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Effect of soil application of zinc and iron on nodulation and soil fertility status after harvest of mothbean in inceptisol

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Abstract
A field experiment was conducted during 2022-23 *Kharif* season at Regional Agricultural Research Station, Vijayapura to study the influence of zinc and iron on growth and yield of mothbean. The experiment was laid out in a split plot design with four levels of zinc in main plot (0, 2.5, 5 and 7.5 kg ha^{-1}) and four levels of iron in sub plot (0, 2.5, 5, 7.5 kg ha$^{-1)}$ with one absolute control. Application of zinc sulphate alone @ 7.5 kg ha^{-1}, iron sulphate alone @ 7.5 kg ha^{-1} or combination of zinc sulphate and iron sulphate @ 7.5 kg ha^{-1} each did not show any significant difference in soil chemical properties *viz.*, pH, electrical conductivity and organic carbon. The soil available nitrogen, phosphorus and potassium also did not show any significant difference with application of zinc sulphate @ 7.5 kg ha^{-1} alone, iron sulphate application @ 7.5 kg ha^{-1} alone and their combinations. In contrast application of zinc sulphate @ 7.5 kg ha^{-1} alone, and iron sulphate application @ 7.5 kg ha^{-1} alone recorded significantly higher values of DTPA- extractable zinc and iron with increase in the dosage of zinc sulphate and iron sukphate respectively.

Keywords: Growth, iron, mothbean, yield, zinc

Introduction
Moth bean, scientifically known as *Vigna aconitifolia* L., belongs to the legume genus *Vigna* and possesses remarkable adaptability to arid and semi-arid regions. Its ability to thrive across diverse eco-geographical zones as well as harsh climatic conditions, particularly in the Indian subcontinent, highlights its significant importance. This legume goes by several names, like mat bean, math, mattenbohne, matki, dew bean, Turkish gram, and haricot papillon. Moth bean takes center stage primarily for its protein-rich seeds, sprouts, and edible green pods, which serve as a valuable source of nutrition. Moth bean [*Vigna aconitifolia* (Jacq)], is believed to have originated in the regions of India, Pakistan, Myanmar, and Sri Lanka, according to De Candolle (1986) [3]. Moth bean's cultivation is particularly concentrated in arid and semi-arid regions, with a majority taking place in the North-Western states of India like Rajasthan, Maharashtra, Gujarat, Punjab, Haryana, Jammu and Kashmir, Madhya Pradesh, and Uttar Pradesh. Among these, Rajasthan stands out as the top contributor in terms of moth bean production.

Micronutrient deficiency is a severe problem in soil and plants worldwide (Imtiaz *et al.*, 2010) [5]. Micronutrients like iron (Fe), zinc (Zn), boron (B), and molybdenum (Mo) exert the most significant influence on pulse crop production. Up until the 1980's, zinc deficiency was the primary micronutrient limitation affecting crop production. However, as high yielding crop varieties were developed, chemical fertilizers gained attention, and cultivation practices became more intensive and deficiencies in other micronutrients started to emerge vaguely. Among the cationic micronutrients, zinc (Zn) remains the most deficient, with approximately 49% of soils showing this deficiency. Following closely behind are iron (Fe), manganese (Mn), and copper (Cu), which are currently deficient in 12 per cent, 4 per cent, and 3 per cent of soils, respectively. Micronutrients are those vital elements required by plants in very minimal quantities, these play a pivotal role in overall plant development.

Inadequate supplies of these nutrients can result in micronutrient deficiency, which is a severe problem in soil and plants worldwide. Consequently, gaining a thorough understanding of micronutrient deficiencies and exploring methods to rectify them becomes of paramount importance. Identifying deficiencies in soil is the first step, and rectifying the micronutrient balance is crucial. Various nutrient management practices come into play, aiding in the restoration of soil equilibrium and the enhancement of micronutrient levels. These practices pave the way for healthier plants and improved agricultural yields. The deficiency of Zn and Fe is most commonly observed in Northern Dry Zone of Karnataka. Keeping in view the important role of zinc and iron in crop production, current study was carried out with chelated application of Zn and Fe to overcome the micronutrient deficiencies in soil and help the increase in crop growth and yield.

