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Anbar Journal of Agricultural Sciences
(University of Anbar – College of Agriculture)

IMPACT OF NANO-CONVENTIONAL NPK FOLIAR APPLICATION AND ROW DISTANCE ON SOME GROWTH AND CHEMICAL TRAITS OF SUNFLOWER (HELIANTHUS ANNUUS L.)

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Article info

Received: 2024-05-02
Accepted: 2024-06-05
Published: 2024-12-31

DOI-Crossref:
10.32649/ajas.2024.148303.1196

Cite as:
Hashim, J. J., and Kakarash, S. A. (2024). Impact of nano-conventional npk foliar application and row distance on some growth and chemical traits of sunflower (helianthus annuus l.). Anbar Journal of Agricultural Sciences, 22(2): 1050-1069.

Abstract

Sunflower cultivars are widely cultivated for their oil-rich seeds and ornamental value, making them a staple crop in many agricultural regions. To enhance sunflower plant growth and maximize crop yield, companies and farmers commonly utilize fertilizers containing nitrogen, phosphorus, and potassium. This study explored the effect of different levels of NPK fertilizers, including nano-conventional NPK foliar applications at two stages 30 and 55 days after planting and two row distance (50, 70 cm) on the growth and chemical traits of sunflower using a factorial experimental design within a Randomized Complete Block Design (RCBD) with three replicates. Data collected was analyzed to determine the growth parameters and chemical components of the sunflower. The study found that the recommended soil NPK fertilizer significantly affected all the growth parameters which included the highest value for chlorophyll content (38.73 and 36.48 SPAD), leaf area (3984.43 and 3912.09 cm^2), dry matter (102.94 and 131.16 g $plant^{-1}$). Nano NPK foliar application at different levels showed positive and significant effects on chlorophyll content, leaf area, and dry matter weight. Nitrogen (N), phosphorus (P), and potassium (K) content in the leaves also increased with nano NPK application in 2022 at 1.679%, 0.432%, and 1.281%. The highest level of N, P and K were recorded from conventional NPK at 0.513%, 0.369%, and 0.462%, respectively in 2021. On the other hand, the lowest values for most of the studied traits were recorded for the control treatment.

Higher levels of conventional NPK foliar applications resulted in increased growth parameters and nutrient content. The impact of conventional NPK foliar applications was more pronounced compared to nano NPK application. Data collection at different stages revealed variations in growth and nutrient accumulation over time.

Keywords: Nano NPK and NPK fertilizer, Foliar spray, Row distance, Dry matter, NPK content.

تأثير الرش الورقي بالسماد NPK النانوي والتقليدي والمسافة بين الصفوف في بعض الصفات الخضرية والنوعية لنبات زهرة الشمس (.Helianthus annuus L)

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الخلاصة

تتم زراعة محصول زهرة الشمس على نطاق واسع لبذورها الغنية بالزيت وقيمتها الجمالية، مما يجعلها محصولاً أساسيًا في العديد من البلدان الزراعية. وبهدف تعزيز نمو نبات عباد الشمس وزيادة إنتاجيته، تستخدم الشركات والمزارعون الأسمدة الكيميائية التي تحتوي على كل من عناصر النيتروجين والفوسفور والبوتاسيوم. تهدف هذه الدراسة إلى معرفة تأثير مستويات مختلفة من السماد NPK النانوي والتقليدي التي تم تطبيقها، والرش الورقي على مرحلتين 30 و55 يوم بعد الزراعة وعلى مسافة بينية بين الصفوف 50، 70 سم. التصميم التجريبي: استخدمت الدراسة ترتيب التجارب العاملية الكاملة (RCBD) بثلاث مكررات.

ظهرت النقاط الرئيسية التالية من الدراسة: إن تطبيق الأسمدة NPK النانوية والأسمدة التقليدية اثر بشكل كبير على معايير النمو والمكونات الكيميائية لمحصول عباد الشمس. أظهر تطبيق الرش بالسماد النانوي NPK بمستويات مختلفة تأثيرات إيجابية على محتوى الكلوروفيل ومساحة الورقة ووزن المادة الجافة مع زيادة مستويات تركيز السماد النانوي NPK، كما زاد محتوى النيتروجين والفوسفور والبوتاسيوم في الأوراق مع معاملة الرش بالسماد النانوي NPK أدت المستويات العالية من الرش الورقي بـ NPK التقليدي إلى زيادة معايير النمو والمادة

الجافة مقارنة بالمستويات المنخفضة. كان تأثير الرش الورقي التقليدي بـ NPK أكثر وضوحًا مقارنةً بتطبيق النانو NPK بينما لم تؤثر المسافات بين الصفوف معنويا على مؤشرات النمو والمحتوى المادة الجافة لنبات زهرة الشمس. كشف جمع البيانات في مراحل مختلفة عن اختلافات في النمو وتراكم العناصر الغذائية مع مرور الوقت.

كلمات مفتاحية: نانو NPK، الرش الورقي، المسافة بين الصفوف، المادة الجافة، محتوى NPK في الاوراق.

Introduction

Sunflower (*Helianthus annuus* L.) is a widely cultivated and versatile oil-producing crop, and the fourth most extensively grown oil seed crop globally in terms of land area. It is a significant supplier of edible vegetable oils on a global scale because of its abundant oil content 45-55% and high levels of non-saturated fatty acids 60% (2). Sunflower oil contains varying levels of essential vitamins such as K, E, D, and A. Sunflower seed cakes are a valuable source of protein and carbohydrate at 30-35% and 18-19%, respectively making them an important component in animal and poultry feed formulations (35).

Seed yield, oil and protein content determine sunflower productivity and fluctuates widely depending on various factors including environmental conditions and agronomic practices such as sun radiation, temperature, rainfall (1, 12, 21, 29 and 32), and plant density as well as planting patterns and nutrition (2, 6 and 37).

The amount of fertilizer applied for sunflower cultivation should be based on soil type, growth stage, and environmental conditions. Excessive fertilization can lead to nutrient burn resulting in stunted growths and poor yields while proper fertilizer and better environmental conditions enhance growth and yields and improves nutrient absorption (20).

Foliar fertilizer is a technique used to ensure that the nutrients reach the active parts of the plant, preventing nutrient fixation in the soil (24). Its application enhances nutrient absorption by plants compared to other methods, ultimately improving fertilizer efficiency. Moreover, it is believed that nanotechnology could revolutionize agricultural production through the use of nano-formulation fertilizers.

