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Effect of integrated nutrient management on growth and yield of hybrid maize (*Zea mays*. L)

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Abstract
A field trial was carried out at the Experimental Farm in the Department of Agronomy at Annamalai University, located in Chidambaram, Cuddalore district, Tamil Nadu, during the *kharif* season of 2024, to investigate the effects of integrated nutrient management on the growth and yield improvement of hybrid maize. The experiment was laid out in randomized block design (RBD) with nine treatments and replicated thrice. The treatments included of different combinations of recommended dose of fertilizers with organic amendments such as vermicompost, poultry manure, pressmud and azophos biofertilizer applied as soil application. From the results, revealed that the application of 100% RDF + 25% N through vermicompost + azophos @ 4 kg ha^{-1} (T_5) was significantly influenced the higher growth parameters *viz*., plant height (236.7 cm), LAI (6.41), DMP (15634 kg ha^{-1}), CGR (17.83, 10.02 g m^{-2} day^{-1}), AGR (2.67, 1.50 g plant^{-1} day^{-1}) and yield attributes like cob length (24.3 cm), cob diameter (6.07 cm), No. of grains cob^{-1} (515), grain yield (7508 kg ha^{-1}) and stover yield (10018 kg ha^{-1}). It was closely followed by the application of 100% RDF + 25% N through poultry manure + azophos @ 4 kg ha^{-1}. The research indicated that the combined use of inorganic fertilizers, vermicompost, and azophos greatly improves the growth and productivity of hybrid maize.

Keywords: INM, vermicompost, yield, hybrid maize, azophos, growth

Introduction
Maize (*Zea mays* L.) is regarded as a versatile crop cultivated in both tropical and temperate regions globally. In India, maize ranks as the third most significant food grain, following wheat and rice. Due to its superior genetic production potential compared to other cereal crops, maize can adapt to a wide range of agro-climatic conditions. As a result, it is often referred to as "miracle crop" and is also known as the "Queen of cereals."

Worldwide, maize is cultivated across 206.19 million hectares, resulting in a total yield of 1228.09 million metric tonnes, with an average output of 5.96 metric tonnes for each hectare. In India, maize is cultivated over 11.24 million hectares, resulting in a total production of 37.67 million metric tonnes, which equates to an average yield of 3.35 metric tonnes per hectare. (United States Department of Agriculture, 2023) [1]. Among the various maize producing countries, India positioned 4th in terms of the area under cultivation and 7th in overall production globally, contributing approximately 4% of the world's maize area and around 2% of the total production (Indian Council of Agricultural Research – Indian Institute of Maize Research).

Maize crop is referred as an exhaustive feeder and its productivity as mainly depends on nutrient management. The strategies for nutrient management are crucial for the sustainable cultivation of the crop. High yielding hybrid maize varieties are known to respond well to the application of chemical fertilizers. (Kumar *et al*., 2016) [2]. Chemical fertilizers are recognized as the main provider of nutrients for plants. Soil health is supported by the application of organic materials, which enhance soil organic matter, physical and chemical properties, and beneficial microorganisms. The function of organic manure is to uphold soil fertility and enhance crop yields, which primarily involves the application of organic materials like vermicompost, poultry manure, and pressmud. It is recommended to reduce the use of synthetic fertilizers and complement them with organic manures such as vermicompost, poultry manure, pressmud, and

biofertilizers to achieve sustainable productivity, profitability, and soil health.

INM pertains to systems, which aims to enhance and sustain soil fertility to support crop productivity, utilizing chemical fertilizers in combination with organic manures that provide rich nutrients through biological processes. The integration of organic materials alongside chemical fertilizers proves effective in boosting nutrient availability in the soil, enhancing the physico-chemical characteristics of the soil, and ultimately increasing crop productivity (Sharma *et al*., 2020) [3]. The utilization of organic manures as a sustainable nutrient source for the importance of plant growth. Incorporating organic manures along with the inorganic fertilizers can enhance crop productivity by reducing soil bulk density, improving water retention capacity and improving the efficiency of essential macro and micronutrients. Achieving a proper balance between organic and inorganic fertilizers is essential not only for improving crop yields but also for preserving soil health.

Nitrogen is one of the key macro elements that can restrict maize production (Baral and Adhikari., 2015) [4]. Phosphorus is essential for numerous physiological processes in plants, including the formation of phospholipids, nucleic acids, adenosine triphosphate, enzymes, and its contribution to the overall dry weight of the plant (Sharifi *et al*., 2024) [5]. Potassium is another vital nutrient for agricultural crops, offering numerous beneficial effects on plants, including its involvement in carbon metabolism, enzyme activation, and enhancing resistance to diseases and pests (EL-Shal., 2016) [6].

