NARC Publication Serial No. 00173-183/2014/2015

A Handbook of SOIL SCIENCE

Government of Nepal
Nepal Agricultural Research Council (NARC)
National Agriculture Research Institute (NARI)

Soil Science Division

Khumaltar, Lalitpur, Nepal

July 2015

A Handbook of

Soil Science

Government of Nepal
Nepal Agricultural Research Council (NARC)
National Agriculture Research Institute (NARI)

Soil Science Division

Khumaltar, Lalitpur, Nepal
July 2015

A Handbook of Soil Science

Correct citation: SSD 2015. A Handbook of Soil Science. BH Adhikary (ed.), Soil Science Division (SSD), NARC, Khumaltar, Lalitpur.102 p.

Editor: BH Adhikary, Chief Soil Scientist, Soil Science Division (NARC), Khumaltar, Lalitpur

Printed copies: **200 pcs.**

Printed by: Siddhartha Printing Press, Lalitpur. Mobile: 9849627689

Published by: Soil Science Division, National Agriculture Research Institute (NARI),
Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Nepal

Layout and Computer Design: Sushil Lamichhane and Rashila Manandhar K.C., Soil Science Division, NARC, Khumaltar, Lalitpur

Preface

Researcher, Students and academicians in Nepal have constantly felt necessity of reading materials in the field of Soil Science. Recognizing the shortage of text book, Soil Science Division, NARC decided to make a handbook of Soil Science to fulfill the needs of Soil Science researchers, students and soil related academicians to some extent. Different contributors from Soil Science Division have put their effort to bring their articles in the form of this book.

The purpose of this book is to supply or disseminate information's on the role of Soil Science in food production and its implications on the environment. We are aware that soil is the basis of all living things. We grow our crops in soils and the nutrients required by the plants are taken up from the soils. In recent years our soils have been depleted of the plant nutrients because of so many causes such as land degradation, unbalanced use of fertilizers, soil erosion, deforestation, increase in soil acidity, depletion of soil organic matter and so on. We need to protect our soils from depletion of plant nutrients by the generation of appropriate environmentally friendly technologies which help increase our crop productivity. Healthy soils produce healthy crops.

Nepalese agriculture is at watershed, less attention is given to the Soil Science. Many technologies have already been developed but only some of these have been reached to the farmers. We are running short of the productive land and are forced to produce more or increase crop productivity per unit area of land. This is only possible if we can enrich our soils and increase soil productivity.

This book covers some of the important sectors of Soil Science. Information's on GIS, Soil Fertility, Soil Microbiology, Soil Chemistry and Soil Environment are briefly described in this book. I believe that this book will be very much beneficial to the students, farmers, researchers and scientists of the country.

At last, I would like to thank and acknowledge to all the Authors for their great contributions in publishing this book.

Bishnu Hari Adhikary
Chief Soil Scientist

Table of Contents

List of Tables

List of Figures

Chapter 1: Soil Fertility

Causes, Effect and Management of Soil Acidity

Binita Thapa, B.Sc. Ag.
Technical Officer

Introduction

Soil reaction denotes the degree of acidity or alkalinity in a soil and is one of the most important soil properties influencing plant growth. Soil acidity refers to the accumulation of acid – forming cations (such as H^+ and Al_3^+) along with the formation of relatively insoluble Fe- and Al-oxides and their combinations occurs in soils due to continued leaching and crop removal of basic cations (such as $Ca^{2+,}$ Mg^{2+}, K^+ and Na^+). Among the different types of problem for cultivation, soil acidity is a measure problem mainly in hilly and mountain regions of Nepal. When the pH of the soil becomes low the availability of the Al^{3+}, H^+ ions as well micronutrients like Mn, Fe, Cu etc. increased as a toxic level and other plant requiring elements becomes unavailable to the plants.

Causes of Soil Acidity

Parent material

Parent material is what the actual soil is made of. It's usually some type of stone, much the way that sand is pulverized rock. Shale and limestone are more alkaline than acidic, so the soil that results from these rocks tends to have a high pH. Soil that results from granite, which has an acidic chemical composition, will result in more acidic soil. This is one of the reasons that areas near rocky shorelines aren't good for growing plants or crops.

Organic matter decay

Decaying organic matter produces H^+ which is responsible for acidity. The breakdown of organic matter releases carbon dioxide (CO_2), which reacts with moisture in the soil to create trace amounts of carbonic and other weak acids. These acids slowly accumulate, raising the pH of the soil.

Rainfall and leaching

The other way soil becomes acidic is via leaching due to excessive rainfall or irrigation. Too much water results in key nutrients, such as potassium, magnesium, and calcium, being washed out (leached) from soil. These elements all prevent soil from being acidic, so when they're leached out, the pH level of the soil starts to drop, resulting in acidic soil.

Use of fertilizers

The amount of acid added to the soil by nitrogenous fertilizers varies according to the type of fertilizer. The most acidifying are ammonium source of fertilizer because ammonium ion is converted to nitrate by producing hydrogen ions.

$$NH_4+ + 2O_2 = NO_3- + 2H^+ + H_2O$$

When there is more nitrate than the plant can use, the nitrate is at risk of draining – leaching - below the plants roots and into the ground water system. This leaves the soil more acidic.

The other most common fertilizer used is urea which decomposes as follows:

$$CO(NH_2)_2 + 2H+ + 2H_2O = 2NH_4+ + H_2CO_3$$

Two hydrogen ions are consumed for each urea molecule decomposed. This tends to increase pH in the surrounding soil. Likewise, the monocalcium phosphate $Ca(H_2Po_4)_2$ often used as fertilizer can also be a factor to increase soil acidity. It will react with water to form dicalcium phosphate ($CaHPO_4$) and phosphoric acid (H_3PO_4).

$$Ca(H_2PO_4)_2 + H_2O = CaHPO_4 + H_3PO_4$$

The phosphoric acid progressively releases hydrogen ions to the soil to raise soil pH.

$$H_3PO_4 = H^+ + H_2PO_4^- = 2H^+ + HPO_4^{2-} = 3H+ + PO_4^{3-}$$

All reactions in soil have hydrogen ions as a byproduct of the reaction, so are acidifying.

Acid rain

Rainfall becomes acidic due to the presence of carbon dioxide in the atmosphere which combines with rainwater to form weak carbonic acid. Many industries produce waste gases such as sulphur dioxide (SO_2), oxides of nitrogen (collectively known as NOx). These pollutants are converted, through a series of complex chemical reactions, into sulphuric acid, nitric acid or hydrochloric acid, increasing the acidity.

Carbon dioxide + Water = Carbonic acid (weak)
Sulphur dioxide + Water = Sulphuric acid
Nitrogen oxides + Water = Nitric acid

These strong acids completely dissociated to form H^+ ions and sulfate or nitrate anions.

Effects of Soil Acidity

Nutrient toxicity

Soil acidity can lead to elemental toxicities for plants by aluminum, iron, manganese, and zinc due to the increased solubility of these elements at low pH values.

Nutrient availability

The availability of some plant nutrients is greatly affected by soil pH.The “ideal” soil pH is close to neutral, and neutral soils are considered to fall within a range from a slightly acidic pH of 6.5 to slightly alkaline pH of 7.5. It has been determined that most plant nutrients are optimally available to plants within this 6.5 to 7.5 pH range, plus this range of pH is generally very compatible to plant root growth.Nitrogen (N), Potassium (K), and Sulfer (S) are major plant nutrients that appear to be less affected directly by soil pH than many others, but still are to some extent. Phosphorus (P), however, is directly affected. At alkaline pH values, greater than pH 7.5 for example, phosphate ions tend to react quickly with calcium (Ca) and magnesium (Mg) to form less soluble compounds. At acidic pH values, phosphate ions react with aluminum (Al) and iron (Fe) to again form less soluble compounds. The availability of the micronutrients manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and boron (B) tend to decrease as soil pH increases. Most of the micronutrients tend to be less available when soil pH is above 7.5, and in fact are optimally available at a slightly acidic pH, e.g. 6.5 to 6.8. The exception is molybdenum (Mo), which appears to be less available under acidic pH and more available at moderately alkaline pH values. The effect of soil pH on Nutrient Availability is shown in this chart.

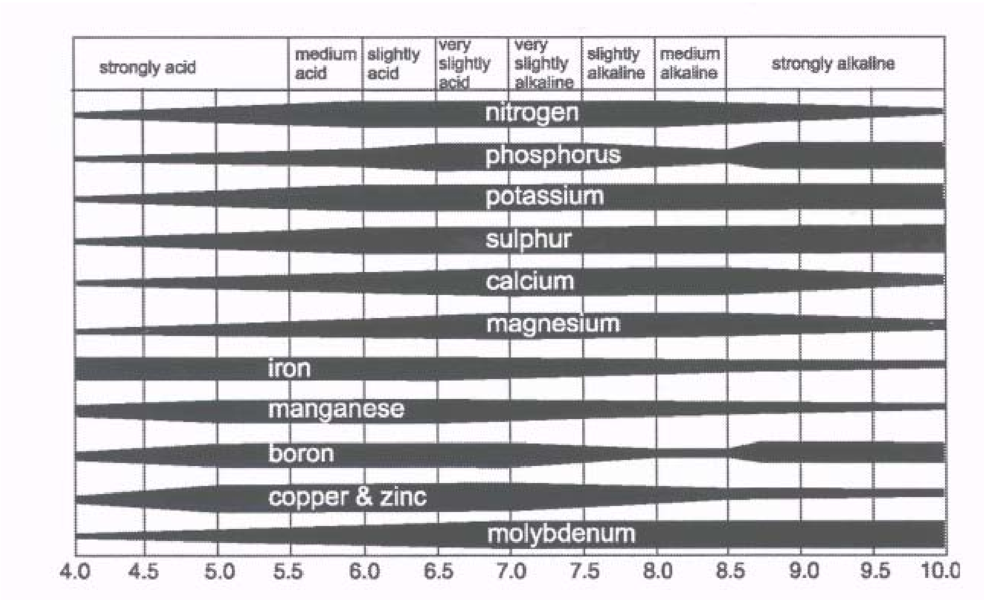


Figure 1: Chart of the Effect of Soil pH on Nutrient Availability

Microbial Activity

Soil reaction has a definite influence / effect on quantitative and qualitative composite on of soil microbes. Most of the soil bacteria, blue-green algae, diatoms and protozoa prefer a neutral or slightly alkaline reaction between PH 4.5 and 8.0 and fungi grow in acidic reaction between PH 4.5 and 6.5 while actinomycetes prefer slightly alkaline soil reactions. Soil reactions also influence the type of the bacteria present in soil. For example nitrifying bacteria *(Nitrosomonas and Nitrobacter)* and diazotrophs like *Azotobacter* are absent totally or inactive in acid soils, while diazotrophs like *Beijerinckia, Derxia,* and sulphur oxidizing bacteria like *Thiobacillus thiooxidans* are active in acidic soils.

Managing Acidity in Soils

- **Liming**
  Soil acidity can only be corrected by neutralizing the acid present, which is done by adding a basic material. Spreading lime remains the most effective remedy for soil acidity. As lime dissolves in the soil, calcium (Ca) from the lime moves to the surface of soil particles and replaces the acidity. The acidity reacts with carbonate (CO3) to form carbon dioxide (CO2) and water (H2O). The end result is neutralization of soil acidity.
- **Reduce Leaching of Nitrogen**
  Use split applications of fertilizer; use lower rates of less acidifying fertilizers like urea, ammonium nitrate and anhydrous ammonia; avoid acidifying fertilisers such as mono ammonium phosphate or sulphate of ammonia; sow crops early; and include perennial rather than annual pastures.
- **Reduce the level of calcium removal**
  Adopt less acidifying rotations (e.g. less legumes) and less hay cutting; use of good irrigation management to minimize leaching.
- **Addition of organic matter**
  Organic matter increases the cation exchange capacity of the soil. As the base saturation increases, the relative amount of "acid cations" decreases. In addition, organic matter forms strong bonds, known as "chelates," with aluminum. Chelation reduces the solubility of aluminum and soil acidity.
- **Additions of wood ash**
  Like organic matter, wood ash increases base saturation and forms chelates with aluminum.
- **Flooding**
  This effect is only good for the time for which the soil is flooded. Flooded or paddy mineral soils are 'self-liming'. When they are flooded and become anaerobic (lack of oxygen in the soil atmosphere) for a period of time, the pH rises toward neutrality even when the soil pH was originally acidic. If the soil is subsequently drained and becomes more aerobic (more oxygen in the soil atmosphere), the pH will return to an acidic state However, care must be taken if the soil contains manganese-oxide minerals, since flooding conditions may lead to manganese toxicity.

- **Encourage maximum growth**
  Sow crops as soon as possible after the first rain: apply adequate nutrients; reduce long fallow; and grow deep-rooted summer-growing perennials.
- **Grow acid tolerant crops**
  Crops like rice, potato, oat, buckwheat, tea, etc. can tolerate acid to some extent.
- **Return plant materials to the paddock**
  Retain crop stubble; feed stock on the same paddock from which hay was cut.

References

Buckles D, B Triomphe and G Sain. 1998. Cover crops in hillside agriculture, Farmer innovation with *Mucuna*. International Development Research Centre, Ottawa, Canada. 230.

Elevitch C and K Wilkonson. 1999. Nitrogen fixing tree start-up guide. Agro-forester. P.O. Box 428 Holualoa, HI 96725. http://www.agroforester.com

Lindsay WL and HF Stephenson. 1959. Nature of the reactions of monocalciumphosphate monohydrate in soils: I. The solution that reacts with the soil. *Soil Sci. Soc.Amer.Proc.* 23:12-18.

McLean EO. 1971. Potentially beneficial effects from liming: chemical and physical. *Soil Crop Sci. Soc. Fla. Proc.* 31:189-196.

Norman MJT. 1979. Annual cropping system in the tropics: An introductionUniversity Presses of Florida. Gainesville, FL

Sanchez PA and Terry J Logan. 1992. Myths and science about the chemistry and fertility of soils in the tropics. *In* R. Lal and P. A. Sanchez (eds.). Myths and science of soils of the tropics. Soil Science Society of America special Publication no. 29.

Soares W, V Edson Lobato, E Gonzalez and GC Naderman, Jr. 1975. Liming soils of the Bazilian Cerrado. *In* Elemer Bornemisza and Alfredo Alvarado (eds.) Soil management in tropical America. Proc. of a Seminar at CIAT, Cali, Columbia, Soil Sci. Dept., NC State Univ., Raleigh, NC. Feb 10-14, 1974.

Thomas GW and WL Hargrove. 1984. The chemistry of soil acidity. Soil Acidity and Liming. Agronomy Monograph No. 12 (2nd Ed.). American Society of Agronomy, Madison, WI. pp 3-56.

Use of Humic Acid in Agriculture

Shree Prasad Vista, Ph. D. (Soil Fertility)
Senior Soil Scientist

Background

Microorganisms in soil work ceaselessly day and night. Due to the biological activities of microorganisms and through chemical and biological humification of plant and animal matters, humic acids (HA) are formed. Humic acids are complex organic molecules that are formed by the breakdown of organic matter. Humic acid influences soil fertility through its effect on the water-holding capacity of the soil. Humic acids make important contributions to soil stability and soil fertility leading to exceptional plant growth and micronutrient uptake. Humic acids contain humic acid and fulvic acid, which are natural and organic in nature. It is a good source of plant nutrients and vitamins. Both macro and micronutrients are available in humic acids. The fertility of a soil is determined by the content of HA. Cation exchange capacity (CEC) and water holding capacity (WHC) of HA are very high. HA bind the insoluble metal ions, oxides and hydroxides and in turn slowly release them to the plants. This unique property of HA helps the plant to obtain plant nutrients as and when required. Those who intend to opt for organic farming HA can be a boon to improve quality and quantity of the produced. Production system is Nepal is largely traditional in remote areas. Under such situation, HA can boost up production and productivity to a large extent.

Benefits of humic acids to soils

Physical

Humic acids have been proved to improve soil structure by restricting nutrient and water losses in light soils. In case of compact soils, soil aeration and water retention are improved. This facilitates easy cultivation to the growers. Therefore, organic farmers can be benefitted more with the use of HA. It has the ability to bind metal ions and under sloppy land type, it can help preventing soil erosion by enhancing the combining ability of soil colloids. It also helps in preventing soil cracking and surface runoff of water, thereby minimizing soil erosion. It loosens the soil thereby increasing soil aeration and WHC of the soil which ultimately support to resist drought. With the use of HA there is higher absorption of solar energy in the soil as it darken the soil colour. Sometimes, less soil solarization may require in soils with continuous use of HA.

Chemical

Chemically, HA neutralize soil reaction. Nutrient and water uptake by plants are optimized as it retain both nutrients and soil moisture for longer period. HA are rich in both organic and mineral nutrients and due to high water retention properties, leaching of nutrients is also minimized to a great extent. It also acts as a natural chelator for metal ions under alkaline conditions and promotes their uptake by the roots. It has high CEC and also promotes conversion of nutrient elements (N, P, K + Fe, Zn and other trace elements) into forms available to plants thereby enhancing its uptake and availability to plants.

Biological

Biologically HA stimulates the plant and activities of microorganisms in soil. It stimulates plant enzymes and increases their production. HA catalyses many biological processes promoting growth and proliferation of desirable micro-organisms in soil. It also enhances plant's natural resistance against disease and pest. Plant root growth is encouraged, especially vertically and enable better uptake of nutrients, better root formation and respiration. HA play vital role in increasing the quality of yields; improving their physical appearance and nutritional value specially vitamin and mineral content of plants.

Ecological

Soils with a high content of humic have low nitrate leaching and better nutrient efficiency. Low content of nitrate is an indicator and a prerequisite for organic agriculture. HA reduces soluble salts in soils thereby decreasing their probable toxicities. Generally, humic acids reduce root burning which comes about through excessive salt concentrations in soils after fertilization. HA are an effective means to fight against soil erosion. This is achieved both by increasing the ability of soil colloids to combine and by enhancing root system and plant development. Humic acids chelate nutrient compunds, especially iron, in the soil to a form suitable for plant utilization. Thus, the nutrient supply of plants is optimized. High increases up to 70% in yield, accompanied by a reduction up to 30% in the use of fertilizers and pesticides, as well as better and healthier growth of greengrass, ornamentals, agricultural crops and woods can be attained with the regular application of first-quality humic acids. Furthermore, water holding capacity of soils is increased considerably, which means that the use of water can be reduced substantially.

Economical

Best economic results can be obtained in light and sandy soils poor in humus as well as on recultivation fields. The diverse positive impacts of humic acids are to be observed particularly in such soils. This is true for almost all soils in dry and warm regions. As a result of the high mineralization rate of organic substances, providing these soils with stable humic acids is indispensable for the maintenance and improvement of soil fertility. It reduces material and labour costs.

Implication of Humic acids in Agriculture

Humic acid is technically not a fertilizer, although in some walks people do consider it that. Humic acid is an effective agent to use as a complement to synthetic or organic fertilizers. In many instances, regular humic acid use will reduce the need for fertilization due to the soil's and plant's ability to make better use of it. In some occurrences, fertilization can be eliminated entirely if sufficient organic material is present and the soil can become self sustaining through microbial processes and humus production. Current researches on humic acids have shown multiple effects on crop plants. When different levels of HA (0, 100, 500, and 1000 mg/L) were applied to nutrient solution, it was found beneficial for plant growth by improving nutrient uptake and hormonal effects. The effect of HA on growth, macro—and micronutrient contents, and postharvest life of gerbera (*Gerbera jamesonii* L.) cv. ‘Malibu’ were examined. Root growth increased at 1000 mg/L HA incorporated into the solution. Macro- and micronutrient contents of leaves and scapes including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn) were significantly enhanced by HA. However, high levels of HA decreased some nutrient contents. Five-hundred mg/L HA increased the number of harvested flowers per plant (52%). Higher HA levels extended the vase life of harvested flowers by 2—3.66 days and could prevent and delay bent neck incidence. These postharvest responses were most probably due to Ca accumulation in scapes and hormone-like activity of HA.

Extraction of Humic Acids (International Humic Substance Society Method)

A number of methods for the extraction of humic substances from soil using mild alkali extractant have been developed and used. Those methods are all generally successful and yield comparable results. However, extraction method developed by the International Humic Substance Society (IHSS) is accepted worldwide and this method for the extraction of humic substances from soils is briefly outlined in this section.

Materials

1. Hydrochloric acid (HCl), 1 *M*, 6 *M*
2. Sodium hydroxide, 1 *M*, 0.1 *M*
3. Potassium hydroxide (KOH), 0.1 *M*
4. Potassium chloride (KCl)
5. Hydrofluoric acid (HF) concentrated, 0.3 *M*
6. XAD-8 resin
7. Visking dialysis tubing [MWCO (molecular weight cut-off)] 10,000 dalton

Method

Step 1

Equilibrate the sample to a pH value between 1-2 with 1 M HCl at room teperature. Adjust solution volume with 0.1 M HCl to provide a final concentration that has ratio of 10 mL liquid/1 g dry sample. Shake the suspension for 1 hour.

Step 2
Separate supernatant from the residue by decantation after allowing solution to settle (or by low speed centrifugation). Save supernatant for XAD-8 isolation.

Step 3
Neutralize the soil residue with 1 M NaOH to pH=7.0 then add 0.1 NaOH under an atmosphere of N_2 to give a final extractant to soil ratio of 10:1.

Step 4
Extract the suspension under N_2 with intermittent shaking for a minimum of 4 hours. Allow the alkaline suspension to settle overnight and collect the supernatant by means of decantation or centrifugation.

Step 5
Acidify the supernatant with 6 M HCl with constant stirring to pH=1.0 and then allow the suspension to stand for 12-16 hours.

Step 6
Centrifuge to separate the humic acid (precipitate) and fulvic acid (supernatant - FA Extract 2) fractions.

Step 7
Redissolve the humic acid fraction by adding a minimum volume of 0.1 M KOH under N_2. Add solid KCl to attain 0.3 M (K^+) and then centrifuge at high speed to remove suspended solids.

