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Impact of Nano-fertilizers and Nutrient Management on Growth and Yield of Strawberry

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Abstract: In the pursuit of enhancing agricultural practices, this research delves into the intricate interplay between nano-fertilizers, nutrient management strategies, and their collective impact on the growth and yield metrics of strawberries. The present research was carried out to ascertain the impact of nano-fertilizers (ZnO and FeO) and integrated nutrients management (Phosphate solubilizing bacteria (PSB) & *Azotobacter*) on strawberry (Fragaria x ananassa Duch.) Cv. Winter Dawn. The results of present work showed different treatments of nano fertilizers and nutrients management has variable impact on strawberry growth such as treatment 7 (T_7: 50% Recommended dose of fertilizer) + FYM + vermicompost + *Azotobacter* + 150 ppm nano-ZnO + 150 ppm nano-FeO) showed highest growth parameters regarding number of leaves (14), plant height (11.24 cm), leaf area (74.86 cm^2) and chlorophyll content (52.41 µmol/m^2) etc. compared with other treatments. However, treatment (T_9: 50% RDF + FYM + vermicompost + *Azotobacter* + PSB + nano-ZnO + nano-FeO) indicated bit similar regarding number of leaves (13.33), plant height (11.96 cm), leaf area (74.08 cm^2) and chlorophyll content (53.06 µmol/m^2) etc. The biochemical parameters were also observed higher in treatment (T_9). Considering above results, it can be concluded that the dose, i. e., 50% RDF along with FYM, vermicompost and *Azotobactor* + ZnO + FeO (150 ppm) could enhance growth and yield of strawberry.

Keywords: Winter Dawn, FYM, Vermicompost, PSB, Azotobacter, ZnO, FeO.

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Research Article

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1. Introduction

Nano-fertilizers have been identified as a potential tool to achieve sustainable intensification in agricultural. This is a reason being their ability to synchronize the release of nutrients, such as nitrogen and phosphorus, with increases in yield and production of crops, while simultaneously decline the amount of fertilization inputs [*El-Bialy et al.*, 2023]. Due to the ability of consistent and slow release of nutrients, nanofertilizers can enhance nutrient use efficiency (NUE) and help plants to uptake nutrients easily [*Reddy and Chhabra*, 2022]. Recent studies have reported significant improvements in crop production with 30% increases crop yield compared with conventional fertilizers input [*Mandal et al.*, 2021; *Weber et al.*, 2021].

Integrated nutrient management (INM) is another strategy which can serves as a safe and effective approach for managing crop residues and producing high-quality compost [*Kumar et al.*, 2018]. It involves the integration and management of both chemical and organic fertilizers to maintain fertility of the soil by providing the necessary nutrients to plants. INM focuses on timely nutrient application to optimize crop yields and minimize environmental impacts. It offers economic options for meeting crop nutrient requirements, reducing costs, improving soil physiochemical conditions, preserving soil nutrients, and promoting better physiological functions in plants [*Mandal et al.*, 2021]. Additionally, INM provides sustainable solutions for managing agricultural waste while safeguarding the environment.

Strawberry (*Fragaria* × *ananassa* Duch.) is a highly nutritious soft fruit that is globally favoured and cultivated worldwide nearly 75 countries. China is leading producer of strawberries, with an estimated production of approximately 3,336,690 tons during the 2020–2021 period, whereas USA follows with a production of around 1,055,963 tons of strawberries [*Food and Agriculture Organization of the United Nations*, 2023]. Strawberry is an herbaceous crop having prostrate growth habit, fleshy fruit contains small seeds on the exterior, and enriched with vitamins and minerals, making it a popular choice among consumers [*Kumar et al.*, 2018]. The preferred pH range for soil cultivation of strawberries is approximately 4.5–6.5.

