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Status of Mn and Fe in Agricultural Soils of Western Ethiopia: Laboratory Assessment

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ABSTRACT

One hundred and sixty soil samples at depth of 0-15 cm were collected from Nitisols of Western Ethiopia following three elevational positions (low, mid and high altitudes) at 1300, 1800 and 2300 masl, respectively, and two farming practices (traditional and intensive). The objectives of the study were to assess the status of manganese and iron in Nitisols and examine effects of altitude and farming practices on the status. The status was determined using diethylene triamine pentaacetic acid-triethanolamine (DTPA-TEA), ammonium bicarbonate diethylene triamine pentaacetic acid (AB-DTPA) and Mehlich III methods using atomic absorption spectrophotometer. There were no textural variation among all samples and all the samples were classified in the clay textural class. The pH measured in water varied between 4.24-6.21. Sixty four percent and fourteen percent of the samples were low in available phosphorus and organic carbon, respectively. Comparing the results of extractable manganese and iron in Nitisols of Western Ethiopia with critical levels of manganese and iron from literature, the amounts of extractable manganese and iron were in the sufficient range. The manganese status was higher in traditional farms than in intensive farms in low and high altitudes. In mid altitude, on the other hands, the status of manganese in intensive farms was higher than that in traditional ones. The iron status was mostly higher in traditional farms than in intensive farms in all altitudes. Irrespective of farming practices the status of manganese and iron increased with the increase in altitude. The amounts of manganese were higher than those of iron in all the three altitudes using the three methods. Comparing the extracting power of the methods used for determining manganese and iron, the result of soil analysis showed that DTPA-TEA was superior to the others followed by AB-DTPA and Mehlich III.

Key words: altitude, farming practice, Nitisols, manganese, iron

INTRODUCTION

In Ethiopia the role of micronutrients in crop production has not yet been studied systematically, except the study on micro and macro-nutrient distribution in Ethiopian Vertisol landscape (Fisseha, 1992) and investigation done by Desta (1983) in which considerable variation in micronutrient contents of soils and crops was reported. Manganese and iron levels were usually

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adequate, but zinc content varied from low to high and copper seemed to be deficient. However, what was satisfactory for traditional and subsistence agriculture will not remain satisfactory for modern agriculture based on the increased use of inputs required for high production levels. The micronutrient deficiency problems will grow in number and intensity of occurrence and become more serious, first on those soils inherently deficient in the specific micronutrients, and later even on those soils that are presently marginal in micronutrient supply. These marginal soils will become more responsive because of a depletion of available micronutrients.

In Ethiopia in the past, few investigations (Sillanpaa, 1982; Godfrey *et al*., 1987; Fekadu, 1987; Saleh *et al*., 1990) were either incidental or exploratory in nature, which made it difficult to obtain a real assessment of magnitude of micronutrient problems. Due to these factors, there is very little information available in Ethiopia about micronutrients levels in soils. Test for micronutrient based on soil extraction are not in routine use as an aid for predicting micronutrient deficiencies.

Schutte and Amdurer (1960) stated that deficiencies of micronutrients could be severe in tropical soils that had been fully weathered and had been strongly leached in humid climates. Also it would be expected that as farming becomes more intensive, higher yielding crop varieties were introduced and more nitrogen, phosphorus and potassium fertilizers were used, deficiencies of micronutrients might become a more serious fertility problem. Before the problem of micronutrient deficiency reaches a critical stage in the immediate future, it would be wise to make a comprehensive study on the status of micronutrients in different altitudes and farming practices in the regions of the country.

Therefore, the objectives of the study were to assess the status of Mn and Fe in Nitisols of Western Ethiopia, to examine effects of altitude and farming practices and to examine relationship of the status with soil properties.

MATERIALS AND METHODS

Collection and preparation of soil samples

One hundred and sixty composite soil samples at 0-15 cm depth from a total area of 247 hectares were collected from Western Ethiopia farmers' field. Two farming practices were considered (intensive and traditional farming) following three elevational positions, i.e. 25 soil samples each from intensive and traditional farms from low altitude at 1300 meter above mean sea level, and 25 soil samples each from intensive farms and 30 soil samples each from traditional farms, from mid and high altitudes at 1800 and 2300 meter above mean sea level, respectively. Samples from each field were taken using auger (made from stainless steel) from twelve different spots at 0-15 cm depth. They were mixed very well in a plastic container and a composite sample was taken in a plastic bag for laboratory analysis.

