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Soil and Plant Testing for Iron: An Appraisal

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ABSTRACT

Iron (Fe) deficiency chlorosis in crops is common in high-pH calcareous soils. Soil and plant testing is routinely used for diagnosing iron (Fe) deficiency chlorosis in crops, with mixed results. This article presents an overview of the factors that influence soil and plant tissue testing results. It is clear that soil tests for Fe are dominantly influenced by soil pH, bicarbonate, and moisture regime rather soil test result per se. This is because the solubility of Fe is more regulated by soil pH and moisture regime. Plant tissue testing for Fe can complement the results of soil testing for Fe. But at times, especially in calcareous soils, total Fe in plant tissue is not related to Fe deficiency, but metabolically active Fe is better at diagnosing the occurrence of the disorder. A combined use of soil and plant tissue testing seems more helpful in diagnosing Fe deficiency chlorosis disorder in crops.

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Introduction

Soil and plant tests are conducted to assess the nutrient status of soils (Dahnke and Olson 1990; Black 1993; Mills and Jones 1996; Reuter and Robinson 1997). It is of critical importance to assess the inherent nutrient-supplying capacity of the soils, as soils widely differ in their nutrient-supplying capacity, which needs to be considered to make judicious and efficient use of nutrients applied from external sources. The available nutrient status for various nutrient elements determined by soil tests is used for recommending nutrient application from external sources. The basic principle in recommending nutrient application based on soil test result is that the soil test values are proportional to the nutrients that become available during the growing season, although we know that the presence of a certain amount of available nutrient in the soil is no guarantee that it will become available during the growing season (Dahnke and Olson 1990; Black 1993) because other growing conditions such as adequate soil water and the absence of insect pests, diseases, and weeds are necessary for proper crop growth and production (Marschner 1995).

Nevertheless, the soil tests do provide indexes of nutrient availability and help in judicious and efficient use of applied nutrients; however, there is always an element of uncertainty due to other factors that are also necessary for optimum growth and production of plants. The situation is even relatively more unreliable in the soil testing for nutrients such as iron (Fe) because the availability of applied or soil Fe is dominantly determined by factors other than Fe extracted by a chemical reagents such as diethylenetriamine pentaacetic acid (DTPA) (Lindsay and Norvell 1978).

The main objective of this communication is to allude to the factors that make the soil test for Fe rather less reliable. It is important to understand the limitations in the use of soil test results especially for Fe, although as mentioned earlier the soil tests have their value along with certain limitations in their application in practical agriculture. The use of plant tissue testing for diagnosing Fe deficiency chlorosis in crops is also covered by citing examples from published literature. The

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ultimately aim is to improve the diagnosis of Fe deficiency in crops. It is realized that most of the literature dealing with the issues relating to soil and plant testing for Fe is rather dated and little attention has been paid to allude to the problems and overcoming them in the recent published literature; hence this attempt. Extension literature, however, does occasionally bring attention to the difficulties faced in the use of soil and plant testing for diagnosing Fe deficiency chlorosis in crops.

Factors affecting soil and plant testing for Fe

As discussed in the introduction, soil tests for various nutrient elements are used to assess their availability in the soil and to optimize the use of plant nutrients added from external sources for optimum plant growth and production. As such, soil tests play an important role in the judicious use of fertilizers (Black 1993; Sahrawat and Wani 2013).

It is known that Fe deficiency in soils is commonly associated with high soil pH and bicarbonate and low organic-matter content. An important feature of Fe deficiency in the field is that it appears in patches or in irregular areas of the field (Chen and Barak 1982; Rao, Sahrawat, and Burford 1987). On the other hand, Fe toxicity in submerged soils is associated with a toxic amount of reducible Fe in solution, pH in the acidic range (generally water pH < 5.5), low general fertility status, and light soil texture, with preferential occurrence of Fe toxicity to lowland rice in the field (Narteh and Sahrawat 1999; Sahrawat 2004; Sahrawat et al. 1996).

Although Fe is one of the most abundant elements in the earth, Fe deficiency in upland crops is a serious nutrient disorder. This is due to extremely low solubility of Fe in aerated, upland soils (Ponnamperuma 1972).

