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RESEARCH ARTICLE

Sustainable agriculture: Influence of macro- and micro-nutrient levels, mixture and humic acid on growth and quality parameters of kharif maize (*Zea mays* L.)

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Abstract

A field experiment entitled "Sustainable agriculture: Influence of macro- and micro-nutrient levels, mixture and humic acid on growth and quality parameters of kharif maize (*Zea mays* L.)" was conducted at Agricultural farm, Lovely Professional University, Punjab during the kharif season of 2020-2021. The experiment was carried out in a randomized block design with ten treatments and three replications each. The treatments were as follows-T0:Control (Recommended dose of fertilizer; RDF), T1: RDF+ soil application of MM 10 kg/ha at 30 DAS, T2: RDF+ foliar application of MM 1% at 30 DAS, T3: RDF+ seed priming with MM 1% before sowing, T4: 75% RDF+ soil application of MM 10 kg/ha at 30 DAS, T5: 75% RDF+ foliar application of MM 1% at 30 DAS, T6: 75% RDF+ seed priming with MM 1% before sowing, T7: T_4+ humic acid 1% at 30 DAS, T8: T_5+ humic acid 1% at 30 DAS, T9: T_6 + humic acid 1% at 30 DAS. Among the various treatments, T8 exhibited higher growth attributes after 30 DAS, including plant height (cm), number of leaves per plant, leaf area, leaf area index, dry matter accumulation, chlorophyll index, CGR, RGR and NAR. Additionally, maize treated with T_5+ humic acid 1% at 30 DAS showed improved quality in terms of protein contents in both grain and stover.

Keywords

zero hunger; life on land; sustainable agriculture; consumption and production; foliar application; chlorophyll; CGR

Introduction

Maize is the second most important crop in terms of production, following wheat, and it is grown in various regions, including the tropics, sub tropics and temperate zones. Maize is available in a range of cultivars, such as field corn, sweet corn, popcorn and baby corn (1). In India, it holds the third position in terms of production, following wheat and rice (2). India ranks 4th in terms of area and 7th in terms of production of maize among the various maize-growing countries. Due to its higher genetic production potential compared to other cereals, maize is renowned as the 'Queen of cereals' or the 'Miracle crop' worldwide (3). Maize is cultivated in over 166 countries, covering a total area of approximately 193.7 million hectares. These countries have collectively produced nearly 1147.7 million tonnes of maize, with an average productivity of 5.75 tonnes per ha. Among the total maize production, approximately 61% is utilized as animal feed, 17% is consumed by humans, and around 22% is used for industrial purposes (4). They have developed the Corn Belt, a large area dedicated exclusively to growing corn. Mexico is the largest importer of maize from the USA accounting for 99% of the imports. Mexico is also known for having the original maize plant called 'teosinte', which is valuable for further research and hybridization purposes (5). Due to the increasing demand and the need to combat hunger, the world requires higher maize production. It is crucial to address this need while ensuring sustainable practices and minimizing residual effects. Providing proper nourishment to the global population is a top priority for maize-growing countries. Among the current agro-management practices, fertilizer application is commonly followed to enhance the growth and yield of maize (6). Macro-nutrient fertilizers, such as nitrogen, phosphorous and potassium are of utmost importance as they play a major role in biochemical and physiological reactions, including photosynthesis and energy transfer metabolisms (7). During the time of the green revolution, the primary focus was on NPK nutrition to crops. However, it is important to note that plants require 17 essential elements for their growth and development. Among these elements, micro-nutrients which are needed in small quantities, also play a significant role in plant metabolic activities and overall improvement (8). While the content of the trace elements in in the soil may be adequate, their availability to plants is often insufficient. The presence of trace elements is crucial for proper metabolism of macro-nutrients like N, P, K, Mg, Ca and S. They act as a cofactor in various plant activities (9). Humic acids improve soil physical, chemical and biological conditions and they have both direct and indirect effects on plant growth (10). These compounds are widely used by many growers as an alternative to pesticides, as they have positive effect such as increased minerals uptake, promotion of root length, and increased fresh and dry weight of plants. Additionally, it also assists in seed germination, root and shoot development and the uptake of macro- and micro-nutrients (10). The aim of this research was to evaluate the impact of different macro-nutrient levels, a micro-nutrient mixture along with humic acid on growth and quality parameters of kharif maize.

Materials and Methods

A field experiment was conducted at agricultural research farm, Lovely Professional University in Phagwara, Punjab during kharif season 2021. The objective was to study the influence of macro-nutrient levels, micro-nutrient mixture (Zn, Cu, Fe, Mn and B) along with humic acid on kharif maize. The pH of the soil was near neutral due to the previous cropping systems involving like maize, wheat, rice and mustard. The farm is located at an elevation of 250 m, near the intersection of latitude 310° 22′ 31.81′′ North and longitude 750° 23′ 03.02′′ East and 20 Km away from Jalandhar city in Punjab, India.

