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Effects of Foliar NPK Application on Growth, Yield and Nutrient Content of Sweet Corn Grown on Rengam Series Soil

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Abstract: The present study was carried out to evaluate the effects of different rates of macronutrients as a foliar spray on the growth performance, yield, and nutrient content of sweet corn grown in the Rengam soil series. The treatments consisted of five rates of macronutrients as a foliar fertilizer at 0, 25, 50, 75, and 100 % NPK. Foliar NPK was applied 25 and 50 days after sowing to the sweet corn seedlings. The results showed that fresh cob weight, cob number, flowering, and dry matter yield of sweet corn significantly increased at the rate of 75%, and 100% of NPK foliar fertilizers. The macro and micronutrient concentrations in ear leaf, mature leaves, stem, cob, and flowers of 75 and 100% NPK treated corn were significantly increased over the control plants. The macronutrient content in the whole plant was also significantly higher at 75% and 100% NPK treatments. Fe and Mn contents in the whole plant were also the highest in 75% and 100% NPK treatments. Macronutrient concentration in ear leaf and whole corn plants significantly correlated with the fresh cob yield of corn. It is concluded that foliar application of N, P, and K macronutrients (75 to 100% NPK) enhanced the yield and quality of sweet corn.

Keywords: Cereal, maize, macronutrient, spray, quality, soil series.

Introduction

Sustaining healthy soil is the only choice for the production of high-quality foods. Nutrient elements regulate plant growth and development, and different soils have a deficiency of nutrients, thus the plant's physiological processes are disrupted in poor soil (Groth *et al.,* 2020). The nutrient availability, biochemical reactions, and fertility of soil regulate crop growth and yield under different conditions. Seed priming, soil application, and fertigation are used to apply macro and micronutrients to plants, but the foliar method is more economic and beneficial. The foliar macronutrients applied to the plants are absorbed directly compared to the macronutrients applied to the soil. Numerous variables, including the physical and chemical characteristics of the applied nutrient solution, environmental factors, plant type, and morpho-physiological characteristics of the plant, affect the absorption and translocation of foliar nutrients in plants (Shahid *et al.,* 2017; Kah *et* *al.,* 2019). However, the effectiveness of the foliar spray not only depends on the nutrient uptake by the leaf and stem, but also on the subsequent transfer of nutrients by phloem and xylem flow within the plants.

Corn is a most important cereal crop also known as maize belonging to the poaceae family with corn being cultivated worldwide. Corn is a source of food for humans and feeds for animals, and it serves as raw materials for many industries for the production of corn starch, syrup, corn oil and bioethanol or biofuel (Nord *et al.,* 2021). The importance and use of corn differ from one country to another, as most developed countries use it as livestock feed, Corn starch is known to be a raw material for the cosmetic products manufacturing industries, which can be applied topically to reduce skin rashes and irritation (Marto *et al.,* 2018). Cosmetic products made of corn starch are a better alternative to carcinogenic petroleum products which form a major part of cosmetic raw materials. Corn needs a lot of macro and micronutrients for growth and development (Marto *et al.,* 2018). The removal of nutrients from the soil has increased due to improvements in corn output, which coincided with this period of rapid growth and development. The nutrient demand may exceed soil supply capacity (Garland *et al.,* 2021). The nutritional status of corn during the growing season can be determined by plant tissue analysis. The deficiency of one or more essential nutrient elements can retard crop growth, development, and yield (Khoshgoftarmanesh *et al.,* 2010).

Nutrient solubility and absorption by the plant roots depend on soil properties. Soil pH is one of the most important factors that can affect nutrient availability near the root zone. Foliar fertilization is the finest way to supply nutrients to plants that grow in poor-quality soil (Begum & Fry, 2022). By using the foliar fertilization method, it is possible to use chemical fertilizers effectively. Foliar fertilization is one of the most eco-friendly and target-oriented methods of delivering nutrient elements in precise amounts (Shahid *et al.,* 2017). Foliar application of plant growth promoting chemicals also increases the growth and development of plants (Khandaker *et al.,* 2022). Furthermore, foliar fertilization is an economical way of augmenting nutrient elements when they are unavailable from the soils. Foliar fertilization has a 3 - 5 five times higher efficiency than soil-applied fertilizer and hence reduces the use of chemical fertilizers significantly (Shafiee *et al.,* 2012). Foliar spray of fertilizer improved the root growth and increase macro and micronutrient uptake which enhanced the growth and development of wheat (Zain *et al.,* 2015). Foliar application of micronutrient elements increases the yield of wheat and improved the grain quality nutrients content (Jalal *et al.,* 2020). Much research has been reported about the foliar spray of micronutrients on crops and their effects on growth, development, and yield. However, less research has been conducted about foliar macro nutrients application and their effects on crop growth, development, and yield (Senanayake *et al.,* 2023).

