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Effect of sole and conjoint application of iron and manganese on herb yield, nutrient uptake, oil quality *vis-a-vis* their optimal level in spearmint (*Mentha spicata* Linn. emend. Nathh. cv. 'Arka')

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A study was conducted to investigate the response of *Mentha spicata* Linn. emend. Nathh. cv. 'Arka' an essential oil bearing plant, to sole and conjoint application of different level of Fe and Mn with respect to its influence on herb yield, nutrient uptake and oil quality. For this a pot experiment was conducted under glasshouse conditions during the year 2005 at Central Institute of Medicinal and Aromatic Plants (CIMAP) in Lucknow. *M. spicata* plants were grown through suckers with four graded levels of iron and manganese, viz. Fe- 0, 5, 10 and 15 mg/kg and Mn 0, 2.5, 5 and 10 mg/kg and a combination of both these elements. From the results obtained, it is evident that the fresh weight, dry weight, oil yield and chlorophyll content showed a significant increase with increase in Fe supply; the optimal level of Fe as revealed by the results was Fe 10 mg/kg supply. Sole supply of manganese showed the optimal level to be Mn 2.5 mg/kg; beyond which growth parameters showed a gradual and significant decline. Sole supply of Fe and Mn 10 mg/kg and 2.5 mg/kg, respectively, showed maximum carvone percentage in *M. spicata* oil.

Keywords: *Mentha spicata*, Iron, Manganese, Carvone, Micronutrient, Essential Oil, Spearmint.

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Introduction

Micronutrients play many complex roles in plant nutrition. Use of micronutrients is becoming increasingly important to agriculture as crop removal of these essential elements has increased manifold. Very small application of micronutrients may produce dramatic results. Soil and plant tissue tests confirm that these elements are limiting crop production over wide areas and suggest that attention to them will, in all likelihood, increase production in future.

M. spicata commonly known as spearmint is an annual herb. On steam distillation of fresh herb it yields aromatic oil which is rich in carvone, limonene, cineole and dihydrocarvone. Carvone is responsible for the aroma of the essential oil which has a commercial application in tooth-pastes, chewing gums and for flavours in the pickle industry. Perusal of the literature reveals that much of the work has been focused on the effect of macro-nutrients supplied as inorganic source or in combination with manure[1-2]. However, aromatic plants are not much studied with respect to micronutrient requirement. Micronutrients have a significant impact on herb yield and oil production in *Mentha.*

Iron is abundant in the earth crust, its bioavailability is often restricted by very low solubility of Fe (III)-oxides under aerobic conditions[3-4]. This leads to reduced crop production[5]. Manganese is also essential for all stages of plant development as it imposes a significant limitation on crop productivity[6]. Manganese is toxic when in excess concentration[7] and produces various phyto-toxic effects[8]. Uptake of phosphate is adversely affected by excess Mn concentration[9]. The interaction of Mn with other elements such as Fe can also be important[10].

Micronutrient deficiencies are not only due to low content of these elements in soil but more often due to their unavailability to the growing plant. At low level of a micronutrient deficiency, reduced plant growth may occur. As the level of nutrient is increased, plants respond by taking up more of the nutrient and increasing their growth. If the level of the nutrient availability has been reached that is sufficient to meet the plant needs, raising the level further will have

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little effect on plant growth, although the concentration of nutrient may continue to increase in the plant tissue. At some level of availability, the plant may take too much nutrient, which leads to adverse physiological reactions in the plant. Therefore, it becomes necessary to work out the optimal limit for micronutrients, although these limits may vary from plant to plant.

The present trial was, therefore, carried out with a view to evaluate the effect of sole and combined application of Fe and Mn on the growth parameters, oil yield and quality and to work out the optimal level of supply of Fe and Mn for *M. spicata.*

Materials and Methods

A pot experiment was conducted on *M. spicata* cv. 'Arka' at Central Institute of Medicinal and Aromatic Plants (CIMAP) research farm, Lucknow, during the year 2004-2005. The experiment was conducted in glazed China clay pots, in which nine kg of air dried and sieved (< 2 mm) soil was taken. *Mentha* plants were raised from suckers, three of which were planted in each pot. The experimental soil was having pH 8.2, electrical conductivity 0.117/dSm, $KMnO_4$ extractable N 65 mg/kg, Olsen P 40 mg/kg, NH_4OAC extractable K 58 mg/kg and DTPA extractable Fe, Mn, Zn, 7.3, 4.2 and 4.9 mg/kg, respectively. *M. spicata* plants were treated with three graded levels of each iron (supplied as $FeSO_4.7H_2O$) and manganese (supplied as $MnSO_4.H_2O$) and their combinations as given in Table 1. The experiment was laid out in completely randomized design (CRD) having 15 combinations with three replications. Nitrogen, phosphorus and potassium were supplied 50 mg/kg, 30 mg/kg and 30 mg/kg as basal dressing through urea, single super phosphate and muriate of potash, respectively.

