Original Research Article

YIELD AND BIOMASS RESPONSES OF MAIZE (*Zea mays*) TO THE APPLICATION OF FOLIAR FERTILIZERS

ABSTRACT

Aims: We examine the effect of foliar fertilization on the yield and biomass of maize seedlings.
Study design: The experiment was conducted under high yield potential plant growing chamber conditions using the hydroponics techniques under the phytotron.
Methodology: The maize seedlings were grown in a nutrient solution containing macro- and micro-nutrients and thereafter, fertilizer solutions were applied on leaf surface. Different combinations of root and foliar nutrient supply treatments were used. In the high series, nutrient supply treatments with a high concentration of the macro- and micro-nutrients with two series (H1 and H2); and the low nutrient solution with a low concentration of the macro- and micro-nutrients with four series L1, L2, L3, and L4. H1 and L1 were non-foliar fertilized. H2, L2 and L3 were sprayed with the fertilizer daily and L4 was sprayed with the fertilizer once in a week. The treatment lasted for three weeks.H1and H2 with optimal root NPK and the low series nutrient supply treatments L1, L2, L3, and L4 with one-tenth of the optimal root NPK supply was used. The results were analyzed with one-way ANOVA and Tukey post-hoc test.
Results: Foliar NPK application with the low and high nutrients solution gave the highest shoot dry biomass and N and P uptake, and lateral root formation compared to the non-fertilized plants. Under field conditions, foliar spraying of NPK high-P significantly increased the shoot dry biomass of maize compared with the treatment without P in all cases. Foliar fertilizers with high concentrations of NPK improved maize yield suggesting that appropriate management of P and N resources is a prerequisite for a sustainable maize yield.
Conclusion: Foliar fertilizers with high concentrations of NPK improved maize yield suggesting that appropriate management of P and N resources is a prerequisite for a sustainable maize yield.

Keywords: foliar fertilizers, sustainability, soil fertility, yield, maize.

1. INTRODUCTION

Major cereal crops are staple foods that have the role to provide great amount of dietary macronutrients such as carbohydrates, lipids and proteins, and micronutrients such as minerals, vitamins, as well as functional compounds, which can improve human health [1]. In particular, maize is one of the major crops cultivated over the world, mainly in developing countries, with a varied range of consumed forms and utilizations. Maize is a plant with high nutrient demands because of its ability to form abundant vegetative mass and a high quantity of seeds at the unit area. It is a great consumer of nitrogen, phosphorus, potassium, magnesium and calcium, as well as micro elements [2].

Fertilization is an important factor in maize production technology to achieve optimum yield of seeds, the root, the shoot and the biomass. Because of this, the efforts for the biofortification of this crop are of great interest [3]. High maize yields can only be obtained through the application of optimal nutrient doses in balanced proportions. However, soil mineral reserves and soil fertilization are not always sufficient to satisfy the needs of crops because fertilizer applications to the soil can be subjected to undesirable processes such as leaching, runoff and being tied up in the soil in unavailable forms. Foliar applications of nutrients have been designed to be an integral component of overall plant nutrition programs. Foliar application of plant nutrients has potential advantages over soil application for fertilization of crops in that it increases the efficiency of fertilizer use and allow relief of physiological stress [4]. They are used in other situations to help plants through short but critical periods of nutrient demand, such as vegetative growth, bud differentiation, fruit set and fruit growth [5]. Foliar feeding is of great importance because it corrects soil deficiencies especially those caused by micronutrients and overcome the soils inability to transfer nutrients to the plant under low moisture conditions. Foliar fertilization with micronutrients have been intensively used in the late years because this practice allows the application of minerals at the appropriate time during plant development (according to plant needs), it allows uniformity in nutrient distribution and increase in the nutrient absorption, and consequently it avoids losses in the environment [6].

The effectiveness of foliar applied nutrients is determined by: the condition of the leaf surface, in particular the waxy cuticle; the cuticle is only partially permeable to water and dissolved nutrients and, as a result, it can limit nutrient uptake; the length of time the nutrient remains dissolved in the solution on the leaf's surface; the movement of elements from a high concentration to a low concentration. For diffusion to occur, the nutrient must dissolve; and the type of formulation.