Additionally, the yield component as well as the protein and starch content in maize seeds increases with a foliar spray of nutrient elements (Davoodi *et al.,* 2020). Foliar application of nutrient elements at tilling, stem elongation, and boot stage of wheat laterally with conventional chemical fertilizer increased the yield and quality of wheat (Ronga *et al.,* 2019). A foliar spray of nutrients improves the efficacy and rapidity of nutrient utilization required by the crop for maximum growth and yield (Oosterhuis *et al.,* 2013). For sustainable and productive crop cultivation, foliar fertilization techniques have become an ever more important tool, which is used worldwide (Shahid *et al.,* 2017). The Rengam Series is a member from family of Rengam, which is a fine, kaolinitic, isohyperthermic, red-yellow Tipik Lutualemkuts. It typifies this family which is developed over coarse grained acid igneous rocks (*Cataldo et al.,* 2021). Rengam soil series was chosen for this experiment as its available probably the most widespread soil in Peninsular Malaysia. Due to applying the fertilizers through the soil, some of the nutrient will be fixed in the soil and its remain unavailable for the plant. The effect of foliar fertilization has not been widely used in corn for improving yield and quality. The objective of this research is to determine the effects of different percentages of macronutrients as a foliar spray on the growth, development and yield performance of sweet corn grown in Rengam series soil.

Materials & Methods

Experimental location and Rengam series soil

The present study was performed at the Centre of Agriculture, Chembong located at 2° 37' 0" North, 102° 5' 0", East, Negeri Sembilan, Malaysia during the period from June 2020 to August 2020. Temperature hovers around 32°c and at night it like 24°c. During the period of the experiment, Kampong Chembong gets an average of 120.57 mm of rain and approximately seven rainy days in the month. Humidity is close to 78%.

Sweet Corn var. Thai Super Sweet was selected as the experimental crop, the seeds of this sweet corn variety were purchased from Bumi Maju Agro, Kuala Terengganu, Malaysia. The land was prepared for corn cultivation by ploughing and leveling. The soil type of the experiment is Rengam soil and the plot size of each treatment was 4 m × 5 m. Weeds were removed after ploughing and preemergent herbicide atrazine was sprayed to avoid weed germination and growth during corn growth and development.

The Rengam soil is a fine structure, kaolinite, isohyperthermic, and red-yellow under the Rengam family. The Rengam family developed from coarse-grained igneous acidic rocks. The Rengam series soil consists of a thin coarse brown sandy clay loam A horizon and uniform brownish yellow to yellowish brown coarse sandy clay to clay loam B horizon. The soil consists of subangular blocky structures and friable consistency which gets firmer with depth. Rengam soils occur on rolling, undulating and hilly terrain and are derived from granitic parent materials.

Seed sowing and treatment application

Two corn seeds were sown directly in the field at 75 cm (row-to-row distance) × 25 cm (plant-to-plant distance) in a plot size of 4 m × 5 m. All the experiments consisted of 5 treatments (0, 25, 50, 75 & 100% foliar macronutrients) including control. The foliar macronutrient fertilizers of 120kg N. ha^{-1}, 100 kg P_2O_5 ha^{-1} and 150 kg K20. ha^{-1} were used at different rates. Treatments of 25 % consisted of 11.1 g of urea as a source of N, 9 g of P and 10.4 g of K. The 50% treatment consisted of 22.2g of Urea as a source of N, 18g of P and 20.8 of K. While the 75% treatment consisted of 33.3g of urea as a source of N, 27g of P and 31.2g of K. The 100% treatment consisted of 44.4 g of urea as a source of N, 36.2g of P and 41.6g of K, in addition, to the control treatment. The fertilizer rates used in this study are recommended by the Malaysian Agricultural Research and Development Institute, (MARDI). The macronutrients as foliar fertilizers were applied at two stages during the growing period of sweet corn which was at 25 and 50 days after sowing the seeds. The foliar treatment procedure was used to reduce leaching and volatilization losses of nitrogen. Sweet corn plants were watered manually twice a day.

Measurement of yield and growth parameters

Corn plants were harvested 75 days after sowing the seeds. A ruler was used for the measurement of the cob length. The width of the fresh cob was also measured using a digital vernier caliper (Mitutoyo absolute dogmatic, Japan). The fresh cobs were weighed on an electronic scale (GF-3000 by A&D, Japan). The relative yield of sweet corn based on fresh cob weight was determined using a procedure by Sanderman *et al.*(2017). The highest yield was used to find the relative % yield obtained from other treatments, and a curve at 90% was plotted on the % yield line graph, which can then be used to determine the actual rate of F = fertilizer that will give an optimum yield of 90% (Hossain *et al.,* 2016)

$$\text{Relative yield } (\%) = \frac{y}{y} \times 100 \ldots\ldots.. \text{equation 1}$$

$$\text{Relative yield } (\%) = \frac{x}{y} \times 100 \ldots\ldots\ldots \text{equation 2}$$

$$\text{Relative yield } (\%) = \frac{w}{y} \times 100 \ldots\ldots\ldots \text{equation 3}$$

$$\text{Relative yield } (\%) = \frac{t}{y} \times 100 \ldots\ldots.. \text{equation 4}$$

Where, y, x, w, & t are fertilizer rates. The rate with the highest yield was selected and used in getting the percentage of the yield of other treatments against the highest, and then the result was plotted as a graph.

