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Research Article

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A Sustainable Approach: Effect of Integrated Nutrient Management Practices on Growth, Phenology and Yield of Sunflower (*Helianthus annuus* L.)

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Abstract

Sunflower, an important oil seed crop, needs a balanced nutrition for its optimum growth and thorough maintenance of soil health. A field experiment was conducted to study the effect of integrated use of organic, inorganic and growth regulators on growth, phenology as well as yield of sunflower at Agricultural Experimental Farm, Lovely Professional University Phagwara, Punjab during the spring season of 2023. There were 10 treatments viz. 3 types of organic sources, viz. farmyard manure (FYM), poultry manure and vermicompost, inorganic nutrients and growth regulators. The experiment was laid out in a randomized block design. After analysis, the data clearly showed significant differences among treatments in sunflower growth and yield. Along with that a prominent impact of integrated use of organic, inorganic fertilizers and growth regulators was found under treatments in case of yield. Among all treatments T5-50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS showed the best results in the case of growth parameters (Plant height, leaf area, number of leaves per plant, stem girth), yield parameters (capitulum weight, capitulum diameter, seeds per head and seed yield), and oil quality parameters (Oil content%, oil recovery and protein content%). 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 days after sowing (DAS) is thus recommended for sunflower cultivation in sandy loamy soils considering the growth and yield of sunflower.

Keywords

Sustainability, Responsible crop production, Hidden hunger, Integrated nutrient management, Growth regulators and oilseeds

Introduction

The botanical term "*Helianthus annuus* L." is commonly referred to as the sunflower, also known by its vernacular name "Suraj Mukhi." Sunflower is a day-neutral perennial oilseed crop that is indigenous to the regions of the United States and Southern Mexico. The chromosomal number of this is 2n = 34. The plant is classified under the Asteraceae family [1]. According to Mahapatra et al. this crop holds the third position in terms of yield, following soybeans and peanuts [2]. It is well recognized as one of the most significant oilseed crops cultivated worldwide, known for its high quality. India is recognized as one of the leading global producers and consumers of vegetable oil. The Indian vegetable oil economy ranks 13th globally, trailing behind countries such as Russia, Ukraine, and the European Union. The countries included in figure 1 are Argentina, China, Turkey, the United States, Kazakhstan, South Africa, Moldova, and Burma, each of which is associated with production.

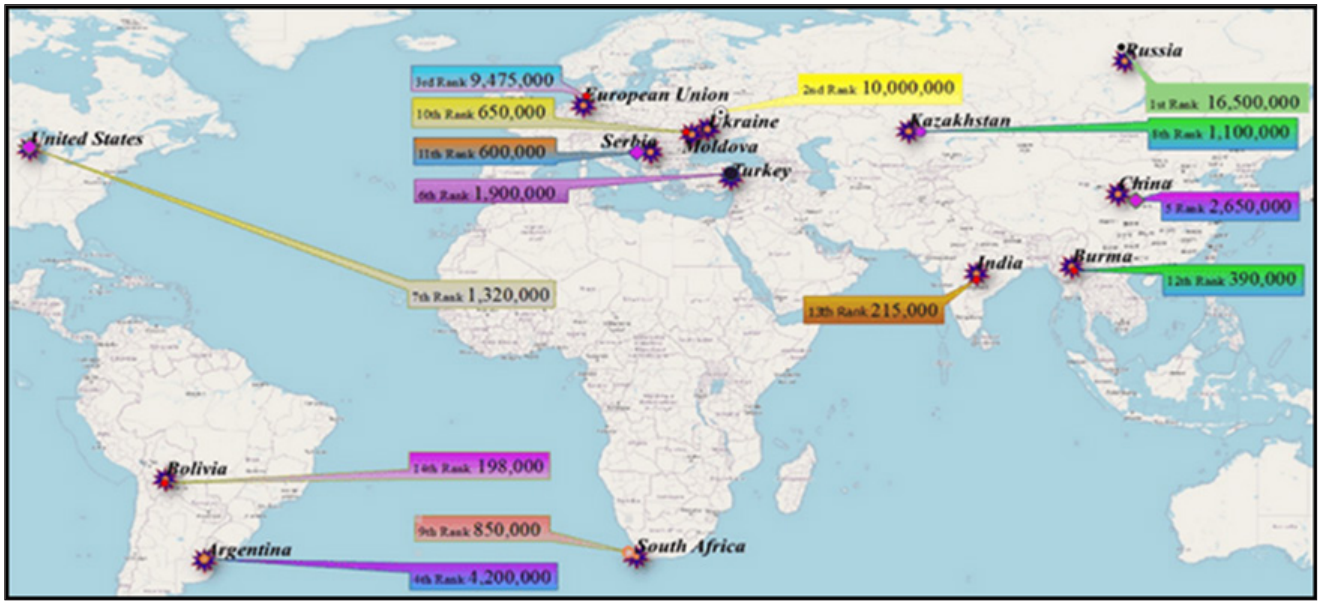

Figure 1: Production economics (metric tons) of sunflower worldwide.

The global consumption of domestically produced sunflower oil in the period of 2021-2022 amounted to 18,782 metric tons. Notably, the European Union held the leading position in terms of consumption, as depicted in figure 2. The vegetable oil sector in India has the position of being the fourth largest globally, including approximately 14.5% of the total oil seed area and contributing to 6.6% of the overall global production. Sunflower has demonstrated significant potential as an oil seed crop for year-round production across various agro-climatic areas because of its thermo-photo-insensitivity. Additionally, it may be effectively integrated into crop rotation schedules at any given time. Sunflower agriculture has had a significant rise in prominence over the last twenty years in the region of Punjab. Presently, sunflower crops cover an area of 2.5 thousand hectares, resulting in a production output of 4.5 thousand tons and an average yield of 17.95 quintals per hectare. Sunflower oil comprises two types of unsaturated fats, namely monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA).