The experiment used the RASI 3033 hybrid variety of maize, which was sown on July 2nd, 2021, with a spacing of 60 cm x 25 cm. For micro-nutrient mixture (MM) five salts of Zn, Fe, Cu, Mn and B was taken (Table 1). Proper cultural practices, disease and pest control precautions were taken throughout the crop period. Observations of growth parameters were taken at 30, 60 and 90 DAS including plant height (cm), leaf area index, Chlorophyll, dry matter accumulation along with weather parameters like, minimum and maximum temperature, relative humidity, rainfall, bright sunshine hrs and quality parameters like protein content in grains and Stover of kharif maize were monitored. Chlorophyll was measured with SPAD meter. The leaf area index was calculated with this following Equation .

Table 1. Ten treatments were taken in three replications using randomized block design

Treatments	Treatment description
T0	Control (Recommended dose of fertilizer)
T1	RDF+ soil application of MM@10 kg/ha at 30 DAS
T2	RDF+ foliar application of MM@1% at 30 DAS
T3	RDF+ seed priming with MM@1% before sowing
T4	75% RDF+ soil application of MM@10 kg/ha at 30 DAS
T5	75% RDF+ foliar application of MM@1% at 30 DAS
T6	75% RDF+ seed priming with MM@1% before sowing
T7	T_4+ humic acid@1% at 30 DAS
T8	T_5+ humic acid@1% at 30 DAS
T9	T_6 + humic acid@1% at 30 DAS

*Note: Micro-nutrient mixture (12.5g $FeSO_4$, 25g $MnSO_4$, 100g $ZnSO_4$, 350g Borax and 4.5g $CuSO_4$)

$$LAI = \frac{\text{Total leaf area of plant (cm)}}{\text{Ground area (cm)}}$$

Crop Growth rate: (gm^{-2}day^{-1})

Crop growth rate (CGR) indicated the rate at which the crop was growing and it was represented as gm^{-2}day^{-1}. It was computed by formulae (11).

Relative growth rate (RGR) (gg^{-1}day^{-1})

Relative growth rate is the rate of increase in dry weight per unit dry weight and is expressed in gram per gram per day. RGR was calculated by using the formula suggested by (12).

Net assimilation rate (NAR) (gm^{-2}day^{-1})

Net assimilation rate (NAR) was estimated using the formula given by (15) and expressed in gm^{-2}day^{-1}.

Weather and climatic conditions

The experiment location was situated in a subtropical zone characterized by mild winters and hot summers. The region experienced the heaviest rainfall during the summer months of July, August and September. The primary source of precipitation was the southwest monsoon, which typically started in the latter half of June and lasted until the end of September. The monsoon season brought the highest amount of rainfall, with June to September being the period of heaviest rainfall. The coldest weather occurred between January and December, although the specific temperatures are not provided. Table 2 contains data representing the precipitation levels during the month of July, which is a significant month for precipitation due to the monsoon.

Table 2. Monthly averages of meteorological data of Kapurthala, recorded during the period of crop growth

Month	Temperature (°C)			Relative Humidity %	Rainfall Average (mm)	Bright Sunshine hours
	Minimum	Maximum	Average			
July	26.1	33.6	29.6	76	226	6.1
August	25.4	32.3	28.6	82	194	4.4
September	23.3	32.1	27.5	76	89	4.6
October	18.2	31	24.3	61	17	3.1

Statistical data analysis

The data collected from the experiment were subjected to a randomized block design and analyzed using analysis of variance (ANOVA). The mean values along with their standard deviation (Mean ± SE_m) were determined and presented in the Table 1. The data analysis was conducted using with SPSS software (California). Duncan multiple range test (DMRT) used to check the variation between the treatments. The relation between the growth parameters was found by Pearson's correlation at 1% and 5% level of significance (to check the significant and non-significant parameters).

Results and discussion

Growth parameters of maize

Plant height (cm)

The plant height (cm) of maize exhibited significant variability across a wide range of macro-nutrient levels, micro-nutrient mixtures and humic acid concentrations at all intervals. The most substantial increases in plant height was observed up to 60 DAS. However, after reaching maturity, the growth rate of plant height significantly slowed down.

At 90 DAS, the treatment with 75% RDF+ foliar application of MM 1%+ humic acid 1% at 30 DAS (168.60 cm) demonstrated significantly higher plant height (cm), which is statistically on par with RDF+ foliar application of MM 1% at 30 DAS (166.30 cm). When 75% RDF+ seeds were primed with 1% MM before being sown, the plants grew to their shortest heights, on average. (149.89 cm). Similar findings were reported by (13) (Table 2).

