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Research Paper

Micro-nutrient management for soil fertility, nutrients uptake and productivity of greengram (*Vigna radiata*) and finger millet (*Eleusine coracana*) under semi-arid *Alfisols*

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ABSTRACT

Three field experiments of greengram [*Vigna radiata* (L.) Wilczek] followed by finger millet [*Eleusine coracana* (L.) Gaertn.] in sequence with 12 treatments of micro-nutrients in combination with recommended NPK fertilizers applied to finger millet were conducted during 2005–2007 in a semi-arid *Alfisols* at Bengaluru, Karnataka. The effects of treatments on available soil and plant uptake of nutrients and yield of crops were assessed. Using the relationships of yield with soil and plant nutrient variables, regression models of yield through soil and plant variables were calibrated and effects of variables on crop yields were assessed. The models gave high and significant yield predictability in the range of 0.92–0.98 through different variables. The model of plant uptake through soil nutrients indicated that soil sulphur, iron and zinc had a significant positive effect; while soil N, K, boron and molybdenum had a negative effect on plant nutrient status in greengram. Similarly, soil P, manganese and zinc had a significant positive effect, while soil N, K and iron had a negative effect on plant uptake of nutrients in finger millet. Based on a relative efficiency index (REI) criterion, recommended NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed (9.68) was superior for maximum plant uptake, while recommended NPK + FYM @ 10 t/ha (9.21) was superior for maximum soil fertility of nutrients in greengram. In finger millet, recommended NPK + FYM @ 10 t/ha (8.70) showed the maximum REI for soil nutrients, while recommended NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha (9.71) the maximum REI for plant uptake of nutrients. The combined REI over soil and plant nutrients for both crops indicated that application of NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed could be prescribed for attaining maximum plant uptake of nutrients and productivity of greengram and finger millet in sequence, apart from maintaining maximum soil fertility of nutrients under semi-arid *Alfisols*.

Key words : Finger millet, Greengram, Micro-nutrients, Productivity, Plant uptake, Relative efficiency index, Soil fertility

Finger millet, an important rainfed crop grown under semi-arid *Alfisols* of Karnataka in south India, is a promising source of calcium (Ca), iron (Fe), zinc (Zn) and protein. The crop is sustainable even under low rainfall situation (Maruthi Sankar *et al.*, 2011) and responds even to better rainfall, macro-and micronutrient application under rainfed conditions. Umesh Gupta and Subhas Gupta (2005) described that boron (B) and other trace elements, such as chromium (Cr), nickel (Ni) etc., are required for food-producing animals. Hence, field calibration data are needed to improve fertilizer recommendations for micro-nutrient anions and molybdenum (Mo).

Upadhyaya *et al.* (2011) reported genetic variability for grain Fe, Zn, Ca and protein content in finger millet. They found that accessions rich in Zn gave significantly higher grain yield than those rich in Fe and protein content. In soybean experiments conducted in soils with low N and without any fertilizer N application, Rubens Jose Campo *et al.* (2009) found that inoculation of Mo-rich seeds produced plants with increased N and Mo content in the grain, higher grain yield and total N. Mo-rich soybean seed did not require external application of Mo.

Application of starter and top dressed N in combination with two split FeEDTA fertilization was beneficial to improve early growth and yield of inoculated soybean in Mediterranean-type soils. The starter N increased the biomass and leaf area index, whereas Fe did not affect growth parameters; while both N and Fe had a positive effect on

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the growth parameters at later stages and soybean yield (Caliskan *et al.,* 2008).

The recent survey in *Alfisols* in Bengaluru indicated a deficiency of micronutrients like Zn, B, Cu, Mo, apart from NPK, necessitated the studies to assess the crop response to micro-nutrient application under rainfed condition in *Alfisols*. Hence the present study on greengram followed by finger millet with different combinations of NPK and micronutrient doses applied to only finger millet with the objective of identifying a superior treatment for attaining maximum yield of crops, plant uptake and maintaining maximum soil fertility in semi-arid *Alfisol*.

MATERIALS AND METHODS

Three field trials with 12 micro-nutrient treatments were conducted on 'China Moong' variety of greengram followed by 'GPU 28' of finger millet in sequence during 2005–07 in a semi-arid *Alfisol* at University of Agricultural Sciences in Bengaluru in Karnataka. In each trial, the different micro-nutrient treatments were applied only to finger millet and not to greengram. In addition to the micronutrients, the recommended NPK fertilizer doses of 13:25:25 kg/ha for greengram and 50:40:25 kg/ha for finger millet were also applied in each treatment. A net plot size of 3 m × 3 m was maintained for greengram and finger millet in each year. Similarly, a row to row spacing of 30 cm and plant to plant spacing of 10 cm were maintained for both crops every year. Twelve treatments were T_1, Control (recommended NPK); T_2, NPK + FYM @ 10 t/ha; T_3, NPK + $ZnSO_4$ @ 12.5 kg/ha (soil); T_4, NPK + $ZnSO_4$ @ 0.5% (foliar spray); T_5, NPK + borax @ 10% kg/ha (soil); T_6, NPK + borax 0.25% (foliar spray); T_7, NPK + Mo @ 2 g/kg seed; T_8, NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha; T_9, NPK + $ZnSO_4$ @ 0.5% + borax @ 0.25% (foliar spray); T_{10}, NPK + $ZnSO_4$ @ 12.5 kg/ha + Mo @ 2 g/kg seed; T_{11}, NPK + borax @ 10 kg/ha + Mo @ 2 g/kg seed; T_{12}, NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed. The field trial were laid out in a randomized block design with 3 replications.

The greengram was sown on 24, 17 and 25 May and harvested on 30 July, 25 July and 3 August during 2005, 2006 and 2007 respectively. The finger millet was sown on 12, 14 and 7 August and harvested on 14 December, 27 November and 27 November during 2005, 2006 and 2007 respectively. The rainfall during the crop season was 82.2 mm in 7 rainy days, 209.6 mm in 11 rainy days and 297.5 mm in 21 rainy days for greengram; and 583.8 mm in 33 rainy days, 238.6 mm in 17 rainy days and 444.6 mm in 29 rainy days for finger millet occurred from sowing to harvesting during 2005, 2006 and 2007 respectively.

