Mineral Nutrient Depletion in US Farm and Range Soils

By Michael Karr, Ph.D.

ARCPACS Certified Professional Soil Scientist

I. Summary Conclusion

Agriculture, both crops and livestock, depletes soils of mineral nutrients, because of the removal of nutrients contained in the produce sold. Since the 1950's the increase in farm productivity and efficiency has not always resulted in a corresponding increase in the replenishment of mineral nutrients to the soils through commercially available means. This is because many growers in the US do not have sufficient management expertise to account for or replace all plant nutrient elements removed. In public range and forest tracts leased by ranchers, there has been relatively little effort to replace minerals removed by livestock. Consequently, there is evidence of widespread mineral nutrient depletion in U.S. farm and range soils.

II. Introduction

A. Overview of Report

This report explores the major concepts and relationships between soil formation, soil aging, accelerated soil erosion, and the effects of long-term heavy cropping on soil mineral nutrient supplying power in the United States.[1][1] In general, most soils are mineral soils. In fact, after subtracting out water and air spaces, most soils have over 95% mineral content. However, not all minerals in soils contain nutrient elements. Because of this, soils vary widely in their nutrient content.

B. Terminology

Below are definitions of key terms in this report.

- Rocks are hard inorganic mixtures of minerals. Examples include granite and basalt.
- Minerals are pure inorganic, crystalline compounds, like quartz or garnet.
- Mineral elements - means the inorganic components of soil minerals or plants. Potassium, magnesium, iron, etc. are mineral elements. Not all are good for plants. Minerals containing significant amounts of lead, mercury, arsenic, etc. are not desired in soils.

- Essential mineral elements are chemical elements which are required for the growth and reproduction of plants. Synonyms for this term are essential elements, mineral nutrients, plant nutrients, or nutrients.
- Mineralize means the microbial breakdown of soil organic matter to release its mineral elements.
- Mineral nutrient depletion - in this report, mineral nutrient depletion refers to the loss of supplying power of the soil to provide mineral nutrients relative to the needs of plants.

III. Mineral Nutrients in US Soils

Currently 17 elements (nickel is the newest addition) are recognized as essential for a plant to grow and reproduce with viable seed. Of those, 13 are found in soil minerals.[2][2] Other elements occurring in soil minerals have been demonstrated to provide some benefits to plants, although they have not yet been conclusively shown as essential for a plant to complete its life cycle.

Mineral nutrients are divided into three main categories: macroelements, microelements and beneficial elements. All three categories of mineral nutrients are necessary for a healthy, nutrient-rich plant. Each mineral nutrient is briefly discussed below.

A. Macroelements

Carbon, hydrogen and oxygen make up the backbone of all biomolecules, and are supplied by the air and water. Six other macroelements are found in soils: nitrogen, phosphorus, potassium, calcium, magnesium and sulfur.

Nitrogen is required by plants to make amino acid, proteins, enzymes and the light capturing molecule, chlorophyll. Before plants can use nitrogen, it must be converted from atmospheric N_2 gas to available forms. Lightening and soil bacteria, either free-living or symbiotic in plant roots, can do this in natural systems. [3][3] Nitrogen that is made available by any of these processes must be captured by plants and converted to biomass, otherwise it is lost by leaching or by conversion back to atmospheric nitrogen (N_2)

Phosphorus is the backbone of DNA reproductive and RNA coding for making biomolecules, and is required for energy transfer and use within plant and animal cells. Soil minerals such as apatite are sources of phosphorus.

Potassium is required for moving sugars and carbohydrates within plants, and for plant adjustments to drought conditions. Feldspars and micas are examples of soil minerals containing potassium.

Calcium is required for plant cell walls and root growth. Feldspars, calcite and gypsum are calcium containing soil minerals.

Magnesium is the central element in the chlorophyll molecule, and is involved in the activation and inhibition of enzymes. Biotite, olivene and vermiculite are magnesium sources in soils.