Materials that are reduced to a nano-scale exhibit distinct characteristics that can lead to innovative applications. Nanoparticles possess high surface-area-to-volume ratios, facilitating enhanced interaction and synchronization of nutrient release with crop requirements through the mechanisms utilized in nano-fertilizers. (3 and 36) reported that compared to traditional fertilizers, nano fertilizers enhance growth parameters such as leaf areas, dry matter production, chlorophyll content, rate of photosynthesis which leads to higher production and translocation of photosynthesis at different parts of the plant. Furthermore, 8 showed that utilizing 100% nano-N fertilizer resulted in notable growth enhancements in sunflower plants.

On the other hand, plant density impacts the growth characteristics and productivity of sunflowers by optimizing the leaf area index. Such optimization aims to mitigate inter-plant competition by facilitating increased light penetration into the plant canopies, thus promoting an augmented photosynthesis process and rate which, in turn, results in a higher yield per unit area. Furthermore, it proves crucial in determining the most favorable aboveground conditions that enable plants to access essential environmental growth factors, facilitate the accumulation and production of dry matter, and ultimately maximize both seed yield and quality (10). (19) stated that plant characteristics such as growth and yield as well as the properties of sunflower plants are noticeably affected by variations in plant densities. They observed that the greatest averages for leaf area was achieved at the lowest plant density of 45,000 plants ha^{-1}. Little or no studies have been conducted on the influence of nano NPK on some growth and chemical traits of sunflower crops. As such, this research sought to fill that gap by investigating the effects of nano and conventional NPK foliar applications and row spacing on those characteristics in sunflowers.

Materials and Methods

This study was conducted at the Grdarasha Research Station, College of Agricultural Engineering Sciences, University of Salahaddin-Erbil in the Erbil Governorate during the two growing seasons of autumn 2021 and spring 2022. It investigated the effects of nano and conventional NPK foliar applications on some growth parameters and the N, P, and K chemical components of sunflower crops through different row spacing. A factorial experiment was conducted using Randomized Complete Block Design (RCBD) with three replicates. The research involved each treatment being represented by a combination of three factor levels. The first factor included eight treatments of NPK fertilizer as follow: F1= control (no fertilizer), F2 = NPK fertilizer of soil application with 240 kg ha^{-1} (according to standard recommendation), F3 = 100 ppm, F4 = 150 ppm, and F5= 200 ppm for foliar nano NPK, while the conventional NPK foliar application was: F6= 300 ppm, F7= 500 ppm, and F8 = 700 ppm. The second factor was two distances between the rows (50 and 70 cm), with 30 cm distance between plants. The third factor included data collection at three stages: S1= control (before first spray), S2 = after 10 days from first spraying and 30 days after planting, S3= after 10 days from second spraying and 55 days after planting.

Each replicate comprised 16 experimental units with each covering 3×2.5 m^2 and the distance between experimental units and blocks were 75 and 100 cm, respectively. In addition, the amount of irrigation water was standardized across all treatments to mitigate the impact of variations in their volumes. Sunflower seeds were sown on 9 July 2021 and 10 March 2022, then harvested on 10 October 2021 and 4 July 2022, for both seasons, respectively. Analysis of chemical and physical properties of the experimental soils were carried out at 0 to 30 cm depths. The soil was clay loam in texture, the pH was 7.43, organic matter was 0.86%, Ec 0.8. dS/m^{-1}, available nitrogen was 0.09 %, and available phosphorus and potassium were 9.5 and 240 ppm, respectively.

Five plants were randomly selected from each treatment to measure the traits:

1. Chlorophyll content: determined by using SPAD apparatus (25).
2. Total leaf area per plant (cm^2): calculated using Image J software (14).
3. Dry matter (g $plant^{-1}$): determined after drying plants at 70°C for 72 hours till constant weight (18).
4. Nitrogen Content %: total nitrogen was determined in sunflower leaf using the micro-Kjeldahl apparatus according to (11).

5. Phosphorus Content %: determined according to the colorimetric method (V- 1100 digital) as described by Gupta 2000 (16) using spectrophotometer at 410 nm.
6. Potassium content %: total content measured by the flame photometric (BWB Technologies) method described by (10).

Statistical Analysis: The data collected were analyzed using analysis of variance (ANOVA) in randomized complete block design (RCBD) utilizing SAS version 9.1 2003, (13) was used for means comparison at 0.01 and 0.05 levels of significance for the field and lab data. Finally, the statistical charts and spider charts were drawn using excel software to visualize the results.

Results and Discussion

Effect of nano-conventional NPK foliar applications and row distance on chlorophyll content (SPAD): The data presented in Fig.1 depict the SPAD value as an index of chlorophyll content. The highest values were recorded from the application of soil NPK fertilizer (F2) treatment, with SPAD values of 38.73 and 36.48 during both growing seasons. Conversely, the F1 treatment produced the lowest values of 35.68 and 34.13 SPAD for both seasons, respectively. These results emphasize the importance of macronutrients such as nitrogen, phosphorus, and potassium in enhancing the quality and productivity of crops (31). The findings also support the work of (28), who demonstrated that the application of soil NPK fertilizer recorded the highest value of chlorophyll content compared to the control treatment. The research also highlighted the role of growth stages in influencing chlorophyll content. Spraying NPK fertilizer at the S3 stage yielded the highest chlorophyll content of 38.75 and 36.27 SPAD, surpassing the values obtained from the first (S1) and second (S2) stages during both growing seasons 2021 and 2022, respectively. This suggests that the timing of fertilizer application is crucial for optimizing chlorophyll content and, consequently, crop health. On the other hand, row spacing did not significantly affect chlorophyll content.

While both factor interactions between different NPK fertilizer types and stages of application as well as a row spacing significantly affected chlorophyll content, the highest SPAD values of 39.48 and 36.86, 41.10 and 37.92, and 38.80 and 36.26 were recorded for the combination treatment of F2 x D1, F2 x S1 and F2 x S3, and D1 x S3 and D2 x S3 for both growing seasons, respectively. Meanwhile, the lowest values were found from interaction treatments of control with other treatments such as D1 and S2. The study revealed substantial differences in chlorophyll content among the various treatments with values ranging from 32.57 to 42.33 and 32.30 to 38.50 SPAD. The lowest values were associated with the treatment combination of F3 x D2 x S2 and F1 x S2 x D2, while the highest were observed for F2 x S1 x D1 and F2 x S3 x D1 for both growing seasons, respectively.