Vermicompost is an eco-friendly organic waste product that is transformed into an organic source for agricultural use and for improving soil health. It aids in nutrient retention and increases the effectiveness of chemical fertilizers, while also helping to neutralize soil acidity. Moreover, it improves the soil's structure, texture, aeration, and water retention capacity, while also minimizing soil erosion.

Microbial activity is crucial in agriculture as it plays an important role in the movement and availability of essential minerals for plant growth, ultimately reducing the need for chemical fertilizers (Verma *et al*., 2018) [7]. Azophos is a composite biofertilizer inoculum that contains both Azospirillum and Phosphobacteria. It enhances the release of organic acids through a proton extrusion mechanism, promoting growth and improving the growth characteristics of maize. The inclusion of Azophos has facilitated the fixation of nutrients in the soil, ensuring a consistent supply of nutrients throughout the growth period, which has contributed to improved root and shoot development (Kumar *et al*., 2015) [8].

Materials and Methods

A field trial was carried out during the *kharif* season (from July to October) in 2024 at the Experimental farm of the Agronomy Department at Annamalai University, located in Annamalai Nagar, Chidambaram, Tamil Nadu. The experimental farm is situated at a latitude of 11° 24' N and longitude of 79° 44' E, with an elevation of + 5.79 m above the mean sea level. The climate of Annamalai Nagar is relatively warm, featuring hot summer months. Throughout the cropping season, the highest temperature recorded fluctuated between 30.6 °C and 37.5 °C, averaging 35.18 °C. The lowest temperature ranged from 19.4 °C to 22.8 °C, with an average of 20.95 °C. Relative humidity varied from 64 to 80 percent, averaging at 70.41 percent, while the crop experienced a total rainfall of 385.12 mm over the course of 21 rainy days. The soil had a clayey loam texture, with an initial fertility status indicating 230 kg ha^{-1} of available nitrogen (low), 21.50 kg ha^{-1} of available phosphorus (medium) and 262 kg ha^{-1} of available potassium (medium).

The experiment was laid out in randomized block design (RBD) with nine treatments and replicated thrice. The treatment comprised of T_1 – control, T_2 – 100% RDF (250:75:75) kg NPK ha^{-1}, T_3 – 100% RDF + azophos @ 4 kg ha^{-1}, T_4 – 75% RDF + 25% N through vermicompost + azophos @ 4 kg ha^{-1}, T_5 – 100% RDF + 25% N through vermicompost + azophos @ 4 kg ha^{-1}, T_6 – 75% RDF + 25% N through poultry manure + azophos @ 4 kg ha^{-1}, T_7 – 100% RDF + 25% N through poultry manure + azophos @ 4 kg ha^{-1}. T_8 – 75% RDF + 25% N through pressmud + azophos @ 4 kg ha^{-1}, T_9 – 100% RDF + 25% N through pressmud + azophos @ 4 kg ha^{-1}.

The hybrid maize variety NK 7328 was chosen for this experiment, and the seeds were planted in rows with a spacing of 60 cm, while the plants were spaced 25 cm apart. Seeds were sown at a depth of 5 cm, with two seeds placed in each hole. The recommended fertilizer application was 250:75:75 kg ha^{-1} of N, P_2O_5, and K_2O, following the fertilizer schedule. Urea (46% N), single super phosphate (16% P_2O_5), and muriate of potash (60% K_2O) were used to supply the required nitrogen, phosphorus, and potassium nutrients, respectively. The recommended dose of phosphorus and potassium were applied as a basal. Half dose of nitrogen was also applied at basal, while the remaining half dose of nitrogen was top-dressed in two applications on the 25th and 45th days after sowing (DAS). Fertilizers were applied at two levels: 75% and 100% of the recommended dose of fertilizers (RDF), supplemented with vermicompost, poultry manure, pressmud, and azophos according to the treatment schedule. A need-based practices for plant protection was taken based on economic threshold of pests and diseases. The total and net plot dimensions were 5 × 4 m and 3.8 × 3.6 m, respectively. The net plot area was employed to assess crop yields. Observations of the crop were recorded at 30 DAS, 60 DAS, and during the harvest stage. The crops were manually harvested at physiological maturity, and yields were measured at a moisture level of 14%. Biometric data from plant samples and computed data were statistically analyzed using the method outlined by Gomez and Gomez [9]. The critical difference was established at a 5% probability level when the F test indicated that the treatment difference was significant.