The collected soils were air-dried on plastic trays, gently crushed using pestle and mortar and passed through a 2-mm sieve.

Analytical procedure

Particle size analysis was determined using hydrometric method according to Van Reeuwijk (1992). pH measurements were made in water and in 1*M* KCl in 1 : 2.5 soil : water or solution suspension using a digital pH meter. Electrical conductivity was measured from 1 : 2.5 soil : water suspension using digital electrical conductivity meter. Organic carbon was determined using Walkley-Black's method (1934). Available phosphorus was determined according to Olsen *et al*. (1982) and Bray II method of Bray and Kurtz (1945). Available manganese and iron were determined using three extractants namely, diethylene triamine pentaacetic acid-triethnolamine (DTPA-TEA) (Lindsay and

Norvell, 1978), ammonium bicarbonate diethylene triamine pentaacetic acid (AB-DTPA) (Halvin and Soltanpour, 1981) and Mehlich III (Mehlich, 1984) using atomic absorption spectrophotometer. These methods were selected by summarizing research findings which had been conducted to evaluate the reliability of soil testing methods for individual micronutrients using acid or base extractions, chelating and complexing agents and simultaneous extraction. For each element, table was constructed to see their statistical significance of indices obtained from the use of different methods in reflecting the micronutrient status of soils. Finally the three most superior methods were selected for determining Mn and Fe of the soil under investigation.

RESULTS AND DISCUSSION

pH, organic C and available P of the soils

Statistical analysis on soil pH, organic C and available P contents of one hundred and sixty soil samples collected for the study is presented in Table 1. Soil pH in H_2O and in 1*M* KCl ranged from 4.24-6.21 and 3.43-4.99 with standard deviation of 0.403 and 0.347, respectively, indicating wide range from extremely acidic to slightly acidic. Mean percent organic C of the soils was 3.24% (range was 1.46-5.75%) with a standard deviation of 1.15. Available phosphorus ranged from 0.60-15.0 ppm. Sixty four percent of the soil samples were low in available P. There was no textural variation of the sampled areas and all the samples were classified in the clay textural class (14-22% sand, 24-32% silt and 50-61% clay).

Mn status

Frequency distribution for extractable Mn and Fe in Nitisols collected from the areas at low, mid and high altitudes of Western Ethiopia were presented in Table 2 and Table 3, respectively. The tables indicate the distribution of the soil samples in different ranges of Mn and Fe and their maximum, minimum and mean values were indicated in Table 4. The distribution of extractable Mn in low altitude Nitisols was in the frequency distribution ranges of 30.0-75.0, 25.0-70.0 and 5.0-20.0 mg kg^{-1} in intensive farms using DTPA-TEA, AB-DTPA and Mehlich III, respectively. In traditional farms the distribution was in the ranges 25.0-95.0, 25.0-85.0, and 5.0-80.0 mg kg^{-1}, using DTPA-TEA, AB-DTPA and Mehlich III, respectively. The distribution tables showed that the amounts obtained by DTPA-TEA and AB-DTPA were in similar ranges with most of the samples from 30.0-40.0 mg kg^{-1} in both farming practices, but with Mehlich III method, majority of the samples were in the range of 10.0-20.0 mg kg^{-1}. The mean values of extractable Mn were 43.5, 39.1 and 12.2 mg kg^{-1} for DTPA-TEA, AB-

Table 1 Characterization of pH, organic carbon and phosphorus of the samples.

Statistics	pH in H_2O	pH in 1*M* KCl	Organic C, %	Available P, mg kg^{-1} (Olsen method)
Mean	5.23	4.21	3.24	3.76
Median	5.21	4.20	2.90	3.40
Mode	5.03	3.92	1.60	3.00
Maximum	6.21	4.99	5.75	15.00
Minimum	4.24	3.43	1.46	0.60
Standard deviation	0.403	0.347	1.15	2.03

Table 2 Frequency distribution of soil samples with different ranges in the amounts of Mn extracted by three methods of extraction for Nitisols in low, mid and high altitudes.