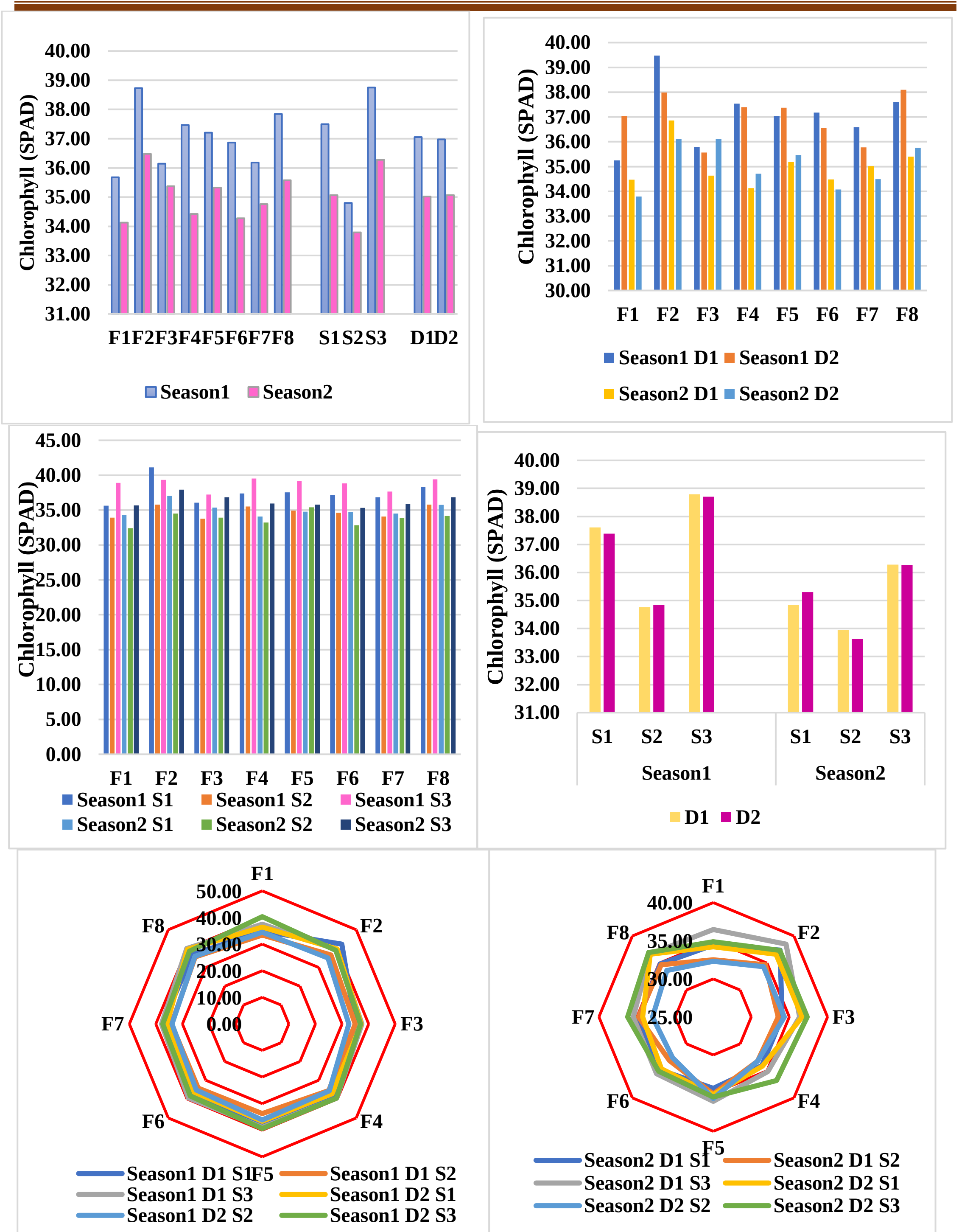

Figure 1: Effect of NPK fertilizer, stage of application, row spacing and their interactions on chlorophyll content (SPAD).

Effect of nano-conventional NPK foliar application and row distance on total leaf area per plant (LA) cm^2: Leaf area is an important characteristic in sunflower cultivation that directly affects plant growth and overall yield. Understanding the factors that influence leaf area can help farmers optimize fertilizer application and row spacing to enhance sunflower production (12). The results revealed that different fertilizer treatments had a significant effect on leaf area in sunflowers.

Fig. 2 shows that the highest leaf areas at 3984.43 and 3912.09 cm^2 were obtained from the application of soil NPK fertilizer (F2). This was followed by conventional

NPK with a concentration of 700 ppm (F8) and nano NPK with a concentration of 200 ppm (F5). On the other hand, the control treatment (F1) recorded the lowest leaf areas of 3154.54 and 2568.49 cm^2 in both growing seasons. The higher leaf areas can be attributed to the effect of nitrogen in the fertilizers, which promotes growth and influences the physiological and metabolic processes of sunflowers (27). Similarly, (28) reported that different types of NPK fertilizer had a significant effect on leaf area although it was not significantly affected by phosphorus levels, as indicated by (30 and 33). Also, the results indicated that spraying stage had a significant effect on leaf area, the highest values recorded for treatment S3 (6939.46 and 5821.01 cm^2) and the lowest for treatment S1 during both years. Similarly, treatment D2 exhibited the highest leaf area while the lowest was for D1 in 2021-2022. The increase in leaf area can be attributed to favorable environmental conditions that resulted in less competition between plants due to wider spacing. This led to increased light penetration within the sunflower canopies, thereby enhancing the rate of assimilation (22). These findings emphasize the importance of considering environmental conditions and spacing when evaluating the impact of fertilizer application on leaf area.

Among all possible two-factors interactions, F8 x D2 and F5 x D2 exhibited the highest leaf areas, which were 4309.67 and 4220.62 cm^2. Conversely, the lowest leaf areas were recorded from treatment F1 x D1 during both growing seasons, measuring 2763.78 and 2436.62 cm^2, respectively. Additionally, the highest leaf areas, at 7617.00 and 7172.92 cm^2 and 7477.25 and 6598.156 cm^2, were obtained from the interaction treatments of F2 x S3 and D2 x S3 in both seasons, respectively. These results support the findings of (22), who observed significant influences of plant spacing, nitrogen fertilization levels, and their interactions on leaf area in sunflowers.