MUFAs have been found to effectively reduce the concentration of low-density lipoprotein (LDL) cholesterol, commonly referred to as "bad" cholesterol, in the bloodstream. Additionally, MUFAs have been observed to elevate the levels of high-density lipoprotein (HDL) cholesterol, often referred to as "good" cholesterol. MUFAs are a type of fat that confers many health benefits. Based on prevailing dietary guidelines, MUFA and PUFA play a crucial role in supporting the biochemical processes associated with the cardiovascular system, cognitive function, digestive health, and cellular maintenance. Approximately 85% of the lipids present in sunflower oil consist of MUFA. MUFAs have been found to have a positive

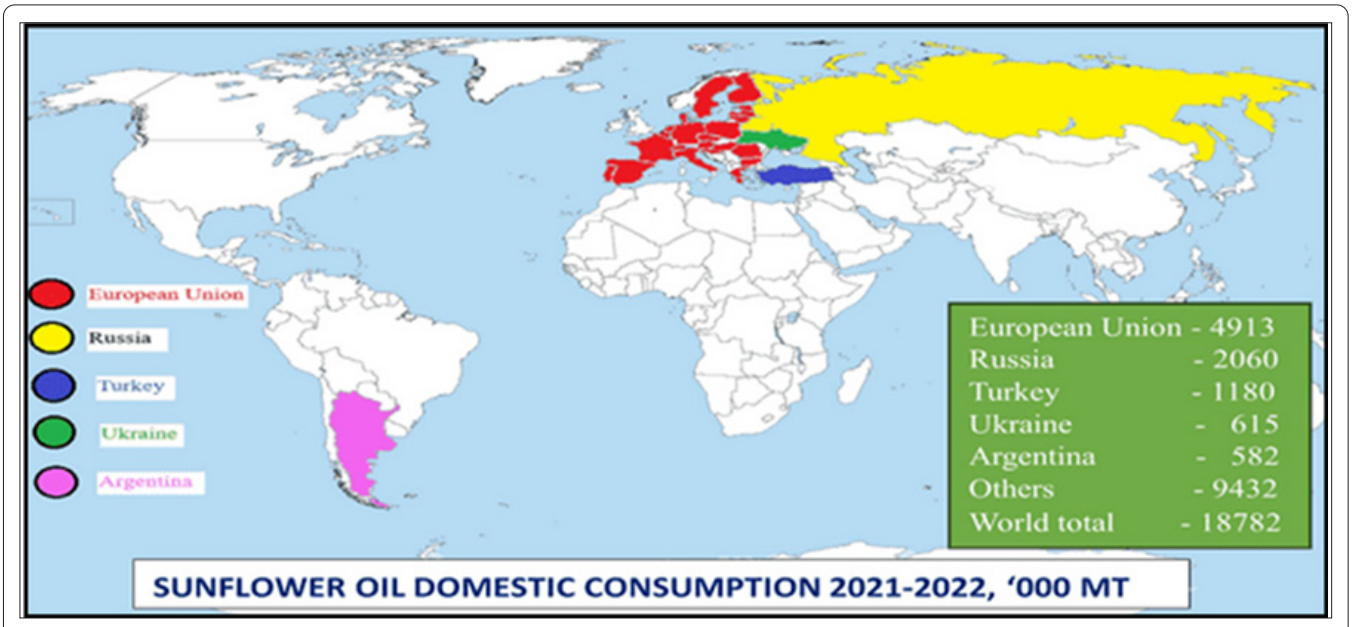

Figure 2: Domestic consumption of sunflower oil worldwide on world map.

impact on lipid profiles by increasing HDL levels, commonly referred to as "good cholesterol," while simultaneously reducing LDL levels, known as "bad cholesterol." PUFAs have been shown to contribute to the reduction of LDL cholesterol, commonly referred to as "bad" cholesterol [3].

This reduction in LDL cholesterol levels has been associated with a decreased chance of developing cardiovascular diseases and other related disorders. Nevertheless, the yield remains comparatively lower in relation to the average productivity observed in leading sunflower-producing nations globally. The cultivation of sunflowers predominantly occurs on marginal and sub-marginal land, often in conditions of limited moisture. However, the inadequate selection of cultivars and the absence of enhanced agronomic crop management practices have also been identified as contributing factors to the low productivity of sunflower. The sunflower (*H. annuus* L.) is favored by farmers due to its favorable attributes such as its high yield potential, short growing season, and significant profit margins, in addition to its potential as an oil seed crop. The plant exhibits a remarkable capacity to thrive in many environmental circumstances and a wide range of soil compositions. Sunflowers possess the potential to mitigate the prevailing shortage of edible oil within the nation due to their significant role in emergency crop management strategies [4].

The current state of our nation is characterized by a significant scarcity of edible oil, which may be attributed to several factors including population growth, an increase in per capita income, and heightened demand from oil-dependent industries. The importation of edible oil serves to fulfil a portion of the existing demand. Consequently, there is a necessity for the company to augment its oil production capacity in order to meet the escalating demands of its customers. The present fertilizer production in India is insufficient to meet the substantial demand for plant nutrients within the country. The continuous application of substantial amounts of chemical fertilizers has been observed to have detrimental effects on crop yields, water supplies, and wildlife populations. The effective management of soil organic matter, along with the judicious use of organic inputs such as animal manure, crop residues, and green manure, will play a pivotal role in the advancement of sustainable agricultural systems in the next decades.