Results and Discussion

Growth parameters

The result of this study on combined application of organic manure, inorganic fertilizer along azophos on hybrid maize revealed that the growth characters were markedly influenced by the application of 100% RDF + 25% N through vermicompost + azophos @ 4 kg ha^{-1} (T_5). The highest value of growth parameters such as plant height, leaf area index, and dry matter production (236.7 cm, 6.41, and 15634 kg ha^{-1}, respectively) are illustrated in Table 1. This might be due to the increased availability of nitrogen may have contributed to faster cell division and enlargement, which, along with sufficient amounts of phosphorus and potassium, supports quicker cell division and enhanced cell growth. Wailare and Kesarwani (2017) [10] and Adhikari *et al*, (2021) [11] reported same outcomes. Leaf area index indicates the ratio of leaf area of the plant to the ground area occupied by the individual plant. Usually, as a crop develops through its growth stages, the leaf area index increases until it hits the peak growth stage, after which it stabilizes and starts to decline during the harvesting phase due to leaf drop and drying. The positive impact of vermicompost on leaf area index could be due to the production of specific phytohormones and

vitamins, along with an increase in chlorophyll, leading to a greater leaf area index in maize. Significant, increase in the yield due to combined application of chemical fertilizer along with vermicompost and biofertilizer could be ascribed to their direct influence on dry matter production in leaf and stem by virtue of increased photosynthetic efficiency. The beneficial effect of vermicompost on dry matter production (DMP) might be related to prolonged availability of nutrients from a combination of organic manure (vermicompost) and inorganic fertilizer (NPK) sources until maturity which likely enhanced biomass yield. Similar finding of Athokpan *et al*. (2017) [12]. Moreover, the lowest growth parameters were measured in control (T_1) plots.

Growth oriented analysis

Among the various combination of integrated nutrient management practices, at both stages of observation *i.e*., 30 DAS to 60 DAS and 60 DAS to at harvest stage, as the application of 100% RDF + 25% N through vermicompost + azophos @ 4 kg ha^{-1} (T_5) numerically improved the crop growth rate (CGR) and absolute growth rate (AGR). The higher CGR of 17.83, 10.02 g m^{-2} day^{-1} and AGR of 2.67, 1.50 g plant^{-1} day^{-1} at 30-60 DAS and 60-at harvest, respectively as given in Table 2. This might be due to availability of nutrients at early crop growth stages from organic and inorganic sources besides the presence of growth promoting hormones. Similar results were reported by Singh *et al*. (2018) [13] and Biswas and Dutta (2020) [14]. Conversely, soil application of azophos exhibit synergistic effects as Azospirillum fix nitrogen can complement the phosphorus-solubilizing activity of phosphobacteria, providing a more balanced nutrient supply to maize crop. The bacteria can enhance the uptake of nutrients, particularly nitrogen, and may improve the efficiency of nutrient utilization by plants. In the present investigation, found that azophos and in combination with chemical fertilizers significantly increased the leaf area, crop growth rate (CGR) and absolute growth rate (AGR). The findings of Kafle and Sharma (2018) [15] support to the present results. However, the least value of crop growth rate and absolute crop growth rate were recorded under control (T_1) plots.

Yield parameters and yield

In respect to yield traits, which were furnished in Table 3, showed significant variation in all the treatments. The combined application of 100% RDF + 25% N through vermicompost + azophos @ 4 kg ha^{-1} (T_5) produced significantly higher yield parameters *viz.*, cob length (24.3 cm), cob diameter (6.07 cm), number of grains per cob (515), grain yield (7508 kg ha^{-1}) and stover yield (10018 kg ha^{-1}) which was significantly higher over rest of the treatments. This may be attributed to the positive impact of vermicompost and biofertilizer on microbial and root proliferation in soil which caused solubilizing effect of native nutrients. Baradhan and Kumar (2018) [16] and Snehaa *et al*. (2019) [17] reported similar results. Moreover, vermicompost relatively added large amount of macro and micro nutrients especially P, Ca and Mg which involved in enzymatic activity and impart physico-chemical and biological activities of soil resulting in more photosynthates assimilation and subsequent conversion of assimilates into yield attributes in larger fraction which ultimately resulted in higher grain and stover yield. The effect of NPK concentration on these traits, facilitated by enhanced photosynthetic efficiency and nutrient accumulation, has ultimately resulted in a greater biological yield with this application. The results observed align closely with the findings of Deewan *et al*. (2017) [18]. The combined application of inorganic fertilizer along with azophos increased nutrient uptake by the plant resulting in ideal growth of the plant parts, as well as metabolic processes like photosynthesis which resulted in the maximum accumulation and translocation of photosynthates to the economic parts of the plant ensuring the higher yield that may be related to increased source (leaves) and sink (economic part) strength. The results of the experiment are in accordance with the research findings reported in maize by Salama and Badry (2020) [19]. Whereas, the lowest yield attributed were recorded in control (T_1) plots.

