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Uptake kinetics of micronutrients in fennel (*Foeniculum vulgare Mill.*) with N input

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ABSTRACT

Study of nutrients uptake kinetics in crop plants is very important to determine the need of nutrients during crop growing period at a specific time, which relies upon a wide variety of factors, like plant species and their varieties, environmental conditions, soil properties, nutrients supply and soil microorganism etc. Therefore, to study the uptake kinetics of micronutrients, field experiments were carried out on sandy loam soil of Typic Haplustepts with six N levels i.e. 0, 40, 60, 80, 100 and 120 kg ha^{-1} and compared with absolute control. Uptake of micronutrients and their uptake rate was calculated at 11-60, 61-90, 91-120 and 121-180 day interval. Result revealed that the uptake of iron, zinc, manganese and copper increased with increased levels of applied nitrogen and advancing age of crop plants. It was highest at 120 kg N ha^{-1} during 121-180 days after sowing (DAS). Uptake of Fe and Mn was exponential while Cu was linear up to 180 days, whereas Zn made plateau beyond 120 DAS of the crop. Uptake rate of Fe and Cu showed linear pattern with increasing levels of N (upto 120 N kg ha^{-1}) at all the four stages of the crop. However, uptake rate of Mn and Zn was different with rates of N application and was nearer to the linear trend up to 91-120 DAS. Fe uptake rate was remarkably higher during 121-180 DAS over the 91-120 DAS with all the levels of applied N. Uptake rate of Mn drastically reduced during 121-180 DAS than 91-120 DAS with all the levels of N. Hence, it can be concluded that application of N have positive response for uptake and uptake rate of micronutrients in fennel irrespective of growth stages, while uptake rate of Mn and Zn varied with stageswhereas the uptake rate of Fe and Cu continued, or even increased after plant senescence appeared, reflects that Zn and Mn are more responsible for growth of areal parts of fennel and Fe and Cu for root growth. Hence later stage application of Zn and Mn may be discouraged, while Cu and Fe application may continue for higher yield, nutrients use efficiency andratooning. Whereas, Mn and Zn uptake rate reduced with senescence of crop. This is because of fennel is an 'Herbaceous perennial bushy' plant and root remains active even beyond the senescence of aerial part of crop.

Key words: Ajmer fennel-1, micronutrients, uptake kinetics, yield

INTRODUCTION

Micronutrients are essential elements need for crop growth and these are required relatively in small quantities (ppm). A series of chemical and biochemical processes take place inside a plant which govern via these elements directly or indirectly for synthesis and breakdown of organic compounds. The Fe, Zn, Mn and Cu play an important role in plant growth and development. One of the most critical function of micronutrients in plant is to serve as catalysts or coenzymes in various metabolic biochemical reactions. Iron is taken up by plants as ferrous (Fe^{2+}) or ferric (Fe^{3+}) ions. The function of iron in plants depends on the ready transitions between its two oxidation states in soil solution. Ferric iron tends to be tied up in organic chelates and make it available for absorption by the plants. Zinc is the most important micronutrient that is in general short supply and poorly available in soil. Unlike other metal ions (Cu, Fe and Mn), zinc is a divalent cation (Zn^{++}) that does not undergo valence changes and therefore has no redox activity in soil. Zinc acts either as a metal component of enzymes or as a functional, structural and regulatory cofactor of a large number of enzymes. Manganese uptake is primarily in the form of Mn^{++}. It serves as an activator for enzymes in growth processes and also assists in chlorophyll formation. It is a part of the photosynthetic system where water splits and oxygen gas liberates. Copper present in plants in complexed form. In soil solution, it present as cuprous (Cu^{+}) and cupric (Cu^{++}), while its role in plants is enzyme activation (Adhikari *et al.* 2016; Havlin *et al.* 2013). Nutrient uptake kinetics is a mechanism by which plants capture essential nutrient for their growth and development. Study of nutrients uptake kinetics in crop plant is very important to determine the uptake rate of

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nutrients with time interval or the need of nutrients during crop growing period at specific time. Uptake kinetics study is also necessary for nutrients requirements of plant, productivity and growth kinetics. Uptake kinetics and growth kinetics are dynamic and interdependent processes, optimizes the nutrient supply to obtain desirable yield. Fennel (*Foeniculum vulgare Mill.*) is an important seed spice crop in India, however there is no information available on micronutrient uptake kinetics with respect to N supply. However, studies available on mineral content in fennel with respect to biological, medicinal and dietary purpose, particularly for functions in living organisms (Barros, 2010) Uptake pattern of nutrients in fennel was worked out by Aishwath, (2017) and growth kinetics in coriander with lime (Aishwath *et al.* 2015). In maize crop, demand for micronutrients depends mainly on the crop productivity and the variation of dry matter composition of genotypes of the species (Bray, 1948). An another study on maize, micronutrient contents are more at the beginning of the development of the maize crop, and then decrease up to physiological maturity (Ciampitti *et al.* 2013). Macronutrients uptake kinetics in fennel revealed that N and K uptake rate had negative and P uptake rate had positive relation with increased doses of N input and age of crop (Sharma *et al.* 2020). Therefore, based on the research gap, present investigation was carried out to assess the micronutrients uptake and their kinetics in fennel with nitrogen input at various growth stages.

MATERIAL AND METHODS

Field experiments were carried out during *Rabi* season of 2015-2016 and 2016-2017 at ICAR-National Research Centre on Seed Spices, Tabiji, Ajmer, Rajasthan, India. This was laid out between 74° 35'39" to 74° 36' 01"E longitude and on 26° 22'12" to 26° 22' 31" N latitude. Climate of the Ajmer area characterized as semi-arid. The average annual rainfall of the area is 536 mm and most of it, 85-90% receives from June to September. July and August are most rainy months contributing 60.0% of the average rainfall. Soil moisture control section remains dry for more than 90 cumulative days and hence moisture regime classified as Ustic. Mean annual temperature is 24.5 to 25.0°C. May is the hottest month and temperature shoots up 45^{o}C and sometimes goes beyond it. January is the coolest month of the season and temperature remains around 7.0°C. Sometimes, frost is also occurring in this month.