Sulfur is required for plant synthesis of sulfur containing amino acids. Mineral sources of sulfur include gypsum and epsomite. Soil organic matter is also a substantial reservoir of sulfur. Maintaining soil organic matter levels is thus important to maintaining the sulfur supplying power of soils.

The above nutrient elements are the major elements. Generally plant tissue levels for nitrogen and the other macronutrients found in soil minerals range from 1000 to 100,000 ppm (0.1 -10%) on a dry matter basis.

B. Microelements

Equally important to the plant's life cycle, although required in lesser amounts, are the microelements.[4][4] Microelements are generally needed from 0.05 to 100 ppm in dry plant tissue.

Iron, Manganese, Zinc and Copper are often called the metal micronutrients. They are responsible for the extraction of energy from high energy biomolecules like sugars and starches (electron transport chain). They are also heavily involved in the regulation of enzymes that mediate cellular biosynthesis and metabolism. Soil minerals include pyrite, limonite and olivine (iron); manganite, pyrolusite and rhodonite (manganese); franklenite, smithsonite and willemite (zinc); Chalcopyrite, chalcocite, and bornite (copper).

Boron is present in some shales and in mineral tourmaline. Organic matter is also a large potential source of plant-available boron in soils. Boron is involved in the development and growth of new cells (meristems).

Molybdenum is needed for enzymes that convert nitrogen into other forms needed for plant utilization; and is needed by for nitrogen fixation by rhizobium bacteria in the roots of legumes. It exists in very small amounts in various soil minerals.

Chlorine is used by plants to help balance cation/anion charges in plants, to help plants adjust to water stress (osmotic adjustment), and in the photosynthesis process (photosystem II). Soil minerals that contain chlorine include halite and $MgCl_2$.

Nickel is involved in nitrogen metabolism, and is essential for plants supplied with nitrogen in the form of urea.

C. Beneficial Elements

Some are not (or have not yet been) classified as required for all plants to complete their life cycle. A few are listed here, but the actual list may include dozens more. We currently just do not have the knowledge to know how many trace and hyper-trace elements we may need and in what amounts and proportions, and for what nutritional reasons.

Cobalt is essential for microorganisms that fix atmospheric nitrogen into plant-available forms. Granites and other acidic rocks are sources of cobalt.

Increases in plant growth attributable to Vanadium have been reported for asparagus, rice, barley, lettuce and corn.

Sodium can partially substitute for potassium in plants, when potassium is limiting, and helps plants, like sugar beets, resist drought stress.

Silicon contributes to the structure of cell walls, strengthening tissues, reduces water loss and helps regulate some enzyme acitivities.

D. Conditions Required for Plant Nutrient Uptake

Plant absorption of mineral nutrients is dependent upon not only the presence of the necessary mineral nutrients in the appropriate amounts but also the existence of favorable conditions to facilitate absorption.

The nutrient elements must be in the right forms.[5][5] They must be in the soil solution. Plant roots live in an environment of water coated soil particles. The nutrient elements must be dissolved in the water in order for them to get to plant roots for uptake. The nutrient elements must be in the right concentration range. If too dilute, the plants can't get enough of the element. If too concentrated, it may be toxic to plants or prevent the uptake of other elements. The nutrient elements must be close to the plant roots. If a plant root is unable to get close to the nutrient element, perhaps because it is too deep, or because the soil is compacted, then the element will not be absorbed.

In natural systems, living plants capture most of the elements released by decomposing primary minerals, and by decomposing organic matter.[6][6] The small amount that is lost is made up (at least partially) by the release of elements from primary minerals. This continues until the quantity of primary minerals is reduced to the point that it cannot supply enough nutrient elements to keep up with plant demands. In natural systems, this depletion can occur in a few thousand years in warm & very wet climates, or nearly forever in cool dry climates. Removal of nutrients by cropping and grazing accelerates this process.