Step 8
Reprecipitate the humic acid as in step 5. Centrifuge and discard supernatant.

Step 9
Suspend the humic acid precipitate in 0.1 M HCl/0.3 M HF solution in a plastic container. Shake overnight at room temperature.

Step 10
Centrifuge and repeat HCl/HF treatment (step 9), if necessary, until the ash content is below 1 percent.

Step 11
Transfer the precipitate to a Visking dialysis tube by slurring wiyh water and dialyze against distilled water until the dialysis watr gives a nagative Cl^- test with the $AgNO_3$.

Step 12
Freeze-dry the humic acid.

Step 13
Pass the supernatant from step 2 through a column of XAD-8 (0.15 ml of resin per gram of initial sample dry weight at a flow rate of 15 bed volumes per hour). Discard the effluent, rinse the XAD-8 column containing sorbed fulvic acid with 0.65 column volumes of distilled water.

Step 14
Back elute the XAD-8 column with 1 column volume of 0.1 M NaOH, followed by 2-3 column volumes of distilled water.

Step 15
Immediately acidify with 6 M HCl to pH=1. Add concentrated HF to a final concentration of 0.3 M HF. Solution volume should be sufficient to maintain fulvic acid solubility.

Step 16
Pass the supernatant from step 6 through a column of XAD-8 (1.0 mL of resin per gram of initial sample dry weight).

Step 17
Repeat steps 14 and 15

Step 18
Combine the final eluates from steps 15 and 17 and pass this solution through XAD-8 resin in glass column (column volume should be 1/5 of sample volume). Rinse with 0.65 column volumes of distilled water.

Step 19
Back elute with 1 column volume of 0.1 M NaOH followed by 2 column volumes of distilled water. Pass eluate through H^+- saturated cation exchange resin (Bio-Rad AG-MP-5) using three times the mole of Na ions in solution).

Step 20. Freeze-dry the eluate to recover the H^+- saturated fulvic acid.

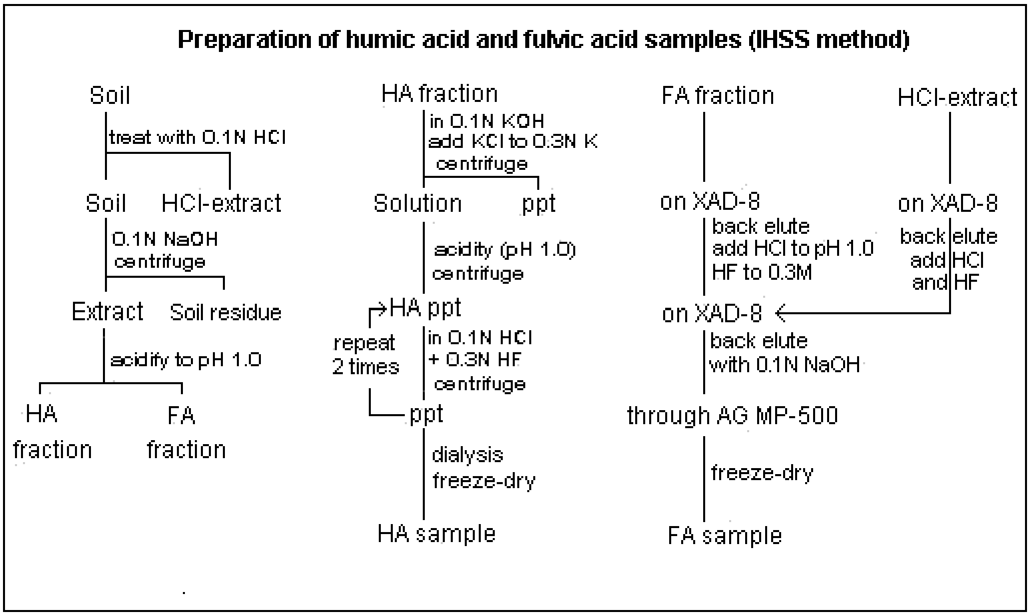


Figure 2: Techniques of humic and fulvic acid preparation.

Economic Rationalization of Phosphorus Crisis and Scope of Sustainable Agriculture in Developing Countries

Shree Prasad Vista, Ph. D. (Soil Fertility)
Senior Soil Scientist
Shyam Kumar Basnet,
Research Scholar, Agricultrual Economics
Swedish University of Agricultrual Sciences

Background

The global population size was 6 billion in 2000 and is forecasted to about 9.2 billion in 2050, 10.4 billion in 2100 and 11 billion in around 2200 with the assumption of current average level of fertility rate being maintained. The population growth rate of developed countries will be more or less stationary till 2035 and start to be a negative. But it is around 1.15 in least developed countries and 0.5 per cent in less developed countries by 2050. In the case of Asia, the population is around 4 million at current year and is expected to rise up to 5.2 million by 2050 (UNPD 2009). Asia continent alone carries over 60 per cent of global population.

Conversion of forest land into agriculture has been increasing rapidly due to rapid population growth. Out of 12 per cent of the globe, the least developed countries alone had 8 per cent in 2005. But the expansion of crop land is being limited due to unsuitability for agriculture purpose and reserved for other usages (UNPD 2007). FAO statistics revealed that there is no substantial room for increment of food production in developed countries. It is projected that the total world cereal production will be 2.4 and 2.9 billion tonnes by 2015 and 2030, respectively. But the harvested land will be 1.5 and 1.6 billion hectares by 2015 and 2030, respectively from 1.4 billion hectares in 2002 (FAO 2005). Per capita food consumption rise from 2789 in 1999/01 to 3130 kcal/person/day by 2050. This increase in world average reveals the rising consumption of developing countries, from 2654 in 1999/01 to 3070 k Cal/person/day by 2050 (FAO 2006). It is thus crucial to increase food production through boosting productivity in developing countries. Agricultural intensification is required to meet the increasing food demand.

Phosphorus is an essential element for the plants and animals. It supplies nutrient to the human beings through either plant (crops, vegetables and fruits), or animals (meat). Phosphorus is usually applied in the form of phosphatic fertilizer and bone meal into the soil to make it available to the plants. Besides, phosphorus compounds are also widely used in explosives, nerve agents, friction matches, fireworks, pesticides, toothpaste and detergents (Darius 2009). But it is an indispensable requisite to meet the increasing demand of crop production.

Phosphorus Production and Demand

Phosphate rock is a finite reserve and non-renewable resource. It is 11^{th} common element abundance in the earth's crust (Syers *et al.* 2008). About 90 per cent of global phosphate rock is extracted for food production and the remaining for industrial application (Cordell 2008). China, the USA and Morocco are the leading phosphate rock producers accounting for 65 per cent of the world in 2007 (Jasinski 2008). Rees (1985) argued that the resource availability depends on annual consumption rates. It is reported the total phosphorus resource and reserves base in the earth's crust was 28.8×10^{15} metric tons and it lasts for 881 years for 2 %, 376 years for 5 % and 200 years for 10 % annual consumption growth rate. It is identified that key non-renewable resources such as oil and phosphate rock follow a Hubbert production curve, indicating a continuous increase of production till to reach a maximum and after that, it will decline, and becomes scarce. Within non-renewable resources, oil can be replaced with other forms of energy, but there is no any substitute of phosphorus. Oil is unavailable once it is used, while the phosphorus can be captured after use and recycled for further usage. The US Geological Survey estimated in 2007 that there were about 18 billion metric tonnes phosphate rock reserves out of 24.3 billion tones (USGS 2008). Jasinski (2006) reported that the supply of phosphorus is estimated to finish in 345 years at 2007's rate of consumption. The Hubbert curve fitting postulated the most likely peak production in around 2033 and start to drop-off (Ward, 2008). But the historical phosphate production data assumed that there were approximately 9 billion tones ultimate recoverable resource of which 6.3 billion tones have already been used and only 2.7 billion tones is remaining in stock. Morrison (2009) reported that about 15 billion metric tons phosphorus resources are a profitable higher-grade mine and estimated for about 100 years, but Sameus (2009) estimated only for 60-90 years at current market prices. About 35 billion tons of lower-grade one will remain further extraction. Ward (2008) categorized the higher-grade as "easy" (e.g. rich island guano deposits places like Nauru) and lower-grade one as "hard" phosphate reserves. The total area under both curves of Fig. 1 is 24.3 billion tones but the purple coloured area denotes the easy reserves and the white area for hard one. It was claimed that peak production of hard one is unpredictable since the unavailability of past production data.The global fertilizer consumption was sharply increased by 5 per cent and of phosphorus by 5.1 per cent in 2006/07. The developing and least developed countries have strong growth in consumption while the developed countries had negative growth rates, especially in Western Europe (Heffer and Prud'homme, 2008). The total fertilizer production is expected to grow from 206.5 to 241 million tones and its demand from 197 to 216 million tones million tonnes during the period of 2007/08 to 2011/12. Fertilizer demand is increasing day by day. The affecting factors of demand can be categorized into macro and micro level. At the macro level, the underlying causes of increasing fertilizer demand are population growth, increasing oil prices and commodity prices, trade, additional agricultural land and technology (FAO 2008).

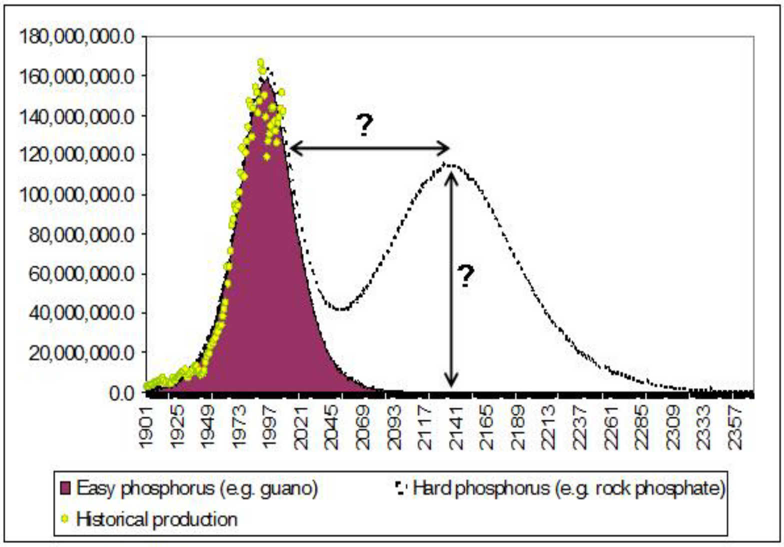


Figure 3: Phosphorus peak production (Source: Ward, 2008)

The population has positive correlation with greater requirement of agricultural crops. Rapidly growing population of the developing and least developed countries demands more food and fibre crop to feed and clothe the additional people, which leads to increase demand of fertilizer. Continuous increase in oil prices induced the growth in agricultural prices as input and also boosts up demand of agricultural crops for the production of alternative energy sources (bio-fuels). Soared bio-fuel production impacts on increasing fertilizer demand for higher agricultural production. High commodity prices due to increased demand lead to increase fertilizer consumption required to support higher levels of production. Expanded world trade increases consumption of goods which ultimately leads to greater fertilizer demand for higher production. Adoption of improved technology such as recycling of organic phosphorus sources, improving nutrient use efficiency, is likely to lead reduction in fertilizer demand. But the technology adoption is slowest in developing and least developed countries. Likewise, the immediate causes of increasing demand at the micro level are fertilizer and other agricultural input prices, product prices, irrigation facilities, improved seeds and credit availability, and promotion and awareness of fertilizer use. In case of Phosphate fertilizer, the expected annual growth rate of world demand and supply is around 2 and 3.2 percent, respectively. By the end of 2011/12, the global phosphate surplus is expected to rise on 2.9 million tonnes from 0.4 million tonnes at 2007/08 (FAO, 2008). Fertilizer demand may be even larger if bio-fuels expansion continues and economic growth of developing countries even soars up (Tenkorang and Lowenberg-DeBoer 2008). It is estimated that the demand from Asia will increase by 2.4 per cent annually, but the dependency on import will reduce relatively. But there is no substitute of phosphorus in agriculture (USGS, 2009) and cannot be manufactured or synthesized (Cordell 2008). Thus, this increased demand decreases the phosphorus production over the clock and provokes the world price due to higher cost of processing of lower quality one (Jasinski 2008). In all, it will be sure of completing the phosphate reserve in the future, but the matter of discussion is only the time duration.

Nutrient Flow and Environmental Threats

Soil-Plant interaction in relation to phosphorus uptake is essential to understand for improving the efficient use of phosphorus fertilizer. Since the phosphorus ions are highly immobile in soil solution, loss from leaching is very uncommon. Mainly, phosphorus ion concentration in the soil solution and P-buffer capacity of the soil determine the rate and extent of phosphorus uptake (Syers *et al.* 2008). It is necessary to have a certain amount of phosphorus in the soil to obtain an optimal crop yield. Phosphorus deficient soil can not yield crop maximum and phosphorus enriched soil too can not do the same. Soil erosion and removal of crop residues are the main causes of phosphorus losses from soil (Smith et al. 1999). Soil erosion sweeps away phosphorus to the rivers and lakes, and causes eutrophication- the over-enrichment of reserved water bodies. Intensified agricultural farming has been increasing with excess use of fertilizers in developing countries and is likely to increase eutrophication (Holliday and Gartner 2007). Excess growth of biomass on nutrient enriched water bodies causes suffocation to fish and other aquatic organisms and ultimately leads to loss of aquatic biodiversity (Horrigan, et al. 2002). Soil erosion and landslides are very common in LDCs. Intensive agriculture farming in LDCs is inviting an alarming situation both in aquatic environments and natural resource management. Loss of phosphorus from the harvest of the above ground portion of the crop is sizeable than of nitrogen and potassium (KSU 1988). In addition, crop residue removal also exaggerates the soil erosion (Al-Kaisi and Guzman 2007). It thus causes nutrient loss in the short run and negative effect on soil quality, water quality and agriculture sustainability in the long run. Cordell *et al.* (2009) presented a system approach to understand the phosphorus cycle, particularly in global food production and consumption. The inner white area is anthrosphere –human activity system and the outer one are natural environment. In the above figure, it is shown that about 14 million metric tonnes phosphorus are being lost from different sources of organic phosphorus such as animal manure, human excreta, crop residues and household food waste and 8 million metric tonnes from arable soil every year through erosion.Within these sources, disposal of human excreta carries about 3 million metric tons phosphorus into water bodies every year. In the very past days, there was no this loss from land but in today, all this goes to landfills as sludge.

Domestic animals harvest a large amount of phosphorus from vegetation, but more than 50 per cent of it is getting loss to the natural environment. In developing countries, the animal manure has been used as fuel for cooking as a substitute of firewood and cooking gas at a massive scale. The rising crisis of petroleum gas and firewood has extensively induced the use of animal manure as the energy source of cooking. Generation of alternative energy sources such as biogas makes possible to recycle phosphorus of animal manure into the soil. In addition, efficient use of manure and composting bolster the soil management in a sustainable way.

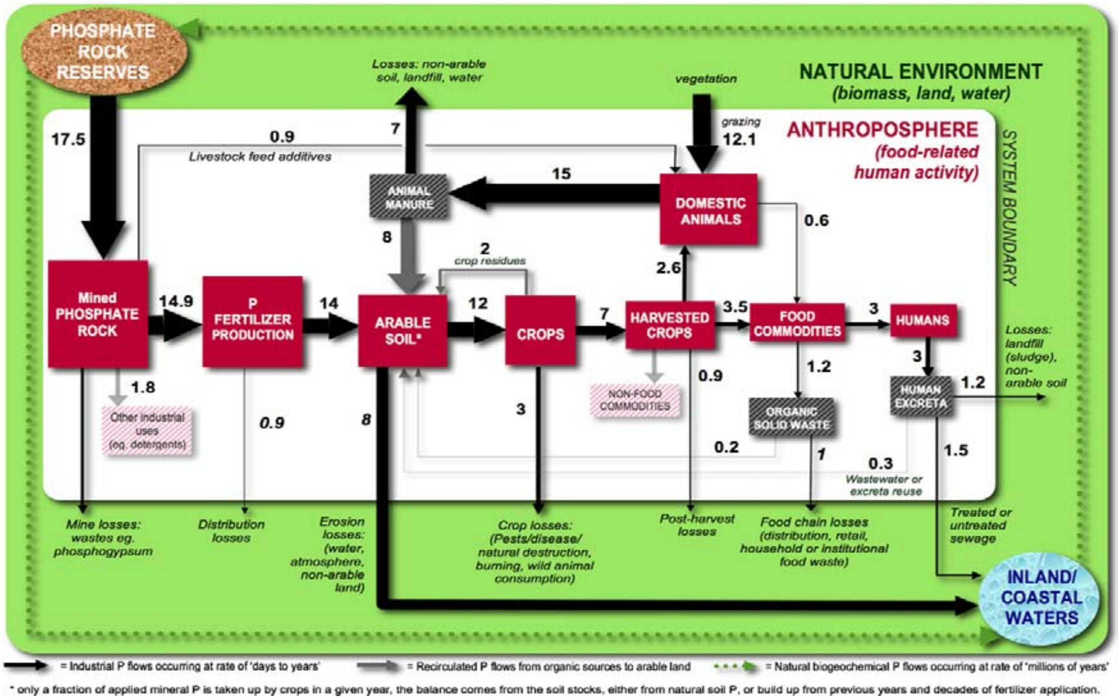


Figure 4: Flows of phosphorus through the global food production and consumption system Units are in million tonnes per year. (Source: Cordell et al. 2009).

Phosphorus Use and Sustainable Management

Crop production lead to removal of phosphorus from soil in the products and residues. This removal should balance from successive fertilizer applications for sustainable management. But the application at higher doses than required is unwise from both environmental and economic sides. In developing countries, farmers do the maximization of crop output and minimization of input use, which lead to the development of phosphorus deficit soil. In most developed countries, soils are enriched with phosphorus while it is deficient in many developing countries (Weikard and Seyhan 2009). Desai and Gandhi (1990) reported that the removal of primary nutrients by crop production was increased by 70 per cent between 1961 and 1984. During the period of 1970-96, fertilizer use in developing countries was increased rapidly in Asia due to rapid population growth and growing food demand. The developed countries increased their fertilizer consumption very marginally due to very low population growth and stagnated agricultural exports (Matthews and Hammond 1999). The fertilizer consumption growth rate in Asia was the highest among the developing countries. In case of phosphorus, consumption in Asia has doubled over the past 10 years and is forecasted to grow at an annual rate of 5 per cent over the coming 5 years (Belmehdi and Nyiri 1990). But Asia is poor in phosphorus resource and has to depend on import to increasing food requirement. Use of both organic matter and fertilizer is essential to increase the soil productivity and crop yields. But use of organic phosphorus through recycling crop and animal wastes is not enough to maintain soil fertility and supply of phosphorus by chemical fertilizer is necessary (Zhu and Xi 1990). Phosphorus resources are existed only in a few parts of the world in control of handful countries. Vlek *et al.* (1997) estimated that the nutrient requirement for developing world would be double by 2020. Later on, Zhang and Zhang (2007) reported that fertilizer consumption depends on human population. They argued that the growing world population causes to intensify the use of fertilizer nutrients and increase the world's total fertilizer consumption by 32.1 per cent and of phosphorus by 25.8 per cent by 2030 against the current level. Consumption in Asia would increase by 54 to 55 percent by the same year, while it was forecasted to decline continuously in Europe. This supports the call for efficient use of fertilizer and adoption of different cropping practices made by Vlek *et al.* in 1997. Nutrient management is thus becoming prime importance due to increasing population pressure on food demand and land resources (Grote *et al.* 2005). Recycling and reusing of crop and animal wastes, though less sizeable, recover phosphorus and reduce the mine phosphorus requirement (Cordell 2009). In addition, minimizing fertilizer cost-to-crop yield ratio can be achieved through the improvements in farming systems and recycling methods of municipal and industrial wastes (Liang and Bang 1990). Struvite crystallization from animal waste is a successful and promising technology for the recovery of phosphorus (Burns and Moo, 2002). However, recycling of animal waste along with crop residue through composting is the easiest and least energy-intensive method of recycling phosphorus and can continue indefinitely (Hren 2008). Urine diversion from faeces matter in the toilet makes the farmers easier to collect it as liquid fertilizer. It could provide more than half the phosphorus to fertilize cereal crops (Cordell *et al.* 2009). Thus, proper management of agronomic practices and maximum use of recycled crop and animal wastes reduce the pressure of the high demand of phosphorus fertilizer for sustainable agricultural production in developing countries.

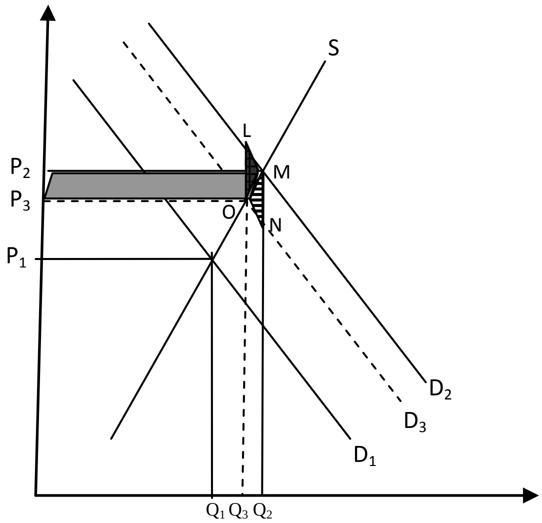


Figure 5: Gains and Losses from nutrient management and recycling

Economic viability and Comparative Advantage

Farmers can obtain profitable yields and minimize adverse environmental impacts by adopting proper management of phosphorus fertilizer and choice of cropping systems. Because of increasing practices of using manure for fuel and grazing animals over the common areas, manure is in short supply in developing countries (Waskon 1994). This poor supply of manure or compost brings serious economic consequences. Farmers have been applying many phosphorus fertilizers, but the productivity is low. Integrated farming with animal and crop enterprises do the recycling nutrients in the soil and makes the ecosystem healthy and sustainable. It is noteworthy to maintain the principles of minimizing imports by maximizing opportunities for recycling, maximizing resource use efficiency and making soil ecosystem healthy (Cornish and Oberson 2008).