Water soluble formulations generally work better for foliar applications as they are more easily absorbed when compared to insoluble solutions. Ideally, foliar feeds should be applied in the cooler morning or evening hours. It is not advisable to spray leaves during the heat of the day. The combined effects of fertilizer and sunlight on the foliage could cause tissue damage. When spraying the foliage of plants, a fine mist is preferable to large droplets as greater leaf contact will be made. The undersides of the leaves should be sprayed as well. Generally, plants are sprayed until droplets start to drip on to the ground.

Recognizing the necessity of advanced and appropriate technology to increase farm income and promote information the use of foliar fertilizers as supplement, hence, the general objective of the study which is determine the effect of foliar fertilizers on the yield and biomass of maize seedlings. This general objective will be achieved via the following specific objectives:

- to determine the appropriate dosages for application of the foliar fertilizer on maize for optimum growth and yield performance.
- to assess maize biomass, yield and early growth response to starter application of foliar fertilizers
- to compare responses with and without additional foliar fertilizer.

2. EXPERIMENTAL DETAILS

The experiment was conducted for maize at the Institute of Botany and Ecophysiology of Szent Istvan University Gödöllő, Hungary. Studies were located under high yield potential plant growing chamber conditions using hydroponics. The macronutrient treatment included N, P, K with other compounds such as KNO3, Ca(NO3)2.4H2O, K(H2PO4), MgSO4.7H2O, K2SO4 and CaSO4.2H2O.
The micronutrient used include: Mn, Zn, Cu, Mo, and B; in the following compounds $MnCl_2.4H_2O$, $ZnSO_4.7H_2O$, $CuSO_4.5H_2O$, $(NH_4)SMo7O_{24}.4H_2O$, H_3BO_3 (Table 1.). Iron was applied in form of EDTA complex (Fe-EDTA).

Table 1. The composition of nutrient solutions with high (HIGH) and low (LOW) NPK contents (modified Hoagland solution for maize)

Macronutrients	Concentration (mM)	
	HIGH	LOW
N	15	1.5 (10%)
P	1	0.1 (10%)
K	6	0.6 (10%)
Ca	5	2.75
Mg	2	2
S	2	4.25
Micronutrients	**Concentration (µM)**	
Mn	11	
Zn	4	
Cu	0.8	
Mo	0.5	
B	47	
	(mg/l)	
Fe-EDTA	20	

A high and low nutrient solution was prepared using the above macro and micro nutrient measurements in mg/l. After measurement, each of the solution were added into a big measuring cylinder of 15 litres. The stock solutions of the macro and micro nutrients were filled into the plant pots. The maize seeds were pre-germinated in the germinator for a day; and then they were transplanted into the various series of the high and low nutrient solution; before they were being transferred to the plant chamber for adequate growth. The foliar fertilizer was also prepared with the above elements in mM. After two weeks of planting, foliar fertilizer was applied.

Figure 1: The stock solutions and the macro and micro nutrients used during the experiment.

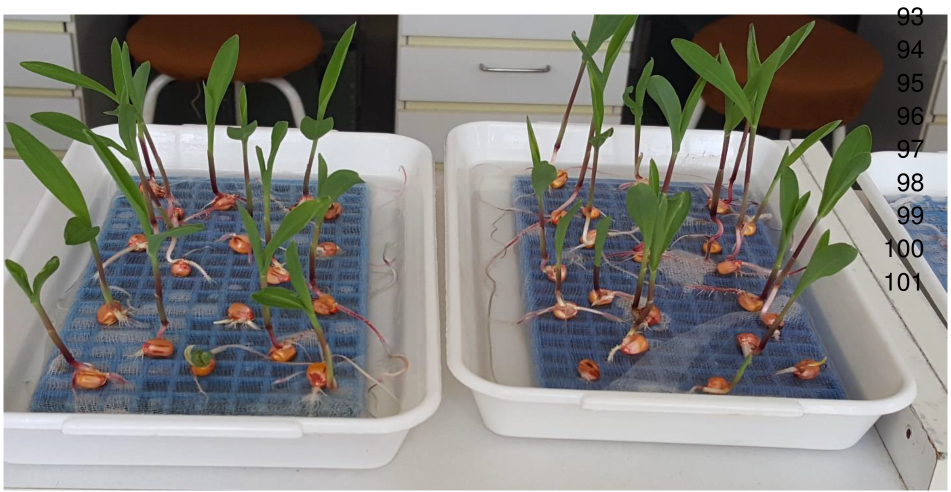

Figure 2: The pre-germinated maize seedlings

The foliar fertilizer was applied twice a day for three weeks the high nutrient series maize plants: H1 and H2 with each having five series under them; and the low nutrient series maize plants: L1, L2, L3, L4 also each of them have five series under them thereby making it thirty maize plants in total. The H1 and L1 were treated daily with water and they are the control while L4 was treated with foliar fertilizer once per week; the other series were treated with foliar fertilizer daily.