Iron in soils occurs in ferric [Fe(III)] and ferrous [Fe(II)] forms. In which form Fe occurs is governed by soil pH, presence of bicarbonate, and aeration status of the soil (Rao, Sahrawat, and Burford 1987; Black 1993). Equally importantly, Fe in the ferric form has poor solubility in the soil solution and decreases the availability of Fe to crops. On the other hand, Fe(II) predominates in submerged soils with poor aeration, anoxic conditions, and relatively low pH (Ponnamperuma 1972; Sahrawat 2004).

To sum up, soil pH, aeration status of the soil, presence of bicarbonate, moisture status, and redox condition of the soil determine the availability of Fe to crops rather the amount of extractable Fe in the soil per se. The availability of Fe in the soil is governed by complex interactions among various factors; moreover, it is improbable for a chemical extractant to mimic the complex interactions and predict the availability of Fe to plants in the field (Rao, Sahrawat, and Burford 1987; Sahrawat, Rao, and Burford 1987; Black 1993).

For example, results from Rao, Sahrawat, and Burford (1987) in Table 1 show that there was no difference in soil pH (1:2 soil to water ratio) and the amount of DTPA-extractable Fe, zinc (Zn), and manganese (Mn) (Lindsay and Norvell 1978) in the soil samples collected from the areas in the field with normal and chlorotic growth of groundnut. The results of soil analysis from both normal and chlorotic areas of the field had extractable Fe, Zn, and Mn in the sufficiency range (Sahrawat and Wani 2013). Of course, the soil pH was in the alkaline range.

It should not be entirely surprising if the soil test for Fe does not satisfactorily work in the field because most soil tests for Fe do not discern between the forms of Fe (ferrous or ferric, which control solubility and availability of Fe in the soil); and therefore, in some situations soil test for Fe may have little meaning or value for Fe nutrition of the plants. Thus soil test for Fe might not be consistently

Table 1. Soil pH and DTPA-extractable Fe, Zn, and Mn in surface soil samples taken from areas in the field with normal and chlorotic growth of groundnut.

Source of soil sample	pH	DTPA-extractable nutrients ($mgkg^{-1}$)		
		Fe	Zn	Mn
Normal growth area	8.3	2.5	1.2	3.5
Chlorotic growth area	8.3	2.7	1.3	3.6

Source: Adapted from Rao, Sahrawat, and Burford (1987).

successful in diagnosing the deficiency of Fe in the field. Because more than the quantity of extractable Fe, bicarbonate, soil pH, and moisture status play critical roles in the availability of soil Fe to growing plants (Chen and Barack 1982; Rao, Sahrawat, and Burford 1987) .

Also, the source of Fe applied to the soil affects the quantity of extractable Fe and its availability to growing plants. For example, the use of chelated Fe sources compared to unchelated Fe source enhances the duration and amount of Fe made available in high pH soils, following their application to the soil. The chelated Fe sources keep Fe in solution even at relatively higher soil pH (Sahrawat 1988). Moreover, iron chelates used for supplying Fe to plants also differ in their capacity to keep Fe in soil solution (Marschner 1995).

A study was carried out to determine the efficacy of three sources of Fe [ferrous sulfate ($FeSO_4$), iron ethylenediaminetetraacetic acid (FeEDTA), and iron ethylenediamine-N,N'-bis (FeEDDHA)] added at a rate of 100 mg Fe kg^{-1} soil to two soils differing in soil pH (Vertisol, pH 8.3, and Alfisol, pH 5.8). After fertilization with three sources of Fe, the soils were incubated at –33kPa soil moisture at 30 °C for 8 weeks, and DTPA-extractable Fe was determined periodically. The results (Table 2) showed that FeEDDHA was most effective in both Vertisol and Alfisol soils in maintaining high amounts of extractable Fe during 8 weeks. Both $FeSO_4$ and FeEDTA were completely ineffective in the Vertisol, although they were moderately effective in the Alfisol. It was concluded from the results that FeEDDHA is the most effective source of Fe for soil application in the high pH Vertisols (Sahrawat 1988).