Observations were recorded on soil nutrients, plant uptake and grain yield of crops in each plot every year. Soil samples were collected from each plot at 0–30 cm depth before sowing of the crops and analysed for organic carbon (OC, %); available soil N (SN, kg/ha); P_2O_5 (SP, kg/ha); K_2O (SK, kg/ha); sulphur (SS, ppm); iron (SFe, ppm); manganese (SMn, ppm); copper (SCu, ppm); zinc (SZn, ppm); boron (SB, ppm); and molybdenum (SMo, ppm). Similarly, plant samples were collected from each plot at harvest and analysed for uptake N (UN, kg/ha); P (UP, kg/ha); K (UK, kg/ha); sulphur (US, kg/ha); iron (UFe, g/ha); manganese (UMn, g/ha); copper (UCu, g/ha); zinc (UZn, g/ha); boron (UB, g/ha); and molybdenum (UMo, g/ha) every year.

The differences in the effects of fertilizer treatments on greengram and finger millet yield could be tested in each year and also when pooled over years based on the standard analysis of variance (ANOVA) procedure (Gomez and Gomez, 1984). The treatments could be compared and superior treatments could be identified based on least ssignificant difference (LSD) criteria at $P < 0.05$ level of probability. Similarly, the effects of treatments on available soil fertility and plant uptake of N, P, K and micro-nutrients could be tested in each year and also when pooled over years based on the LSD criteria.

The effects of soil nutrients on plant uptake of nutrients could be assessed based on a regression model of plant uptake through soil nutrients. The influence of soil nutrients on plant uptake of nutrients could be assessed based on (i) the coefficient of determination (R^2), (ii) standard error of the expected plant uptake of nutrients, and (iii) the regression coefficient indicating the effect of soil nutrient on plant uptake of a nutrient. The regression model of uptake of N (UN) through soil N (SN) could be given as:

$$UN = \pm \alpha \pm \beta_1 (SN) \pm \beta_2 (SN^2) \quad \text{... (1)}$$

In (1), β_1 is the linear regression coefficient and β_2 is the quadratic regression coefficient of soil N measuring effect of soil N on plant uptake N. Similarly, the regression models of plant uptake of all other nutrients could be calibrated for assessing the effects of soil nutrients on plant uptake of nutrients in each.

Based on the relationship of soil and plant nutrients with yield, two regression models of yield through soil and plant nutrients could be calibrated to predict crop yield and identify variables which have a significant influence on yield of greengram and finger millet. A separate regression model of yield of greengram and finger millet through soil fertility of nutrients could be postulated as:

$$Y = \pm \alpha \pm \beta_1 (OC) \pm \beta_2 (SN) \pm \beta_3 (SP) \pm \beta_4 (SK) \pm \beta_5 (SS) \pm \beta_6 (SFe) \pm \beta_7 (SMn) \pm \beta_8 (SCu) \pm \beta_9 (SZn) \pm \beta_{10} (SB) \pm \beta_{11} (SMo) \quad \text{... (2)}$$

In (2), α is intercept and β_1 to β_{11} are regression coefficients measuring the change in yield for unit change in different soil nutrients. Similarly, the effects of plant uptake of nutrients on greengram and finger millet yield could be postulated as

$$Y = \pm \alpha \pm \beta_1 (UN) \pm \beta_2 (UP) \pm \beta_3 (UK) \pm \beta_4 (US) \pm \beta_5 (US) \pm \beta_6 (UFe) \pm \beta_7 (UMn) \pm \beta_8 (UCu) \pm \beta_9 (UZn) \pm \beta_{10} (UB) \pm \beta_{11} (UMo) \quad \text{... (3)}$$

In (3), α is intercept and β_1 to β_{11} are regression coefficients measuring change in yield for unit change in the plant uptake of nutrients. Thus based on models (1), (2) and (3), the treatments could be assessed for superiority and a superior treatment could be identified.

Relative efficiency index (REI) was proposed as an integrated function of the performance of crops for different soil and plant nutrients. The REI of each treatment could be determined by converting the values of variables to linear scores in the range of '0 to 1' separately for each variable. The estimates of REI could be derived as follows:

(i) In the first step, the values of each variable could be arranged in ascending or descending order depending on whether a higher value was considered 'good' or 'bad' for the parameter with the objective of getting highest score value '1' for the most efficient treatment and lowest value '0' for the most inefficient treatment. Since the objective is to identify a treatment which is superior for different variables, the values of each variable could be arranged in the descending order.

(ii) In the second step, we compute the first-order differences of each treatment with respect to the lowest value; and equate the lowest difference to '0' and highest difference to '1'.

(iii) In the third step, we determine the relative efficiency of each treatment with respect to the superior treatment having the highest first-order difference for each criterion.

(iv) In the fourth step, the relative efficiency scores of each variable, now in 0 to 1 scale, could be summed and ranked for each treatment.

Based on the procedure, the treatment with maximum REI could be chosen as efficient for attaining significantly higher yield, plant uptake of nutrients, apart from maintaining maximum soil fertility of nutrients over the years.

RESULTS AND DISCUSSION

Effect of fertilizer treatments on soil fertility of nutrients

In greengram, the mean organic carbon ranged from 0.41% [NPK + $ZnSO_4$ @ 0.5% + borax @ 0.25% (foliar spray)] to 0.46% (NPK + FYM @ 10 t/ha); while SN ranged from 198 kg/ha (NPK + borax 0.25% (foliar spray)) to 207 kg/ha (NPK + FYM @ 10 tonnes/ha); SP ranged from 76.7 kg/ha (NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha) to 83.0 kg/ha (NPK + FYM @ 10 tonnes/ha); and SK ranged from 163 kg/ha (NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed) to 182 kg/ha (NPK + FYM @ 10 tonnes/ha) over years. In case of micronutrients, SS ranged from 9.9 ppm [NPK + $ZnSO_4$ @ 0.5% + borax @ 0.25% (foliar spray)] to 11.3 ppm [NPK + $ZnSO_4$ @ 12.5 kg/ha (soil)]; SFe from 28.7 ppm [NPK + $ZnSO_4$ @ 12.5 kg/ha (soil)] to 30.0 ppm (NPK + Mo @ 2 g/kg seed); SMn from 17.8 ppm (NPK + Mo @ 2 g/kg seed and NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed) to 18.7 ppm (NPK + FYM @ 10 tonnes/ha); SCu from 0.793 ppm [Control, NPK + $ZnSO_4$ @ 12.5 kg/ha (soil) and NPK + $ZnSO_4$ @ 0.5% (foliar spray)] to 0.837 ppm (NPK + FYM @ 10 tonnes/ha); SZn from 0.83 ppm (Control) to 1.07 ppm NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha); SB from 0.373 ppm [NPK + $ZnSO_4$ @ 12.5 kg/ha (soil)) to 0.513 ppm (NPK + borax @ 10% kg/ha (soil)]; and SMo from 0.183 ppm (NPK + $ZnSO_4$ @ 12.5 kg/ha (soil) and NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha) to 0.197 ppm (NPK + FYM @ 10 tonnes/ha) over years. The coefficient of variation was in a range of 1.2% for SN to 12.0% for SB over years (Table 1).