Fig. 2 also shows that the interaction between NPK fertilizer types, stages of application, and row spacing had a significant impact on leaf area. The leaf area varied significantly depending on the treatment combinations that ranged between 1138.33 and 647.42 cm^2 under the treatment combination of F1 x D1 x S1 and F1 x S1 x D2 to 8356.333 and 8825.230 cm^2 for the treatment combination of F8 x D2 x S3 and F5 x D2 x S3. This variation can be attributed to the individual effects of the studied factors, which created different conditions for plant growth.

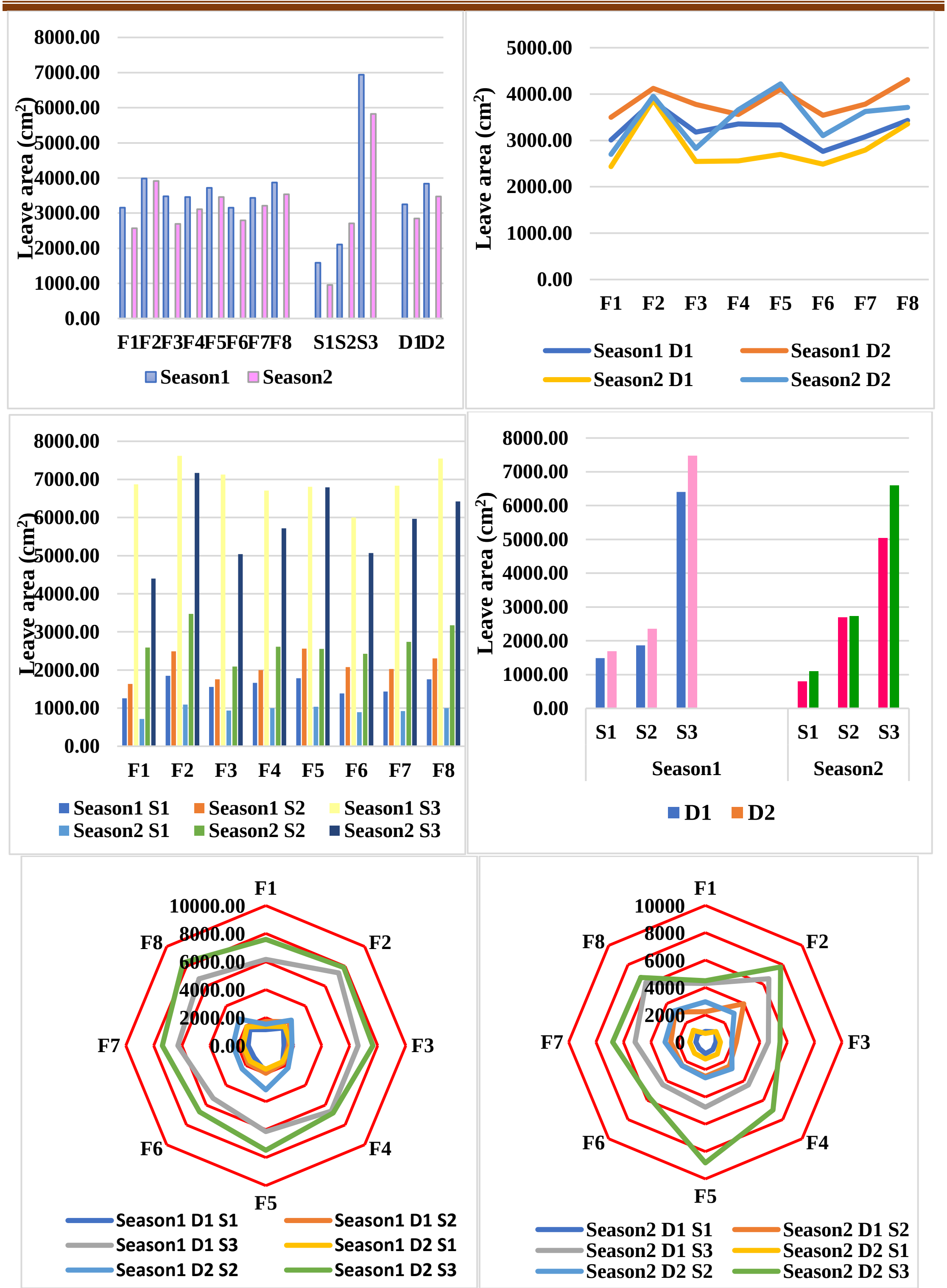

Figure 2: Effect of NPK fertilizer, stage of application, row spacing and their interactions on leaf area (cm^2).

Effect of nano-conventional NPK foliar applications and row space on dry matter weight (g $plant^{-1}$): The impact of NPK fertilizer types on the dry matter weight of sunflower hybrid is statistically significant at a p-value of 0.05. As seen in Fig. 3, fertilizer application resulted in an increase in dry matter weight compared to untreated plots. The fertilizer treatments of F2, F5 and F8 improved dry mater weight compared with the control (F1) with the highest values at 102.94 and 131.16 g $plant^{-1}$ from F2 treatment and the lowest at 76.36 and 84.98 g plant^{-1} from F1 during both seasons, respectively. (8) demonstrated that dry matter accumulation increased significantly with higher NPK levels during both 2000 and 2001. These results agree with (26) who also point out the benefit of foliar NPK applications in achieving maximum dry matter weight. These studies show that NPK fertilizers and their appropriate application contribute to increased dry matter weight in sunflower hybrid plants. Further, the stages of fertilizer application play a vital role in increasing the dry matter weight of sunflower hybrid. On average, the dry matter weight recorded the highest values at 165.28 and 243.06 g plant^{-1} during the S3 stages after second season while the first stages (S1) recorded the lowest values at 28.32 and 10.00 g plant^{-1}. This may be attributed to the increase in plant surface area at the later growth stages. Interestingly, row spacing did not have a statistically significant impact on dry matter weight.

