RESEARCH ARTICLE OPEN ACCESS

ASWAN JOURNAL OF AGRICULTURAL AND BIOLOGICAL SCIENCES

Aswan University, Faculty of Agriculture and Natural Resources, Egypt

10.21608/AJABS.2025.398548.1006

Impact of planting methods and foliar zinc oxide nanoparticles on sunflower growth and oil fatty acid composition

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10.21608/ajabs.2025.398548.1006

Received: 07/07/2025

Revised: 23/07/2025

Accepted: 04/08/2025

Published: 01/10/2025

Abstract

This study was conducted over two successive summer seasons (2020 and 2021), at the Agronomy Experimental Farm, Faculty of Agriculture, Assiut University, Egypt. The objective was to evaluate the effects of different planting methods and foliar applications of zinc oxide nanoparticles on key physiological traits of the sunflower cultivar Giza 102. A randomized complete block design (RCBD) arranged in a strip plot format with three replications was used. Planting methods beds, ridges, and flat drills were assigned to vertical strips, while zinc oxide nanoparticle concentrations (0, 50, 100, 150, 200, and 250 ppm) were assigned to the horizontal strips. The results indicated that both planting methods nanoparticle concentrations, and their interaction, significantly or highly significantly affected most of the measured traits. These indicated leaf area index (LAI), leaf area duration, total chlorophyll content, net assimilation rate, crop growth rate, and relative growth rate. The highest net assimilation rates, 51.89 and 37.03 g/m²/week in the first and second seasons, respectively, were recorded when sunflower was grown on ridges or beds and treated with 150 ppm zinc oxide nanoparticles topically. Moreover, this treatment improved oil quality by increasing the content of unsaturated fatty acids, particularly oleic and linoleic acids.

Keywords: Planting Methods; Zinc; Physiological.

Introduction

Sunflower (*Helianthus annuus L.*), a member of the Asteraceae family, is one of the most important oilseeds crops globally due to its high oil yield and valuable nutritional properties. While oil content and seed composition can vary depending on genotype and environmental conditions; sunflower seeds typically contain 45–50% oil (Pereyra-Irujo et al., 2009). Sunflower oil is widely preferred for human consumption because of its high proportion of unsaturated fatty acids (approximately 89%) and its relatively low saturated fatty acid content (around 11%).

In Egypt, sunflower production reached 15,817 tons harvested from 15,430 feddans, with an average yield of 1.025 tons per feddan (FAO, 2019). However, domestic production satisfies only about 2% of the national demand for edible oils, with the remaining 98% met through imports (Aswaq Financial Co., 2018). This wide gap has prompted nationalizes aimed at enhancing local oilseed production through improved agronomic practices and the selection of high-yielding cultivars. Sowing technique plays a vital role in determining crop phenology, morphology, and yield. Appropriate planting methods can reduce weed pressure, improve water and nutrient use efficiency, and decrease seed rates without compromising productivity (Holm et al., 2002). Ridge and furrow systems in particular have been shown to enhance water availability, nitrogen uptake, and overall crop performance compared to flat sowing/1(Nasrullah et al., 2009). Zinc (Zn) is an essential micronutrient involved in numerous physiological functions, including gene expression, protein synthesis, membrane stability, and enzymatic activity (Shahhoseini et al., 2020; Velasco et al., 2020). It also plays a critical role in vegetative growth by participating in the biosynthesis of phytohormones, particularly auxins, which regulate cell division and elongation (Pandey et al., 2010). Moreover, zinc contributes to the efficiency of photosynthetic processes and carbohydrate metabolism by stabilizing or activating several key proteins (Rehman et al., 2012). Recent advancements in nanotechnology have introduced nano-fertilizers as a promising alternative to conventional fertilizers. According to Prasad et al. (2017), Gkanatsiou et al. (2019), and Kolenčík et al. (2020), nano-fertilizer formulations containing nanoparticles such as zinc oxide (ZnO) have demonstrated significant potential in enhancing plant nutrition, improving crop performance, and promoting sustainable agricultural practices. Numerous oilseed cultivars have been created in sunflower breeding to maximize the content of essential fatty acids, especially oleic and linoleic acids. As a result, different varieties of sunflower oil, including high linoleic, high oleic, and mid-oleic, have been identified. Both genetic and environmental factors affect the fatty acid profile of sunflower oil; high oleic varieties (>80% monounsaturated fatty acids) provide better nutritional quality and oxidative stability (Skorić et al., 2008).

According to Said & Mohamed (2021), sunflower yield parameters were significantly impacted by the interplay between micronutrient nanoparticles and the timing and frequency of foliar treatments. Iron, manganese, and zinc nanoparticles were used in three foliar sprays at 30, 50, and 70 days after sowing, which produced the maximum seed and oil yields (3.47 and 3.55 t/fed; 1765.88 and 1770.67 kg/fed, respectively).

Objectives

The present study was undertaken to investigate the effects of different sowing methods and foliar application of zinc oxide nanoparticles on the crop growth rate and net assimilation rate as well as on the composition of saturated and unsaturated fatty acids of sunflower (*Helianthus annuus L.*)

Materials and methods

This experiment was conducted over two consecutive summer seasons (2020 and 2021) at the Agricultural Experimental Farm, Faculty of Agriculture, Assiut University, Egypt. The study aimed to evaluate the effects of different planting methods and foliar applications of zinc oxide nanoparticles (ZnO NPs) on the productivity and oil quality of sunflower (*Helianthus annuus* L.) cultivar Giza 102. The physical and chemical characteristics of the experimental soil are presented in **Table 1**

Table 1. Selected physical and chemical properties of the experimental soil.

season	2020	2021
Mechanical analysis (%)		
Sand	27.40	27.80
Silt	23.60	23.20
Clay	49.00	49.00
Soil type	Clay	Clay
Chemical analysis:	7.75	7.70
pH	1.90	1.80
Organic matter % Total N%	0.08	0.09

The soil in both seasons was classified as clay, with a stable texture and slightly alkaline pH. Organic matter and nitrogen content showed minimal variation between the seasons, indicating consistent fertility conditions throughout the study.