In the above graph, D_1 is the present demand curve of phosphorus fertilizer, and P_1 and Q_1 are the current price and quantity demanded, respectively. The demand curve will shift from D_1 to D_2 in future due to the factors other than phosphorus fertilizer price, but the supply varies with its own price. The quantity demanded will increase from Q_1 to Q_2 and the price from P_1 to P_2. The developing and least developed, especially Asian, countries have to import the whole increased amount since they don't have own production. But those countries can adopt better management practices to increase fertilizer use efficiency and bring down the demand curve at D_3 and the quantity demanded at Q_2. The consumer surplus of developing countries will increase by a grey coloured area –P_2MOP_3 and get marginal benefits of an area of a triangle-MNO from reduced import consumption and environmental cost. In the same way, the environmental damage cost for fertilizer production will be reduced by an area of triangle –LMO due to less demand and less production. At the producers' side, there seems an apparent loss in producer surplus, but won't be an actual loss in market since there is a sort of oligopoly market of finite phosphate reserves. They can produce and sell at any future time with optimal extraction. They can enjoy with reduced environmental damage and can optimize the extraction for a longer time period. Thus, the developing countries have to focus on research and extension to identify and promote nutrients recycling opportunities to reduce phosphorus imports and the farmers of them should be alert on the potential costs of over-depleting soil phosphorus. In this way, adoption of best fertilizer management practices and recycling opportunities in the developing and least developed countries can provide the comparative advantage to both phosphate fertilizer producing and consuming countries.

Conclusion

This chapter outlines how increasing phosphorus production and demand invites environmental threats and future phosphorus crisis. It examines phosphorus nutrient flow and its management for the comparative advantage and economic viability of developing and least developed countries. Most developing countries do not have phosphorus reserves and their requirement is dependent on imports. The fastest growing population of developing nations has been demanding more phosphorus to grow food production. The continuous depletion of finite, non-renewable rock reserves has been leading towards decrease production and increase marginal cost of production. Inefficient use of fertilizers and soil management is inviting eutrophication in reserve water bodies. Soil erosion, removal of crop residues and wastage of manures are the main causal factors of losing phosphorus from agriculture. Recycling of municipal and industrial wastes and struvite crystallization are the new technologies to recover the phosphorus loss. But many developing countries have a far access to these technologies at present. Management of cropping practices such as composting is the easiest and least energy-intensive way to recover phosphorus in soil. Generation of alternative energy sources such as biogas will increase the use of animal manure into the soil. Adoption of such management practices leads to lessening the pressure of increasing demand and provides comparative advantage and economic viability to the phosphorus poor countries. Thus, increasing farmers' awareness of better cropping practices and the ill-effects of imbalance use of fertilizers on the environment help to minimize the growing environmental risk and maximize economic incentives.

References:

Al-Kaisi M and Guzman J. 2007. How residue removal affects nutrient cycling. Integrated Crop Management, Iowa State University, Department of Agronomy, May 21. Available at: http://www.ipm.iastate.edu/ipm/icm/2007/5-21/cycling.html

Belmehdi A and Nyiri KF. 1990. Phosphorus Fertilizer use in Asia and Oceania. Pages 85-95 in Phosphorus requirements for Sustainable Agriculture in Asia and Oceania. International Rice Research Institute (IRRI), Manila, Phillipines.

Burns RT and Moo LB. 2002. Phosphorus Recovery from Animal Manures using optimized struvite precipitation. Proceedings of Coagulants and Flocculants: Global Market and Technical Opportunities for Water Treatment Chemicals, May 22-24, Chicago.

Cordell D.2008. Eight reasons why we need to rethink the management of phosphorus resources in the global food system. The Story of P Information Sheet 1, Global Phosphorus Research Initiative, Institute for Sustainable Futures, University of Technology, Sydney (UTS) Australia and Department of Water and Environmental Studies, Linköping University (LiU) SWEDEN. Available at: www.phosphorusfutures.net

Cordell D. 2009. The story of phosphorus.Institute for sustainable futures and University of Technology, Sydney.

Cordell, D. *et al.* 2009 [b]. The story of posphorus : Global food security and food for thought. Global Environment Change, doi:10.1016/j.gloenvcha.2008.10.009.

Cornish PS and Oberso A. 2008. New Approaches to Phosphorus Regulation and Management. 16th IFOAM Organic World Congress, Modena, Italy, June 16 – 20. Availabale at: http://orgprints.org/view/projects/conference.html

Darius VR. 2009. Phosphours, a key element in all plant (and animal) life.Daves's Garden, January 14. Available at: http://davesgarden.com/ guides/articles/ view/ 1990/.

Desai GM and Gandhi V. 1990. Phosphorus for Sustainable Agricultural Growth in Asia: an assessment of alternative sources and Management. Pages 73-83 in Phosphorus requirements for Sustainable Agriculture in Asia and Oceania. International Rice Research Institute (IRRI), Manila, Phillipines.

FAO. 2005.Summary of World Food and Agricultural Statistics 2005. (Food and Agriculture Organization). United Nations: Rome.

FAO. 2006. World agriculture: towards 2030/2050. Interim report on Prospects for food, nutrition, agriculture and major commodity groups. Global Perspective Studies Unit. (Food and Agriculture Organization). United Nations: Rome.

FAO. 2008.Current World Fertilizer Trends and Outlook to 2011/2012. (Food and Agriculture Organization). United Nations: Rome.

Grote U, Craswell E and Vlek P. 2005. Nutrient flows in international trade: Ecology and policy issues. Environmental Science and Policy. 8: 439-451.

Heffer P and M Prud'homme. 2008. Outlook for World Fertilizer Demand, Supply and Supply/Demand Balance. Turk J. Agric. For. (32), pp: 159-164.

Holliday VT and Gartner WG. 2007. Methods of soil P analysis in archeology. Journal of Archeological Science, 34, pp: 301-333.

Horrigan L, Lawrence RS and Walker P. 2002. How sustainable agriculture land address the environmental and human health harms of industrial agriculture. Environmental Health Perspectives, 110(5), May.

Hren S. 2008. The Carbon-Free Home: 36 Remodeling Projects to Help Kick the Fossil-Fuel Habit. Chelsea Green Publishing, pp: 189.

Jasinski SM. 2006. Phosphate Rock.Mineral Commodity Summaries. USGS. USA.

Jasinski SM. 2008. 2007 Minerals Yearbook.Phosphate Rock (Advance Release). US Department of the Interior, US Geological Survey, August, pp: 56.1-56.3.

KSU (Kansan State University). 1988. Phosphorus Facts: Soil, Plant and Fertilizer. Cooperative Extension Service, Manhattan, Kansas, October, pp: 1-8.

Liang ZZ and Bang XZ. 1990. Recycling phosphorus from crop and animal wastes in China.Proceedings of a Symposium on Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania. International Rice Research Institute (IRRI), Phillipines, Manila.

Matthews E and Hammond A. 1999. Critical Consumption Trends and Implication: Degrading Earth's ecosystems. World Resources Institute, pp: 1-72. Available at: http://nzdl.sadl.uleth.ca/cgi-bin/library?e=d-00000-00---off-0envl--00-0--0-10-0---0---0prompt-10---4-------0-1l--11-en-50---20-about---00-0-1-00-0-0-11-1-0utfZz-8-00&a=d&cl=CL1.1&d=HASH01d3eac93725c2e617a9536b.5.2

Morrison L. 2009. Enough Phosphorus for the Future. February 15. Available at: http://cornandsoybeandigest.com/inputs/fertilizer/0215-enough-future-phosphorus/

Rees JA. 1985. Natural Resources: allocation, economics, and policy. Taylor and Francis, pp: 17.

Sameus E. 2009. Phosphote rock is a non-renewable resources. 3R Environmental Technologies Ltd. 26th January. Available at :www.3ragrocarbon.com

Smith VH, Tilman GD and Nekola JC. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine and terrestrial ecosystems. *Environmental Pollution.* 111(1-3): 179-196.

Syers JK, Johnston AE and Curtin D.2008. Efficiency of Soil and Fertilizer Phosphorus use: Reconciling changing concepts of soil phosphorus behaviour with agronomic information. FAO Fertilizer and Plant Nutrition Bulletin 18, United Nations, Rome.

Tenkorang F and Lowenberg-DeBoer J. 2008.Forecasting Long-term Global Fertilizer Demand. Food and Agriculture Organization of United Nations: Rome.

UNPD. 2007. Rural Population, Development and the Environment. (United States Geological Survey) (Wall Chart), Available at: http://www.un.org/esa/population/publications/2007_PopDevt/2007_PopDevt_Rural.htm

UNPD. 2009. World Population Prospects: The 2008 Revision. (United States Geological Survey). Available at: http://esa.un.org/unpp

USGS . 2008. Mineral Commodities Survey 2008, January, pp: 125: United States.

USGS. 2009. Mineral Commodities Summaries. (United States Geological Survey). US Department of the Interior: United States.

Vlek PLG, Ruhne RF and Denich M. 1997.Nutrient resources for crop production in the tropics. Phil. Trans. R. Soc. Lond. B., pp: 975-985.

Ward J. 2008. Peak phosphorus: Quoted reserves vs. production history. Energy Bulletin, August 26.

Waskon RM. 1994. Best Management Practices For Phosphorus Fertilization. Colorado State University Cooperative Extension, Bulletin # XCM – 175, August.

Weikard HP and Seyhan D. 2009. Distribution of Phosphorus resources between rich and poor countries: The effect of recycling. *Ecological Economic*. 68 (6): 1749-1755.

White S and Cordell D. 2008. Peak Phosphorus: The Story of P Information Sheet 1, Global Phosphorus Research Initiative, Institute for Sustainable Futures, University of Technology, Australia and Department of Water and Environmental Studies, Linkoping University (LiU) Sweden. Available at: www.phosphorusfutures.net

Zhang WJ and Zhang XY. 2007. A forecast analysis on fertilizers consumption worldwide. Environmental Monitoring and Assessment, 133 (1-3), October, pp: 427-434.

Zhu Zhao-liangandXi Zhen-Bang. 1990. Recycling Phosphorus from crop and animal wastes in China.Pages 115-123 in Phosphorus requirements for Sustainable Agriculture in Asia and Oceania. International Rice Research Institute (IRRI), Manila, Phillipines.

Soil Fertility Management in Organic System

Shova Shrestha, M.Sc. (Soil)
Soil Scientist

Overview

Soil is the main source of plant nutrition. Nutrients are the primary building blocks for plant growth and development. When a nutrient is missing, plants shows symptoms of stress or deficiency. Plants are primarily made up of carbon (C), oxygen (O), and hydrogen (H). Since it's acquire these elements from carbon dioxide (CO_2) and water (H_20), they are not considered soil nutrients. Soil nutrients that are in the largest amounts in plants are Nitrogen (N), Potassium (K), Phosphorus (P), Calcium (Ca), Magnesium (Mg), and Sulfur (S), are called macronutrients. Plant micronutrients are nutrients found in smaller amounts in plants, but are essential for growth and development. These micronutrients include Chlorine (Cl), Iron (Fe), Boron (B), Manganese (Mn), Zinc (Zn), Copper (Cu), Molybdenum (Mo), and Nickel (Ni). Continuous cultivation in the same field, without considering the inert soil fertility cause decreases the production and productivity of the land. Researchers have recognized the decreasing the status of soil fertility in the country and have recommended the use of organic source of nutrients to increase the soil fertility and crop productivity. Prior to the introduction of the chemical fertilizer, organic manure was the main source of the plant nutrition. After the introduction of the chemical fertilizers, farmers are more attracted towards chemical fertilizer and neglect organic source of plant nutrition. Over a century, Hills and Mountains farmers are following the traditional farming practices, which is similar to organic farming. However ,many of them have no idea that their traditional practices is called organic agriculture. The traditional farming knowledge and skill give the positive point for promoting the organic agriculture in Nepal. And government of Nepal has formulated policy providing certain subsidies in organic fertilizer and certification process of organic products.

Organic farming aims to create an economically, socially and environmentally sustainable agriculture.The emphasis is placed upon self-sustaining biological systems, rather than reliance on external inputs. Organic farming is much more than simply replacing synthetic inputs with natural ones, though it is described as this. The International Federation of Organic Agriculture Movements (IFOAM) defines organic agriculture as "*a whole system approach based upon a set of processes resulting in a sustainable ecosystem, safe food, good nutrition, animal welfare and social justice*. Organic production therefore is more than a system of production that includes or excludes certain inputs. A common phrase used to characterize organic growing "feeding the soil, not the plant". Organic matter is maintained in the soil through the addition of compost, animal manure, and green manures and the avoidance of excess tillage and nitrogen applications. Another common aspect of organic agriculture is growing plants without synthetic fertilizers or pest control chemicals. Management of soil fertility is one of the major challenges facing the organic grower. Soil fertility needs to consider soil nutrient status, soil physical condition and biological health. When organic nutrients are added to the soil, microbial activity increases. In this sense, organic farmers are “feeding the microbes. Increased microbial activity and improves soil physical properties. If microbial activity increases, soil tilth improves. In addition, microbial activity speeds nutrient cycling, increasing the availability of nutrients for plant uptake Organic farming aims to build up, or at least maintain, soil nutrient reserves whilst at the same time maximizing nutrient recycling and reducing external inputs.

Organic source of plant nutrition are usually by product of farming and related industries from plant and animal sources. The main constraint of organic source of nutrient applied in field (Like compost) are bulky, slow releasing nature of nutrients, and lack of raw material for preparing the compost and FYM in Nepal. In organic Farming, farmers are depending upon the inherent soil properties for plant growth. Soil fertility’ can be considered to be a measure of the soil’s ability to sustain satisfactory crop growth, both in the short- and longer-term. Organic farming recognized the soil as being central to a sustainable farming system.

Soil organic matter as centre of organic system

Organic matter is an important constituent of every soil. There are four main components of soil: mineral matter, organic matter, air and water. Mineral matter is made of sand, silt and clay size particles. The soil water contains dissolved minerals and is the main source of water and nutrients for plants. The air in the soil is needed for plant roots and soil microorganisms to obtain oxygen. Organic matter includes plant and animal materials in various stages of decomposition. Soil organic matter has numerous functions in soil.

Soil pH buffering capacity

Organic matter has the ability to moderate major changes in the soil pH. Soil p^H is a measure of acidity or alkalinity as determined by the amount of positively charged hydrogen (H^+) ions in the soil solution. Organic matter buffers the soil against major to hit in pH by either taking up or releasing H^+ into the soil solution, making the concentration of soil solution H^+ more constant result isstable pH close to neutral aresuitable for the specific crop to be grown.

Soil structure and tilth

The arrangement of these primary soil particles into aggregates is the soil structure. Soil structure affects the size and the distribution of soil pores, which are important for the movement of air water for root penetration. The bad soil structure leads to poor root penetration reducing access to nutrients, impeded drainage, poor microbial activity, soil erosion and ultimately decrease the yield of crop.

Soil erosion

The degree of surface soil aggregation will determine how tightly the soil particles are held during rain or wind. Stable soil aggregates resist movement by wind or water because they are larger than primary particles of silt or clay. Soil pores created by aggregation also promote water infiltration, thereby reducing runoff and erosion.

Reduce environmental pollutants

Soil organic matter buffers the soil from rapid changes in soil pH. It also binds organic pollutants, keeping them out of the soil solution where they would be taken up by plants or leached into ground water. Organic matter also provides sites for microbes to colonize and decomposes organic pollutants and it sequesters carbon and can mitigate greenhouse gas emissions which is emerging issue on of global warming and its connection to human activities that promote greenhouse gas emissions (Carbon dioxide or CO_2, methane or CH_4, nitrous oxide or N_2O). Carbon sequestration or storage in soil is considered a means to reduce greenhouse gas (CO_2 or CH_4) emissions.

Soil Organic Matter Building with Different Sources

Cover Crops

Cover crop improves soil quality and it helps to reduce the weeds infestation. Cover crop incorporated into the soil as a green manure, increase soil organic matter content. The cover crops conserve the added nutrients and feed microbes. It has following activities in soil

- It improves the soil biology activities.
- It decreases arthropod pests in soil
- It helps to reduce the weed infection in field.
- It increases the soil organic matter
- It helps to decrease disease in crop
- It also helps to decrease leaching and soil erosion.

Crop rotations and minimum tillage

Farmers must consider long-term cropping rotations in organic farming system.The nutrient application and utilizationcan be considered for the entire cropping cycle rather than on individual crop-by-crop basis. Tillage smoothes the soil surface and reduces natural soil aggregation and earthworm channels. Porosity and water infiltration are decreased following most tillage operations.

Using legumes as nitrogen sources

Organic growers are using legume cover crops as green manures in rotations to meet the N needs of crops. Through asymbiotic association with the legumes, *Rhizobia* bacteria convert atmospheric N_2into an organic form that the legume uses for growth. The accumulation of N in cover crops depends on the length of the growing season, climate, and soil conditions. Legume residues contain phosphorous, potassium, and other nutrients that are recycled in relatively available forms for subsequent crop use. Legume cover crops can provide nitrogen for subsequent crops without contributing to problematic increases in soil P, K, and trace metal concentrations.

Green manuring

Green manuring is the effective method to meeting the nutrient requirement in vegetable as well as paddy crop .In Nepal, many farmers in Hill and Terai using the various plants as a green manure. In Hills, farmer used Titepati (*Artemesia Vulgaris*) Banmara (*Eupatorium adenophorum*) Asuro (*Adhatoda Vacica*) and in Terai Dhaincha (*Sesbania Cannabina*) in the low land and Sunhemp (*Crotolaria Juncea*) in upland condition. The other legumes crop like Mungbean, Cowpea, Crotolaria also used as green manuring practice in paddy as well as cash crops. Some of the plant material using as manuring in Hills and their nutrient content are given below (Table 1).

Table 1: Nutrient content of locally available plant materials.

Plant species	N%	P%	K%
Asuro (*Adhotoda vasica*)	4.3	0.88	4.49
Titepati (*Attemesia vulgaris*)	2.3	0.42	4.90
Khirro (*Sapium insigne*)	2.79	0.79	0.89
Banmara (*Eupatorium Spp*)	2.35	0.71	5.43

Source: (Maskey and Bhattarai, 1984)

Mulches

Mulches are organic materials that are spread on top of the soil and left on the soil surface, rather than being incorporated into the soil. Like winter cover crops, mulches can protect soil from the impact of falling rain and soil erosion and can help to reduce weed pressure.

Compost

Compost is an excellent source of organic matter. Composting is closed the recycling loop by turning waste materials into a soil amendment. Organic matter, whether in compost or soil, originates from living plants, animals, and other organisms. Organic matter consists mostly of C but also includes many other nutrients, such as N, P, K, Ca, Mg, Fe, S, and others. The ratio of C to N (C: N) is one factor in determining how quickly N will become available for plant uptake. Compost with a low C: N ratio will provide mineral N quickly. More C-rich compost, with a C:N ratio of approximately 20:1 or higher, decrease mineral N availability in the weeks following application. This temporary reduction in mineral N is called immobilization. It occurs as soil microorganisms decompose the compost and use its C, N, and other minerals for their own growth and population. In addition to C:N, the total N content is also important in planning amendment applications and estimating the amount of nitrogen that will become available over a single season. Compostare great for enhancing the physical condition of soil while building soil organic matter that serves as a slowrelease reservoir of nutrients.

Manure

Animal manures vary in nutrient content and nutrient availability. Rain will leach nutrients out of the manure, so storing manure under a roof or plastic cover will retain more nutrients. The type and quantity of animal bedding will affect nutrient availability.The quantity of nutrients in manures varies with type of animal, feed composition,quality and quantity of bedding material, length of storage and storage condition. In organicsystems, it is particularly important to conserve manure nutrients for both economic and environmental reasons.

Cattle urine

Cattle urine is used as liquid manure and organic pesticide. Nitrogen is the most important macronutrient for plants, which is high crop productivity, can only be achieved by making sufficient nitrogen available to crops. Nitrogen is also the most limiting nutrient in farms across Midhillsregions in Nepal. Cattle urine is a viable alternative to mineral fertiliser. Of the nitrogen excreted by cattle, 60% is found in the urine and only 40% in dung. In traditional shed in Nepal, urine is left to be absorbed in the bedding material and the excess urine is drain out of the shed. Nepal government, Department of

Agriculture focus on improved cattle shed and urine collection for increase the crop yield and reduced the chemical input. Improved cattle sheds mostly designed with the intention to collect urine in pit or drum. This pit is generally located in the shed itself or just outside connected to the drainage channel and protected from sunshine, rainfall and runoff water. Where urine is collected for incorporation in farmyard manure, the pit may be directly connected to the manure pit or heap. Urine that is going to be used as liquid manure or organic pesticide which is use alone or fermented with other botanicals and be stored in a drum for fermentation and apply in crop mixing with water in different concentration depend upon the stage and type of the crop.

Vermicompost

Vermicomposting is a simple biotechnological process of composting, in which certain species of earthworms are used to enhance the process of waste conversion and produce a better end product. The application of organic matter including vermicompost favorably affects soil pH, microbial population and soil enzyme activities (Maheswarappa *et al*. 1999). It also reduces the proportion of water-soluble chemical species, which cause possible environmental contamination(Mitchell and Edwards 1997). In Nepal, vermicompost is gaining popularity among the organic as well as conventional growers in Nepal. Municipal yard waste includes leaves, brush and grass clippings that are collected curbside in most municipalities as used as composting making as well as the use as feeding materials for vermicompost.

Bacterial fertilizer

Nitrogen is the most limiting nutrient for crop growth and development. Atmosphere around earth contains about 76 percent of nitrogen however this element Nitrogen cannot be taken neitherbyplant or by animal directly to meet their nutrient requirements. Bio fertilizer is a substance which contains living microorganism, when applied to seed, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant. Bio-fertilizers add nutrients through the natural processes of nitrogen fixation, solubilizing phosphorus, and stimulating plant growth through the synthesis of growth-promoting substances. Bio-fertilizers reduce the use of chemical fertilizers and pesticides and it is eco- friendly and economically viable.