Table 1—Treatment details

S.No	Treatments
T_0	Control
T_1	Fe 5 mg/kg
T_2	Fe 10 mg/kg
T_3	Fe 15 mg/kg
T_4	Mn 2.5 mg/kg
T_5	Mn 5 mg/kg
T_6	Mn 10 mg/kg
T_7	Fe 05 + Mn 2.5 mg/kg
T_8	Fe 10 + Mn 2.5 mg/kg
T_9	Fe 15 + Mn 2.5 mg/kg
T_{10}	Fe 05 + Mn 05 mg/kg
T_{11}	Fe 10 + Mn 05 mg/kg
T_{12}	Fe 15 + Mn 05 mg/kg
T_{13}	Fe 05 + Mn 10 mg/kg
T_{14}	Fe 10 + Mn 10 mg/kg
T_{15}	Fe 15 + Mn 10 mg/kg

Suckers of *M. spicata* were planted in the last week of January 2005, the sprouts emerged out after 15 days of planting. Old plants (110 days) were harvested and data on the yield of fresh herbage, dry matter, oil yield and chlorophyll content in young leaves was recorded. Chlorophyll was determined spectrophotometrically in 85% acetone[11]. Stem, leaf and root parts were separated and cleaned against surface contamination by successive repeated washing with 0.1N HCl, running tap water, deionized water and finally glass distilled water. Representative samples of plant parts after oven drying at 70°C were acid digested[12] for analysis of N, P, K and micronutrients Fe, Mn and Zn in plant tissue[13] by atomic absorption spectrophotometer (Unichem model 969). Total oil content of leaves was estimated by hydro distillation of 100 g of fresh plant material in a Clevenger apparatus[14].

Data on all observations were subjected to analysis of variance (ANOVA) and least significant difference (LSD) was calculated using F method[15].

Results and Discussion

Result in Figs 1 & 2 indicated that there was a significant effect in herb yield and chlorophyll content of graded levels of Fe and Mn and their combined application on *M. spicata.* Maximum fresh herb of stem, leaf and root weight were observed in T_4, T_4 and T_7, respectively. The increase in stem, leaf and root weight was about 88, 99 and 131%, respectively, over control. Among combined application of Fe and Mn, maximum stem, leaf and root weight were recorded in T_7 which is comprised of lowest rate of iron and manganese (Fe 5 mg/kg+ Mn 2.5 mg/kg). Stem and leaves which are major sources of essential oil, produced almost same weight in T_{10}, T_{11}, T_{13} and T_{14}, however, these were highly significant over control. The sole application of Mn 2.5 mg/kg (T_4) produced highest stem and leaf yield which may be attributed to proper root development as indicated by its higher root weight. Manganese supply improves the root growth and its activity as reported by Mou *et al*[16]. But increasing supply of Fe with constant rate of Mn negatively affected stems and leaves fresh weight which indicates the antagonistic effect of these two elements on yield. The root yield did not follow any definite pattern under combined application of Fe and Mn supply. Maximum chlorophyll content