In finger millet, the soil organic carbon ranged from 0.37% (Control and NPK + Mo @ 2 g/kg seed) to 0.44% (NPK + FYM @ 10 tonnes/ha); while SN ranged from 225 kg/ha [(NPK + $ZnSO_4$ @ 12.5 kg/ha (soil)] to 243 kg/ha (NPK + FYM @ 10 tonnes/ha); SP ranged from 88.7 kg/ha (Control) to 93.7 kg/ha (NPK + FYM @ 10 tonnes/ha); and SK ranged from 212 kg/ha [NPK + $ZnSO_4$ @ 12.5 kg/ha (soil) and NPK + borax 0.25% (foliar spray)] to 221 kg/ha (NPK + FYM @ 10 tonnes/ha). In case of micro-nutrients, SS ranged from 9.5 ppm (Control) to 14.1 ppm (NPK + $ZnSO_4$ @ 12.5 kg/ha (soil)); SFe from 29.9 ppm to [NPK + borax 0.25% (foliar spray)] to 32.4 ppm (NPK + FYM @ 10 tonnes/ha); SMn from 18.6 ppm [NPK + $ZnSO_4$ @ 12.5 kg/ha (soil)] to 20.3 ppm (NPK + FYM @ 10 tonnes/ha); SCu from 0.793 ppm [NPK + $ZnSO_4$ @ 12.5 kg/ha (soil)] to 0.860 ppm (NPK + FYM @ 10 tonnes/ha); SZn from 0.78 ppm (Control) to 1.27 ppm (NPK + $ZnSO_4$ @ 12.5 kg/ha + Mo @ 2 g/kg seed); SB from 0.350 ppm [NPK + $ZnSO_4$ @ 12.5 kg/ha (soil)] to 0.567 ppm (NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed); SMo from 0.197 ppm (Control) to 0.230 ppm (NPK + FYM @ 10 tonnes/ha) over years. The coefficient of variation ranged from 1.1% for SK to 22.0% for SZn over years (Table 1). The variation in the nutrient status is ascribed for the application of micronutrient, balanced fertilization and synergetic influence

Table 1. Effect of micronutrients on soil nutrients status in greengram–finger millet at Bengaluru (mean data of 3 years)

Treatment	OC (%)	SN (kg/ha)	SP (kg/ha)	SK (kg/ha)	SS (kg/ha)	SFe (ppm)	SMn (ppm)	SCu (ppm)	SZn (ppm)	SB (ppm)	SMo (ppm)
Greengram											
Control (recommended NPK)	0.42	199	77.0	174	10.0	28.9	17.9	0.793	0.83	0.377	0.190
NPK + FYM @ 10 tonnes/ha	0.46	207	83.0	182	11.1	29.9	18.7	0.837	0.87	0.407	0.197
NPK + $ZnSO_4$ @ 12.5 kg/ha (SA)	0.42	201	77.3	175	11.3	28.7	18.1	0.793	1.04	0.373	0.183
NPK + $ZnSO_4$ @ 0.5% (FS)	0.43	203	80.0	175	10.1	29.3	18.0	0.793	0.88	0.377	0.190
NPK + Borax @ 10% kg/ha (SA)	0.43	200	78.0	175	10.0	29.4	18.2	0.813	0.87	0.513	0.187
NPK + Borax 0.25% (FS)	0.42	198	80.0	175	10.2	29.7	18.0	0.803	0.85	0.383	0.190
NPK + Mo @ 2 g/kg (ST)	0.42	200	78.7	176	10.2	30.0	17.8	0.813	0.85	0.410	0.193
NPK + $ZnSO_4$ (SA) + Borax (SA)	0.43	199	76.7	177	10.8	29.6	18.0	0.833	1.07	0.440	0.183
NPK + $ZnSO_4$ (FS) + Borax (FS)	0.41	200	78.3	178	9.9	29.4	18.2	0.803	0.84	0.400	0.187
NPK + $ZnSO_4$ (SA) + Mo (ST)	0.42	202	77.3	178	10.8	29.5	18.1	0.823	1.06	0.410	0.187
NPK + Borax (SA) + Mo (ST)	0.42	201	78.3	175	10.0	29.9	18.0	0.823	0.87	0.497	0.193
NPK + $ZnSO_4$ (SA) + Borax (SA) + Mo (ST)	0.42	199	77.7	163	10.8	29.9	17.8	0.817	1.06	0.493	0.187
SEm±	0.003	0.46	0.35	0.89	0.10	0.08	0.047	0.003	0.020	0.010	0.001
CD (P=0.05)	0.008	1.34	1.02	2.62	0.28	0.24	0.138	0.008	0.058	0.030	0.002
Finger millet											
Control (recommended NPK)	0.37	226	88.7	213	9.5	30.7	19.4	0.797	0.78	0.353	0.197
NPK + FYM @ 10 t/ha	0.44	243	93.7	221	10.1	32.4	20.3	0.860	0.89	0.427	0.230
NPK + $ZnSO_4$ @ 12.5 kg/ha (SA)	0.39	225	90.7	212	14.1	30.1	18.6	0.793	1.23	0.350	0.213
NPK + $ZnSO_4$ @ 0.5% (FS)	0.39	230	91.7	214	9.8	31.2	19.2	0.820	0.83	0.357	0.200
NPK + Borax @ 10% kg/ha (SA)	0.38	229	90.7	216	9.7	30.9	19.3	0.827	0.84	0.550	0.203
NPK + Borax 0.25% (FS)	0.40	228	90.7	212	10.0	29.9	19.4	0.817	0.81	0.400	0.203
NPK + Mo @ 2 g/kg (ST)	0.37	229	93.0	215	10.0	30.4	19.6	0.820	0.80	0.360	0.207
NPK + $ZnSO_4$ (SA) + Borax (SA)	0.38	229	92.0	214	13.3	31.8	19.7	0.813	1.24	0.517	0.203
NPK + $ZnSO_4$ (FS) + Borax (FS)	0.38	230	91.0	214	10.1	31.0	20.1	0.800	0.81	0.410	0.210
NPK + $ZnSO_4$ (SA) + Mo (ST)	0.38	230	90.3	213	13.0	31.1	19.5	0.817	1.27	0.363	0.203
NPK + Borax (SA) + Mo (ST)	0.39	231	91.7	215	10.0	30.6	20.0	0.810	0.83	0.533	0.203
NPK + $ZnSO_4$ (SA) + Borax (SA) + Mo (ST)	0.39	229	90.3	214	13.2	30.3	19.5	0.817	1.26	0.567	0.203
SEm±	0.003	0.85	0.26	0.48	0.35	0.14	0.089	0.003	0.041	0.014	0.001
CD (P=0.05)	0.01	2.48	0.76	1.40	1.02	0.40	0.26	0.010	0.12	0.04	0.004