Recently, breeding of new varieties that is suitable for subtropical regions and research on different combinations for its nutrients requirements has as a result to boosting the cultivation of strawberry even some of the non-traditional regions [*Usenik et al.*, 2005]. Cultivation of strawberry is profitable under subtropical regions due to the development of some cultivars that are suitable for such areas [*Saini et al.*, 2021]. Quality of fruits is found excellent in hilly areas as compared with plain regions. Similarly, the colour and flavour development are not proper in plains as compared to hilly varieties. To overcome from such challenges appropriate nutrient balance is required. Thus, the series of experiments are needed to standardize the appropriate dose or combination of nutrients. Considering the importance of strawberry and role of nanofertilizers in crop improvement, the present study was aimed to evaluate integrated use of nano fertilizers and nutrient management to improving crop yield and quality produce.

2. Materials and Methods

2.1. Experimental setup and treatment details

The experiment was carried out at "Lovely Professional University" (Phagwara) Punjab, India during the 2022–23. Experimental plot is located at 31.2242° N latitude and 75.77° E longitude, is situated approximately 768 ft (237 meters) above mean sea level. The region experiences an average annual rainfall of 816 mm. In the study, uniform-sized strawberry's runners carefully transplanted in the first week of November (2022–23) season.

The experiment consisted of following treatments such as

T_0: Control 100% RDF,

T_1: 50 % RDF+ FYM + ZnO + FeO,

T_2: 50% RDF + FYM + *Azotobacter* + ZnO + FeO,

T_3: 50% RDF + FYM + Phosphate solubilizing bacteria + ZnO + FeO,

T_4: 50% RDF + Vermicompost + ZnO + FeO,

T_5: 50% RDF+ Vermicompost + *Azotobacter* + ZnO + FeO,

T_6: 50% RDF+ Vermicompost + PSB + ZnO + FeO,

T_7: 50% RDF+ FYM + Vermicompost + *Azotobacter* + ZnO + FeO,

T_8: 50% RDF + FYM + Vermicompost + PSB + ZnO + FeO,

T_9: 50% RDF+ FYM + *Azotobacter* + PSB + ZnO + FeO.

Note: RDF: Recommended dose of fertilizer, FYM: Farm Yard Manure, PSB: Phosphate solubilizing bacteria

2.2. Observation of Plant Growth, Sample Collection and Analysis

Urea was applied in two splits at the concentration of 23.9 g per square meter and DAP was applied at the amount of 21.7 g and MOP was applied at the amount of 20 g per square meter, before transplanting of runners and after that on flowering while phosphorus and potash were applied prior to planting. The solutions of *Azotobacter* and PSB were prepared by dissolving 50 ml of these bio-fertilizers into 20 liters of water. Nanoparticles of ZnO and FeO were prepared at concentration of 150 ppm. Commercial nano Zinc oxide and Iron oxide fertilizers were used in the form of foliar application on plants of Strawberry Cv. Winter Dawn. Nano-ZnO and FeO were obtained from ad-nano Technologies Pvt Ltd prepared by the chemical precipitation method containing the purity rate 99.9%, average particle size 30–80 nm and bulk density 0.58 g/cm^3.

At the initial stage, black polythene mulching (thickness 200 gauges) was used. Plant's growths were noted at a day's interval of 15 initially. Biochemical observations were recorded after the harvesting of the fruits. After the physiological maturity of the fruits per hectare yield of crop and yield of crop per plant was recorded.

Leaves (fully opened) counted (randomly) and the average was calculated. The plant's height was individually measured using a measuring scale, leaf area meter is used to measure leaf area. SPAD 502 (m) was used to measure the chlorophyll content in the leaves. Weight of fruits was noted using an electric weighing machine (g). The length of fully developed berries was measured using a vernier calliper and expressed in centimetres. TSS in the fruits was calculated using a refractometer (digital) and expressed in degrees Brix.

