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Full Length Article

Comparative Changes in the Nutrient Status of two Lemongrass Populations in Reciprocal Swap Arrangement: Prospects for Cross-Locational Adaptability and Survival

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Abstract

Maintenance of tissue mineral nutrient contents in requisite amounts is pivotal for normal plant growth. Shifting of a plant population from one locationto the other may lead to altered growth and tissue nutrient patterns, which may be of great adaptivevalue. The available data on the involvement of mineral nutrient in the plant adaptability and survival in changed climates in reciprocal swap arrangement may help explore the mechanism of adaptability across the locations.In this two year study, two lemongrass [*Cymbopogan citratus* (DC) Stapf] populations one each from Quetta and Faisalabad were used to measure the shoot and root biomass and tissue concentration of nitrate-N, phosphate-P, potassium (K^+), sulfate-S and calcium (Ca^{2+})in reciprocal swap experiments. Faisalabad native (FN) and Quetta native (QN) populations were reciprocally swapped at Faisalabad (called Faisalabad adapted; FA) and Quetta (Quetta adapted; QA).The data for growth and some nutrient contents were recorded in each month from June to December fortwo successive years (2015 and 2016). Tissue analysis revealed that shoot exhibited greater contents of all the nutrients than root. FN and QA populations had higher contents of the measured nutrient during the summer months (Jun–Jul), which declined during the winter months (Nov–Dec), while FA and QN behaved in a reverse manner. Changes in nitrate-N and K^+ were sharper than the others in both the lemongrass parts. Root tissue had greater dry mass and nutrients (especially Ca^{2+}) in relatively adverse conditions (summer months in Faisalabad and winter months in Quetta), which may be beneficial for better adaptation of these populations to prevailing conditions. Although no significant difference was found in the years, the adapted populations tended to display the pattern of nutrient slightly similar to the native population in 2016 than those observed in 2015. In conclusion, a steadier root biomass across the locations appeared to be a major reason of adaptability and survival of lemongrass populations in reciprocal swap arrangement.

Keywords: Root biomass; Nutrients; Temperature; Locations; Adaptation; Pakistan

Introduction

Various macro- and micronutrients in optimal amounts are a prerequisite for normal plant growth and development. Tissue nutrients play a pivotal role in the processes like osmotic adjustment, stomatal oscillation, enzyme activation, synthesis of macromolecules etc. (Silvestre Fernandes and Pereyra Rossiello, 1995; Fageria and Moreira, 2011). Seasonal variations in different mineral contents take place in different plants (Villares and Carballeira, 2003; Strike and Vance, 2017).

Nitrogen a vital micronutrient required by plants as it is the part of nucleic acids, various enzymes, energy carrying compounds (NAPH, ATP). It is mainly absorbed as nitrate from the soil. Its deficiency results in stunted growth and low yield in plants (Epstein and Bloom, 2005; Wahid *et al.*, 2007; Zhong *et al.*, 2018). Seasonal decline in tissue-N was linked with the distribution of N to new sinks during spring and winter seasons (Maier *et al.,* 1996). Various environmental stresses induced changes in Ca^{2+} concentration since it acts as a second messenger and activates different physiological processes (Reddy and Reddy, 2004). Concentrations of phosphorus, nitrogen and Ca^{2+}were stable from January to March, but K^+ concentration remained steady even with a declined vegetative growth in macadamia (Stephenson *et al.,* 1986; Maier and Chvyl, 2002). Maier and Chvyl (2002) reported a decline in tissue K^+ from January to August, but an increase from November to December. In winter season low soil temperature was linked with a decline in mineralization (Eghball *et al.*, 2002). Ca^{2+} concentration increased during May to September, although its contents were related to leaf age (Stephenson *et*

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al., 1986). Maier *et al.* (1996) observed the seasonal variations in S contents. Higher S contents were noted in Australian wax flowers from September to December but a lower one detected from December to April.