SA, Soil application; FS, Foliar spray; ST, Seed treatment among nutrients (Gopal Reddy and Suryanarayana Reddy, 1998).

Effect of fertilizer treatments on plant nutrient uptake

In greengram, the mean uptake of N ranged from 43.4 to 47.1 kg/ha; P from 5.99 to 6.64 kg/ha; K from 35.73 to 38.70 kg/ha and S ranged from 5.67 to 6.13 kg/ha. In case of micro nutrients, Fe from 2,647 to 2,701 g/ha; Mn from 133 to 145 g/ha; Cu from 19.1 to 28.6 g/ha; Zn from 120 to 133.7 g/ha; B from 42.2 to 47.5 g/ha; and Mo from 5.00 to 5.63 g/ha over years. The control gave the minimum mean uptake of all nutrients except Cu, in which NPK + borax 0.25% (foliar spray) gave minimum over years. Application of NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed showed the maximum plant uptake of all nutrients except N and S in which NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha revealed the maximum uptake over years. The variation ranged from 0.6% for Fe to 11.4% for Cu over years. The mean greengram yield ranged from 447 kg/ha under control to 512 kg/ha under NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed with variation of 4.4% over years (Table 2).

In finger millet, the plant uptake of N ranged from 57.6 to 62.9 kg/ha; P from 10.87 to 12.10 kg/ha; K from 51.50 to 54.50 kg/ha and S ranged from 11.63 to 12.67 kg/ha. Among micronutrients, Fe from 3,787 to 3,906 g/ha; Mn from 157.3 to 167.7 g/ha; Cu from 40.7 to 46.9 g/ha; Zn from 164.3 to 177.3 g/ha; B from 65.3 to 75.3 g/ha; and Mo from 10.47 to 11.97 g/ha. The control showed the minimum of all nutrients, while NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha showed maximum of all nutrients except P, K, Fe in which NPK+$ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed revealed the maximum mean uptake over years. In finger millet, the variation was in a range of 1.0% for Fe to 4.8% for Cu over years. The mean finger millet yield ranged from 2590 kg/ha under control to 3597 kg/ha under NPK + Mo @ 2 g/kg seed with variation of 9.7% over years (Table 2). The results are in agreement with the findings of Pandey *et al.* (2009).

Table 2. Nutrient uptake and grain yield in greengram with finger millet as influenced by micronutrient application (mean data of 3 years)

Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Fe (g/ha)	Mn (g/ha)	Cu (g/ha)	Zn (g/ha)	B (g/ha)	Mo (g/ha)	Grain yield (kg/ha)
Greengram											
Control (recommended NPK)	43.4	5.99	35.73	5.67	2647	133.0	25.1	120.0	42.2	5.00	447
NPK + FYM @ 10 tonnes/ha	45.5	6.31	37.43	6.00	2667	138.7	26.7	124.0	44.8	5.30	496
NPK + $ZnSO_4$ @ 12.5 kg/ha (SA)	45.4	6.40	37.47	6.08	2673	140.3	27.2	126.7	44.9	5.37	500
NPK + $ZnSO_4$ @ 0.5% (FS)	43.6	6.09	36.53	5.79	2650	136.3	25.5	122.7	43.3	5.10	467
NPK + Borax @ 10% kg/ha (SA)	44.0	6.23	37.20	5.93	2662	136.7	25.9	125.3	44.2	5.17	481
NPK + Borax 0.25% (FS)	43.8	6.07	36.70	5.71	2653	133.7	19.1	123.0	43.8	5.10	457
NPK + Mo @ 2 g/kg (ST)	44.2	6.07	36.80	5.78	2655	134.7	20.1	123.7	43.0	5.00	468
NPK + $ZnSO_4$ (SA) + Borax (SA)	47.1	6.60	37.97	6.13	2691	142.0	27.9	130.0	46.3	5.53	505
NPK + $ZnSO_4$ (FS) + Borax (FS)	44.0	6.06	37.50	5.79	2651	135.7	25.3	123.7	44.8	5.07	465
NPK + $ZnSO_4$ (SA) + Mo (ST)	45.7	6.48	37.53	6.08	2681	139.3	26.9	126.3	45.9	5.43	498
NPK + Borax (SA) + Mo (ST)	44.6	6.19	37.57	5.99	2663	138.0	26.3	125.7	46.1	5.27	488
NPK + $ZnSO_4$ (SA) + Borax (SA) + Mo (ST)	46.0	6.64	38.70	6.12	2701	145.0	28.6	133.7	47.5	5.63	512
SEm±	0.232	0.04	0.15	0.03	3.41	0.70	0.57	0.71	0.31	0.04	4.2
CD (P=0.05)	0.68	0.12	0.44	0.10	9.98	2.04	1.68	2.08	0.90	0.12	12.2
Finger millet											
Control (recommended NPK)	57.6	10.87	51.50	11.63	3787	157.3	40.7	164.3	65.3	10.47	2590
NPK + FYM @ 10 t/ha	59.4	11.43	54.13	12.20	3878	163.0	43.6	169.7	69.0	11.13	2952
NPK + $ZnSO_4$ @ 12.5 kg/ha (SA)	59.3	11.37	53.77	12.33	3869	165.0	45.4	174.7	72.0	11.63	2809
NPK + $ZnSO_4$ @ 0.5% (FS)	58.3	11.10	52.67	11.97	3810	159.3	42.2	167.0	68.0	10.87	2625
NPK + Borax @ 10% kg/ha (SA)	58.3	11.17	52.83	11.90	3810	162.0	43.7	168.3	70.7	10.90	2719
NPK + Borax 0.25% (FS)	58.1	11.10	52.53	11.83	3839	159.7	42.0	167.0	68.0	10.70	2608
NPK + Mo @ 2 g/kg (ST)	57.9	10.97	53.77	11.70	3801	159.7	41.0	165.7	68.3	10.80	3597
NPK + $ZnSO_4$ (SA) + Borax (SA)	62.9	12.00	54.33	12.67	3888	167.7	46.9	177.3	75.3	11.97	2903
NPK + $ZnSO_4$ (FS) + Borax (FS)	57.7	11.37	53.03	11.83	3840	160.7	42.2	167.7	69.3	11.10	2636
NPK + $ZnSO_4$ (SA) + Mo (ST)	59.5	11.70	54.20	12.43	3874	165.3	44.9	173.3	73.3	11.87	2823
NPK + Borax (SA) + Mo (ST)	58.7	11.37	53.37	11.83	3847	160.0	42.0	167.3	73.7	11.30	2760
NPK + $ZnSO_4$ (SA) + Borax (SA) + Mo (ST)	60.5	12.10	54.50	12.57	3906	166.3	46.5	176.0	75.3	11.93	2787
SEm ±	0.294	0.08	0.18	0.07	7.49	0.64	0.410	0.854	0.635	0.102	53.3
CD (P=0.05)	0.86	0.22	0.52	0.20	21.92	1.88	1.20	2.50	1.86	0.30	156