The experiment followed a randomized complete block design (RCBD) in a strip-plot arrangement with three replications. The main plots are assigned to three planting methods: planting on beds (120 cm wide), on ridges, and in hills using a flat-drill system. The subplots received six concentrations of ZnO NP applied as foliar sprays: 0 (control), 50, 100, 150, 200, and 250 ppm. Each plot measured 3.5 m × 3.0 m (10.5 m²). Sunflower seeds of the cultivar Giza 102 were obtained from the oil Crops Department, Agricultural Research Center (ARC), Egypt, were manually sown in 60 cm spaced rows. Sowing dates were June 25 (2020) and June 26 (2021). Foliar applications were carried out 30 days after sowing, using a back sprayer at a rate of 0.5 liters per plot. The ZnO nanoparticles (30–40 nm, 99% purity) were purchased from Sigma-Aldrich (Saint Louis, MO, USA) and prepared by dissolving the appropriate quantity (50–250 mg) in one liter of distilled water per treatment. Weed control was performed using pre-emergence herbicide (Amex 48%, containing N-sec-butyl-4-tert-butyl-2,6-dinitroaniline). The field had previously been cultivated with wheat during the preceding winter season. All other agronomic practices recommended for sunflower cultivation were uniformly applied.

Measured Traits:

1- Growth and Physiological Parameters:

a. Leaf Area Index:

The leaf area of each plant (cm2) was calculated at the end of the growing season using a device Area meter AM350.

LAI may be described most simply as: LAI = s / G where s is the functional (green) leaf area of the canopy per ground area G as described by/1Williams (1946).

b. Leaf Area Duration (LAD) in m^2 week^{-1}.

The Leaf Area Duration (LAD) indicates the importance and continuity of the leaf surface area, performing its function, during the growth period of the crop as described by Hunt (1982).

$$\textbf{LAD} = \frac{(LA_2+LA_1)\times(T_2-T_1)}{2}$$

(LA1): - The area of the leaf surface of the plant in the first period of time (T1).

(LA2): - The area of the leaf surface of the plant in the second time period (T2).

c. Total chlorophyll using SPAD apparatus at 60 days after planting.

Total chlorophyll (mg/m^2): Total chlorophyll (Chl. "a + b) was determined in sunflower leaves at 60 days after planting by Chlorophyll Meter SPAD-502 Plus reported by Dash et al. (2007).

SPAD calibration equations:

y = $0.118 x^2 + 0.919 x + 7.925 = mg/m^2$/1Where, y represents chlorophyll concentration in mg/m^2, **X** represents SPAD value.

d. Net Assimilation Rat (NAR) in g m^{-2} week^{-1}:

The net Assimilation rat **(NAR),** based on leaf area, is defined as the amount of increase in dry matter, per unit area of leaf surface, per unit time, and is estimated from the following equation described by Watson (1958).

$$\textbf{NAR} = \frac{W_2 - W_1}{LA_2 - LA_1} \times \frac{\log_e LA_2 - \log_e LA_1}{T_2 - T_1}$$

(W1): - Total dry weight of the plant in the first period of time **(T1).** 45 days after planting, the samples taken in a random way were dried at a temperature of 70 OC until the weight was stable.

(W2): - Total dry weight of the plant in the second time period **(T2).** 60 days after planting, the samples taken in a random way were dried at a temperature of 70 OC until the weight was stable.

(LA1): - The area of the leaf surface of the plant in the first period of time **(T1).**

(LA2): - The area of the leaf surface of the plant in the second time period **(T2).**

Log $_e$ = logarithme népérien = 2.303×log10.

e. Crop Growth Rate (CGR) in m^{-2} of land day^{-1}.

Calculated as:/1**CGR** = NAR × LAI/1by Williams (1946).

f. Relative Growth Rate (RGR) in g day^{-1}: -

The relative rate of growth is defined as the increase in the dry matter of the plant in a period of time in relation to the weight at the beginning of this period, and it is calculated from the following equation. as decided by Grime and Hunt (1975).

$$\text{Relative Growth Rate } \textbf{(RGR)} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

(W1) = The total weight of the plant at the beginning of the period **(T1).** 45 days after planting, the samples taken in a random way were dried at a temperature of 70 OC until the weight was stable. **(W2)** = Total dry weight of the plant in the second time period **(T2).** 60 days after planting, the samples taken in a random way were dried at a temperature of 70 OC until the weight was stable.

Log $_e$ = logarithme népérien = 2.303×$\log_{10}$.

2-Fatty acids composition:

Sunflower seeds were manually cleaned of all foreign matter and broken seeds. Husked seeds were then subjected to fatty acid analysis:

Preparation of Fatty Acid Methyl Esters (FAMEs):

Fatty acid methyl esters were synthesized using a mixture of 5 mL of 3% sulfuric acid in absolute methanol and 2 mL of benzene, following the method of Rossel & Phil (1983). This facilitated the conversion of fatty acids into methyl esters suitable for gas chromatography.

Gas Chromatographic Analysis:

FAMEs were analyzed using a Perkin-Elmer gas chromatograph (Model F22) equipped with a flame ionization detector (FID). Nitrogen was used as the carrier gas. The chromatographic separation was performed on a 3-meter-long glass column (3 mm internal diameter) packed with diethylene glycol succinate (DEGS) supported on Chromocarb W (80–100 mesh).

•Column oven temperature: 190°C to 230°C (ramped at 4°C/min)

•Injector and detector temperatures: 220°C

•Gas flow rates:

•Nitrogen and hydrogen: 30 mL/min

•Air: 300 mL/min

•Chart recorder speed: 1 cm/min

Fatty acids were identified by comparing the retention times of sample peaks with those of authentic FAME standards. Relative concentrations were quantified based on peak areas using an electronic integrator.

