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Mapping of Fe and impact of selected physico-chemical properties on its bioavailability in the apple orchards of Murree region

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Abstract

A survey was carried out to examine and map the Fe status in the soil and foliage of apple orchards in the Murree region to assess the Fe status. Thirteen apple orchards were selected and surveyed from apple producing area on Union Council basis. Sixty five apple trees were selected to collect plant and 130 soil samples from surface and subsurface profile. Foliage Fe concentration was deficient in 46% of the surveyed apple orchards. AB-DTPA extractant technique was used to determine soil available Fe content. Soils of all apple orchards were adequate in plant available Fe content. Factors positively influencing the availability of Fe content included organic matter, clay and silt, whereas pH, sand and calcium carbonate negatively influenced the availability of Fe in orchard soils. Contradictory behavior of soil and foliage Fe content in terms of no or poor correlation indicated a need to mitigate this contradictory behavior by evaluating various extractants and their critical values for the apple orchards.

Keywords: Apple, Fe, orchards, soil testing, plant analyses, correlation, mapping

Introduction

Iron deficiency is most common phenomenon in the plants, animals and the human being. It is estimated that Fe deficiency affects about 500 million to 2 billion people throughout the world. Iron deficiency is well distributed in the developing countries (Bell and Dell, 2008). In Pakistan average yield of orchards that is about 9 tonnes per hectare and the average yield of apple orchards that is about 3.9 tonnes per hectare is the main concern of this study. Orchard soils located in the calcareous soils of Murree region represent the main apple growing area of the Punjab province (Ahmad *et al*., 2010). Alkaline conditions prevailing in apple orchards soils exacerbate the micronutrient deficiency as the bioavailability of Fe decreases 1000 times for each unit rise in the pH reaching to minimum within the range of 7.4 to 8.5 (Rashid, 2005). Iron is an important constituent of dehydrogenases, ferredoxins and is vital for the photosynthesis and energy transformation. It is involved in the chlorophyll synthesis and oxidation and reduction processes during respiration. It is an essential element for the metabolism due to its redox properties (Tagliavini and Rombola, 2001). Important nutritional disorder caused by the Fe deficiency includes chlorosis. Interveinal chlorosis induced by Fe, results in the yellowing of leaves and pre-mature leaf drop followed by the dieback of twigs and branches. Severe consequences of the Fe chlorosis may be the 20 to 30 percent decrease in the yield of the stone fruits (Cleik and Katkat, 2007). Plant roots absorb Fe from the soil solution but before the absorption, it has to pass through several chemical reactions and processes. Reasons for the appearance of chlorosis not only include Fe deficiency but is also closely associated with the pH, $CaCO_3$, poor aeration, and low temperature of soil resulting in low oxygen content and low microbial activity in the soils. In alkaline soils, rapid microbial respiration may produce sufficient carbon dioxide that reacts with water to form HCO_3^- ion which is taken up by the plants that immobilizes iron within the plants and may consequently leading to Fe deficiency in plants (Basar, 2000). Soil tests are rapid chemical analyses to assess the plant available nutrient status, salinity and elemental toxicities of soil. It also includes interpretation, evaluation, fertilizer and amendment recommendations based on the results of chemical analyses (Peck and Soltanpour, 1990). Plant tests indicate the bioavailability of iron content from the soil to the plants. Iron deficiency is less reported in the orchard soils of Pakistan but the iron deficiency in the foliage of orchards is still prevalent. Usually, no or poor correlations are established for Fe content in the soil and foliage of fruit orchards (Shah and Shahzad, 2008). This might be due to the calcareousness of the soils. Annual removal of iron in orchard is relatively low and Fe content in the soils are usually adequate to meet the demand of trees and observed deficiency in the foliage might be due to several soil related characteristics leading to iron chlorosis. Surveying and mapping for the geo-graphic distribution of micronutrients is a beneficial tool for understanding the micronutrients status. Maps covering large area improve our understanding of the nature and extent of micronutrient deficiency, adequacy and toxicity, and assist in determining their relationship with climate, soil properties and soil genetic characteristics determined at similar scale (White and Robert, 1999; Aishah *et al*., 2010, Shi *et al*., 2007). This research work was conducted for diagnosing and mapping of the iron status of soils and foliage, and to examine the influence of various factors governing the Fe

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bio-availability in the apple producing areas of Murree region.