Thus to diagnose the deficiency of Fe in crops, a plant tissue test is considered relatively more useful, but preparing the plant tissue for testing poses problems in that contamination with Fe during sampling and preparing for analysis is challenging to avoid (Mills and Jones 1996; Reuter and Robinson 1997). Moreover, at times total Fe status of plant tissue may not provide a reliable index of the occurrence of Fe deficiency in the crop (Katyal and Sharma 1980; Mehrotra, Sharma, and Agarwala 1985; Rao, Sahrawat, and Burford 1987).

It has been, for example, observed that Fe deficiency chlorosis in groundnut commonly occurs in high pH, calcareous soils such as Vertisols. The chlorosis occurrence is irregular in the field and it gets accentuated during temporary waterlogging with rainfall events. Furthermore, we have observed that waterlogging increased the amount of ferrous Fe in the soil and consequently also increased the amount of total Fe taken up by the crop, although Fe deficiency was accentuated during temporary waterlogging (Rao, Sahrawat, and Burford 1987; Sahrawat, Rao, and Burford 1987). The cause for this anomaly is that along with Fe, bicarbonate is also taken by the crop, which renders the metabolically active Fe (ferrous Fe) metabolically inactive within the plant tissue (Rao, Sahrawat, and Burford 1987). Also, Fe deficiency chlorosis was found to be related to metabolically Fe rather than total Fe in the plant tissue.

Some results summarized in Table 3 clearly illustrate the point that the occurrence of Fe deficiency chlorosis in groundnut, growing on a calcareous Vertisol, was not related to total Fe content in the leaf tissue but was related to o-phenanthroline-extractable Fe in the fresh leaf. The amount of ferrous Fe extracted by o-phenonthroline in fresh leaf tissue seems a better test to diagnose the occurrence of Fe chlorosis in groundnuts, and this technique can be used as an

Table 2. Dynamics of DTPA-extractable Fe (mg kg^{-1}soil) in two soils fertilized (at a rate of 100 mg Fe kg^{-1} soil) with three Fe sources during 8 weeks and incubated at 30 °C.

Soil	Fe source	Weeks of incubation			
		0	2	5	8
Alfisol	$FeSO_4$	18	15	13	9
	FeEDTA	19	16	15	15
	FeEDDHA	25	25	20	20
	SE ±	0.2	0.4	0.2	0.1
Vertisol	$FeSO_4$	7	3	2	2
	FeEDTA	8	2	2	2
	FeEDDHA	19	19	17	14
	SE ±	0.2	0.3	0.1	0.4

Source: Adapted from Sahrawat (1988).

Table 3. Total and o-phenanthroline extractable iron in groundnut (cv. TMV2) collected from field with normal and chlorotic growth of groundnut.

Source of leaves	Extractable Fe ($mgkg^{-1}$fresh tissue)	Total Fe ($mgkg^{-1}$ dry wt)
Normal growth	11.1	69
Chlorotic growth	5.9	95
SE ±	0.53	3.6

Source: Adapted from Rao, Sahrawat, and Burford (1987).

index for selecting groundnut cultivars that resist Fe deficiency when grown on calcareous, high pH soils prone to Fe chlorosis (Rao, Sahrawat, and Burford 1987; Sahrawat, Rao, and Burford 1987).

Conclusions

From this brief overview of literature on soil and plant tissue testing for Fe, it can be concluded that combined use of both soil and plant tissue testing might prove more useful than just soil testing alone. For soil testing, soil pH, bicarbonate, and moisture regime play dominant roles in the availability of Fe to plants. For plant tissue testing, the testing for metabolically active Fe rather than total Fe in the plant tissue might prove more useful, especially in calcareous, high pH soils. Efforts should be made to develop soil testing methods that are able to better discern the forms of Fe in the soil under test. For the use of plant tissue testing to diagnose Fe chlorosis deficiency, there is need for further research to determine whether total Fe or metabolically active Fe is a better index for diagnosing the disorder in a range of crops.

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