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ROOT ZONE TEMPERATURE INFLUENCES NUTRIENT ACCUMULATION AND USE IN MAIZE

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Abstract

Root-zone temperature (RZT) changes with season, geographical location and global warming. Nutrient accumulation and use behaviour of two maize (*Zea mays* L.) genotypes were evaluated under low (22.4 ± 5°C) and high (28.8 ± 5°C) root-zone temperatures. In greenhouse study, hybrid maize (FHY-396) and indigenous variety (EV-7004) were sown in calcareous loam soil filled in pots. Shoot and root dry matter yield of both the genotypes was significantly (p<0.05) increased at the higher RZT. On an average, shoot dry matter at the higher RZT was 38% more for hybrid and 52% for indigenous variety (EV-7004). Concentration and uptake of estimated nutrients (P, K, Cu and Zn) was significantly (p<0.05) influenced by RZT. At the higher RZT, shoot concentrations of both Cu and Zn were increased by about 30%. There was 1.5-fold increase in P, 1.4-fold increase in K, 1.9-fold increase in Cu and 1.8-fold increase in Zn uptake at the higher RZT. Nutrient uptake (uptake g^{-1} root) and use efficiencies (shoot utilization efficiency and usage index) were significantly (p<0.05) increased at the higher RZT. Genotypes also differed significantly (p<0.05) for P and Zn utilization efficiencies. Conclusively, RZT had a pronounced role in nutrient uptake from soil and their use by plants and hence on plant growth.

Introduction

Root-zone temperature (RZT) is an important plant growth factor (Pregitzer & King 2005). It may affect rate related physico-chemical and biological processes of nutrient availability in soils and their uptake by plants. The RZT influences critical nutrient concentration required for optimum growth of plant (Hussain *et al*., 2010). Rates of organic matter decomposition and nutrition diffusion are directly related to soil temperature. Hence, root-zone temperature (RZT) is a major factor controlling plant growth and development. The RZT changes with season of the year and geographical location of the area. Moreover, global warming is increasing the mean annual Earth's surface temperature at the rate of 0.2°C per-decade (Hansen *et al.,* 2006). This may increase the significance of RZT in crop production. Sustainable crop production under changing climatic conditions is a worldwide concern. Shoot physiological parameters such as photosynthetic rate and stomatal conductance are widely evaluated under temperature change while root physiological characteristics such as kinetics of nutrient uptake and transport are seldom addressed. Nevertheless, plant response to global temperature change is a synchronised interaction between root and shoot (Farrar & Jones, 2000). Root is the main organ controlling water and nutrient flux to shoot. Despite the growing recognition, influence of soil temperature on nutrient uptake by plants has not been comprehensively investigated (Bassirirad, 2000).

Maize is an important cereal crop of the world. In Pakistan, it is the most important cereal after wheat and rice. Two maize crops are planted annually in the country. Spring maize crop sown during February-March and autumn maize sown during July-August (Chaudhry, 1994). Significant differences in climate, especially in temperature, exist between two seasons in the area (Anon., 2006). Generally, atmospheric temperature linearly correlates with soil surface temperature with a minute difference of ±2°C (Pregitzer *et al.,* 2000). This results in comparably elevated root-zone temperature (RZT) for autumn maize as compared to spring maize. Moreover, the maize cultivated areas ranges from arid to humid with wide differences in RZT. Khaliq *et al*., (2009) have reported that maize yield varies under varying environments of the areas. The temporal and spatial changes in RZT may have a pronounced role in maize nutrition.

In consideration of plant biomass production in relation to nutrient supply, the efficiency of absorption and use plays important role. Crop genotypes also differ in nutrient utilisation efficiencies (Maqsood *et al*., 2009; Aziz *et al.,* 2006). Shoot nutrient utilisation efficiency (NUE) and usage index (NUI) are generally explored to sort efficient genotypes that can produce well at nutrient deficient levels. The NUI is preferred as it accounts for absolute increase in growth (Siddiqi & Glass, 1981). As RZT influence nutrient availability and uptake, it might also affect nutrient use (NUE and NUI) by plants. Nevertheless, no consideration is given to RZT changes for nutrient use by plants. Moreover, investigations are missing for crop specific nutrient uptake response to changing RZT. Therefore, two maize genotypes (hybrid maize, FHY-396 and indigenous variety, EV-7004) were evaluated for biomass production, nutrient accumulation and nutrient use (NUE and NUI) under the influence of low and high root zone temperatures (RZT).