However, organic manure is insufficient in meeting the current enormous nutrient demands of modern agriculture. The achievement of optimizing crop output, preserving soil productivity, and ensuring ecological equilibrium can be accomplished through the judicious application of both inorganic fertilizers and organic nutrient sources. The use of organic manures in conjunction with fertilizers can effectively address the issue of an imbalanced N:P:K ratio and the consequent emergence of micronutrient deficiencies [5]. The objective of integrated nutrient management is to strategically combine organic sources in order to fulfil the nutrient requirements of crops and cropping systems. This approach is highly significant in maintaining and enhancing agricultural productivity in contemporary agriculture. In the context of intensive cropping systems, the accelerated turnover of nutrients, inadequate recycling of organic sources, and excessive use of high analysis fertilizers contribute to the depletion of certain micronutrients in the soil, as well as the potential for environmental pollution. It is widely acknowledged that the utilization of either chemical fertilizers or organic manure in isolation is insufficient for achieving sustainable agricultural production.

Therefore, the current investigation was conducted to assess the impact of FYM, vermicompost, poultry manure, and inorganic fertilizers (comprising macro and micronutrients) on the growth, yield, and oil quality of sunflower.

Materials and Methods

Preliminary information

A field experiment on sunflower in spring season 2022–2023 was conducted in Lovely Professional University Phagwara, Punjab. The LPU campus is located in the district of Kapurthala, which is between the Sutlej and the Beas rivers, in the Central Plain Region of Punjab (31.2560°N, 75.7051°E). The Trans-Gangetic Plains region is home to the experimental field, namely the Northern Plain Agro-Ecological Sub-Region. The average annual precipitation received by the region is 628 mm. Ganga Kaveri-2002 was used as a planting material and crop was sown in end of January with 60 cm × 30 cm spacing by dibbling methods on ridges by following all the intercultural package and practices of PAU, Ludhiana. The experiment was followed by the Randomized Block Design with 10 treatments, and 3 replications viz. T1- Control (Recommended NPK alone), T2-50% Nitrogen (N) through vermicompost + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS, T3-50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS, T4-50% N through FYM + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS, T5-50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS, T6-50% N through poultry manure + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS, T7-50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS, T8-50% nitrogen (N) through vermicompost + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS, T9-50% N through poultry manure + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS, T10-50% N through FYM + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS.

Crop protection measures have been implemented depending on the necessity of foliar using a knapsack. The different morphological and physiological observations such as plant height, leaf area, and number of leaves per plant, stem girth and dry weight were measured following standard protocol. The morphological attributes and the average value were recorded from the five random plants chosen from each plot, to determine the result of the data relation to the treatment.

Chlorophyll index

Looking at the greenness of the leaf, a mature leaf was

chosen to observe the amount of chlorophyll content at the leaf using the soil plant analysis development (SPAD) meter. The average of the three values taken from one leaf using a SPAD meter is the result of the chlorophyll content [6].

Crop growth rate (gday^{-1}m^{-2}) (CGR)

The gain in dry matter production on a unit of land in a unit of time. It can be calculated using the formula given by Watson [7].

Relative growth rate (g g^{-1}day^{-1})

The total increase in dry weight of the plant at two intervals. It was coined by Williams [8].

Yield attributes

The yield attributes such as capitulum weight, capitulum diameter, number of seeds per head and seed yield are observed at the harvest stage by following standard protocols.

Quality attributes

Oil content (%)

Seeds of sunflower were kept in the hot air oven at 70 °C for drying of seeds it removes all the moisture from the seeds and after those seeds were ground with the help of pestle mortar and its powder is withdrawn then oil extraction is done by the method of Soxhlet method of oil extraction [9] with the help of SOCS Plus apparatus and it's calculated by the following formula:

$$\text{Oil content (\%)} = \frac{\text{Weight of oil flask + ether extract − weight of flask oil}}{\text{Substances taken}} \times 100$$

Oil recovery (kg ha^{-1})

Oil yield is computed by multiplying the seed yield with the concentration of oil. The following formula is used to compute oil recovery:

$$\textit{Oil recovery } kgha^{-1} = \frac{\text{Seed yield (kg / ha)} \times \text{oil content (\%)}}{100}$$

Protein content (%)

The seed powder which was extracted from dried seeds was used in analyzing nitrogen % in powdered seeds with the help of Kjeldahl's method [10] and then the nitrogen % was multiplied by 6.25 to compute the protein content of seeds.

Statistical analysis

With the SPSS 22 version of the software, the generalized linear model under univariate techniques was used to determine the differences between the means. To find the best treatment, a mean separation method was used with a probability of $p<0.05$ and Duncan multiple range test. Fishers least significant difference test was used as a post- hoc test to see if there was a big difference between the means. The calculations were based on the least significant difference at a 5% level of significance. Correlation is found between the growth and yield parameters by bivariate and Pearson's correlation method by SPSS.

Results and Discussion

Effect of integrated nutrient management practices on growth parameters of sunflower

Plant height (cm)

Plant height of sunflower continuously increased up to 90 DAS. Maximum height (194.47 cm) was attained with the application of 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was followed by 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS and 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with (189.83 cm and 187.37 cm) plant height respectively.