Leaf area index

The rise in the leaf area index (LAI) was observed until 60 days after sowing (DAS), indicating an increase in the leaf surface area. However, after reaching full maturity, the LAI started to decline. At 60 DAS, the treatment with 75% recommended dose of fertilizer (RDF) + foliar application of a 1% micro-nutrient mixture (MM) and 1% humic acid showed a significantly higher LAI (4.142) compared to the treatment with 75% RDF + foliar application of a 1% MM at 30 DAS (4.087) and the control group (RDF) (4.080). Conversely, seed priming with a 1% MM before planting resulted in the lowest LAI (2.829) among the treatments with 75% RDF. The high LAI observed at 30 DAS could be attributed to the application of the recommended dose of fertilizers. Meanwhile, at 60 DAS, the increase in LAI might be attributed to the application of humic acid and the micro-nutrient mixture, which could have influenced the uptake of both macro- and micro-nutrients. This, in turn, could enhance photosynthesis and other metabolic activities in the plant, leading to the generation and expansion of new leaves (14) (Table 4).

Table 4. Influence of micro-nutrient mixture, macro-nutrient levels and humic acid on plant height and leaf area index of *kharif* maize (*Z. mays* L.)

Treatments	Plant height (cm)			Leaf Area Index		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T0	49.30^{c} ±1.3	148.60^{abc} ±3.1	160.80^{abc} ±0.5	1.071^{a} ±0.03	4.080^{a} ±0.4	3.813^{ab} ±0.05
T1	53.40^{b} ±1.8	147.33^{bcd} ±5.8	159.20^{bc} ±2.7	1.069^{a} ±0.03	3.807^{ab} ±0.2	3.622^{cd} ±0.11
T2	59.70^{a} ±1.5	154.03^{ab} ±5.7	166.30^{ab} ±1.8	1.072^{a} ±0.01	4.087^{a} ±0.3	3.750^{bc} ±0.04
T3	48.20^{c} ±2.1	147.57^{bcd} ±2.5	158.5^{bcd} ±3.4	1.074^{a} ±0.03	3.763^{ab} ±0.3	3.551^{d} ±0.15
T4	44.60^{d} ±1.7	141.67^{cde} ±4.7	152.70^{cd} ±3.5	1.049^{a} ±0.01	3.232^{bc} ±0.4	3.083^{f} ±0.01
T5	44.80^{d} ±1.1	140.27^{de} ±3.1	151.50^{cd} ±0.9	1.039^{a} ±0.04	3.323^{bc} ±0.4	3.144^{f} ±0.12
T6	43.10^{d} ±1.2	138.73^{e} ±3.7	149.89^{d} ±2.4	1.047^{a} ±0.02	2.829^{c} ±0.6	2.669^{g} ±0.02
T7	44.80^{d} ±1.7	149.27^{abc} ±4.2	160.20^{abc} ±1.4	1.041^{a} ±0.04	3.593^{ab} ±0.2	3.326^{e} ±0.06
T8	43.80^{d} ±1.3	156.30^{a} ±4.0	168.60^{a} ±2.1	1.045^{a} ±0.03	4.142^{a} ±0.3	3.914^{a} ±0.15
T9	43.90^{d} ±1.6	147.53^{bcd} ±4.6	158.6^{bcd} ±2.5	1.035^{a} ±0.01	3.686^{ab} ±0.2	3.487^{d} ±0.06

T0: Control (RDF), **T1**: RDF+ soil application of MM 10kg/ha at 30 DAS, **T2**: RDF+ foliar application of MM 1% at 30 DAS, **T3**: RDF+ seed priming with MM 1% before sowing, **T4**: 75%RDF+ soil application of MM 10kg/ha at 30 DAS, **T5**: 75% RDF+ foliar application of MM 1% at 30 DAS, **T6**: 75% RDF+ seed priming with MM 1% before sowing, **T7**: T4+ humic acid 1% at 30 DAS, **T8**: T5+ humic acid 1% at 30 DAS, **T9**: T6 + humic acid 1% at 30 DAS. Data is in the form of Mean ±SDM at p<0.05. The mean followed by different letters was significantly different at p<0.05, according to DMRT for separation of means.

Chlorophyll Index (SPAD value)

During the vegetative stage of the maize plants, the chlorophyll content was observed to be high. As the plants progressed towards maturity, there was a gradual decrease in the chlorophyll content. At 60 DAS, chlorophyll content was significantly high in 75% RDF+ foliar application of MM 1%+ humic acid 1% at 30 DAS (55.53) which is statistically at par with RDF+ soil application of MM 10 kg ha^{-1} at 30 DAS (54.90). While low chlorophyll content (46.98) was noticed in: 75% RDF+ seed priming with MM 1% before sowing. The decrease of chlorophyll at later stages of crop growth might be due to aging of leaf as well as translocation of nitrogen (precursor of chlorophyll) more towards reproductive organs. And application of humic acid after 30 DAS resulted in higher chlorophyll content in 75% RDF+ foliar application of MM 1%+ humic acid 1% which might be due to enhances the uptake of macro- and micro-nutrient s which helped in the synthesis of chlorophyll. Similar findings were reported earlier (15) (Table 5).