Figure 3: The maize seedlings at the first week of experiment

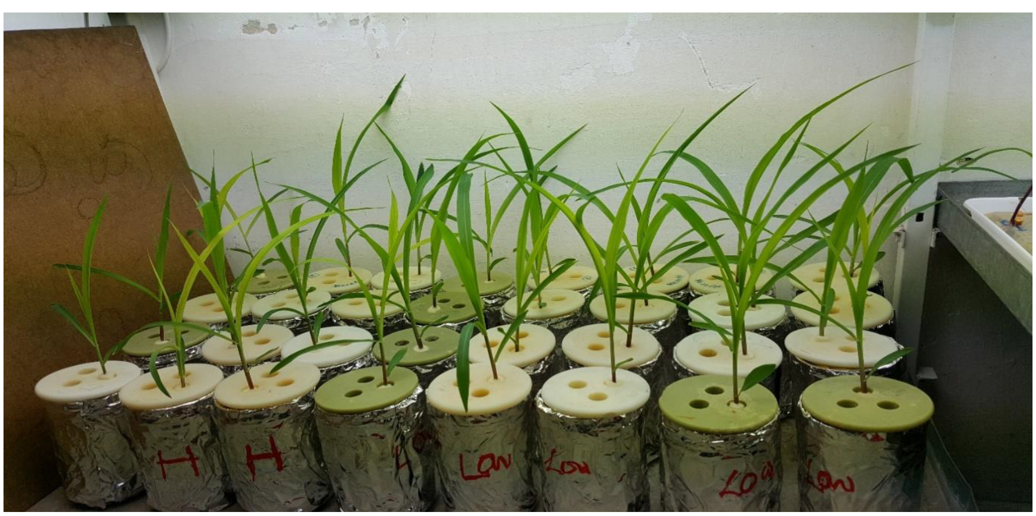

Figure 4: The maize seedlings at the second week of experiment before foliar fertilization.

Figure 5: The maize seedlings at the third week of foliar fertilization with the foliar sprayer.

A sprayer with a good nozzle was used to spray the nutrient solution or water. The foliar fertilizer wet the whole leaf surface. All treatments were replicated five times. For the analysis of dry matter yield, the plant was cut into two segments the upper segment consisting of the shoot region including the leaves which were treated with foliar fertilizer and the bottom segment consists of the root region that was inside the nutrient solution.

2.1 Analysis of plant growth

The accumulation of evapotranspiration and evaporation was taken note of by respectively checking the level of nutrient solution content in the pots. There was serial addition of nutrient solution to the pots where evapotranspiration has occurred. After the second week, pictures were taken of the plant samples using a canon G9 digital camera where the root length and the relative growth of the different series was determined using image J. The values of the root length of the different series were measured and calculated respectively. The plant material was oven-dried at 60ºC for two days and the dried samples were weighed.

Figure 6: The oven dried plant material sample

2.2 Statistical analysis

All the determination was carried out and subjected to one-way analysis of variance (ANOVA) whereby analysis for each variable was done separately according the concentration of the various nutrient solutions (High and low nutrient solutions) and the time of application of foliar fertilizer (according to series 1 and 2). This was followed by the Tukey-Kramer range test to establish the honest significance difference (HSD) in means between the various group means at <0.05 confidence level. HSD is minimum distance between two group means that must exist before the difference between the two groups is considered.

3. RESULTS AND DISCUSSION

3.1 Effect of foliar fertilization on root elongation

Root lengths were determined two times during the experimental period, first (1st series of measurement) after one-week long exposure, then two weeks later (2nd series of measurement). At the first time the exposure time was too short to have a significant effect on the root elongation, while the three-week long exposure resulted in significant differences among the treatments (Fig. 7). The low solution series have longer lateral roots and the foliar fertilizer application decreased the root elongation. Less frequent applications have lower inhibitory effects. The results also demonstrate the effect of the different nutrient supply in the root zone on the root development.