Plant growth, among other geographical factors is influenced by altitude, longitude and latitude. Alpine plants growing at low altitude with short life span grew like colonial carpets and displayed lower nutrient contents in different body parts (Galland, 1986). Kiirner (1989) studied mineral contents of plant growing at different altitude in various climatic regions, and reported that N concentration fluctuated with latitudinal and altitudinal trends. At lower altitude, N content declined, but increased at higher altitude in herbaceous and evergreen plants. N content decreased from sub-arctic to equatorial regions representing latitudinal decline. Growth of plants at high altitude may be regulated by high nutrient concentration via high metabolic activity.

Lemongrass [*Cymbopogan citratus* (DC) Stapf] responds better and grows well in response to N, P and K fertilizer application (Rao *et al.*, 1998). It can grow in a wide range of salt (up to 16 dS m^{-1}) and pH (up to 9.2) levels and is fairly tolerant of relatively adverse conditions without loss of leaf oil quality (Dagar *et al.*, 2004). Long term cultivation of lemongrass improved the soil fertility and decreased the EC and pH in the top soil while decreased the organic carbon content with an increase in soil depth (Singh *et al.*, 2014). Growing lemongrass in sewage sludge amended soil for six months resulted in enhanced amounts of zinc, copper, iron, cadmium and nickel but manganese remained within permissible limits. However, the contents of these metals were within permissible limits of WHO for the medicinal plants (Gautam and Agrawal, 2017).

Lemongrass has gained a considerable importance due to being a great source of essential oil and due to having a lot of medicinal attributes (Barbosa *et al.*, 2008; Akhila, 2010). Although it shows variable growth patterns in various climates butcan grow successfully by virtue of its inherent potential. One of the reasons in its survival in varied climates may be assigned to acquire and assimilate essential nutrients in requisite amounts to produce dry matter. The studies on the changes in the nutrient contents of the plant species in cross-locational adaptability are entirely scanty and needs to be thoroughly investigated. We hypothesize that ability to accumulate nutrient contents in any area may be closely linked to the ability to adapt and survive in any area. This study was conducted to explore the time course changes in the nutrient contents of lemongrass population and possible association of the nutrient contents in the dry matter yield across the locations in a reciprocal swap arrangement.

Materials and Methods

Source of Lemongrass Propagules and Description of Experimental Sites

Field experiments were conducted to determine the cross-locational adaptability of lemongrass populations native to Faisalabad and Quetta locations in terms of morphological and physiological mechanisms. One lemongrass population was obtained from Baluchistan Agricultural Research and Development Center, Arid Zone Research Institute (AZRI), Quetta (30.1798° N latitude; 66.9750° E longitude; 1679 m above sea level). The other population was obtained from University of Agriculture, Faisalabad (31.4504° N latitude; 73.1350° E longitude; 184.4 m above sea level). Both these lemongrass populations were reciprocally swapped to study their cross-locational adaptability by growing under natural field conditions in Quetta and Faisalabad based on the growth and tissue nutrient patterns. The experiment was performed in Randomized Complete Block Design with three replications. Maximum and minimum temperature data for the experimental years 2015 and 2016 for Faisalabad was obtained from the Weather Observatory, Department of Agronomy, University of Agriculture Faisalabad; while that of Quetta region was obtained from Meteorological Department, Quetta (Table 1).

Prior to planting the lemongrass population, the soils from both the locations were analyzed for physicochemical properties (Hussain *et al.*, 2010). Faisalabad soil was more fertile due to having higher organic matter and P contents. The K was higher in Quetta soils while NO_3^--N contents were similar in the soil from both the locations. Saturation percentage of Faisalabad soil was lower than that of Quetta soil. Soil at Quetta locations was more alkaline as compared to Faisalabad due to the presence of higher amount of lime. The electrical conductivity of soil extract (ECe) was lower in Faisalabad soil as compared to Quetta soil. Sodium availability in Quetta soil was higher than from Faisalabad soil. In Faisalabad soil, the Cl^- concentration was higher than the Quetta soil. Furthermore, a higher Ca+Mg contents was analyzed in Quetta soil samples. Besides, sodium adsorption ratio (SAR) was also higher in Quetta soil (Table 2).