Nutrients analysis for corn

Nutrients, namely N, P, K, Ca, Mg, Cu, Zn, Fe and Mn, were analyzed using the dry ash method for roots, leaves, stems, cob, and flowers. Finely ground dried mature leave samples of 1g were taken and placed in a crucible. Then the crucible samples were put into a muffle furnace at 500 °C for 5 hours. The crucible with white and greyish ash was left to cool, 2 ml of 37 concentrated HCl were added, and let to evaporate till dry on a hot plate. 10 ml of 20% HNO3 was added to the water bath for one hour. The mixture was transferred into a 100 ml volumetric flax and the volume was made until the mark of 100 ml with distilled water. After that, the mixture was shaken and filtered using Whatman filter paper number 2. The macronutrients were analyzed by using the Inductively Coupled Plasma Mass Spectrophotometer (ICP). Nutrient uptake was calculated using dry weight multiplied by nutrient concentration on various parts of the corn. The total nutrient uptake of the corn plant was calculated by considering the nutrient uptake from various corn plants.

Soil nutrient analysis

Before planting the corn seeds, the soil used for the study experiment was analyzed according to the methodologies reported in Table 1, to get the soil characteristics. The soil characteristics of the Rengam soil series are reported in Table 2

Table (1): Methods for soil analyses

Method	Reference
Semi-micro Kjeldahl	Bremner & Mulvaney, 1965
Bray & Kurtz No.2	Bray & Kurtz, 1945
1 N NH_4 OAc at pH 7.0	Dilipkumar *et al.,* 2012
0.1 N HCL	Raji *et al*., 2021
Walkley & Black	Piper, 1950
1:2.5 soil: solution	Kusin *et al.,* 2018
pipette	Day, 1965

Table (2): Characteristics of experimental soil (Rengam series soils)

Chemical Properties	Rengam series
Carbon (%)	2.30
pH (H_2O)	4.80
pH (KCl)	3.51
Nitrogen (%)	0.12
Phosphorus (mg. kg^{-1})	13.09
Potassium (cmol (+) kg^{-1})	0.17
Calcium (cmol (+) kg^{-1})	0.74
Magnesium (cmol (+) kg^{-1})	0.14
Copper (mg. kg^{-1})	0.01
Zinc (mg. kg^{-1})	0.41
Iron (mg. kg^{-1})	32.17
Manganese (mg. kg^{-1})	1.31
Aluminium (cmol (+) kg^{-1})	2.67
Aluminium saturation (%) *	71.8
CEC (cmol (+) kg^{-1})	7.14
Effective CEC (cmol (+) kg^{-1})	3.73

* Based on ECEC (Effective cation exchange capacity)

Experimental design and data analysis

This current research was performed followed by Randomised Complete Block Design (RCBD) with four (4) replicates. The experimental area was divided into four blocks and the size of each block or plot was 20 m2. All the collected data were analyzed using SAS software (version 9.1), (SAS institute, Inc., Cary, MC, United States of America). The mean values of treatments were DMRT (Duncan Multiple Range Test) at a $p < 0.05$ level of probability.

Results & Discussion

Fresh cob weight, cob number and dry matter yield

The results of fig. 1 revealed that an increase in the rate of the macronutrients as a foliar application affected the fresh cob weight positively. A significantly increasing trend was observed with the increasing rate of the treatment up to 75% NPK (fig. 1). No significant difference was found between 75% and the 100% NPK treatments. The results showed higher values of cob number when increasing the rate of macronutrients as a foliar, (fig. 2.) with a significant difference between the 50% and the 75% NPK treatments.

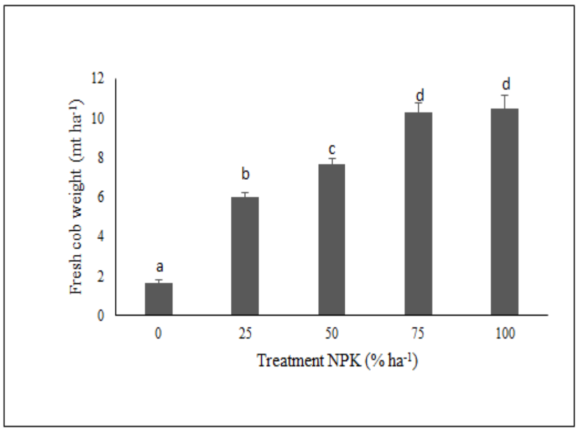

Fig. (1): Corn fresh cob weight at different NPK foliar concentrations ranging from 0 (control) to 100 %. Different letters indicate significant difference (DMRT, $p < 0.05$).