As plants take up nutrients from the soil solution, the soil solution must be continually re-supplied with nutrients from other reservoirs. Clays and organic matter can adsorb and hold mineral nutrient elements, and then release them to the soil solution as the soil solution is depleted. However the clays must get nutrient elements from the primary minerals in the soils. For the primary minerals to supply enough nutrient elements, the following conditions must exist:

1. The primary minerals must be rich in nutrient elements.[7][7]
2. The primary minerals must be finely divided (very small particles).[8][8]
3. Finely divided primary minerals must be present in sufficient quantities.[9][9]
4. The primary minerals need to be relatively soluble for sufficiently rapid release to occur.[10][10]

External fertilization is practiced to compensate for the limitations on the nutrient supplying power of soil primary minerals relative to the expanding needs of high yielding plants. However, unless all nutrients removed are accounted for though soil and plant tissue testing, and corrected accordingly via fertilization, deficiencies in one or more plant nutrients are likely to occur over time.

IV. Soil Fertility - Genesis and Destruction in Natural Systems

Even before agriculture depletes the mineral nutrient content of U.S. soils, the mineral nutrient content of mature and aging soils is depleted by other natural factors. The composition of primary materials from which soil is formed initially determines the soil's total mineral nutrient content. The secondary clay materials formed from the decomposition of the primary materials can reduce the rate of loss of mineral nutrients, but are not itself a major source of these nutrients. Finally, the weathering process and soil erosion will continue to cause mineral nutrient depletion. Of U.S. soils, the soils in the southeastern United States are the most vulnerable to nutrient mineral losses from natural and human-caused factors.

A. Primary Minerals - The Reservoir of Nutrient Elements

The main reservoir of plant nutrient elements in developing soils are primary minerals in rocks and other parent materials[11][11] that have not been altered chemically since their deposition and crystallization from molten lava. However, some parent materials are composed of nutrient poor primary minerals (granite, aeolian sands, light colored rocks), while other parent materials are composed of more nutrient rich primary minerals (volcanic ash, basalt, dark colored rocks).

Water chemically alters parent minerals that have been physically broken down into small enough particles to create significant surface area. Soils in areas of high rainfall form and age much faster than those in drier areas. As these minerals are chemically altered, they lose silica and release mineral elements, including mineral nutrient elements required by plants. Plants absorb available mineral nutrient elements and release them when their biomass decomposes after they die. In natural systems, new growing plants recapture most of the elements released by decomposing plant residues. Thus the cycling of mineral nutrient elements taken up by plants (when the biomass is not removed) allows them to accumulate in the growing quantity of soil organic matter in developing soils. The cycling, however, is not 100% efficient. Some of these nutrient elements are also lost over time by leaching so a continual re-supply is provided by the decomposing primary minerals for as long as the primary minerals last.

C. Secondary (Swelling Clay) Minerals - The Holder of Nutrient Elements

Secondary minerals are formed from the decomposition of primary minerals, and are re-precipitated into new structures.[12][12] The secondary minerals are ~~first~~ the swelling clays, which have a large negative electrostatic charge. Clays attract and hold elemental nutrient ions released by primary minerals[13][13] and decomposing organic matter. Clays thus reduce the rate of loss of released nutrient elements by leaching, and provide a readily available nutrient source for plants.[14][14]

D. Aging Soils and Nutrient Losses

Old, aging soils, like those found in the southeast US, and the tropics worldwide, are most vulnerable to nutrient mineral loss. In those aging soils the supply of finely divided, nutrient rich primary minerals is limited.

As soils continue to weather, more primary minerals decompose, and the soils eventually lose nutrient elements by leaching. The secondary swelling clay minerals become unstable and fall apart. More silica is lost and the minerals re-form as non-swelling clay minerals. These non-swelling clay minerals have a low electrostatic charge, and thus have a low capacity to attract and hold onto elemental nutrient ions. The supply of primary minerals that contain nutrients to replenish the soils also becomes limited. Finally, for the soils that have been completely weathered, the silica in the non-swelling clay is lost, and the clay falls apart. All that is left are oxides of iron and aluminum, organic matter, and primary minerals too large or too insoluble to break down quickly.

In old aging soils the soil nutrient ecosystem becomes dependent upon the organic matter fraction, i.e. the plants that absorb the nutrients then return them to the soil when decomposing. The organic matter fraction thus contains the bulk of slowly available nutrients. If the land is farmed and crops removed, the soil's fertility is removed with it.