However minimum plant height (157.46 cm) recorded in control (RDF) (Table 1). Supplementary remaining nutrient treatments were found to be significantly better in case of improvement height of plant. The availability and uptake of nutrients are crucial factors influencing plant growth. The utilization of both organic and inorganic nutrient sources, as well as the careful consideration of timing and application methods, can have a beneficial effect on plant development. This finding suggests that the combination of nutrient administration methods, concentrations, and timings resulted in the highest level of growth compared to the other treatments examined in the research. The observed growth could perhaps be attributed to the appropriate nutritional and micronutrient balance resulting from the specific combination of vermicompost, seed treatment, and foliar application of manganese sulphate. Furthermore, the temporal aspect of nutrient delivery is of utmost importance as it aligns with distinct phases of plant growth and development. This result is supported by the findings of Thapaa et al. [1] and Mallick and Majumder [11].

Number of leaves per plant

Number of green leaves per plant increased from 30 DAS to 90 DAS. Highest number of leaves (28.33) was observed in those plots where 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS applied. This treatment was at par to 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS with 26.67 leaves. Least number of leaves per plant (20.67) was recorded in control. The observed results could be attributed to several factors. Vermicompost offers organic nutrients and enhances soil structure, hence facilitating the cultivation of robust and thriving plants. Manganese has a crucial role in facilitating photosynthesis and several physiological processes within plants. The delivery of nutrients through the leaves, known as foliar application, facilitates a direct and effective process of nutrient absorption. The precise amalgamation and concentrations of these treatments may have facilitated the creation of advantageous circumstances for sunflower plants, resulting in an increased leaf count. This result is in conformity with the findings of Aruna and Mohammad [12] and Açikbaş [13].

Table 1: Effect of integrated nutrient management practices on growth attributes of sunflower.

Treatments	Plant height (cm)	No. of leaves plant^{-1}	Leaf area (cm^2)	Stem girth (cm)	Chlorophyll index (SPAD)	Dry matter accumulation (g)
T1 (R.D.F) Control	157.46^{i} ± 1.82	20.67^{d} ± 1.70	310.8^{g} ± 1.2	9.87^{b} ± 0.78	56.28^{ab} ± 1.75	178.80^{ghhhg} ± 1.56
T2 - 50% N through vermicompost + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	180.85^{c} ± 1.14	21.67^{d} ± 1.91	334.4^{e} ± 1.7	10.63^{ab} ± 0.20	57.16^{ab} ± 0.98	218.13^{e} ± 1.86
T3 - 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	189.03^{b} ± 1.33	26.67^{ab} ± 0.47	459.2^{b} ± 1.2	11.31^{a} ± 0.43	57.87^{ab} ± 0.49	297.73^{a} ± 1.88
T4 - 50% N through FYM + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	177.13^{d} ± 1.53	22.22^{d} ± 1.10	322.7^{f} ± 1.4	10.92^{ab} ± 0.32	58.64^{a} ± 0.87	228.07^{d} ± 1.84
T5 - 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	194.47^{a} ± 1.67	28.33^{a} ± 1.25	474.4^{a} ± 2.2	12.20^{a} ± 0.43	59.39^{a} ± 1.49	302.30^{a} ± 1.84
T6 - 50% N through poultry manure + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	172.49^{e} ± 1.65	21.78^{d} ± 1.03	421.7^{d} ± 1.8	10.63^{ab} ± 0.81	55.04^{b} ± 2.17	273.57^{b} ± 2.66
T7 - 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	187.37^{b} ± 1.32	25.67^{bc} ± 0.47	456.3^{b} ± 1.6	11.28^{a} ± 0.46	59.03^{a} ± 0.58	238.17^{c} ± 1.37
T8 - 50% N through vermicompost + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	168.87^{f} ± 1.33	22.44^{d} ± 0.79	442.9^{c} ± 1.3	10.83^{ab} ± 0.38	57.96^{ab} ± 1.33	201.13^{g} ± 3.44
T9 - 50% N through poultry manure + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	165.65^{g} ± 1.74	20.78^{d} ± 0.16	452.7^{bc} ± 1.8	11.23^{a} ± 0.57	57.22^{ab} ± 1.56	198.90^{g} ± 3.27
T10 - 50% N through FYM + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	162.29^{h} ± 1.50	23.33^{cd} ± 1.41	441.9^{c} ± 15.3	10.62^{ab} ± 0.42	57.62^{ab} ± 1.40	209.87^{f} ± 2.04

Leaf area (cm^2)

Highest leaf area (474.4 cm^2) was recorded in those plots where 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS applied. This treatment was closely followed by 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% AT 40 AND 60 DAS and 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with 459.2 cm^2, 456.3 cm^2. Minimum leaf area (310.8 cm^2) was recorded in control (RDF). The remaining treatments showed significant variation among themselves. The maximum leaf area was observed in plots where the specific combination of 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS applied. These findings indicate that the specific combination of vermicompost, seed treatment, and foliar application of manganese sulphate, administered at the prescribed dosages and timings, exhibited a favorable influence on the growth and expansion of sunflower plant leaves. The observed outcomes may be attributed to the impacts of the treatments on plant nutrition and growth.