Methodology

The field experiment was carried out at Regional Agricultural Research Station (RARS), Vijayapura during *kharif* 2022, under Northern Dry Zone of Karnataka (Zone 3), located at a latitude 16^0 49^1 North, longitude $75^0 43^1$ East and an altitude of 593.8 m above mean sea level (MSL). The experiment was carried out by adopting split plot design with four main plots which consisted different levels of zinc sulphate *viz.*, MP_1- 0 kg ha^{-1} $ZnSO_4$, MP_2- 2.5 kg ha^{-1} $ZnSO_4$, MP_3- 5 kg ha^{-1} $ZnSO_4$ and MP_4- 7.5 kg ha^{-1} $ZnSO_4$ and four sub plots which consisted of different levels of iron sulphate *viz.*, SP_1- 0 kg ha^{-1} $FeSO_4$, SP_2- 2.5 kg ha^{-1} $FeSO_4$, SP_3- 5 kg ha^{-1} $FeSO_4$ and SP_4- 7.5 kg ha^{-1} $FeSO_4$ replicated thrice and one absolute control. Zinc sulphate and iron sulphate were chelated with vermicompost in 1:1 ratio and applied 15 days before sowing. Seeds of KBMB-1 variety at a seed rate of 15 kg ha^{-1} was used. Zinc was applied in the form of $ZnSO_4.7H_2O$ and iron was applied in the form of $FeSO_4.7H_2O$. Soil pH was determined in 1:2.5 soil water suspension using glass electrode pH meter after being stirred for 30 minutes at 25 °C (Sparks, 1996) [13], Electrical conductivity was determined in supernatant solution of 1:2.5 soil water extract by using conductivity meter at 25 °C (Sparks, 1996) [13], The available nitrogen was determined by the alkaline permanganate method given by Subbiah and Asija (1956) [14], whereas available phosphorus was determined by Olsen (1954) [11] method. Available potassium was determined using 1 N neutral ammonium acetate at pH 7.0 (Merwin and Peech, 1951) [10]. Available micronutrients determined by 0.005M DTPA + 0.001M CaCl2 + 0.1M triethanolamine at pH 7.3 (Lindsay and Norvell, 1978) [8]. The experimental site consisted of shallow Inceptisol having clay texture, with a pH of 8.31, low in available nitrogen (175 kg ha^{-1}), medium in available phosphorus (31.05 kg ha^{-1}), and high in potassium (362.0 kg ha^{-1}). The soils were deficient in DTPA extractable micronutrients viz., zinc (0.48 mg kg^{-1}) and iron (2.78 mg kg^{-1}). The analysis and interpretation of data were carried out using the Fischer's method of analysis of variance technique as described by Gomez and Gomez (1984) [4]. The level of significance used in 'F' test was P = 0.05. Critical difference values were calculated wherever the 'F' test was found significant. In case of non-significant effects, values of standard error of mean are presented in tables.

Results and discussion

Number of nodules and effective number of nodules

Number of nodules and effective number of nodules varied significantly with different levels of $ZnSO_4$ and $FeSO_4$ alone and their combinations. Application of $ZnSO_4$ @ 7.5 kg ha^{-1} recorded significantly higher number of nodules and effective number of nodules (17.38 and 10.50 respectively) and superior over all other levels of zinc sulphate. Adequate fertilization of Zn was found to increase the size and number of nodules, as it might be positively involved in the synthesis of leghaemoglobin in cowpea (Marsh and Waters, 1985) [9]. Zinc is known to be involved in symbiotic nitrogen fixation through development of nodules and therefore, the supplementation of zinc has increased the efficiency of nodulation and activity of nodulation in soybean (Zhang and Yang, 1996) [17]. Similarly, application of $FeSO_4$ @ 7.5 kg ha^{-1} recorded significantly higher number of nodules and effective number of nodules (16.62 and 10 respectively) and was superior over all other iron sulphate levels. Increase in number of nodules might be due to iron's dominant effect on nodule formation which ultimately increased the number of nodules plant^{-1}. Increased symbiotic relationship between the legume and rhizobium, led to enhanced rhizobial colonization in the rhizosphere

The combination of zinc sulphate and iron sulphate @ 7.5 kg ha^{-1} recorded significantly higher number of nodules and effective number of nodules (19.89 and 12.78 respectively). The increase in number of nodules and effective number of nodules may be attributed to cumulative effect of both zinc and iron on nodulation. Both zinc and iron play an eminent role in increasing number of nodules and effective number of nodules. The results of the experiment are in line with research findings of Brear *et al.*, (2013) [2] reported that iron deficiency reduced initiation and development of nodules, similarly Kobraee *et al.*, 2011 also reported positive effect of iron and zinc on number of nodules in soybean.