Materials and Methods

Sampling and processing

A field survey was conducted to determine Fe content and diagnosing the Fe deficiency in the apple orchards of Murree region. Thirteen apple orchards were selected, one from each apple producing Union Council and one orchard each from the Hill Fruit Research Sub Station, Lower Topa and Hill Fruit Research Station, Sunny Bank. Global positioning system (GPS) was used for precise site identification and indicating the surveyed areas in the maps. Maps were prepared by using Arc View GIS software that can be used by the scientific community interested to conduct the research in the area. Diagnostic plant samples, i.e., recently matured leaves in the month of July and August were collected from five trees in an orchard. Samples were collected around the canopy and dried using hot air oven, and processed for analysis. Soil samples were collected from the surface (0-15 cm) and subsurface (15-30 cm) under the canopy of each apple tree. Samples were air dried, ground with wooden mottle and pestle, and passed through 2 mm sieve.

Soil and plant analyses

The soils were analyzed for texture (Gee and Bauder, 1982), pH (Mclean, 1982), $CaCO_3$ content (Leoppert *et al*., 1984), electrical conductivity (Mclean, 1982), organic matter (Nelson and Sommers, 1982) and AB-DTPA extractable Fe (Soltanpour and Workman, 1979). Plant leaf samples were dry ashed and the extract was analysed for Fe by atomic absorption spectrophotometery (Chapman and Pratt, 1961). Critical values used to classify the soil into low, medium, and high in plant available Fe contents included the critical values described by Soltanpour (1985).

Mapping

Base maps were developed for the surveyed area using GPS and GIS technology. Location coordinates were noted with GPS and downloaded in to GIS software to create the digital maps of the area (Figure 1). Arc View GIS 3.2 was used as computerized mapping system in order to prepare GIS database. Maps were prepared to indicate the site specific Fe contents in the soils and foliage of apple orchards (Figure 2 and 3).

Results and Discussion

Physico- chemical characteristics of soils

Information related to physico-chemical properties (ECe, $CaCO_3$, pH and texture) is summarized in Table 1. The soil texture of the surveyed area ranged from sandy clay loam to clay loam. Clay loam was dominant texture distributed over 47% followed by sandy clay loam that was distributed over the 23% of the surveyed area. Clay and loam soil texture constituted 30 % with contribution of 15% each in the surveyed area. Soils located in the Union Councils, Charhan, Murree, Ghel, Ghora Galli, and Hill Fruit Research Station Sunny Bank had clay loam texture. Soil located in the Dewal and Sehr Bagla was loamy in texture, whereas soil texture of Union Councils Derya Galli and Phugwari was sandy clay loam. Textural classes of soils of all apple orchards suggested that soils are suitable to grow apple and other stone fruits and have good ability to supply nutrients to plants. Soils were free from salinity hazard and electrical conductivity ranged from 0.15 to 1.8 dS m^{-1}. Soil pH ranged from 7.2 to 8.4 indicating that soils of apple orchard were slightly alkaline to strongly alkaline. This increasing trend of high pH is the indicator for Fe deficiency due to its low solubility at alkaline pH. Organic matter content (Table 1) ranged from 1.1 to 3.7% signifying that enough amount of organic matter was present for the maintenance of soil aggregation and preventing nutrients from leaching (Milne and Haynes, 2003). Lime content ($CaCO_3$) ranged from 0.43 to 23.7 % and Union Council Charhan had maximum mean value, i.e., 23.7 % whereas the minimum $CaCO_3$ content were minimum in soils of apple orchard located in Union Council Ghora Galli. When compared with the classifying criterion described by Amin and Ikram (2007), soils of ochards ranged from non calcareous to strongly calcareous. Soils of the apple orchards located in Ghora Galli were classified as non calcareous. Orchards located in Union Council Murree, Dewal, Hill Fruit Research Station Sunny Bank, Punjab Fruit Research Station Lower Topa, Sehrbagla, Rawat and Phugwarri were found moderately calcareous. Use of materials like Pyrite as described by Castelo-Branco *et al*. (1999) seems to be necessary for improving the bioavailability of Fe and other micronutrients for good quality fruit production.

Fe status in the soils of surveyed apple orchards

The concentration of bio-available Fe in the upper soil ranged from 8.24 µg g^{-1} to 63.76 µg g^{-1} soil with a mean value of 27.03±14.40. In lower soils, it ranged from 5.78 to 47.96 µg g^{-1} soil with a mean value of 25.12±11.63 (Figure 4). Soils of all surveyed apple orchards were classified adequate in bioavailable Fe content when compared with AB-DTPA soil test values rcommended by Soltanpour, 1985.