Dry Matter Yield and Nutrient Analysis

Dry matter yield: Shoot and root dry weights were measured after harvesting in each month from Jun to Dec during the years 2015 and 2016 and drying these plant parts in an oven at 65°C.

Nitrate-N: To measurenitrate-N with the methods of Kowalenko and Lowe (1973), 0.5 g of dried grinded material was extracted in 5 mL of distilled water by boiling for 1 h, filtered and made the volume up to 50 mL. A 3 mL of the extract was added to 7 mL of working chromotropic acid solution with the thrust of a pipette filler and briefly vortexed. After letting stand for 20 min, the intensity of yellow colored complex was read at 430 nm, using distilled water as blank. The nitrate-N content in plant samples was ascertained by preparing a standard curve (10–100 mg/L NO_3^-).

Phosphate-P: To measure phosphate-P with the methods of Yoshida *et al.* (1976), 1 mL of the extract from the above was added to 2 mL of the 2N HNO_3 and diluted to 8 mL. After adding 1 mL of molybdate-vandate reagent, the final volume was made up to 10 mL. After vortexing and letting stand for 20 min at room temperature, the color intensity was measured at 420 nm, while distilled water was used as blank. The amount of phosphate-P was determined from the unknown samples by preparinga standard curve from 2.5 to 15.0 mg/L PO_4^{3-} standard series.

K^+ and Ca^{2+}: Both these ions were determined using the method of Yoshida *et al.* (1976). Dried ground material (0.2 g) was digested in 2 mL of acid mixture (HNO_3 and $HClO_4$ in 3:1 ratio). After the samples were cleared, the volume was made up to 10 mL with deionized water. The amounts of K^+ and Ca^{2+} in the samples were determined using flame photometer (Sherwood 410, UK), while standard curves were constructed by preparing graded series (0–40 mg/mL) separately for both the ions.

Sulfur-S: Tendon *et al.* (1993) method was used for determination of sulfur-S contents.Ten mL of extract was taken in a 50 mL volumetric flask and added with 1 mL of 6N HCl and 1 mL of 0.5% gum acacia solutions. Swirled and added 0.5 g barium chloride crystals and waited for 1 min. Flasks were swirled again until the crystals were dissolved. Transmittance of the solution was taken on spectrophotometer at 440 nm. To prepare standards of sulfur 0.543 g of K_2SO_4 was dissolved in distilled water, diluted to 1 L to make 100 ppm stock solution. Prepared graded series of 0, 4, 8, 12, 16, and 20 mg/L solutions. Add 25 mL of salt buffer to each standard.

Statistical Analysis

The design of the experiment was randomized complete block with three replications. The data were subjected to statistical analysis using analysis of variance sources (Steel *et al.*, 1996) and finding significance of variance sources at $P<0.05$.

Results

Growth Characteristics

The data recorded during the years 2015 and 2016 indicated significant ($P<0.01$) difference in the shoot and root dry weight over different months in four populations of lemongrass. The FN population during the year 2016 indicated the highest shoot dry weight followed by the same population in the year 2015. The FA population although indicated a lower shoot dry weight in both the years, it displayed a relatively greater shoot dry weight in the year 2016. Likewise, QN and QA populations although indicated much reduced shoot dry weight during both the years, their performance was better during the year 2016 at the respective locations. As regards root dry weight, the value of this attributes was greater in FN and FA populations but higher during the year 2016. However, the QN and QA populations showed remarkably reduced root dry weights in both the years. It is however important to note that the populations at Faisalabad displayed steadier root dry weight as compare to those of Quetta native and adapted populations.

