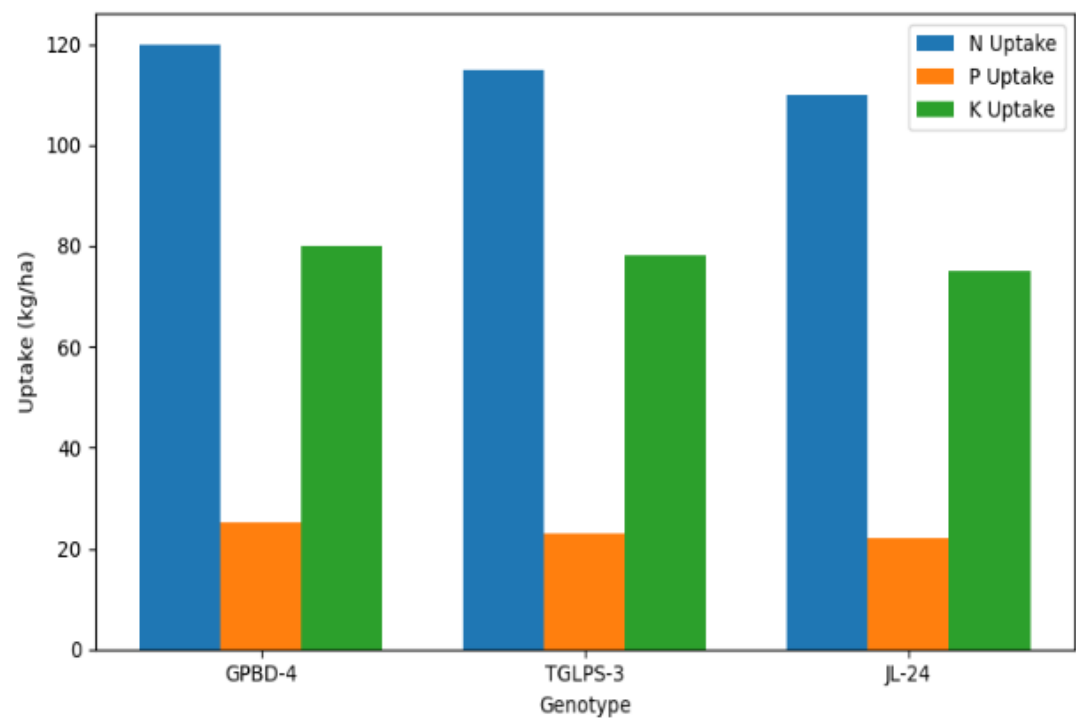


Figure 5: Nutrient uptake (N, P, K) by groundnut genotypes.

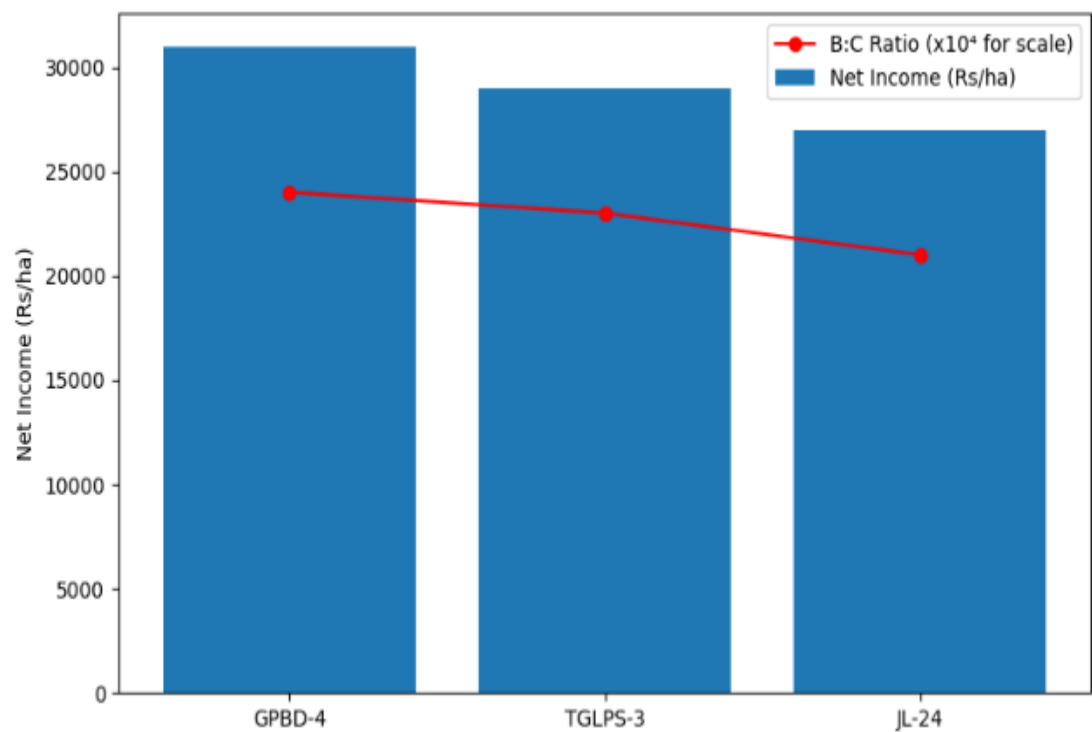


Figure 6: Economic returns and benefit: cost ratio of groundnut genotypes.