Ascorbic acid content in the fruit was estimated titrimetrically using 2,6-dichloro-phenolindophenol dye following a modify procedure from A.O.A.C. Value of ascorbic acid was expressed as mg per 100 g of fruit pulp of fresh fruits. Titratable acidity (% citric acid) was determined by extracting and filtering the juice of fresh fruits. The 5 ml of the juice were taken and diluted with water (distilled) to a total volume of 50 ml. The diluted juice was titrated over 0.1N NaOH with the help of phenolphthalein used as an indicator. The endpoint was indicated by a light pink color, and the observed values were defined as citric acid/100 ml of juice. At the time of harvest, the amount of fruit per plot was calculated, and the ratio of fruit per plant was determined.

2.3. Statistical analysis

Statistical analysis of on plant's growth, yield and quality parameters was done significantly and the results were interpreted accordingly. To assess the performance of the different treatments, the data were analysed using analysis of variance (ANOVA). Significance tests were conducted at a 5% significance level. The analysis was performed using OPSTAT, which calculates measures such as the standard error of means SE(m), standard error of differences SE(d), and critical difference (CD) among all treatments.

3. Results

3.1. Impact of Nano-fertilizer and INM on Plant's Growth Indices

With the growth phase of the crop, significant variations were found between all the treatments such as total number of leaves, plant's height, spreading of plants as well as area of leaves. There was a steady rise of these morphometric indices. The rate of increase in these growth parameters were diminished in the later stages of plant growth (Figure 1). The treatment T_7:– 50% RDF + FYM + Vermicompost + *Azotobacter* + ZnO + FeO*)* showed the Maximum number of leaves (14), while the control (T0, 100% RDF) had the lowest number of leaves (12) as shown in in Figure 2. Maximum plant height (12.32 cm) was observed in treatment T_5:- 50% RDF + Vermicompost + *Azotobacter* + ZnO + FeO) as comparison with T0 (9.88 cm) (Figure 3).

The maximum leaf area (74.86 cm^2) was recorded in T_7 treatment compared to the untreated (T0) plants (72.12 cm^2). The chlorophyll content was highest in T_5: 50 % RDF + Vermicompost + *Azotobacter* + ZnO + FeO) with a value of 53.06, followed by T_9: – 50% RDF+ FYM + *Azotobacter* + PSB + ZnO + FeO) at different intervals of 30, 60, 90,

(a) **(b)** **(c)**

Figure 1. a) Vegetative growth stage, b) Phase of flowering, c) Fruiting phase of crop.

and 110 days. The best results were observed in T_7 (Figure 4) and T_5 after following the other treatments. It was observed that the simultaneous application of ZnO and FeO nanoparticles at a concentration of 150 ppm each led to enhanced growth and increased yield in strawberry.

3.2. Effect on Quality and Yield Parameters

The quality parameters e. g., weight of fruits, fruit length, TSS of fruits, ascorbic acid content, total sugars, fruits per plant significant variations were observed. The maximum fruit weight (10.59 g) was recorded in T_5 (Figure 5). The maximum (5.01 cm) fruit length was under the treatment of T_9 plants. The plants treated with T_9, shows variations as compared with control (3.05 cm) in case of length of fruits.