Vermicompost is a valuable source of organic nutrients that contribute to the enhancement of soil fertility and the promotion of optimal plant health. Manganese plays a critical role in many metabolic activities, encompassing vital functions such as photosynthesis and the activation of enzymes. The delivery of nutrients through the leaves, known as foliar application, enables direct uptake of nutrients, hence offering a particularly effective approach for treating shortages in plant nutrition. The concurrent application of these treatments is believed to have facilitated the creation of ideal circumstances for the growth of sunflowers, resulting in a notable augmentation in leaf area. This result is supported by the findings of Anandakumar et al. [14] and Sai Kumar et al. [15]

Stem girth (cm)

According to different nutrient combinations the stem girth has been observed to vary between 9.87 cm to 12.2 cm. Findings of the study revealed that maximum stem girth (12.2 cm) was recorded in treatment 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was non- significant to 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at

40 and 60 DAS and 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with 11.31 and 11.28 cm respectively. Least stem girth (9.87 cm) recorded in control (RDF). 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS. The observed results could be explained through the combined effects of the treatments on overall plant health, nutrient availability, and growth processes [16].

Vermicompost offers organic nutrients and enhances soil structure, hence facilitating root development and nutrient absorption. Manganese plays a crucial role in a range of biochemical and physiological processes within the plant, encompassing cell division and elongation, hence exerting an impact on stem growth. The administration of nutrients through foliar spraying enables a direct absorbing mechanism, hence enhancing the efficiency of addressing nutritional shortages. The combination of these treatments is expected to generate favorable conditions for sunflower plants, facilitating the allocation of resources towards stem growth and consequently leading to an augmentation in stem girth. The same results were obtained by the study of Afzal et al. [17] and Hellegers [18].

Chlorophyll index

Chlorophyll index is the measure of greenness in leaves. Chlorophyll is the pigment responsible for capturing light energy during photosynthesis, which is crucial for plant growth and energy production. The maximum chlorophyll index (59.39 SPAD) was recorded in 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was non -significant to 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS, 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with value 59.03 and 58.64 SPAD respectively. Supplementary remaining all the treatments were at par to these treatments. Whereas the least chlorophyll index was recorded in control (RDF). The observed outcomes may be ascribed to the impacts of the treatments on the availability of nutrients and the physiology of plants.

The presence of organic matter inside vermicompost has the potential to enhance various aspects of soil quality, including soil structure, water retention, and nutrient availability. This phenomenon has the potential to result in an augmentation of root development and an increase in nutrient absorption, both of which are crucial for the synthesis of chlorophyll. Manganese is a crucial micronutrient required for the process of chlorophyll production. It fulfils a function within the process of photosynthesis by aiding in the synthesis of chlorophyll molecules. The direct application of manganese sulphate onto the leaves facilitates efficient absorption of nutrients, so effectively treating any potential shortages in micronutrients that could potentially hinder the formation of chlorophyll. This result is in conformity with the findings of Sial et al. [16].

Dry matter accumulation

Dry matter of the plant was recorded continuously up to 90 days which has been continuously increased and varied between 178.8 g to 302.3 g. Maximum dry matter accumulation (302.3 g and 297.73 g) per plant was recorded with the application of 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS and 50% N through poultry manure + seed dressing and foliar application of Sodium molybdate @ 0.2% at 40 and 60 DAS. These two treatments showed the same effect on dry matter, so these were non-significant among themselves. 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS and 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS closely followed by 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5 % at 40 and 60 DAS with 273.57 g dry weight. Minimum dry matter (178.8 g) was recorded in control.

The observed results could be attributed to the combined effects of the treatments on plant nutrition, nutrient availability, and physiological processes. The presence of organic matter in vermicompost serves to enhance the nutrient content and structural integrity of the soil. This phenomenon has the potential to facilitate the growth of roots, hence improving the absorption of nutrients and promoting an increase in the accumulation of dry matter. Manganese is involved in a multitude of biochemical activities, encompassing vital functions such as photosynthesis and the activation of enzymes. Sufficient availability of manganese can potentially enhance metabolic activity and promote development. Manganese is involved in a multitude of biochemical activities, encompassing vital functions such as photosynthesis and the activation of enzymes. Sufficient availability of manganese can lead to increased metabolic activity and development. This result is in conformity with the findings of Afzal et al. [17].

CGR and RGR

CGR and RGR determine the rate of the growth of a plant. CGR ranged from 4.04 to 6.77 $gday^{-1}m^{-2}$ Highest CGR (6.77 $gday^{-1}m^{-2}$) was recorded in those plots where 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS applied. This treatment was closely followed by 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS-50 % N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2 % at 40 and 60 DAS with 6.62 $gday^{-1}m^{-2}$ CGR. The lowest CGR (4.04 $gday^{-1}m^{-2}$) was recorded in control (RDF). RGR ranged from 0.01547 to 0.01842 $gg^{-1}day^{-1}$. Maximum RGR (0.01842 $gg^{-1}day^{-1}$) was recorded in 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS-50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was non-significant to 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS - 50 % N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2 %

at 40 and 60 DAS with 0.01823 $gg^{-1}day^{-1}$ RGR. Lowest RGR (0.01547 $gg^{-1}day^{-1}$) was recorded in control (Table 2).

The presence of organic matter in vermicompost serves to enhance the nutrient content and structural integrity of the soil. This phenomenon has the potential to facilitate the growth of roots, hence improving the absorption of nutrients and promoting an increase in the accumulation of dry matter. This result is in conformity with the findings of Gül et al. [4].

Effect of integrated nutrient management practices on yield and yield parameters of sunflower

Capitulum weight (g)

Capitulum weight varied with different nutrient combinations and ranged from 375.56 to 513.59 g. Maximum capitulum diameter (513.59 g) was recorded with 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS. This treatment was closely followed by 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with 496.66 g respectively. Minimum capitulum weight (375.56 g) was recorded in control. The observed increase in capitulum weight can be attributed to the favorable conditions generated by the specific combination of treatments, which likely prompted sunflower plants to concentrate resources towards the production of larger flower heads. Manganese plays a crucial role in a multitude of metabolic processes, encompassing flower formation among its key functions. The optimization of manganese availability has the potential to enhance flower growth. The direct application of manganese sulphate to the leaves as a foliar method ensures the direct provision of essential micronutrients to the plants, hence potentially facilitating the formation of flower heads. The same results were obtained by the study of Sial et al. [16] and Afzal et al. [17].