Organic fertilizers

Most organic fertilizers contain a variety of nutrients, but the amounts are not necessarily balanced according to plant needs or soil availability. There are different commercial nutrient sources on organic farms however in Nepal. Lime and Bone meal are mostly used for organic grower as well as conventional growers in Nepal.

There are some commercial nutrients sources on which can be used in organic farm as well as Conventional farming system.

Agricultural Lime

Most of Nepal soils are acidic. These acidic cations replace calcium, magnesium, and potassium on cation exchange sites in the soil. Generally, acidic conditions are not favorable for vigorous plant growth. Plant nutrient availability is strongly tied acidity of the soil solution. Decreasing soil pH directly increases the solubility of manganese (Mn), zinc (Zn), copper (Cu), and iron (Fe). At pH values less than approximately 5.5, phytotoxic levels of Mn, Zn, or aluminum (Al). Liming increases soil $p^H$and also supplies significant amounts of calcium (Ca) and magnesium (Mg), depending on the source of the lime. Indirect effects of liming include increased availability of P, molybdenum (Mo), and boron (B). Liming also produces more favorable conditions for microbial population and increase processes of nitrogen fixation and nitrification.

Phosphorus Sources

Rock Phosphate

It is not readily available for plant use in soils with pH above neutral. In order for rock phosphate to become plant available, the acidity of the soil solution must dissolve the P into a plant-available inorganic P. So that checks the pH of your soil prior to applying rock phosphate as your P source. Organic grower in different part of the world used Rock phosphate to increase the Phosphorus content in Soil.

Bone meal

This byproduct of the livestock industry is well known among the organic growers. Bone meal also should be applied to soils that have a pH below 7 to provide the necessary acidic soil solution for the P to convert to plant-available P.

Potassium Sulfate and Potassium

These two sources of K_2O are commonlyused in both organic and conventional agriculture. Both products are available innatural deposits, although most potassium sulfate fertilizer is manufactured by causing reaction between sulfuric acid and potassium chloride with a high electrical current.

Feldspar

One of the major potassium bearing minerals of granite, feldspar powder is fairly easily obtained through the ceramics trade. However, most feldspar K_2O is as tightly bound within its mineral structure as is the K_2O in green sand.

Biotite (Black mica): Black mica andcertain other micas contain several percent total K_2O. Because of mica's physical structure, the K_2O is relatively available in microbial active environments.

Conclusion

Managing soil fertility for crop production can be challenging. Soil management requires knowledge of crop nutrient requirements, soil nutrient residual levels, and the types and characteristics of organic fertilizers that will be used. Nutrient sources include organic amendments, are cover crops, green manure, compost etc. The soil organic matter functions as a reserve of slow-release nutrients that can provide some nutrients throughout the growing season, as well as in years to come and play a vital role in sustainable organic farming. There are many kind of organic sources of fertilizer are found in Nepalese as well as world market however locally available organic source of nutrient should be encourage to used the farmer. Organic certification body certifies the organic product also based on input use in farm so have to consider the rule and regulation before apply the fertilizer use in crop for sale the organic product in international market. Soil fertility management in organic farming could be complex and integrated approach however in long term it contributes the healthy soil and healthy life. In Nepal, organic farming is increasing and the world market of organic food also increasing day by day so it leads to increase the engagement in organic farming business which could be trigger great opportunity to local employment and enhance the local resources use in farming which ultimate improved the economic condition of people.

References

Bhattarai S,Maskey SL, Gami SK and Shrestha RK. Training manual on IPNS. Soil Science Division . Nepal Agricultural Research Council.

CooperbandL.2002. Building soil organic matter with organic amendments. University of Wisconsin-Madison, Agricultural center for integrated agriculture system.

Elliott AL, Davis JG, Waskom RM, Self JR and Christensen DK. Phosphorus fertilizer for organic farming system.http://www.ext.colostate.edu/pubs/crops/00569.html. Access in 2.7.2015.

http://www.mofga.org/Publications/MaineOrganicFarmerGardener/Fall2006/Basics of Organic Soil Fertility/tabid/518/Default.aspx access in 30.6.2015

http://www.safs.msu.edu/soilecology/pdfs/OrganicFarming.htm

http://www.safs.msu.edu/soilecology/pdfs/OrganicFarming.htm. Access in 30.6.2015.

Maheswarappa HP, Nanjappa HV and Hegde MR. 1999. Influence of organic manures on yield of arrow root, soil physico-chemical and biological properties when grown as intercrop in coconut garden. *Annals of Agricultural Research* 20(3):318–323

Mitchell A and Edwards CA. 1997. The production of vermicompost using Eisenia foetida from cattle manure. *Soil Biology and Biochemistry.* 29:3–4http://ejournal.icrisat.org/agroecosystem/v2i1/v2i1vermi.pdf Access in 1.7.2015

Nagavallemma KP, Wani SP, Stephane Lacroix, Padmaja VV, Vineela C, Babu Rao M and Sahrawat KL. 2004. Vermi-composting: Recycling wastes into valuable organic fertilizer. Global Theme on Agri. ecosystems Report no. 8. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. http://ejournal.icrisat.org/agroecosystem/v2i1/v2i1vermi.pdf Access in 7.1.2015

Chapter 2: Soil Chemistry

Basic Principles of the Different Instruments Used in Soil Science Laboratory

Dinesh Khadka, M.Sc.(Soil)
Technical Officer

Most of the analytical methods used for soil and plant analysis involve some kind of instrument. Therefore, it is very important to know about the basic principles of the instruments in order to get the reliable results. The most commonly used instruments in soil and plant analysis are given below:
1. Spectrophotometer
2. Flame photometer
3. Atomic absorption spectrophotometer (AAS)

Spectrophotometer

The spectrophotometer has well been called the workhorse of the modern laboratory. In particular, ultraviolet and visible spectrophotometry is the method of choice in most laboratories concerned with the identification and measurement of organic and inorganic compounds in a wide range of products and processes. It is an instrument that measures the amount of photons (the intensity of light) absorbed after it passes through sample solution. In soil science lab, it is use to determine carbon (C), phosphorus (P), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), sulphur (S) and boron (B) content of samples. The spectrophotometer can be classified based on the different purpose:

Classification based on the range of wavelength of light source

There are 2 kinds of spectrophotometer based on the range of wavelength of light. They are:

i. **UV-visible spectrophotometer**: it uses light over the ultraviolet range (185 - 400 nm) and visible range (400 - 700 nm) of electromagnetic radiation spectrum.
ii. **IR spectrophotometer**: it uses light over the infrared range (700 - 15000 nm) of electromagnetic radiation spectrum.

Classification based on the beam of light

There are 2 major classifications of spectrophotometer based on the beam of light. They are:

i. **A double beam spectrophotometer:** It compares the light intensity between 2 light paths, one path containing the reference sample and the other the test sample.

ii. **A single beam spectrophotometer:** It measures the relative light intensity of the beam before and after the test sample is introduced. Although comparison measurements from double-beam instruments are easier and more stable.

Component of Spectrophotometer

A spectrophotometer, in general, consists of two devices; a spectrometer and a photometer. A spectrometer is a device that produces, typically disperses and measures light. A photometer indicates the photoelectric detector that measures the intensity of light.

Spectrometer

It produces a desired range of wavelength of light. First a collimator (lens) transmits a straight beam of light (photons) that passes through a monochromator (prism) to split it into several component wavelengths (spectrum). Then a wavelength selector (slit) transmits only the desired wavelengths.

Photometer

After the desired range of wavelength of light passes through the solution of a sample in cuvette, the photometer detects the amount of photons that is absorbed and then sends a signal to a galvanometer or a digital display.

The spectrophotometer consists of five parts. They are as follows:

a) Light source
b) Monochromator
c) Sample compartment
d) Detector

Light source

In spectrophotometer, two kinds of lamps, a Deuterium for measurement in the ultraviolet range and a tungsten lamp for measurement in the visible and near-infrared ranges, are used as the light sources of a spectrophotometer.

Monochromator

It is use to isolate the wavelength of interest and eliminate the unwanted second order radiation. All monochromators contain the following component parts;

- An entrance slit
- A collimating lens
- A dispersing device (usually a prism or a grating)
- A focusing lens
- An exit slit

Sample compartment

A container that contains a sample is usually called "cell"; three types are available: plastic, glass and quartz cells. It is use to accommodate the sample solution

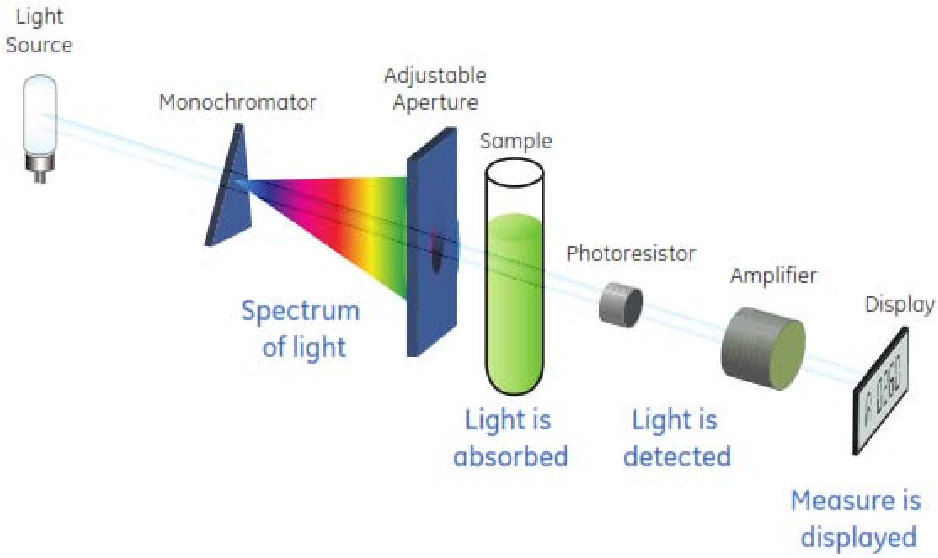


Figure 6: Schematic diagram of Spectrophotometer

Detector

It is use to receive and convert the transmitted light to an electrical signal.

Digital display

It is use to show absorbency and transmittance

Working Principle of Spectrophotometer

A spectrophotometer is used to provide light of certain energy (wavelength) and to measure the absorbance of that light. The basic operation of the spectrophotometer includes a white light radiation source which passes through a monochromator. The monochromator is either a prism or a diffraction grating which separates the light into the colored components and allows only light of a particular wavelength to strike the sample.

The sample is poured into a cuvette, which is similar to a small test tube. The light passes through the sample, and the unabsorbed portion strikes a photo detector, which produces an electrical signal proportional to the intensity of light. The signal is converted to an understandable output that is used in the analysis of the sample.

The Quantitative measures of concentration are one of the cornerstones of biological science. Of all the methods that have been devised for measuring concentration, by far the most widely applied is absorption spectrophotometry. It works by following Beer–Lambert law, which states that the quantity of light absorbed by a substance dissolved in a fully transmitting solvent is directly proportional to the concentration of the substance and the path length of the light through the solution. Mathematically it can be expressed as:

$A = \log_{10} I_0/I = \varepsilon \times c \times l$

Where, A is absorbance of light,

I_0 is the intensity of the incident light at a given wavelength,

I is the transmitted intensity,

c is concentration, usually measured in moles per liter;

l is the length of the light path, usually 1 cm; and

ε is a proportionality constant known as the molar extinction coefficient, with the units of liters per mole per centimeter.

General precaution to use spectrophotometer

i. warm up for about 15 minutes to run spectrophotometer
ii. Don't touch the clear sides of the cuvette during sample analysis
iii. Cuvette should be cleaned properly and must be wiped with tissue paper.

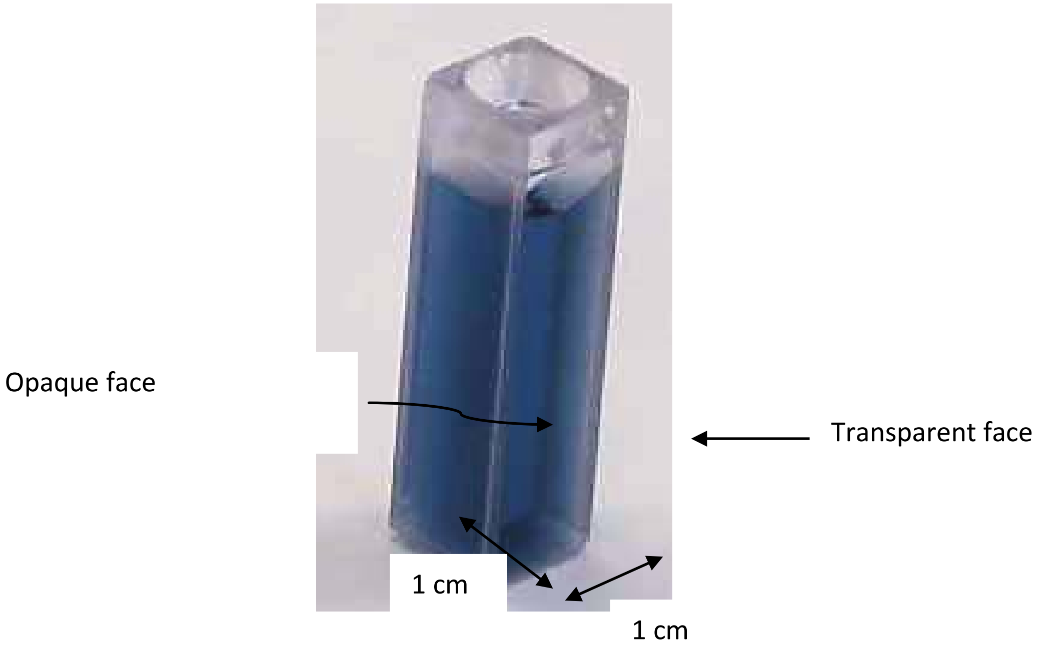


Figure 7: Use of Cuvette

Flame Photometer

It is another instrument used in the soil science laboratory. In soil science lab, we can use this instrument to determine potassium (K), sodium (Na), Lithium (Li), Barium (Ba) and Calcium (Ca) content of samples. The estimation of the alkali metals by flame photometry is by far its most important application in routine chemical analysis. For this widespread requirement, low temperature flame photometry provides the most reliable and convenient procedure available. Flame photometer is also very cost effective and easy to use.The analysis of alkali and alkaline earth metals by flame photometry has two major advantages:

- Their atoms reach the excited state at a temperature lower than that at which most other elements are excited.
- Their characteristic wavelengths are easily isolated from those of most other elements due to wide spectral separation.

The analysis of Na, K, Li, Ba and Ca are typically determined at low temperatures, i.e. 1500-2000°C, therefore suitable fuel mixtures are propane/air, butane/air and natural gas/air.

Components of Flame-photometer

A flame photometer consists of the following basic components:
a) Nebuliser and mixing chamber
b) Atomizer burner
c) Simple colour filters (interference type)
d) Photo-detector
e) Amplifier and Readout Device

Nebuliser and mixing chamber

It is a way of transporting a homogeneous solution into the flame at a steady rate. The process is called nebulisation and consists of thermal vapourisation and dissociation of aerosol particles at high temperatures producing small particle size with high residence time. A number of nebulisation methods are available. They are as follows:

- Pneumatic nebulisation
- Ultrasonic nebulisation
- Electrothermal vapourisation
- Hydride generation (used for certain elements only)

Atomizer burner

The sample is introduced in the form of a fine spray at a controlled rate into the flame of a burner with the help of nebuliser. In the burner, the analyte undergoes a number of processes. Two types of atomisation burners have been used in flame photometry. They are as follows:

- Pre-mix or Lundegarh burner
- Total consumption burner

From the burner different coloured flame come out regarding to the determined metals. In flame photometry a flame is used for (i) converting the sample from liquid or solid state into the gas phase; (ii) decomposing the sample into atoms, and/or (iii) exciting these atoms into light emission. The table below gives details of the measurable atomic flame emissions of the alkali and alkaline earth metals in terms of the emission wavelength and the colour produced.

Table 2: Flame colour produced by different elements in the flame photometer

Element	Emission Wavelength (nm)	Flame Colour
Sodium (Na)	589	Yellow
Potassium (K)	766	Violet
Barium (Ba)	554	Lime Green
Calcium (Ca)	622	Orange
Lithium (Li)	670	Red

Simple colour filters (interference type)

It is a means of isolating light of the wavelength to be measured from that of extraneous emissions. Filter can be used as a monochromator to isolate a particular spectral line. Filters are generally made from materials which are transparent in a small selective wavelength region. The filter chosen is one which has a wavelength range in which it is transparent to emission from the element of interest. Filters have been designed for use in the determination of lithium, sodium, potassium, calcium and other elements.

Photo-detector

It is a means of measuring the intensity of radiation emitted by the flame. Photo emissive cells or photomultiplier tubes are commonly employed for the purpose.

Amplifier and Readout Device

The output from the detector is suitably amplified and displayed on a readout device like a meter or a digital display.

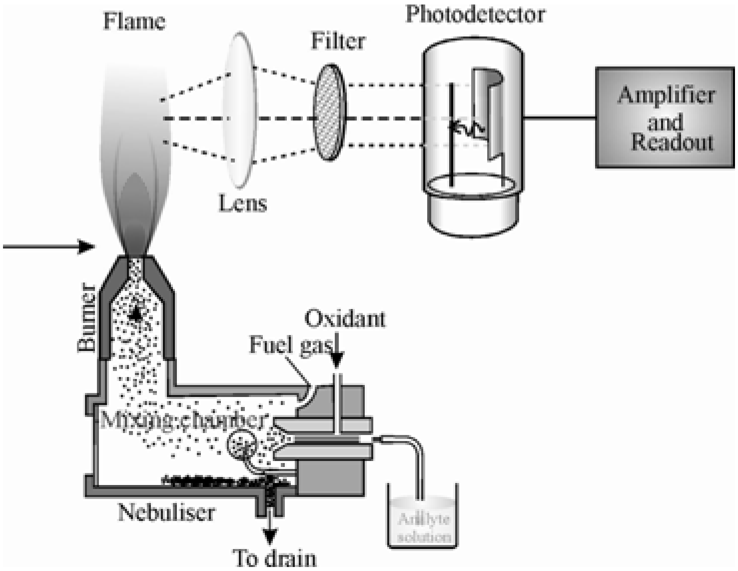


Figure 8: Schematic diagram showing flame photometer

Working Principle of Flame Photometer

Flame photometer is based on the principle of emission spectroscopy. Principles of operation Flame photometry relies upon the fact that the compounds of the alkali and alkaline earth metals can be thermally dissociated in a flame and that some of the atoms produced will be further excited to a higher energy level. When these atoms return to the ground state they emit radiation which lies mainly in the visible region of the spectrum. Each element will emit radiation at a wavelength specific for that element.

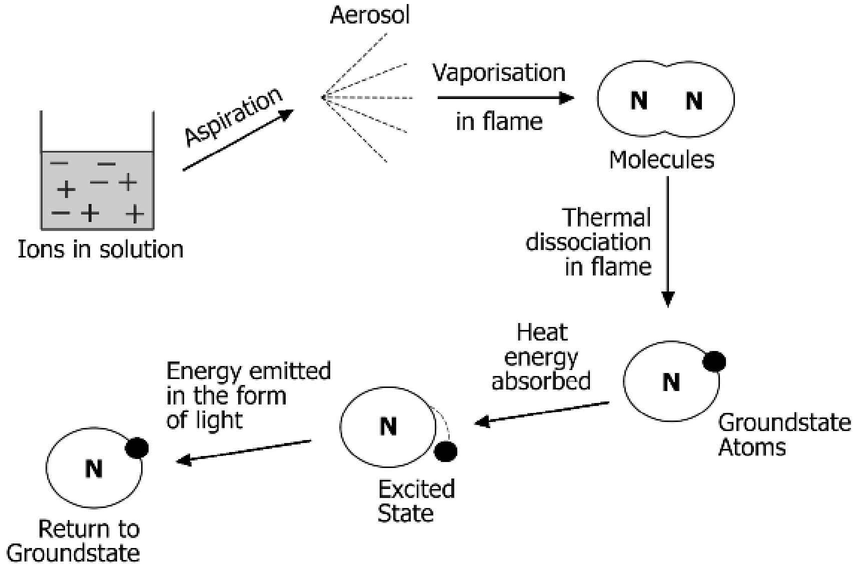


Figure 9: The process involved in Flame Photometer

In a flame photometer, the solution is aspirated through a nebulizer (or aspirator) into the flame. After the sample matrix evaporates, the sample is atomized. Atoms then reach an excited state by absorbing heat from the flame. When these excited atoms return to their lowest energy state, they give off radiation in certain wavelengths, leading to the creation of a line spectrum. A filter pre-selected based on the atom being analyzed is used in flame photometry. The emission line's intensity is then practically measured and is related to the solution's original concentration.

Over certain ranges of concentration the intensity of the emission is directly proportional to the number of atoms returning to the ground state. This is in turn proportional to the absolute quantity of the species volatized in the flame, i.e. light emitted is proportional to sample concentration. Comparison of emission intensities of unknowns to either that of standard solutions (plotting calibration curve), or to those of an internal standard (standard addition method), allows quantitative analysis of the analyze metal in the sample solution.

The intensity of the light emitted could be described by the Scheibe-Lomakin equation

$$I = k \cdot c^n$$

Where, c = the concentration of the element

k = constant of proportionality

n ~1 (at the linear part of the calibration curve), therefore the intensity of emitted light is directly proportional to the concentration of the sample.

Precaution to use flame photometer

i. It is most important that the nebuliser, mixing chamber and burner are kept clean by carrying out the correct shutdown procedure and by periodic maintenance. If high salt solutions are aspirated, correspondingly longer periods should be spent aspirating distilled water prior to shutdown.
ii. Take care when preparing standards. The performance of the instrument depends upon the accuracy and purity of the calibration standards.
iii. The top of the instrument chimney unit becomes very hot when running and can cause severe burns if touched.
iv. Regularly observe the performance of nebulizer for efficient work.