Table 1: Influence of integrated nutrient management on growth of hybrid maize

Treatments		Plant height	Leaf area index		Dry matter production
		Harvest (cm)	30 DAS	60 DAS	Harvest (kg ha^{-1})
T_1	Control	140.8	1.32	2.56	7428
T_2	100% RDF (250:75:75) kg NPK ha^{-1}	152.9	1.76	3.19	10962
T_3	100% RDF + Azophos @ 4 kg ha^{-1}	164.3	2.04	3.74	11889
T_4	75% RDF + 25% N through Vermicompost + Azophos @ 4 kg ha^{-1}	196.3	2.94	4.82	13427
T_5	100% RDF + 25% N through Vermicompost + Azophos @ 4 kg ha^{-1}	236.7	3.91	6.41	15634
T_6	75% RDF + 25% N through Poultry manure + Azophos @ 4 kg ha^{-1}	182.9	2.47	4.38	12853
T_7	100% RDF + 25% N through Poultry manure + Azophos @ 4 kg ha^{-1}	220.3	3.52	5.94	14972
T_8	75% RDF + 25% N through Pressmud + Azophos @ 4 kg ha^{-1}	167.7	2.18	3.81	12175
T_9	100% RDF + 25% N through Pressmud + Azophos @ 4 kg ha^{-1}	208.3	3.20	5.46	14283
S.Ed		4.19	0.11	0.187	179.29
CD (p=0.05)		8.89	0.23	0.397	380.11

Table 2: Influence of integrated nutrient management on crop growth rate and absolute growth rate at different stages of hybrid maize

Treatments		CGR (g m^{-2} day^{-1})		AGR (g plant^{-1} day^{-1})	
		30-60 DAS	60-at harvest	30-60 DAS	60-at harvest
T_1	Control	11.19	4.13	1.68	0.62
T_2	100% RDF (250:75:75) kg NPK ha^{-1}	13.14	7.23	1.97	1.08
T_3	100% RDF + Azophos @ 4 kg ha^{-1}	13.20	8.12	1.98	1.21
T_4	75% RDF + 25% N through Vermicompost + Azophos @ 4 kg ha^{-1}	14.32	9.03	2.15	1.35
T_5	100% RDF + 25% N through Vermicompost + Azophos @ 4 kg ha^{-1}	17.83	10.02	2.67	1.50
T_6	75% RDF + 25% N through Poultry manure + Azophos @ 4 kg ha^{-1}	13.91	8.92	2.08	1.33
T_7	100% RDF + 25% N through Poultry manure + Azophos @ 4 kg ha^{-1}	17.07	9.76	2.55	1.46
T_8	75% RDF + 25% N through Pressmud + Azophos @ 4 kg ha^{-1}	13.39	8.32	2.01	1.24
T_9	100% RDF + 25% N through Pressmud + Azophos @ 4 kg ha^{-1}	16.30	9.31	2.44	1.39
S.Ed		0.072	0.132	0.028	0.015
CD (p=0.05)		0.151	0.274	0.063	0.031

Table 3: Influence of integrated nutrient management on yield parameters and yield of hybrid maize

Treatments		Cob length (cm)	Cob diameter (cm)	No. of grains cob^{-1}	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
T_1	Control	10.2	2.61	142	2241	3728
T_2	100% RDF (250:75:75) kg NPK ha^{-1}	12.7	3.25	203	3859	5756
T_3	100% RDF + Azophos @ 4 kg ha^{-1}	14.8	3.72	257	4481	6655
T_4	75% RDF + 25% N through Vermicompost + Azophos @ 4 kg ha^{-1}	18.9	4.74	367	5786	7894
T_5	100% RDF + 25% N through Vermicompost + Azophos @ 4 kg ha^{-1}	24.3	6.07	515	7508	10018
T_6	75% RDF + 25% N through Poultry manure + Azophos @ 4 kg ha^{-1}	17.5	4.32	319	5236	7476
T_7	100% RDF + 25% N through Poultry manure + Azophos @ 4 kg ha^{-1}	22.5	5.67	467	6932	9354
T_8	75% RDF + 25% N through Pressmud + Azophos @ 4 kg ha^{-1}	15.8	3.86	269	4708	6795
T_9	100% RDF + 25% N through Pressmud + Azophos @ 4 kg ha^{-1}	20.3	5.24	414	6359	8596
S.Ed		0.49	0.114	7.90	148.16	170.8
CD (p=0.05)		1.13	0.221	16.4	294.3	362.3

Conclusion

Considering the above results, it has been concluded that the application of 100% RDF + 25% N through Vermicompost + Azophos @ 4 kg ha^{-1} (T_5) significantly recorded higher growth and yield oh hybrid maize. This treatment was followed by the application of 100% RDF + 25% N through Poultry manure + Azophos @ 4 kg ha^{-1} (T_7). Hence, the adoption of integrated nutrient management to be an effective practice for augmenting higher growth and productivity of hybrid maize.

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