Capitulum diameter

Highest capitulum diameter (22.7 cm) was recorded with the application of 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was non-significant with 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS and at par with 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS and T2 with 22.39 cm, 21.47 cm and 21.27 cm respectively. Remaining all integrated combination treatments were significant among themselves. Minimum head diameter (19.69 cm) was recorded in control (RDF). Maximum capitulum diameter recorded with 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% that could be attributed.

The presence of organic nutrients in vermicompost has the potential to enhance plant growth and development, hence potentially resulting in increased size and breadth of flower heads. Manganese is involved in a multitude of physiological activities, encompassing cellular division and elongation. Sufficient manganese concentrations have the potential to impact the general growth of plants and contribute to increased diameters of flower heads. This result is in conformity with the findings of Hellegers [18].

Number of seeds per head

Number of seeds per head is the important attribute

Table 2: Effect of integrated nutrient management on CGR and RGR of sunflower.

Treatments	CGR ($gday^{-1}m^{-2}$)	RGR ($gg^{-1}day^{-1}$)
T1 (R.D.F) Control	$4.04^{e} \pm 0.09$	$0.01640^{de} \pm 0.000392$
T2 - 50% N through vermicompost + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	$5.23^{c} \pm 0.06$	$0.01661^{cd} \pm 0.000304$
T3 - 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	$6.62^{b} \pm 0.11$	$0.01823^{a} \pm 0.000257$
T4 50% N through FYM + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	$5.29^{c} \pm 0.05$	$0.01722^{bc} \pm 0.000249$
T5 - 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	$6.77^{a} \pm 0.10$	$0.01842^{a} \pm 0.000222$
T6 - 50% N through poultry manure + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	$5.29^{c} \pm 0.07$	$0.01547^{f} \pm 0.000277$
T7 - 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	$6.53^{b} \pm 0.09$	$0.01751^{b} \pm 0.000165$
T8 - 50% N through vermicompost + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	$4.59^{d} \pm 0.15$	$0.01591^{ef} \pm 0.000203$
T9 - 50% N through poultry manure + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	$4.65^{d} \pm 0.05$	$0.01668^{cd} \pm 0.000528$
T10 - 50% N through FYM + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	$4.74^{d} \pm 0.08$	$0.01636^{de} \pm 0.000195$

which contributed towards yield. The number of seeds ranged from 801.07 to 936.5. Maximum number of seeds (936.5) was recorded under 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was closely followed by 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with 910 seeds per head. The lowest number of seeds per head (801.07) was recorded under control. The maximum number of seeds per sunflower head was observed in plots where the specific combination of treatments mentioned above was applied. These findings indicate that the specific combination of vermicompost, seed dressing, and foliar application of manganese sulphate, at the prescribed quantities and timings, yielded favorable outcomes in terms of the growth and yield of sunflower seeds. Vermicompost, due to its organic nutrient content and ability to build soil structure, has the potential to facilitate robust plant growth. This, in turn, may result in the development of more robust reproductive structures, such as increased seed production [18].

Seed yield (kg ha^{-1})

The seed yield ranged from 1773.33 to 2156.67 kg ha^{-1}. Maximum seed yield (2156.67 kg ha^{-1}) was recorded in 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was at par to 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS and 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with 2076.67 and 2056.67 kg ha^{-1} respectively. The remaining all other treatments were found significant among themselves. Minimum seed yield (1773.33 kg ha^{-1}) was recorded in control (Table 3). The utilization of organic nutrients derived from vermicompost has the potential to augment the overall well-being of plants, stimulate vigorous development, and facilitate a greater abundance of flower heads, hence leading to a subsequent augmentation in seed production. Sufficient manganese concentrations are imperative for a range of metabolic activities, encompassing those associated with the initiation of flowers, the production of fruits, and the maturation of seeds. The application of manganese sulphate to the foliage of plants can supply them with essential micronutrients required for the successful development of seeds. This result is supported by the findings of Anandakumar et al. [14] and Sai Kumar et al. [15].

Effect of integrated nutrient management practices on quality parameters of sunflower

Oil content (%) and Oil recovery (kg ha^{-1})

Highest oil content (42.8%) was recorded in 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was closely followed by 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS and 50% N through

Table 3: Impact of nutrient management practices on yield attributes of sunflower.