Statistical analysis:

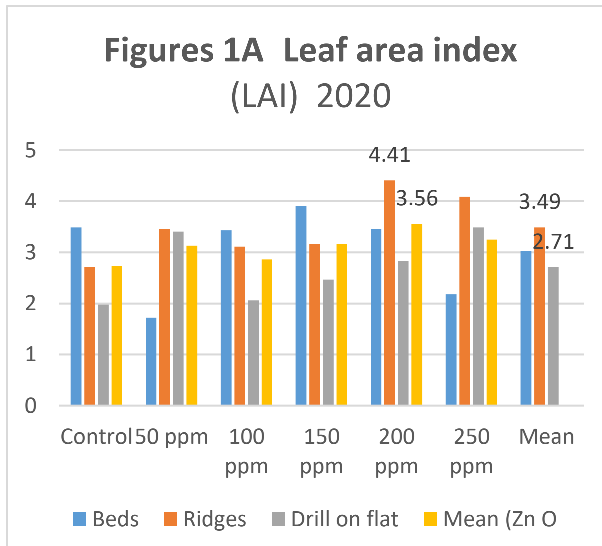
All collected data were subjected to analysis of variance (ANOVA) using the SAS Statistical Software Package version 9.2 (SAS, 2008). Mean comparisons were conducted using the revised least significant difference (R-LSD) test at a 5% significance level (Gomez & Gomez, 1984). Since the variances between the two seasons were not homogeneous, a combined analysis was not performed.

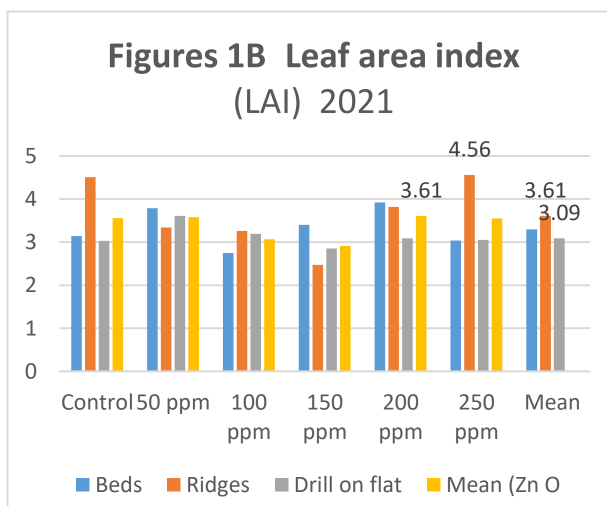
Results and discussions

A. Leaf Area Index (LAI):

The Leaf Area Index (LAI) is a critical indicator of canopy efficiency in intercepting light and utilizing water, making it a reliable measure of plant growth and vigour. It often reflects the effectiveness of agronomic practices such as fertilization and irrigation and planting techniques. LAI is influenced by/1canopy structure, which in turn is affected by is influenced by cultivar characteristics, environmental conditions, and field management. As illustrated in. Figures 1A and 1B planting methods had significant effect on LAI, with ridge planting achieving the highest LAI values of 3.49 and 3.61 in 2020 and 2021, respectively. While flat drilling resulted in the lowest 2.71 and 3.09. The superior performance of ridge planting may be attributed to better plant spacing, enhanced aeration, and optimal root and shoot development, while flat planting likely caused waterlogging and reduced leaf expansion.

Foliar application of ZnO nanoparticles also significantly influenced LAI. The 200-ppm treatment recorded the highest LAI values, 3.56 and 3.61 in 2021 and 2021, respectively, likely due to improved leaf formation and expansion and enhanced physiological processes. These findings align with previous studies by Al-Doori (2014), Ashraf et al. (2014), and Abou-Bakr et al. (2019). A significant interaction was also observed between planting method and ZnO concentration. Ridge planting combined with 200 ppm ZnO in 2020 and 250 ppm in 2021 yielded the highest LAI values (4.41 and 4.56, respectively).





season	2020		2021	
Test (F) and	R. LSD 0.05	Test/1(F)	R. LSD 0.05	Test (F)
A	0.19	*	0.29	**
B	0.50	*	0.64	*
A*B	0.76	**	0.70	**

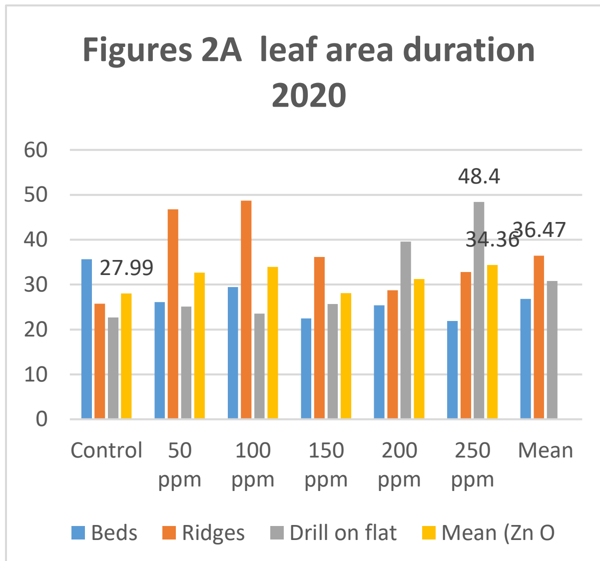
* and ** indicate significance at the 5% and 1% levels of probability, respectively.