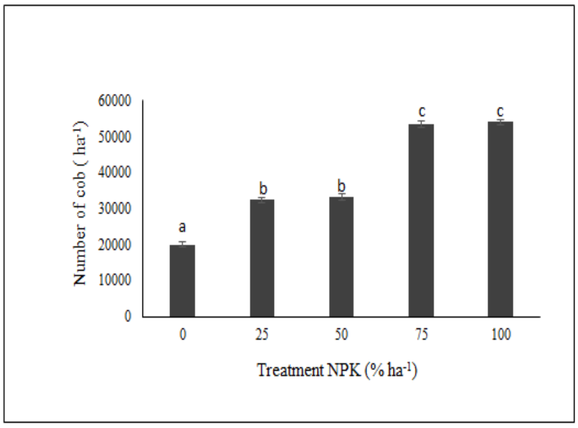

Fig. (2): Mean values (on 4 replicates) of cob number of sweet corn grown on Rengam series soil. Different letters indicate significant difference (DMRT, $p < 0.05$).

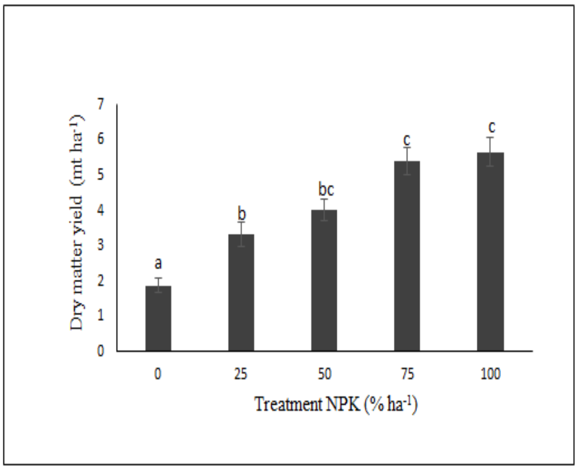

Fig. (3): Mean values (on 4 replicates) of dry matter yield of sweet corn grown at different NPK treatments. Different letters indicate significant difference (DMRT, $p < 0.05$).

The dry matter yield of sweet corn showed an increasing trend at increasing macronutrient rate as a foliar application (fig. 3), with the highest values being for the 75% and the 100% NPK rate with no significant difference observed between the two (DMRT at $p = 0.05$) to achieve higher yields. The control treatment produced the lowest dry matter content of sweet corn.

In this study, different concentrations of NPK fertilizers were applied as a foliar spray to investigate the effects of foliar macronutrients on the growth, yield and internal nutrients content of sweet corn grown on Rengam series soil. This study confirmed that foliar spray of macronutrients increased growth, yield and nutrient levels in sweet corn plants. We found that foliar spray of macronutrients increased the fresh cob weight, cob number and dry matter yield of sweet corn. Mineral nutrients play a significant role in plant metabolic functions from cell division to differentiation, formation of chlorophyll, photosynthesis, respiration, enzyme activity, fixation and reduction of nitrogen. In this study, the increase in fresh cob weight might be due to the foliar application of macronutrients by increasing enzyme activity, pollen viability and seed formation. Suganya *et al.* (2020) stated that foliar application of micronutrients increases the cob weight of corn by increasing plant growth, and physiological and biochemical processes. The foliar spray of nutrient elements regulates the leaf area, leaf area index, chlorophyll content and growth rate of the crop (Nadeem *et al.,* 2019). In addition, foliar fertilizations increase the synthesis and translocation of non-structural carbohydrates from the leaf to stems or other sink areas, which stimulates the sucrose phosphate synthase (SPS) activity, and in turn, increases filled grain number and grain weight per panicle in rice plants (Mahmoodi *et al.,* 2020). The foliar fertilizations of macro and micronutrients increase crop growth, development, and yield (Haider *et al.,* 2020). Shahid *et al.* (2017) reported that applications of foliar urea at the boot stage when nitrogen availability is very low increases the grain filling percentage and grain yield. Foliar (N) increases grain number (6% more than the control), 1000 seed weight, and stover yields of corn (Adhikari *et al.,* 2021).

In this study, it was found that the cob number of corns increased with the concentration of NPK foliar fertilization. The macronutrients N, P, and K may increase cell division, extension, and cell proliferation, thus increasing the cob number per corn plant. A multi-nutrient solution as a foliar spray affects pollen formation, and pollen viability and increases the number of grains in the cob. Potassium and magnesium participate in the transportation of photosynthates from the source to the sink and exerted a positive effect on the weight of grains in the cob (Kolisnyk *et al.,* 2020). Kihara *et al.* (2020) reported that a combined application of macro and micronutrients was better than conventional fertilizers which lacked micronutrients, and corn yield was higher with the combined fertilizer. The foliar application of macro and micronutrients is used when plants or soil lack the availability of some nutrients (Yaseen *et al.,* 2018). Appling a nutrient as a foliar can increase the growth, development, and yield of many crops (Yaseen *et al.,* 2018) and improve the quality of cereals, vegetables and fruits under calcareous and alkaline conditions (Ma *et al.,* 2020).