Atomic Absorption Spectrophotometer (AAS)

Atomic absorption spectrophotometer (frequently referred to as AAS) was introduced in the early 1960s, and at the time, it revolutionized elemental analytical chemistry. With AAS, the analyst can determine concentration of over 62 different metals in a solution, whose alternative assay methods were frequently difficult and tedious. In soil science division, we generally use this instrument to determine Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn) and Molybdenum (Mo) content of the soil and plant samples. There are two types of AAS. They are as follows:

Flame AAS (FAAS normally "AAS")

In flame AAS, Flame atomic absorption methods are used for direct aspiration determinations. They are normally completed as single element analyses and are relatively free of inter element spectral interferences.

Graphite Furnace AAS (GFAAS)

The GFAA and flame AAS measurement principle is the same. The difference between these two techniques is the way the sample is introduced into the instrument. In GFAA analysis, an electrothermal graphite furnace is used instead. The sample is heated stepwise (up to 3000ºC) to dry. The advantage of the graphite furnace is that the detection limit is about two orders of magnitude better than that of AAS.

Components of AAS

Atomic absorption spectrometers have 4 principal components. They are as follows:

a) Radiation source

b) Atomizers
c) Monochromator
d) Detector
e) Read out device

Radiation source

All commercially available atomic absorption spectrophotometers use a radiation source that emits the characteristic spectrum of the element to be determined. Generally two types of sources are in use: line sources and continuum sources. Initially continuum sources were used and the primary radiation required was isolated with a high resolution monochromator. However, these had low radiant densities and did not provide sufficiently high sensitivity. Nowadays, the hollowcathode lamp (HCL), belonging to the first type, has been most widely used. The electrodeless discharge lamps (EDL) – another line sources are also frequently employed for the particular purpose.

The light source is usually a hollow cathode lamp contains a tungsten anode and a hollow cylindrical cathode made of the element to be determined. These are sealed in a glass tube filled with an inert gas (neon or argon). Each element has its own unique lamp which must be used for that analysis.

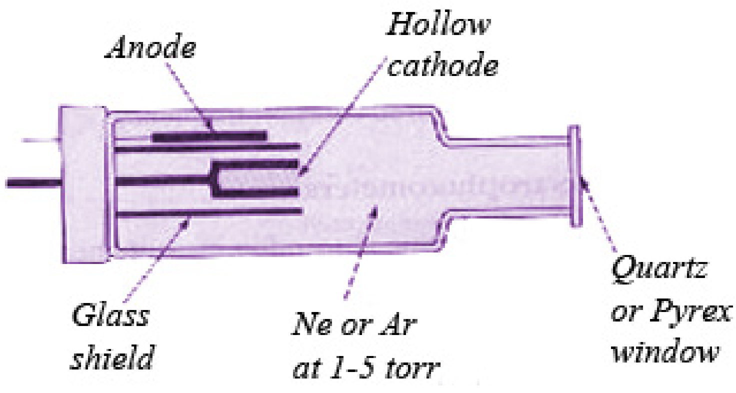


Figure 10: Hollow Cathode Lamp

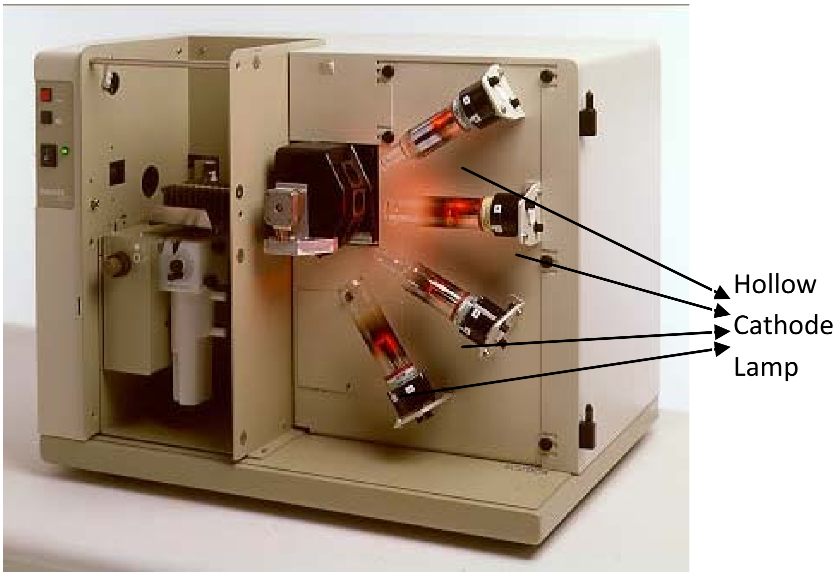


Figure 11: Position of Hollow Cathode Lamp in AAS

Atomizers

Atomization is separation of particles into individual molecules and breaking molecules into atoms. This is done by exposing the analyte to high temperatures in a flame or graphite furnace. A range of temperatures from 2000 to 3000 K can be produced from fuel and oxidant mixtures which are safe to handle. Propane, hydrogen and acetylene can be used as fuel gases and air or nitrous oxide used as the oxidant. Two common types of atomisers used for generating atomic species in the vapour phase are flame atomisers and electrothermal atomisers.

Monochromator

Monochromator is used to select the specific wavelength of light which is absorbed by the sample, and to exclude other wavelengths. The selection of the specific light allows the determination of the selected element in the presence of others. Most commercial AAS instruments use diffraction gratings as monochromators.

Detector

The function of a detector is to measure the intensity of the light radiation falling on it and the most common type of detector is the photomultiplier. The detector must be able to cover the spectral range from 190-860nm which poses some problems for sensitivity, particularly at the longer wavelengths.

Read out device

The readout systems include meters, chart recorders and digital display meters. Now a days, however, microprocessor controlled systems are commercially available where everything can be done by touch of a button. In Modern instruments consist fast display of the experimental conditions, absorbance data, statistical values and calibration curves, etc.

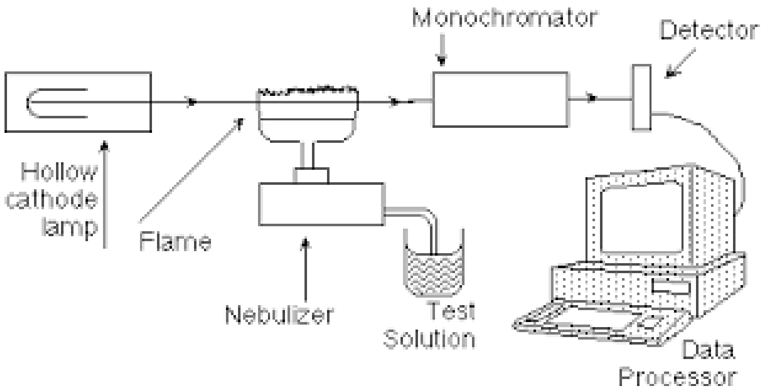


Figure 12: Schematic Diagram of an Atomic Absorption Spectrometer (AAS)

Working Principle of AAS

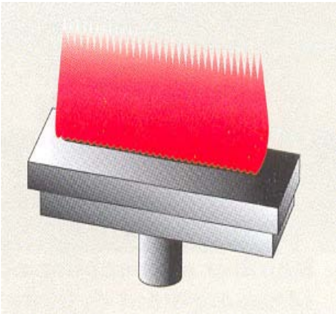
When the homogeneous solution of a representative sample is sprayed onto a flame (Air-Acetylene or Acetylene-Nitrous oxide), free atoms formed in the flame absorb characteristic radiation of the same element emitted by a hollow cathode lamp and undergo transitions to excited energy levels. This energy absorption by free atoms of the sample formed in the flame is proportional to the concentration of atoms formed in the flame and is governed by Lambert-Beer Law. Atomic absorption spectrophotometer is based on the principle that when a sample, in the form of a homogenous liquid, is aspirated into flame where "free" atoms of the element, to be analyzed, are created. A light source (hollow cathode lamp) is used to excite the free atoms formed in the flames by the absorption of the electromagnetic radiation. The decrease in energy (absorption) is then measured which follows the Lambert-Beer's law i.e. the absorbance is proportional to the number of free atoms in the ground state.

The amount of light absorbed is proportional to the number of analyzed atoms. A calibration curve is constructed by running several samples of known concentration under the same conditions as the unknown. The amount the standard absorbs is compared with the calibration curve and this enables the calculation of the concentration in the unknown sample. It is an extremely sensitive method, allowing concentrations as low as one part per billion to be measured. Atomic absorption spectroscopy is also quicker than conventional methods such as volumetric analysis.

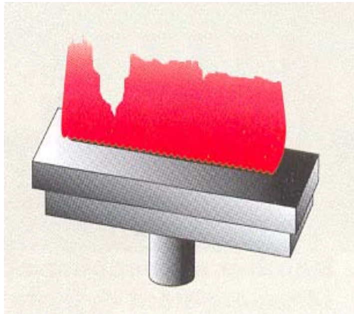
Maintenance of AAS

Weekly maintenance

i. Cleaning the Burner head



Normal



Clogged (by carbide or salt etc.)

ii. Cleaning the Chamber with diluted water or alcohol

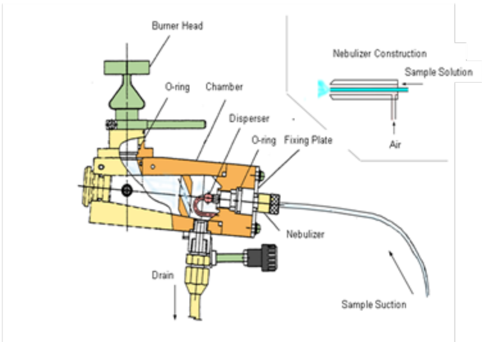
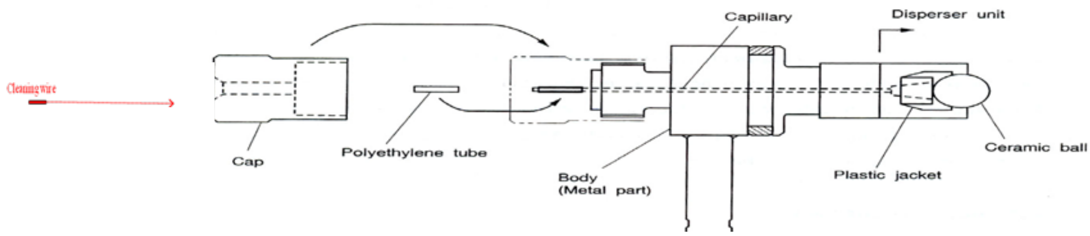


Figure 13: Steps in maintenance of AAS.

iii. Cleaning the Nebulizer by certain kinds of wire as shown in figure



Nebulizer

Figure 14: Cleaning of Nebulizer.

Yearly maintenance (Calibration work)

i. Wavelength Accuracy
ii. Noise Level
iii. Absorption
iv. Repeatability (measure about 5 times and CV should be < 2%)
v. Stability (stability = < 6.0 %)
vi. Detection limit

Detection limit = (2.0 x 3 x S) / A

Where, A= mean value of particular standard (measurement should take 3-5 time)
S= standard deviation of blank (measurement should take 3-5 time)

References

Awady ME. 2015. Spectrophometry. Website: deltauniv.edu.eg/.../Lecture%209-Spectrophotometry%20(1).pdf (Retrived in May 8, 2015).

Beaty RD and JD Kerber. 1993. Concepts, Instrumentation and Techniques in Atomic Absorption Spectrophotometry. The Perkin-Elmer Corporation, Norwalk, CT, U.S.A. Website:www.ufjf.br/baccan/files/2011/05/AAS-Perkin.pdf (Retrived in May 8, 2015).

BWB technologies. 2012. A guide to Flame Photometer Analysis. BWB Technologies UK Ltd. Website:www.bwbtech.com/(Retrived in May 12, 2015).

Erxlben A. 2009. Atomic Absorption Spectroscopy. Website: www.nuigalway.ie/.../CH205_atomic_absorption_spectroscopy.pdf(Retrived in May 10, 2015)

Flame Photometer Models PFP7 and PFP7/C Operating and Service Manual. Website: www.jenway.com/adminimages/pfp7_manual(2).pdf (Retrived in May 2, 2015).

Jones, J.B. 2001. Laboratory Guide for Conducting Soil Tests and Plant Analysis. CRC Press New York, U.S.A. pp. 259-266.

Sanda *et al.* 2012. Spectrophotometric Measurements Techniques for Fermentation Process. Website: http://www.huro-cbc.eu/(Retrived in May 15, 2015).

Thermo Fisher Scientific. 2008. Atomic Absorption Spectrometry Methods Manual. Thermo Fisher Corporation Mercers Row, Cambridge, United Kingdom.Website: www.thermoscientific.com/...manuals/AAiCE-Methods-Manual-V5.pdf(Retrived in May 8, 2015).

Verma R and KK Sharma. 2014. Practical Manual for Soil Chemistry, Soil Fertility and Nutrient Management. Department of Soil Science and Agricultural Chemistry Shri Karan Narendra College of Agriculture. pp. 8-11.

Fundamental Principles of Plant Essential Nutrient Extraction

Dinesh Khadka, M.Sc. (Soil)
Technical Officer

Each method has certain chemical principle for the determination from the soils. The different analytical methods as well as chemical principle involved during extraction and determination are described under the following headings.

Total Nitrogen

Kjeldahl method

The Kjeldahl method is a means of determining the nitrogen content of organic and inorganic substances. The Kjeldahl method may be broken down into three main steps:

Digestion

Figure 15: Automatic digestion unit for digestion

It is the decomposition of nitrogen in organic samples utilizing a concentrated acid solution. This is accomplished by boiling a homogeneous sample in concentrated sulphuric acid. The end result is an ammonium sulfate solution.

Organic N + H_2SO_4 (Sulphuric acid) $\longrightarrow$ $(NH_4)_2SO_4$ (Ammonium sulphate) + H_2O + CO_2 + other sample matrix by product

Neutralization and Distillation

Figure 16: Automatic Distillation unit for distillation.

After digestion, the digest is diluted with distilled water and then neutralized with Sodium hydroxide (NaOH) which converts the ammonium sulphate into ammonia gas.

$$(NH_4)_2SO_4 + 2NaOH \longrightarrow 2NH_3 + Na_2SO_4 + 2H_2O$$

Ammonium sulphate, Sodium hydroxide, Ammonia gas, Sodium sulphate

Then, the produced ammonia is distilled into a boric acid solution where ammonia is converted into ammonium ion and boric acid is converted into borate ion.

$$NH_3 + H_3BO_3 \longrightarrow NH_4^+ + H_2BO_3^- \text{ (Colour changed)}$$

Ammonia gas, Boric acid, Ammonium ion, Borate ion

Titration (Direct Titration)

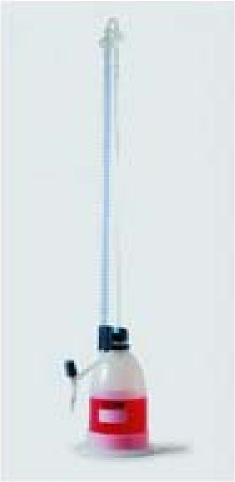


Figure 17: Burette for titration.

The borate ion is then titrated with standard HCl or H_2SO_4. Here, borate ion converted to boric acid by receiving H^+ from the titrating acid.

$$H_2BO_3^- + H^+ \longrightarrow H_3BO_3 \text{ (Colour change is reversed)}$$

Available Phosphorus

Figure 18: Spectrophotometer.

Extraction

The plant available phosphorus from the soils can be determined by the various methods among them two methods namely; modified Olsen's and Bray and Kurtz No. 1 is described.

Modified Olsen's Method

This method has been found widely applicable in slightly acid, neutral, alkaline and calcareous soils. In this method, the soil is shaken with 0.5M $NaHCO_3$ (pH: 8.5) in the presence of Darco-G 60 (which absorbs the dispersed organic matter in the sample and thus, helps giving a clear extract). (Olsen and Sommers 1982, Olsen et al. 1954).
At high pH, P is held by Ca as

$$Ca_3(PO_4)_2 \longleftrightarrow 3Ca^{2+} + 2PO_4^{3-}$$

If Ca^{2+} is removed, more $Ca_3(PO_4)_2$ will be dissociated to counteract the effect of the removal (Le-Chaterlier's principle) hence Ca is removed by $NaHCO_3$ even, Ca has a strong affinity for CO_3^{2-} to form $CaCO_3$, hence more$Ca_3(PO_4)_2$ dissolves. If we continue to remove Ca by precipitating it as CO_3^{2-}, the reaction goes to the right, more and more P will be released into solution. In addition $NaHCO_3$ in solution will also have NaOH, the NaOH will react with Fe in the $FePO_3$ to form $Fe(OH)_3$, this will also release more P into solution. The overall reaction shown as following;

$$NaHCO_3 \longrightarrow Na^+ + HCO_3^-$$

$$(Colloid)\ PO_4^{-3} + HCO_3^- \longrightarrow (Colloid)HCO_3^- + PO_4^{3-}$$

The overall reaction:

$$Ca_3(PO_4)_2 + 6NaHCO_3 \longrightarrow CaCO_3 + 2H_3PO_4 + 3Na_2CO_3$$

Bray and Kurtz No. 1

This procedure is primarily suitable for soils which are moderately to strong acidic (pH around 5.5 or less). In acidic soils phosphate is complexed with Al and Fe as $AlPO_3$ and $FePO_3$. The extraction solution of this method is 0.03M NH_4F in 0.025N HCl, here the F^- ion complexes Al and Fe forming AlF and FeF. In this way, phosphate ion becomes free for determination.

$$3NH_4F + 3HCl + AlPO_4 \longrightarrow H_3PO_4 + (NH_4)_3AlF_6$$

$$3NH_4F + 3HCl + FePO_4 \longrightarrow H_3PO_4 + (NH_4)_3FeF_6$$

Color development

Figure 19: Showing color development during phosphorus determination.

Phosphorus in the extract is treated with ammonium molybdate, which results in the formation of heteropoly complexes (phosphomolybdate or phosphomolybdic acid). Phosphomolybdic acid is reduced by ascorbic acid to form a blue complex. The absorbance of developed blue colour should read in Spectrophometer.

Phosphate + Molybdate ⟶ Phosphomolybdic Acid

Phosphopmolybdic Acid + Ascorbic Acid ⟶ Reduced Phosphomolybdate complex

Ammonium Acetate method

Figure 20: Flame photometer.

Extraction and determination

In general available potassium includes exchangeable and water soluble potassium in soils except that of saline or saline- sodic soils. Available K is determined by 1N neutral ammonium acetate (CH_3COONH_4) solution. The ammonium ions replace potassium ions absorbed on the soil colloids as

(Colloid) K^+ + CH_3COONH_4 ⟶ (colloid)NH_4^+ + CH_3COOK

The estimation of potassium in the extract is carried out with the help of flame photometer.

Calcium and Magnesium

EDTA Titration method

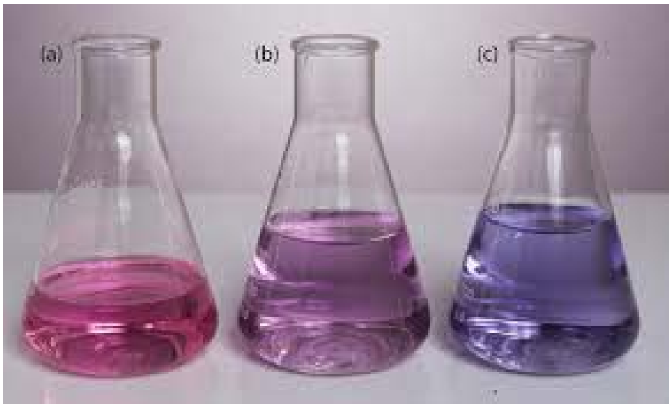


Figure 21: Colour changed during calcium and magnesium determination.

Figure 22: Colour changed during calcium determination (Purple).

Extraction

Available Calcium and magnesium is determined by extracting the soil by shaking with 1N neutral ammonium acetate (1N CH_3COONH_4) solution. The ammonium ions replace Ca and Mg ions absorbed on the soil colloids as:

(Colloid) Me^+ + CH_3COONH_4 ⟶ (colloid)NH_4^+ + CH_3COOMe

The estimation of calcium and magnesium in the extract is carried out with the EDTA titration method.

Titration

The most widely used method for the determination of Ca^{+2} and Mg^{+2} is by complemetric titration, involving ethylene diamine tetra-acetic acid (EDTA). Complexometry is a chemical technique using the formation of a colored complex to indicate the end of a titration. Most often used reagent in complexometric analyses is EDTA – Ethylene Diamine Tetra Acetic acid. EDTA is a chelating ligand. The trade name of EDTA is “versenate”. EDTA itself is almost insoluble in water. Because of that, in analytical chemistry one uses its disodium salt, Na_2EDTA.EDTA contains four carboxyl groups and two basic (alkaline) nitrogen in molecule. So, it is dissociating in complicated manner. However, it is the completely dissociated form (Y^{-4}) which forms stable complexes with metals. It is dominating only in very high pH.

The bonding energy of H^+ by EDTA is much lower than that of metals, and during complexation deprotonation occurs (exchange reaction). Thus, ions H_2Y^{-2} formed when the sodium salt of EDTA is dissolved in water react with cations in the following way:

$$H_2Y^{-2} + Me^{+2} \leftrightarrow 2H^+ + MeY^{-2}$$

It is clear that higher pH will shift this equilibrium right, towards formation of complex. In analyses of metal ions detection of the endpoint is mainly based on substances that change color when creating complexes with determined metals.