Factors influencing the bio-availability of Fe

Factors influencing Fe availability were determined by establishing the correlation coefficient of available Fe with various soil factors responsible for nutrient availability, like organic matter, $CaCO_3$ pH, sand, silt and clay in order to know the extent of these factors to influence the availability of Fe (Table 2).

Effect of organic matter on Fe bio-availability

The results revealed that iron availability was positively

Table 1: Physico-chemical characteristics in the soils of surveyed apple orchards

Site	Soil pH	O.M. (Percent)	$CaCO_3$ (Percent)	Degree of Calcareousness	Texture
Derya Galli	7.61	1.4	18	Strongly Calcareous	Sandy Clay Loam
Murree	7.28	3.0	13.0	Moderately Calcareous	Clay Loam
Ghel	7.49	3.3	15.94	Strongly Calcareous	Clay Loam
Alyot	8.20	1.2	18.7	Strongly Calcareous	Clay
Ghora Galli	7.93	2.6	0.43	Non Calcareous	Clay Loam
*Sunny Bank	7.68	2.8	3.93	Moderately Calcareous	Clay Loam
**PFR	7.93	3.7	6.0	Moderately Calcareous	Sandy Clay Loam
Charhan	7.79	1.08	23.74	Strongly Calcareous	Clay Loam
Dewal	7.80	1.8	1.4	Slightly Calcareous	Loam
Sehrbagla	7.89	2.0	1.0	Slightly Calcareous	Sandy Clay Loam
Rawat	8.29	1.7	7.0	Moderately Calcareous	Clay
Tret	8.42	3.4	17.0	Strongly Calcareous	Loam
Phugwari	8.35	1.6	14.0	Moderately Calcareous	Clay Loam

*Punjab Fruit Research Hill Station, Sunny Bank; **Punjab Fruit Research Hill Station, Lower Topa