Crop growth rate ($gm^{-2}day^{-1}$)

Among various macro-nutrient levels, micro-nutrient mixture along with humic acid treatmentsthere exists a significant variation in crop growth rate (CGR). At 30-60 DAS interval CGR was significantly highest (21.27 $gm^{-}2day^{-1}$) in 75% RDF+ foliar application of MM 1%+ humicacid 1%. While the lowest (15.80 $gm^{-}2day^{-1}$). CGR was observed in 75% RDF+ seed priming with MM 1% before sowing. While at 60-90 DAS, 75% RDF+ foliar applicationof MM 1%+ humic acid 1% showed significantly higher (24.1316.68 $gm^{-}2day^{-1}$) CGR which is statistically at par with 75% RDF+ soil application of MM 10 kg ha^{-1}+ humic acid 1%. While the lowest (19.76 $gm^{-}2day^{-1}$) was recorded at 75% RDF+seed priming with MM 1% before sowing. The crop growth rate is the direct reflection of dry matter accumulation. Similar findings were reported by (16) in which high CGR was noticed when a micro-nutrient mixturewas applied by foliar method and mentioned high nitrogen resulted in chlorophyll synthesis, while phosphorus and potassium ensured root development and stomatal opening of capture of sunlight as well as CO_2, resulting in high photosynthesis and thereby, high CGR (Table 6).

Table 5. Influence of micro-nutrient mixture, macro-nutrient levels and humic acid on chlorophyll content and dry matter accumulation of *kharif* maize (*Z. mays* L.)

Treatments	Chlorophyll content (SPAD value)			Dry matter accumulation (g)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T0	49.66^{abc} ±2.1	51.53^{b} ±2.1	42.35^{ab} ±0.9	16.70^{ab} ±1.609	88.60^{c} ±3.167	183.32^{ef} ±1.71
T1	52.13^{a} ±0.9	54.90^{a} ±1.3	40.09^{cd} ±0.8	18.47^{a} ±1.595	99.47^{b} ±2.802	190.54^{d} ±2.23
T2	50.02^{ab} ±1.6	52.62^{ab} ±2.2	42.62^{ab} ±1.2	18.97^{a} ±1.650	102.47^{b} ±3.164	197.16^{c} ±2.66
T3	42.44^{d} ±0.6	47.32^{c} ±2.0	39.45^{d} ±1.0	18.33^{a} ±2.157	104.33^{b} ±3.700	184.96^{de} ±3.50
T4	45.67^{bcd} ±2.1	47.63^{c} ±3.0	41.21^{bc} ±0.7	15.10^{bc} ±2.358	86.20^{cd} ±3.504	189.02^{de} ±0.34
T5	43.62^{cd} ±1.7	49.32^{bc} ±2.3	38.56^{d} ±0.1	12.17^{d} ±0.924	87.80^{c} ±4.015	186.64^{de} ±0.16
T6	41.80^{d} ±1.9	46.98^{c} ±1.5	39.42^{d} ±0.5	13.50^{cd} ±0.656	81.80^{d} ±2.800	177.53^{f} ±6.72
T7	49.03^{abc} ±0.3	51.94^{b} ±1.3	41.47^{bc} ±0.3	17.03^{ab} ±1.250	104.93^{b} ±2.948	208.64^{b} ±6.01
T8	47.13^{bcd} ±2.2	55.53^{a} ±1.1	43.20^{a} ±1.4	15.47^{bc} ±0.833	111.20^{a} ±1.778	219.80^{a} ±3.76
T9	42.44^{d} ±1.4	49.29^{bc} ±0.7	39.53^{d} ±1.2	16.40^{ab} ±0.458	104.60^{b} ±1.637	199.21^{c} ±0.18

T0: Control (RDF), **T1**: RDF+ soil application of MM 10kg/ha at 30 DAS, **T2**: RDF+ foliar application of MM 1% at 30 DAS, **T3**: RDF+ seed priming with MM 1% before sowing, **T4**: 75% RDF+ soil application of MM 10kg/ha at 30 DAS, **T5**: 75% RDF+ foliar application of MM 1% at 30 DAS, **T6**: 75% RDF+ seed priming with MM 1% before sowing, **T7**: T4+ humic acid 1% at 30 DAS, **T8**: T5+ humic acid 1% at 30 DAS, **T9**: T6 + humic acid 1% at 30 DAS. Data is in the form of Mean ±SDM at $p<0.05$. The mean followed by different letters was significantly different at $p<0.05$, according to DMRT for separation of means.