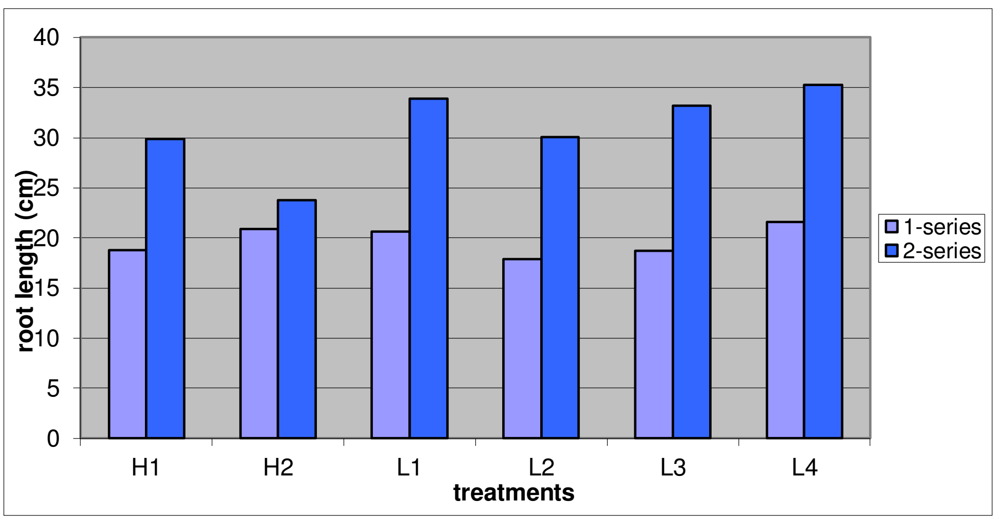

Figure 7. The root length of the maize seedlings after one week(1-series) and three weeks (2-series) exposure on different nutrient solution (high 'H' and low 'L' nitrogen supply) and different foliar fertilization: H1 and L1 with water on every day, H2 and L2 with NPK on every day, L3 three times per week, while L4 one time per week with NPK and water on the other days, respectively.

The results as shown in table 2 reveals that there is a strong statistical difference among the groups. Pair-wise comparison test for the root length measurement among the groups was significant $P<0.05$. The pair-wise comparison was done between the results of the control groups and the H2, L2, groups which were daily treated with foliar fertilizer while the L3 thrice a weekL4 group was treated only once in a week. The Tukey post hoc test between the control group H1 and the H2, L2, L3, and L4 indicated a strong significant difference among the groups and there was also significant difference between the two control groups (H1 and L1).

Table 2. ANOVA table of the 1st series root length measurement

	Df	Sum Sq	Mean Sq	F value	*P*
Groups	5	554.8	110.97	6.913	0.001

Residuals	84	1348.3	16.05

3.2 Effect of foliar fertilization on the relative growth rate of the root length (Percent/day)

The relative growth rate of root elongation was strongly decreased by foliar fertilizer at optimal nutrient supply in the hydroponic nutrient solution; especially for the high nutrient solution series because of the high nitrogen concentration in the nutrient supply and the everyday treatment with foliar fertilizer. This effect on the relative growth rate, did not appear on the low nutrient solution series.