Extractable Mn mg kg^{-1}	Sufficiency[1/]	Low altitude Nitisol						Mid altitude Nitisol						High altitude Nitisol					
		DTPA-TEA		AB-DTPA		Mehlich III		DTPA-TEA		AB-DTPA		Mehlich III		DTPA-TEA		AB-DTPA		Mehlich III	
		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples	
		I[2/]	T[3/]	I	T	I	T	I	T	I	T	I	T	I	T	I	T	I	T
0.0-3.0	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.0-4.0	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.0-5.0	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.0-10.0	S	0	0	0	0	6	2	0	0	0	0	0	1	0	0	0	0	0	0
10.0-15.0	S	0	0	0	0	16	8	0	0	0	0	6	17	0	0	0	0	0	1
15.0-20.0	S	0	0	0	0	3	7	0	0	0	0	4	1	0	0	0	0	0	0
20.0-25.0	S	0	0	0	0	0	3	0	0	0	0	4	8	0	0	0	0	2	4
25.0-30.0	S	0	2	3	2	0	2	0	1	0	1	6	2	0	0	0	0	4	11
30.0-35.0	S	4	2	9	1	0	0	0	6	0	3	1	1	0	0	0	1	10	9
35.0-40.0	S	9	3	5	6	0	2	0	3	0	5	0	0	0	0	1	2	8	5
40.0-45.0	S	3	6	2	4	0	0	0	2	1	3	1	0	1	1	2	2	1	0
45.0-50.0	S	3	3	2	5	0	0	1	1	2	2	0	0	4	5	7	2	0	0
50.0-55.0	S	3	3	2	2	0	0	4	5	6	6	3	0	4	1	10	4	0	0
55.0-60.0	S	1	3	1	2	0	0	5	7	4	7	0	0	12	2	4	3	0	0
60.0-65.0	S	1	1	0	1	0	0	3	4	2	1	0	0	3	4	1	3	0	0
65.0-70.0	S	0	0	1	0	0	0	2	1	1	2	0	0	1	6	0	2	0	0
70.0-75.0	S	1	0	0	0	0	0	2	0	3	0	0	0	0	2	0	3	0	0
75.0-80.0	S	0	0	0	1	0	1	1	0	2	0	0	0	0	4	0	4	0	0
80.0-85.0	S	0	1	0	1	0	0	3	0	1	0	0	0	0	2	0	4	0	0
85.0-90.0	S	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0
90.0-95.0	S	0	1	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0
95.0-100.0	S	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
100.0-105.0	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
105.0-110.0	S	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
110.0-115.0	S	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Total		25	25	25	25	25	25	25	30	25	30	25	30	25	30	25	30	25	30

1/ : D = Deficient; S = Sufficient; 2/ : I = Intensive farms; 3/ : T = Traditional farms

Table 3 Frequency distribution of soil samples with different ranges in the amounts of Fe extracted by three methods of extraction for Nitisols in low, mid and high altitudes.