Thus, in old, highly weathered soils, the mineral nutrient content is dependent upon the cycling of organic matter. Erosion and crop removal deplete the organic matter fraction. When the organic matter fraction is depleted the mineral nutrient elements are depleted, and the productive capacity of the soil declines.

V. How Mineral Nutrients Are Depleted in US Soils.

A. Crop Removal and Livestock Operations

The practice of removing part or all of the crops grown from the soil accelerates the loss of nutrients from the soil. The cycling of nutrients from plant uptake and release is interrupted by crop removal. This loss, if not corrected by fertilization, must be made up by nutrient release from primary soil minerals and from soil organic matter.

Heavy tillage of soils adds oxygen which accelerates the decomposition of soil organic matter and increases ~~in~~ the release of nutrient elements. In soils with high levels of native soil humus, this "mining" of soil nutrients can occur over decades with little sign of soil exhaustion. Eventually, the humus content drops low enough so that it cannot supply enough nutrients to feed the crop. Nitrogen is usually the first element that is affected by soil tilling. Since primary soil minerals are not reservoirs of nitrogen, fertilization with nitrogen or rotation with nitrogen fixing crops (legumes) becomes necessary early on to maintain production.

In livestock operations the cycling of nutrients in the soil is also interrupted. Meat and dairy products are sold off-farm, so the organic material is not returned to the soil. In some areas large feedlots have replaced on-farm operations. Typically in large feedlots the manure is not returned to the farm. If the manure created is not returned to the farm, the nutrients contained are lost.

B. Soil Erosion

Soil erosion is particularly devastating on older, more highly weathered soils in the southeast U.S. since the supply of tiny nutrient-rich primary minerals is already limited. Erosion removes the soil organic matter where much of the soil's nutrient reserve exists. Soils that are low in organic matter, or have lost much of it through erosion exhausts the soil's native nitrogen supply quickly compared to soils unaffected by erosion or low organic matter. Erosion of soil organic matter not only causes nitrogen loss, but also loss of other nutrients, including sulfur and boron.

Soil erosion is a problem on privately held lands and public lands alike. For decades, overgrazing on public lands has resulted in soil erosion, which is severe in many areas. This overgrazing plus erosion has reduced the incidence and tonnage of palatable forage species available to livestock. Thus the yield of nutrients from those soils to livestock via forage has been substantially reduced by erosion and overgrazing.

Standards for allowable levels of soil erosion were set by the Soil Conservation Service at 3 - 5 tons/acre/year for most soils. Today, soil erosion in the U.S. is nearly twice that level, although declining due to the implementation of protective measures.[15][15]

C. Increased Nutrient Demand by Higher Yielding Crops

Advances in plant breeding and management expertise have resulted in crops with far higher yield potential. For example, corn yields of 50 bushels an acre were considered quite good in the 1930's. Since the 1960's, corn yields over 200 bushels an acre are not uncommon on more productive soils. This greatly increased demand by the new crops on the nutrient resources of most soils cannot be sufficiently met by natural release from primary minerals and organic matter. Thus the deficiency of the rate of nutrients released by soils for these super crops is induced by the high yield crops' greatly increased demands on the soil.

Usually, the ability of a soil's primary minerals to supply enough phosphorus and potassium becomes limited under high yield cropping because both elements are required in relatively large amounts by plants. Thus, those elements are usually applied as fertilizer salts in conventional farming systems, or as biomass or crushed rocks containing these elements in certified organic systems. Almost all fertilization regimes now require regular inputs of those elements due to the effects of high yield crops.

D. Depletion of Nutrient Bases Creates Soil Acidity

As cropping continues on mature soils, and as soils age in natural systems under leaching conditions, the soils slowly become acidic. As basic nutrient elements like potassium, calcium and magnesium are lost via leaching and crop removal, acidic elements are created or released from clay minerals. There are other sources of acidity in soils (nitrification of ammonium nitrogen), but the loss of nutrient bases, without sufficient replacement by release from primary minerals, eventually leads to acid soils.