SA, Soil application; FS, Foliar spray; ST, Seed treatment

Correlation between soil and plant uptake of nutrients in greengram and finger millet

In greengram, there was a significant negative correlation between uptake and soil nutrients in case of N (-0.88**); K (–0.42*); B (–0.74**); and Mo (–0.47**). This indicated that the plant uptake N, B and Mo decreased with an increase in the corresponding soil nutrients at P < 0.01 level, while the plant uptake K decreased with an increase in soil K at P < 0.05 level. There was a significant positive correlation of soil and uptake of nutrients for Fe (0.90**) and Zn (0.44**) at P < 0.01 level; and S (0.42*) at P < 0.05 level indicating that the plant uptake increased with an increase in the soil nutrients.

In finger millet, there was a significant negative correlation between uptake and soil nutrients in case of organic carbon (–0.55**); N (–0.96**); K (–0.87**); and Fe (–0.67**) indicating a decrease in the plant uptake with increase in soil nutrients in organic carbon, N, K and Fe at P < 0.01 level. There was a significant positive correlation in case of Mn (0.49**) and Zn (0.57**) at P < 0.01 level and P (0.33*) at P < 0.05 level indicating that the plant uptake significantly increased with increase in the soil nutrients (Table 3).

Correlation of grain yield with soil and plant uptake of nutrients

The greengram yield had a significant positive correlation with organic carbon (0.66**), S (0.47**), Fe (0.83**), Cu (0.55**) at P < 0.01 level and Mo (0.34*) at P < 0.05 level. It had a significant negative correlation with soil N (–0.85**); P (–0.49**); K (–0.50**) and B (–0.51**) at P < 0.01 level. In case of plant uptake of nutrients, the greengram yield had a significant positive correlation of 0.69** with N, 0.81** with P, 0.75** with K, 0.98** with S, 0.61** with Fe, 0.58** with Mn, 0.47** with Cu, and 0.83** with B over years. Greengram being a leguminous crop, organic carbon helps for balanced nutrition; Mo and Fe for nodulation; S is a source of protein and Cu for enzymatic activation in protein metabolism. While, external nitrogen shows negative correlation as it fixes the nitrogen through rhizobia.

The finger millet yield had a significant positive correlation with soil P (0.85**) at P < 0.01 level, and Cu (0.43*) at P < 0.05 level. Similarly, it had a significant negative correlation with soil N (–0.66**) at P < 0.01 level, and soil K (–0.33*) and Mn (–0.34*) at P < 0.05 level. In case of plant uptake, the yield had significant positive correlation of 0.65** with N, 0.66** with K, 0.56** with Fe, and 0.76** with B at P < 0.01 level, while it had a significant correlation of 0.38* with P, 0.41* with S, 0.37* with Mn at P < 0.05 level (Table 4). Finger millet, being a cereal responds to nitrogen uptake and cause for higher yield.

Table 3. Correlation between soil and plant uptake of nutrients upon micronutrient management in greengram–finger millet cropping system (pooled data of 3 years)

Variable-1: Plant uptake	Variable-2: Soil nutrient	Greengram	Finger millet
N	OC	0.11	–0.55**
N	N	–0.88**	–0.96**
P	P	0.06	0.33*
K	K	–0.42*	–0.87**
S	S	0.42*	–0.16
Fe	Fe	0.90**	–0.67**
Mn	Mn	0.09	0.49**
Cu	Cu	–0.31	0.20
Zn	Zn	0.44**	0.57**
B	B	–0.74**	0.16
Mo	Mo	–0.47**	0.06

Critical r-value at P < 0.05 level with 34 degrees of freedom = 0.33; Critical r-value at P < 0.01 level with 34 degrees of freedom = 0.42; *P < 0.05; **P < 0.01

Table 4. Correlation of grain yield with soil and plant nutrients in greengram–finger millet cropping system with micronutrient management (pooled data of 3 years)

Variable	Greengram		Finger millet	
	Soil nutrients	Plant nutrients	Soil nutrients	Plant nutrients
OC	0.66**		–0.24	
N	–0.85**	0.69**	–0.66**	0.65**
P	–0.49**	0.81**	0.85**	0.38*
K	–0.50**	0.75**	–0.33*	0.66**
S	0.47**	0.98**	0.08	0.41*
FE	0.83**	0.61**	–0.05	0.56**
MN	0.05	0.58**	–0.34*	0.37*
CU	0.55**	0.47**	0.43*	–0.34*
ZN	–0.13	–0.12	–0.07	–0.19
B	–0.51**	0.83**	–0.10	0.76**
MO	0.34*	–0.21	0.20	–0.38*

Critical r-value at P < 0.05 level with 34 degrees of freedom = 0.33; Critical r-value at P < 0.01 level with 34 degrees of freedom = 0.42;

Effect of soil nutrients on plant uptake of nutrients in greengram and finger millet