Materials and Methods

Soil: Bulk surface soil sample (0–15 cm) was collected from Layllpur soil series (*Typic Calciargid)*, air-dried and ground to pass through a 2 mm sieve. A sub-sample of the sieved soil was analysed for various physico-chemical properties by following standard methods (Table 1).

Growth conditions and treatments: All the 20 pots were filled with 2.5 kg soil pot^{-1}. Treatments comprised of two RZT (low and high RZT) and two maize genotypes (hybrid, FHY-396 and indigenous variety, EV-7004). A completely randomised design was used in factorial arrangement and treatments were replicated five times (Steel *et al*., 1996). Basal uniform rates of NPK fertilisers were uniformly applied @ 60 mg N kg^{-1} soil, 30 mg P kg^{-1} soil and 25 mg K kg^{-1} soil as urea, ammonium di-hydrogen phosphate and potassium sulphate. None of the micronutrients was applied. This nutrient application strategy was followed to match with farmers' current practice in the area. After application of NPK fertilisers, the soil in each pot was thoroughly remixed and equilibrated for two weeks before sowing. Five pre-soaked healthy seeds of each genotype were sown per pot and seedlings were harvested to two plants per pot at plant establishment. Temperature treatment was started when plants were nine days old. For this, half of the pots were kept daily in ice cold water for three hours and rest of the pots were kept at ambient green house temperature. The temperature treatment resulted in soil temperature difference between two sets of pots for at least seven hours a day, ensuring a mean daily temperature difference (low; 22.4 ± 5°C and high; 28.8 ± 5°C) of 4.2˚C (Fig. 1). Distilled water was used to maintain moisture contents of the soil at field capacity in all the pots during the experimental period. A second dose of N @ 30 mg kg^{-1} soil was applied as urea after 20 days from sowing. During the experimental period, the average temperatures in the greenhouse were 30 ± 5˚C at different times of the day and 20 ± 3˚C during the night. Light intensity varied between 300 to 1400 µmol photon m^{-2} s^{-1} and relative humidity varied from 35% (midday) to 85% (midnight).

Table 1. Selected physical and chemical properties of the soil (layllpur series) used.

Soil characteristic		Unit	Value
[1]Soil great group		---	*Typic Calciargid*
[2]Particle size distribution	Sand	%	35.6
	Silt	%	37.5
	Clay	%	26.9
[3]Textural class		---	Loam
[4]pH_s		---	7.9
[5]EC_e		dS m^{-1}	2.57
[6]Organic matter		%	0.75
[7]Calcium carbonates ($CaCO_3$)		%	5.0
[8]Olsen-P		mg kg^{-1} soil	9.5
[9]Extractable K		mg kg^{-1} soil	146
[10]Extractable Zn		mg kg^{-1} soil	1.10
[10]Extractable Cu		mg kg^{-1} soil	0.21

[1]USDA taxonomic system; [2]Hydrometer method (Gee & Bauder, 1986); [3]USDA classification; [4]pH of saturated soil paste; [5]Electric conductivity of saturated soil paste extract; [6]Walkley-Black method (Nelson & Sommers, 1982); [7]Acid dissolution (Allison & Moodie, 1965); [8]Sodium bicarbonate extractable (Olsen & Sommers, 1982); [9]Ammonium acetate (1 N) extractable (Richards, 1954); [10]DTPA (0.005 M) extractable (Lindsay & Norvell, 1978)