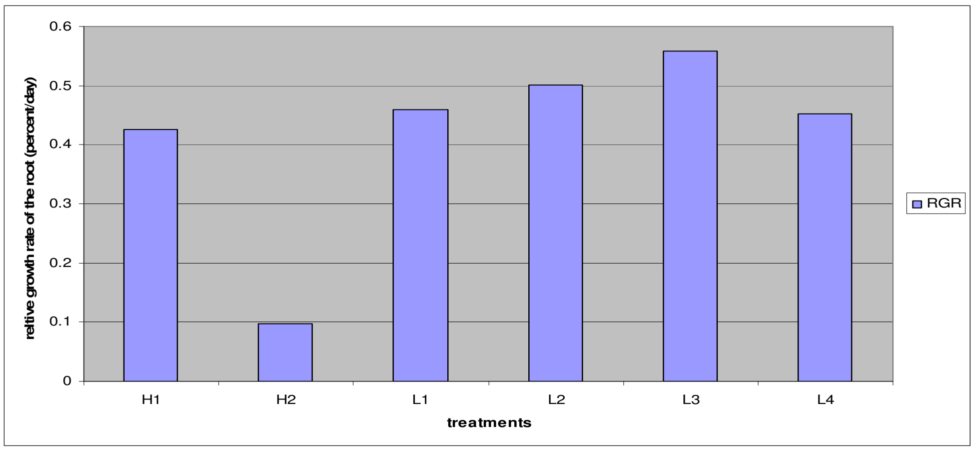

Figure 8: The relative growth rate of the root lengths of the maize seedlings after one week (1-series) and three weeks (2-series) exposure on different nutrient solution (high 'H' and low 'L' nitrogen supply) and different foliar fertilization: H1 and L1 with water on every day, H2 and L2 with NPK on every day, L3 three times per week, while L4 one time per week with NPK and water on the other days, respectively).

The statistical analysis, as shown in table 3, reveals that there was a significant difference among the group. The pairwise comparison test went further to prove this as seen between the control group L1 and groups L2 and L3 and also among group H2 and L2 and L3. The pairwise comparison for the relative growth rate among the groups indicated that there was a significant difference *P<0.05*.

Table 3. ANOVA table for the relative growth of the root length

	Df	**Sum Sq**	**Mean Sq**	**F value**	***p***
Groups	5	2.724	0.5448	5.778	0.000
Residuals	84	7.921	0.0943		

3.3 Effect of foliar fertilizer on the dry weight of the root and shoot

The dry weight root and shoot graph below illustrates the effect of foliar application on the root and shoot biomass (Dry weight). However, high nutrient content solution resulted in shorter and thicker root system (the “H” series) while the low nutrient content solution resulted in longer but weaker and thinner root system (the “L” series). Additional nutrient applied on the foliar surface induced more intense shoot development resulting in higher above ground biomass. The less frequent application of foliar fertilizer L4 has low effect on the shoot biomass increase. The final biomass in this experiment is independent on the nutrient supply.

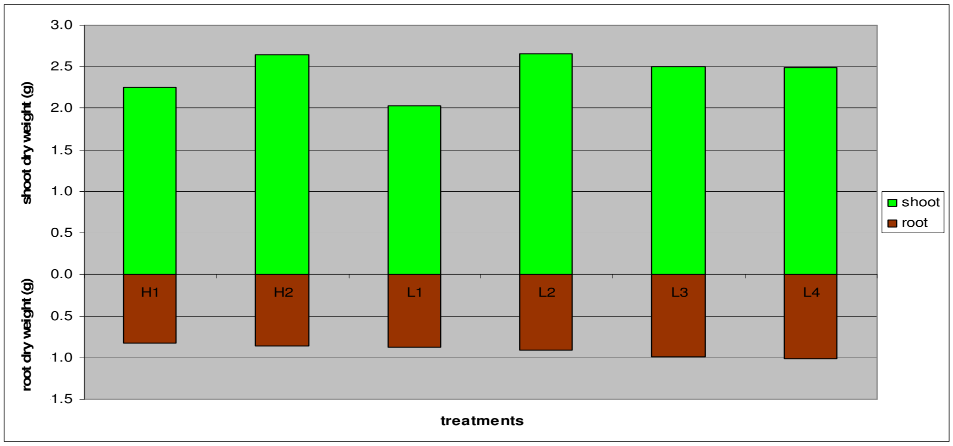

Figure 9: The dry weight of the root and shoot of the maize seedlings after one week (1-series) and three weeks (2-series) exposure on different nutrient solution (high ‘H’ and low ‘L’ nitrogen supply) and different foliar fertilization: H1 and L1 with water on every day, H2 and L2 with NPK on every day, L3 three times per week, while L4 one time per week with NPK and water on the other days, respectively).

Table 4. ANOVA table for the dry root

	Df	Sum Sq	Mean Sq	F value	p
Groups	5	1.163	0.23266	2.486	0.058
Residuals	25	2.339	0.09358		

Table 4 indicated that there was no significant difference in the dried root weight among the groups P>0.05

Table 5: ANOVA table for the dry shoot

	Df	Sum Sq	Mean Sq	F value	p
Groups	5	4.924	0.9848	1.926	0.126
Residuals	25	12.783	0.5113		

Table 5 indicated that there was no significant difference in the dried shoot weight among the groups P>0.05.