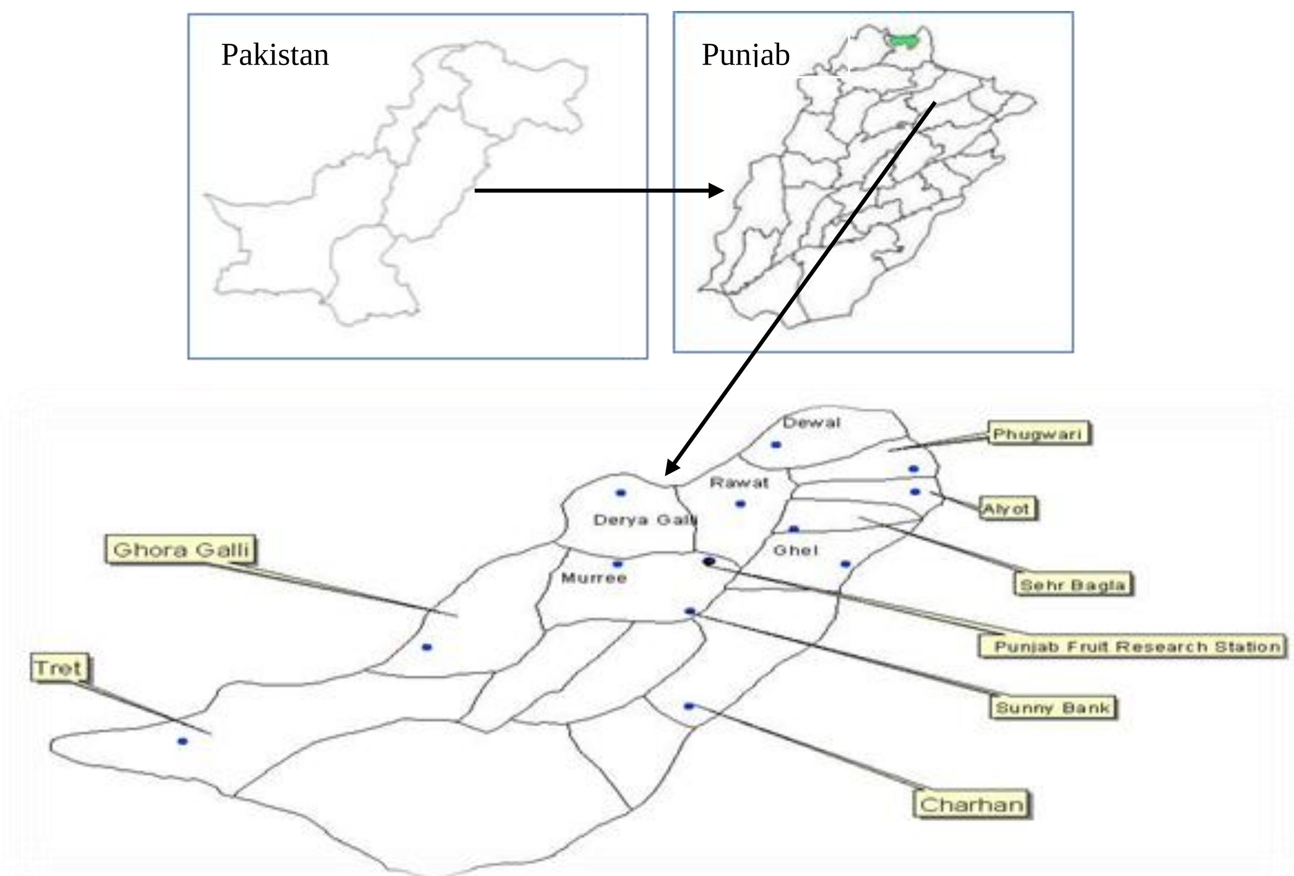

Figure 1: Geo-graphical location of the surveyed area

Table 2: Correlation coefficient values of AB-DTPA extractable Fe content with various Physico-chemical properties of surveyed apple orchard soils

Orchard's Site	pH	O.M.	$CaCO_3$	Clay	Silt	Sand
Derya Galli	-0.15N.S	0.20 *	- 0.52*	0.38N.S	0. 88**	-0.58*
Murree	-0.14N.S	0.65 *	-0.034N.S	0.063 N.S	0.82*	-0.34N.S
Ghel	- 0.62*	0.95**	-0.032N.S	0.13 N.S	0.33N.S	-0.032N.S
Alyot	-0.24N.S	0.95**	-0.47 N.S	0.03 N.S	0.013N.S	- 0.47 N.S
Ghora Galli	-0.46N.S	0.28N.S	- 0.58 *	0.089 N.S	0.49 N.S	- 0.52*
Sunny Bank[1]	-0.36N.S	0.89**	- 0.80*	0.80**	0.56*	- 0.80**
PFR[2]	- 0.60*	0.93**	- 0.88**	0.60*	0.55*	- 0.88**
Charhan	-0.27N.S	0.69*	- 0.51*	0.58*	0.089N.S	- 0.51*
Dewal	- 0.60**	0.57*	- 0.57*	0.58 *	0.58*	- 0.85**
Sehrbagla	- 0.1 N.S	0.91**	-0.047N.S	0.074N.S	0.013NS	-0.047N.S
Rawat	-0.33N.S	0.93*	- 0.87**	0.64 *	0.54*	- 0.87**
Tret	-0.23N.S	0.89**	- 0.86**	0.012 NS	0.68*	- 0.86**
Phugwarri	-0.25N.S	0.88**	- 0.79**	0.73*	0.25N.S	- 0.79**

Sample Size= 130; *$P \leq 0.05$ ** $P \leq 0.01$

[1]Punjab Fruit Research Hill Station, Sunny Bank, N.S Non Significant correlation coefficient

[2]Punjab Fruit Research Hill Station, Lower Topa

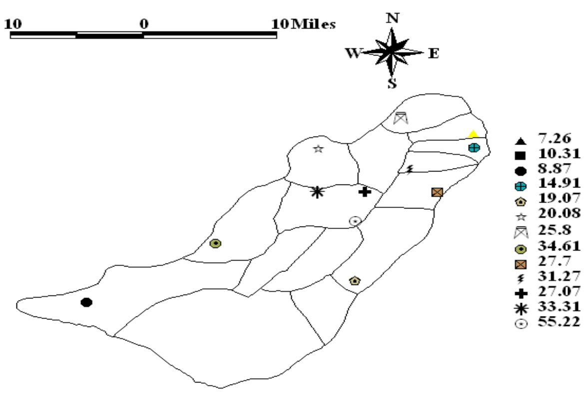

Figure 2: Spatial distribution of Fe content (µg g^{-1} soil) in the profile up to the depth of 30 cm