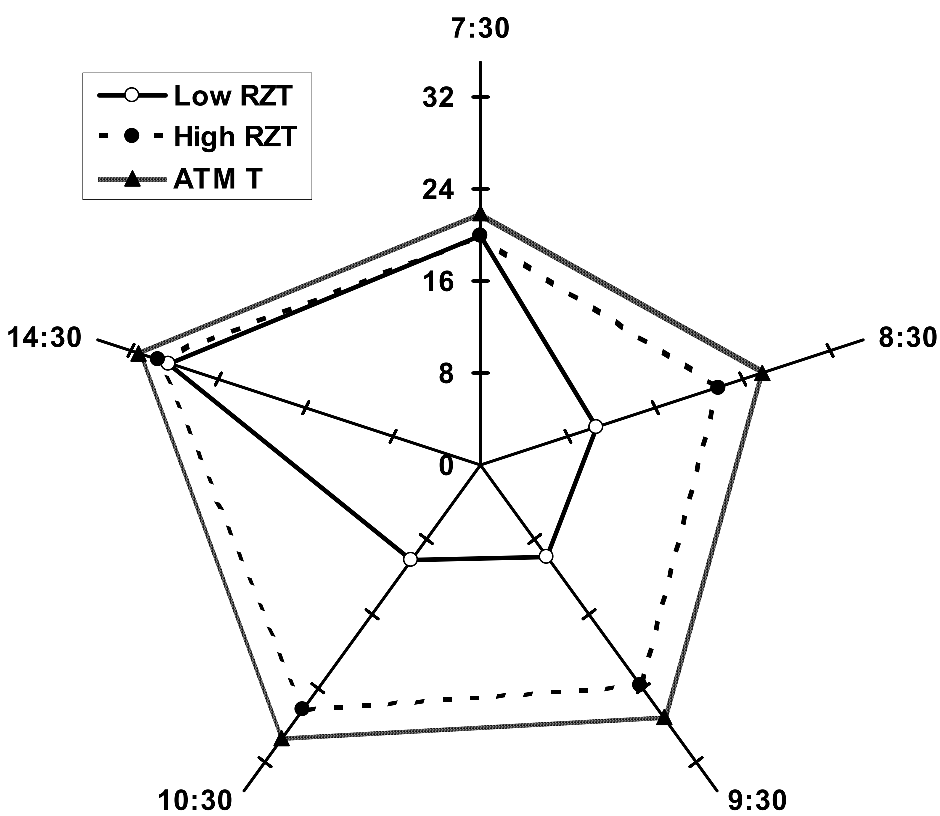

Fig. 1. Daily cycle of low root-zone temperature (RZT), high RZT (ambient) and atmospheric temperature (ATM T) of pots and greenhouse measured in Celsius scale (°C)
(On an average, low and high RZT differed by 4.2°C)

Biomass and nutrient accumulation: Plant shoots and roots were harvested 31 days after sowing, washed with distilled water and blotted dry with tissue paper. The root and shoot samples were air-dried and then oven dried at 65˚C to a constant weight in a forced air driven oven. After recording dry matter yield plant samples were finely ground with a Wiley mill fitted with stainless steel chamber and blades. One gram homogenised sub-sample of finely ground plant samples was digested in a di-acid (HNO_3:$HClO_4$) mixture (Jones & Case, 1990). The effect of treatments was evaluated on four nutrients (P, K, Cu and Zn). The Cu and Zn concentration in the digest was estimated by atomic absorption spectrophotometer, while, P was determined on spectrophotometer after developing yellow color by vanadate-molybdate method (Chapman & Pratt, 1961).

Potassium concentration in plant samples was determined by flame photometry. Uptake of various nutrients in plant tissues was calculated by multiplying dry matter of plant tissue with respective nutrient concentration. Nutrient uptake by plant per unit root dry matter was calculated by dividing total uptake of a nutrient (shoot + root) with total dry matter of root.

Nutrient use: Nutrient use behaviour of the genotypes was studied by shoot NUE and shoot NUI. Following formulas (Siddiqi & Glass, 1981) were manipulated:
Shoot NUE = Shoot dry matter ÷ Shoot nutrient concentration
Shoot NUI = Shoot dry matter × NUE

Statistical analysis: The data obtained for dry matter yields, nutrient concentration, nutrient uptake, and nutrient use (NUE and NUI) by maize genotypes were statistically analysed using *Statistix 9*®; an analytical statistics program. Least square difference (LSD) test was applied to check treatment significance (Steel *et al.*, 1996).