In almost all soils, the most abundant available nutrient element is calcium, followed by magnesium. When soils become acid, and those elements are lost, the application of crushed limestone is needed to neutralize the soil acidity, and replace the calcium and magnesium. Federal subsidies to farmers for the application of lime to acid soils was highly successful in the mid-twentieth century. The federal government has discontinued those subsidies and not all farmers have continued adding lime frequently enough to replace the calcium and magnesium removed by cropping and from acids created by nitrogen fertilizers.

E. Development of Micronutrient Deficiencies through Long-Term Crop Removal

The long-term, heavy demands of high-yielding crops on the nutrient supply by soil primary minerals and organic matters may show up as shortages of micronutrient elements (iron, manganese, zinc, copper, boron, nickel, molybdenum, etc.). Many soils are naturally low in available levels of one or more of these elements. But heavy crop demands over time may increase the severity of the deficiency, and begin to exhaust the soil's ability to supply sufficient quantities of other micronutrient elements. Such deficiencies, if mild, often do not show visible symptoms in the plants. A slight yield decline may or may not be noticed. Soil and plant tissue testing are needed to verify these mild deficiencies. Many farmers do not perform these micronutrient tests on plants and soils until the deficiencies become severe enough to be noticed.

If micronutrient deficiencies are identified, soluble sources of those nutrients must be applied to the soil. Foliar applications of micronutrients[16][16] may provide temporary relief, but must be repeated at regular intervals unless the soil deficiencies are corrected. Additions of organic matter or humates (oxidized lignites) may provide organic acids that help speed the release of micronutrient elements from primary minerals, if the necessary primary minerals are present.

F. Western Alkaline Soils

Soils in the more arid regions of the western U.S. are irrigated to supply enough water to grow crops and to leach out salts that may exist in high levels in the soil. In some areas the irrigation water is high in salts so extra water must be applied to prevent salt buildup and leach out the excess salts. When this happens, some nutrient elements are also leached out with the water (nitrogen, potassium, boron, etc.). Those elements must eventually be replaced if soil primary mineral release of these elements cannot keep up with plant demand.

However, sodium, bicarbonates and the natural hardness (calcium + magnesium) of much western irrigation water keeps the soil alkaline. That alkalinity, whether native or induced through irrigation, greatly reduces the solubility of mineral elements like phosphorus, iron, manganese and zinc. Plants cannot absorb insoluble mineral elements. This type of chemically induced "deficiency" is corrected by a variety of strategies, including concentrating fertilizers in a band, foliar feeding micronutrients, soil acidification, growing adapted varieties of crops, increasing organic matter contents through biomass addition, and long rotations with forage crops. Again, sufficient management expertise is needed, or access to such expertise must be utilized, to maintain nutrient levels and balances.

G. Over-Fertilization with Some Nutrient Elements can Create Deficiencies in the Supply of Other Nutrients.

Soils are complex systems, and this fact holds true when considering the plant availability of mineral nutrient elements. Fertilization with highly soluble commercial sources of nutrients has an effect on the plant availability of other nutrients. For example, heavy fertilization with ammonium-N may reduce potassium availability. High levels of ammonium-N or magnesium can reduce calcium availability. However, when high amounts of macronutrients are applied, often micronutrient availability is adversely affected. High applications of nitrate-N may reduce iron availability. Long term phosphorus application will reduce zinc availability and, to a lesser extent, iron availability.

Since most growers fertilize with macronutrients, and fewer test for or apply micronutrients, this form of induced micronutrient deficiency can be a significant problem in many soils.

H. Livestock Grazing on Public Lands

Public lands (Bureau of Land Management; Forest Service) have been leased by ranchers for grazing by livestock for nearly a century. Although the deposition of manure does return some mineral elements to the soils, the nutrients captured in the weight gain the animals accrue is removed. Fertilization of these public lands by the US Government and the lessors is not usually practiced. Thus this slow deficit in nutrient balance has been continuing for a long time.