There were six levels of N i.e., 0, 40, 60, 80, 100 and 120 kg ha^{-1} and these were compared with absolute control. The treatments were arranged in a Randomized Block Design (RBD) with three replications. Seeds of the crop (Ajmer Fennel-1) were sown in the 50 cm line to line apart and distance from plant to plant was maintained at 15 cm by thinning. Cultural practices were uniformly followed during the growing seasons in both the years. The crop was harvested when seeds were matured. Plant samples were collected at various growth stages i.e. 60, 90, 120 and 180 days. Root and shoot sample were washed with tap water and then 0.1M HCl followed by deionized water. After air dry, plant samples were dried in oven at 70^{o}C till the constant weight obtained. Dry weight was taken after properly dried samples. Dried plant material was ground in stainless steel blender and passed it through 2 mm mesh sieve and thereafter stored in paper bags at cool and dry place till subsequent chemical analysis. Place 0.5 g of ground plant material in 100 ml volumetric flask. To this, added 10 ml of diacid mixture (9:4 mixture of HNO_3:$HClO_4$) and content of flask was mixed by swirling. The flasks were placed at low heat on hot plate in a digestion chamber. Then the flaskswere heated at higher temperature until the production of red NO_2 fumes ceases. The contents are further heated until no black particle appeared in the digested material. The completion of digestion is also confirmed when the liquid become colourless. After cooling the flask, distill water was added up to 100 ml mark.Iron, zinc, manganese and copper contents were estimated from aliquot using Atomic Absorption Spectrophotometer (Chapman and Pratt, 1962).

The nutrient uptake rate was calculated by using the formula given below:-

$$\text{Nutrients uptake rate (pg s}^{-1}\text{ plant}^{-1}\text{)} = \frac{\text{Nutrients accumulation at particular stage}}{\text{Time taken to accumulate of that nutrients}}$$

Soil available Fe, Zn, Mn and Cu were also estimated by the DTPA method of (Lindsay and Norvell, 1978) using Atomic Absorption Spectrophotometer. The initial soil status of N, P,

K, Fe, Zn, Mn and Cu was 132, 9.99, 232.2, 10.26, 1.75, 21.35 and 2.09 (in kg ha^{-1}) or 56.87, 4.30, 99.88, 4.41, 0.75, 9.78 and 0.90 (in mg kg^{-1}). The data obtained during both the years were pooled and analyzed by ANOVA and treatment differences were expressed as Least Significant Differences (LSD) at 5% probability to determine the significantdifference among the treatment means (Cochran and Cox, 1987).

RESULTS AND DISCUSSION

Biomass accumulation

Biomass accumulation increased with increased levels of N (Fig.1). Biomass accumulation was 10, 42 and 81 times higher at 90, 120 and 180 days as compared to 60 days. However, it was highest at 120 kg N ha^{-1}or last stages of the crop. This might be due to increased N input influenced photosynthetic rates, growth rates and plant productivity (Granath *et al.* 2009). High N accumulation rates in high-yielding winter wheat crops were associated with increased demands of nutrients, in terms of both increased amounts and tissue concentrations (Hamner *et al.*2017).El-Seifi *et al.*(2015) was also reported that ammonium sulfate at level of 90 kg fad^{-1} enhanced plant growth, production of dry matter and improved yield of fennel. It is obvious that higher N input improved the more rhizospheric N and readly taken up by the crop from the abundance (Aishwath, 2004; Sharma *et al.* 2018).