Grain and Straw yield

The application of different levels of zinc sulphate and iron sulphate significantly influenced the grain and straw yield of mothbean. Significantly higher grain yield of 721 kg ha^{-1} and straw yield of 2119 kg ha^{-1} was recorded with application of zinc sulphate @ 7.5 kg ha^{-1} alone. Among the different iron sulphate levels, application of iron sulphate @ 7.5 kg ha^{-1} recorded significantly higher grain yield of 696 kg ha^{-1} and straw yield of 2063 kg ha^{-1}. However, among the different combinations of zinc sulphate and iron sulphate, grain and straw yield was found to be non-significant. The increase in the grain and staw yield of mothbean crop is due to application of optimum dose of zinc sulphate and iron sulphate after chelation with vermicompost. Also the proper channelization of photosynthates during the reproductive stage of crop might have been influenced by zinc, since it is involved in electron transport system. Zinc application induced better root growth and increased sink pool (pod numbers plant^{-1}) and ultimately achieved higher seed yield in chickpea (Krishna and George, 2017) [7]. The enhanced iron accessibility to the plant could have potentially activated several enzymatic and metabolic processes, consequently enhancing the crop's yield. Similar findings were also reported by Trivedi *et al.* (2011) [15].

Table 1: Influence of different levels of zinc sulphate and iron sulphate on nodulation and yield of mothbean

Treatments	Number of nodules	Effective number of nodules	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Zinc sulphate levels (MP)				
$ZnSO_4$ @ 0 kg ha^{-1} (MP_1)	12.96	7.23	571	1764
$ZnSO_4$ @ 2.5 kg ha^{-1} (MP_2)	15.23	8.93	651	1963
$ZnSO_4$ @ 5 kg ha^{-1} (MP_3)	16.06	9.42	684	2030
$ZnSO_4$ @ 7.5 kg ha^{-1} (MP_4)	17.38	10.50	721	2119
S. Em.±	0.34	0.20	15.57	48.61
C.D (0.05)	1.16	0.70	53.87	168.22
Iron sulphate levels (SP)				
$FeSO_4$ @ 0 kg ha^{-1} (SP_1)	13.95	7.95	602	1840
$FeSO_4$ @ 2.5 kg ha^{-1} (SP_2)	15.04	8.69	648	1947
$FeSO_4$ @ 5 kg ha^{-1} (SP_3)	16.01	9.43	682	2026
$FeSO_4$ @ 7.5 kg ha^{-1} (SP_4)	16.62	10.00	696	2063
S. Em.±	0.27	0.21	15.72	38.61
C.D (0.05)	0.79	0.62	45.89	112.70
Interactions (MP×SP)				
MP_1SP_1	12.60	6.80	562	1737
MP_1SP_2	13.00	7.00	565	1749
MP_1SP_3	13.02	7.60	575	1776
MP_1SP_4	13.21	7.50	583	1792
MP_2SP_1	14.10	8.12	594	1822
MP_2SP_2	14.98	8.87	654	1972
MP_2SP_3	15.87	9.27	670	2004
MP_2SP_4	15.97	9.45	687	2053
MP_3SP_1	14.35	8.32	616	1869
MP_3SP_2	15.20	9.00	661	1985
MP_3SP_3	17.28	10.09	721	2104
MP_3SP_4	17.40	10.28	741	2163
MP_4SP_1	14.76	8.56	637	1930
MP_4SP_2	16.98	9.89	711	2083
MP_4SP_3	17.88	10.76	763	2220
MP_4SP_4	19.89	12.78	774	2243
S. Em.±	0.54	0.43	31.44	77.22
C.D (0.05)	1.59	1.24	NS	NS
Absolute control	10.51	5.2	320	1390
S. Em.±	0.55	0.41	30.57	94.34
C.D (0.05)	1.60	1.18	88.06	271.76