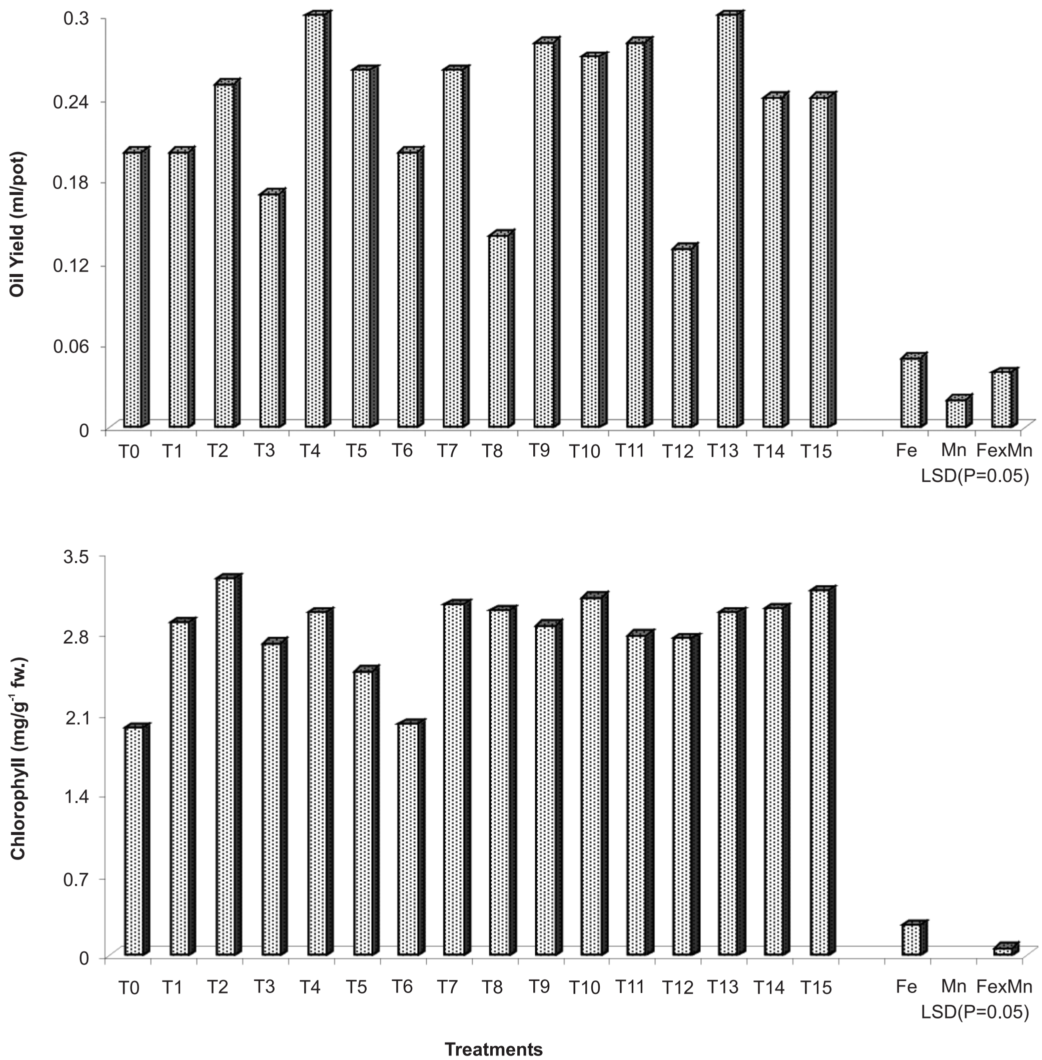

Fig. 1–Effect of Fe and Mn application on oil yield and chlorophyll content of *Mentha spicata*

recorded with T_2 (Fe 10 mg/kg) followed by T_{15} and T_{10}. Increasing rate of Fe supply with constant dose of Mn 10 mg/kg has positive effect on chlorophyll content but other combinations of Fe with lower dose of Mn exhibited reverse effect on it. Chlorophyll content decreased as sole application of Mn increased. High concentration of Mn probably causes oxidative stress which affects the photosynthetic reaction negatively. Hence, chlorophyll content reduces as result of unfavorable condition. These results corroborate with Lei *et al*[17].

Concentration of macronutrients

Nitrogen, phosphorus and potassium in plant tissue:

Nitrogen concentration in stem, leaf and root tissue increased with increase in sole Fe supply from 5 mg/kg to Fe 15 mg/kg and Mn from 2.5 mg/kg to 10 mg/kg level (Fig. 3). Nitrogen concentration showed an increase of 107, 115 and 93% in stem, leaf and root, respectively, over control in treatment T_3 (sole Fe supply 15 mg/kg). Treatment T_6, where Mn was supplied 10 mg/kg resulted in 80, 103 and 70% increase in tissue nitrogen concentration of stem, leaf and root, respectively, over control. Maximum increase in tissue nitrogen concentration was recorded in treatment T_{12}, where plants received integrated supply of Fe 15 mg/kg and Mn 5 mg/kg. Further, under combined application of iron and manganese, nitrogen concentration showed significant increase with increase in Fe supply from 5 to 15 mg Fe/kg. These observations strengthen the involvement of Fe in nitrogen metabolism, as it is a constituent of nitrogenase, ferredoxin and leghaemoglobin[7].