Foliar spray of mineral nutrients increased the chlorophyll content of the leaf and photosynthesis which increased the crop growth rate and dry weight (Tondey *et al.,* 2021). The leaf chlorophyll content is the key factor of photosynthesis regulation, and plant growth rate is significantly correlated with leaf chlorophyll content. In this study, dry matter increasing due to the foliar application may be due to a higher photosynthetic rate and carbohydrate translocation from the leaves to the grains (Wasaya *et al.,* 2017). Foliar application of nutrients affects the net photosynthetic rate and plays a significant role in dry matter accumulation and translocation in above-ground parts of the plant (Majeed *et al.,* 2020). The optimum concentration of foliar nutrients increased photosynthesis, improved accumulation, and translocation of photosynthates in the grain, produced a healthy panicle (Liang *et al.,* 2017), and increased the yield of grain and dry matter content (Singh *et al.,* 2014). The macronutrient N regulates the growth and development of many crops. N is a primary constituent required for protein synthesis and production of plant growth regulators, neurotransmitters and antioxidant compounds (Culman *et al.,* 2013). The essential macronutrient (K) has important functions in plant development, osmoregulation, membrane potential regulation, cotransport of carbohydrates, and stress adaptation. (Sanyal *et al.,* 2020; Sardans & Peñuelas, 2021). For the synthesis of nucleic acids, the development and stability of membranes, the metabolism of energy, as well as numerous other vital physiological and biological processes involved in plant growth and development, phosphorus is a crucial macronutrient (Hasan *et al.,* 2016).

Nutrient uptake in the ear and mature leaves

The concentration of P and K differed from the control in a similar way for all the macronutrient rates (table 3).

The amount of N, P, K, Ca, and Mg concentration in 100% NPK foliar treatment were 1.1, 2.61, 1.61, 8.2- and 2.76-times higher compare to the control group. Micronutrient contents were highest in the 50

% NPK foliar treatment. The macronutrient content of corn ear leaf showed an increasing rate trend, especially for N, Ca and Mg, with the highest rate at 100%. The micronutrient concentration had an increasing trend up to 100% in the case of Zn and Fe but was lower at 100% compared to 75% treatments in the case of Cu and Mn, with the highest content of Cu at 75% and of Mn at 25% (table 3).

Table (3): Macronutrient and micronutrient concentration in ear leaf of sweet corn grown on Rengam series soil taken at silking

Treat NPK	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
	(%)					(mg.Kg^{-1})			
0	1.47a	0.13a	1.50a	0.10a	0.13a	10.3a	13.0a	60.5a	30.0a
25	2.11b	0.26b	2.36b	0.23b	0.20b	15.5b	18.0b	87.5b	49.5b
50	2.29b	0.27b	2.35b	0.45c	0.22b	16.5b	20.5c	94.0b	43.0b
75	2.49c	0.28b	2.37b	0.69d	0.30b	17.5b	13.5b	120.5c	42.0b
100	2.52c	0.34b	2.42b	0.82d	0.36b	12.5b	15.5b	128.5c	33.5a

Different letters in the same column of the table indicate significant difference (DMRT, $p < 0.05$).

The macronutrient content in corn leaves was highest at the 75% and 100% NPK treatment (table 4). A significant difference (DMRT, $p < 0.05$) from the control was present for N, P and K starting from the lowest treatment tested (i.e. 25%), while it was not significant until 75% NPK for Ca and 50% NPK for Mg. The highest amount of N and K content was recorded in the 75% NPK treatment, whereas, P, Ca and Mg content were highest in the 100% NPK treatment. Micronutrient concentration showed a similar pattern with the highest concentrations reached with a treatment of 75% NPK. A difference with the control was observed at 25% NPK for Fe and Mn, but only at 50% NPK for Cu and Zn (table 4).

Table (4): Nutrient uptake of N, P, K, Ca, Mg, Cu, Zn, Fe and Mn by corn leaves

Treat NPK	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
	kgha-^{1}					g ha^{-1}			
0	8.54a	0.99a	9.19a	1.94a	1.14a	5.13a	14.50a	295.8a	22.80a
25	21.17b	2.60b	21.67b	4.93a	2.06a	10.57a	18.14a	291.8ab	90.65b
50	26.00b	3.04b	24.60b	5.01a	3.22ab	10.73ab	23.40b	270.8ab	87.95ab
75	35.70c	4.27c	38.26c	12.45b	4.69bc	14.50b	43.80c	391.0b	115.90b
100	34.20c	4.30c	30.40c	12.94b	5.40c	17.30b	42.30c	313.3ab	87.4b

Different letters in the same column of the table indicate significant difference (DMRT, $p < 0.05$).

Our results show that exogenous foliar application of macronutrients increased the internal level of macro and micronutrient content in the ear leaf, mature leaves, corn stem, corn cob, cornflower and whole plant of the corn. This elevated level of nutrients may improve the chlorophyll content, net photosynthetic rate, sucrose phosphate synthase (SPS) activity, and accumulation of photosynthates in the plants. Thus, the treated corn plants produced a higher number of cobs and increased the fresh cob weight and dry matter yield compared to the control corn plants especially in dry land areas, foliar spray of N, P and K increase crop growth and production (Shahid *et al.,* 2017; Cakmak & Kutman, 2018). However, foliar spray macronutrients such as foliar (P) decreased the Zn content in wheat seed and leaf. A foliar spray of macronutrients is a complementary strategy to amend soil nutrient deficiency and is widely used in sustainable agriculture. Plant leaves not only capture light and CO_2 for photosynthesis, but they also absorb nutrients as it is already recognized and used in nutrient management systems (Shahid *et al.,* 2017). Spraying of macronutrients to the wheat leaf induced root growth which led to enhancing the absorption of nutrient elements from the soil (Zain *et al.,* 2015). Thus, elevated levels of macro and micronutrient content in the plants play a significant role to improving the yield and quality of the crop.