However, the interactions between NPK fertilizer types and row spacing (F x D) demonstrated a significant influence on plant dry matter weight, with the highest values of 111.11 and 134.23 g plant^{-1} observed from F2 x D1 and F2 x D2, while the lowest 72.06 and 79.45 were registered for the F3 x D1 and F1 x D1 for both seasons, respectively. Similar results align with the conclusion by (7) who demonstrated that total dry matter was significant between different plant populations and nitrogen rates during the 2012 and 2013 growing seasons. In addition, it was noted that the dry matter was affected by the interaction between fertilizer treatment and stages of application. The highest values of 189.92 and 291.50 g plant^{-1} were obtained from the interaction treatments F5 x S3 and F2 x S3 while the lowest 26.58 and 7.50 g plant^{-1} were from the combination treatment of F1 x S1 during 2021 and 2022, respectively. On the other hand, the application of fertilizers during the S3 stages of the growing season resulted in higher dry matter weight values, possibly due to the impact on leaf area and subsequent increase in photosynthesis rates. Furthermore, the weight of dry matter was significantly affected by the treatment combinations between D x S, with the maximum dry matter of 173.13 and 248.88 g plant^{-1} attained from D1 x S3 and D2 x S3 while the minimum dry weight for plants at 27.96 and 9.25 g plant^{-1} were from the D1 x S1 treatment combination for both growing seasons. This indicates the importance of optimizing these factors for maximizing crop productivity. Among the three factor interactions, the treatment combination of NPK fertilizer types, row spacing, and stages of application (F x D x S) also had a significant effect on dry matter weight. The highest values 211.83 and 298.33 g plant^{-1} were recorded from the treatment combinations of F5 x D1 x S3 and F2 x D2 x S3, while the lowest values 26.67 and 6.67 g plant^{-1} were obtained from F1 x D1 x S1 in 2021 and 2022, respectively.

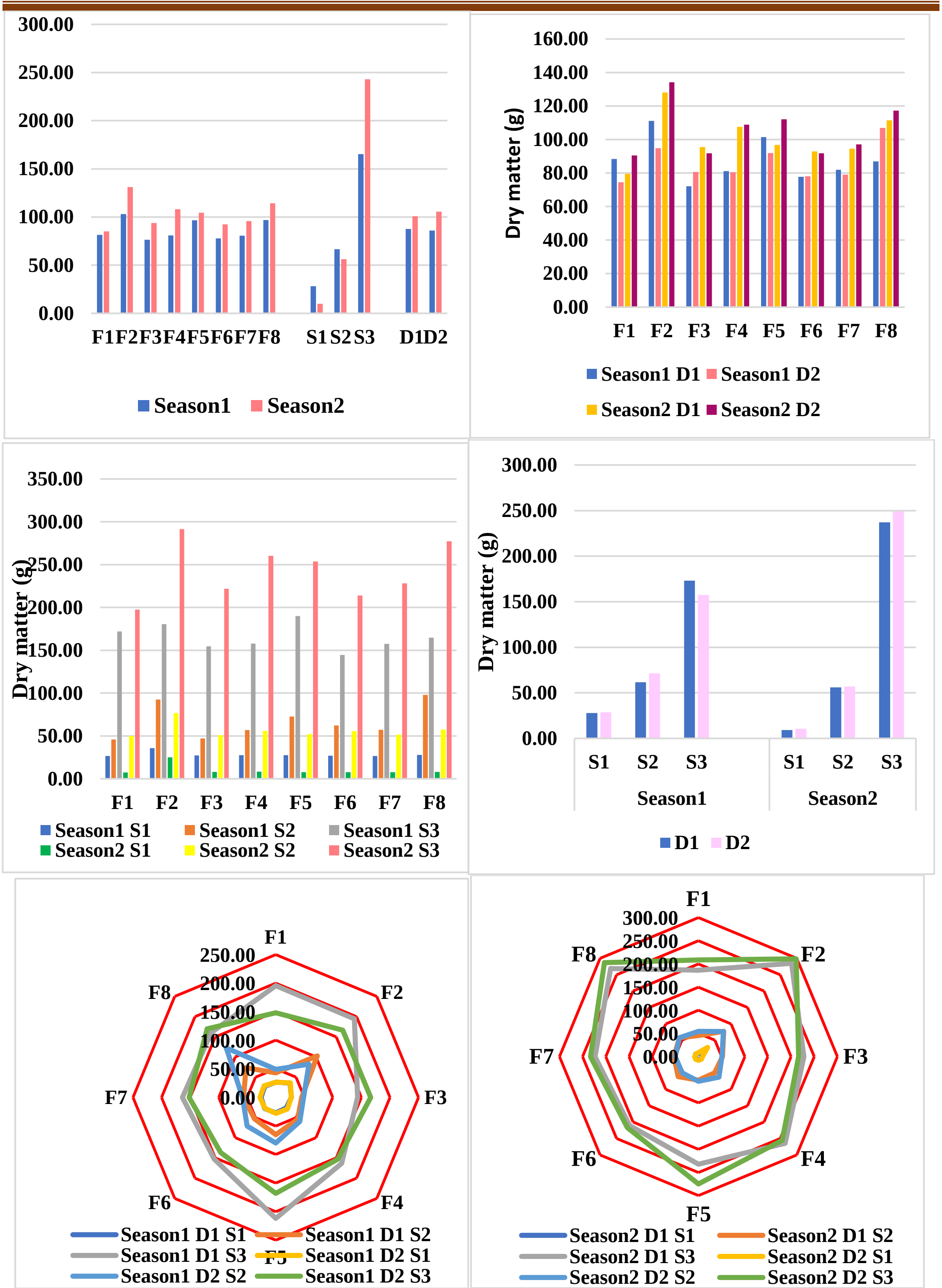

Figure 3: Effect of NPK fertilizer, stage of application, row spacing and their interactions on dry matter (g plant^{-1}).