The relationship between soil test values and plant uptake of nutrients was examined based on a graphical plot depicted in Fig.1 for greengram and Fig.2 for finger millet. The effects of soil nutrients on plant uptake of nutrients were assessed based on the regression coefficients, coefficient of determination (R^2) and standard error of the expected plant uptake of nutrients as postulated in model (1). The regression models of plant uptake of nutrients through soil nutrients in greengram and finger millet are

Table 5. Regression models indicating effects of soil nutrients on plant uptake in greengram– finger millet cropping system with micronutrient management (pooled data of 3 years)

Regression model	R^2	SE
Greengram		
UN = –219 + 3.24* (SN) – 0.01* (SN²)	0.81**	5.0
UP = –30.4 + 0.91 (SP) – 0.01 (SP²)	0.05	1.2
UK = –860** + 11.11** (SK) – 0.03** (SK²)	0.49**	6.0
US = –79** + 15.41** (SS) – 0.69** (SS²)	0.35**	0.8
UFE = –16491** + 1184 (SFE) – 17.97** (SFE²)	0.92**	104.0
UMN = 888 – 84.32 (SMN) + 2.37 (SMN²)	0.02	5.2
UCU = 245 – 515.02 (SCU) + 302.02 (SCU²)	0.12	3.9
UZN = 221 – 225.22 (SZN) + 129.13 (SZN²)	0.20*	9.5
UB = 195** -595.01** (SB)+ 534.30** (SB²)	0.71**	7.8
UMO = 91 – 828.76 (SMO) + 1968.35 (SMO²)	0.24**	1.2
Finger millet		
UN = 226** – 0.97 (SN) + 0.001 (SN²)	0.93**	3.2
UP = 500** - 10.68** (SP) + 0.06** (SP²)	0.58**	1.5
UK = –19 + 0.86 (SK) – 0.002 (SK²)	0.77**	4.8
US = –51* + 10.81** (SS) – 0.45** (SS²)	0.27**	2.6
UFE = –3964 + 560.45 (SFE) – 9.91 (SFE²)	0.51**	147.8
UMN = –10 + 15.47 (SMN) – 0.34 (SMN²)	0.25**	7.1
UCU = 234 – 490.88 (SCU) + 315.02 (SCU²)	0.08	3.7
UZN = 192** - 64.83 (SZN) + 41.91 (SZN²)	0.34**	7.0
UB = 3 + 308.77 (SB) – 334.13 (SB²)	0.09	10.4
UMO = –12 + 220.98 (SMO) – 514.45 (SMO²)	0.01	1.2

* and ** indicate significance at $P < 0.05$ and $P < 0.01$; R^2, Coefficient of determination; SE, Standard error of estimate of yield

given in Table 5. The model indicated that soil N, Fe, B and Mo had a significant effect on the plant uptake of respective nutrients in greengram at $P < 0.01$ level; while soil K, S and Zn had a significant effect on the respective uptake of nutrients at $p < 0.05$ level. This was indicated by significant R^2 of 0.81 for N, 0.49 for K, 0.35 for S, 0.92 for Fe, 0.20 for Zn, 0.71 for B, 0.24 for Mo nutrients.

The regression model of greengram indicated that soil S, Fe and Zn had a significant positive effect; while soil N, K, B and Mo had a significant negative effect on the plant uptake of respective nutrients. In finger millet, soil P, Mn and Zn had a significant positive effect; while soil N, K and Fe had a significant negative effect on the plant uptake of respective nutrients. In finger millet, soil N, P, K, S, Fe, Mn and Zn were significant at $P < 0.01$ level with R^2 of 0.93, 0.58, 0.77, 0.27, 0.51, 0.25 and 0.34 respectively. The standard error of the estimated plant uptake was low for all nutrients in both crops.

Regression models for predicting yield through soil and plant nutrients

The regression models postulated in 2 and 3 were cali-

Table 6. Regression model of grain yield through soil and plant nutrients in greengram–finger millet cropping system with micronutrient application (pooled data of 3 years)

Variables	Regression model	R^2	SE
Greengram			
Soil nutrients	GY = –188 + 376.15* (OC) – 1.34** (SN) + 1.71** (SP_2O_5) + 0.001 (SK_2O) + 9.74 (SS) + 13.21** (SFE) + 17.56* (SMN) – 21.94 (SCU) + 100.61** (SZN) + 84.38 (SB) – 26.25 (SMO)	0.97**	13
Plant uptake	GY = 546* + 6.80** (UN) + 14.90 (UP) – 0.66 (UK) + 59.38** (US) – 0.40** (UFE) + 2.72* (UMN) – 1.95 (UCU) + 0.13 (UZN) + 1.82 (UB) – 25.69 (UMO)	0.98**	10
Finger millet			
Soil nutrients	GY = –1983 + 2912.7* (OC) – 16.43** (SN) + 56.23** (SP_2O_5) – 0.27 (SK_2O) + 22.68 (SS) + 33.85 (SFE) + 32.22 (SMN) + 72.93 (SCU) + 147.18 (SZN) + 292.25 (SB) + 187.88 (SMO)	0.97**	115
Plant uptake	GY = –4506* + 35.42* (UN) – 70.34 (UP) + 32.17 (UK) – 95.69 (US) + 0.34 (UFE) + 16.21 (UMN) – 16.59 (UCU) + 13.28 (UZN) + 12.71 (UB) – 88.81 (UMO)	0.98**	105

* and ** indicate significance at $P < 0.05$ and $P < 0.01$; R^2, Coefficient of determination; SE, Standard error of estimate of yield

brated for predicting greengram and finger millet yield through soil and plant uptake of nutrients over years and are given in Table 6. The models could be used for predicting yield through (i) soil nutrients of organic carbon, N, P, K, S, Fe, Mn, Cu, Zn, B and Mo nutrients (Model 1); and (ii) plant uptake of N, P, K, S, Fe, Mn, Cu, Zn, B and Mo nutrients (Model-2). In greengram, the Model 1 gave predictability of 0.97 and Model 2 gave predictability of 0.98 which were significant at $P < 0.01$ level with standard error as 13 and 10 kg/ha respectively over years. In finger millet also, the Model 1 gave R^2 of 0.97, while Model 2 gave R^2 of 0.98, which were significant at $P < 0.01$ level with standard error of 115 and 105 kg/ha respectively over years.