Dry matter accumulation (g)

Dry matter accumulation (DMA) showed significant variations among different macro-nutrient levels, micro-nutrient mixture and humic acid. Maize plants continued to accumulate dry matter throughout the crop growth period. The dry matter accumulation was maximum between 60 to 90 DAS. While at 90 DAS treatment 75% RDF+ foliar application of MM 1%+ humic acid 1% at 30 DAS (219.80 g) showed significantly higher dry matter accumulation while the lowest dry matter accumulation was observed in 75% RDF+ seed priming with MM 1% before sowing (177.53 g). Similar findings have been reported in previous studies where the application of humic acid and foliar application of micro-nutrient mixture might result in higher uptake of both macro- and micro-nutrients (16). That might increase photosynthesizing area and activity i.e., production of more no. of leaves as well as expansion of leaves through influencing the growth of stem and node (Table 5).

Relative growth rate (RGR; $mgg^{-1}day^{-1}$)

At 30-60 days after sowing, the RGR was substantially highest (28.62 $mgg^{-1}day^{-1}$) in 75% RDF+ foliar application of MM 1%+ humic acid 1%. While the rate of germination reduction (RGR) that was detected in 75% RDF+ seed primed with MM 1% before sowing was the lowest (23.03 $mgg^{-1}day^{-1}$). While at 60-90 DAS T8: 75% RDF+ foliar application of MM 1%+ humic acid 1% showed significantly highest (11.69 $mgg^{-1}day^{-1}$) RGR which is statistically at par with 75% RDF+ foliar application of MM 1% having 11.37 $mgg^{-1}day^{-1}$ and lowest (8.29 $mgg^{-1}day^{-1}$) RGR was recorded in 75% RDF+ seed priming with MM 1% before sowing. RGR decreased as the plant aged as a result of an increase in the construction of developing tissues to replace older tissues. Additionally, the leaves of the plant progressively lose chlorophyll and become dried out,

Table 6. Influence of micro-nutrient mixture, macro-nutrient levels and humic acid on CGR, RGR and NAR

Treatments	CGR ($gm^{-2}day^{-1}$)		RGR (mgg^{-1}/day^{-1})		NAR (gm^{-2}/day^{-1})	
	30-60 DAS	60-90DAS	30-60 DAS	60-90DAS	30-60DAS	60-90DAS
T0	16.69^{cd} ±0.243	20.24^{cd} ±0.951	24.41^{bc} ±1.079	9.33^{c} ±0.678	0.0024^{b} ±0.00042	0.0015^{e} ±0.00006
T1	19.47^{b} ±0.968	22.56^{ab} ±0.698	26.83^{ab} ±1.668	10.06^{bc} ±0.405	0.0027^{ab} ±0.00010	0.0019^{abcd} ±0.00010
T2	19.53^{b} ±1.027	22.85^{ab} ±1.295	27.24^{ab} ±1.630	10.93^{bc} ±0.645	0.0027^{ab} ±0	0.0020^{abcd} ±0.00015
T3	16.81^{cd} ±1.239	21.02^{bcd} ±0.623	24.45^{bc} ±2.090	9.41^{c} ±0.216	0.0024^{b} ±0.00025	0.0016^{de} ±0.00015
T4	18.00^{bc} ±0.731	21.04^{bcd} ±0.707	25.23^{bc} ±2.803	9.48^{c} ±0.420	0.0024^{ab} ±0.00015	0.0017^{cde} ±0.00025
T5	18.56^{b} ±0.933	21.54^{bcd} ±0.929	25.23^{bc} ±0.905	9.86^{c} ±0.565	0.0025^{ab} ±0.00020	0.0017^{cde} ±0.0002
T6	15.80^{d} ±1.298	19.76^{d} ±1.215	23.04^{c} ±1.308	8.29^{d} ±0.519	0.0019^{c} ±0.00012	0.0014^{e} ±0.00012
T7	19.60^{b} ±0.845	23.05^{ab} ±1.924	28.57^{a} ±1.363	11.37^{a} ±0.443	0.0028^{a} ±0.00006	0.0021^{ab} ±0.00017
T8	21.27^{a} ±0.511	24.13^{a} ±1.103	28.63^{a} ±1.363	11.69^{a} ±0.678	0.0029^{a} ±0.00012	0.0022^{a} ±0.00040
T9	19.11^{b} ±0.466	21.96^{bc} ±0.331	26.34^{ab} ±0.630	9.95^{bc} ±0.796	0.0026^{ab} ±0.00017	0.0018^{bcde} ±0.00015

T0: Control (RDF), **T1**: RDF+ soil application of MM 10kg/ha at 30 DAS, **T2**: RDF+ foliar application of MM 1% at 30 DAS, **T3**: RDF+ seed priming with MM 1% before sowing, **T4**: 75% RDF+ soil application of MM 10kg/ha at 30 DAS, **T5**: 75% RDF+ foliar application of MM 1% at 30 DAS, **T6**: 75% RDF+ seed priming with MM 1% before sowing, **T7**: T4+ humic acid 1% at 30 DAS, **T8**: T5+ humic acid 1% at 30 DAS, **T9**: T6 + humic acid 1% at 30 DAS. Data is in the form of Mean ±SDM at $p<0.05$. The mean followed by different letters was significantly different at $p<0.05$, according to DMRT for separation of means.

which ultimately results in a reduction in the activity of photosynthetic and RGR. These results are in corroborate with the findings of (17) (Table 3).