Extractable Fe mg kg^{-1}	Sufficiency[1/]	Low altitude Nitisol						Mid altitude Nitisol						High altitude Nitisol					
		DTPA-TEA		AB-DTPA		Mehlich III		DTPA-TEA		AB-DTPA		Mehlich III		DTPA-TEA		AB-DTPA		Mehlich III	
		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples		No.of samples	
		I[2/]	T[3/]	I	T	I	T	I	T	I	T	I	T	I	T	I	T	I	T
0.0-4.8	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.8-10.0	S	0	0	0	0	10	7	0	0	0	0	18	9	0	0	0	0	0	0
10.0-15.0	S	0	1	0	0	13	16	0	0	0	0	7	18	0	0	0	0	0	0
15.0-20.0	S	0	1	1	3	1	1	1	0	0	0	0	3	0	0	0	0	5	0
20.0-25.0	S	1	7	1	8	0	1	0	0	2	1	0	0	0	0	1	1	7	6
25.0-30.0	S	2	8	12	7	1	0	1	2	0	3	0	0	0	0	3	5	4	8
30.0-35.0	S	11	3	7	2	0	0	0	8	9	2	0	0	3	0	4	8	6	8
35.0-40.0	S	6	1	0	2	0	0	5	6	8	11	0	0	2	0	8	6	3	3
40.0-45.0	S	1	3	2	1	0	0	10	2	1	2	0	0	5	1	4	3	0	4
45.0-50.0	S	2	0	1	1	0	0	4	4	1	3	0	0	10	1	2	0	0	1
50.0-55.0	S	1	1	0	0	0	0	1	1	4	3	0	0	0	4	1	2	0	0
55.0-60.0	S	0	0	0	1	0	0	3	3	0	0	0	0	0	5	1	2	0	0
60.0-65.0	S	0	0	0	0	0	0	0	1	0	0	0	0	0	3	0	1	0	0
65.0-70.0	S	0	0	0	0	0	0	0	1	0	2	0	0	0	2	1	0	0	0
70.0-75.0	S	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	2	0	0
75.0-80.0	S	0	0	0	0	0	0	0	1	0	2	0	0	2	4	0	0	0	0
80.0-85.0	S	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0
85.0-90.0	S	0	0	1	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0
90.0-95.0	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95.0-100.0	S	1	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0
Total		25	25	25	25	25	25	25	30	25	30	25	30	25	30	25	30	25	30

[1/] : D = Deficient; S = Sufficient; [2/] : I = Intensive farms; [3/] : T = Traditional farms

Table 4 Maximum, minimum and mean values of extractable Mn and Fe in low, mid and high altitudes Nitisols of Western Ethiopia as obtained from three different methods of extraction (mg kg^{-1}).

Elements and extraction methods	Intensive farming			Traditional farming			Grand mean
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	
Low altitude							
Mn-DTPA-TEA	71.4	30.6	43.5	65.2	28.8	46.2	44.9
Mn-AB-DTPA	65.6	28.6	39.1	65.8	30.0	45.2	42.2
Mn-Mehlich III	19.3	6.4	12.2	46.1	8.2	19.0	15.6
Fe-DTPA-TEA	99.2	23.6	38.3	44.8	14.2	28.8	33.6
Fe-AB-DTPA	87.5	17.8	32.6	49.0	15.4	28.2	30.4
Fe-Mehlich III	28.4	7.2	11.5	19.6	5.6	11.6	11.5
Mid altitude							
Mn-DTPA-TEA	110.8	46.2	69.1	65.2	32.6	48.9	59.0
Mn-AB-DTPA	98.6	44.0	64.5	69.2	30.0	48.7	55.9
Mn-Mehlich III	54.3	10.5	25.4	30.3	9.8	16.7	21.1
Fe-DTPA-TEA	57.4	19.4	43.0	95.7	26.2	43.9	43.5
Fe-AB-DTPA	56.3	20.2	37.2	75.4	21.8	41.4	39.3
Fe-Mehlich III	13.0	5.2	9.2	16.0	7.2	11.4	10.3
High altitude							
Mn-DTPA-TEA	66.8	42.6	55.8	94.2	40.2	66.4	61.1
Mn-AB-DTPA	63.6	40.0	51.0	82.6	32.6	61.2	56.1
Mn-Mehlich III	40.7	23.8	32.5	38.6	13.9	29.4	31.0
Fe-DTPA-TEA	87.9	33.6	50.5	99.4	43.1	68.1	59.3
Fe-AB-DTPA	66.6	23.2	39.4	71.8	22.6	40.0	39.7
Fe-Mehlich III	37.4	15.2	26.8	45.2	22.8	31.6	29.2

DTPA and Mehlich III, respectively, in intensive farms, and were 46.2, 45.2 and 19.0 mg kg^{-1} for DTPA-TEA, AB-DTPA and Mehlich III, respectively, in traditional farms. The results indicated that using the three methods the extractable Mn status was higher in traditional farms than in intensive farms in low altitude Nitisols (Table 4). Thus, the statistical analyses of the results (Table 4) are agreeable with frequency distribution, except with DTPA-TEA method in which the extractable Mn status was lower in traditional farms than in the intensive farms.