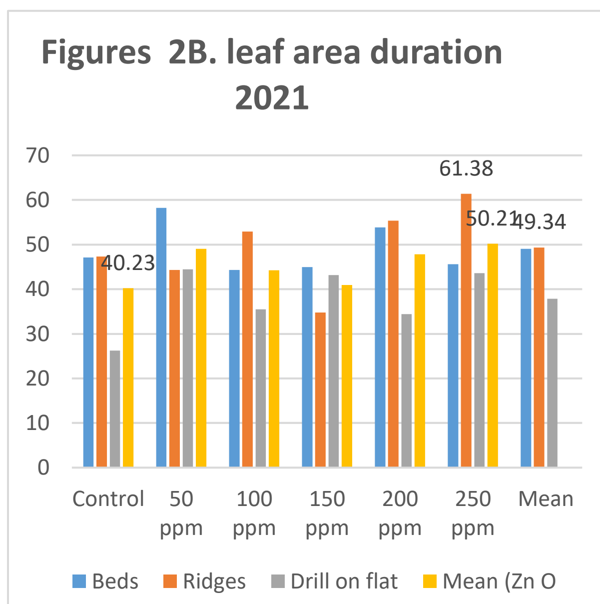
B. Leaf Area Duration (days):

Leaf Area Duration (LAD) represents the persistence and functional effectiveness of the leaf surface throughout the crop's growth cycle. It is a key physiological parameter that reflects the plant's ability to maintain photosynthetically active foliage over time, thereby contributing to biomass accumulation and yield. As shown in Figures 2A and 2B, LAD was significantly influenced by planting methods in both 2020 and 2021. Ridge planting resulted in the highest LAD values, 36.47 days in 2020 and 49.34 days in 2021. These results may be attributed to more favorable growth conditions, including improved soil aeration, moisture distribution, and nutrient uptake efficiency associated with ridge planting.

Foliar application of ZnO nanoparticles also had a highly significant effect ($P \leq 0.01$) on LAD in both seasons. The 250 ppm ZnO treatment recorded the highest LAD values—34.36 days in 2020 and 50.21 days in 2021—while the untreated control exhibited the lowest values (27.99 and 40.23 days, respectively). The enhanced LAD under ZnO application may be explained by zinc's role in promoting antioxidant activity, delaying leaf senescence, and maintaining chloroplast structure and function, which collectively extend the productive lifespan of leaves.

A highly significant interaction was observed between planting methods and ZnO NP concentration during both seasons. In 2020, ridge planting combined with 100 ppm ZnO yielded the highest LAD (48.70 days), whereas in 2021, ridge planting with 250 ppm ZnO produced the greatest LAD (61.38 days). These results highlight the synergistic benefits of optimal planting configuration and zinc nutrition in sustaining leaf activity and maximizing photosynthetic efficiency. The enhanced LAD observed in ridge planting systems is likely due to better aeration and elevation, which reduce moisture stress and improve metabolic efficiency. These results are consistent with findings reported by Al-Doori (2014).





season	2020		2021	
Test (F) and LSD	R. LSD 0.05	Test/1(F)	R. LSD 0.05	Test (F)
A	2.70	**	3.28	**
B	3.00	**	2.52	*
A*B	3.78	**	5.03	**

***and ** indicate significance at the 5% and 1% levels of probability, respectively.**

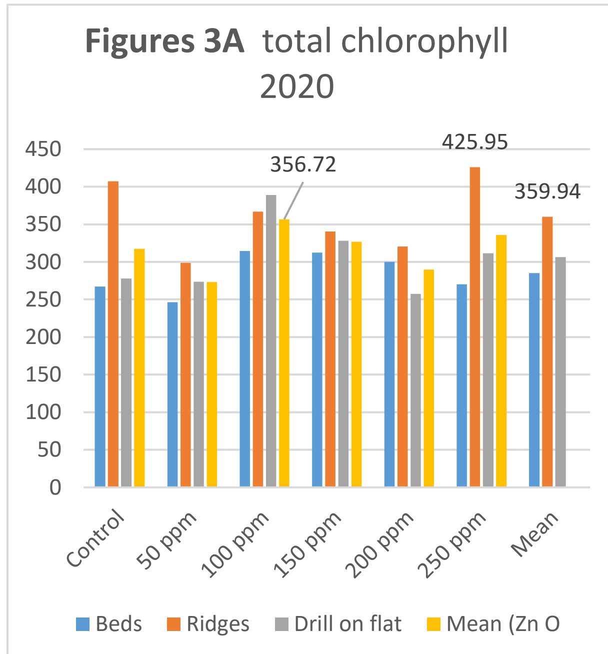
C. Total Chlorophyll content (mg m^{-2}):

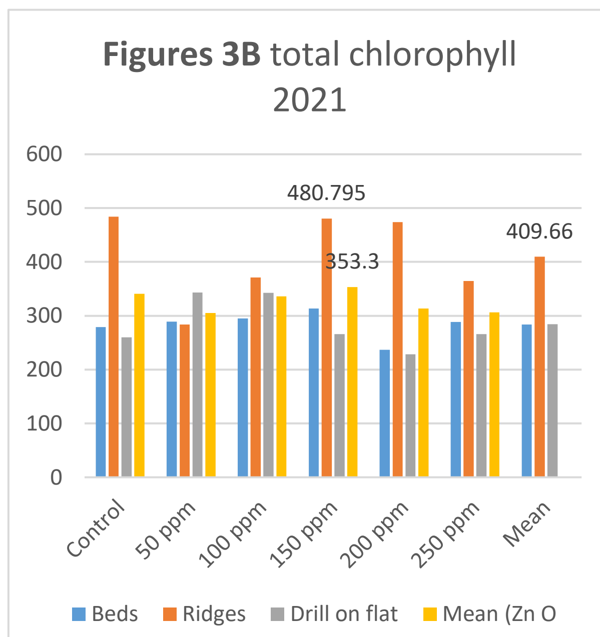
Accurate measurement of leaf pigments, particularly chlorophyll, is essential for assessing plant stress, fertilizer effects, and overall vegetative growth, especially in agricultural systems where yield depends on plant health. Chlorophyll plays a central role in photosynthesis by capturing sunlight and converting it into energy, making it a key determinant of crop productivity.