Table 3. Simple correlation between different growth parameters (Averaged over one year)

Variable	r
Plant height and LAI	0.899**
Plant height and SPAD	0.781*
Plant height and DMA	0.728**
DMA and CGR	0.916**
DMA and RGR	0.929**
CGR and RGR	0.959**

*Indicates significant at 5% level of significance, ** Indicates significant at 1 % level of significance

Net assimilation rate ($gm^{-2}day^{-1}$)

The net assimilation rate (NAR) of kharif maize under different levels of macro-nutrients and micro-nutrient mixture, along with humic acid, was measured at 2 specific time intervals: 30-60 days after sowing (DAS) and 60-90 DAS. NAR was significantly highest (0.0029 $gm^{-}2day^{-1}$) in 75% RDF+ foliar application of MM 1%+ humic acid 1% at 30-60 DAS while the lowest (0.0018 $gm^{-}2day^{-1}$) RGR was observed in 75% RDF+ seed priming with MM 1% before sowing. While at 60-90 DAS, 75% RDF+ foliar application of MM 1%+ humic acid 1% showed significantly highest (0.0022 $gm^{-}2day^{-1}$) NAR which is statistically at par with 75% RDF + soil application of MM 10 kg ha^{-1} + humic acid 1% having 0.0021 $gm^{-}2day^{-1}$. And lowest (0.0014 $gm^{-}2day^{-1}$) NAR was recorded in 75% RDF+ seed priming with MM 1% before sowing. During later intervals, the NAR was reduced and we know that LAI is a contributing factor to NAR, so by an increase in leaf area index during growing season, more leaves are completely or partially are under shadow and this decrease NAR. While during early stages there was less competition between shrubs and canopy, higher NAR was observed. These results are in corroboration with the findings of (18) Table 6.

Correlation

A correlation coefficient of pooled values of 2 successive years for different plant growth contributing characters were studied with themselves and found positive. The value of correlation coefficient varied from 0.959 to 0.781, that indicated these parameters were highly significant and inter correlated with each other. The data revealed that CGR and RGR showed the greatest correlation coefficient (0.959), however least con-elation coefficient (0.728) was observed for plant height (cm) and dry matter accumulation (Table 3).

Quality parameters of maize

Protein content in maize grain and stover

Protein contents of maize grain under different levels of macro-nutrients and micro-nutrient mixture along with humic acid were analysed in laboratory and data as discussed below.75% RDF+ foliar application of MM 1%+ humic acid 1% at 30 DAS showed significantly higher protein (%) in grain of maize i.e., 8.21 % and is statistically at par with 75% RDF+ soil application of MM 10 kg ha^{-1}+ humic acid 1% at 30 DAS (7.83%) and found to be better among the other macro- and micro-nutrient level treatments. While the lowest protein (%) in grain of maize was observed in treatment T6: 75% RDF+ seed priming with MM 1% before sowing i.e., 6.83%. According to data represented, 75% RDF+ foliar application of MM 1%+ humic acid 1% at 30 DAS (2.73%) showed significantly high protein content in stover which is found to be better among the other macro- and micro-nutrient level treatments. While 75% RDF+ seed priming with MM 1% before sowing showed low protein content in stover i.e., 1.38%. Humic acid helps in better translocation of macro- and micro-nutrients that were applied (19). Nitrogen is considered a precursor of protein. Increased uptake of nitrogen thereby, probably resulted in increased protein content of maize grain as well as stover (19) Table 7.

Table 7. Influence of micro-nutrient mixture, macro-nutrient levels and humic acid on protein content and NPK content of *kharif* maize (*Z. mays* L.)