Results and Discussion

The soil used in the study was alkaline (pH_s > 7), non-saline (EC_e < 4 dS m^{-1}), calcareous ($CaCO_3$ > 3%) and low in organic matter (< 1%) (Table 1). The soil was loam having 35.6% sand, 37.5% silt and 26.9% clay. It was marginally deficient in plant available nutrients (P, K, Cu and Zn).

Plant growth: It is widely acknowledged that soil temperature is one of the primary factors affecting plant growth (Pregitzer & King 2005) and could be even more important than air temperature (Körner & Paulsen, 2004). Shoot and root dry matter yield of both hybrid maize (FHY-396) and indigenous variety (EV-7004) was significantly (p<0.05) increased at the higher RZT (Fig. 2). On an average, shoot dry matter at the higher RZT was 38% more for hybrid maize (FHY-396) and 52% for indigenous variety (EV-7004). Improved shoot growth revealed better nutrition. Different authors have reported improved growth and photosynthesis rate by rising soil temperature (Day *et al.*, 1991; Landhäusser *et al.*, 1996; Schwarz *et al.*, 1997).

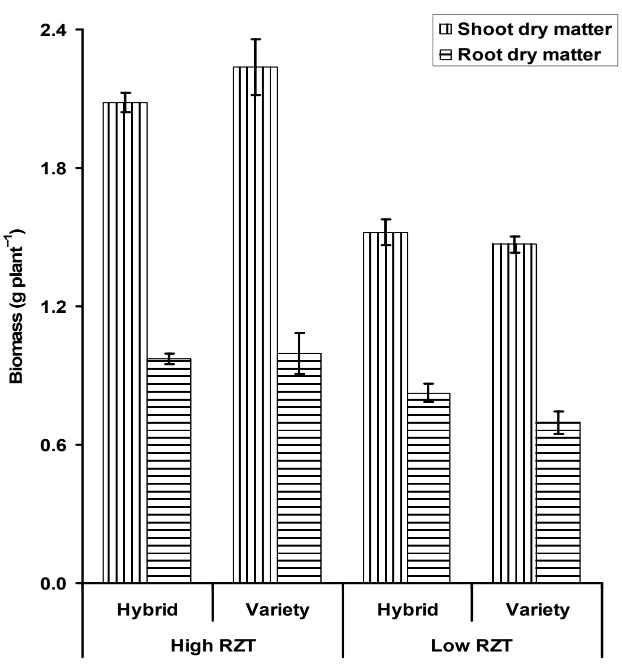

Fig. 2. Biomass production by hybrid maize (FHY-396) and indigenous variety (EV-7004) at low and high root-zone temperatures (Low and high RZT differed by 4.2°C)

Root is the main organ involved in water and nutrient uptake. It plays a critical role in determining plant response to soil applied treatments. Similar to shoot growth, RZT had a pronounced effect on root growth (Fig. 2). Increase in root growth at the higher RZT was 18% in hybrid maize and 43% in indigenous variety. Rates of enzymatic reactions, cell division and expansion are directly related to soil temperature (Taize & Zeiger, 1991; Larcher, 1995), and hence the capacity of plants to construct root tissue as well as root tissue morphology and function are also affected (Pregitzer *et al.*, 2000).

Concentration of nutrients: There was a significant (p<0.05) effect of RZT on concentration of various nutrients in maize genotypes (Table 2). Shoot concentrations of Cu and Zn was increased by about 30% at high RZT than at low RZT. At the higher RZT, shoot P concentration was increased by 5%, whereas, K shoot concentration was decreased at high RZT as compared to low RZT. Nevertheless, root concentration of all the estimated nutrients (including K) was increased at the higher RZT. Ions typically move across the root into the xylem by traversing several layers of plasmalemma. Ion movement across the cell membrane is highly sensitive to changes in soil and root temperature (Chapin, 1974).