VI. Solutions to Soil Mineral Nutrient Depletion

The cycling of nutrients that occurs in stable productive natural landscapes is at least partially interrupted when agriculture is practiced. It is an unescapable fact of life that farming removes nutrients from soils, because the foodstuffs and fibers produced are sold to off-farm consumers. Without some nutrient replacement, by whatever means, eventually the rate supply of available mineral nutrient elements by soil primary minerals will slow substantially.

Although soils differ widely in the relative amounts of the various mineral nutrient elements that can become available to plants, there are four principles of managing soil nutrient depletion.

1. <u>Test your soil, water and plants for mineral nutrient elements</u>.[17][17]

2. <u>Add nutrient elements to the soil, as needed.</u>

As stated previously, the elements needed in the greatest amounts and released most slowly into available forms by soil components will need supplementation first. Fertilization with the macronutrients nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur is done in greater quantity and with more frequency than fertilization for the micronutrients iron, manganese, zinc, copper, boron, molybdenum, chlorine and nickel.[18][18]

3. <u>Help to maintain and increase the organic matter content in soils</u>.

Organic matter holds water and mineral nutrient elements, and is itself a source of nutrients. The greater the organic matter content of the soils, the more mineral nutrient elements are cycled under good cropping management. Nutrient loss by crop removal is still unavoidable, but the nutrients left behind will suffer less loss by leaching. In addition, organic acids secreted by decomposing organic matter will help keep nutrients available for plant uptake by complexing them, and by aiding in the dissolution rate of nutrient containing primary minerals.[19][19]

4. Keep the soil on the farm.

Finally, planning and implementing sound wind and water erosion control practices will reduce the loss of the organic matter rich topsoil.

VII. Why the Depletion Is Not Corrected In Many Soils

Although there are procedures and tools to reduce or eliminate mineral nutrient depletion in U.S. soils they are not used adequately by numerous in the agricultural industry. Thus nutrient depletion continues in many farm and range soils across the United States.

A. Knowledge & Varying Management Skills of Farmers

Farmers vary widely in their knowledge about soil fertility and the "Best Management Practices" for food and fiber production. Some rarely test their soils, some only add N-P-K fertilizers, many do not include micronutrient testing in their programs, and some only test and remediate when plant deficiencies are severe enough to be noticed. Since plants often suffer from "hidden hunger," before deficiencies are exhibited externally, the concentrations of the limiting elements in the crops with "hidden hunger" are lower than for well-managed crops.

B. Economics

Agricultural produce, meat, and dairy products are graded for quality on the basis of factors, such as protein content, oil, sugar, shelf-life and crispness; not on levels of specific mineral elements. Although low levels of mineral nutrient elements will adversely affect these indices of quality, it is not the only cause of poor quality. Because of this, mineral nutrient testing is not necessarily the first "suspect" the grower addresses when seeking to improve quality. Moreover, farmers are not paid a premium for produce that is relatively high in trace elements.

Soil, plant and water testing is a good investment, with demonstrated excellent returns. However it is time consuming and not cheap. Fertilization with "chemical" fertilizers is the least expensive short-term solution to nutrient deficiencies.

Using natural inorganic or organic sources of nutrients is more difficult, and usually more expensive. Because nutrient element contents are lower, and nutrient release rates are usually slower, more must be purchased. In addition, hauling and application expenses can be very high. For standard commodity crops like corn, soybeans and wheat; it is very difficult to make a profit using natural sources of elements at current crop prices. For higher cash value crops, it is a more viable alternative.

Practices designed to maintain or increase soil organic matter vary in their economic applicability. Generally they are hard to support economically because the benefits gradually accrue over several years, instead of showing immediate economic returns.[20][20] With current razor thin margins on crop receipts, one needs deep pockets to go this route over the long term.

Planting biomass producing crops that are later turned back into the soil is difficult to do if one expects to maintain a continuous income by crop receipts. A short cover crop is often acceptable only in areas with a long enough growing season so that the main cash producing crop can be planted. Extending the crop rotation sequence to include more forage and other soil-building crops may also be harder to do economically. Interrupting short rotations of high cash value crops with lower cash value soil building crops is a risk many growers are not willing to take.