Effect of nano-conventional NPK foliar application and row distance on nitrogen content (%) in leaves: Fig. 4 illustrates the significant variations in nitrogen concentration (%) among different types of NPK fertilizer. The highest nitrogen values 0.513 and 1.679 % were recorded with treatments F8 and F7 respectively, while the lowest 0.349 and 1.377 % were for the F1 and F3 control treatments in the respective 2021 and 2022 study years. This is in alignment with previous research highlighting the positive impact of nano NPK foliar application on nitrogen percentage in sunflower crops (9, 17 and 26). Further, the stage of application (S) and different spaces between rows (D) significantly influenced nitrogen content with the highest values recorded from S3 and D2 and the lowest from S1 and D1 for both growing seasons. Statistical analysis of the data reveals that the combination of NPK fertilizer types and a row spacing had a remarkable effect on nitrogen content in leaves. The highest values 0.552 and 1.843 % were obtained from F8 x D2 and F7 x D2 treatment combinations while the lowest were obtained in F1 x D1 and F5 x D1 of 0.333% and 1.222 % in both growing seasons, respectively. The interaction between NPK fertilizer and stages of application (F x S) also significantly affected nitrogen content. The highest values 0.665 and 1.763 % were achieved from the F8 x S3 treatment and the lowest nitrogen content 0.305 and 0.903 % were recorded from the treatment combinations of F1 x S1 and F3 x S1, respectively.

Similarly, it was noted that nitrogen content was affected by the interaction between row spacing and stage of application. Notably, the highest nitrogen values were recorded under the interactions D2 x S3 and D2 x S2 with values of 0.611% and 1.679 %, while the lowest N% was obtained in treatment combination D1 x S1 (0.315 and 1.343 %) respectively, in both 2021 and 2022. Among the three-factor interactions, the study found a significant effect on this trait. The highest nitrogen contents 0.720 and 2.005% were recorded from combination treatments of F8 x D2 x S3 and F7 x D2 x S2, while the lowest values 0.300 and 0.535 % were derived from F1 x D1 x S1 and F3 x D1 x S1. This highlights the complex relationships between multiple factors and their influence on nitrogen availability.

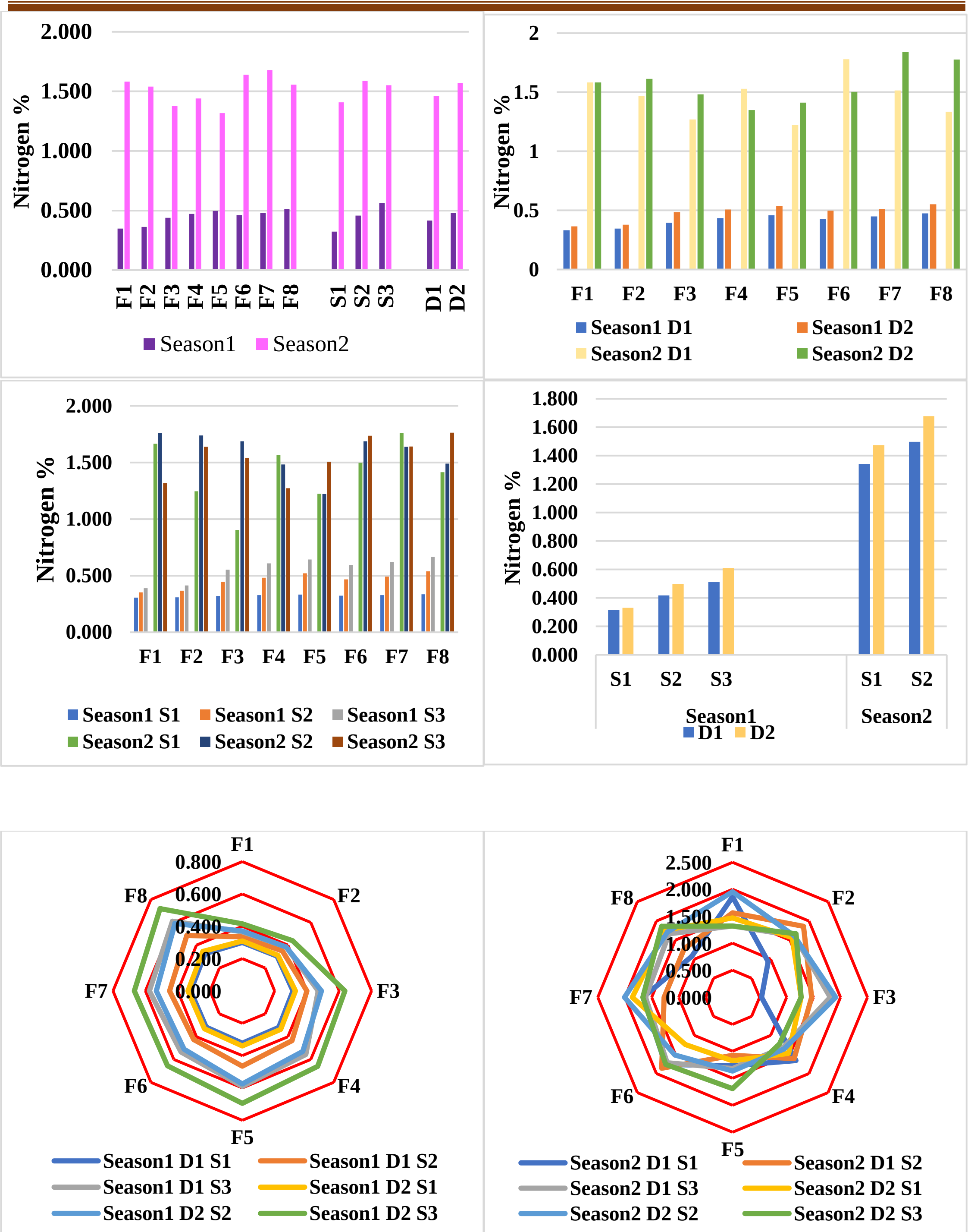

Figure 4: Effect of NPK fertilizer, stage of application, row spacing and their interactions on nitrogen content (%).

Effect of nano-conventional NPK foliar application and row distance on phosphorus content (%) in leaves: Phosphorus is a crucial nutrient for plant growth and development and plays a vital role in various metabolic processes essential for maximizing crop productivity and yield (34). Based on the data presented in Fig. 5, the highest mean values of phosphorus were observed in treatments F8 and F5, with percentages of 0.369% and 0.432%, while treatments F1 and F8 exhibited the lowest mean values 0.201 and 0.314 % during 2021 and 2022, respectively. (4 and 9) found that foliar applications of nano NPK significantly increased phosphorus content in sunflower leaves. An analysis of growth stages (Fig 5) reveals that stage S3 constantly produced the highest phosphorus content, with percentages of 0.355 and 0.435 in both seasons. For row spacing, 70 cm spacings (D2) led to the highest values of phosphorus contents 0.336 and 0.377 %, whereas 50 cm (D1) resulted in the lowest percentage at 0.266 and 0.339 in 2021 and 2022, respectively.