Genotypes also differed significantly (p<0.05) for shoot and root concentrations of P and Zn (Table 2). Irrespective of RZT, hybrid maize (FHY-396) attained more shoot and root Zn concentrations while indigenous variety (EV-7004) attained more P concentration.

Root-to-shoot concentration ratio is a reliable tool to study relative translocation of a nutrient from roots to shoots. There was a significant (p<0.05) effect of RZT on translocation of K, Cu and Zn (Table 2). Translocation of both the micronutrients (Cu and Zn) increased at the higher RZT. However, K heavily accumulated in roots with a reduction of its translocation to shoots at the higher RZT. The relative translocation of nutrients from roots to shoots seemed to be controlled by RZT. Similar findings were observed by Mozafar *et al*., (1993).

Uptake of nutrients: Uptake (contents $plant^{-1}$) of all the estimated nutrients (P, K, Cu and Zn) in shoots and roots of maize genotypes was significantly (p<0.05) increased at high RZT compared to low RZT (Table 3). There was 1.5-fold increase in P and 1.4-fold increase in K shoot uptake when plants were grown at the higher RZT. Shoot uptake of Cu and Zn was more vividly influenced. A 1.9-fold increase for Cu and 1.8-fold increase for Zn was observed at high RZT than at low RZT. Cleve *et al*., (1990) found that soil warming improves foliar N, P and K contents. An 83% in shoot Zn uptake was observed in barley with rising RZT from 10°C to 23°C (Schwartz *et al.*, 1987).

Root is the mineral nutrient uptake organ of plants, and its growth undoubtedly affects nutrient uptake and transport. Nutrient uptake in roots was also similarly affected and it was remarkably more for Cu and Zn (Table 3). Indigenous variety (EV-7004) accumulated significantly (p<0.05) more shoot P than hybrid maize (FHY-396), whereas, hybrid maize (FHY-396) accumulated more root Zn concentration than indigenous variety (EV-7004).

Nutrient uptake per unit parameter of root is an excellent characteristic to estimate efficiency of roots to uptake soil nutrients (Blair & Cordero, 1978; Hussain *et al.,* 2009). Root-zone temperature significantly (p<0.05) affected nutrient uptake per unit root dry matter (Table 3). On an average, there was 12% increase in P, 40% increase in Cu and 31% increase in Zn uptake per unit root dry matter. Increased uptake per unit root dry matter at the higher RZT could be attributed to root morphology and function, and soil physico-chemical and biological processes that are dependent on RZT (Barber, 1995).

Table 2. Nutrient concentrations in hybrid maize (FHY-396) and indigenous variety (EV-7004) at low and high root-zone temperatures (RZT).

Nutrient		High RZT		Low RZT		$LSD_{(0.05)}$
		Hybrid (FHY-396)	Variety (EV-7004)	Hybrid (FHY-396)	Variety (EV-7004)	
		Shoot nutrient concentration				
P	mg g^{-1}	2.70	3.09	2.56	2.96	0.13
K		5.12	4.86	5.71	5.64	0.38
Cu	µg g^{-1}	12.47	12.83	9.83	9.67	0.67
Zn		21.33	19.50	17.05	15.03	1.17
		Root nutrient concentration				
P	mg g^{-1}	2.88	3.33	2.82	3.23	0.09
K		2.22	2.26	1.93	2.16	0.31
Cu	µg g^{-1}	41.67	40.83	35.00	35.00	1.92
Zn		38.39	27.63	31.08	24.58	1.37
		Ratio-to-shoot concentration ratio				
P		1.07	1.08	1.10	1.09	0.06
K		0.44	0.46	0.34	0.38	0.06
Cu		0.80	0.71	1.17	0.09	0.09
Zn		1.80	1.42	1.82	1.64	0.08

(Low and high RZT differed by 4.2°C)

Table 3. Nutrient uptake in hybrid maize (FHY-396) and indigenous variety (EV-7004) at low and high root-zone temperatures.