Nutrient Relations

Shoots accumulated higher amounts of the nutrients (nitrate-N, phosphate-P, K^+, sulphate-S and Ca^{2+}than root in all lemongrass populations over the years 2015 and 2016, although no significant ($P>0.05$) difference was recorded in both the years (Fig. 2). FN and QA population (basically belonging to Faisalabad) indicated a greater contents of all the relatively sharper trend of accumulation of all the nutrients in the year 2015 as compared to 2016 while reverse of it was true for FA and QN populations (basically belonging to Quetta). A comparison of individual nutrient accumulation pattern revealed that during the year 2016, the behavior of both the adapted populations was relatively different from the years 2015 and tended to behave like the native population at Faisalabad or Quetta location especially under extreme conditions i.e., summer months in Faisalabad and winter months in Quetta (Fig. 2). These results indicated a slow shift in the adaptability in the adapted population in an area.

Discussion

Changes in the dry matter yield of any plant species under a defined set of conditions are a reliable indicator of its survival and adaptability (Gratani, 2014; Hanna *et al.*, 2018). In this study we found that high ambient temperature in Faisalabad in summer months and subzero temperature in Quetta in the winter months (Table 2) were the stressing factors for the growth of lemongrass populations, as both shoot and root dry mass declined substantially in the respective seasons (FN and FA in summer and QN and QA in winter months). However, FN and FA populations showing relatively lesser dry matter in the summer of 2015 and QN and QA behaving so in the winter of 2015 performed relatively better in the respective months in 2016. It is quite interesting to note that root dry mass was quite more improved than shoot in the year 2016 especially in the adapted population, thereby showing a pivotal role of root in the adaptability and survival in a new location. It is known that more plasticity and proliferationof root system is a successful adaptive strategy of plants to survive in a new environment (Lipiec *et al.*, 2013; Khan *et al.*, 2016). Such a tendency in the second year of the experiment, although at a quite low pace, alludes to the role of root development in adaptation and survival of the population in the new location (Fig. 1).

Changes in rate of tissue nutrient accumulation could be among numerous determinants of growth and survival of

Table 1: Physicochemical characteristics of soil samples from Quetta and Faisalabad locations

Characteristics	Quetta soil	Faisalabad soil
P (mg/kg)*	1.56	2.24
K (mg/kg)*	184.00	162.00
NO_3^--N (mg/kg)*	0.29	0.29
Organic matter (%)	0.53	1.10
Saturation percentage	39.82	38.56
pH	8.15	8.05
EC (dS/m)	1.35	0.44
Na^+ (mg/kg)	6.84	1.75
HCO_3^- (mg/kg)	2.95	2.63
Cl^- (mg/kg)	5.75	1.68
Ca+Mg (mg/kg)	18.15	4.18
Sodium adsorption ratio	2.54	1.17

*AB-DTPA Extractable

Table 2: Average monthly maximum and minimum ambient temperatures (°C) in Quetta and Faisalabad locations recoded during the experimental years 2015 and 2016

Months	Faisalabad 2015		Faisalabad 2016		Quetta 2015		Quetta 2016	
	Max. Temp	Min. Temp	Max. Temp	Min. Temp	Max. Temp	Min. Temp	Max. Temp	Min. Temp
June	43.0	21.6	44.2	23.3	37.7	17.0	40.0	14.0
July	40.2	23.4	42	21.7	38.0	19.0	40.0	17.5
August	38.0	23.0	38.2	22.6	36.4	13.0	37.5	13.0
September	38.0	21.0	38	22.3	32.0	8.5	36.0	11.0
October	36.8	13.0	37.6	14.4	30.5	3.5	33.5	1.5
November	35.5	7.0	30.3	10.0	25.4	-2.0	27.0	-3.0
December	26.5	3.6	28	5.0	25.8	-7.0	25.5	-5.0