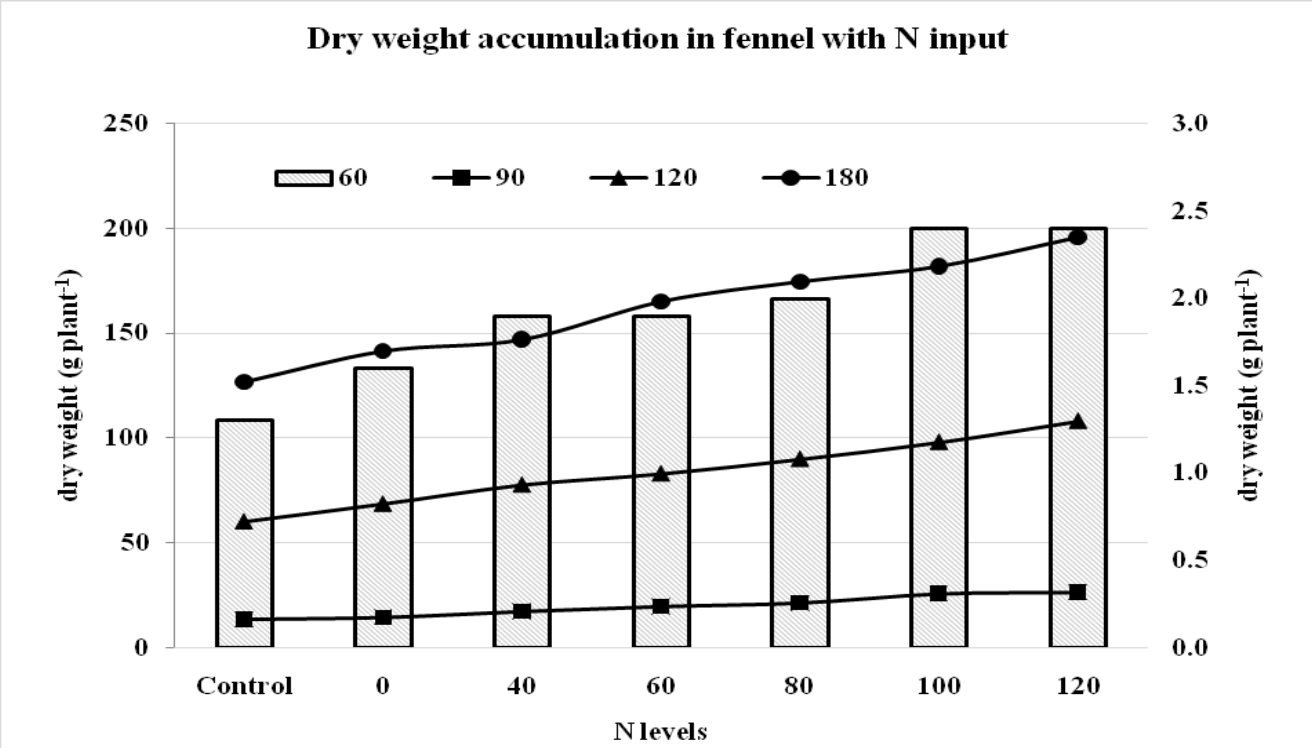

Fig.1: Dry weight accumulation in fennel with graded levels of applied N

Fe Uptake and its kinetics

Iron uptake at 11-60 days increased at higher levels of N as compared to control (Table 1). However, at the age of 61-90 days, the uptake of iron was more at their alternative successive levels of N application. Whereas, uptake at 91-120 days was higher at their each successive levels of N, except 60 and 80 kg N ha^{-1}. It indicates that N input encourages Fe uptake in fennel. These findings corroborate to the finding of Klikocka and Marks (2018), they found more micronutrient content in wheat with increasing doses of applied N. Lower uptake at initial levels might be due to crop response by basal dose of N only. Rest of split doses were applied at later growth stages gave very distinctive results. The uptake of iron increased linearly with N levels at 61-90, 91-120 and 121-180 days stages of crop.

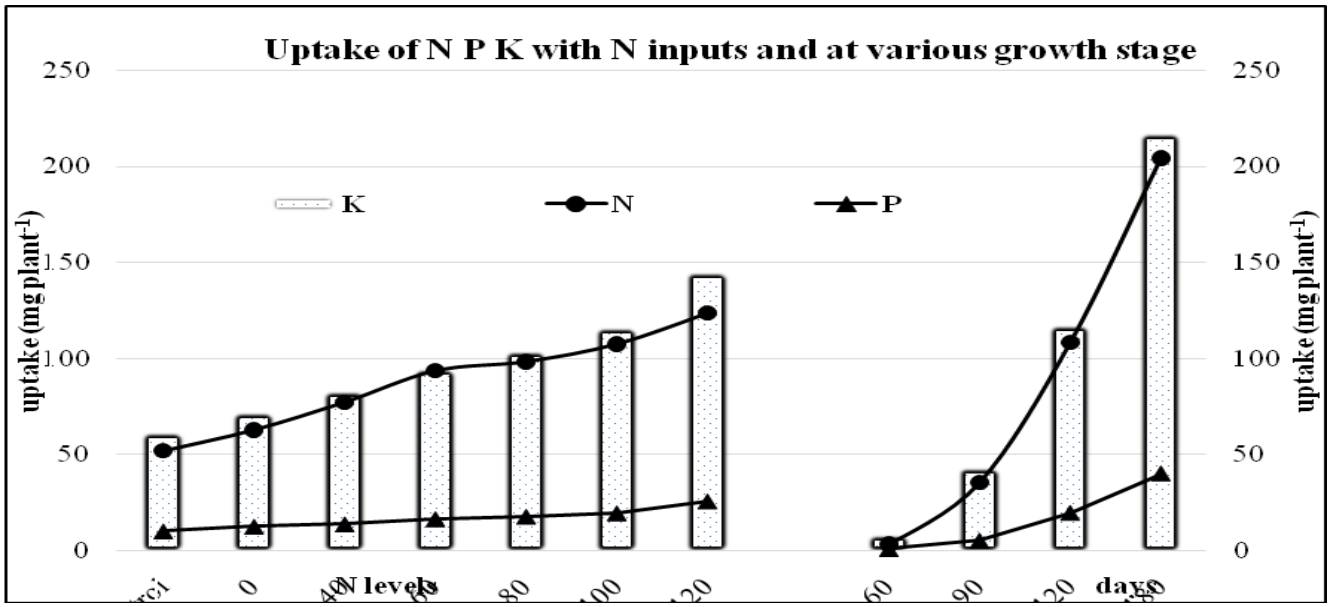

Fig. 2: Uptake of N P K with N inputs and at various growth stages

The r^2 values of these corresponding uptakes at phenological stages were 0.975, 0.988, 0.978 and 0.970. Based on the mean value of iron uptake with N levels also showed the positive trend (r^2 = 0.978) with N application (Fig. 3). In case of phonological stages, uptake value of Fe was exponential beyond 61-90 days of fennel (Fig. 4). The r^2 value of uptake with this phenological stage was 0.969. The use of high doses of nitrogen has a beneficial effect on the uptake of iron through wheat grain (Kutman *et al.* 2011). Iron is an essential micronutrient for nitrate and sulfate reduction and energy production within the plant might be given a complementary effect for both higher biomass and nutrient uptake (Morrissey and Guerinot, 2009).