The data in Figures 3A and 3B show that planting methods had a highly significant effect ($P \leq 0.01$) on total chlorophyll content in both 2020 and 2021 seasons. Ridge planting resulted in the highest chlorophyll concentrations (359.94 and 409.66 mg m^{-2}, respectively), likely due to improved environmental conditions favoring optimal growth.

Zinc oxide nanoparticles (ZnO NPs) treatments also significantly influenced chlorophyll levels. In 2020, the highest chlorophyll content (356.72 mg m^{-2}) was recorded with 100 ppm ZnO, whereas in 2021, 150 ppm ZnO led to the maximum value (353.3 mg m^{-2}). The increase is attributed to zinc's role as a structural and catalytic component in pigment biosynthesis enzymes (**Balashouri and Prameeladevi, 1995).**

The interaction between planting methods and ZnO concentration was significant in both seasons. Sunflowers grown on ridges and sprayed with 250 ppm ZnO in 2020 or 150 ppm in 2021 exhibited the highest chlorophyll content (425.95 and 480.80 mg m^{-2}, respectively). This improvement is likely due to the combined effect of better nutrient uptake in ridges and zinc's involvement in chlorophyll synthesis. These results agree with previous findings by Al-Doori (2014).





season	2020		2021	
Test (F) and LSD	R. LSD 0.05	Test/1(F)	R. LSD 0.05	Test (F)
A	19.37	**	7.95	**
B	20.90	**	28.26	*
A*B	32.83	**	30.16	**

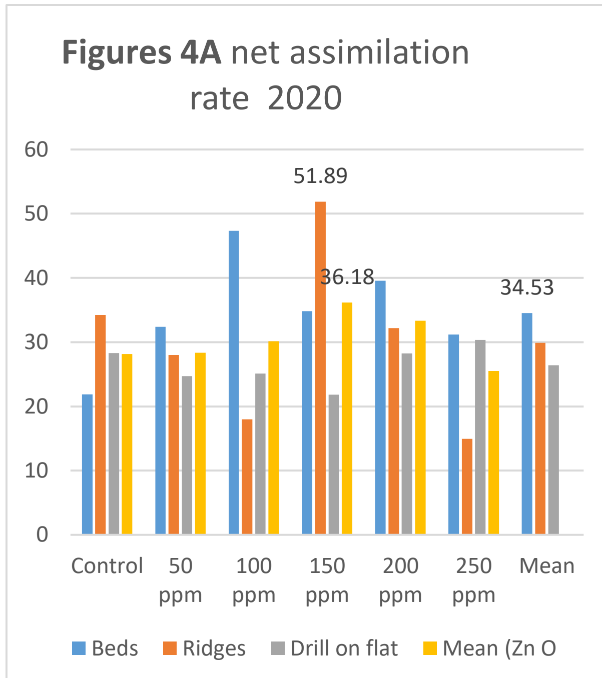
D. Net Assimilation Rate (NAR).

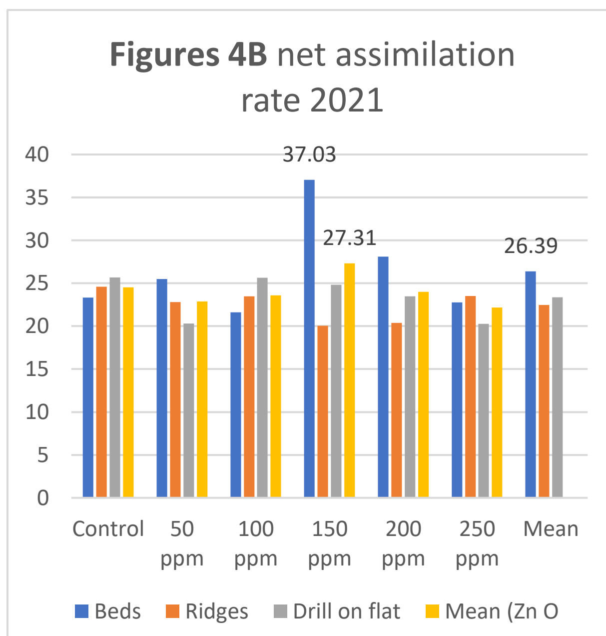
Figures 4A and 4B present the effects of planting methods, zinc oxide nanoparticle (ZnO NPs) concentrations, and their interaction on the net assimilation rate (NAR) of sunflower during the 2020 and 2021 seasons. Planting method significantly influenced NAR, with bed planting producing the highest mean values (34.53 and 26.39 g/m²/week in 2020 and 2021, respectively), outperforming both ridge and flat drill methods. This improvement is likely due to better aeration and reduced flooding in bed planting, enhancing nutrient uptake and photosynthesis, consistent with findings by Gillett et al. (2001).

ZnO NP treatments also showed highly significant effects on NAR. Foliar application at 150 ppm yielded the highest NAR values (36.18 and 27.31 g/m²/week), followed by 200 ppm and 100 ppm treatments. The lowest NAR was observed at 250 ppm ZnO, suggesting excessive zinc may inhibit growth. Zinc's essential role in enzymatic processes and chlorophyll synthesis likely explains these results, aligning with **Faizan *et al.* (2018).**

The interaction between planting methods and ZnO concentration was highly significant. In 2020, ridge planting combined with 150 ppm ZnO gave the highest NAR (51.89 g/m²/week), while in 2021, bed planting with the same ZnO concentration produced the peak NAR (37.03 g/m²/week). These outcomes reflect the combined benefits of improved root environment in ridges or beds and zinc's role in photosynthesis and enzyme activity.