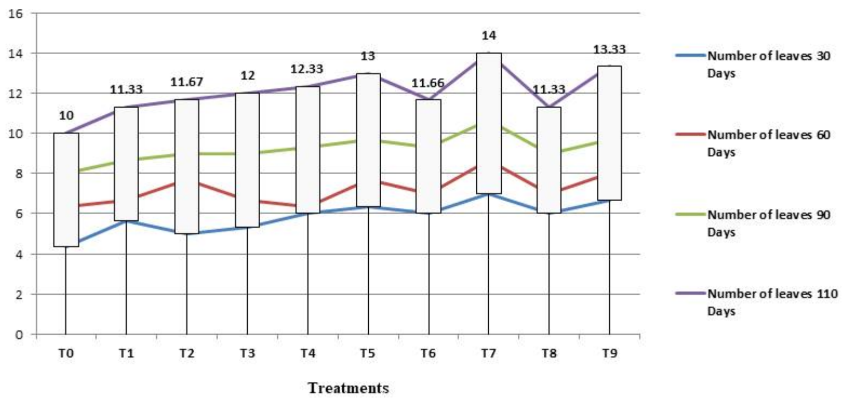

Figure 2. Role of nano-fertilizers and integrated nutrient management on number of leaves of plants of crop strawberry (*Fragaria* × *ananassa Duch.*) Cv. Winter Dawn.

Maximum fruit TSS 6.95° brix was noted down in T_7 treatment followed by the T_9, 6.55° brix as compared with the control 5.53° brix. Increased TSS (° brix) levels in high nitrogen-related levels are likely to be because of the certainty that nitrogen absorption may play a role in the regulation during fruit ripe stage, the carbohydrate conserves of roots along with stems are heavily absorbed by the fruit which may result in higher TSS fruit set. Maximum value of ascorbic acid (mg/100 gm pulp) 52.29 mg/100 gm was noted in the treatment T_7 after following the treatment T_9 that is 50.79 (mg/100 gm pulp) as compared to control 48.63 (mg/100 gm pulp).

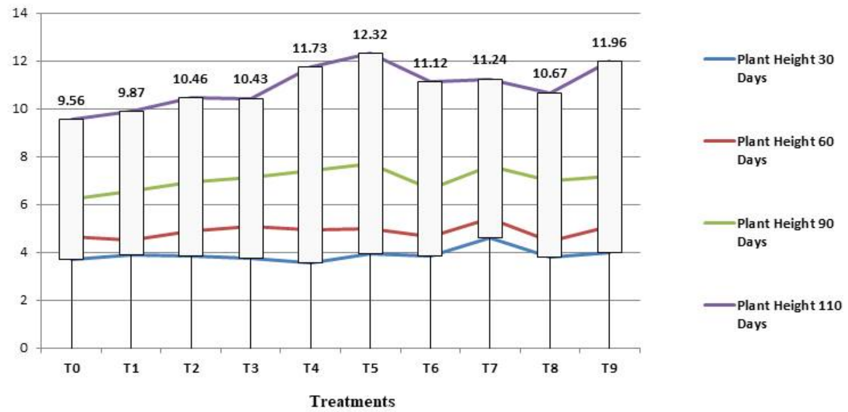

Figure 3. Role of nano-fertilizers and integrated nutrient management on plant height of crop strawberry (*Fragaria* × *ananassa Duch.*) Cv. Winter Dawn.

Total sugar was recorded maximum in treatment T_9 (7.50%) followed by T_7 (7.45%) as compared with the control (6.54%) (Figure 6). Harvested fruits from the plants which were treated with the vermicompost, were found producing fruits with higher total sugars (%) in higher amount. Maximum fruit yield/plant 116.78 g was noted in the T_7 followed by 100.69 g in T_9 respectively. Minimum fruit yield per plant 57.48 g was recorded in T_0 (Figure 6).

(a) **(b)**

Figure 4. Comparison of total number of fruits per plant RDF with T_7.

4. Discussion

Application of manures such as vermicompost, farmyard manure and poultry manures along with nano-fertilizers e.g., Zinc oxide and Iron oxide, and bio-fertilizers like *Azotobacter*, *Beijerinkia*, and *Azospirillum*, has been found to enhance vegetative growth parameters in strawberry crop. When *Azotobacter* is applied in combination with farmyard manure, it enhances the vegetative growth due to improved nutrient uptake by the plants at a slower pace [*Usenik et al.*, 2005]. Significant role of *Azotobacter* is attributed to its ability to fix atmospheric nitrogen, while FYM enhances the soil's water and nutrient holding capacity. *Azotobacter*, has been demonstrated to elevate the mobilization of nutrients within the soil matrix. This, in turn, establishes a continuum of nutrient accessibility, thereby ensuring an enduring nutrient reservoir to fuel the botanical maturation process [*Sharma et al.*, 2018].