Nutrient		High RZT		Low RZT		$LSD_{(0.05)}$
		Hybrid (FHY-396)	Variety (EV-7004)	Hybrid (FHY-396)	Variety (EV-7004)	
		Shoot nutrient uptake				
P	mg $plant^{-1}$	2.81	3.46	1.95	2.17	0.37
K		10.82	11.36	7.96	7.52	4.68
Cu	µg $plant^{-1}$	26.0	28.8	15.0	14.2	3.25
Zn		22.2	21.8	13.0	11.0	2.35
		Root nutrient uptake				
P	mg $plant^{-1}$	1.40	1.66	1.16	1.13	0.30
K		53.37	54.23	43.46	41.44	2.26
Cu	µg $plant^{-1}$	12.1	12.8	8.1	6.7	1.88
Zn		18.7	13.8	12.8	8.5	2.71
		Total nutrient uptake per unit root dry matter				
P	mg g^{-1} root	4.33	5.23	3.78	4.76	0.89
K		66.00	66.86	62.42	70.74	10.74
Cu	µg g^{-1} root	39.18	42.42	28.02	30.25	7.61
Zn		42.04	36.13	31.30	28.28	4.64

(Low and high RZT differed by 4.2°C)

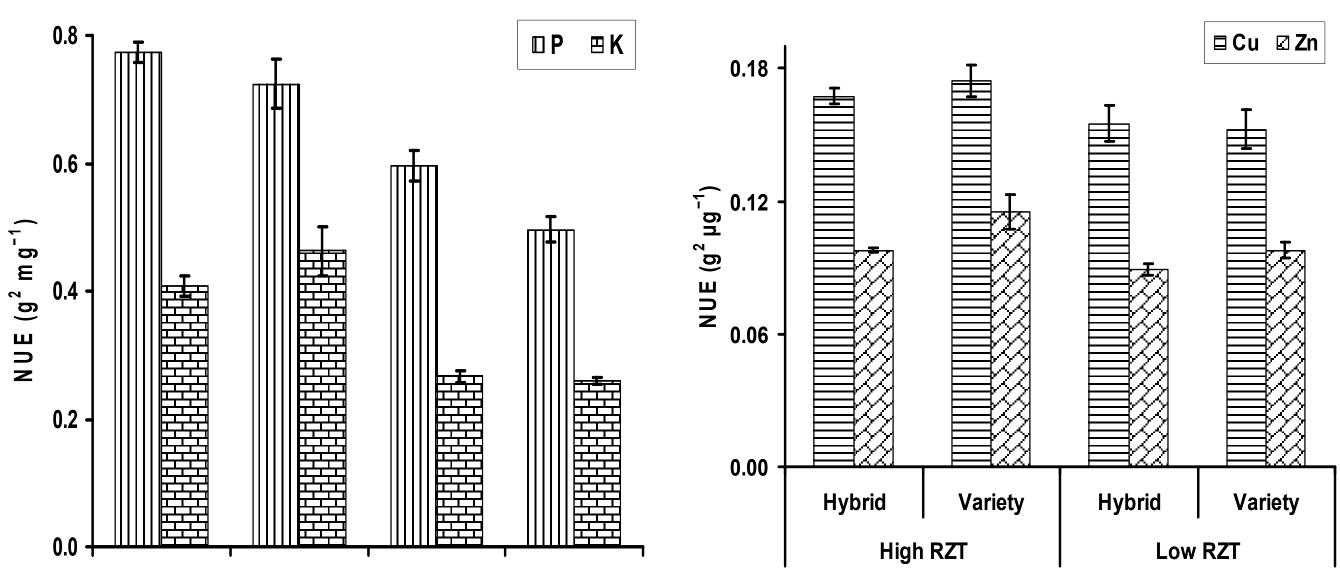

Fig. 3. Nutrient utilisation efficiencies (NUE) of hybrid maize (FHY-396) and indigenous variety (EV-7004) at low and high root-zone temperatures (RZT) (Low and high RZT differed by 4.2°C)