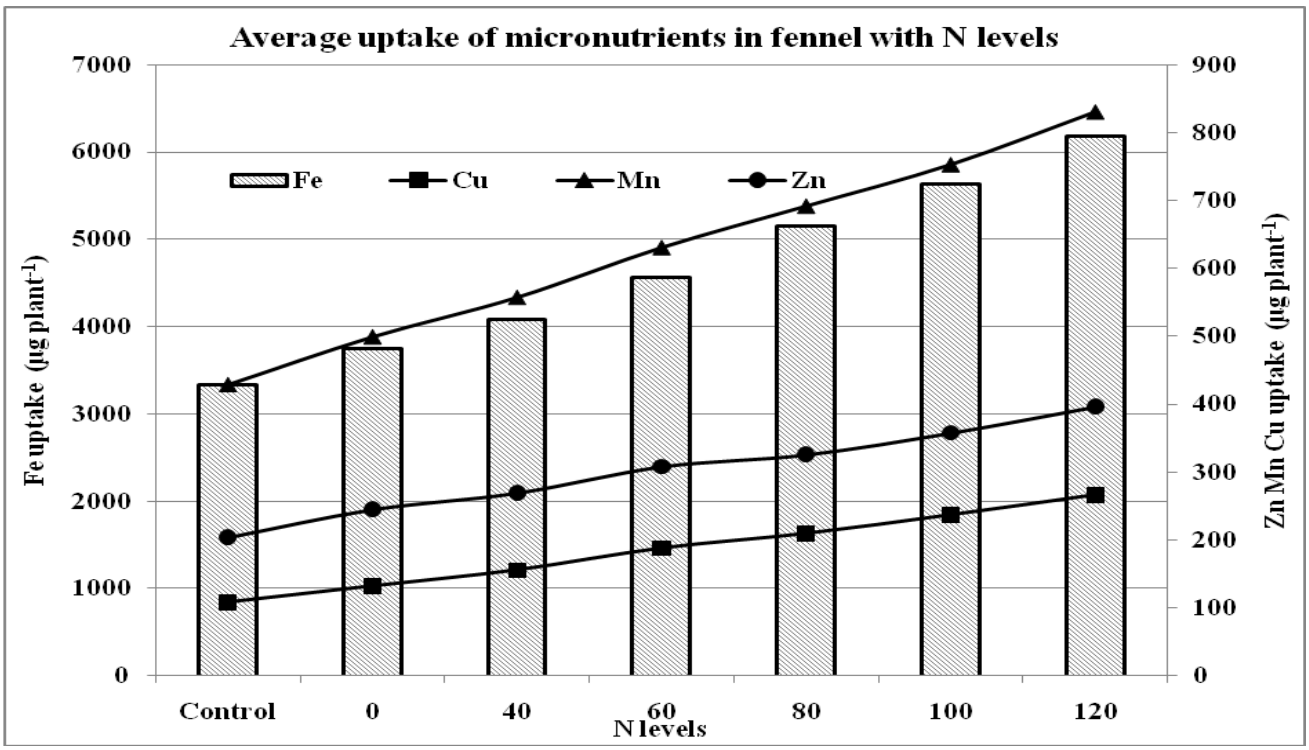

Fig. 3: Average uptake of micronutrients in fennel with N levels

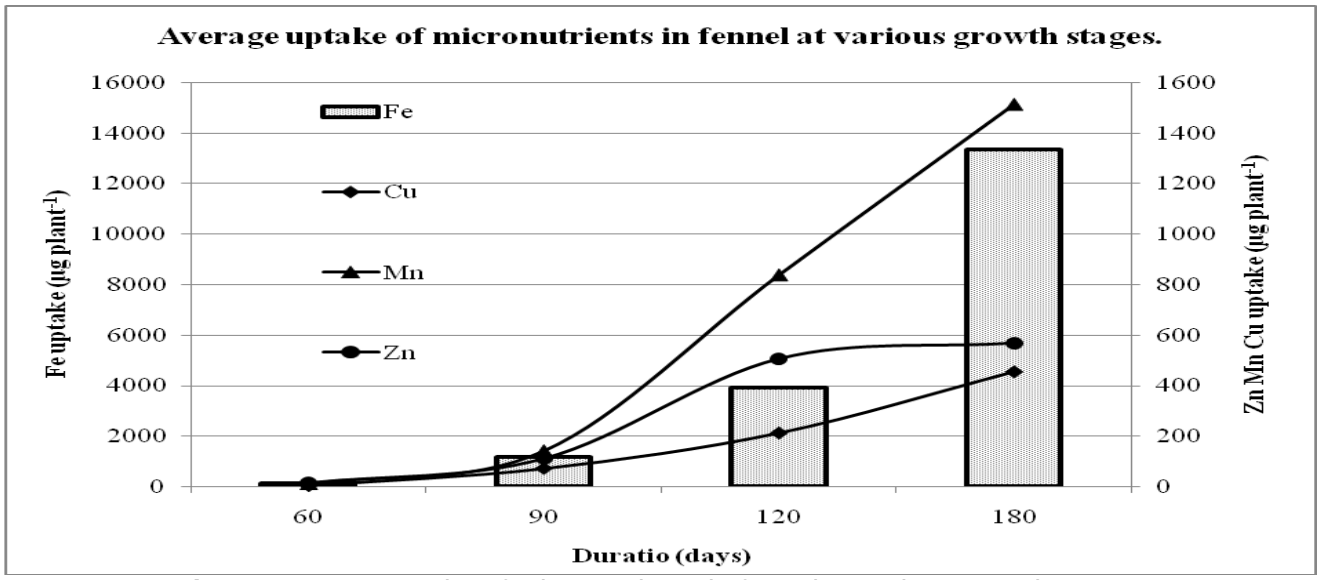

Fig. 4: Average uptake of micronutrients in fennel at various growth stages

In general, iron uptake rate was higher with N application over the control (Table 2). However, uptake rate was higher at N_{100} and N_{120} over the N_{40} and N_{80}. At 11-60 and 61-90 days, the uptake rate was higher over their alternative successive levels of N application. Uptake of Fe at 91-120 days was higher with their each successive levels of applied N, except 60 kg N ha^{-1}. Likewise uptake rate was also higher over their proceeding levels of N except N_{40} at 121-180 days. The uptake rate was not much distinct at initial growth stages; however difference was widened at later growth stages (Fig. 5). It might be due to nitrogen was applied in split doses, hence full dose response appeared clearly at later stages. Irrespective of N input, uptake rate increased linearly (r^2 = 0.989) up to maturity of crop (Fig. 6). This might be due to fennel root growth continue even after senescence of aerial part of crop resultant uptake rate continued up to 180 days of crop. Similarly, mean value of Fe uptake rate was linear (r^2 = 0.981) with the doses of N input, this indicates that higher availability of N encouraged more uptake of Fe in fennel. Sharma *et al.*(2020), reported higher macronutrients uptake and their uptake rate at higher N input.