3.4 Effect of foliar fertilizer on the ratio of the root to shoot biomass (Relative unit).

The application of the foliar fertilizer significantly decreased the root to shoot ratio independently on the NPK content on the nutrient solutions. However, the different nutrient solution without foliar fertilizer also resulted in slightly different root to shoot ratio. The decrease was induced by the enhanced biomass allocation to the shoots instead of the roots. The final roots dry weight of the different treatments didn't differ; although we proved differences in the lateral root lengths. These findings indicate that low N supply in the nutrient and foliar solution increases the root elongation while the high N supply inhibits the elongation, improvement and density of the lateral root system

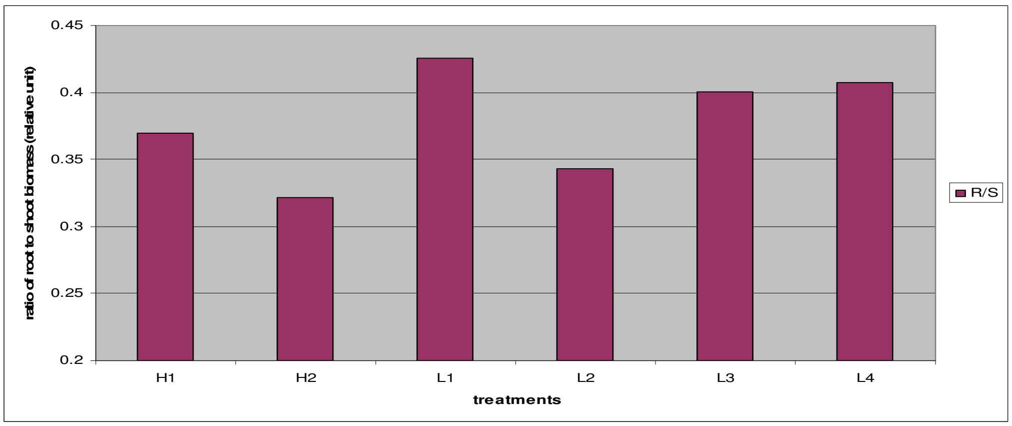

Figure 10: The ratio of the root to shoot biomass of the maize seedlings after one week (1-series) and three weeks (2-series) exposure on different nutrient solution (high 'H' and low 'L' nitrogen supply) and different foliar fertilization: H1 and L1 with water on every day, H2 and L2 with NPK on every day, L3 three times per week, while L4 one time per week with NPK and water on the other days, respectively).

The statistical analysis indicated that there was a significant difference among the groups. The pair wise comparison for the root/shoot ratio among the groups was significant *P<0.05*. The test was conducted between groups H1 and L3, L1 and H2, H2 and L3 and the results of the analysis indicated there was a significant difference among the groups.

Table 6: ANOVA table for the ratio of the root to shoot biomass

	Df	Sum Sq	Mean Sq	F value	p
Groups	5	0.07004	0.014008	5.352	0.00177
Residuals	25	0.06543	0.002617		