In regard to the interactions between NPK fertilizer and row spacing, it was noted that phosphorus content varied significantly among them. The lowest values were recorded with treatment combinations of F1 x D1 and F8 x D1, ranging between 0.187% to 0.303% in 2021 and 2022, respectively. Conversely, the highest values were observed in both combination of F8 x D2 and F5 x D2, with values ranging from 0.412% to 0.454% in the same periods. On the other hand, the two-factor interactions (F x S) were also found to be significant. Treatment combination F8 x S3, F5 x S3 produced phosphorus contents of 0.460% and 0.564%, while F1 x S1, F2 x S1 recorded the lowest percentage 0.166 and 0.180 % in 2021 and 2022, respectively. Finally, the interaction among all the three studied factors significantly influenced the concentrations of phosphorus. Maximum percentages of 0.525% and 0.626 % were obtained in the treatments F8 x D2 x S3 and F5 x D2 x S3, while the minimum percentage 0.162 and 0.142 % were recorded in the treatment combinations of F1 x D1 x S1 and F2 x D1 x S1, during both growing seasons.

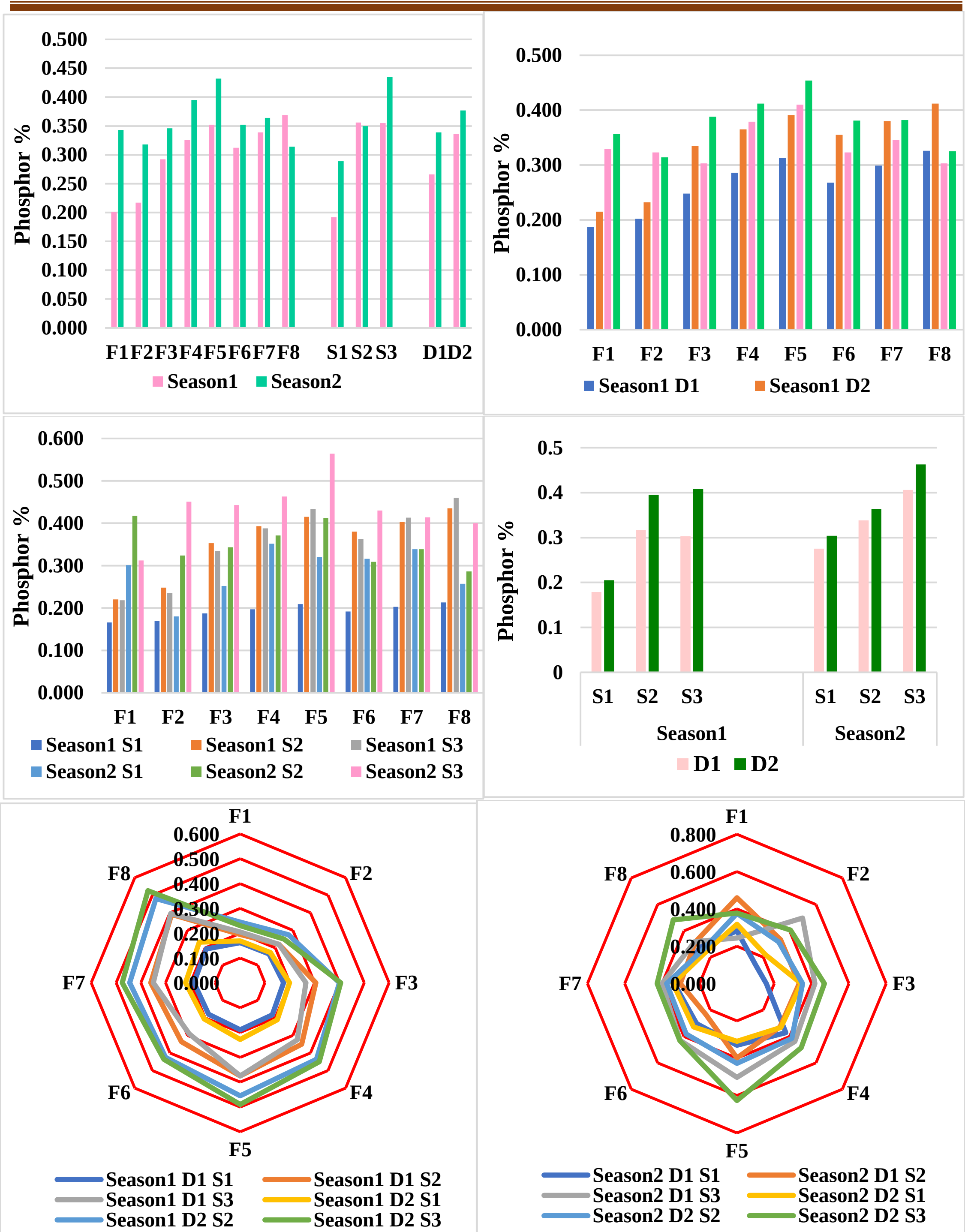

Figure 5: Effect of NPK fertilizer, stage of application, row spacing and their interactions on phosphorus content (%).

Effect of nano-conventional NPK foliar application and row distance on potassium content (%) in leaves: Potassium is an essential macronutrient and has a critical role in various physiological processes in sunflower crops (34). Fig. 6 presents the potassium concentrations in leaves as influenced by NPK fertilizer types, stages of application, a row spacing and all possible interactions among them. It appears that F8 and F5 treatments significantly yielded the highest mean values of potassium concentration at 0.462% and 1.281% during both seasons. These results agree with (4 and 23) who reported that the potassium content in leaves were significantly affected by different types of NPK fertilizer with the highest value 2.66% recorded from nano (NPK) compared to control treatment. Furthermore, potassium concentrations in sunflower leaves were observed to vary during different foliar stages of growth. S3 stage had the highest potassium content 0.514 and 1.225 %, while S1 exhibited had the lowest at 0.282% and 1.189% in years 2021 and 2022, respectively. As for row spacing, the highest mean values during both seasons 0.451 and 1.246 % were recorded from the D2 row spacing of 70 cm while the D1 (50 cm) recorded 0.370% and 1.170%.