Zn Update and its kinetics

Zinc uptake increased at higher levels of N only at 11-60 days crop stage as compared to control (Table 1). However, at the age of 61-90 and 121-180 days, the update of zinc was more at their alternate successive levels of applied N, whereas, uptake during 91-120 days was higher at their each successive levels of nitrogen. Significant and positive impact of N application was reported on grain yield, content and uptake of Zn in spring wheat grain DM (Kilkocka and Marks, 2018). It might be due to nitrogen fertilizer increased the rizopheric activity and Zn availability in soil leads to higher uptake by wheat crop (Soltani*et al.* 2014). The uptake of Zn increased linearly with N levels at 61-90, 91-120 and 121-180 days and their r^2 values were 0.979, 0.991 and 0.953, respectively. Based on the mean value of Zn uptake with N application, also showed the positive trend (r^2 = 0.983) as given in Fig. 3 irrespective of growth stages. Overall uptake value of Zn with stages made plateau beyond 91-120 days of crop growth (Fig. 4). The r^2 value of uptake to that phenological stagewas 0.910. This might be due to N input encourages Zn uptake, which was lower at initial stages as some of its splits doses was applied at later stages.

Zn uptake rate was higher with N application over the control (Table 2). However, at 11-60, 61-90 and 121-180 days, the uptake rate was higher over their alternate successive levels of N application. Likewise uptake rate was also higher over their preceding levels of N except N_{40} and N_{80} at 121-180 days. Zinc uptake rate was linear with the applied doses of N and r^2 value was 0.987, this indicates that higher availability of N encourages more uptake of Zn in fennel (Fig. 5). Irrespective of N input, uptake rate increased till 91-120 days and slow down at maturity of crop (Fig. 6). This might be due to

Table 1: Uptake of Fe, Zn, Mn and Cu by fennel with applied doses of N

Treatment	Fe uptake (µg plant^{-1}) at days				Zn uptake (µg plant^{-1}) at days				Mn uptake (µg plant^{-1}) at days				Cu uptake (µg plant^{-1}) at days			
	60	90	120	180	60	90	120	180	60	90	120	180	60	90	120	180
Control	99.6	790.1	2568.4	9865.7	9.49	68.9	346.0	388.7	6.83	90.7	551.8	1063.0	2.08	42.8	124.2	263.2
N_0	133.5	900.4	3063.8	10903.0	12.22	77.8	400.5	487.5	8.80	108.1	653.3	1224.1	2.65	48.4	154.0	323.1
N_{40}	161.1	1011.7	3583.7	11538.9	14.90	95.6	467.6	497.8	10.96	120.6	777.3	1318.2	3.33	60.2	180.9	378.5
N_{60}	160.9	1142.4	3961.1	12968.2	15.01	108.4	506.9	601.0	10.96	138.9	834.9	1535.9	3.49	68.8	207.0	472.8
N_{80}	172.1	1256.4	4268.9	14876.6	15.97	120.4	548.4	616.9	11.58	148.1	913.5	1692.0	3.79	78.3	237.3	519.3
N_{100}	196.6	1535.5	4864.0	15909.8	19.89	150.3	608.9	651.0	13.92	185.7	1014.3	1795.8	4.94	98.1	273.4	572.3
N_{120}	200.1	1624.5	5331.1	17576.7	20.49	159.4	667.8	737.2	14.50	196.9	1128.6	1980.1	5.40	103.7	306.9	650.8
CD at 5 %	25.4	150.0	323.6	643.8	2.45	14.5	28.3	23.0	2.17	18.9	53.2	60.8	0.725	9.53	16.43	31.83

Subscript values of N are in kg ha^{-1}. days: Growth stages of crop during sampling was done for uptake pattern study and its kinetics, µg: microgram

Table 2: Uptake rate of Fe, Zn, Mn and Cu by fennel with applied doses of N

Treatment	Fe uptake rate (pg s^{-1} plant^{-1}) at days				Zn uptake rate (pg s^{-1} plant^{-1}) at days				Mn uptake rate (pg s^{-1} plant^{-1}) at days				Cu uptake rate (pg s^{-1} plant^{-1}) at days			
	11-60	61-90	91-120	121-180	11-60	61-90	91-120	121-180	11-60	61-90	91-120	121-180	11-60	61-90	91-120	121-180
Control	19.2	304.8	990.9	1903.1	1.83	26.6	133.5	75.0	1.32	35.0	212.9	205.1	0.402	16.5	47.9	50.8
N_0	25.8	347.4	1182.0	2103.2	2.36	30.0	154.5	94.0	1.70	41.7	252.0	236.1	0.512	18.7	59.4	62.3
N_{40}	31.1	390.3	1382.6	2225.9	2.87	36.9	180.4	96.0	2.11	46.5	299.9	254.3	0.641	23.2	69.8	73.0
N_{60}	31.0	440.8	1528.2	2501.6	2.89	41.8	195.6	115.9	2.11	53.6	322.1	296.3	0.674	26.5	79.9	91.2
N_{80}	33.2	484.7	1647.0	2869.7	3.08	46.5	211.6	119.0	2.23	57.1	352.4	326.4	0.731	30.2	91.6	100.2
N_{100}	37.9	592.4	1876.6	3069.0	3.84	58.0	234.9	125.6	2.68	71.6	391.3	346.4	0.954	37.9	105.5	110.4
N_{120}	38.6	626.8	2056.7	3390.6	3.95	61.5	257.6	142.2	2.80	76.0	435.4	382.0	1.042	40.0	118.4	125.5
CD at 5 %	4.89	57.9	124.9	124.2	0.472	5.59	10.91	4.44	0.419	7.29	20.54	11.73	0.140	3.68	6.34	6.14