Figures 4A and 4B. Average net assimilation rate (g/m²/week) of sunflower influenced by planting methods, zinc oxide nanoparticle concentrations, and their interaction during the 2020 and 2021 growing seasons.





season	2020		2021	
Test (F) and LSD	R. LSD 0.05	Test/1(F)	R. LSD 0.05	Test (F)
A	6.32	**	1.22	**
B	3.71	**	1.38	**
A*B	6.20	**	2.10	**

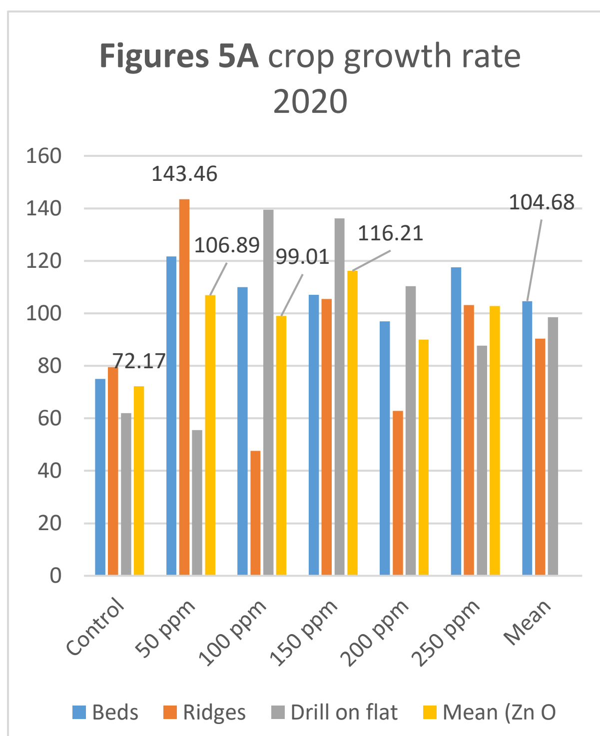
*** and ** indicate significance at the 5% and 1% levels of probability, respectively.**

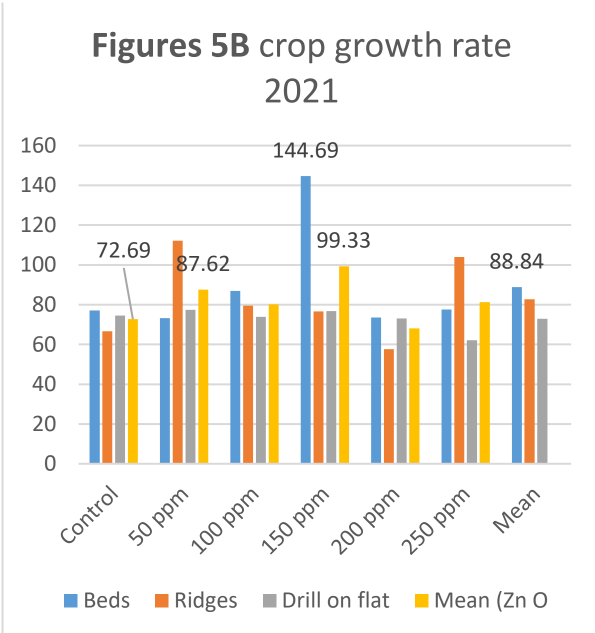
E- Crop Growth Rate (CGR) (grams dry matter/m² of land/day):

The data presented in Figures 5A and 5B illustrate the effects of planting methods, nano-zinc oxide (ZnO NPs) concentrations, and their interaction on the crop growth rate (CGR) of sunflower during the 2020 and 2021 growing seasons. The results clearly indicate that planting methods had a significant effect ($P \leq 0.05$) on CGR in both seasons, with planting on beds producing the highest average growth rates of 104.68 and 88.84 g/m²/day for the first and second seasons, respectively. This increase in growth rate can be attributed to the advantages of bed planting, which raises the plants above the soil surface, improving aeration, root ventilation, and access to water and nutrients. Consequently, these conditions promote a higher net assimilation rate (as shown in Figures 4A and 4B), leading to enhanced crop growth.

Furthermore, the data reveals that different concentrations of nano-zinc oxide had a highly significant effect ($P \leq 0.01$) on CGR in both seasons. Foliar application of nano-ZnO at 150 ppm resulted in the highest crop growth rates of 116.21 and 99.33 g/m²/day in 2020 and 2021, respectively. This was followed by applications of 50 ppm (106.89 and 87.62 g/m²/day) and 100 ppm (99.01 and 80.11 g/m²/day). In contrast, the lowest CGR values were recorded in control plants without ZnO NPs treatment, with averages of 72.17 and 72.69 g/m²/day. The superiority of nano-zinc oxide treatments over control is likely due to the essential role of zinc as a micronutrient involved in many enzymatic processes, promoting cell division and elongation, as well as enhancing photosynthesis, thereby boosting growth rate.

Regarding the interaction between planting methods and nano-ZnO concentrations, the data in Figures 5A and 5B demonstrate a highly significant interaction effect ($P \leq 0.01$) on CGR in both seasons. Specifically, in 2020, the combination of planting on ridges and foliar application of 50 ppm nano-ZnO produced the highest growth rate of 143.46 g/m²/day. In 2021, planting on beds combined with 150 ppm nano-ZnO foliar spray resulted in the highest CGR value of 144.69 g/m²/day. This enhanced growth can be explained by the synergy between the favorable environmental conditions created by ridge or bed planting—which improve root aeration, nutrient uptake, and water availability—and the beneficial physiological effects of zinc on enzymatic activity and photosynthesis. These combined factors optimize plant growth compared to planting on flat soil, where plants are more exposed to waterlogging and nutrient leaching, limiting growth.