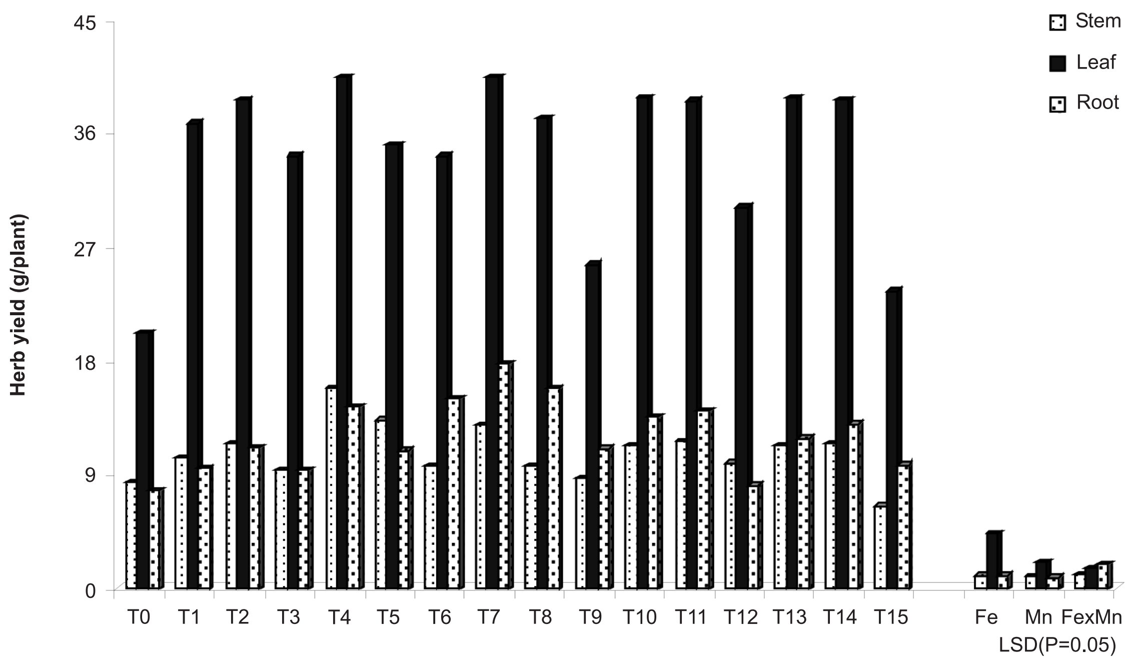

Fig. 2–Effect of Fe and Mn application on herb yield of *Mentha spicata*

Iron and manganese applied either singly or in combination showed antagonistic effect on potassium and phosphorus (Fig. 3). Tissue phosphorus concentration significantly decreased with increase in iron supply from 5-15 mg/kg and manganese from 2.5-10 mg/kg. Combination treatments i.e. T_7-T_{15} also showed gradual decrease in tissue concentration of phosphorus in shoot as well as roots. Treatment T_3 where Fe was supplied 15 mg/kg showed 5, 10 and 15% decrease in phosphorus concentration in stem, leaves and root over its one third supply in treatment T_1, respectively.

Figure 3 indicated that potassium concentration decreased when treated with graded level of either sole or combined application of Fe and Mn. Potassium concentration showed a decrease of 22, 10 and 14% in stem, leaf and root tissue when supplied with Fe 15 mg/kg over its one third supply (T_1). Manganese supply 10 mg/kg resulted in 25, 19 and 49% decrease in tissue phosphorus concentration over its one-third supply in treatment T_4. Data also revealed that under integrated supply of iron and manganese, potassium concentration in plant tissue showed a sharp decline with increasing Fe concentration. Potassium concentration in stem ranged from 0.340-1.076%, in leaf from 0.870-336% and in root from 0.74-1.79%. Iron and manganese had an antagonistic effect on potassium and phosphorus concentration in plant tissue, with increase in Fe and Mn supply phosphorus and potassium concentration decreased. These results are in conformity with those obtained by Mehrotra *et al*[18] and Oertli and Opoku[19] who observed antagonism of Fe and Mn with phosphorus and potassium.

Concentration and uptake of micronutrients Fe, Mn and Zn in plants

Concentration and uptake of iron in stem, leaves and root increased (Tables 2 & 3) with increase in its supply from 5-15 mg/kg in treatment T_1 to T_3. The increase being 5, 122 and 32% in concentration and 205, 136 and 118% in uptake over control in stem, leave and root, respectively in treatment T_1. Maximum iron concentration was reported in roots receiving 15 mg/kg Fe. In treatment T_3 the root iron concentration increased three times over roots of control plants. With increase in Fe supply, concentration and uptake of manganese decreased. The decrease was maximum when iron was supplied 15 mg/kg. This decrease in Mn concentration was 7, 5 and 34% in stem, leaves and root, respectively over one third supply of iron (5 mg/kg). Uptake of Mn by *Mentha* also showed similar decrease, which was up to, the extent of 40, 28 and 39% in stem, leaves and root over 5 mg/kg Fe supply, respectively (Table 3). Zinc concentration in stem and leaves tissue increased