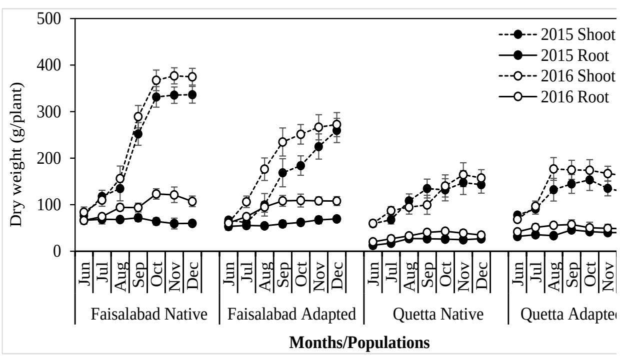

Fig. 1: Differences in some growth characteristics of native and adapted lemongrass populations from Faisalabad and Quetta studied during 2015 and 2016 planted in a reciprocal swap manner

plants in a new location (Sveinbjrnsson *et al.*, 1992; He *et al.*, 2016; Razaq *et al.*, 2017). In these experiments analysis of five macronutrients were done in the shoot and root of lemongrass populations native to and adapted in Faisalabad and Quetta. The Faisalabad conditions were much hotter than the Quetta, with chilling to freezing temperatures in Quetta (Table 2). So, different patterns of nutrient accumulation were observed in the lemongrass population growing in Quetta than those in Faisalabad (Fig. 2). As a C_4 species lemongrass requires more water and nutrients to adjust to the prevailing suboptimal conditions (Calatayud *et al.*, 2008). It was noted that trend of all nutrient was similar in both shoot and root but the relative concentration of all the nutrient was greater in root in the year 2016. Furthermore, all these nutrients showed greater tissue contents during both the experimental years during summer in Faisalabad native and Quetta adapted lemongrass population and during winter in Quetta native and Faisalabad adapted population in the body parts (Fig. 2). Fry and Huang (2004) opined that if nutrients are available in surplus amounts in the root zone during heat stress, plants use most of their stored energy to grow faster so under low temperature stress during winter these plants can scarcely use the available energy to overcome stress conditions. This showed that more the prevailing adverse temperature more likely is the acquisition of nutrients by the plant roots and their transport to the aerial parts. In this perspective, nutrients tend to increase the tolerance in plants under different temperature regimes (Waraich *et al.*, 2012).

From the changes in nutrient data it can be emphasized that the nutrients taken up under more adverse conditions were not fully metabolized and incorporated into the body parts. Instead due to the prevailing adverse conditions they play role in the maintenance of osmotic balance. Under such circumstances, the role of nutrients found in the soluble phase increased for binding water by acting as osmotica (Epstein and Bloom, 2005). However, when the temperature becomes favorable for growth these nutrients are partitioned into different body parts (Taiz *et al.*, 2015). The functional roles of the nutrients like K^+ and Ca^{2+} becomes more pivotal,which help the plant to adapt, adjust and survive under the subversive circumstances.These roles are the maintenance of cellular water balance sustained activities of enzymes of photosynthesis and respiration, or structural role in cell wall (Van Brunt and Sultenfuss,