Indicator Eriochrome Black T, substance used at pH between 7 and 11. It is blue when free, and red-orange when forming complex with a metal ion. Both magnesium and calcium can be easily determined by EDTA titration in the pH 10 against Eriochrome Black T. Reactions taking place during titration are:

$[MeIn]^+ + H_2EDTA^{-2} \rightarrow [MeEDTA]^{-2} + 2H^+ + In^-$ (where, Me – Mg or Ca, In-indicator)

Wine-red colour blue colour

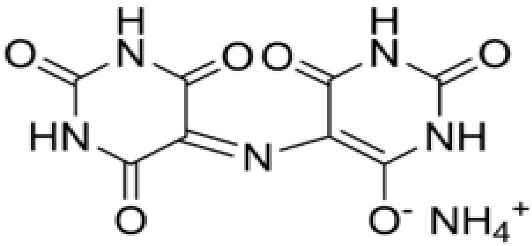
The end point of titration can be easily detected with Eriochrome Black T, which forms wine-red complex with both Ca^{2+} and Mg^{2+} ions. Addition of EDTA causes gradual expulsion of indicator from complexes (because those with EDTA are stronger). Finally, only blue color of free (non-bonded) indicator is present.

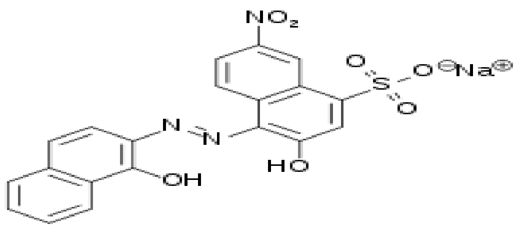
Another indicator, Murexide, forms orange-red complexes with calcium at pH=12 (and higher). At this pH, magnesium precipitates as $Mg(OH)_2$.

$[CaIn]^+ + H_2EDTA^{-2} \rightarrow [CaEDTA]^{-2} + 2H^+ + In^-$ (where, In - indicator)

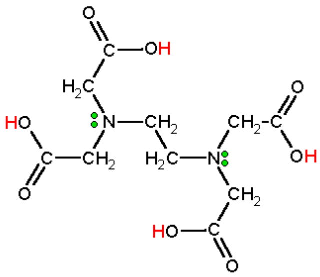
Orange-red colour Purple colour

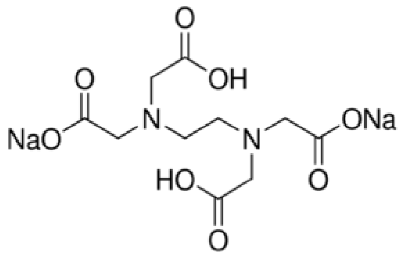
So, for simultaneous determination of Mg and Ca one needs two titrations: one at pH=10 and using Eriochrome Black T (the sum of moles of both metals is obtained) and second, at pH=12 and using Murexide (only calcium is titrated). The magnesium content is determined subtraction second from the first.





Murexide　　　　Erichrome Black T





EDTA　　　　EDTA disodium salt

Sulphur

Turbiditimetric method

Extraction (0.15% $CaCl_2$)

In this method soil is shaken with 0.15% $CaCl_2$ solution. Chloride ions displace adsorbed sulphate during extraction and sulphate ion becomes free. Calcium ions suppress the extraction of soil organic matter and hence eliminate the contamination caused by extractable organic S.

$$CaCl_2 \longrightarrow Ca^{+2} + 2Cl^-$$

$$\text{Colloid]}SO_4^{-2} \longrightarrow \text{Colloid]}Cl^- + SO_4^{-2}$$

Colour Development

The filtrate is analyzedfor S by the turbidimetric method in which the turbidity produced due to Precipitation of sulphate as barium sulphate is measured on a spectrophotometer. Gum acacia solution is added to stabilize the turbidity so that the precipitate of barium sulphate does not settle down.

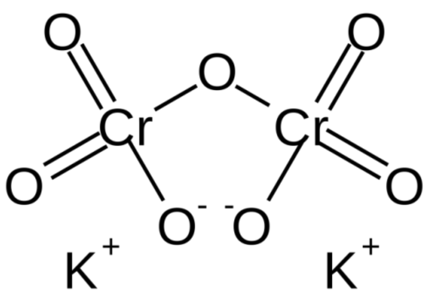
$$BaCl_2 \longrightarrow Ba^{+2} + 2Cl^-$$

$$SO4^{-2} + Ba^{+2} \longrightarrow BaSO_4 \text{ (Precipitate)}$$

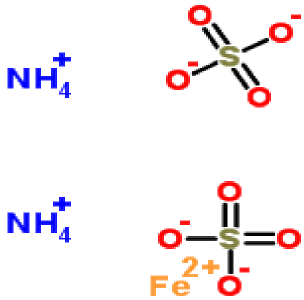
Figure 23: Color developed for sulphur determination.

Soil Organic Matter

Walkley and Black method



Potassium dichromate



Ferrous ammonium sulphate

In Walkley and black method of organic matter determination, a known weight of soil is treated with excess volume potassium dichromate in the presence of concentrated sulphuric acid. Potassium dichromate and sulphuric acid reaction produces nascent oxygen, which combines with the carbon of soil organic matter to produce CO_2. The highest temperature, attained by the heat of dilution reaction, produced on the addition of H_2SO_4 is approximately 120^0 C, which is sufficient to oxidize the active forms of the soil organic C, but not the simple inert form of carbon, that may be present (Walkley 1947).

The excess volume of $K_2Cr_2O_7$ not reduced by the organic matter is titrated back, against a standard solution of ferrous ammonium sulphate in presence of NaF or phosphoric acid and diphenylamine or ferroin indicator. The difference between the moles of dichromate

initially reacted with the soil and moles of dichromate that remain after soil digestion is proportional to the SOC content of the soil sample.
This method potentially suffers from a number of interferences and low recoveries. A correction factor must be used due to the incomplete oxidation reached with this temperature (Walkley and Black, 1934). This factor varies for different soils, different horizons of a soil profile or organic fractions. The most common correction oxidation factor is based on the supposition that 76% of OC is oxidized in this procedure. Therefore, a correction factor which takes into account that only the easily oxidizable (approximately the 76% of total OC) is measured has to be included and calculated as follows:

Oxidation factor =100/76 = 1.33
Another factor (1.724) converts OC to OM. This conversion factor of 1.724 is the result of attributing 58% to the content of OC in the OM.

The oxidation of carbon

$$2K_2Cr_2O_7 + 8H_2SO_4 \longrightarrow 2K_2SO_4 + 2Cr_2(SO4)_3 + 8H_2O + 6[O]$$

$$3C + 6[O] \longrightarrow 3CO_2$$

$$2K_2Cr_2O_7 + 4H_2SO_4 + 3C \longrightarrow 2K_2SO_4 + 2Cr_2(SO4)_3 + 8H_2O + 3CO_2$$

$$2Cr_2O_7^{2-} + 2C^0 + 16\ H^+ \longrightarrow 4Cr^{3-} + 3CO_2 + 8H_2O$$

In this reaction, the carbon in SOC, assumed to have an average oxidation state of zero (C^0), is oxidized to CO_2 (g) (C^{IV}) by the $Cr_2O_7^{-2}$ (aq) (Cr^{VI}) in an excess of acid (provided by H_2SO_4).

The titration procedure

$$2FeSO_4\ (NH_4)_2SO_4 + K_2Cr_2O_7 + H_2SO_4 \longrightarrow 2Cr_2\ (SO4)_3 + 2(NH_4)_2SO_4 + Fe_2(SO_4)_3 + K_2SO_4^{+7}$$

$$Cr_2O_7^{-2} + 6Fe^{+2} + 14H^+ \longrightarrow 3Cr^{+3} + 6Fe^{-3} + 7H_2O$$

Following digestion, the soil suspension is cooled and titrated with a solution containing standard Ferrous ammonium sulphate [$FeSO_4(NH_4)_2SO_4$]. During the titration, the $Cr_2O_7^{-2}$ that was not consumed by SOC is reduced by Fe^{+2}.

The reaction of diphenylamine indicator

$$2C_6H_5NHC_6H_5 \xrightarrow[-H_2O]{+O} 2(C_6H_5.NHC_6H_4) \xrightarrow[-H_2O]{+O} C_6H_5N\text{-}C_6H_4C_6H_4N\text{-}C_6H_5$$

Diphenylamine Diphenylamine benzidine (Violet)

References

Olsen SR and LE. Sommers. 1982. Phosphorus. In: *Methods of soil analysis, Agron. No. 9, Part 2: Chemical and microbiological properties, 2nd ed*. (A. L. Page, ed.), Am. Soc. Agron., Madison, WI, USA. Pp. 403 – 430

Olsen SR, CV Cole, FS Watanabe and LA Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U. S. Dep. Agric. Circ. 9, USA. 39.

Walkley A. 1947. A critical examination of a rapid method for determining organic carbon in soils. Effect of variations in digestion conditions and inorganic soil constituents. *Soil Sci*. 63:251-263.

Chapter 3: Soil Microbiology

Importance of Bio-fertilizer in Agriculture

Sanu Keshari Bajracharya, M.Sc. (Microbiology)
Bishnu Hari Adhikary, M.Sc. (Soil Fertility)

Introduction

In soil millions of beneficial micro-organisms are at work in fixing atmospheric nitrogen, solubilizing soil phosphorus and degrading ligno-cellulosic wastes. Very often micro-organisms are not as efficient and sufficient in the soil as one would expect them to be and therefore artificially multiplied cultures of selected micro-organisms play a vital role in nature's way of recycling organic resources. Thus bio-fertilizer (microbial inoculant) are product which contain living cells of efficient strains of nitrogen fixing, phosphate solubilizing or cellulolytic micro-organisms which when applied to seed, soil or plant surface accelerate microbial process and provide nutrients to the plants. Microbial bio-fertilizer can also be defined as biologically active living inputs and contain one or more types of beneficial microorganisms. Bio-fertilizers add nutrients through the natural process of N-fixation, solubilizing phosphorus and stimulating plant growth through the synthesis of growth promoting substances. Bio-fertilizers play various specific roles in plant growth besides supplying nutrients, suppressing diseases and pests and increasing water use efficiency. Use of bio-fertilizers is both economical and eco-friendly since they increase crop productivity and reduce soil fertility and soil texture damage. Broadly there are seven types of bio-fertilizers. Among these, bio-fertilizer N-fixation by various bacteria has been studied and used extensively in agriculture globally. List of microbial bio-fertilizers and its benefits are given below (Table 3).

Table 3: List of important micro-organisms used as bio-fertilizers.

Micro-organisms	Activity	Association	Uses in crops
Rhizobium	N_2-fixation	Symbiotic	Legumes(pulses, oilseeds, pasture and fodder crops
Azotobacter	N_2-fixation	Asymbiotic	
Azospirillum	N_2-fixation	Asymbiotic/ Symbiotic	Graminaceous crops (wheat, rice, jowar sugarcan,)
Blue green algae	N_2-fixation	Asymbiotic	Rice, wheat, maiz, vegetables, fruits
Azolla-Anabaena	Phosphorus solubilization	Symbiotic	Rice
Phosphorus solubilizer	Phosphorus solubilization	Asymbiotic	Many crops
Mycorrhiza	Phosphorus solubilization	Asymbiotic/ Symbiotic	Many crops including pulses

Rhizobium bio-fertilizer

Dutch scientist Beijrinck isolated *Rhizobium* from root nodules in 1888. In 1889, first species of *Rhizobium leguminoserum* was identified. *Rhizobium* belongs to the family Rhizobiaceae. Initially, the root nodule bacteria were divided into two genera - fast growing *Rhizobium* and slow growing *Bradyrhizobium* (Kreig and Halt 1984). At present, the listing of *Rhizobium* genera consists of seven species *Rhizobium*.*Rhizobium* is anaerobic heterotrophic soil microorganism which is gram negative and appears as a small rod shaped under the microscope. It is quite versatile in nature i.e. it can use a variety of substrate as nutrients. It can survive at low temperature and tolerate up to 50^{o} C for more than a few hours. It can survive in soil for several years under dry storage conditions. It is able to enter into a symbiotic relationship with leguminous crops both food legumes and pasture and fodder legumes like lentil, chickpea, soybean, black gram, cowpea, bean, clover, berseem, vetch, ipil ipil, etc and forms nodules on the roots. Thus, *Rhizobium* is also called nodule bacteria.Plants cannot utilize atmospheric N directly. But *Rhizobium* in association with the compatible legume can fix appreciable amount of N and convert it into nitrogenous compound (NH_4^+) in presence of *nitrogenase* enzyme which are utilized by plants for their growth and gets their food from the plants. In the nodules oxygen level is controlled by the oxygen binding protein *leg hemoglobin*. Legume *Rhizobium* symbiosis fixes at least 70 million metric ton N ha^{-1} (Brockwell and Bottomly 1995). The values estimated for nodule bacteria are impressive and falls on the range of 200-300 kg N ha^{-1} (Peoples *et al*. 1995). List of legumes and their nitrogen fixation in field in Nepal are given in Table 4.

Table 4: Legumes and their nitrogen fixation in field.

S.N	Types of legumes	Nitrogen fixation kg ha^{-1} yr^{-1}
1	Lentil	72
2	Chickpea	84
3	Soybean	59
4	Groundnut	153
5	Mash bean	28
6	Pigeon pea	412
7	Faba bean	80

Source: Maskey *et al.*

Types of *Rhizobium* and their specific host

Rhizobium is very specific to their host selection to form effective nodules in the root system and to fix more nitrogen from the atmosphere. They are fast and slow grower to form colony in the artificial media in the laboratory condition. So the *Rhizobium* groups and their host legumes are given in the Table 5.

Table 5: Rhizobia species and cross inoculation group of host plants.

S. N	Growth Characteristics	Species of Rhizobium	Legume Host
1	Fast Grower- Colony appears in plate in 3-5 days	*R.trifoli* *R.leguminoserum* *R.phaseoli* *R.meliloti*	Clover, Berseem Vetch, Faba-beans, Lentils, Peas, Lathyrus Rajma bean Lucern, Fenugreek
2	Slow Grower- Colony appears in the plate in 7-10 days	*(Bradyrhizobium)* *R japonicum.* *R.lupini* *Rhizobium vigna.* (Cowpea type)	Soyabean, Lupinus Cowpea, Black gram, Pigeon pea Peanut, Mungbean, Desmodium, Stylo, Lablab, Kudzu, Siratro, Centrosema, Lotononis, Ipil ipil, Rice bean, Lima bean, Chickpea, Sunhemp, Calopo, Puero.

Rhizobia are also able to produce acid or alkali on YEMA (Yeast extract mannitol agar) medium. Based on this criterion, the fast growing *R. trifoli*, *R. leguminoserum*, *R. phaseoli and R. meliloti* could be grouped as acid producers. Besides, these fast growing *Rhizobia* have low percentage of Guanine + Cytosine composition (58-63). Slow growing *Rhizobia* do not produce acid on YEMA medium. Therefore, they are called non acid producers. In contrast to the fast growing *Rhizobia*, they have somewhat higher percentage of Guanine+ Cytosine composition (62.8-65.8).

Criteria in selecting a strain for production of bio-fertilizer:

- Ability to form effective nitrogen fixing nodules with all the hosts for which the inoculant is recommended
- Ability to possess this trait under a wide range of field conditions.
- Ability to survive in soil in absence of the host.
- Ability to compete well with the native strains in the soil.

- Ability to prompt nodulation over a range of root temperatures.
- Greater survival in carriers and in seed.

Mass culture and inoculation

Rhizobium inoculation was first done in USA and commercialized by private companies in 1930's (Mishra and Dadhich 2010). It is an eco-friendly technology. It is also cheap and laboratory based technology. It can not be produced in the field condition. There are certain steps to be followed in the preparation of bacterial inoculums which are as follows:-

- *Rhizobium* isolated from the effective nodules are sub-cultured at equal intervals and maintained YEMA (Yeast mannitol agar) medium in the laboratory condition in pure form and are used to produce inoculum for the field.
- The isolated pure culture of *Rhizobium* is further multiplied in the liquid media to have the maximum cell population of 10^{-9} cells ml^{-1} of liquid media for the fast grower and 10^{-6} or 10^{-7} for the slow grower.
- A carrier based inoculum is prepared by mixing the liquid culture in sterilized carrier material like charcoal and soil at the ratio of 1:3 or peat soil.
- *Rhizobium* inoculums are produced in two quantities - 200 g per packet and 40 g per packet

Needs of *Rhizobium* inoculation

- Absence of effective nodules in the root system of legumes
- Absence of proper *Rhizobium* in the soil
- Acidic soil condition
- Prolonged water logged condition in the soil.
- High soil temperature during sowing
- If legumes are never grown before.

Factors affecting nitrogen fixation

- More nitrogen content in the soil suppresses the atmospheric nitrogen fixation and nodulation.
- If phosphorus is less in the soil, addition of 30-40 kg P_2O_5 ha^{-1} has direct beneficial effect on pasture production.
- Acidic soil condition pH of the soil if below 6 adversely affect the pasture production and nitrogen fixating capacity. Application of lime at rate of 1-2 t ha^{-1} is generally recommended every alternative year depending upon the pH level of the soil.
- Micro-nutrient like Molybdenum and Iron if low in soil, nitrogen fixation and nodulation is also low. Application of these micronutrients 20-22 g ha^{-1} is beneficial.

Method of *Rhizobium* bio-fertilizer application

Seed inoculation

It is mostly adopted method.

- Make a 10 percent sugar solution (100 ml water plus10 g sugar)
- Boil and cool the solution.
- Moisten the seed in solution and throw the excess solution.
- Pour needed amount of inoculum.
- Mix the seed well with *Rhizobium* inoculant.
- Sow the seed immediately.
- In acid soil lime coating after mixing with inoculant is advisable.

Slurry method

- Make a 10 percent sugar solution (100 ml water plus 10 g sugar).
- Boil them together to dissolve the sugar.
- Allow them to cool.
- Pour required amount of inoculum into sugar solution and stirred well.
- Mixed with seed and sow the seed immediately.

Soil inoculation

- 10 g inoculum mixed with 1 kg of soil.
- Apply the inoculum in furrow.
- This amount of inoculant is enough for 100 m long.
- The inoculant can be also applied with the simple mechanical seed applicator.
- *Rhizobium* inoculant can also be broadcasted like fertilizer in the field where pasture legumes like clover, lucern or siratro is sown by broadcasting if soil moisture is sufficient or if the field is just irrigated.

Some important points to remember during inoculation

- Use the correct inoculant for each legume
- Protect inoculant from direct sunlight and keep them in cool place.
- Use the recommended amount of inoculant
- Inoculate seed just before planting or sowing
- Always use inoculant before its expiry date.
- Do not use inoculant again once it opens.
- Do not mix inoculant and mineral fertilizer together.
- Do not mix inoculated seeds with fungicides and pesticides.

***Rhizobium* bio-fertilizer packets and its recommendation**

According to size of seeds *Rhizobium* inoculant is recommended

Table 6: Recommended doses of Rhizobium inoculums.

Types of seeds	Inoculum ha^{-1}	Inoculum $ropani^{-1}$	Inoculum $kattha^{-1}$
Small seeds : clover, siratro, smallpea, blackgram, lucern, berseem, mungbean, lentil etc.	800 g (4packets each with 200 g)	40 g	27 g
Large seeds : Cowpea, broad bean, soybean, lablab, beans, soybean, peanut, etc	1000 g (5packets each with 200 g	50 g	33 g

Evaluation of the inoculated field

- Plant should be green and healthy looking.

- Nodules should be big and fleshy and in the tap root system.
- Nodules if opened should have pink or red pigment/color.
- Numbers of effective should be more.

Agricultural importance of *Rhizobium* inoculation

Both inoculation successes and failure at field levels have been reported in literature from time to time. Mostly responses to Rhizobium inoculation have been demonstrated with principal grain legumes such as lentil, chickpea, soybean, groundnut, black gram, faba bean. Inoculation of *Rhizobium* increased the grain yield of different legumes from 17-60% (Maskey *et al*. 2001) are known to be leaving behind some residual nitrogen in soil. In some experiments, significant residual effect was reported in the yield of subsequent crop like wheat, rice and maize which was seen always more in *Rhizobium* inoculated series than in inoculated ones. Maximum residual effect was seen in soybean which increased the yield of subsequent crop of wheat by 65.9%over corresponding un-inoculated controls. Failure to obtain desired response may due to:

- The presence of native ineffective strains, which could not be displaced by newly introduced effective strains.
- The presence of native of antagonists of *Rhizobia* which minimize the number of *Rhizobia* in the rhizosphere.
- The availability of soil conditions which limit symbiosis caused by acidity, alkalinity, factors relating to soil structure, application of insecticides and fungicides, high nitrate to soil.

***Azotobacter* biofertilizer**

Beijerinck was the first to isolate and describe *Azotobacter*. It is an aerobic and heterotrophic micro-organism. It is microscopic non-symbiotic bacteria which live freely in soil and supply nitrogen to the cereals and vegetable crops. These bacteria grow well on a nitrogen free medium. This cell protein is then mineralized in soil after the death of *Azotobacter* cells thereby contributing towards the nitrogen availability of the crop plants. *Azotobacter* species are sensitive to acidic pH, high salts, and temperature above 35^{o}C.

There are four important species of *Azotobacter* viz. *A. Chroococcum, A. agilis, A. beijerinkii and A. vinelandii* of which *A. chroococcum* is most commonly found in the soils. *Azotobacter* are known to fix on an average 10 mg of N g^{-1} of sugar in pure culture on a nitrogen free medium. A maximum of 30 mg N fixed per gram of sugar have been reported by many researcher. However, *Azotobacter* is a poor competitor for nutrients in soil. Most efficient strains of *Azotobacter* would need to oxidize about 1000 kg of organic matter for fixing 30 kg of N ha^{-1}. This does not sound realistic for our soils which have very low active carbon status. Besides, soil is inhabitated by a large variety of other microbes, all of which compete for the active carbon. The population of *Azotobacter* is very low in soils of Nepal and is not more than 10 thousand to 1 lakh g^{-1} of soil. The Population of *Azotobacter* is mostly influenced by other micro-organisms present in soil. There is some micro-organism which stimulates the *Azotobacter* population in soil thereby increasing the nitrogen fixation by *Azotobacter*. On the other hand there are some micro-organisms which adversely affect the *Azotobacter* population and hence nitrogen fixation process is hampered. For example *cephallosporium* is most commonly found organisms in soil which restricts the growth of *Azotobacter*.