In greengram, based on Model 1, the effects of soil P, Fe and Zn were positive and significant at $P < 0.01$, while the effects of organic carbon and Mn were positive and significant at $P < 0.05$ level. Compared to this, soil N had a significant negative effect on yield at $P < 0.01$ level. Based on Model 2, the effects of uptake N and S were positive and significant at $P < 0.01$ level, while the effect of Mn was positive and significant at $P < 0.05$ level. Similarly, the effect of uptake Fe on yield was negative and significant at $P < 0.01$ level.

In finger millet, based on Model 1, the soil organic carbon at $P < 0.05$ and soil P at $P < 0.01$ level had a significant positive effect, while soil N had a significant negative effect on yield over years at $P < 0.01$ level. The uptake N had a significant positive effect on yield over years at $P < 0.05$ level based on Model 2.

Relative efficiency index values of different treatments

A relative efficiency index of treatments was determined by assigning '0' score to the treatment with lowest performance and '1' to the treatment with the best performance for soil and plant nutrients. The cumulative values of REI are determined for each group of variables and are ranked for assessing the performance of treatments. The REI along with the ranks of treatments are given in Table 7. In greengram, application of NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed was superior with maximum REI of 9.68 for plant nutrients; while NPK + FYM @ 10 tonnes/ha was superior with maximum REI of 9.21 for soil nutrients. Application of NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha was the second best for plant uptake nutrients with REI of 8.52, while NPK + $ZnSO_4$ @ 12.5 kg/ha + Mo @ 2 g/kg seed was the second best for soil nutrients with REI of 5.24. Based on overall REI values, NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed was superior for greengram

Table 7. Relative efficiency index in greengram–finger millet cropping system with micronutrient application (pooled data of 3 years)

Treatment	Soil nutrients	Rank	Plant uptake	Rank	Over- all	Rank
Greengram						
Control (recommended NPK)	1.62	12	0.63	12	2.25	12
NPK + FYM @ 10 tonnes/ha	9.21	1	5.24	5	20.07	2
NPK + $ZnSO_4$ @ 12.5 kg/ha (SA)	3.28	10	6.16	4	14.76	5
NPK + $ZnSO_4$ @ 0.5% (FS)	3.52	8	2.33	9	8.19	9
NPK + Borax @ 10% kg/ha (SA)	4.32	6	3.93	7	11.53	7
NPK + Borax 0.25% (FS)	3.45	9	1.50	11	6.09	11
NPK + Mo @ 2 g/kg (ST)	4.02	7	1.78	10	7.78	10
NPK + $ZnSO_4$ (SA) + Borax (SA)	5.12	4	8.52	2	19.68	3
NPK + $ZnSO_4$ (FS) + Borax (FS)	2.99	11	2.97	8	8.45	8
NPK + $ZnSO_4$ (SA) + Mo (ST)	5.24	2	6.69	3	17.42	4
NPK + Borax (SA) + Mo (ST)	5.22	3	5.01	6	14.09	6
NPK + $ZnSO_4$ (SA) + Borax (SA) + Mo (ST)	4.54	5	9.68	1	21.18	1
Finger millet						
Control (recommended NPK)	1.02	12	0.00	12	1.02	12
NPK + FYM @ 10 tonnes/ha	8.70	1	5.22	5	20.26	2
NPK + $ZnSO_4$ @ 12.5 kg/ha (SA)	3.13	8	6.58	4	14.28	5
NPK + $ZnSO_4$ @ 0.5% (FS)	2.90	10	2.40	9	7.07	9
NPK + Borax @ 10% kg/ha (SA)	3.71	6	3.33	7	9.86	7
NPK + Borax 0.25% (FS)	2.34	11	2.31	10	5.98	11
NPK + Mo @ 2 g/kg (ST)	3.05	9	1.97	11	6.71	10
NPK + $ZnSO_4$ (SA) + Borax (SA)	5.69	2	9.71	1	21.21	1
NPK + $ZnSO_4$ (FS) + Borax (FS)	3.33	7	3.22	8	9.04	8
NPK + $ZnSO_4$ (SA) + Mo (ST)	4.21	4	7.32	3	16.41	4
NPK + Borax (SA) + Mo (ST)	4.07	5	4.02	6	11.81	6
NPK + $ZnSO_4$ (SA) + Borax (SA) + Mo (ST)	5.00	3	9.14	2	17.56	3