Soil fertility status post-harvest

The soil chemical properties like pH, EC and organic carbon were not significantly influenced by application of zinc sulphate and iron sulphate. Application of different levels of zinc sulphate and iron sulphate to mothbean crop did not show any significant difference with soil pH, however among different levels of zinc sulphate, application of $ZnSO_4$ @ 7.5 kg ha^{-1} recorded numerically lower pH of 8.16 compared to other levels. Similarly among $FeSO_4$ levels, the treatment receiving $FeSO_4$ @ 7.5 kg ha^{-1} recorded lower soil pH of 8.17 compared to other levels of iron sulphate. Electrical conductivity also followed the same trend, however, there was slight numerical increase in EC of 0.33 dS m^{-1} due to application of $ZnSO_4$ alone and $FeSO_4$ alone as compared to initial value of the experimental site (0.30 dS m^{-1}). Organic carbon did not show any significant difference with application of different levels of zinc sulphate and iron sulphate. A slight decrease in soil pH was observed when sulphate fertilizers were applied in conjunction with vermicompost. This decrease in pH may be attributed to the acidic nature of sulphate fertilizers and the release of certain organic acids during the decomposition of the applied vermicompost and farmyard manure (FYM). In terms of soil electrical conductivity and organic carbon, there was a minor increase compared to the initial soil EC and organic carbon value. This slight increase in EC and organic carbon could be attributed to the rise in soluble salts due to the application of chelated micronutrients along with vermicompost.

The soil available nitrogen, phosphorus and potassium did not show any significant difference due to application of different levels of zinc sulphate, iron sulphate and their combinations. However numerically higher values of soil available nitrogen (187.1, 185.8 kg ha^{-1} respectively), phosphorus (32.18, 32.07 kg ha^{-1} respectively) and potassium (352.4, 350.8 kg ha^{-1}) were recorded with zinc sulphate application @ 7.5 kg ha^{-1} alone, iron sulphate @ 7.5 kg ha^{-1} alone. This improvement in soil nitrogen can be attributed to the application of zinc and iron fertilizers, which boosted microbial activity in the rhizosphere and facilitated the mineralization of both native and applied fertilizers. There was a slight build up in phosphorus and potassium in the soil after the harvest of the crop. This might be a result of the fixation of the applied phosphorus, particularly since the soil at the experimental site is slightly calcareous in nature. In contrast, DTPA extractable micronutrients *viz.*, zinc and iron were significantly influenced due to application of zinc sulphate and iron sulphate alone @ 7.5 kg ha^{-1} each. Application of zinc sulphate @ 7.5 kg ha^{-1} recorded higher DTPA extractable zinc an iron (0.64 and 4.39 mg kg^{-1} respectively). Similarly, application of iron sulphate @ 7.5 kg ha^{-1} recorded higher DTPA extractable zinc and iron (0.62 and 4.15 mg kg^{-1} respectively). The increase in the zinc content and iron content due to the application of zinc sulphate and iron sulphate might be due to the chelated forms of zinc and iron, which also enhanced the availability of native zinc and iron thorough its solubilizing effect as it was mixed with vermicompost in 1:1 ratio. Similar findings were also recorded by Balai *et al.* (2017) [1].

Table 2: Influence of different levels of zinc sulphate and iron sulphate on soil chemical properties after harvest of mothbean crop

Treatments	pH	EC (ds m^{-1})	Organic carbon
Zinc sulphate levels (MP)			
$ZnSO_4$ @ 0 kg ha^{-1} (MP_1)	8.3	0.30	3.62
$ZnSO_4$ @ 2.5 kg ha^{-1} (MP_2)	8.2	0.32	3.76
$ZnSO_4$ @ 5 kg ha^{-1} (MP_3)	8.2	0.33	3.81
$ZnSO_4$ @ 7.5 kg ha^{-1} (MP_4)	8.2	0.33	3.84
S. Em.±	0.14	0.01	0.05
C.D (0.05)	NS	NS	NS
Iron sulphate levels (SP)			
$FeSO_4$ @ 0 kg ha^{-1} (SP_1)	8.2	0.31	3.65
$FeSO_4$ @ 2.5 kg ha^{-1} (SP_2)	8.2	0.32	3.76
$FeSO_4$ @ 5 kg ha^{-1} (SP_3)	8.18	0.33	3.81
$FeSO_4$ @ 7.5 kg ha^{-1} (SP_4)	8.17	0.33	3.83
S. Em.±	0.21	0.01	0.08
C.D (0.05)	NS	NS	NS
Interactions (MP×SP)			
MP_1SP_1	8.30	0.30	3.51
MP_1SP_2	8.25	0.30	3.65
MP_1SP_3	8.25	0.31	3.66
MP_1SP_4	8.24	0.31	3.67
MP_2SP_1	8.24	0.31	3.68
MP_2SP_2	8.21	0.33	3.71
MP_2SP_3	8.19	0.33	3.81
MP_2SP_4	8.18	0.33	3.84
MP_3SP_1	8.23	0.32	3.69
MP_3SP_2	8.20	0.33	3.80
MP_3SP_3	8.16	0.33	3.87
MP_3SP_4	8.14	0.34	3.89
MP_4SP_1	8.22	0.32	3.70
MP_4SP_2	8.17	0.33	3.86
MP_4SP_3	8.13	0.34	3.90
MP_4SP_4	8.12	0.34	3.91
S. Em.±	0.42	0.01	0.17
C.D (0.05)	NS	NS	NS
Absolute control	8.3	0.3	3.5
S. Em.±	0.38	0.01	0.15
C.D (0.05)	NS	NS	NS