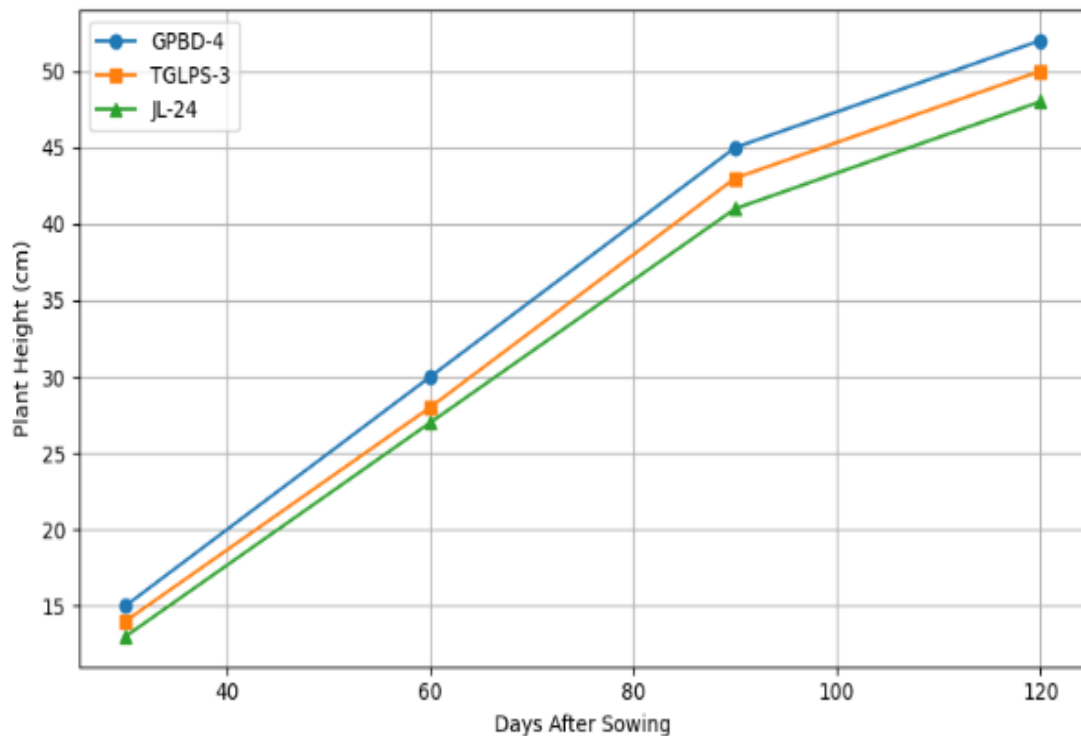


Figure 7: Growth trend of groundnut genotypes over time.

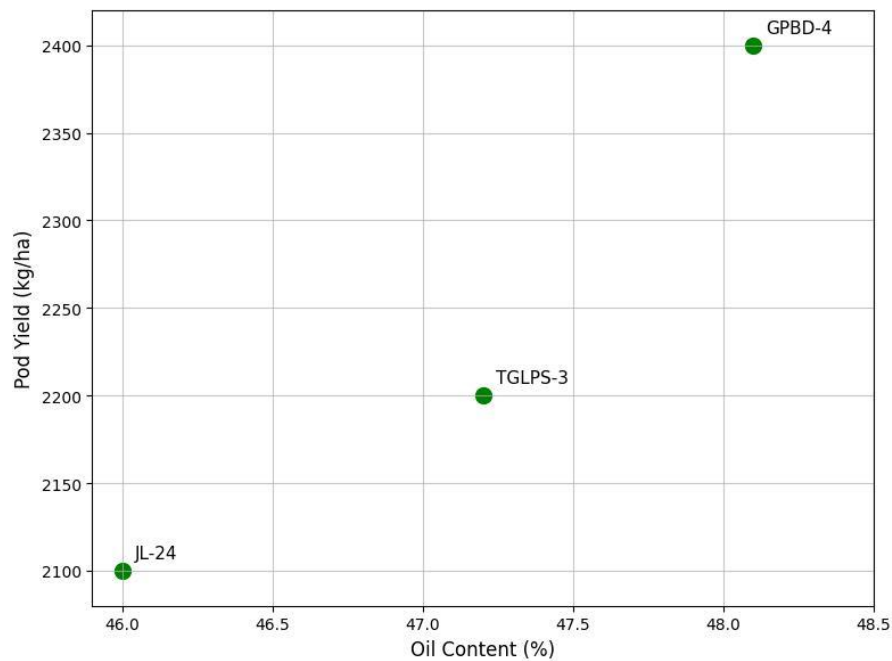


Figure 8: Relationship between oil content and pod yield of groundnut genotypes.

Conclusion

This study shows how NPK management can improve the growth and productivity of groundnuts (*Arachis hypogaea* L.) while also reducing the leaching of

essential nutrients. Continued leaching of nutrients can lead to eutrophication and other forms of biological pollution of water bodies. Adjustment of fertilizer and plant spacing reduced leaching and thus the environmental risks. The results show

that with care, fertilizers, and spacing of plants can be managed to enhance the productivity of groundnuts while reducing pollution of water bodies. Excess nutrients could be avoided, which protects water bodies. Of the genotypes, GPBD-4 was the most successful of the GPBD-4, TGLPS-3, and JL-24 varieties, excelling in growth rate, nutrient uptake, and efficiency, and more importantly, economic benefits. All three showed similarity in oil content and nutritional quality. GPBD-4 was superior in that nutrient uptake was higher, and consequently, growth was more rapid. GPBD-4 had the highest benefit-to-cost (B: C) ratio, economic viability of the three. Even with the viability, TGLPS-3 and JL-24 showed fewer economic returns compared to GPBD-4, making GPBD-4 the best variety in groundnut production with maximum productivity.

In summary, GPBD-4 is the most sustainable and profitable option for environmentally conscious farms, and the improvement of plant spacing and fertilizer calculations in crop yield helps ecologically harmful agricultural practices like pollution, degradation of water habitats, and loss of productive farmland to escape the bounds of unsustainable practices.

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