Subscript value of N are in kg ha^{-1}. days: Growth stages of crop during sampling was done for uptake pattern study and its kinetics, µg: microgram, pg: picogram, s: second

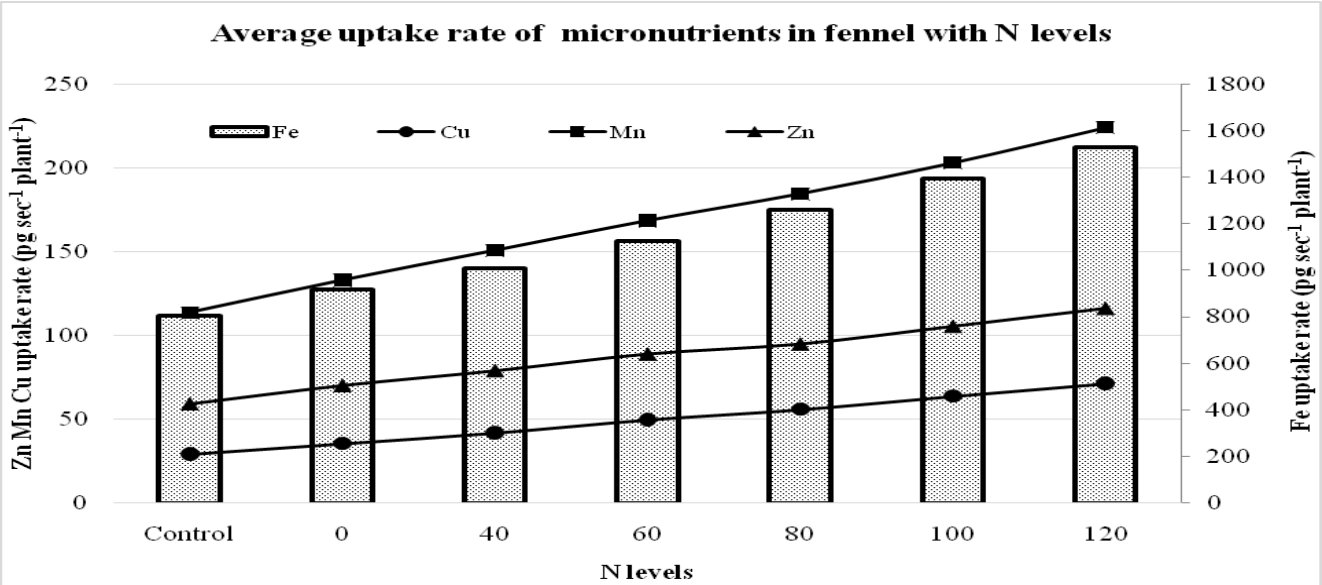

Fig. 5: Average uptake rate of micronutrients in fennel with N levels

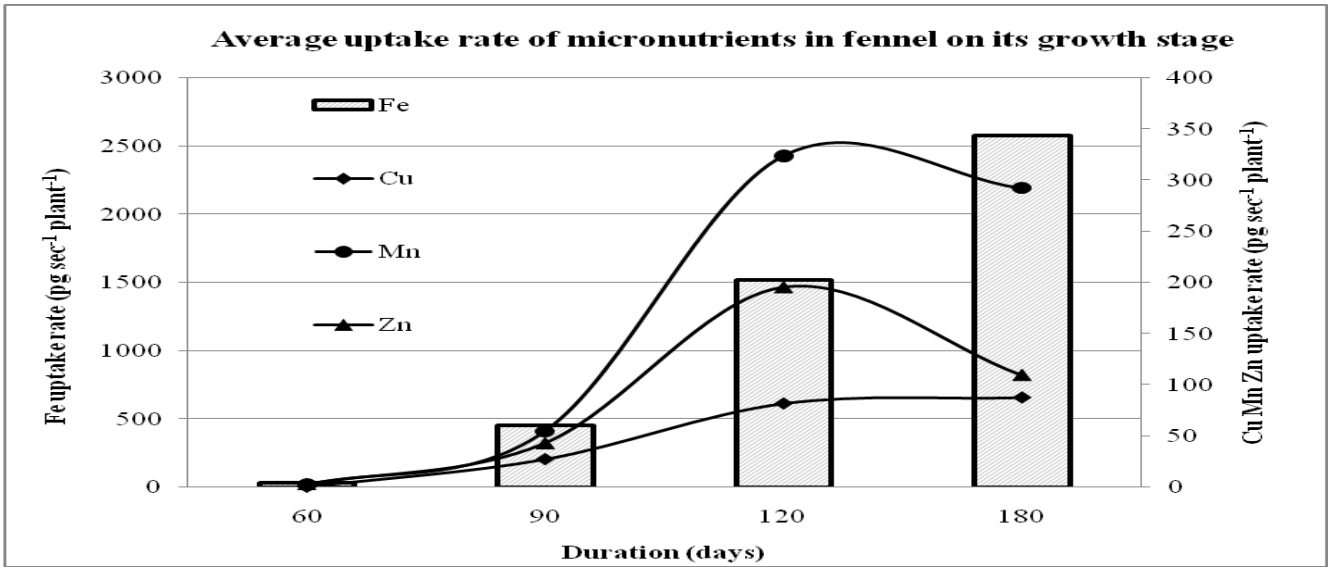

Fig. 6: Average uptake rate of micronutrients in fennel on its various growth stages

fennel is a perennial herbaceous bushy plant, hence some metabolic activities continued even after senescence of aerial part of crop resultant, hence uptake rate continued up to 180 days of crop at slow rate. It is obvious that higher uptake of Zn with higher levels of N as well as later stages resulted higher uptake rate. Moreover rate was lower down at maturity due to senescence of aerial part of fennel.