The interaction between NPK fertilizer types and row spacing further influenced potassium concentrations in sunflower leaves. The F5 x D2 and F4 x D1 interaction treatments produced the highest potassium content at 0.526% and 1.332%. Conversely, F1 x D1 and F3 x D1 treatments had the lowest at 0.291% and 1.025% in both seasons, respectively. Additionally, the maximum rate of potassium content was observed from the F8 x S3 and F5 x S1 treatments with values of 0.611% and 1.360% in both seasons respectively. Moreover, a significant difference in potassium content was noted for growth stages and row spacing. The interaction treatment D2 x S3 and D2 x S2 produced maximum potassium percentages of 0.577% and 1.261%, whilst the minimum at 0.276% and 1.130% were obtained in the D1 x S1 treatment combination during 2021 and 2022, respectively. There were also significant differences among the three factor interactions of types of NPK fertilizer, stages of application and row spacing on potassium content. The highest values at 0.705% and 1.410% were recorded from interaction treatments F8 x D2 x S3 and F5 x D1 x S1, while interaction treatments F1 x D1 x S1 and F2 x D1 x S1 resulted in the lowest potassium contents at 0.252% and 0.625% during both seasons of 2021 and 2022, respectively.

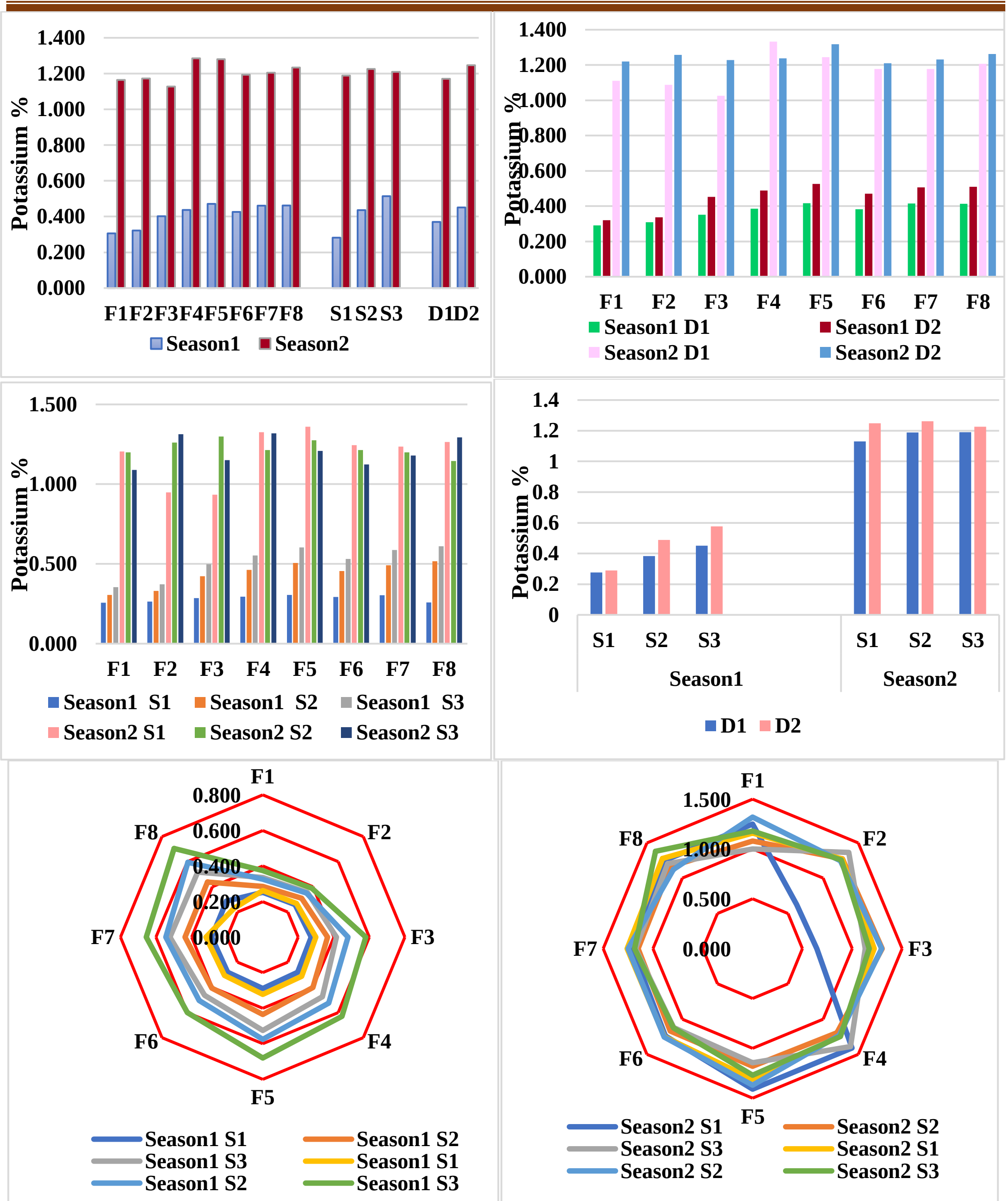

Figure 6: Effect of NPK fertilizer, stage of application, row spacing and their interactions on potassium content (%).

Conclusions

Proper nutrient management is essential for successful cultivation of the sunflower crop. This study demonstrated that both nano and conventional NPK foliar applications enhance sunflower growth parameters and nutrient content. However, conventional NPK foliar applications had a more pronounced effect. Farmers and researchers can utilize these findings to optimize fertilizer application strategies and achieve higher sunflower quality.

Supplementary Materials:

No Supplementary Materials.

Author Contributions:

Author 1: methodology, writing, original draft preparation. Authors 1 and 2: writing, review and editing. Both authors have read and agreed to the published version of the manuscript.

Funding:

This research received no external funding.

Institutional Review Board Statement:

The study was conducted in accordance with the protocol authorized by the College of Agricultural Engineering Sciences, Head of the Field Crops and Medicinal Plant Dept., Scientific Committee, Kurdistan region, Iraq.

Informed Consent Statement:

No Informed Consent Statement.

Data Availability Statement:

No Data Availability Statement.

Conflicts of Interest:

The authors declare no conflict of interest.

Acknowledgments:

The authors thank the Dean of College and the Head of the Field Crops and Medicinal Plants Dept., College of Agricultural Engineering Sciences, University of Salahaddin, Iraq. Special thanks to Dr. Akram and Ms. Bahar for their valuable help and technical assistance in conducting this research.

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