Treatments	Capitulum weight (gm)	Capitulum diameter (cm)	Number of seeds per head	Seed yield (g)
T1 (R.D.F) Control	$375.56^{i} \pm 2.83$	$19.69^{cd} \pm 0.494663$	$801.07^{h} \pm 2.04$	$1773.33^{f} \pm 16.99673$
T2 - 50% N through vermicompost + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	$406.88^{g} \pm 1.39$	$21.27^{abc} \pm 0.837987$	$814.97^{g} \pm 1.89$	$1890.00^{def} \pm 48.98979$
T3 - 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	$483.77^{c} \pm 1.14$	$21.47^{ab} \pm 0.471405$	$898.30^{c} \pm 1.80$	$2076.67^{ab} \pm 61.28259$
T4 - 50% N through FYM + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS	$414.78^{f} \pm 1.64$	$19.40^{d} \pm 0.864099$	$878.80^{d} \pm 2.02$	$1990.00^{bcd} \pm 32.65986$
T5 - 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	$513.59^{a} \pm 1.56$	$22.70^{a} \pm 0.725718$	$936.50^{a} \pm 1.96$	$2156.67^{a} \pm 95.68467$
T6 - 50% N through poultry manure + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	$398.01^{h} \pm 2.23$	$20.00^{bcd} \pm 0.648074$	$856.43^{e} \pm 1.86$	$1896.67^{def} \pm 69.44222$
T7 - 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS	$496.44^{b} \pm 2.45$	$20.86^{abcd} \pm 0.752445$	$910.50^{b} \pm 1.90$	$2056.67^{abc} \pm 46.42796$
T8 - 50% N through vermicompost + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	$426.67^{e} \pm 1.36$	$22.39^{a} \pm 0.665184$	$817.70^{g} \pm 1.68$	$1910.00^{de} \pm 48.98979$
T9 - 50% N through poultry manure + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	$445.00^{d} \pm 1.36$	$20.50^{bcd} \pm 0.828654$	$818.87^{g} \pm 1.67$	$1943.33^{cde} \pm 41.09609$
T10 - 50% N through FYM + seed dressing and foliar application of NAA respectively @ 50 ppm and 20 ppm at 40 and 60 DAS	$426.67^{e} \pm 1.36$	$20.20^{bcd} \pm 0.535413$	$824.97^{f} \pm 1.37$	$1840.00^{ef} \pm 57.15476$

FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with 40.9% and 40.3%. The remaining treatments were significantly better in oil content as compared to control. Minimum oil content (35.6%) was recorded in control. Maximum oil recovery (978.6 kg ha^{-1}) was recorded with the application of 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was significantly followed by 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at 40 and 60 DAS with 898.7 kg ha^{-1}. 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS also showed comparable result as compared to others. All the treatments were significant among themselves. While the least oil recovery (789.5 kg ha^{-1}) was recorded in control as mentioned in figure 3a.

The optimization of oil recovery and oil content in sunflower plants was achieved with the application of a specific combination of 50% N via vermicompost, seed dressing, and foliar spray of manganese sulphate. This observed improvement can potentially be attributable to the treatment methods. N is an essential nutrient that plays a critical role in facilitating plant development and oil production. The application of vermicompost with a N content of 50% is expected to have contributed to a consistent supply of N, hence facilitating the growth and development of the plant. This, in turn, is likely to have resulted in an increase in the accumulation of oil inside the plant. The use of the vermicompost treatment may have potentially enhanced the holistic well-being and nutrient assimilation efficacy of the sunflower plants, hence facilitating an increase in oil extraction. Seed dressing treatments frequently encompass the direct application of beneficial microbes or nutrients onto the seeds.

This phenomenon has the potential to augment the process of germination, facilitate the growth of roots, and optimize the absorption of nutrients. The potential correction of any manganese deficiency in the plants and subsequent optimization of their oil production pathways might have been achieved with the application of manganese sulphate at a concentration of 0.5% via foliar means. The concurrent application of various treatments may have engendered synergistic effects, whereby the distinct treatments mutually augmented their respective advantages. The enhanced availability of nutrients resulting from the application of vermicompost may have acted in conjunction with the effects of manganese sulphate to facilitate the process of oil synthesis. The physiological and biochemical mechanisms exert a significant influence on oil production in plants. It is plausible that the therapies exerted an influence on the enzymatic activity and pathways associated with oil manufacture, hence leading to an increase in the storage of oil. This result is supported by the findings of Anandakumar et al. [14], Sai Kumar et al. [15] and Jat et al. [19].

Protein content (%)

Protein content is directly related to the N content in seed. The protein content significantly varied with different nutrient management practices and has ranged from 17.4 % to 21.4%. Maximum protein content (21.4%) was recorded in 50% N through vermicompost + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS which was at par with 50% N through poultry manure + seed dressing and foliar application of sodium molybdate @ 0.2% at40 and 60 DAS and 50% N through FYM + seed dressing and foliar application of manganese sulphate respectively @ 1.0% and 0.5% at 40 and 60 DAS with 20.5% and 20.2%. as observed in figure 3b. The combination of treatments 50% N through vermicompost, seed dressing, and foliar application of manganese sulfate appears to have led to the maximum protein content in sunflower plants at both 40 and 60 DAS that could be possibly due to 50% N application through vermicompost