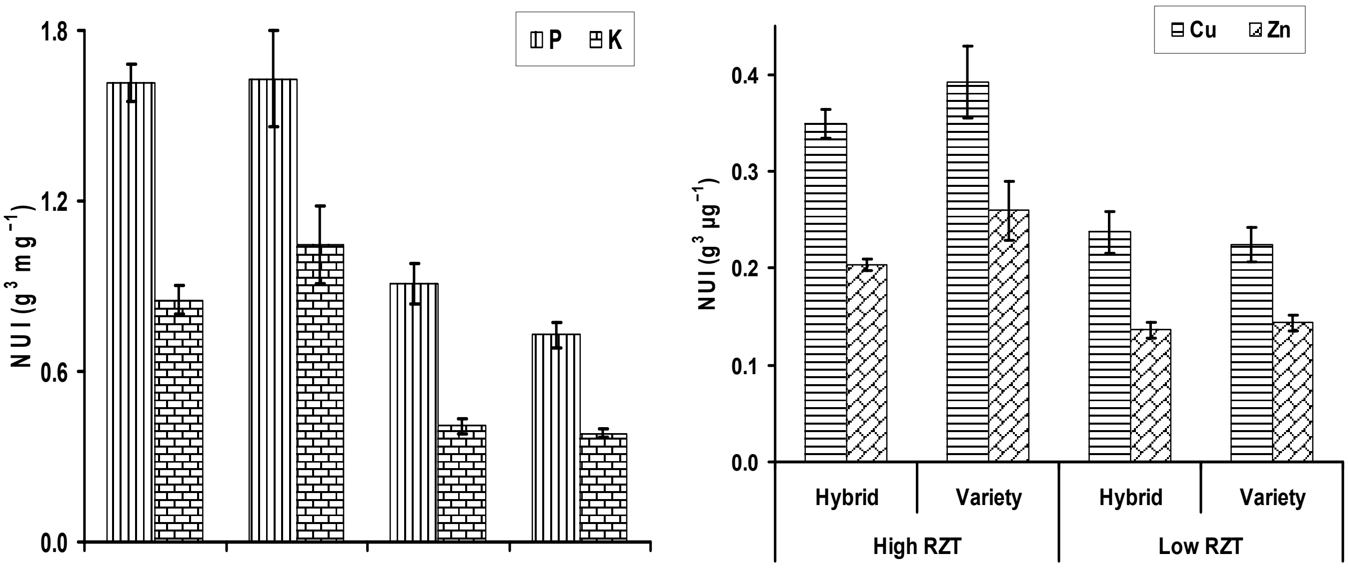

Fig. 4. Nutrient usage index (NUI) of hybrid maize (FHY-396) and indigenous variety (EV-7004) at low and high root-zone temperatures (RZT) (Low and high RZT differed by 4.2°C)

Nutrient utilization efficiency and usage index: Shoot utilisation efficiencies of all nutrients (P, K, Cu and Zn) was significantly ($p<0.05$) increased at the higher RZT (Fig. 3). Increased nutrient utilisation efficiency meant that nutrient activity in plant tissue was more at the higher RZT. However, Gavito *et al.*, (2001) found that P shoot utilisation efficiency decreases in wheat with increase in RZT. Hybrid maize (FHY-396) efficiently utilized shoot P while Zn utilisation efficiency of indigenous variety (EV-7004) was significantly ($p<0.05$) more than maize hybrid (FHY-396).

Nutrient usage index was significantly ($p<0.05$) increased in both the genotypes when grown at the higher RZT (Fig. 4). Because NUI accounts for absolute biomass increase (Siddiqi & Glass, 1981), the effect of RZT was more pronounced on NUI than NUE. Shoot NUI of Cu and Zn was increased about 60% at high RZT than at low RZT. At the higher RZT, P and K usage indexes were increased by 98% and 140%, respectively.

Conclusion

Nutrient accumulation and use (NUE and NUI) varied with RZT and maize genotype. Higher RZT increased concentration, uptake and use of nutrients by plants. Therefore, it must be considered while investigating nutrient use by plants. In addition, further studies are warranted on crop nutrition for sustained production under changing climatic conditions.

Acknowledgement

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