3.5 DISCUSSION

This study confirms that the application of foliar fertilizer promotes the biomass and yield of maize seedlings. It is well established that foliar fertilizers provide more rapid utilization of nutrients and permits the correction of observed deficiencies in less time than would be required by soil application. However, plants respond to foliar application speedily which means that in case of severe nutrient deficiencies, several foliar applications are necessary. Foliar fertilizer is very effective at early growth stages because it increases the potassium and phosphorus supplies at a time when the root system is not well developed [7]. It was also observed that its application in the early growth was very efficient in the hydroponics because we didn't have the opportunity to grow in the field because of seasonal changes. Here in the hydroponics, the foliar fertilizer spray only concentrated on the young seedlings than in the field where there is no full attention on the plants but instead it is wasted on the soil rather on the young plants and also were able to study the root development which is impossible in the field. The hydroponics serve as a very good technique to study many parameters that has to do with the root and shoots of plants which made the nutrient solution to be chosen instead of the field. The foliar fertilizer had a strong effect on the above ground and below ground biomass; this shows that not only the soil application can regulate root elongation but the foliar fertilizer can do so more efficiently and effectively. At the course of this study, it was observed that the nitrogen supply on the leaf surface has same inhibitory effect on root elongation. Previous research has shown that excessive supply of N can inhibit root growth in maize [1]. Roots are very important not only for water and mineral uptake but also for optimizing plant growth by releasing organic acids [8]. The N supply increases the cytokinin synthesis which inhibits root elongation [9]. It was also observed that very low relative growth rate in the high nutrient supply as a result of the daily added N through the foliar fertilizer decreased the root growth, this is also similar in the soil applied N; which otherwise proves that the leaf applied fertilizers has a strong inhibitory effect on the root elongation. Increase in the shoot biomass and reduction of the root biomass by the foliar fertilizer resulted to a short and very dense root system. At optimal nutrient supply, additional nutrient supply on the leaf surface was more efficient as we observed same increase in the H2 and L2 series. Additional and frequent supply of foliar fertilizer on the leaf surface improved the shoot biomass. We observed that the root biomass was more or less the same while the shoot biomass increased decreasing the root to shoot ratio. The utilization of foliar fertilizer is good but it is very sure that less frequent application of foliar fertilizer results to lower yield /biomass while more frequent application of foliar fertilizer has a higher/positive impact on the maize seedlings. With optimal supply of nutrient in the soil, foliar fertilizer improves the biomass production not only in the case of the high and low nutrient supply but it can even be applied after soil fertilizer application. The utilization of leaf fertilizer is efficient and much quicker in its uptake and absorption by plants; incorporating them into organic compounds distributed by the phloem transport to the different plant parts. Addition of foliar fertilizer further improve crop production by increasing the shoot biomass and assimilatory surface; including carbohydrate production. The use of foliar fertilizer is a practice that farmers cannot do without because it improves the crop production independent of the nutrient supply in the soil. The effectiveness of foliar applied fertilizer for plants under drought and salinity cannot be over looked in that it serves as the only possibility for effective nutrient supply to the plants during their vegetative growth because soil salinity causes water deficit in the soil and under extended periods, the salt begins to accumulate in the older leaves and salt injury becomes visible. The supply of nutrients through the roots is restricted under drought and salinized soils because of the negative effect of drought and salinity on nutrient availability [10]. The reasons for this are because of the supply of the required nutrient directly to the location of demand in the leaves and its relatively quick absorption and the independence of root activity and soil water availability [11].

4. CONCLUSION

Foliar application of nutrients is an important crop management approach in boosting crop biomass and yield. It can supplement soil fertilization when nutrient supply from the soil is inadequate or uncertain. Foliar fertilizers offer specific advantages over soil fertilizers when plant demand for nutrient surpass the capacity for root nutrient uptake and when environmental circumstances limit the effectiveness or prevent the application of nutrients to the soil. When nutrients are applied to soils, they are taken up by the plant roots and distributed to the aerial parts; but in the case of foliar application, the nutrients penetrate through the cuticle and the crop response occurs in short time as compared to soil application. They are applied to remedy obvious nutrient deficiencies. If a deficiency is recognized, the missing nutrient is supplied by spraying; if the deficiency is not well defined, complete foliar fertilizers or a mixed micronutrient fertilizer can be employed. Foliar fertilizers are used to protect yield and quality and to fulfil nutrient demands and also improve crop yields. For effective results of foliar fertilization, it is important that the concentration, physical and chemical properties of the sprayed ion would be put into consideration. The characteristics of the environment such as temperature and humidity should be considered because high temperature during the day can cause leaf burning in plants; windy days may drift the applied nutrient solution thereby reducing its efficiency. The use of foliar fertilizers is very efficient and effective in achieving high biomass and yield production in maize plants.

Therefore, this study provides additional evidence which proves that the application of foliar fertilizers is a crop management strategy in maximizing crop yield in agricultural practice.

Following the outcome of this study, it was found that foliar application represents a significant technique in the field of agriculture and crop production because of its many advantages and effectiveness towards the optimization of high crop yields. Foliar feeding is highly recommended in cases when environmental conditions limit the uptake of nutrients by roots as a result of stress, nutrient imbalance in the soil and root disease and also, when a deficiency symptom shows up, a quick step is to apply the deficient nutrient through foliar application.

Therefore, foliar application is highly recommended because with this technique, the farmers or agriculturalists can by-pass nutrient uptake bottlenecks, eliminate nutrient deficiencies within days and avoid soil contamination which will lead to loss of agricultural produce; thereby negatively affecting the yield and biomass of the crops and the global economy at large.

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