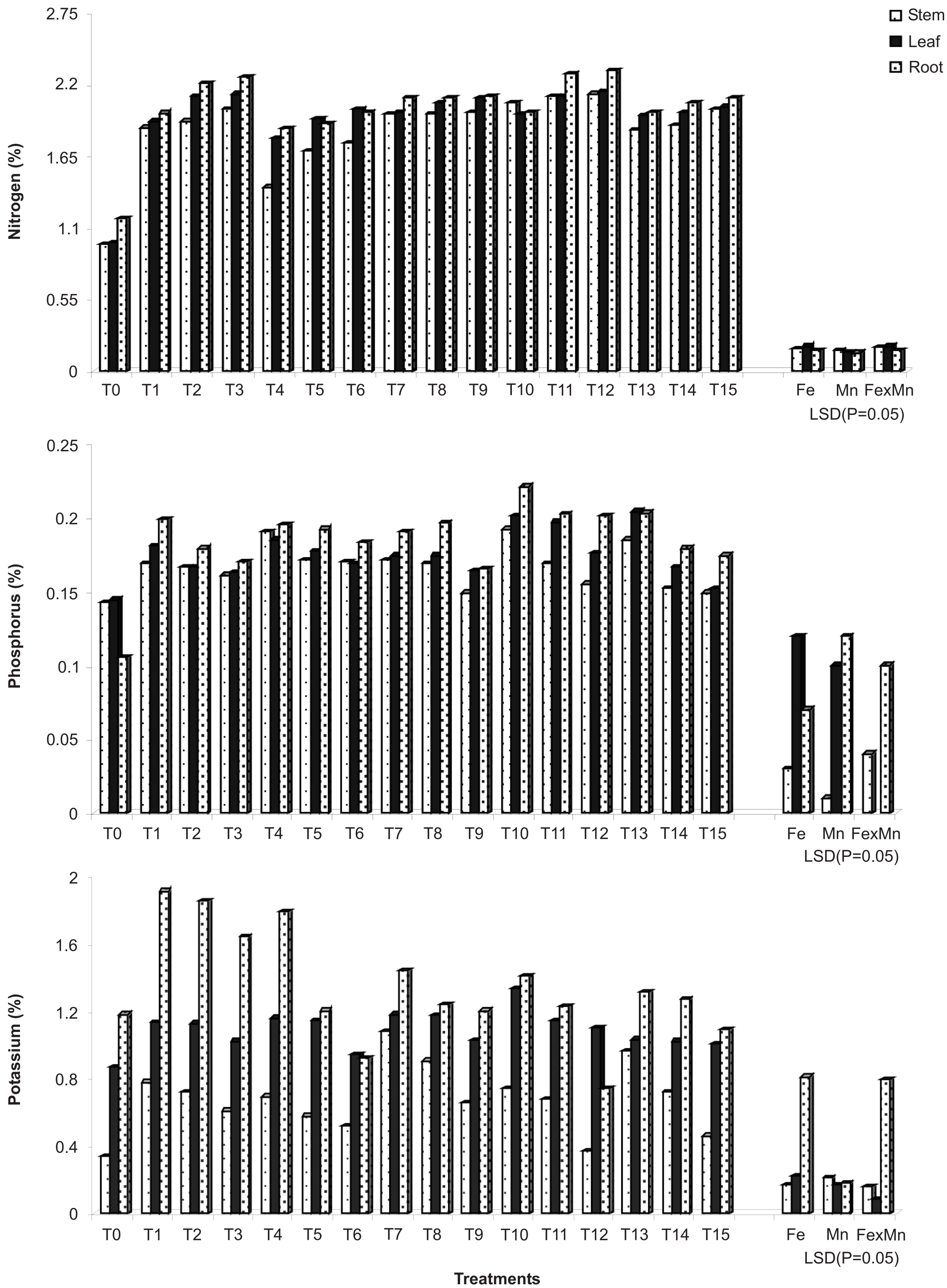

Fig. 3–Effect of Fe and Mn application on tissue concentration of macronutrients in *Mentha spicata*

Table 2—Effect of Fe and Mn application on tissue concentration of micronutrients on *Mentha spicata*