Mn Uptake and its kinetics

Uptake of Mn at 11-60 days was higher at higher levels of N application as compared to control (Table 1). However, at the age of 61-90 days, the uptake of Mn was more at their alternate successive levels of N input, whereas, uptake at 91-120 and 121-180 days was higher at each successive levels of nitrogen. Significant and positive impact of N application on grain yield, content and uptake of Mn in spring wheat grain DM was reported by Klikocka and Marks (2018). Likewise application of N fertilizer increased the concentrations of Mn in above ground tissues in grassland ecosystem (Tian *et al.* 2016). The uptake of Mn increased linearly with N levels at 61-90, 91-120 and 121-180 days and their r^2 value of these stages were 0.990, N. SHARMA,

0.981 and 0.98, respectively (Fig. 3). Based on the mean value of Mn uptake with N levels also showed the positive trend (r^2= 0.987) with N application. Overall uptake value of Mn without considering applied N was exponential beyond 61-90 days of growth stages of fennel (Fig. 4). The r^2 value of uptake with this phenological stage was 0.981, which was significant and positive.

Mn uptake rate was higher with N application over the control (Table 2). However, at 61-90 days, uptake rate was higher over their alternate successive levels of N application. However, at 91-120 and 121-180 days, the rate was higher with their each successive levels of applied N. Mean value of Mn uptake rate was linear with the doses of N input and r^2 value was 0.989 (Fig. 5). Nitrogen addition results in significant increases in the availabilities of micronutrients, such as the available concentrations of Mn in grassland soils reported by Tian *et al.* (2015). This indicates that higher availability N encourages more uptake of Mn in fennel also. Irrespective of N input, uptake rate increased up to 91-120 days and slow down at maturity of crop (Fig. 6) which is obvious that least uptake during senescence of crop.

Cu Uptake and its kinetics

Cu uptake at 11-60 days increased at higher levels of N only as compared to control (Table 1). However, at the age of 61-90 days, the uptake of Cu was more at their alternate successive levels of applied N, whereas uptake at 91-120 and 121-180 days was higher at each successive levels of N input. The uptake of Cu increased linearly with N levels at 61-90, 91-120 and 121-180 days. The corresponding r^2value of these phonological stages were 0.979, 0.982 and 0.987. Based on the mean value of Cu uptake with N levels also showed the positive trend (r^2 0.988) with N application (Fig. 3). Overall uptake of Cu followed linear trend (r^2=0.995) with phonological stages of crop (Fig. 4). Significant and positive impact of N application was reported on grain yield, content and uptake of Cu in wheat (Klikocka and Marks, 2018). Nitrogen fertilization increased the concentration and uptake of Cu in rice also (Lakshmanan*et al.* 2011).

Cu uptake rate was higher over their alternate successive levels of N application at 11-60 and 61-90 days. However, uptake rate at 91-120 and 121-180 days was higher with their each successive levels of applied nitrogen (Table 2). Mean value of Cu uptake was linear (r^2=0.987) with the doses of applied N. This indicates that higher availability N encourages more uptake of Cu in fennel (Fig. 5). Irrespective of N input, uptake rate increased linearly (r^2=0.904) up to maturity of crop (Fig. 6). This might be due to Cu is an important component of enzymes that affect N metabolism in plants (Mills and Jones, 1996). Cu uptake and uptake rate was lower during the initial growth stage due to low production of plant biomass as well as physiological or biochemical process in per unit time.

Comparative uptake kinetics at various growth stages

Overall uptake and uptake rate of Cu, Fe, Mn and Zn was more with higher doses of applied nitrogen. The uptake rate of Cu, Mn and Zn was decreased with increase duration or the age of crop plants (Fig. 6). However, the Fe uptake rate was increased with duration/age of crop plant. The uptake rate of Cu, Mn and Zn was highest at 91-120 days and reduced thereafter. The uptake rate of Fe was highest at 121-180 days. The uptake and uptake rate of Fe, Mn, Zn and Cu was positively influenced by N input up to the age of 120 days of crop plants due to more active growth phase of crop during the period (120 days).

Therefore, it can be concluded from the results that higher doses of nitrogen boost the uptake of Cu, Fe, Mn and Zn and age of crop plants has negative relation for the uptake of Cu, Mn and Zn, whereas Fe uptake rate gave positive relation with doses of applied N and aging of fennel plants. In contrast to Cu, Mn and Zn, Fe uptake rate showed positive relation to applied N. Based on the uptake rate, application of Mn and Zn may be discouraged at later growth stage of fennel, while Fe and Cu application may continue, if ratooning is to be taken.

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REFERENCES

Aishwath, O.P. (2004) Mineral Nutrition and growth of *Withania somnifera. Journal of Tropical Medicinal Plants (Malaysia),* **5**(1): 111- 118.

Aishwath, O.P., Singh, R., Jha, B.K., and Mehta, R.S. (2015) Growth kinetics and yield of coriander under limed acid soils of eastern plateau hill regions. *International Journal of Seed Spices,* **5**(1): 49-55.

Aishwath, O.P. (2017) Nutrients uptake pattern in some important cultivars of fennel under Typic Haplustepts for their management precisely and farm gate budgeting. *International Journal of Seed Spices,* **7**(2): 19-25.