In mid altitude Nitisols, the extractable Mn was in the frequency distribution ranges of 45.0-115.0, 40.0-100.0 and 10.0-55.0 mg kg^{-1} by DTPA-TEA, AB-DTPA and Mehlich III, respectively, in intensive farms and was 25.0-70.0, 25.0-70.0 and 5.0-35.0 mg kg^{-1} by DTPA-TEA, AB-DTPA and Mehlich III, respectively, in traditional farms. The mean values of extractable Mn for mid altitude Nitisols were 69.1, 64.5 and 25.4 mg kg^{-1} by DTPA-TEA, AB-DTPA and Mehlich III, respectively, in intensive farms and 48.9, 48.7 and 16.7 mg kg^{-1} in traditional farms by DTPA-TEA, AB-DTPA and Mehlich III, respectively (Table 4). Accordingly, it indicated that the extractable

Mn in intensive farms was higher than that in traditional ones. The statistical analysis of the results (Table 4) reflected the same result with the frequency distribution of the samples. In this area it was observed during the time of sampling that the farms were extensively using farmyard manures and left over straws, which supported and explained the finding of this study.

In high altitude Nitisols Mn extracted by DTPA-TEA was in the frequency distribution ranges of 40.0-70.0 and 40.0-95.0 mg kg^{-1} for intensive and traditional farms, respectively. The distribution ranges for AB-DTPA extractable Mn were 35.0-65.0 and 30.0-85.0 mg kg^{-1} for intensive and traditional farms, respectively. Using Mehlich III the figures were in the frequency distribution ranges of 20.0-45.0 mg kg^{-1} in intensive farm and 10.0-40.0 mg kg^{-1} in traditional farm. The mean values of extractable Mn for high altitude Nitisols were 55.8, 51.0 and 32.5 mg kg^{-1} for intensive farms and 66.4, 61.2 and 29.4 mg kg^{-1} in traditional farms using DTPA-TEA, AB-DTPA and Mehlich III, respectively (Table 4). The results indicated that using DTPA-TEA and AB-DTPA the status of extractable Mn was higher in traditional farms than in intensive farms. In high altitude Nitisols, the frequency distribution agrees only with Mehlich III method.

The means for amount of extractable Mn, irrespective of farming practice varied among altitudes. The content of extractable Mn increased with the increase in altitude using the three methods, showing mean values of 44.9, 59.0 and 61.1 mg kg^{-1} by DTPA-TEA method in low, mid and high altitudes, respectively. The trend was true for AB-DTPA with mean values of 42.2, 55.9 and 56.1 mg kg^{-1} and Mehlich III with the mean values of 15.6, 21.1 and 31.0 mg kg^{-1} in low, mid and high altitudes. From the frequency distribution (Table 2) the contents of extractable Mn were in sufficient ranges. The sufficiency range (2.9-3.0 mg kg^{-1} Mehlich III and DTPA-TEA extractions) was extrapolated from literature reviews, which were based on either greenhouse evaluation or field calibration research using cereal crops (Mascagni and Cox, 1985; Bansal and Nayar, 1989, 1990).

Fe status

The frequency distribution of Fe (Table 3) showed that in low altitude Nitisols extractable Fe ranged from 20.0-100.0 and 10.0-55.0 mg kg^{-1} by DTPA-TEA method and 15.0-90.0 and 15.0-60.0 mg kg^{-1} by AB-DTPA method, while that by Mehlich III the ranges were between 4.8-30.0 and 4.8-25.0 mg kg^{-1} in intensive and traditional farms, respectively. The mean values of extractable Fe in low altitude were 38.3, 32.6 and 11.5 mg kg^{-1} in intensive farms and 28.8, 28.2 and 11.6 mg kg^{-1} in traditional farms by DTPA-TEA, AB-DTPA and Mehlich III, respectively (Table 4). The results of extractable Fe status by DTPA-TEA and AB-DTPA indicated higher tendency in intensive farms than that in traditional farms. Thus, the statistical analyses of the results are agreeable with the frequency distribution of the samples.