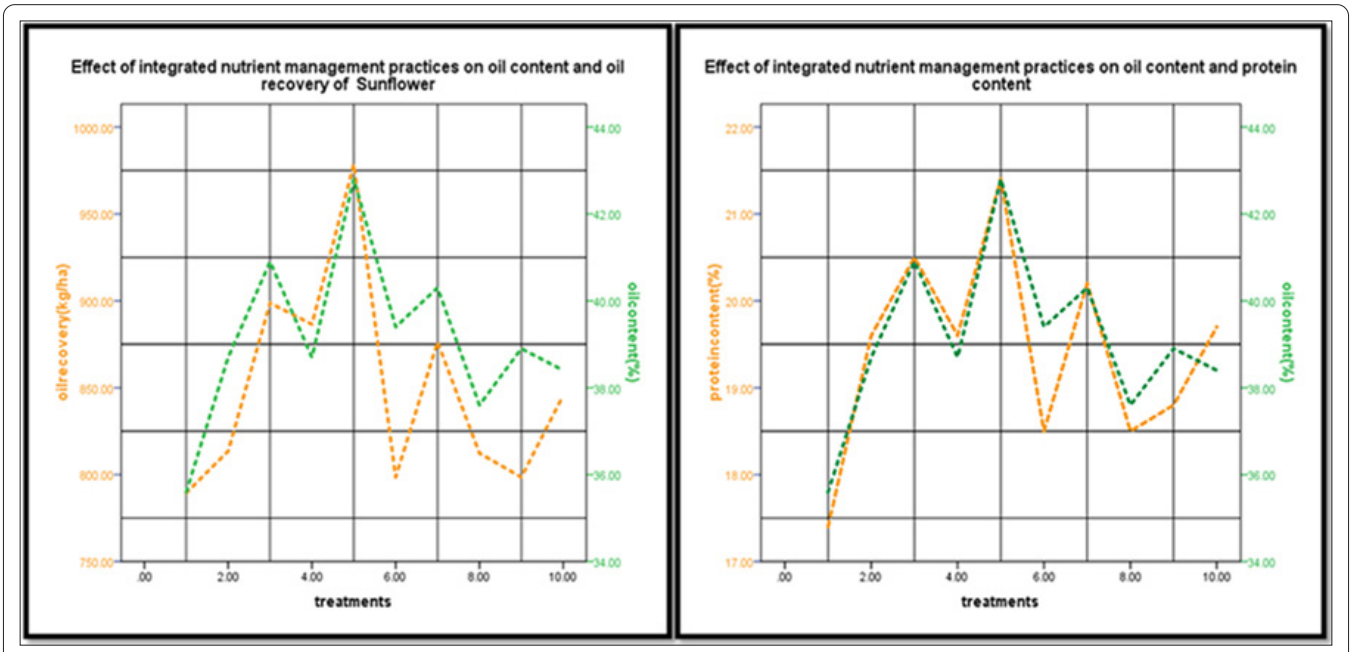

Figure 3: (a) Effect of integrated nutrient management practices on oil content and oil recovery of sunflower and **(b)** Effect of integrated nutrient management practices on oil content and protein content.

Table 4: Correlation of growth attributes with yield attributes of sunflower.

Correlations										
		Plant height	**No. of leaves**	**Chlorophyll index**	**Stem girth**	**Leaf area**	**Capitulum weight**	**Capitulum diameter**	**No. of seeds per head**	**Seed yield**
Plant height	Pearson Correlation	1	0.825**	0.789**	0.601	0.369	0.784**	0.56	0.871**	0.909**
No. of leaves	Pearson Correlation	0.825**	1	0.796**	0.679*	0.617	0.898**	0.616	0.879**	0.854**
Chlorophyll index	Pearson Correlation	0.789**	0.796**	1	0.700*	0.693*	0.912**	0.639*	0.803**	0.938**
Stem girth	Pearson Correlation	0.601	0.679*	0.700*	1	0.317	0.752*	0.477	0.625	0.717*
Leaf area	Pearson Correlation	0.369	0.617	0.693*	0.317	1	0.755*	0.579	0.464	0.56
Capitulum weight	Pearson Correlation	0.784**	0.898**	0.912**	0.752*	0.755*	1	0.626	0.820**	0.909**
Capitulum diameter	Pearson Correlation	0.56	0.616	0.639*	0.477	0.579	0.626	1	0.344	0.55
No. of seed per head	Pearson Correlation	0.871**	0.879**	0.803**	0.625	0.464	0.820**	0.344	1	0.922**
Seed yield	Pearson Correlation	0.909**	0.854**	0.938**	0.717*	0.56	0.909**	0.55	0.922**	1

Note: **. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).

likely provided a consistent source of N, promoting the formation of amino acids, the building blocks of proteins.

For protein synthesis to occur, it is essential to have a sufficient availability of N, along with other necessary nutrients. Manganese plays a crucial role in numerous enzymatic activities occurring in plants, particularly those associated with N metabolism. It is possible that the application of manganese sulphate to the leaves could have enhanced the utilization of N to produce proteins. The concentrations and timing of application of vermicompost and manganese sulphate are expected to have an impact on nutrient availability and absorption. It is plausible that the treatments exerted an influence on plant physiology that was conducive to the process of protein production. This may encompass the stimulation of many pathways and enzymes that are implicated in the biosynthesis of amino acids and proteins. This result is supported by the findings of Sai Kumar et al. [15], Phonglosa et al. [20] and Puste et al. [21].

Correlation of growth attributes with yield attributes

From table 4 there was significant positive correlation exist between growth attributes and yield attributes. If plant height increased, then dry matter of plant also increased due to which capitulum head diameter and weight also increased. More capitulum diameter is directly related to stem girth which again related to number of seed per head. So, due to this positive interaction between the parameters, yield ultimately increased.

Conclusion

In conclusion, the implementation of integrated nutrient management exhibits significant potential in addressing the increasing nutrient requirements of contemporary agricultural practices. Additionally, it can contribute to the preservation of production sustainability by preventing the decline of soil health and the degradation of crop quality. In summary, the findings have demonstrated the sustainability of growth, productivity, and oil production through the implementation of integrated nutrient management techniques, which involve the utilization of various organic manures and inorganic fertilisers from different sources. The implementation of integrated nutrient management practices for sunflower cultivation in Punjab areas, specifically involving the use of 50% N through vermicompost, along with seed dressing and foliar application of manganese sulphate at concentrations of 1.0% and 0.5% respectively at 40 and 60 DAS, is expected to offer an environmentally sustainable, scientifically sound, and economically feasible approach.

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Conflict of Interest

None.

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