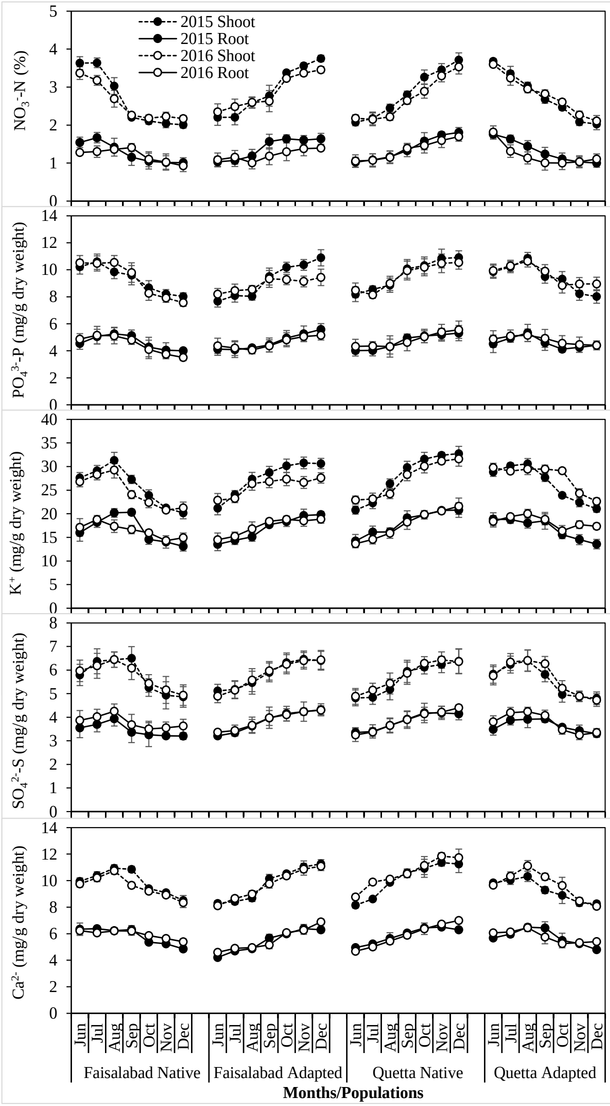

Fig. 2: Changes in some nutrient relations of native and adapted lemongrass populations from Faisalabad and Quetta studied during 2015 and 2016, planted in a reciprocal swap arrangement

1998; Nayyar, 2003; Taiz *et al.*, 2015). Nitrogen is an integral part of proteins, nucleic acids and quite a few N-containing secondary metabolites. Therefore, with reduced tissue nitrogen content the plant cannot show normal growth (Ramalho *et al.*, 1995). Phosphorus is part and parcel of nucleotides in DNA and RNA and also involved in the phosphorylation of various macromolecules. The energy changes in the biological systems are strongly dependent on phosphorylation and de-phosphorylation of ATP with the activity of kinases (Holford, 1997). Hence maintenance of sustained P contents is required. Sulfur is contained in sulfur containing amino acids and glutathione which are important in the stress tolerance by the plants (Schnug, 1988; Epstein and Bloom, 2005).

Conclusion

The optimal concentration of the essential nutrients in the favorable months of growth is pivotal for greater biomass production in these lemongrass populations, although the rate of accumulation of the measurednutrients was similar at two harvest times. Minimal tissue essential nutrients in certain adapted population may be their partial competence to grow and thrive in the new location.A slow shift in the dry matter and nutrient accumulation during the second year of the experiment highlights the adaptive potential and survival of lemongrass populations in the new location.

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References

Akhila, A., 2010. *Essential Oil-bearing Grasses: the Genus Cymbopogon*, p: 108. CRC Press, Taylor and Francis Group

Barbosa, L.C.A., U.A. Pereira, A.P. Martinazzo, C. Álvares Maltha, R. Teixeira and E. de Castro Melo, 2008. Evaluation of the chemical composition of Brazilian commercial *Cymbopogon citratus* (D.C.) Stapf samples. *Molecules*, 13: 1864–1874

Calatayud, A., E. Gorbe, D. Roca and P.F. Martinez, 2008. Effect of two nutrient solution temperatures on nitrate uptake, nitrate reductase activity, NH_4^+ concentration and chlorophyll a fluorescence in rose plants. *Environ. Exp. Bot.*, 64: 65–74

Dagar, J.C., O.S. Tomar, Y. Kumar and R.K. Yadav, 2004. Growing three aromatic grasses in different alkali soils in semi-arid regions of northern India. *Land Degrad. Dev.*, 15: 143–151

Eghball, B., B.J. Wienhold, J.E. Gilley and R.A. Eigenberg, 2002. Mineralization of manure nutrients. *J. Soil Water Conserv.*, 57: 470–473