Agricultural Importance

A characterstic features of *A. Chroococcum*, *A. beijerinkii* and *A. vinelandii* is that they produce polysaccharide/gum while *A.agilis* produces very little gum. *A. Chroococcum* also produces characteristic black pigment called melanin, especially in older cultures due to the oxidation of tyrosine by the enzyme *tyrosinase*. *A. beijerinkii* produces yellow pigment. *Azotobacter* naturally fixes atmospheric nitrogen in the rhizosphere soil. There are different strains of *Azotobacter* each has varied chemical, biological and other characters. However, some strains have higher nitrogen fixing ability than others. *Azotobacter* uses carbon for its metabolism from simple or compound substances of carbonaceous in nature. Besides carbon, *Azotobacter* also requires calcium for nitrogen fixation. Similarly, a medium used for growth of *Azotobacter* is required to have presence of organic nitrogen, micro-nutrients and salt in order to enhance the nitrogen fixing ability of *Azotobacter*. Besides, nitrogen fixation, *Azotobacter* also produces thiamin, riboflavin, nicotin, indol acitic acid (IAA) and gibberellin. Hence it promotes plant growth. When *Azotobacter* is applied to seeds, seed germination is improved to a considerable extent, so also it controls plant diseases due to above substances produced by *Azotobacter*. Field experiments have been done in Nepal on *Azotobacter* inoculation of seeds and seedlings of rice, wheat, maize, tomato, potato, cabbage etc. under different agroclimatic conditions. The lack of organic matter in the soils is a limiting factor for the multiplication of *Azotobacter*. The effect of *Azotobacter* was increased by 154% when compost was used. 6-12% increases in rice yield and 8-12% increased in wheat yield were observed (Maskey and Bhattarai 1984). Inoculation of *Azotobacter* increases 5% in tomato and 3.5-55% in cauliflower (SSD 2000). Adhikary *et al*.(2015) studied the efficacy of *Azotobacter* in maize production and suggested to apply them in areas where recommended dose of NPK could not be supplied or are unavailable. *Azotobacter* is used as bio-fertilizer for all non leguminous crops like cereals, vegetables, fruits, tea, coffee etc.

Azospirillum **bio-fertilizer**

Azospirillum is group of bacteria which are heterotrophic, gram negative, curved rod of varying size. They live freely in rhizospheric soil and capable of fixing nitrogen in roots of many crops such as cereals, sugarcane, oilseed, cotton and fodder crops. *Azospirillum* fixes considerable quantity of nitrogen in the range of 20-40 kg N ha^{-1} in the rhizosphere of the crops. Five species of *Azospirillum* have been described namely- *A. brasilens, A lipoferum, A. amazonese, A. halofraeferens and A. irakense*. The organisms proliferate under both anaerobic and aerobic conditions. It is preferentially micro-aerophilic. Apart from nitrogen fixation, growth promoting substance like IAA, disease resistance and drought tolerance are some of the additional benefits. *A. brasilens and A. lipoferum* are primary inhabitants of rhizospheric soil and intercellular species of root cortex of graminaceous plants. *Azospirillum* is also able to denitrify and reduce nitrate in some cases.

Like a *Rhizobium* and *Azotobacter, Azospirillum* is used as biofertilizer after isolation from soil and then growing in liquid medium and then mixing in soil medium. It is used all the non leguminous crops like rice, maize, wheat, millet, sugarcane, cotton, tomato, potato, sunflower, tea, coffee, rubber, neem etc. In our country, lots of work has not been done still now. But it has been used carrying from neighboring countries.

Algal bio-fertilizer (Blue green algae)

Blue green algae (BGA) are also known as cynobacteria. They are either single celled or consist of branched or unbranched filaments. N- fixing blue green algae posses a peculiar structure known as Heterocyst. Heterocyst is considered to be site of N-fixation. All heterocystous forms of BGA can fix atmospheric nitrogen. Frank (1889) first reported the ability of nitrogen fixation by blue green algae. Commonly found blue green algae are *Nostoc, Anabaena, Cylindrospermum, Aulosira, Plectonema, Oscillatoria, Tolypothrix Calothrix* etc. Besides N-fixation BGA also produce growth promoting substance. Trails have been conducted in India to study the Effect of BGA in rice crop. It is observed that BGA can save 30 kg N ha^{-1} (Venkataraman 1977). As early as 1977,Algal bio fertilizers were introduced and promoted (Venkataraman 1977) and extensively used in India. However, the use of BGA in rice is limited due to temperature, pH and chemical fertilizer. Very little research work has been done in cynobacteria in agriculture field in Nepal.

Azolla

Azolla is a free floating water fern plant and fixes nitrogen in association with BGA *Anabaena azollae*. *Azolla* fonds consist of sporophyte with a floating rhizome and overlapped bi-lobed leaves (fonds) and roots. *Azolla* is extensively used in South and South East Asia particularly in China and Vietnam. *Azolla* contributes 40-60 kg N ha^{-1} in a crop. The utilization of *Azolla* as dual crop on wetland rice is gaining importance in many countries. *Azolla* as a biofertilizer (green manure) for rice crop is its high N content

(3-6%) due to nitrogen fixation and its fast growing, fast decomposition and availability to plants. Six common species of *Azolla* has been identified so far i,e. *A. pinnata, A. microphylla, A. filiculoides, A. caroliniana, A. rubra and A. maxicana* (Adhikary *et al*. 2015).In Nepal, *A. pinnata* and *A. filiculoides* are found widely grown in natural water bodies and swampy lands. All *Azolla* species have their symbiotic relationship with Anabaena (Cynobacteria). *Azolla* plant takes the nutrients from the water and soil and make available to the Anabaena which live in the dorsal lobe of *Azolla*. The Anabaena which fixed atmospheric nitrogen provides to *Azolla* plant. In favorable condition, *Azolla* multiplies very fast with doubling time of 2-5 days. *Azolla* requires phosphorus (15-20 kg ha^{-1}). In phosphorus deficient soil (less than15 ppm), various deficiency symptoms like elongation of roots, reduction in fond size and change in color to purple takes place (Maskey and Bhattarai 1984). Molybdenum is very beneficial for well growth of *Azolla* (Adhikary and Bhattarai 2000).

Phosphorus solubilizing micro-organisms (PSM bio-fertilizer)

Phosphorus is an important major plant nutrient next only to the nitrogen. In acid soil the phosphorus is locked up in the form of iron and aluminum salt which are in insoluble phosphate form. The insoluble inorganic compound of phosphorus is largely unavailable to plants. Several soil bacteria like *Bacillus, Psuedomonas* etc. and soil fungus like *Penicillum, Aspergillus* etc. secrets organic acids (formic acids, lactic acids, fumaric acids, succinic acids etc.). These acids lower the pH and solubilize bound phosphate in the soil. PSM also hydrolyze organic and inorganic phosphorus from insoluble forms to soluble forms and make them available to the plants. This is known as Phosphorus solubilization. A soil microbe responsible for this phenomenon is known as Phosphorus solubilizing microorganism (PSM). It produces enzyme *phosphatase* like *phytase* and hydrolyses which help in solubilization of phosphorus. These miocrobs also reduce P-loss from soil. Efficient strais of PSB and PSF can be successes fully grown in carrier media like other bio-fertilizers and used as seed or soil inoculants. Phosphorus bio fertilizers can be effectively used in crops like rice, pulses, millets, cottons, sugarcane, vegetables and horticultural crops. In Russia, a commertial bio-fertilizer under name of *phosphobacterin* was prepared by using the *Megaterium phosphaticum* and yield increases of 5-10% over corresponding controls were seen.

Figure 24: Use of Azolla in rice.

Mycorrhiza bio-fertilizer

Mycorrhiza is derived from two Greek words *myco* (fungus) and *rhiza* (root). *Mycorrhiza* is of two types namely Endomycorrhiza and Ectomycorrhiza.

Ectomycorrhiza are formed by fungi belonging to the higher Basideomycetes, Ascomycetes and Zygospheric Phycomycetes of endogonaceae. The host plants of these fungi are predominantly trees belonging to the Pinaceae (fir, pine), Betuleaceae (alder), Myrycaceae (eucalyptus) and other families. The hyphae of ectomycorrhiza form a mantle around root and grow into spaces between root cells without penetrating them. Ectomycorrhizal fungi have been introduced in a deficient soil as various inoculants to provide seedling with adequate established forest in newly established forest. In the newly established forest soil, seed inoculation is successfully done to establish established forest.

Endomycorrhiza type is commonly used and much more abundant than ectomycorrhizae. It is also called as Vesicular–arbuscular mycorrhiza (VAM). The name vesicular-arbuscular refers to the formation of typical morphological structure called vesicles and arbuscles in the cortex region of the roots. The hyphae form shrub-like appearances within the root cells are called arbuscles. The hyphae also swell which are called vesicles. The vesicles are thought to be mainly for storage and the arbuscles are thought to be mainly for nutrient exchange and transportation. The fungus receives energy (carbon) from plants and plant receives minerals especially P and water from the fungus. The VAM association is found in most crop plants except in some families of plants (such as cruciferae, Chenopodiaceous, Caryophyllaceous and Cyperaceous). Endomycorrhizae (VAM) is microscopic beneficial fungus. This fungus infects the roots and benefits the plants by absorbing and transporting soil phosphorus and makes it available to the plants.

Isolation, identification and maintenance of VAM of rhizospheric soil are done by wet sieving and sucrose centrifugation method (Gerdemann and Nicholson 1963). VAM inoculum can be prepared by keeping mixed mycorrhizal spores in 3:1 soil media (3 part soil and 1 part sand) in sterilized condition and growing onion, maize, napier inplastic bags and earthen pots. Among the different types of endomycorrhizae *Glomus* and *Acaulosporus* are predominantely found in upland soil (Bajracharya *et al*. 2004). Organic amendments significantly increase the biomass of soil organisms including VAM fungi and enhance rehabilitation of eroded soil (Vaidhya *et a.,* 2007). The mostly used endomycorrhiza is *Glomus* species as bio fertilizer. Except phosphorus supplying to the host plant VAM also transports nitrogen, potassium, magnesium and micronutrients such as zinc, copper, sulphur, boron and molybdenum. VAM fungi increase the diseases resistance of host plant against root pathogens. VAM fungi bind and aggregates soil particles through intensively growing mycelium. Binding of soil particles by VAM fungi is a potential control of soil erosion. They can make water directly available to the plants. They reduce resistance to draught stress.

With a few exception in use of bio fertilizer (inoculation) technology has not been widely adopted by farmers this reflects inadequate demonstration, promotion of the benefits of the inoculations, difficulties in applying inoculants, limited potentials of inoculants production and its quality and distribution and economic constraints of resources poor farmers. However, among all bio fertilizers, there is considerable potential of *Rhizobium* for enhancing biological nitrogen fixation through the inclusion of legumes in farming system in crop rotation or introduction of legumes in fallow land.

However, there are some limitations to be considered:

- Narrow genetic base for mother culture/lack of facilities for selection, identification and authentification of efficient strains.

- Lack of facilities to preserve micro-organisms (Organism bank).
- Unsatisfactory carrier material.
- Lack of quality control facilities
- Lack of trained personnel in production and handling bio fertilizer.

References

Adhikary BH, SK Bajracharya, R Adhikary, KP Bhurer and SP Vista. 2015. Efficacy of *Azolla pinnata* in rice production in the central Region of Nepal. Pp. 34-35. *In Proc of the Abstracts*. Second National Soil Fertility Research Workshop, organized by Soil Science Divison, NARC, Soil Management Directorate, DoA, IRRI, Nepal and CYMMYT, South Asia Regional office, held at March 24-25, 2015. Khumaltar, Lalitapur.

Adhikary BH, J Shrestha and BR Baral. 2011. Efficacy of *Azotobacter* in maiz production in acid soils. Plant Breeding Journal, IAAS, Rampur. *J. Pl. Breed*. 6: 36-41.

Adhikary BH and S Bhattarai. 2000. Response of *Azolla pinnata* growth and nitrogen content to molybdenum applicationin Malepatan soil series. Rice Research Reports. 206-209. *In Proc.* of the 22nd National Summer Crop Research Workshop organized by NARC held on March 27-27, 2000, Lumley, Kaski, Published by NRPP, Hardinath, Dhanusha, Nepal.

Bajracharya SK, SL Maskey and S Bhattarai . 2004. Survey, isolation and identification of endomycorrhizae. *In Proc.* of 4th National Conference on science and technology organized by RONAST held on March 23-26, 2004, Kathmandu, Nepal.

Brockwell J and Bottomley P. (1995). Recent advances in inoculants technology and prospects. *Soil Biol. Biochem*. 27.

Gerdemann IW and TH Nicholson. 1963. *Trans. Br. Mycol. Soc.* 46. 235.

Kreig N and JG Halt. 1984. *Manual of determinative bacteriology*. *Vol.1*. Baltimore.

Maskey S L, S Bhattarai, MB Peoples and DF Herridge (2001). On farm measurement of nitrogen fixation by winter and summer legumes in the hill and terai regions of Nepal. *Field Crop Research.* 70 (2001): 209-221.

Maskey SL and S Bhattarai (1984). Effect of *Azolla* on Rice. *IAAS journal* vo. 3 no 1.

Mishra BK and SK Dadhich. 2010. Methodology nitrogen bio-fertilizer production. *Journal of adv. Dev. Res.* Vol (1) 2010.

Peoples MB, DF Herridge and JK Ladha. 1995. Biological N fixation on efficient sources of nitrogen for sustainable Agriculture Production. *Plant and Soil*. 174: 3-28.

SSD. 2000. *In Proc.* of work shop on Bio-fertilizer and soil fertility management under watershed approach organized by South ASIA Association for Regional Co-operation and Nepal Agriculture Research Council. Soil Science Division, Khumaltar, Lalitapur, Nepal.

Vaidya GS, K Shrestha, BR Khadge , NC Johnson and H Wallender. 2007. Organic matter stimulates bacteria and AM Fungi in purpurea and Luecaena diversifolia plantation on eroded slopes in Nepal. *Online published in Blackwell Synergy in 10th September 2007.*

Venkataraman GS 1977. Report on all India Coordinated project on Algae. *IARI, New Delhi, India.*

Chapter 4: Soil Environment

Biochar and its Implication in Soil Science

Shree Prasad Vista, Ph. D. (Soil Fertility)
Senior Soil Scientist
BH Adhikary, M.Sc. (Soil Fertility)
Chief Soil Scientist

Background

Production and use of charcoal in everyday life is not a new story in Nepal. Charcoal production from cooking has been a major feature for thousands of years. The use of these produced charcoals in the field is not in practice. Charcoal is used by blacksmith for heating iron and in common, it was used for cleaning the teeth in past days. However, with the advancement of science and technology, its use has been widening and the process of making charcoal has also been coming up with modification. The placement of charcoal in soils is what we say biochar in recent days. This is only a practice of application of charcoal in soil with the intention of soil improvement and it is our ancestral way of life that modern science is trying to understand and replicate.

Biochar is a fine grained charcoal high in organic carbon and highly resistant to decomposition. It is produced by the thermal decomposition of organic feedstock/ biomass generally known as pyrolysis, generally at low heating rates under oxygen limited condition. It has significant carbon content, high internal surface area and adsorption properties. It has high cation exchange capacity, better fertilizer retention and less field runoff. It also has significant synergisms with soil microbes over time.

Important sector of biochar use

1. As a Soil Amendment
2. Closing nutrient cycles in agriculture (animal farming)
3. Waste water treatment, sewage sludge pyrolysis
4. Remediation of contaminated soils
5. Carbon sequestration
6. Mitigating Climate Change

Biochar and Environmental Management

There are four complementary and often synergistic objectives which may motivate biochar applications for environmental management, namely soil improvement, waste management, energy production and climate change mitigation. They need to have either a social or a financial benefit, or both and as a result, there are a number of very different biochar systems of different scales. Originally biochar was promoted primarily by the soil community, who were drawn by its remarkable soil enhancement properties. Now however the significance of the climate change benefits offered by biochar is becoming the key driver. Biochar is now acknowledged as one of the main ways of decarbonising the atmosphere. There has been much discussion in the press and the literature regarding the scope for Carbon Capture and Storage – that is sequestering CO_2 gas. The scope for carbon sequestration with biochar however may be just as significant. In the developing regions of the world, where the bulk of the land and the best climatic conditions for biomass production exist, policy incentives to drive Carbon removals may be expected to result in the widespread adoption of biochar soil improvement based on pyrolysis technologies. The potential role of biochar for the removal of carbon dioxide (CO_2) from the atmosphere and storage in soil of very large quantities of Carbon appears to lie mainly in developing countries.

Biochar and the Soil

Biochar can be used as a soil amendment to increase plant growth yield, improve water quality, increase soil moisture retention and availability to plants, reduce soil emissions of GHGs, reduce leaching of nutrients, reduce soil acidity, and reduce irrigation and fertilizer requirements. These properties are very dependent on the properties of the biochar, and may depend on regional conditions including soil type, condition (depleted or healthy), temperature, and humidity. Modest additions of biochar to soil were found to reduce N_2O emissions by up to 80% and completely suppress methane emissions. Conservation of energy is achieved through the avoidance of energy incurred in the production of excess fertilizers. Biochar can be used in the reclamation of degraded and spoiled lands (Acidic and Alkaline soils).

Biochar and Nepal

Research on biochar production and its use in agricultural soil is very limited in Nepal. Very recently, this concept has been gaining importance and popularity. However, only few projects in biochar are running in Nepal and there has been a rapid change in the concepts of biochar use. Earlier, biochar itself was considered as a substitute of fertilizer and now it has been commonly agreed that it is just a carrier of the nutrients. Use of only biochar in soil did not improve crop yield, it locked the nutrients and therefore, in recent years, mixing of nutrients with biochar has become a practice.

Research on biochar is being conducted in Nepal by Kathmandu University from few years back. Application of biochar to soil at low rates (2-4 t/ha) increased growth of both coffee plants and radish. Mixed grass/weed biochar gave the best results for coffee seedlings grown on nursery beds. Application of diluted cattle urine did not have a notable effect on coffee seedlings. Biochar amended soil generally had reduced emission of GHGs. This reduction was significantly lower for N_2O flux. Hence, agroforestry systems in combination with biochar application to soils, offers a potentially viable option for sustainably enhancing agricultural production, while also helping to mitigate greenhouse gas emissions and climate change. Few other researches are also carried by other organizations but all are in a very small scale.

Biochar Research in NARC

Very recently, biochar has gained its popularity in Nepalese agricultural research with the inception of Biochar Project in Nepal and NARC as an implementing body of the project, has initiated scientific research in three agro-ecological zones tested in six different crops. Biochar was prepared with three different kilns using different feedstock in four locations and with six crops. In Hill Crop Research Program, barley and potato were grown using biochar at $4tha^{-1}$ and with seven different treatments. This research represents mid hills condition and for terai condition, research was carried out at RARS, Parwanipur. Onion and maize were grown with seven different treatments. Similarly, one more trial was conducted in sugarcane crop at SRP, Jitpur. To represent foothills, another trial was carried out at Spice Development Center, Panchkhal with ginger crop. All the treatments were replicated five times. One hundred and ten farmers field trial were also carried out side by side to know their perception on biochar. Soil Science Division as a implementing body of the research trial has also started doing some basic research on biochar in green house condition. Pot culture with tomato is undergoing with eight different treatments and five replications. Intensive study is on the way with biochar to test its potentiality in Nepalese agriculture. Results of the research can be obtained with different soil nutrient analysis after completion of the project. Preliminary studies show that there is tremendous potentiality of biochar production and utilization in Nepalese agriculture. Farmers involved in field trial are giving positive response to biochar application.

Way Forward

Though biochar research in NARC is still in preliminary stage, however following points have come up while working in biochar as way forward.

1. Study and assess the nature of the local feed stocks and based on it develop a National Biomass Resource Atlas.
2. Different pyrolysis stove designs should be tested to establish the optimum solutions in the different agro ecological zones.
3. Determination of the optimum way of accounting for, and being credited for the carbon sequestration in the soil.
4. Dose of biochar with respect to location, soil types and climatic variation is a must in near future.
5. Persistivity of agrochemicals in soil amended with biochar must also be studied.

Recycling of Organic Wastes and its Implication in Agriculture

Shree Prasad Vista, Ph. D. (Soil Fertility)
Senior Soil Scientist

Introduction

Organic waste is produced wherever there is human habitation. The main forms of organic waste are household food waste, agricultural waste, human and animal waste. In industrialised countries, the amount of organic waste produced is increasing dramatically each year. Although many gardening enthusiasts 'compost' some of their kitchen and garden waste, much of the household waste goes into landfill sites and is often the most hazardous waste. The organic waste component of landfill is broken down by micro-organisms to form a liquid 'leachate' which contains bacteria, rotting matter and may be chemical contaminants from the landfill. This leachate can present a serious hazard if it reaches a watercourse or enters the water table. Digesting organic matter in landfills also generates methane, which is a harmful greenhouse gas, in large quantity enhancing global warming. Human organic waste is usually pumped to a treatment plant where it is treated, and then the effluent enters a watercourse, or it is deposited directly into the sea. Little effort is made to reclaim the valuable nutrient or energy content of this waste. The concept of organic recycling is particularly relevant to agricultural production. This is mainly because the natural soil-plant –animal –soil system is remarkably and economically effective in operating the principles of bioprocessing and bioconversion, the two aspects forming the underlined idea of organic recycling. The two broad approaches to tackle the problem of organic recycling in soil improvement and crop production could be improvements in the process of composting by reduction in the processing period and enrichment in quality and Utilization of the available organic residues and inorganic wastes in natural plant production cycle.

Organic waste – its types

There are a number of types of organic waste which are commonly discarded. Types and sources of organic waste and some examples of common uses for such waste are mentioned below.

Domestic or household waste

This type of waste is usually made up of food scraps, either cooked or uncooked, and garden waste such as grass cuttings or trimmings from bushes and hedges. Domestic kitchen waste is often mixed with non-organic materials such as plastic packaging, which cannot be composted. It is beneficial if this type of waste can be separated at source – this makes recycling of both types of waste far easier. Domestic or household waste is usually produced in relatively small quantities. In developing countries, there is a much higher organic content in domestic waste.