In mid altitude Nitisols the frequency distribution of extractable Fe was in the ranges of 15.0-60.0 and 25.0-100.0 mg kg^{-1} in intensive and traditional farms using DTPA-TEA method. Using AB-DTPA the range was the same for both farming systems, with the range being 20.0-55.0 mg kg^{-1}, while by Mehlich III the ranges were between 4.8-15.0 and 4.8-20.0 mg kg^{-1} for intensive and traditional farms, respectively. The mean values of extractable Fe in mid altitude Nitisols were 43.0, 37.2 and 9.2 mg kg^{-1} using DTPA-TEA, AB-DTPA and Mehlich III methods, respectively in intensive farms and 43.9, 41.4 and 11.4 mg kg^{-1} in traditional farms (Table 4). Thus, the content of extractable Fe indicated higher tendency in traditional farms than in intensive farms, which was similar to the results from frequency distribution of the samples.

In high altitude Nitisols the frequency distribution of extractable Fe was in the ranges of 30.0-90.0 and 40.0-100.0 mg kg^{-1} in intensive and traditional farms using DTPA-TEA method, respectively. By AB-DTPA method the ranges were 20.0-70.0 and 20.0-75.0 mg kg^{-1} for intensive and traditional farms, respectively, while by Mehlich III the ranges were 15.0-40.0 and 20.0-50.0 mg kg^{-1} in intensive and traditional farms, respectively. The mean values of extractable Fe in high altitude Nitisols were 50.5, 39.4 and 26.8 mg kg^{-1} in intensive farms and 68.1, 40.0 and 31.6 mg kg^{-1} in traditional farms by DTPA-TEA, AB-DTPA and Mehlich III, respectively (Table 4). The results showed that extractable Fe status was higher in traditional farms than in intensive farms on high altitude Nitisols. The above conclusion also agreed with frequency distribution of the samples, except for the results of AB-DTPA method.

From the above it may be concluded that, the Fe status irrespective of farming practices varied among altitudes. The mean values were 33.6, 43.5 and 59.3 mg kg^{-1} for low, mid and high altitudes, respectively using DTPA-TEA method. A similar pattern, the increase in Fe with the increment of altitude was also found with AB-DTPA with the values being 30.4, 39.3 and 39.7 mg kg^{-1}. Mehlich III method gave higher values for low altitude than mid altitude, with the values being 11.5, 10.3 and 29.2 mg kg^{-1} for low, mid and high altitudes, respectively. Thus, the results mostly showed that Fe status increased with the increase in altitudes.

From the frequency distribution of the results (Table 3) the contents of extractable Fe were in sufficient ranges. The sufficiency range (4.8 mg kg^{-1} DTPA-TEA and AB-DTPA extraction) was extrapolated from literature reviews, which were based on either greenhouse evaluation or field calibration research using cereal crops (Lindsay and Norvell, 1978; Halvin and Soltanpour, 1981).

The outputs of the results of Mn and Fe were supported by the findings of Cottenie *et al*. (1981) who had shown that the position of a profile in the toposequence has a strong influence on the micronutrients status and that upper slope profiles had higher Mn and Fe status than did lower members of the toposequence.

By comparing the mean values of analytical results of Mn and Fe (Mn-DTPA-TEA with Fe-DTPA-TEA, Mn- AB-DTPA with Fe-AB-DTPA and Mn-Mehlich III with Fe-Mehlich III) it was clear that the amounts of extractable Mn were higher than those of Fe in all three altitudes using the three methods. These results were supported by the finding of Xiaofu and Selmer-Olsen (1992) and Haque *et al*. (2000), in which the amounts of DTPA-TEA extractable Mn were higher than those of DTPA-TEA extractable Fe.

Correlation among the amounts extracted by different methods and extracting powers of the methods

Correlation among the amounts of Mn and Fe extracted with different methods showed that there were significant and positive correlation among the amounts of each of the nutrients extracted by DTPA-TEA, AB-DTPA and Mehlich III methods (Table 5). With exception for the relationship between Fe by AB-DTPA and Mn by Mehlich III, all correlations were significant at the 0.01 levels. Comparing the extracting power of the methods used for the determination of Mn and Fe, the result of soil analysis showed that DTPA-TEA was superior to the others followed by AB-DTPA and Mehlich III.