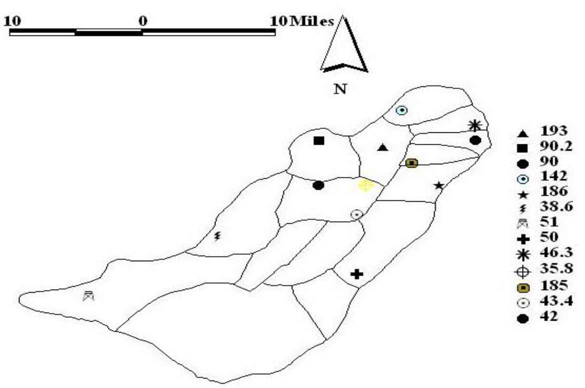

Figure 3: Foliage Fe content (µg g^{-1} DM) indicated in the map exhibiting geo-graphic location of sampled site

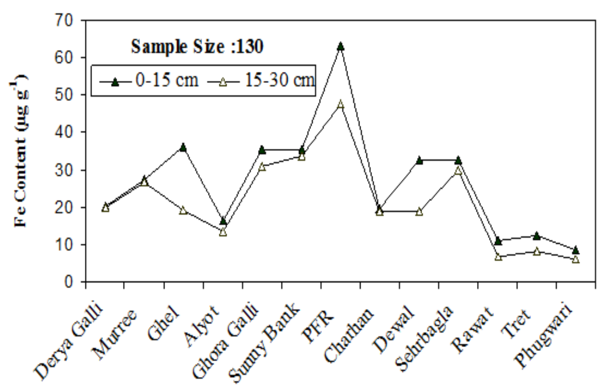

Figure 4: Distribution of AB-DTPA extractable Fe in the surface and sub-surface soils of surveyed apple orchards

influenced by organic matter content present in the soils and significant positive correlation coefficient values were observed for various locations i.e. Derya Galli ($r = 0.20$, $P \leq 0.05$), Murree ($r = 0.65$, $P \leq 0.05$), Ghel ($r = 0.95$, $P \leq 0.01$), Alyot ($r = 0.95$, $P \leq 0.01$), Hill Fruit Research Station Sunny Bank ($r = 0.89$, $P \leq 0.01$), Punjab Fruit Research Station Lower Topa ($r = 0.93$, $P \leq 0.01$), Sehrbagla ($r = 0.91$, $P \leq 0.01$), Rawat ($r = 0.93$, $P \leq 0.05$), Tret ($r = 0.89$ $P \leq 0.01$), Phugwari (0.88 $P \leq 0.01$) , Charhan ($r = 0.69$, $P \leq 0.05$) and Dewal ($r = 0.57$, $P \leq 0.05$). Non significant positive correlation existed between the plant available Fe and the organic matter in the apple orchard located in the Union Council Ghora Galli and had a value of $r = 0.28$. Positive correlations indicated that soil rich in organic matter contain more bio-available fraction of Fe because available soil Fe exists primarily as organic complexes. Soils low in organic matter content is usually low in available Fe and vice versa. Perveen *et al.* (1993) studied micronutrient status of some agriculturally important soil series of the Khyber Pakhtunkhwa Province and their relationship with various physico-chemical properties for 30 soil series. DTPA extractable Fe was sufficient in all soils and positively and significantly correlated with soil organic matter and clay content. Similar results were reported by Khalifa *et al*. (1996) and Goldberg *et al*. (2002).

Table 3: Correlation coefficient values between the foliage Fe content and various soil physico-chemical properties

Physico-chemical Property	Correlation Coefficient Value	Probability Value
Sand	0.492	0.088
Silt	-0.442	0.131
Clay	-0.318	0.289
pH	0.049	0.874
Organic Matter	0.277	0.359
$CaCO_3$	-0.444	0.128
Soil Fe	0.418	0.155