Adhikari, T., Sarkar, D., Mashayekhi, H. and Xing, B. (2016) Growth and enzymatic activity of maize (*Zea mays L*.) plant: solution culture test for copper dioxide nano particles. *Journal of Plant Nutrition,***39**:99–115. doi:10.1080/01904167.2015.1044012.

Barros, L., Carvalho, A.M. and Ferreira, I.C.F.R. (2010) The nutritional composition of fennel (*Foeniculum vulgare*) Shoots, leaves, stems and inflorescences. *LWT - Food Science and Technology,* **43**: 814–818. doi:10.1016/j.lwt.2010.01.010.

Bray, R.H. (1948) Correlation of soil tests with crop response to added fertilizers and with fertilizer requirement. *Diagnostic Techniques for Soils and Crops*, (ed.) H. B. Kitchen (Washington, DC: The American Potash Institute), pp. 53–86.

Chapman, H.D. and Pratt, P.F. (1962) Methods of analysis for soil, plant and water. *Division of Agricultural Sci*ence, University of California, California.

Ciampitti, I.A., Camberato, J.J., Murrell, S.T. and Vyn, T.J. (2013) Maize nutrient accumulation and partitioning in response to plant density and nitrogen rate: I. Macronutrients. *Agronomy Journal,***105**(3): 783-795.

Cocharn, W.G. and Cox, G.M. (1987) Experimental designs, (2nd ed.) Pub. John Wiley and Sons, New York.

El-Seifi S.K., Hassan, M.A., Elwan, M.W.M. and Haggag, O.G. (2015) Plant Growth, Yield, Macro and Micro-Nutrients Uptake of Fennel (*Foeniculumvulgare Mill.*) Positively Affected by N-Sources and Rates as well as Foliar Application of Micronutrients.*Hort Science Journal of Suez Canal Univewrsity*, **4**(1): 7-16.

Granath G., Strengbom J., Breeuwer A., Heijmans M.M., Berendse F. and Rydin H. (2009) Photosynthetic performance in Sphagnum transplanted along a latitudinal nitrogen deposition gradient. *Oecologia,* **159**: 705-715. doi:10.1007/s00442-008-1261-1.

Havlin, J.L.T., Nelson, S.L. and Beaton, J.D. (2013) Soil Fertility and Fertilizers: An introduction to Nutrient Management, (8th ed.), Pub. Pearson. Upper Saddle River, New Jersey.

Hamner, K., Weih, M., Eriksson, J. and Kirchmann, H. (2017)Influence of nitrogen supply on macro and micro-nutrient accumulation during growth of winter wheat. *Field Crops Research,* **213**: 118-129. doi:10.1016/j.fcr.2017.08.002.

Klikocka, H. and Marks, M. (2018) Sulphur and nitrogen fertilization as a potential means of agronomic bio fortification to improve the content and uptake of microelements in spring wheat grain DM. *Journal of Chemistry,* **2018**(2): 1-12. doi:10.1155/2018/9326820

Kutman, U.B., Yildiz, B. and Cakmak, I. (2011) Improved nitrogen status enhances Zn and Fe concentrations both in the whole grain and the endosperm fraction of wheat. *Journal of Cereal Science*, **53**(1): 118–125.

Lakshmanan, R., Prasad, R.Dr. and, Jain, M.C. (2011) Yield and uptake of micronutrients by rice as influenced by duration of variety and nitrogen fertilization. *Archives of Agronomy and Soil science,* **51**(1) 1-14.doi: 10.1080/03650340400026578.

Lindsay, W.L. and Norvell, W.A. (1978) Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Societyof America Journal,* **42**: 421-428.

Mills H. and Jones J. (1996) Plant Analysis Handbook II, A Practical Sampling, Preparation, Analysis and Interpretation Guide. Pub. Athens, Gorgea: MicroMacro.

Morrissey, J. and Guerinot, M.L. (2009) Iron uptake and transport in plants: The good,

the bad, and the ionome.*Chemical Reviews,* **109**(10): 4553–4567.doi:10.1021/cr900112r

Sharma, N. and Aishwath, O.P. (2018) Growth kinetics of fennel with nitrogen application in Typic Haplustepts. *Annals of Plant and Soil Research,* **20**:1–9.

Sharma, N., Jat, B.L. and Aishwath, O.P. (2020) Uptake kinetics of nitrogen, phosphorus and potassium in fennel (*Foeniculum vulgare*) with nitrogen input. *Annals of Plant and Soil Research*, **22**(4): 354-360. doi:10.47815/apsr.2020.10004.

Soltani, S., Khoshgoftarmanesh, A.H., Afyuni, M., Shrivani, M., Schulin, R. (2014) The effect of preceding crop on wheat grain zinc concentration and its relationship to total amino acids and dissolved organic carbon in rhizosphere soil solution. *Biology and Fertility of Soils,* **50**: 239-247.

Tian, Q., Liu, N., Bai, W., Li,L., Chen, J., Reich, P.B., Yu, Q., Guo, D., Smith, M.D., Knapp, A.K., Cheng, W., Lu, P., Gao, Y., Yang, A., Wang, T., Li, X., Wang, Z., Ma, Y., Han, X. and Zhang, W.H. (2016) A novel soil manganese mechanism drives plant species loss with increased nitrogen deposition in a temperate steppe. *Ecology,* **97**: 65–74. doi:10.1890/15-0917.1.

Tian Q.Y., Liu N.N., Bai W.M., Li L.H., Zhang W.H. (2015) Disruption of metal ion homeostasis in soils is associated with nitrogen deposition-induced species loss in an Inner Mongoliasteppe. *Biogeosciences,***12**:3499–3512.-doi:10.5194/bg-12-3499.