Nutrient content in corn stem

The macronutrient content in the corn stem showed the highest concentration at 75% NPK and 100% NPK content of macronutrients as a foliar application for N, K and magnesium Mg (table 5), while for P at 100% NPK the concentration measured was lower than what was found at 75% NPK and for Ca at 100% NPK the concentration was significantly higher than at 75% NPK ($p < 0.05$, DMRT). The micronutrient's highest concentrations in the corn stem were measured at 50% for Cu and at 75% NPK and 100% NPK for Fe, significantly higher Zn content was recorded in the 100% NPK treatment, while for Mn all NPK treatments did not produce any significant effect (table 5). Due to several pores in the leaf viz. stomata, hydathodes and lenticel, the plant can easily absorb nutrient elements applied by foliar spray.

Even though the leaf can absorb minerals by the cuticle present on both surfaces. A nutrient element applied on the leaf surface must enter through a cuticle layer (made of wax or suberin), the cell wall and the cell membrane before being metabolized by the plants. Thus, soil-deficient and unavailable nutrient elements can be applied on the plant surface by foliar spray and this technique is more effective to control nutrient deficiency problems than other techniques (Alengebawy *et al.,* 2021).

Table (5): Nutrient uptake of N, P, K, Ca, Mg, Cu, Zn, Fe and Mn by corn stem.

Treat NPK	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
	kg ha-^{1}					g ha^{-1}			
0	7.83a	0.94a	11.07a	0.91a	0.82a	6.70a	53.9a	51.6a	41.1a
25	18.16b	2.29b	37.92b	3.72b	3.10ab	12.40ab	61.2a	103.2b	53.6a
50	22.12b	2.42b	48.80b	3.67b	3.13abc	20.00b	91.1a	102.2b	55.8a
75	31.06c	3.95c	68.09c	5.34c	4.47bc	16.40a	85.9a	153.6d	58.8a
100	35.40c	2.83b	70.64c	6.96d	6.33c	15.00ab	116.3b	120.1c	42.8a

Different letters in the same column of the table indicate significant difference (DMRT, $p < 0.05$).

Due to unfavourable soil conditions, runoff and leaching, sometimes soil applied nutrients are insufficient for crops to meet requirements which can cease their growth and development and affect the yield and quality of the crop produced. Foliar fertilization provides rapid absorption and utilization of nutrient minerals, which can directly enter plant metabolism systems. When nutrient uptake is restricted from the soil and sink competition occurs among plant organs, then foliar fertilization is the most economical and effective way to achieve quality production and yield (Pradeep & Elamathi, 2007). Foliar application of N increased the amino acid content in the plants. Balawejder *et al.* (2019) stated that foliar fertilizers increase the growth of stems, leaves and roots of corn.

Nutrient content in corn cob and flower

The highest amount of N, P and K in the corn cob were found in the 75 % NPK treatment, whereas Mg content was the highest in both 75% and 100 % NPK treatments. The foliar spray of macronutrients did not have any substantial effect on the Ca content of the corn cob. Micronutrient concentration in the corn cob was highest at 75% NPK for Zn, Fe and Mn and at 100% NPK for Cu (table 6).

Table (6): Nutrient uptake of N, P, K, Ca, Mg, Cu, Zn, Fe and Mn by corn cob

Treat NPK	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
	kg ha^{-1}					g ha^{-1}			
0	3.83a	0.31a	3.45a	0.35a	0.47a	3.02a	3.61a	40.1a	15.0a
25	6.31b	0.98b	4.19ab	0.26a	0.45a	2.93a	3.69a	31.3a	14.5a
50	8.52bc	1.49c	5.53ab	0.33a	0.57a	4.68a	6.95b	46.4ab	15.7a
75	11.58c	1.87d	7.12b	0.52a	0.84bc	4.94a	18.7c	56.6b	26.4b
100	9.93bc	1.55c	5.79ab	0.54a	0.74bc	5.69b	6.94b	51.8ab	18.7a

Different letters in the same column of the table indicate significant difference (DMRT, $p < 0.05$).

In the case of cornflowers, the macronutrient concentration was highest at 75% NPK and 100% NPK treatments for N and Ca and significantly higher at 100% NPK treatment for P, K and Mg (table 7). For micronutrients, Cu had the highest concentration in cornflowers at 50% NPK, Zn at 100% NPK and Mn at 75 % NPK and 100 % NPK. No significant difference from the control was found for Fe at all NPK treatment rates (table 7).