Treatments	Protein content (%)		NPK content (%) in grain		
	Grain	Stover	N	P	K
T0	$7.04^{cd}\pm0.167$	$1.50^{f}\pm0.036$	$1.13^{cd}\pm0.026$	$0.27^{g}\pm0.001$	$0.19^{f}\pm0.002$
T1	$7.29^{c}\pm0.204$	$2.04^{c}\pm0.056$	$1.17^{c}\pm0.033$	$0.36^{c}\pm0.014$	$0.25^{d}\pm0.004$
T2	$7.75^{b}\pm0.293$	$2.33^{b}\pm0.087$	$1.24^{b}\pm0.046$	$0.38^{b}\pm0.003$	$0.27^{c}\pm0.010$
T3	$7.19^{cd}\pm0.253$	$1.71^{e}\pm0.010$	$1.15^{cd}\pm0.040$	$0.29^{f}\pm0.005$	$0.20^{f}\pm0.007$
T4	$7.10^{cd}\pm0.051$	$1.71^{e}\pm0.036$	$1.14^{cd}\pm0.008$	$0.29^{f}\pm0.008$	$0.22^{e}\pm0.002$
T5	$7.09^{cd}\pm0.159$	$1.81^{d}\pm0.041$	$1.14^{cd}\pm0.025$	$0.32^{e}\pm0.009$	$0.23^{e}\pm0.005$
T6	$6.83^{d}\pm0.242$	$1.38^{g}\pm0.056$	$1.09^{d}\pm0.038$	$0.25^{h}\pm0.008$	$0.16^{g}\pm0.001$
T7	$7.83^{ab}\pm0.098$	$2.31^{b}\pm0.098$	$1.25^{ab}\pm0.015$	$0.41^{a}\pm0.016$	$0.29^{b}\pm0.004$
T8	$8.21^{a}\pm0.324$	$2.73^{a}\pm0.045$	$1.31^{a}\pm0.052$	$0.42^{a}\pm0.014$	$0.32^{a}\pm0.011$
T9	$7.29^{c}\pm0.278$	$2.02^{c}\pm0.036$	$1.17^{c}\pm0.044$	$0.34^{e}\pm0.008$	$0.25^{d}\pm0.007$

T0: Control (RDF), **T1**: RDF+ soil application of MM 10kg/ha at 30 DAS, **T2**: RDF+ foliar application of MM 1% at 30 DAS, **T3**: RDF+ seed priming with MM 1% before sowing, **T4**: 75% RDF+ soil application of MM 10kg/ha at 30 DAS, **T5**: 75% RDF+ foliar application of MM 1% at 30 DAS, **T6**: 75% RDF+ seed priming with MM 1% before sowing, **T7**: T4+ humic acid 1% at 30 DAS, **T8**: T5+ humic acid 1% at 30 DAS, **T9**: T6 + humic acid 1% at 30 DAS. Data is in the form of Mean ±SDM at $p<0.05$. The mean followed by different letters was significantly different at $p<0.05$, according to DMRT for separation of means.

NPK content of maize grain

75% RDF + foliar application of MM 1%+ humic acid 1% at 30 DAS (1.31%) showed significantly high nitrogen content in maize grains when compared to other treatments and it is statistically at par with 75% RDF+ soil application of MM 10 kg ha^{-1}+ humic acid 1% at 30 DAS (1.25%). While the lowest percent of nitrogen content was recorded in 75% RDF+ seed priming with MM 1% before sowing (1.09%). According to data, significantly high phosphorous content was observed in 75% RDF+ foliar application of MM 1% + humic acid 1% at 30 DAS i.e., 0.42% which is statistically at par with 75% RDF+ soil application of MM 10 kg/ha+ humic acid 1% at 30 DAS i.e., 0.41%. And low phosphorous content in maize grain was observed in 75% RDF+ seed priming with MM 1% before sowing i.e., 0.25%. 75% RDF+ foliar application of MM 1%+ humic acid 1% at 30 DAS (0.32%) showed significantly high potassium content in maize grains which is found to be better among the other macro- and micro-nutrient level treatments. While the lowest percent of potassium content in maize grain was recorded in 75% RDF+ seed priming with MM 1% before sowing (0.16%).

Conclusion

Based on the research conducted on the application of micro-nutrient mixture, macro-nutrient levels and humic acid on kharif maize, it has been confirmed that the combined application of organic and inorganic sources of nutrients, using appropriate application methods such as soil or foliar, along with the inclusion of micro-nutrients alongside NPK, positively influences the growth and quality of kharif maize production. Considering the findings of the investigation, it is recommended that maize growers in the kharif season in Punjab, India, apply 75% recommended dose of fertilizer (RDF) along with foliar application of a 1% micro-nutrient mixture and 1% humic acid at 30 days after sowing (DAS). This recommended treatment has shown potential for achieving better growth and quality in kharif maize production.