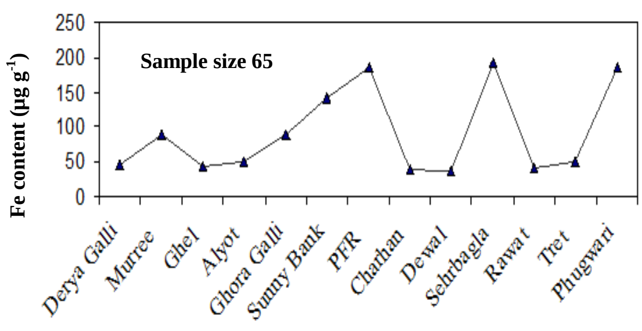

Figure 5: Distribution of Fe content in the foliage of surveyed apple orchards

Effect of silt and clay on Fe bio-availability

Factors positively influencing the availability of Fe also included silt and clay contents. A significant positive correlation was found between siltand Fe content. Correlation coefficient values between the silt and available Fe content were positive at various sites i.e., Derya Galli (r = 0.88, P ≤ 0.01), Murree(r = 0.82, P ≤ 0.01), Hill Fruit Research Station Sunny Bank (r = 0.56, P ≤ 0.05), Punjab Fruit Research Station Lower Topa (r = 0.55, P ≤ 0.05), Rawaat (r = 0.54, P ≤ 0.05), Tret (r =0.68, P ≤ 0.05) and Dewal (r = 0.58, P ≤ 0.05). Non significant positive correlation coefficient values were found in the apple orchards located in the Union Councils Ghel (r = 0.33), Alyot (r = 0.013), Ghora Galli (r = 0.49), Phugwari (0.25), Charhan (r = 0.089) and Sehrbagla (0.013). Clay and Fe were also found to be positively correlated with each other and the correlation coefficient values for various sites were i.e., Hill Fruit Research Station Sunny Bank (r = 0.80, P ≤ 0.01), Punjab Fruit Research Station Lower Topa (r = 0.60, P ≤ 0.05), Charhan (r = 0.58, P ≤ 0.05) Rawat (r = 0.64, P ≤ 0.05) Phugwari (r = 0.73, P ≤ 0.05), Dewal (r = 0.58, P ≤ 0.05) where as a non significant positive correlation coefficient values were observed in the apple orchards located in the Union Councils Derya Galli (r = 0.38), Murree (r = 0.063), Ghel (r = 0.13), Alyot (r = 0.03), Ghora Galli (r = 0.089), Tret (r = 0.012), Sehrbagla (r = 0.074), because iron oxides and hydroxide are found in very fine particles so positive correlation between silt, clay and Fe is the most common phenomenon. Similar correlations were observed by Haque *et al*. (2000).

Effect of sand on Fe bio-availability

Negative correlation between Fe and sand might be due to leaching of Fe from sandy soils. These results were in agreement with Chhabra *et al*. (1996). This negative relationship was significant in the soils of apple orchards located in the Uion Councils Derya Galli (r = -0.58, P ≤ 0.05), Ghora Galli (r = - 0.52, P ≤ 0.05), Rawat (r = -0.87, P ≤ 0.01), Tret (r = -0.86, P ≤ 0.01), Phugwarri (r = -0.79, P ≤ 0.01) , Charhan (r = -0.51, P ≤ 0.05) and Dewal (r = -0.85, P ≤ 0.01) and apple orchards located in the Hill Fruit Research Station Sunny Bank (r = -0.80, P ≤ 0.01) and Punjab Fruit Research Station Lower Topa (r = -0.88, P ≤ 0.01). Non significant relationship was observed in the soils of apple orchards located in the Union Councils Murree (r = -0.34), Ghel (r = -0.032), Alyot (r = -0.47) and Sehrbagla (r = -0.047).

Effect of soil pH on Fe bio-availability

Fe availability to the plants was found to be negatively influenced by the soil pH as significant negative correlation was observed in the apple orchards located in Ghel (r = -0.62, P ≤ 0.05), Punjab Fruit Research Station Lower Topa (r = -0.60, P ≤ 0.05) and Dewal (r = -0.60, P ≤ 0.01) whereas non significant negative correlation was established in the apple orchards located in the Union Councils Derya Galli (r = -0.15), Murree(r = -0.14), Alyot (r = -0.24), Ghora Galli (r = - 0.46), Sehrbagla (r = -0.1), Rawat (r = -0.33), Tret (r = -0.23), Phugwari (-0.25) , Charhan (r = -0.27) and Hill Fruit Research Station Sunny Bank (r = -0.36). Negative correlation established between the soil pH and plant available iron content was not a new phenomenon as Fe availability decreases 1000 times for each unit rise in the pH reaching the minimum within the range of 7.4 to 8.5 (Rashid, 2005). In alkaline soils, rapid microbial respiration may produce sufficient carbon dioxide and reacts with water to form HCO_3^- ion which is taken up that immobilizes the iron within the plants and may consequently leading to Fe deficiency (Basar, 2000).