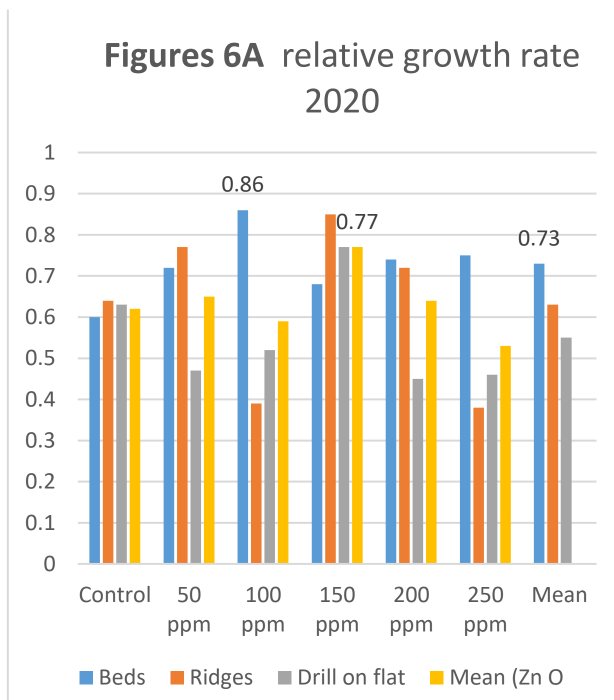
season	2020		2021	
Test (F) and LSD	R. LSD 0.05	Test/1(F)	R. LSD 0.05	Test (F)
R.LSD 0.05	9.89	*	10.11	*
(PM)	7.48	**	11.36	**
ZnO NPs	14.93	**	16.56	**

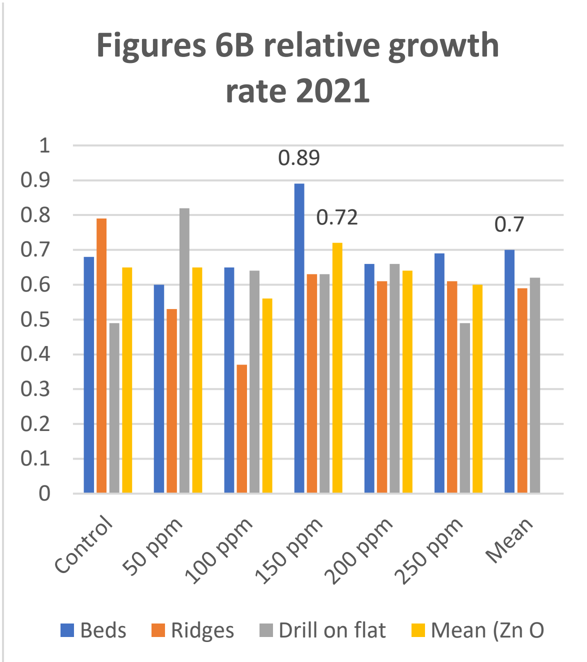
F. Relative Growth Rate (RGR) in g/day:

The data in Figures **6A and 6 B** reveal that planting methods significantly ($P \leq 0.05$) influenced the relative growth rate (RGR) of sunflower in both growing seasons. Sunflowers grown on beds exhibited the highest RGR values, measuring 0.73 and 0.70 g/day in 2020 and 2021, respectively. This increase is likely due to improved aeration and nutrient uptake, as bed planting elevates plants above the soil surface, optimizing light capture and photosynthetic activity, which in turn enhances dry matter accumulation.

Nano-zinc oxide (ZnO NPs) treatments also showed a highly significant effect ($P \leq 0.01$) on RGR during both seasons. Foliar application of 150 ppm ZnO NPs produced the greatest increase in growth rate, with averages of 0.77 and 0.72 g/day in 2020 and 2021, respectively. Lower concentrations (50 and 200 ppm) resulted in moderate increases, while the lowest RGR was observed at 250 ppm in the first season and 100 ppm in the second. The beneficial effect of zinc at optimal concentrations can be attributed to its role in promoting cell division and elongation, thus supporting biomass accumulation.

Furthermore, the interaction between planting methods and ZnO NPs concentrations was highly significant ($P \leq 0.01$) in both seasons. Specifically, sunflowers planted on beds and treated with 100 ppm ZnO NPs in the first season or 150 ppm in the second exhibited the highest RGR values of 0.86 and 0.89 g/day, respectively. This synergy likely results from the combined advantages of improved growing conditions on beds and the physiological benefits of zinc in enhancing photosynthesis and enzymatic activities, ultimately boosting cell growth and relative growth rate. These findings align with previous research by Grime & Hunt (1982).





season	2020		2021	
Test (F) and LSD	R. LSD 0.05	Test/1(F)	R. LSD 0.05	Test (F)
A	0.08	*	0.07	*
B	0.08	**	0.08	**
A*B	0.10	**	0.16	**

2. Fatty acid composition of sunflower oil.

The fatty acid composition of seed oils varies widely among different plant species. Unsaturated fatty acids (USFAS) have favourable effect and positive health benefit than saturated fatty acid (SFAS) (Petersen et al., 2024).

The results for the fatty acids identification and estimation in sunflower kernel meal oil (g/100g oil) after treated by zinc oxide nanoparticles are reported in Tables 2 and 3. From these results it could be noticed that the major fatty acids were oleic and linoleic make up more than 90 % of the total fatty acids in oil samples. The oleic acid content was ranging from 41.23 to 50.26 for the method of beds cultivation, with the observation of an increase in oleic acid as the concentrations of zinc oxide increased, where the highest concentration i.e. 250 ppm in the first season. The oleic acid content was ranging from 24.15 to 36.58 in the second season. So, oleic content was increased because of foliar spray by ZnO in treated samples when compared with control one. The linoleic acid content was found in highest values ranging from 40.55 to 52.26% mg/100g in the first season and 42.26 to 64.64% mg/100g in the second season. Palmitic and stearic as a saturated acids were found in lowest contents with range of 5.09: 6.01 and 3.52: 6.70%, respectively, (Table 2 and 3).