Epstein, E. and A.J. Bloom, 2005. *Mineral Nutrition of Plants: Principles and Perspectives*, 2nd edition. Sinauer Associates, Massachusetts, USA

Fageria, N.K. and A. Moreira, 2011. The role of mineral nutrition on root growth of crop plants. *Adv. Agron.*, 110: 251–331

Fry, J.D. and B. Huang, 2004. *Applied Turf grass Science and Physiology*. John Wiley & Sons Hoboken, New Jersey, USA

Galland, P., 1986. Croissance et strategie de reproduction de deuxespeces pines: *Carex firma* L. and *Dryas octopetala* L. *Bull. Soc. Neuchateloise Sci. Nat.*, 109: 101–112

Gautam, M. and M. Agrawal, 2017. Influence of metals on essential oil content and composition of lemongrass (*Cymbopogon citratus* (D.C.) Stapf.) grown under different levels of red mud in sewage sludge amended soil. *Chemosphere*, 175: 315–322

Gratani, L., 2014. Plant phenotypic plasticity in response to environmental factors. *Adv. Bot.*, 2014: 1–17

Hanna, M., K. Janne, V. Perttu and K. Helena, 2018. Gaps in the capacity of modern forage crops to adapt to the changing climate in northern Europe. *Mitig. Adapt. Strateg. Glob. Change*, 23: 81–100

He, X., E. Hou, Y. Liu and D. Wen, 2016. Altitudinal patterns and controls of plant and soil nutrient concentrations and stoichiometry in subtropical China. *Sci. Rep.*, 6: 24261

Holford, I.C.R., 1997. Soil phosphorus: its measurement and its uptake by plants. *Aust. J. Soil Res.*, 35: 227–239

Hussain, A., G. Murtaza, A. Ghafoor, S.M.A. Basra, M. Qadir and M. Sabir, 2010. Cadmium contamination of soils and crops by long term use of raw effluent, ground and canal waters in agricultural lands. *Int. J. Agric. Biol.*, 12: 851–856

Khan, M.A., D.C. Gemenet and A. Villordon, 2016. Root system architecture and abiotic stress tolerance: current knowledge in root and tuber crops. *Front. Plant Sci.*, 7: 1584

Kiirner, C., 1989. The nutritional status of plants from high altitudes. A worldwide comparison. *Oecologia*, 81: 379–391

Kowalenko, C.G. and L.E. Lowe, 1973. Determination of nitrates in soil extracts. *Soil Sci. Soc. Amer. Proc.*, 37: 660

Lipiec, J., C. Doussan, A. Nosalewicz and K. Kondracka, 2013. Effect of drought and heat stresses on plant growth and yield: A review. *Int. Agrophys.*, 27: 463–477

Maier, N.A. and W.L. Chvyl, 2002. Seasonal variation in nutrient status of Australian wax flowers. *J. Plant Nutr.*, 26: 1873–1888

Maier, N.A., G.E. Barth, M.N. Bartetzko, J.S. Cecil and W.L. Chvyl, 1996. Nitrogen and potassium nutrition of Australian wax flowers grown in siliceous sands, shoot growth and yield responses. *Aust. J. Exp. Agric.*, 36: 355–365

Nayyar, H., 2003. Accumulation of osmolytes and osmotic adjustment in water-stressed wheat (*Triticum aestivum*) and maize (*Zea mays*) as affected by calcium and its antagonists. *Environ. Exp. Bot.*, 50: 253–264

Ramalho, J.C., M.C. Rebelo, M.E. Santos, M.L. Antunes and M.A. Nunes, 1995. Effect of calcium deficiency on *Coffee arabica* nutrient changes and correlation of calcium levels with some photosynthetic parameters. *Plant Soil*, 179: 87–96