C. Little Public Pressure and Funding for Mineral Nutrient Replacement on Public Lands.

Nutrient replacement on public lands has not been an issue in the public consciousness for the entire 20th century, simply because it has not been perceived as a problem. The reduction in soil erosion and charging more for grazing rights on public lands has been more a concern by the public. Since 96%+ of the American public is not involved in agricultural production, they do not have the agricultural training or access to information to draw conclusions regarding nutrients removed by livestock grazing and the logging of mature forest trees on public lands.

CONCLUSION

Mineral nutrient depletion continues to be a problem in U.S. farm, forest and range soils. This depletion is caused by natural processes, such as weathering and erosion, particularly in the sensitive soils of the southeastern United States. More significantly, throughout the United States, human accelerated depletion is caused by the production of high yield crops and livestock grazing. Those activities cause nutrients to be removed and organic matter to be depleted from the soil's natural cycling system. Moreover, when commercial growers attempt to replenish the soils of only some mineral nutrients by fertilization they may exacerbate mineral nutrient imbalances. While methods exist to replenish the soil of its mineral nutrients there is a relative lack of knowledge on how to identify all deficiencies and to fully correct them. In addition, the lack of an economic incentive to implement long term, soil-building solutions perpetuates the relative fragility and inconsistency of US soils' nutrient supplying power.

Michael Karr, Ph.D.

ARCPACS Certified Professional Soil Scientist

BIBLIOGRAPHY

Pages from references listed in bold are submitted with the report.

1. Bohn, H.L., McNeal, B.L. and G.A. O'Connor. 1985. Soil Chemistry. Wiley-Interscience. New York. pp. **5-13; 68-80, 87 - 90. 116 -120.**

2. Chadwick, O. A, and R. C. Graham. 2000 Pedogenic Processes. *In.* Sumner, Malcom E., Ed. 2000. Handbook of Soil Science. CRC Press, New York. pp E45-47; E51-52; E57-62; E65-68.

3. Follett, R.F. and B.A. Stewart. 1985. Soil Erosion and Crop Productivity. American Society of Agronomy, Inc., Madison,WI., **pp. 12 -15; 34 - 47; 57 - 62; 339 - 342.**

4. MacCarthy, P. Malcolm, R.L., Clapp, C.E. and P.R. Bloom. 1990. Humic Substances in Soil and Crop Sciences, Selected Readings. American Society of Agronomy, Inc. Madison WI. **pp 2-3. 180-182**.

5. Peterson, G.W., Nizeyimana, E., Miller, D.A. and B.M. Evans. 2000. The Use of Soil Databases in Resource Assessments. *In.* Sumner, Malcom E., Ed. 2000. Handbook of Soil Science. CRC Press, New York. pp **H76-77.**

6. Singer, M. J., and S.Ewing. 2000. Soil Quality. . *In.* Sumner, Malcom E., Ed. 2000. Handbook of Soil Science. CRC Press, New York. pp. G284; G286, **G287-293.**

7. Tisdale, S. L., Nelson, W. L., Beaton, J.D. and J. L. Havlin. 1993. Soil Fertility and Fertilizers, 5th ed. Macmillan Publishing Co., New York.pp **10-11; 45 - 47; 78-79;** 190;230-31; 266 -267; 292,;296; 304;320; 327;332 -333;337 - 339; 342-343; 346; **561-572., 591- 594; 605-606.**

8. Wilkinson, S.R., Grunes, D.L., and M. E. Sumner. 2000. Nutrient Interactions in Soil and Plant Nutrition. *In.* Sumner, Malcom E., Ed. 2000. Handbook of Soil Science. CRC Press, New York. pp **D89 - D104****.

9. Wysocki, D.A., Schoeneberger, P. J. and H. E. LaGarry. 2000. Geomorphology of Soil Landscapes. . *In.* Sumner, Malcom E., Ed. 2000. Handbook of Soil Science. CRC Press, New York. p.E8 - E10.