From the recorded results it could be noticed that the saturated fatty acid content decreased from 9.28% in the method of cultivation of beds to 8.59, 8.94 and 8.36% in the method of cultivation of beds which was sprayed by ZnO NPs at 50, 200 and 250 ppm, respectively in the first season. More aver, in the second season the satiated fatty acid content decreased from 12.13 % in the method of cultivation of beds to 8.95,10.37, 9.38, 9.81and 8.5% in the method of cultivation of beds with ZnO NPs at 50, 100, 150 ,200, and 250 ppm respectively. While the total unsaturated fatty acid content increased from 90.68% in the method of cultivation of beds to 91.32 ,91.41, and 90.91% ZnO NPs at 50, 200 and 250 ppm in the first season, respectively. While the total unsaturated fatty acid content increased from 74.74% in The method of cultivation bed of beds to 87.83 ,89.23, 87.98 ,90.42 and 91.08 % with sprayed by ZnO NPs at 50, 100,150 ,200 and 250 ppm the second season, respectively

Table 2. Fatty acid composition of oil samples as affected by planting methods and Zinc oxide nanoparticles concentrations in 2020 season.

Fatty acids	Relative concentration (%)																	
	A control	**A 50PPM**	**A 100**	**A 150**	**A 200**	**A 250**	**B control**	**B 50**	**B 100**	**B 150**	**B 200**	**B 250**	**C control**	**C 50**	**C 100**	**C 150**	**C 200**	**C 250**
(C14:0)	----	----	----	0.54	----	----	0.32	0.44	----	----	----	0.31	----	----	----	…	----	----
(C16:0)	6.01	5.42	5.53	5.61	5.39	5.17	5.49	5.23	5.58	5.46	6.00	5.64	5.65	5.58	5.09	5.83	5.23	5.45
(C18:0)	2.68	2.74	2.92	2.45	2.93	3.50	3.11	3.26	3.13	3.24	3.27	3.33	3.34	3.28	2.91	3.41	3.41	2.85
(C20:0)	-----	0.20	----	0.68	0.26	0.27	0.23	0.28	----	----	0.28	0.31	0.26	0.28	0.23	0.26	0.25	0.25
Total Satu- rated fatty acids	8.69	8.36	8.45	9.28	8.59	8.94	9.15	9.21	8.69	8.7	9.55	9.59	9.25	9.14	8.23	9.5	8.89	8.55
(C14:1)	----	----	----	0.31	----	----	----	----	----	----	----	----	----	----	----	----	----	----
(C16:1)	-----	0.19	----	0.14	0.17	0.10	0.12	0.11	----	0.19	0.17	0.34	0.13	0.32	----	0.51	0.10	0.16
(C18:1)	41.29	41.23	42.45	40.67	46.22	50.26	46.56	46.37	42.79	46.4	38.01	46.04	44.70	44.36	47.71	40.81	46.17	41.13
(C18:2)	50.02	49.90	48.23	49.62	45.02	40.55	44.17	43.71	48.14	44.70	52.26	42.96	45.67	46.18	44.07	48.74	44.69	50.00
Total unsated- rat fatty acids	91.31	91.32	90.68	90.74	91.41	90.91	90.85	90.19	90.93	91.29	90.44	89.34	90.5	90.86	91.78	90.06	90.96	91.29

Myristic acid (C14:0), Myristoleic acid (C14:1), Palmitic acid (C16:0), Palmitoleic acid (C16:1),, Stearic acid (C18:0), Oleic acid (C18:1), Linoleic acid (C18:2), Arachidic acid (C20:0) *** (A :- Beds B:- Ridge C:- Drill on flat)

Table 3. Fatty acid composition of oil samples as affected by planting methods and Zinc oxide nanoparticles concentrations in 2021 season.

Fatty acids	Relative concentration (%)																	
	A control	A 50PPM	A 100	A 150	A 200	A 250	B control	B 50	B 100	B 150	B 200	B 250	C control	C 50	C 100	C 150	C 200	C 250
(C14:0)	1.37	0.57	0.15	0.29	0.19	0.16	0.39	0.22	0.42	0.16	0.19	0.26	0.26	1.7	0.54	0.13	0.18	0.14
(C16:0)	6.70	5.09	6.29	5.44	5.1	5.1	6.01	5.08	5.27	5.89	5.79	5.39	4.90	4.23	3.52	5.07	6.52	4.97
(C18:0)	2.07	2.24	3.05	3.86	2.89	2.73	2.85	3.12	2.21	3.26	2.60	2.64	3.55	2.16	2.13	3.25	4.27	2.99
(C20:0)	1.99	1.05	0.88	0.22	1.20	0.51	1.13	0.88	0.87	1.18	1.25	1.27	0.77	1.59	1.79	1.012	0.81	1.29
Total Satu- rated fatty acids	12.13	8.95	10.37	10.82	9.38	8.5	10.38	9.3	8.77	10.49	9.83	9.56	9.48	9.68	7.98	9.46	11.15	9.39
(C14:1)	0.87	0.53	0.13	0.29	0.11	0.11	0.29	0.1	0.43	0.11	0.18	0.23	0.23	0.44	0.44	0.11	----	0.13
(C16:1)	1.80	0.62	0.31	0.25	0.32	0.25	0.45	0.34	0.74	0.15	0.38	0.58	0.31	1.01	.78	0.23	0.50	0.32
(C18:1)	29.81	28.41	24.15	32.31	31.31	30.51	27.23	32	30.71	28.06	26.46	24.70	34.47	36.58	36.45	30.73	29.84	30.83
(C18:2)	42.26	58.27	64.64	55.13	58.68	60.21	57.87	57.61	56.15	60.52	62.74	64.31	54.94	48.68	52.41	58.31	57.15	58.64
Total unsated- rat fatty acids	74.74	87.83	89.23	87.98	90.42	91.08	85.84	90.05	88.03	88.84	89.76	89.82	89.95	86.71	90.08	89.38	87.49	89.92

Conclusion

Based on the results of this study, it is recommended to cultivate sunflowers on beds and apply foliar sprays of zinc oxide nanoparticles at a concentration of 150 ppm. This combination significantly enhances growth rate and net assimilation. Furthermore, ZnO nanoparticle treatments within the range of 150–250 ppm improves oil quality by increasing the proportion of unsaturated fatty acids while reducing saturated fatty acids, thereby promoting the production of nutritionally healthier sunflower oil.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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