Effect of $CaCO_3$ on Fe bio-availability

A negative correlation was observed between soil $CaCO_3$ and plant available Fe. This negative correlation was significant at some sites i.e., Derya Galli ($r = -0.52$, $P \leq 0.05$), Ghora Galli ($r = -0.58$, $P \leq 0.05$), Hill Fruit Research Station Sunny Bank ($r = -0.80$, $P \leq 0.05$), Punjab Fruit Research Station Lower Topa ($r = -0.88$, $P \leq 0.01$) Rawat ($r= -0.87$, $P < 0.01$), Tret ($r = -0.86$, $P \leq 0.01$), Phugwari ($r= -0.79$, $P \leq 0.01$) , Charhan ($r = -0.51$, $P \leq 0.05$) and Dewal ($r = -0.57$, $P \leq 0.05$) and non significant negative correlation at Murree($r = -0.03$), Ghel ($r = -0.032$), Alyot ($r = -0.47$), Sehrbagla ($r = -0.047$). Similar results were found by Chattopadhyay *et al*. (1996), Chinchmalatpure *et al*. (2000) and Nazif *et al.* (2006).

Fe status in the foliage of surveyed apple orchards

Foliage Fe deficiency was observed in some of the surveyed apple orchards. Fe content in the leaves of apple orchards ranged from minimum value of 35.36 µg g^{-1} dry matter and maximum value of 195.25 µgg^{-1} with the mean value of 92 ± 60.64 (Figure 5). When compared with the critical values, orchards located in the Union Councils Derya Galli, Charhan, Ghel, Dewal Sehrbagla and Rawat were found low (<50 µg g^{-1}) in Fe content. Fe deficiency in the foliage regardless of its sufficiency in the soils of apple orchards might be due to high pH resulting in the formation of HCO_3- that is taken up by plants and causes the immobilization of Fe in the plants leading to Fe deficiency in the foliage (Basar, 2000). Orchards located in the Union Council Murree, Ghora Galli, Alyot, Tret , Fruit Research Station Sunny Bank, Phugwari and Punjab Fruit Research Station contained Sufficient (>50 µg g^{-1}) Fe content (Figure 5).

Relationship between foliage Fe content and physico-chemical properties of soils

Mean foliage Fe content values were correlated with various soil physico-chemical properties up to 0-30 cm soil profile (Table 3). A positive correlation was established between the soil organic matter and foliage Fe content. This might be due to the formation of stable complexes with Fe by myriad of substances present in organic matter. More efficient compounds involved in complex formation include humic and fulvic acid which make stable complexes due to their high polyelectrolyte nature and high density acidic functional groups (Steevenson and Ardakani, 1972). A negative correlation between the clay content and foliage Fe content might be due to adsorption of Fe to clays that disturbs the cation ecxchange capacity of soils thus upsetting the uptake of Fe by plants (Ellis and Knezek, 1972). A positive correlation between the sand and foliage Fe content might be due to the more downward convectional flow of nutrient towards the deep roots of apple trees which is a dominant way of nutrient uptake by plants (Wilkinson, 1972). A negative correlation between the foliage Fe content and the lime content in the soils was established due to the fact that availability of Fe decreases in the calcareous soils (Robert and Bernard, 1972). A positive correlation between the foliage Fe content in the apple orchards and soil pH and silt might be due to diversified factors influencing the availability and uptake of Fe by plants and need to be investigated, whereas a positive correlation between the foliage Fe content and of soil's Fe content is not an uncommon phenomenon.

Conclusion

Fe deficiency was observed in the foliage of apple orchards, regardless of its adequacy in the soils when compared with the critical values established by Soltanpour (1985). Fe deficiency in the foliage of 46% apple orchards revealed a need for Fe nutrition management in the apple orchards in order to check iron chlorosis and avoid yield and quality losses in the apple orchards of the Murree area. Almost all micronutrient soil tests are used for all types of soils and croplands including grass lands, cereals and orchard soils. There is need to establish correlation between different existing extractants for micronutrient availability in orchard soils and plant micronutrient content for selection of most suitable soil extraction technique because fruit crops have different physiology as compared to the cereal crops and hence the soil under the cereal crops and orchard's soils may not be classified according to a single criterion. Digital mapping indicating the critical values and Fe content will help to efficient and economical nutrient management. Site specific nutrient recommendation should be made available to the farmers so that they may be able to achieve maximum benefits by applying required nutrients.

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