Treatments	Tissue concentration of micronutrients (%) Iron			Manganese			Zinc		
	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves	Root
T_0	90.0	199.7	497.7	36.4	105.0	60.3	12.0	16.4	30.9
T_1	94.8	443.6	655.6	52.0	126.0	96.0	14.8	38.4	66.4
T_2	142.4	828.4	1239.2	48.8	124.2	64.0	15.6	40.0	36.4
T_3	265.6	1383.2	1531.0	48.4	120.0	63.2	16.8	41.2	34.8
T_4	328.8	702.4	1139.2	38.8	135.2	52.0	11.6	36.4	64.0
T_5	190.4	305.6	673.2	41.6	175.6	89.6	13.2	35.2	52.0
T_6	160.2	200.0	547.6	46.8	179.2	92.0	16.4	31.6	51.6
T_7	197.6	601.2	816.0	50.4	165.2	92.8	39.6	32.0	71.6
T_8	264.8	853.6	1046.8	52.4	174.4	121.6	16.0	31.6	58.0
T_9	352.8	1053.2	1211.2	40.0	128.0	84.0	14.8	28.8	57.6
T_{10}	226.4	397.2	1130.0	65.2	150.0	165.6	11.6	24.4	51.6
T_{11}	110.8	299.6	1117.6	53.2	145.2	98.4	13.6	26.0	54.8
T_{12}	92.4	292.6	959.2	49.2	138.0	82.4	25.2	27.2	62.4
T_{13}	125.2	507.6	945.2	57.6	109.6	98.4	16.0	24.4	54.4
T_{14}	95.0	312.2	719.2	59.6	151.6	101.2	18.0	22.4	60.4
T_{15}	92.9	225.0	811.2	62.2	152.8	108.4	23.2	21.2	70.4
CD at 5 % Treatment									
Fe	17.20	180.92	175.08	0.72	1.20	6.56	0.67	10.17	20.71
Mn	34.63	22.12	108.32	1.60	8.80	8.01	NS	NS	NS
Fe×Mn	20.10	79.60	92.37	NS	26.94	16.64	5.31	2.17	3.76

Table 3—Effect of Fe and Mn application on uptake of micronutrients on *Mentha spicata*

Treatments	Uptake of micronutrients (μg/g) Iron			Manganese			Zinc		
	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves	Root
T_0	200.7	619	1167	80	327	141	27	50	71
T_1	336.3	3219	1692	184	914	248	53	276	170
T_2	559.5	6342	3908	193	949	202	63	306	113
T_3	611.8	7606	3689	110	660	152	39	226	84
T_4	1776.5	4654	4430	215	895	202	66	239	249
T_5	851.2	1625	1992	188	935	266	58	186	154
T_6	561.6	2224	2526	165	1990	424	56	356	235
T_7	843.48	4237	4120	213	1163	469	170	226	364
T_8	908.9	5235	4952	178	1067	577	55	196	274
T_9	921	4243	3645	104	515	253	39	117	172
T_{10}	854	3053	4260	246	1154	626	45	185	196
T_{11}	434	1871	3968	207	908	348	55	163	195
T_{12}	212	1108	2349	113	522	201	58	102	152
T_{13}	410	3398	3449	190	729	358	52	161	197
T_{14}	371	1978	2847	230	964	399	70	139	238
T_{15}	166	893	2482	110	607	330	41	83	214
CD at 5% Treatment									
Fe	55	87	443	17	58	19	5	16	17
Mn	143	606	487	10	201	44	NS	NS	NS
Fe×Mn	25	839	520	28	129	85	26	28	42

with increase in Fe supply (T_1-T_3). Whereas, in root the concentration gradually decreased. Stem, leaves and root showed decrease in Mn uptake with increase in Fe concentration in treatment T_1-T_3. In totality iron has an antagonistic effect on manganese concentration i.e. on increasing Fe concentration the concentration of manganese decreases reaching its minimum in treatment T_3.

Manganese concentration increased (Table 3) with increase in its supply from 2.5 to 10 mg/kg. Stem, leaves and root showed 29, 71 and 77% increase in treatment T_6, respectively, over control. Like concentration, uptake of Mn (Table 3) also showed an increasing trend in leaves and root but Mn uptake in stem decreased with increase in Mn supply. This may be due to high transportation of manganese from stem to leaves. Zinc concentration in leaves and root showed a decrease of 13 and 19%, respectively, in treatment T_6 over one-fourth supply of Mn in treatment T_4.