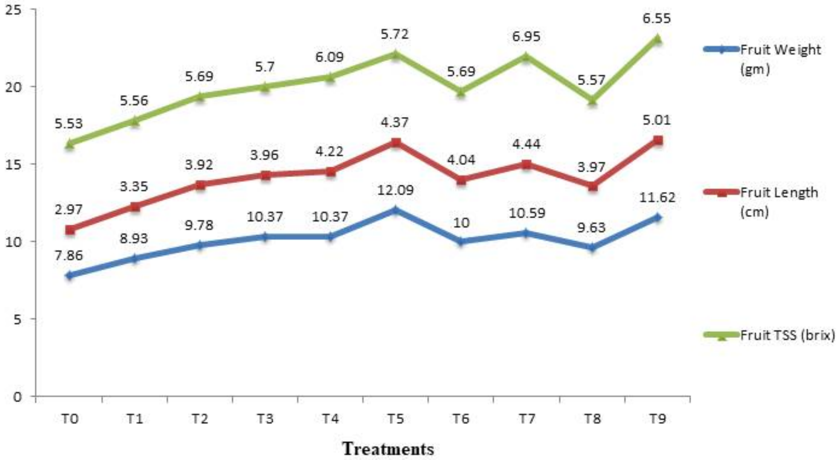

Figure 5. Role of Nano-fertilizers and Integrated Nutrient Management on TSS of fruits, length of fruits, weight of fruits of strawberry.

According to a study conducted in a region of northern India (semi-arid), different levels of vermicompost were applied with bio-fertilizer to maintain the fertilizer requirements of strawberries. Results showed that increasing dose of vermicompost consequently, improve the growth (No. of leaves, leaf length, plant height and plant spreading etc.) of Strawberry plants. Vermicompost applied at the concentration of 10 t/h along with free-living bio-fertilizers enhance the spreading of the plants (16.1%), total area of leaf (31%), and dry matter (17.8%) [*Singh et al.*, 2010].

The application of zinc oxide can positively influence growth of plant and development. For instance, same findings were demonstrated by Laware (2014) in onions [*Laware and Raskar*, 2014]. They reported that lower concentrations of zinc oxide NPs had a significant impact on germination of seeds. However, higher doses of ZnO were found to impair seed germination. Furthermore, the impact of nanoparticles on germination can vary depending on the specific concentrations & plant species involved [*de la Rosa et al.*, 2013]. In a study by [*Raliya and Tarafdar*, 2013], different concentrations of NPs were applied to cucumber, tomato, alfalfa, and it was observed that seed germination of cucumber was enhanced [*Raliya and Tarafdar*, 2013].

In the present study, the combination of vermicompost and farmyard manure with nanofertilizers has shown promising results in increasing flower production and overall yield in strawberry plants. Vermicompost has the potential to produce enzymes, growth hormones, antifungals, and antibacterial compounds, which contribute to improved commercial yields [*Zargar et al.*, 2008]. When these organic manures are applied along with bio-fertilizers and nano-fertilizers, they aid in the decomposition of harmful elements, improve soil structure, promote root development, enhance soil water availability, and increase soil microbial biomass, ultimately leading to better plant growth in terms of height, spreading, leaf area, etc. So, it was observed when vermicompost and neem cake were applied with different doses of free-living bio-fertilizers in strawberries [*Arancon et al.*, 2004].

[*Naidu et al.*, 2001] claimed that the effect of various doses of organic manure and bio-fertilizers (symbiotic) was significant in case of tomato crop growth. They showed maximum number of flowers/plant and early flowering with good yield as compared to non-treated plants. Increase in soil-microbial biomass, vermicompost, along with FYM, having direct role in the production of hormones and humus in the soil [*Naidu et al.*, 2001]. Combined application of FYM, vermicompost, and PSB (bio-fertilizer) resulted in a higher no. of flowers per plant and increased yield compared to non-treated guava plant [*Sharma et al.*, 2018].