Rao, B.R.R., S. Chand, A.K. Bhattacharya, P.N. Kaul, C.P. Singh and K. Singh, 1998. Response of lemongrass (*Cymbopogon flexuosus*) cultivars to spacings and NPK fertilizers under irrigated and rainfed conditions in semi-arid tropics. *J. Med. Arom. Plant Sci.*, 20: 407–412

Razaq, M., P. Zhang, H. Shen and Salahuddin, 2017. Influence of nitrogen and phosphorous on the growth and root morphology of *Acer mono*. *PLoS One*, 12: e0171321

Reddy, V.S. and A.S.N. Reddy, 2004. Proteomics of calcium-signaling components in plants. *Phytochemistry*, 65: 1745–1776

Schnug, E., 1988. Bestimmung des Gesamtglucosinolatgehaltes in vegetativen Pflanzenteilendurch quantitative Analyse enzymatischfreisetzbaren Sulfates. *Anal. Bioanal. Chem.*, 330: 50–55

Silvestre Fernandes, M. and R.O. Pereyra Rossiello, 1995. Mineral nitrogen in plant physiology and plant nutrition. *Crit. Rev. Plant Sci.*, 14: 111–148

Singh, D.K., S.K. Singh, A.K. Singh and V.S. Meena, 2014. Impact of long term cultivation of lemon grass (*Cymbopogon citratus*) on post-harvest electro-chemical properties of soil. *Ann. Agric. Biol. Res.*, 19: 45–48

Steel, R.G.D., J.H. Torrie and D.A. Dickey, 1996. *Principles and Procedures of Statistics. A Biometrical Approach*, 3rd edition. McGraw Hill Book Co., New York, USA

Stephenson, R.A., B.W. Cull, D.G. Mayer, G. Price and J. Stock, 1986. Seasonal patterns of macadamia leaf nutrient levels in south east Queensland. *Sci. Hortic.*, 30: 63–71

Strike, B.C. and A.J. Vance, 2017. Seasonal variation in mineral nutrient concentration of primocane and floricane leaves in trailing, erect, and semierect blackberry cultivars. *HortScience*, 52: 836–843

Sveinbjrnsson, B., O. Nordell and K. Kauhanen, 1992. Nutrient relations of mountain birch growth at and below the elevational tree-line in Swedish Lapland. *Funct. Ecol.*, 6: 213–220

Taiz, L., E. Zeiger, I.M. Møller and A. Murphy, 2015. *Plant Physiology and Development*, 6th edition. Sinauer Associates Inc., Sunderland, Massachusetts, USA

Tendon, H.L.S., 1993. *Methods of Analysis of Soil, Plants, Water and Fertilizers*. Fertilization Development and Consultation Organization, New Delhi, India

Van Brunt, J.M. and J.H. Sultenfuss, 1998. Better crops with plant food. *Potassium: Funct. Potassium*, 82: 4–5

Villares, R. and A. Carballeira, 2003. Seasonal variation in the concentrations of nutrients in two green macroalgae and nutrient levels in sediments in the Rı´asBaixas (NW Spain). *Estuarine Coastal Shelf Sci.*, 58: 887–900

Wahid, A., S. Gelani, M. Ashraf and M.R. Foolad, 2007. Heat tolerance in plants: An overview. *Environ. Exp. Bot.*, 61: 199–223

Waraich, E.A., R. Ahmad, A. Halim and T. Aziz, 2012. Alleviation of temperature stress by nutrient management in crop plants: A review. *J. Soil Sci. Plant Nutr.*, 12: 221–244

Yoshida, S., D.A. Forno, J.H. Cock and K.A. Gomez, 1976. *Laboratory Manual for Physiological Studies of Rice*. International Rice Research Institute (IRRI), Los Banos. The Philippines

Zhong, C., X. Cao, Z. Bai, J. Zhang, L. Zhu, J. Huang and Q. Jin, 2018. Nitrogen metabolism correlates with the acclimation of photosynthesis to short-term water stress in rice (*Oryza sativa* L.). *Plant Physiol. Biochem.*, 125: 52–62

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