Plants when supplied with graded levels of iron 5, 10 and 15 mg/kg in combination with Mn supplied 2.5 mg/kg showed gradual increase in iron concentration in stem, leaves and root. In treatment T_9 (Fe 15 mg/kg + Mn 2.5 mg/kg) the increase in Fe concentration in stem, leaves and root was approximately 4, 5 and 2.5 times, over their control, respectively. Zinc concentration and uptake showed a gradual and significant decrease in treatment T_7-T_9. The decrease was 77% in stem, 48% in leaves and 53% in root uptake of Zn over one third supply of Fe in combination with Mn 2.5 mg/kg.

Combination treatments (T_7-T_{15}) showed maximum iron concentration in stem, leaves and root at treatment T_9 and maximum uptake of Fe by leaves and root was up to approximately 9 and 4 times, respectively in treatment $T_{8,}$ over control. Under combination treatment, plants showed maximum zinc concentration and uptake at supply of Fe 5 mg/kg and Mn 2.5 mg/kg (T_7). The magnitude of increase in Zn concentration was 230, 95 and 131% in stem, leaves and root in treatment T_7 and 6, 5 and 5 times increase in uptake of Zn by plant in stem, leaves and root part, respectively, over control. This increase in Zn concentration and uptake was significant.

Quality of M. spicata oil

M. spicata is rich in volatile oils called terpenes. These ethereal, complex, organic compounds – mainly carvone and neo menthol give mint the taste and aroma that makes it favourite for chewing gum, toothpaste, candy and medicine. Lawrence[20] advocated that the percentage of various constituents in oil varies according to geographical, ecological conditions and genetic make up of the plant. It also varies with nutrient management[2] and with season[21]. Iron and Mn play important role in processes like photosynthesis, biochemical reactions and the isoprenoid pathway which produces several important metabolites and also produces essential oil. Lower or higher concentration of Fe and Mn effects chemical composition of the oil. The increase in oil yield by their application was found by Said-Al Ahl HAH and Omer[22].

Carvone, the major constituent of *M. spicata* oil increased with increase in Fe supply from 5 mg/kg – 10 mg/kg in treatment T_1 and T_2 after which in treatment T_3 it showed a gradual decrease in its content (Table 4). Treatment T_2 receiving 10 mg/kg Fe showed maximum carvone percentage in oil. The extent of increase was up to 22% over control. Least carvone percentage was obtained when plants were given sole supply of Mn 5.0 mg/kg, showing only 6% increase over its respective control. Neo-menthol percentage in oil decreased with increase in sole supply of Mn, the neo-menthol percentage in plants decreased by 79% when supplied with Fe 15 mg/kg

Table 4—Effect of Fe and Mn application on constituents of oil in *Mentha spicata*

Treatments	Constituents of oil (%)		
	Limonene	Neo menthol	Carvone
T_0	10.50	3.04	61.09
T_1	11.85	4.27	63.19
T_2	13.09	2.52	74.76
T_3	10.11	0.65	69.63
T_4	14.74	2.57	64.60
T_5	13.72	4.39	57.36
T_6	11.25	3.88	64.25
T_7	14.88	3.37	63.40
T_8	15.57	3.69	64.35
T_9	11.57	2.14	61.85
T_{10}	15.38	3.99	63.24
T_{11}	16.22	3.28	60.11
T_{12}	10.60	3.19	60.29
T_{13}	13.34	3.59	62.06
T_{14}	12.77	3.21	71.41
T_{15}	13.93	3.58	64.52
CD at 5% Treatment			
Fe	0.59	0.38	2.21
Mn	0.69	NS	NS
Fe×Mn	0.99	0.31	1.41

over control in treatment T_3. Limonene percentage in plant also showed a similar trend as that of neo-menthol. There was 4% decrease over control in limonene percentage in plant under sole supply of iron 15 mg/kg.

Combined application of Fe and Mn resulted in significant and gradual decrease in carvone and neo-menthol percentage when Fe was supplied 5-10 and 15 mg/kg and Mn 2.5 and 5 mg/kg, respectively (T_7-T_9 and T_{10}-T_{12}). Limonene percentage in oil under combined treatments was maximum at supply of Fe 10 mg/kg and Mn 2.5 mg/kg. The extent of increase was 19 and 6% over sole supply of Fe 10 mg/kg and Mn 2.5 mg/kg, respectively. The treatments T_{13}-T_{15} where plants were given integrated supply of Fe (5, 10 and 15 mg/kg) and Mn (10 mg/kg), although gave significant results but there was no definite trend in percentage of different constituents of oil estimated.

Conclusion

Both iron and manganese, either alone or in combination, significantly influenced herb yield, nutrient uptake and oil quality. The optimal level of Fe and Mn was found to be 10 kg/ha and 2.5 kg/ha, respectively. These findings may go a long way in increasing the yield of this monoterpene producing economic plant.