Relationship of Mn and Fe with soil properties

An attempt was made to examine the relationship between the amounts of Mn and Fe and some soil properties (pH, organic carbon and extractable phosphorus) by simple correlation analysis (Table 6), to identify the soil factors involved in regulation of the amounts of extractable Mn and Fe in soils. The values of Mn-DTPA-TEA, Mn-AB-DTPA and Fe-AB-DTPA were highly significantly ($P>0.01$) correlated with pH and the

Table 5 Correlation matrix of the amounts of nutrients extracted by different methods.

Elements and methods	Elements and methods				
	Mn-DTPA-TEA	Mn-AB-DTPA	Mn-Mehlich III	Fe-DTPA-TEA	Fe-AB-DTPA
Mn-AB-DTPA	0.958**				
Mn-Mehlich III	0.635**	0.604**			
Fe-DTPA-TEA	0.434**	0.401**	0.325**		
Fe-AB-DTPA	0.288**	0.298**	0.107^{ns}	0.675**	
Fe-Mehlich III	0.346**	0.271**	0.529**	0.710**	0.336**

** significant at the 0.01 levels; * significant at the 0.05 levels; ^{ns} Non-significant at the 0.05 levels.

Table 6 Correlation of some soil properties with micronutrient tests.

Micronutrients	pH in H_2O	pH in 1*M* KCl	Organic C	Olsen P	Bray II P
Mn-DTPA-TEA	-0.270**	-0.205**	-0.198*	0.195*	0.197*
Mn -AB-DTPA	-0.346**	-0.291**	-0.110 ^{ns}	0.169*	0.232**
Mn-Mehlich III	-0.015^{ns}	0.039 ^{ns}	-0.455**	0.200*	0.141 ^{ns}
Fe-DTPA-TEA	-0.011 ^{ns}	-0.031 ^{ns}	-0.151 ^{ns}	0.050 ^{ns}	0.060 ^{ns}
Fe-AB-DTPA	-0.217**	-0.228**	0.110 ^{ns}	0.055 ^{ns}	0.178*
Fe-Mehlich III	0.343**	0.302**	-0.582**	0.129 ^{ns}	-0.112 ^{ns}

** significant at the 0.01 levels; * significant at the 0.05 levels; ^{ns} Non-significant at the 0.05 levels.

relation was negative. The value of Fe-Mehlich III was highly significantly (P>0.01) correlated with pH and the relation was positive. Organic C was highly significantly (P>0.01) correlated with Mn-Mehlich III and Fe-Mehlich III and the relation was negative. In the case of Olsen P the amount of Mn extracted by all the three methods significantly (P>0.05) correlated and the relationship was positive. Bray-II P was highly significantly (P>0.01) correlated with Mn-AB-DTPA and the relation was positive.

CONCLUSIONS AND RECOMMENDATION

This study has shown that the contents of extractable Mn and Fe of all samples were in sufficient range as compared with critical levels from literature. Since many factors may affect response of plants to nutrient addition, calibration with planting on some of the soils is needed to support this conclusion.

The results indicated that the extractable Mn status was in higher tendency in traditional farms than in intensive farms in low and high altitudes. In mid altitude, on the other hand, the extractable Mn in intensive farms was higher than in traditional ones. Extractable Fe status was higher mostly in traditional farms than in intensive farms in all altitudes. The amounts of extractable Mn and Fe by the three methods irrespective of farming practices increased with the increase in altitudes. The relationship between the amounts of extractable Mn and Fe with soil properties indicated that, Mn-DTPA-TEA, Mn-AB-DTPA and Fe-AB-DTPA were highly negatively correlated and Fe-

Mehlich III was positively correlated with pH. Organic C was highly negatively correlated with Mn-Mehlich III and Fe-Mehlich III. Olsen-P was positively correlated with Mn with all the three methods and Bray II-P was highly positively correlated with Mn-AB-DTPA.

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