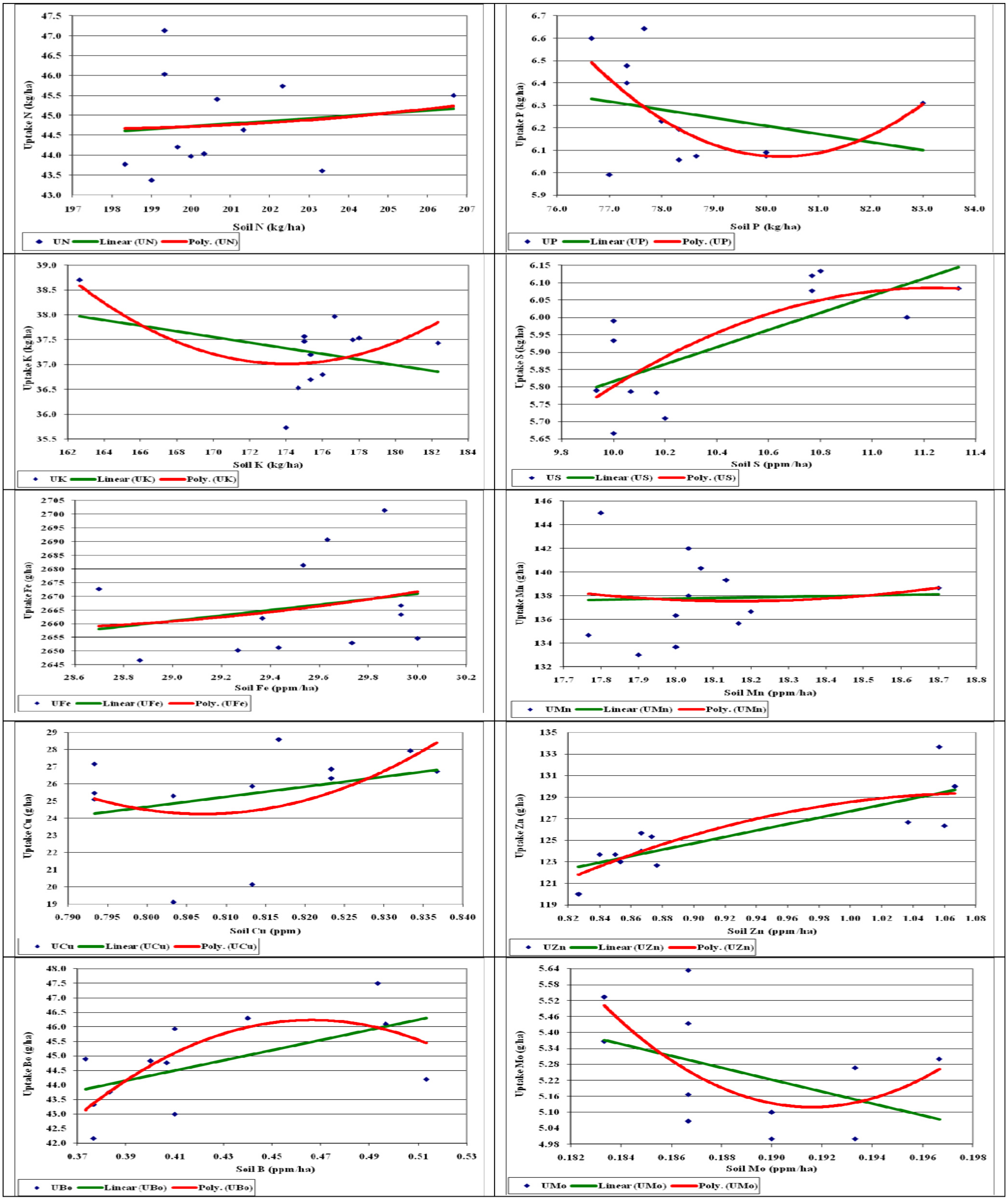

Fig. 1. Effect of soil nutrients on plant nutrients in greengram

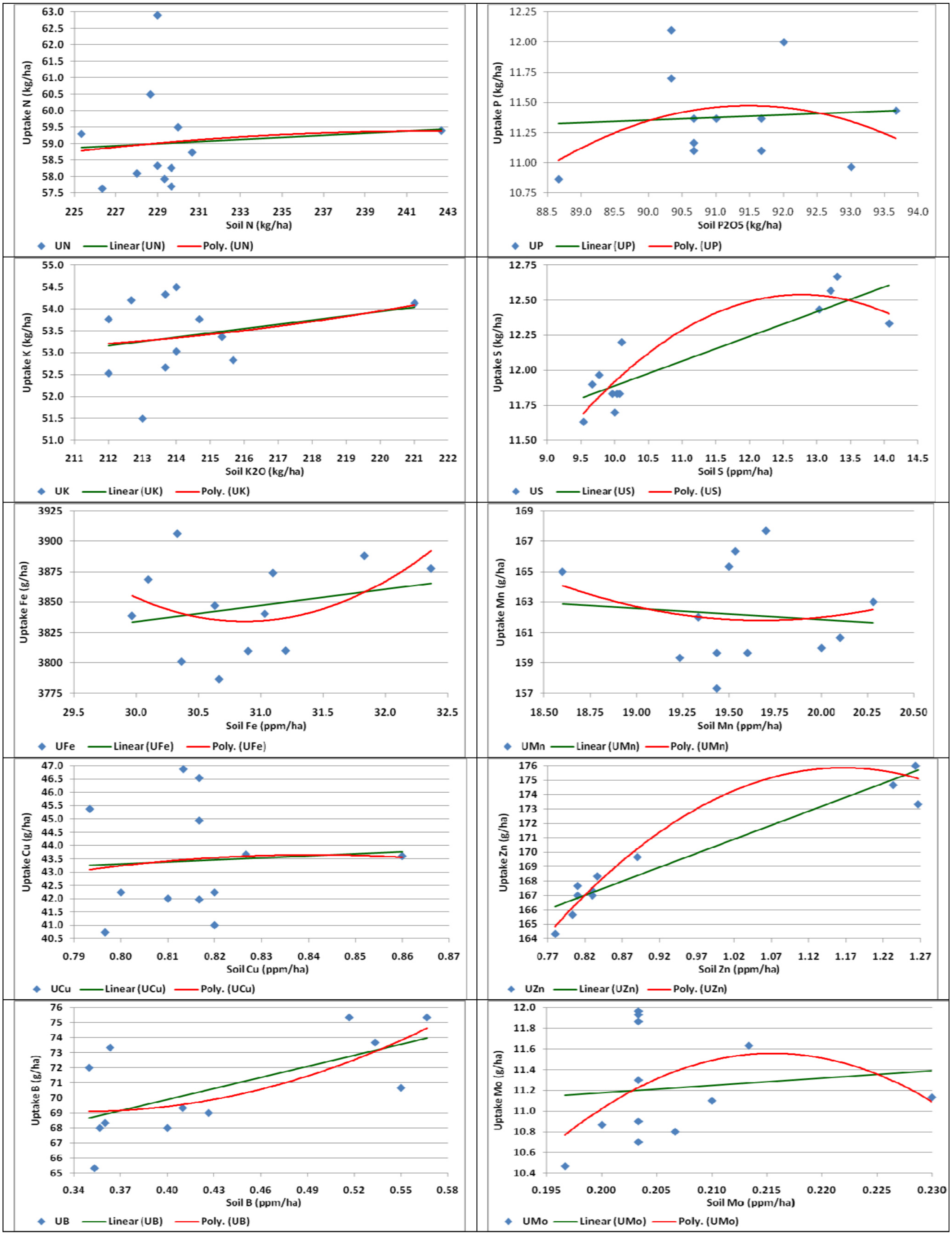

Fig. 2. Effect of soil nutrients on plant uptake in finger millet

with first rank with an index value of 21.18, while NPK + FYM @ 10 tonnes/ha was the second best with a value of 20.07.

In finger millet, recommended NPK + FYM @ 10 t/ha had a maximum REI of 8.70 for soil nutrients, while NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha had a maximum value of 9.71 for plant nutrients. Application of NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha was the second best for soil nutrients with REI of 5.69, while NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed was the second best with 9.14 for plant nutrients. However, NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha was efficient with maximum REI of 21.21 with first rank, while NPK + FYM @ 10 t/ha was the second best with an index value of 20.26 over both soil and plant nutrients based on the study.

It can be concluded that application of NPK + $ZnSO_4$ @ 12.5 kg/ha + borax @ 10 kg/ha + Mo @ 2 g/kg seed could be prescribed for attaining maximum nutrient uptake and productivity of greengram and finger millet in sequence, apart from maintaining soil fertility under semi-arid *Alfisols*

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