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References

1 Patra DD, Anwar M and Chand S, Integrated nutrient management and waste recycling for restoring soil fertility and productivity in Japanese mint (*Mentha arvensis*) and mustard (*Brassica juncea*) sequence in Uttar Pradesh, India. *Agric Ecosyst Envir,* 2000, **80**, 267-275.

2 Patra DD, Anwar M, Chand S, Usha Kiran, Rajput DK and Kumar S, Nimin and *Mentha spicata* oil as nitrification inhibitors for optimum yield of Japanese mint. *Commun Soil Sci Plant Anal,* 2002, **33** (3&4), 451-460.

3 Schmidt W, Iron homeostasis in plants: sensing and signaling pathways, *J Plant Nutr,* 2003, **26**, 2211-2230.

4 Abadia J and Abadia A, Iron and plant pigments, *In:* Iron Chelation in Plants and Soil Microorganisms, eds, L.L. Barton and B.C. Hemming, Academic Press. New York, 1993, 327-343.

5 Tagliavini M and Rombola AD, Iron deficiency and chlorosis in orchard and vineyard ecosystem, *Eur J Agron,* 2001, **15**, 71-92.

6 Husted S, Thomsen MU, Mattsson M and Schjoerring JK, Influence of nitrogen and sulphur form on manganese acquisition by barley (*Hordeum vulgare*), *Plant Soil*, 2004, **268** (1), 309-317.

7 Marschner H, Mineral nutrition of higher plants, 2nd edition Academic Press, London, 1995

8 El-Jaoual T and Cox DA, Manganese toxicity in plants, *J Plant Nutr,* 1998, **21**, 353-386.

9 Mengel K and Kirkby EA, Principle of Plant Nutrition, International Potash Institute, Bern, 1987, pp. 1-687.

10 Knezek B D and Geinert H, Influence of soil Fe and Mn-EDTA interactions upon the Fe and Mn nutrition of bean plants, *J Agron,* 1971, **63**, 617-619.

11 Arnon DI, Copper enzymes in isolated chloroplasts, polyphenolonidase in *Beta vulgaris, Plant Physiol*, 1949, **24**, 1-15.

12 Piper C S, Soil and Plant Analysis. Hassel Press, Adelaide, Australia. 1942

13 Lindsay WL and Norwell WA, Development of DTPA soil test for zinc, iron manganese and copper, *J Soil Sci Soc Amer,* 1978, **42**, 421-428.

14 Clevenger JF, Apparatus for the determination of volatile oil, *J Amer Pharm Assoc,* 1928, **17**, 346.

15 Sokal RR and Rholf FJ, *Biometry:* The Principles and Practices of Statistics in Biological Research, 2nd edn, Freeman, New York. 1981.

16 Mou D, Yao Y, Yang Y, Zhang Y, Tian C and Achal V, Plant height tolerance to excess Mn related with root growth, manganese distribution and antioxidative enzyme activity in grape cultivars, *Ecotox Environ Saf,* 2010 (EPub ahead of print) PMID : 210 75449.

17 Lei Y, Karpelainen H and Li,C, Physiological and biochemical responses to high Mn concentrations in two contrasting *Populus cathayana* populations, *Chemosphere,* 2007, **68** (4), 686-94.

18 Mehrotra SC, Sharma CP and Agarwala SC, Iron phosphorus interaction in chickpea genotypes that differ in tolerance to iron-stress, *In*: *Proc Intern Congr Plant Physiol*, eds. S.K. Sinha, P.V. Sane, S.C. Bhargava and P.K. Agarwala, 2, Feb 1988, 1990, 1146-1150. New Delhi, India.

19 Oertli JJ and Opoku AA, Interaction of potassium in the availability and uptake of iron from ferric hydroxide, *Soil Sci Soc Amer Proc*, 1974, **38**, 451-454.

20 Lawrence BM, Progress in essential oils-corn mint oil, *Perfum flavour,* 1981, **6**, 73-77.

21 Moraes LAS, Facanli R, Marques MOM, Ming LC and Meireles MAA, Phytochemical characterization of essential oil from *Ocimum selloi*, *Annals Brazilian Acad Sci*, 2002, **74**, 183-186.

22 Said-Al Ahl HAH and Omer EA, Effect of spraying with zinc and/or iron on growth and chemical composition of Coriander (*Coriandrum sativum* L.) harvested at three stages of development, *J Med Food Plants*, 2009, **1** (2), 30-46.