Table 3: Influence of different levels of zinc sulphate and iron sulphate on soil chemical properties after harvest of mothbean crop

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Zinc (mg kg^{-1})	Iron (mg kg^{-1})
Zinc sulphate levels (MP)					
$ZnSO_4$ @ 0 kg ha^{-1} (MP_1)	178.0	31.2	343.3	0.48	2.97
$ZnSO_4$ @ 2.5 kg ha^{-1} (MP_2)	182.9	31.8	348.0	0.59	3.97
$ZnSO_4$ @ 5 kg ha^{-1} (MP_3)	184.7	32.0	350.2	0.62	4.22
$ZnSO_4$ @ 7.5 kg ha^{-1} (MP_4)	187.1	32.2	352.4	0.64	4.39
S. Em.±	2.95	0.56	11.36	0.01	0.11
C.D (0.05)	NS	NS	NS	0.04	0.40
Iron sulphate levels (SP)					
$FeSO_4$ @ 0 kg ha^{-1} (SP_1)	179.6	31.4	345.2	0.52	3.50
$FeSO_4$ @ 2.5 kg ha^{-1} (SP_2)	182.6	31.7	347.8	0.58	3.85
$FeSO_4$ @ 5 kg ha^{-1} (SP_3)	184.58	31.95	350.02	0.61	4.05
$FeSO_4$ @ 7.5 kg ha^{-1} (SP_4)	185.80	32.07	350.78	0.62	4.15
S. Em.±	4.53	0.77	12.46	0.01	0.10
C.D (0.05)	NS	NS	NS	0.03	0.30
Interactions (MP×SP)					
MP_1SP_1	176.02	31.01	342.00	0.47	2.75
MP_1SP_2	177.90	31.10	343.00	0.48	2.81
MP_1SP_3	178.40	31.21	344.00	0.48	3.09
MP_1SP_4	179.60	31.37	344.00	0.49	3.21
MP_2SP_1	180.20	31.48	345.00	0.52	3.25
MP_2SP_2	182.90	31.72	347.60	0.58	4.11
MP_2SP_3	183.20	31.97	348.75	0.62	4.22
MP_2SP_4	185.10	32.01	350.56	0.64	4.28

MP_3SP_1	180.60	31.53	346.20	0.54	3.97
MP_3SP_2	183.10	31.81	348.56	0.60	4.15
MP_3SP_3	187.00	32.22	352.78	0.66	4.34
MP_3SP_4	188.00	32.33	353.21	0.67	4.43
MP_4SP_1	181.55	31.61	347.56	0.56	4.02
MP_4SP_2	186.50	32.11	352.12	0.65	4.33
MP_4SP_3	189.70	32.42	354.56	0.68	4.55
MP_4SP_4	190.50	32.56	355.36	0.69	4.68
S. Em.±	9.06	1.54	24.93	0.02	0.21
C.D (0.05)	NS	NS	NS	NS	NS
Absolute control	163.9	27.2	341.0	0.4	2.1
S. Em.±	8.27	1.45	23.89	0.02	0.21
C.D (0.05)	NS	NS	NS	NS	NS

Conclusion

- Nodulation and yield parameters increased with increase in zinc sulphate and iron sulphate levels. The application of zinc sulphate @ 7.5 kg ha^{-1} alone and iron sulphate @ 7.5 kg ha^{-1} alone resulted in increased growth parameters and enhanced the yield parameters.
- Zinc and iron play vital roles in a plant's ability to resist stress such as disease, drought, and temperature fluctuations. Applying these micronutrients can help make the mothbean crop more resilient to adverse growing conditions.

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