**** The reproduction quality is poor - the 2000 page book is very difficult to copy in the middle sections

---

[1][1] As is the case when generalizations are made, specific exceptions will not be outlined.

[2][2] The list of essential and beneficial elements will grow somewhat over times, and that one or more beneficial elements will be reclassified as essential (silicon is the strongest candidate).

[3][3] We can copy this process by industrially converting N_2 gas to ammonia (Haber process).

[4][4] Synonyms are micronutrients, and trace elements.

[5][5] For example atmospheric nitrogen gas (N_2) is not in the right form for plants to use. Even though the plants are bathed in this gas, they can become deficient in nitrogen. The nitrogen must be in the ammonium (NH_4+) or nitrate (NO_3^-) forms for uptake.

[6][6] The two major reservoirs of nutrient elements in soils are in the primary minerals~~,~~ and ~~in~~ organic matter. Secondary minerals (clays) have a charge and can attract and hold mineral

nutrient ions, but are not a major source of most nutrient elements. Organic matter contains all the nutrient elements required by plants and animals, although not always in the optimum ratios.

[7][7] Not all primary minerals are good sources of nutrient elements. Soils that have primary minerals poor in nutrient elements will not be able to support optimal plant growth unless these minerals are supplied externally.

[8][8] Very small particles have enough surface area to allow for significant rates of nutrient release. Sand size particles are far too big for this to happen. Physical weathering must break down the minerals into smaller particles before they can become effective sources of nutrient elements.

[9][9] As soils age, the supply of finely divided primary minerals continually decreases.

[10][10] Primary minerals vary in their solubility .

[11][11] Parent material is the original rocks, sediments, wind-blown or other mineral deposits from which soils develop. Rock parent material is gradually broken down into smaller particles by wetting and drying, freezing and thawing of water in cracks, the action of plant roots, and abrasion by moving water & ice.

[12][12] A soil that is very high in primary minerals, and low in chemically altered (secondary) minerals is termed young.

[13][13] As the primary minerals in developing soils are chemically altered, they release silica and other nutrient elements.

[14][14] Soils that are at this stage of weathering are termed mature, and are often at a maximum of fertility.

[15][15] Worldwide, soil erosion is still very high, and the loss of the productive capability of farmland via erosion is still a severe problem.

[16][16] Micronutrients applied to the foliage of plants.

[17][17] Testing requires determining which nutrient elements are limited in supply in a specific soil, what nutrient elements are not getting to the plants, and what elements are being added with the irrigation water. Without testing, one is trying to manage soil fertility blindfolded.

[18][18] Sources of nutrients are numerous. Nutrients can be industrially concentrated or chemically altered from natural sources (industrial nitrogen fixation, acidulated phosphates, synthetic metal chelates, etc.); The rate of release is very rapid, and nutrient loss by leaching, runoff and subsequent pollution of the environment is possible if not managed tightly. Nutrients can come from natural rocks and minerals (limestone, rock phosphate, greensands, etc). Most need to be finely ground to speed the rate of release of nutrient elements. Nutrients can come from biomass off farm (composts, manures, bone meal, fish by-products, etc). Natural and organic sources of nutrients vary in how rapidly nutrients are released, and have nutrients present in lower concentrations, so management practices need to be adjusted accordingly.

[19][19] To do this, one can plant biomass producing crops that are later turned back into the soil, i.e. cover crops and manure crops. One can also include forage and other soil-building crops in the crop rotation sequence. The addition of humates (oxidized lignites) also stimulates plant growth by releasing humic and fulvic acids that are chemically similar to the humic and fulvic acids released by stable soil humus. Humic substances will increase the solubility of phosphorus and metal micronutrients, increase soil water holding capacity, and accelerate the decomposition of and nutrient release from primary minerals. By adopting a reduced or minimum tillage system, the rate of organic matter decomposition will be slowed.

[20][20] Generally reduced tillage systems work well, because they also help to reduce soil crusting and erosion. There are also savings in fuel, labor and machinery wear costs to help.