Table (7): Nutrient uptake of N, P, K, Ca, Mg, Cu, Zn, Fe and Mn by corn flower

Treat NPK	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
	kg ha^{-1}					g ha^{-1}			
0	1.14a	0.16a	1.41a	0.22a	0.10a	0.62a	4.65ab	8.28a	2.46a
25	1.47b	0.20ab	1.22a	0.28a	0.11a	0.76ab	2.92a	13.00a	4.89b
50	1.74b	0.23ab	1.86b	0.31a	0.22ab	0.91b	4.26ab	39.30a	5.61b
75	2.05c	0.25ab	2.26b	0.41b	0.23ab	0.87ab	4.24ab	16.50a	7.10c
100	2.35c	0.30b	2.55c	0.44b	0.33b	0.70ab	4.95b	20.50a	6.03c

Different letters in the same column of the table indicate significant difference (DMRT, $p < 0.05$).

Total plant nutrient uptake

The macronutrient content of the whole plant showed that the highest values were confined to the highest rates measured at 75% NPK and 100% NPK for all macronutrients (Table 8). In the case of micronutrients for Cu, no significant difference in the rate was found for the 50% NPK, the 75% NPK and the 100% NPK treatments ($p > 0.05$, DMRT); in the case of Zn and Fe the highest values were found at the 75% and 100% NPK treatment rate; Mn showed a higher rate at 75% NPK compared to the 100% NPK treatment (table 8). The correlation between nutrient concentration in corn ear leaf and cob weight was highly significant ($p < 0.01$) for all macronutrients, but not for micronutrients (table 9). Similarly, to the case mentioned for the corn ear leaf, total nutrient uptake by the corn plant showed a positive correlation with the fresh cob yield ($p < 0.01$) for all macronutrients and among the micronutrients for Cu (table 9). However, r values obtained from the correlation test were not higher than 0.604 and below 0.5 in the case of Mg and Cu, whereas the correlation with a nutrient concentration in the ear leaf had r values ranging from 0.880 to 0.986.

Table (8): Total nutrient uptake of N, P, K, Ca, Mg, Cu, Zn, Fe and Mn by corn plant

Treat NPK	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
			kg ha-1				g ha-1		
0	21.3a	2.40a	25.1a	3.41a	2.54a	15.4a	76.7a	395.8a	81.4a
25	42.1b	7.15b	61.3b	9.20b	4.73b	26.7b	85.9b	432.3ab	163.7b
50	58.4b	7.19b	80.8b	9.32b	7.14c	36.3c	125.7c	435.1ab	165.0b
75	80.1c	10.3c	116.1c	18.3c	10.2d	36.7c	155.6d	617.8b	208.1c
100	79.9c	8.40c	109.4c	18.9c	12.8d	38.6c	157.3d	551.6b	155.0b

Different letters in the same column of the table indicate significant difference (DMRT, $p < 0.05$).

Table (9): Correlation between fresh cob yield with nutrient concentration in ear leaf and total nutrient uptake by corn plant grown on Rengam series soil

Nutrient concentration	r (Fresh cob yield with ear leaf)	r (Fresh cob yield with nutrient)
N	0.986**	0.543**
P	0.937**	0.580**
K	0.892**	0.570**
Ca	0.960**	0.604**
Mg	0.880**	0.424**
Cu	-0.031	0.499**
Zn	0.188	0.350
Fe	0.693	0.242
Mn	-0.313	0.209

** Significant at p = 0.01

Foliar spray of NPK maintains leaf nutrition during photosynthesis, increases the internal level of N, P and K content, and regulates C: N ratio of crop plants (Vincente *et al.,* 2014). Shahrajabian *et al.* (2022) stated that foliar spray of N and P at 25 and 50 days after sowing, supplemented the nutrient requirement of the crop. Exogenous N and P may increase the rate of photosynthesis, which elevates the level of carbohydrate content and produces higher dry matter in the crop (Makino, 2003). N and phosphate foliar spray enhance the nitrate reductase (NRase) activity which produces higher chlorophyll content, photosynthesis and other physiological processes related to plant growth and development.

Chemical properties of Rengam soil series after harvest

The soil characteristics after harvest changed with the treatment (table 10). The pH at the treatment of macronutrients as a foliar application at 100% increased consistently with the increase of macronutrient as a foliar application treatment rate, increasing by one unit at the highest treatment concentration (i.e., 100% NPK). Among the nutrients, N, P, Ca and Mg content showed an increase with the treatment percentage rate. Copper (Cu) showed a lower variation, but still an increase from the control. While for Zinc (Zn), there was no difference with the control. For K, Fe and Mn, the difference was only observed at the highest treatment (Table 10).

Table (10): Chemical properties of Rengam series soil after harvest.