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Authors contributions

AS have completed the write-up part, SS has done the technical part and AJ did the statistical analysis.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

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References

1. Erenstein O, Jaleta M, Sonder K, Mottaleb K, Prasanna BM. Global maize production, consumption and trade: trends and R&D implications. Food Security. 2022 Oct;14(5):1295-319. https://ideas.repec.org/a/spr/ssefpa/v14y2022i5d10.1007_s12571-022-01288-7.html https://doi.org/10.1007/s12571-022-01288-7
2. Babu KS, Babu PR, Reddy MS, Kavitha P. Effect of higher levels of nutrients on the growth, yield and economics of maize (*Zea mays* L.). Journal of Agricultural Science. 2020;6(4):207-10. https://sasapjas.org/wp-content/uploads/2022/01/07-Sathish-Babu.pdf
3. Bakry MA, Soliman YR, Moussa SA. Importance of micro-nutrients, organic manure and biofertilizer for improving maize yield and its components grown in desert sandy soil. Research Journal of Agricultural Sciences. 2009;5(1):16-23. http://www.aensiweb.net/AENSIWEB/rjabs/rjabs/2009/16-23.pdf
4. Daur I, Bakhashwain AA. Effect of humic acid on growth and quality of maize fodder production. Pakistan Journal of Botany. 2013 Jan 1;45(S1):21-25. http://www.pakbs.org/pjbot/PDFs/45(S1)/04.pdf
5. Gul S, Khan MH, Khanday BA, Nabi S. Effect of sowing methods and NPK levels on growth and yield of rainfed maize (*Zea mays*

L.). Scientifica. 2015 May 18;2015. https://doi.org/10.1155/2015/198575

6. Al-Juthery HW, Habeeb KH, Altaee FJ, AL-Taey DK, Al-Tawaha AR. Effect of foliar application of different sources of nano-fertilizers on growth and yield of wheat. Bioscience Research. 2018 Oct 1;(4):3976-85. https://doi.org/10.1088/1755-1315/388/1/012046
7. Khaled H, Fawy HA. Effect of different levels of humic acids on the nutrient content, plant growth and soil properties under conditions of salinity. Soil Water Research. 2011 Mar 1;6(1):21-29. https://doi.org/10.17221/4/2010-SWR
8. Liu DY, Zhang W, Liu YM, Chen XP, Zou CQ. Soil application of zinc fertilizer increases maize yield by enhancing the kernel number and kernel weight of inferior grains. Frontiers in Plant Science. 2020 Feb 28;11:188. https://doi.org/10.3389/fpls.2020.00188
9. Makgoba MC, Tshikhudo PP, Nnzeru LR, Makhado RA. Impact of fall armyworm (*Spodoptera frugiperda*) (J E Smith) on small-scale maize farmers and its control strategies in the Limpopo province, South Africa. Jàmbá: Jamba: J of Disaster Risk Studies. 2021;13(1). https://doi.org/10.4102/jamba.v13i1.1016
10. Manasa LP, Devaranavadagi SB. Effect of foliar application of micro-nutrients on growth, yield and nutrient uptake of maize. Karnataka Journal of Agricultural Science. 2015;28(4):474-76. https://www.cabdirect.org/cabdirect/abstract/20163039604
11. Radford PJ. Growth analysis formulae-their use and abuse 1. Crop Science. 1967 May;7(3):171-75. https://doi.org/10.2135/cropsci1967.0011183X000700030001x
12. Blackman GE. The application of the concepts of growth analysis to the assessment of productivity. Functioning of terrestrial ecosystems at the primary production level. UNESCO, Paris. 1968;243-59.
13. Gregory FG. Physiological conditions in cucumer houses. Third Annual Report. Kansas Agricultural Experiment. Cheshunt; 1917.
14. Mikula K, Izydorczyk G, Skrzypczak D, Mironiuk M, Moustakas K, Witek-Krowiak A, Chojnacka K. Controlled release micro-nutrient fertilizers for precision agriculture–A review. Science of the Total Environment. 2020 Apr 10;712:136365. https://doi.org/10.1016/j.scitotenv.2019.136365
15. Radwan FI, Gomaa MA, Rehab IF, Samera IA. Impact of humic acid application, foliar micro-nutrients and biofertilization on growth, productivity and quality of wheat (*Triticum aestivum* L.). Middle East Journal of Agricultural Research. 2015;4(2):130-40. https://www.curresweb.com/mejar/mejar/2015/130-140.pdf
16. Sharifi RS, Namvar A, Sharifi RS. Grain filling and fatty acid composition of safflower fertilized with integrated nitrogen fertilizer and biofertilizers. Pesquisa Agropecuaria Brasileira. 2017;52:236-43. https://doi.org/10.1590/S0100-204X2017000400003
17. Dhopte AM. Agrotechnology for Dryland Farming 2nd. Science Research Journal. 2017.
18. Celik H, Katkat AV, Aşık BB, Turan MA. Effect of foliar-applied humic acid to dry weight and mineral nutrient uptake of maize under calcareous soil conditions. Communications in Commun Soil Science Plant. 2010 Dec 7;42(1):29-38. https://doi.org/10.1080/00103624.2011.528490
19. Biswas DK, Ma BL. Effect of nitrogen rate and fertilizer nitrogen source on physiology, yield, grain quality and nitrogen use efficiency in corn. Canadian Journal of Plant Science. 2016 Jun 15;96(3):392-403 https://doi.org/10.1139/cjps-2015-0186