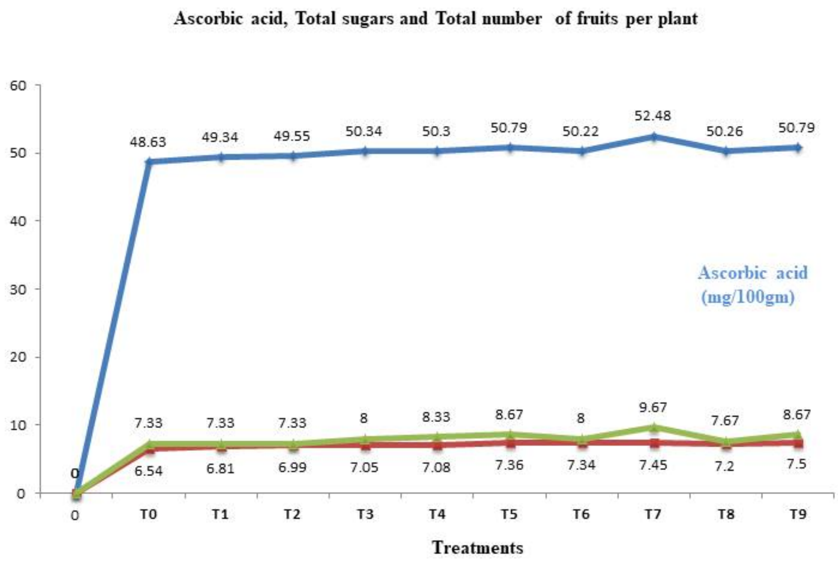

Figure 6. Role of Nano-fertilizers and Integrated Nutrient Management on Vitamin 'C' content (mg/100gm) and total no. of fruits per plant of crop strawberry (*Fragaria* × *ananassa Duch.*) Cv. Winter Dawn.

Azotobacter (biofertilizer) along with FYM and vermicompost in strawberry results in good fruit length, maximum number of fruits per plant but combination of PSB (phosphate solubilizing bacteria) with press mud and poultry manure improves the weight and shape of fruits [*Nazir et al.*, 2006]. These results indicate that the combination of farm waste manures, bio-fertilizers and nano-fertilizers positively influences nitrogen fixation, phytohormone production, and nutrient uptake, leading to improvements in fruit quality characteristics [*Sajjadi et al.*, 2017]. Nano-fertilizers boost nutrient use efficiency by enabling a slow and constant release of nutrients, thus assisting nutrient uptake by plant.

5. Conclusion

Based on the meticulous research study conducted within the timeframe of 2022–23, a consecutive series of conclusions can be derived, highlighting the pre-eminence of treatments T_7 and T_9. These treatments, denoted as T_7 comprising 50% of the recommended dosage of fertilizers in conjunction with farmyard manure, vermicompost, *Azotobacter*, ZnO, and FeO, and T_9 encompassing an analogous composition but incorporating phosphate solubilizing bacteria, ZnO, and FeO, have distinctly emerged as the most optimal. Their superiority is evidenced in terms of augmenting the growth dynamics, enhancing the intrinsic quality, and amplifying the overall yield parameters of the esteemed Strawberry Cv. Winter Dawn. In summation, it is unequivocally affirmed that the judicious amalgamation of farmyard manure and vermicompost fortified with *Azotobacter*, bolstered further by the incorporation of ZnO and FeO at a concentration of 150 ppm, bestows momentous and noteworthy outcomes upon the cultivation of Strawberry Cv. Winter Dawn.

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Conflict of Interest. Authors declared that they have no conflict of interest.

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