Treat NPK	pH	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
	(H_20)	%	ug^{-1}		(cmol kg^{-1})	$g\ ha^{-1}$				
0	4.6	0.24	0.10	0.10	0.31	0.10	0.27	0.21	0.01	0.01
25	4.4	0.26	0.12	0.12	0.33	0.10	0.27	0.21	0.02	0.01
50	4.7	0.31	0.23	0.13	0.40	0.18	0.21	0.22	0.02	0.01
75	4.8	0.43	0.36	0.12	0.43	0.38	0.25	0.20	0.02	0.01
100	5.6	0.45	0.35	0.14	0.50	0.43	0.31	0.21	0.04	0.02

Calcium (Ca), magnesium (Mg) and manganese (Mn) with fewer mobile elements cannot simply translocate from the roots to the other plant parts (Aziz *et al.,* 2019). Thus, the mineral nutrient application only at the root zone may not be meeting the plant requirements for proper root growth, development, and efficient nutrient use. So, the foliar spray of nutrients is an alternative approach to delivering nutrients to the crops for optimum growth, development, and yield. Based on the above discussion, it can be summarized that foliar application of macronutrients (NPK) at 25 and 50 days after sowing of corn increased the fresh weight of the cob, the number of cobs and dry matter yield in Rengam series soil.

In our study, the foliar spray of macronutrients increased the growth and physiological parameters of corn (data not shown), which are closely correlated with the yield attributes of corn. Taheri *et al.* (2020) stated that the foliar spray of micronutrients increased growth and yield, which might be attributed to increased photosynthetic rate, accumulation of photosynthates and increased production. Plants can absorb foliar urea swiftly, and the absorbed urea easily hydrolyses in the cell cytoplasm (Nicoulaud & Bloom, 1996). Ali *et al.* (2016) stated that a foliar spray of K is more beneficial to crop growth, development and economic yield than a soil application. Foliar fertilization is six to twenty times more effective as compared to application in the soil (Krishnasree *et al.,* 2021). Supplementary foliar application of fertilizer during the early growth stages of a crop, enhanced mineral content in the plant, thus increasing crop yield (Kolota & Osinska, 2001). The foliar spray of nutrients increased the micronutrient content in wheat grain and this positive effect may be ascribed to the improved physiological activities in root cells which enhanced the absorption of nutrients from the soil (Arif *et al.,* 2006).

Conclusion

The foliar application of macronutrients positively affected all the studied characteristics of corn in this research. In conclusion, results showed that a significant increase was recorded in the cob number of sweet corns at the rate of 75%, and 100% NPK of macronutrient foliar fertilizers. Also, a significant increase in the fresh weight of the cob and dry matter yield was seen on plants treated with two foliar sprays of macronutrients at the rate of 75% and 100% NPK. The findings of this study could be useful to improve crop growth and achieve more yields and quality improvement of crops. Using a rate of 75% NPK as a foliar spray is recommended for corn production in terms of economic viability as compared to the 100% NPK.

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B.A.M: Experimentation, data collection, wrote and revised the manuscript.

M.M.K: Wrote and revised the manuscript, and supervision.

A.M.A.: Suggestion the proposal of the article & supervision

N.F.H.N.: Reviewed the manuscript and supervision.

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Conflicts of interest

The authors declare that they have no conflict of interests.

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تأثير الرش بال NPK على نمو وحاصل والمكونات المعدنية لنبات الذرة الحلوة النامية على سلاسل من تربRengam

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المستخلص: أجريت الدراسة الحالية لأختبار تأثير المعدلات المختلفة لسماد ال NPK بالرش الورقي على أداء النمو والمحصول والمحتوى الغذائي لمحصول الذرة الحلوة من صنف Thai super sweet المزروعة في سلسلة تربة. Rengam يتضمن البحث من 5 معاملات وهي عبارة عن رش محصول الذة الحلوة بسمادNPK كسماد ورقي وبتراكيز 0 ، 25 ، 50 ، 75 ،100 ٪ / هكتار .وبدات معاملات الرش الورقي للنباتات بسماد الNPK بواقع رشتين الاولى بعد 25 يوما والرشة الثانية كانت بعد 50 يومًا لنبات الذرة الحلوة .أظهرت النتائج زيادة معنوية في وزن الكوز الطازج وعدد الكوز وحاصل الوزن الجاف للذرة الحلوة المعاملة بتراكيز75 ٪ و100 ٪ من سماد ال. NPK واظهرت النتائج ايضا ان النباتات المعاملة بتراكيز75 ٪ ،100 ٪ NPK احرز زيادة في نسبة العناصرالغذائية في أوراق الأذن والأوراق الناضجة والساق والكوز والزهور لمحصول الذرة الحلوة مقارنة بالنباتات الاخرى المعاملة بباقي التراكيز. كما اظهرت نتائج البحث ان نسبة المغذيات الكبيرة في النبات الكامل أعلى بشكل ملحوظ في النباتات المعاملة بتراكيز75 ٪ و100 ٪ ، ايضا كان محتوى الحديد والمنغنيز في النبات الكامل هو الأعلى أيضًا في معاملات 75٪ و100 ٪ مقارنة بباقي التراكيز .يرتبط تركيز المغذيات الكبيرة في أوراق الأذن ونباتات الذرة معنويا بإنتاجية الذرة الطازجة . من خلال النتائج المتحصل عليها يتضح ان استخدام الرش الورقي لنبات الذرة الحلوة بسماد NPK بتراكيز 75 و 100%عزز كمية الحاصل والنوعية للذرة الحلوة.

الكلمات المفتاحية: الحبوب، الذرة الحلوة، العناصر الكبرى، الرش، النوعية، انواع من الترب