Commercially produced organic waste

By this, we mean waste generated at institutional buildings, such as schools, hotels and restaurants. The quantities of waste here are much higher and the potential for use in conjunction with small-scale enterprise is good.

Animal and human waste

It is worth mentioning that there is serious health risks involved with handling sewage. Raw sewage contains bacteria and pathogens that cause serious illness and disease. It should be stressed that health and safety procedures should be followed when dealing with sewage and that people involved with its handling should have a clear understanding of the health risks involved. Raw sewage should never be applied to crops which are for consumption by humans or animals.

Agricultural residue

This is the 'waste' which remains after the processing of crops (e.g. maize stalks, rice husks, foliage, etc.). There are a wide variety of applications for this residue, ranging from simple combustion on an open fire to complex energy production processes that use this waste as a fuel stock.

Potential uses of Organic waste in Agricultural sector

Organic waste has high potential of using in agricultural sector, some of which are listed below;

- As a mulch
- As green manure
- Incorporation of waste after stabilization to the soil

If the waste is applied as such in the soil then there is health hazard risk, environmental pollution including air, soil and ground water. Therefore, this waste needs to be stabilized first through composting.

Methods of processing organic waste

Organic waste can be used for soil improvement, animal raising and to provide a source of energy. Different levels of processing are required for achieving it and some of the common approaches of using organic waste will be briefly highlighted. Some of the options in the form of a flow diagram are shown below.

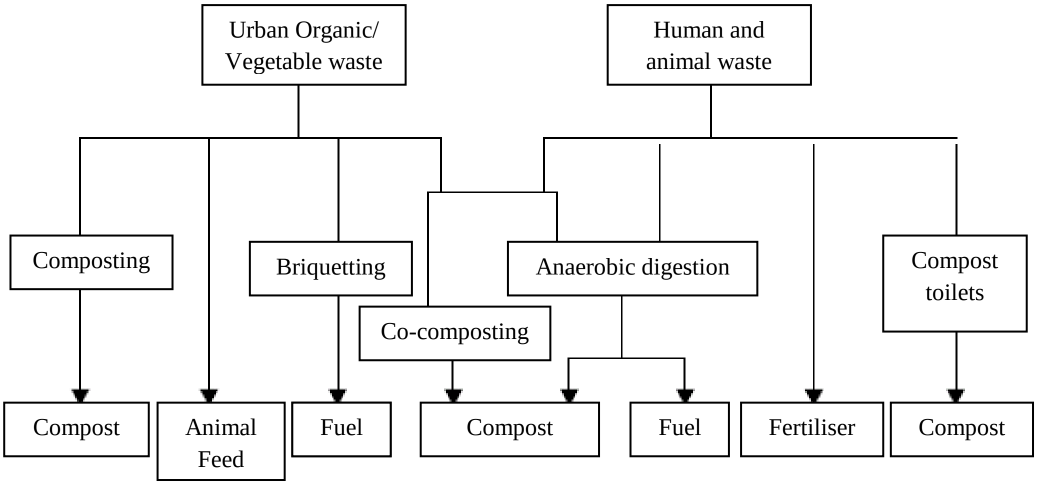


Figure 25: *Flowchart showing processing options of Organic Waste.* Sources:www.practicalaction.org

Availability of organic waste for recycling

Issues and Technologies

It is estimated that 5.2 million tons of solid waste are generated daily worldwide, of which 3.8 million tons are from developing countries. As waste generation increases significantly, it results in greater demand for both waste collection and innovative treatment options. The goal of municipal solid waste (MSW) management—which deals principally with household waste but includes commercial waste generated in municipal areas—is to treat the waste in an environmentally and socially acceptable manner, with appropriate clean technologies. Failure to achieve this goal results in serious local, regional, and global public and environmental health problems, including air pollution, soil and groundwater contamination, and emissions of greenhouse gases (GHGs). The three main MSW treatment options are landfilling, composting, and incineration. All waste disposal options eventually decompose organic materials into simpler carbon molecules, such as carbon dioxide and methane. The composition of organic waste also varies with the place and habit of the people.

In industrialized countries with rich experience in waste management, incineration isrecognized as the single most effective method for MSW treatment, as it reduces wastevolume by 90% and eliminates methane emissions. Incineration yields heat, which is captured through waste-to-energy facilities to produce electricity. However, there are a number of key differences in the waste characteristics of industrialized countries and less developed countries. The waste in developing countries, particularly in South Asia, is characterized by a significantly higher density and moisture, mainly organic waste with low caloric values (700–1,000 kilocalories). SAARC countries agreed to encourage nongovernment organizations (NGOs) and private companies to establish community-based segregation at source, separate collection, and resource recovery from wastes with particular focus on composting.

Potential organic waste in Nepal and South Asia

The organic matter within MSW streams in the region averages around 70%. Nepal produces the least amount of total organic waste compared to other Asian countries. Only 0.5 million tons of organic waste is produced every year and the total solid waste by mass is estimated to be only 0.7 million tons. Of the total 0.7 million tons of solid waste, 0.5 million tons/year are organic waste in Nepal. The high volume of organic waste in the region is an important consideration for developing appropriate management plans and treatment options. In Nepal, a household generates only 0.36 kg of waste per day of which the organic matter percentage of the waste is about 74% (ADB 2011). There is high potential of harvesting all waste in Nepal to its best.

Resource recovery potential from Municipal organic waste in Nepal

By recycling organic waste into compost, SAARC region would have the potential to produce around8 million tons of compost worth about $710 million. Alternatively, if the entire 33.4 million tons of organic waste were used to produce electricity from biogas, the potential is estimated at 1,670 million cubic meters (m^3) of biogas and 3,340 million kilowatt-hours (kWh)/year of electricity (ADB 2011). If 3,340 million kWh is converted into per day generation, the amount of electricity that may be generated is estimated at 9,150 megawatt-hours, which has a market value of $701 million year^{-1}.

The most prevalent existing treatment option throughout the region is land filling, as it remains the cheapest and easiest way to dispose of waste. However, most landfills are not scientifically engineered and are poorly maintained, effectively turning into open, unsanitary dumpsites. Collection rates in the region are typically low, at 50%–60%, with the uncollected waste dumped into drains, rivers, and open spaces, causing severe public and environmental health problems. In Nepal, the waste collection and segregation is not done at household level. There are certain local youth clubs or groups who collect household waste every alternate day. Due to unmanaged waste disposal, water pollution, greenhouse gas emission, odour nuisance, air pollution from burning garbage, etc. are some of the public and environment health nuisances. During rainy season and at times when employees at Municipality go on strike with their demand, there are always heavy chances of spread of disease in the locality.

Nepal has a great potential of recovering all the organic waste resources. Out of total 0.5 million tons of organic waste, 0.13 tons compost could be prepared which substantially will benefit agricultural sector. Even through anaerobic digestion, biogas or electricity could be generated. From the landfill gas extraction, electricity could also be generated. The most important and neglected but having high potential of organic waste recycling is the making of briquettes. Briquettes are becoming very popular these days but generally the raw materials used are all freshly obtained plant materials.

Technological options for recycling organic waste

Composting

Composting is an aerobic process (requiring oxygen) where microorganisms decompose organic materials under controlled conditions. This process reduces the waste volume by up to one-third. Composting can be applied on various scales, from individual households to large centralized facilities with the capacity for several hundred tons of waste per day. Composting is based on microbial degradation of food, vegetables, fruits, leaves, grasses, and crop residues. This is a traditional practice for agricultural waste, and is also applicable to municipal organic waste. The production of compost is not intended to replace chemical fertilizers altogether; rather, it is simply intended to act as a soil amendment, which can improve overall soil health and agricultural sustainability.

Various methods of composting could be implemented for preparation of compost from the organic waste. Since organic waste is one of the major inputs of composting in this case, proper C:N ratio, moisture and temperature should be maintained. Other inputs include soil, cowdung, N fertilizer like urea, etc. based on the types of available organic wastes. In case, the organic waste have enormous odour, sufficient turning can be done or these days there are many microbial inoculants available in the market such as EM, Jeevatu, etc. should be incorporated timely. These microbial inoculants are even helpful in repelling flies and other vectors.

Enrichment of compost with N fixing bacteria and Phosphate solubilizing microorganisms is the only possible means to improve nutrient content as well as humus content of finished compost. With the aim of reducing the period of composting and enriching the low analysis compost, phosphor composting where low grade rock phosphate @ 2.5% w/w and pyrite @10% w/w on dry basis are blended with organic wastes, cowdung, soil and FYM in the ratio of 8:1:0.5:0.5. In association the composting microbes may also be used like *Trichurus spiralis, Paecilomyces* and Phosphate solubilizer *Aspergillus* may be used.

Vermicomposting

Vermicomposting is a simple biotechnological process of composting, in which certain species of earthworms are used to enhance the process of waste conversion and produce a better end product. Vermicomposting differs from composting in several ways. It is a mesophilic process, utilizing microorganisms and earthworms that are active at 10–32°C (not ambient temperature but temperature within the pile of moist organic material).

Vermiculture is the culture of earthworms. The goal is to continually increase the number of worms in order to obtain a sustainable harvest. The worms are either used to expand a vermicomposting operation or sold to customers who use them for the same or other purposes. The species of earthworms that are being used for vermicompost production are *Eisenia foetida*, *Eudrilus eugeniae*, *Perionyx excavatus*, *Lumbricus rubellus* and *Pheretima elongata*. They are responsible for breakdown of dead organic matter into plant nutrients. Earthworms, besides producing enormous amount of worm casts over the years, modify the structure of the soil and in its turnover.

Vermiculture revolution for safe waste management

Earthworms have over 600 million years of experience in waste and land management, soil improvement and farm production.

Vermiculture biotechnology promises to provide cheaper solutions for:

1. Management of municipal and industrial solid wastes (organics) by biodegradation and stabilization and converting them into nutritive organic fertilizer (vermicompost). It amounts to converting ‘trash into treasure’ or getting ‘wealth from waste’ or ‘gold from garbage’.
2. Restoring and improving soil fertility and boosting food productivity by worm activity and use of vermicompost without recourse to the destructive agro-chemicals. It amounts to getting ‘green gold’ (crops) from ‘browngold’ (vermicompost). Nations of world today is seeking the most cost-effective, economically viable, environmentally sustainable and socially acceptable technology that can convert all ‘organic waste’ into a valuable ‘resource’ to be used back into the human society. It involves about 100-1000 times higher ‘value addition’ than other biological technologies.

Organic manure from organic wastes as nutrient source

Organic manure has been used as a source of nutrient and soil conditioners for years. On an average, FYM at 10 ton /ha supplies 50-110 kg of N, 15-20 kg of P_2O_5 and 50-60 kg of K_2O of which only 15-30 kg of N, 15 kg of P_2O_5 and 35 kg of K_2O become available during first season of application.

Crop residue management

Crop residue incorporation has been practiced since long time. One of the major organic wastes in Nepal is crop residue. In some areas of western part of Nepal, after harvesting of wheat, burning of wheat stalk is common. However, if this could be managed then, a lion share of the soil organic matter could be supplemented through crop residues only.

Green-manuring

The green manure crop supplies organic matter and additional nutrients, particularly N if it is a legume crop which fix N. Incorporation of 10t/ha of green manure supplements 40-50 kg of N/ha and has shown promising results in rice where green manure is incorporated with fertilizers. In north India, it is reported that up to 100 kg N/ha can be accumulated by Dhiancha which can be used by rice.

Biochar

Organic waste can be converted to biochar with adequate management. Biochar is most commonly produced by pyrolysis of the biomass. Pyrolysis allows the production of biochar by heating with essentially little to no oxygen present. In addition to the biochar, the process also results in bio-oils and synthesis gas or syngas that are used for further combustion and renewable fuels. The process of pyrolysis requires the use of kilns and furnaces to heat the biomass in a three stage reaction process noted in the equations below. In the initial stage of production the biomass loses water and other residue. Then the residue goes through further pyrolysis and biochar begins to form. Finally the biochar produced begins to decompose forming the carbon rich charcoal used for application.

Key issues in scaling up organic waste management

Mixed waste

This is undoubtedly the key constraint to improved sector performance. Recycling of mixed municipal waste lead to production of inferior-quality compost, which in turn gives rise to higher operational costs and marketing problems. An additional disadvantage of bringing mixed waste to a compost plant is that the volume of reject materials would be large, and these would have to be transported and disposed appropriately, resulting in additional costs.

Quality and processing standards

Quality standards and registration of the compost by the Ministry of Agricultural Development, as well as its promotion by the public sector, are vital for scaling up efforts. However, the key issue for promoting the use of compost in agricultural soils is the methods of production, which must ensure that the compost is of suitable quality for safe and beneficial reuse and reliable performance in agricultural production. To protect human health, compost production must ensure that organic waste materials are effectively sanitized with heat to destroy human pathogens (disease organisms). Compost piles should reach a minimum temperature of 55°C, thereby causing the thermal death of pathogens and plant propagules.Additionally, compost quality standards are required to ensure the absence of phytotoxic compounds (compounds toxic to plant growth) and other elements associated with immature composts which can be detrimental to plant growth. Standards must ensure that such risks are addressed, and that compost products can be safely used and will deliver reliable agronomic performance.

Community awareness

A greater effort is needed to increase the level of awareness of local communities and encourage source segregation of waste. Segregation of recyclable waste at source is not conscientiously practiced by households, shops, etc.. Farmers must also be trained on the benefits of municipal organic waste, and to shift their full reliance away from chemical fertilizers.

Technological issues

The selection of appropriate technology depends on the physical and chemical composition of the waste, its moisture content, the prevailing climate conditions, and the type of waste collection method used (mixed or sorted).

Environmental issues

The location of the compost plants and open composting without shed and buffer areas also affect the project’s viability. Odor problems will be observed in plants where anaerobic conditions prevail, and when the composting is undertaken in an open yard. Formal environmental clearance from the government is also an important issue for establishing plants.

Financing issues

Community level organization must be created to support the organic waste sector. Chemical fertilizer subsidies by governments distort the market for organic compost. Chemical fertilizers are typically sold at a subsidized price, so in the medium to long term, such subsidies should be reduced, rather than providing the same level of subsidies to organic composts.

Management issues

Selection of the correct management model for the operation of compost and other recycling plants is also an important factor for its sustainability. It should be managed well to run for long term.

Public–private partnership

For proper functioning of organic waste management, PPP model should be followed so that there is equal participation from every individual.

Consideration for future research

- Monitoring of accumulated heavy metals due to sludge, urban waste and agro-industrial waste
- Study on ground water pollution
- Study on green house gas emission due to addition of crop residues

Policy related considerations

- Every household should be encouraged to segregate organic waste at source
- Government should encourage CBOs, youth clubs, etc. for organic waste recycling at household level through certain scheme
- Government subsidy should be given in machineries or other raw materials in recycling organic wastes
- Government should strictly punish to those who through waste outside the specified location.

Conclusion

Looking to huge quantity of wastes as minerals or resources in Nepal, there is atremendous scope for using such solid wastes for agricultural purposes. It is also being increasingly realized that composting, vermicomposting as well as biochar production is an environment friendly process to convert a wide variety of wastes into valuable agricultural inputs and environmental problems become minimized. Compost and biochar are excellent sources of humus and plant nutrients resulting in improving of soil biophysical properties and organic matter status in addition to increase crop yield. Beside these, recycling of these organic wastes into compost, vermicompost and biochar reduces carbon dioxide emission thus contributing to reduction ofgreen house gases and global warming thereby sequestering lions' share of atmospheric carbon to the soil.

References

ADB 2011. Towards Sustainable Municipal Organic Waste Management in South Asia. Asian Development Bank. A Guidebook for Policy Makers and Practitioners.

http://biocharinnovation.wordpress.com/workshop-india/.

www.practicalaction.com.org

Chapter 5: Modern Techniques in Soil Science

Nanotechnology

Shree Prasad Vista, Ph.D (Soil Fertility)
Senior Soil Scientist

Background

In general, nanotechnology comprises of two words, 'nano' and 'technology'. Nano means very small particles of the range 1 $x10^{-9}$ and technology is the making, modification, usage, and knowledge of materials, tools, machines, techniques, crafts, systems, methods of organization in order to solve a problem, improve a pre-existing solution to a problem, achieve a goal or perform a specific function. In short, nanotechnology is the practical application of scientific concepts and techniques in the performance of nanoparticles or nanomaterials. Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. Nanoscience and nanotechnology are the study and application of extremely small things that can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering.

The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled "There's Plenty of Room at the Bottom" by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology (CalTech) on December 29, 1959, long before the term nanotechnology was used. In his talk, Feynman described a process in which scientists would be able to manipulate and control individual atoms and molecules. Over a decade later, in his explorations of ultraprecision machining, Professor Norio Taniguchi coined the term nanotechnology. It wasn't until 1981, with the development of the scanning tunneling microscope that could "see" individual atoms, which modern nanotechnology began.

Nanotechnology (NT) is being visualized as a rapidly evolving field that has potential to revolutionize agriculture and food systems and improve the conditions of the poor. Nanotechnology when applied as a tool, in tandem with other measures, can seek to address some of the world's most critical sustainable development problems in the areas of water, energy, health and environment, agriculture, and biodiversity and ecosystem management. These five areas, collectively known as WEHAB, were identified in the 2002 United Nations Johannesburg Summit on Sustainable Development. A UN Survey on potential applications of nanotechnology in developing countries identified agricultural productivity enhancement as the second most critical area of application for attaining the millennium development goals while energy conversion and storage was ranked first and water treatment as the third areas needing focus.

The role that nanotechnology can play in soil science is being percieved as the most potential area in the world of agriculture. Nanotechnology has found applications in controlling release of nitrogen, characterization of soil minerals, studies of weathering of soil minerals and soil development, micro-morphology of soils, nature of soil rhizosphere, nutrient ion transport in soil-plant system, emission of dusts and aerosols from agricultural soil and their nature, zeoponics, and precision water farming. In its stride, nanotechnology converges soil mineralogy with imaging techniques, artificial intelligence, and encompass bio molecules and polymers with microscopic atoms and molecules, and macroscopic properties (thermodynamics) with microscopic properties (kinetics, wave theory, uncertainty principles, etc.), to name a few. Similar to the water-saving nano-membranes, along with zeolites and hydrogels, there are other applications of nanotechnology to soil science. There are also new analytical techniques for characterization of soil properties. Notable among these are nanoscale secondary ionmass spectrometry and nano-microscopy to study physical infra-structure of micro-aggregates of 10-50 μm scale.

Basic Concepts

It's hard to imagine just how small nanotechnology is. One nanometer is a billionth of a meter, or 10^{-9} of a meter. We can just imagine how small it is from the following examples:

- There are 25,400,000 nanometers in an inch
- A sheet of newspaper is about 100,000 nanometers thick
- On a comparative scale, if a marble were a nanometer, then one meter would be the size of the Earth

Nanoscience and nanotechnology involve the ability to see and to control individual atoms and molecules. Everything on Earth is made up of atoms—the food we eat, the clothes we wear, the buildings and houses we live in, and our own bodies.

But something as small as an atom is impossible to see with the naked eye. In fact, it's impossible to see with the microscopes typically used in a high school science classes. The microscopes needed to see things at the nanoscale were invented relatively recently—about 30 years ago.

Once scientists had the right tools, such as the scanning tunneling microscope (STM) and the atomic force microscope (AFM), the age of nanotechnology was born.

Although modern nanoscience and nanotechnology are quite new, nanoscale materials were used for centuries. Alternate-sized gold and silver particles created colors in the stained glass windows of medieval churches hundreds of years ago. The artists back then just didn't know that the process they used to create these beautiful works of art actually led to changes in the composition of the materials they were working with.

Today's scientists and engineers are finding a wide variety of ways to deliberately make materials at the nanoscale to take advantage of their enhanced properties such as higher strength, lighter weight, increased control of light spectrum, and greater chemical reactivity than their larger-scale counterparts.

Some Uses of Nanotechnology

Nano iron and its derivatives

Remediation has grown and evolved, continually developing and adopting new technologies and improving the remediation process. One of the most established systems is that termed "pump-and-treat". Pump-and-treat systems operate on the basis of removing contaminated groundwater from the ground, downstream of the contamination site, and then treating it before returning it to the ground. This technology it takes a long time to achieve cleanup goals and it is expensive to operate and maintain.

Reducing capabilities of metallic substances, such as zero-valent iron (ZVI), were examined for their ability to treat a wide range of contaminants in hazardous wastewater. The most common use of ZVI has been in the form of permeable reactive barriers (PRBs) designed to intercept plumes in the subsurface and subsequently remediate them. However, new technologies are now available to compete with PRBs. Nanoscale iron particles and their derivatives offer more alternatives to many remediation technologies. The small particle size of the nano iron (1-100 nm) facilitates a high level of remedial versatility.

Nanotoxicity of Engineered Nanoparticles and Nanomaterials

The use of engineered nanoparticles and nanomaterials for environment treatment has raised concerns for human exposure which dash from the absence of specific technologies orienting the removal of engineered nanomaterials from the water, and the safety of the new nanoparticles and nanomaterials that may be used by the water industry. These concerns are often based on its large mobility, small sizes, thus implying a greater potential for exposure as they are dispersed over greater distances and their persistence in the environment increases.

Table 7: Pollutants remediated by nano iron technology.

Carbon tetrachloride	Chrysoidine	*cis*-Dichloroethene
Chloroform	Tropaeolin	trans- Dichloroethene
Dichloromethane	Acid Orange	1,1- Dichloroethene
Chloromethane	Acid Red	Vinyl Chloride
Hexachlorobenzene	Mercury	PCBs
Pentachlorobenzene	Nickel	Dioxins
Tetrachlorobenzenes	Silver	Pentachlorophenol
Trichlorobenzenes	Cadmium	NDMA
Dichlorobenzenes	Bromoform	TNT
Chlorobenzene	Dibromochloromethane	Dichromate
DDT	Dibromochloromethane	Arsenic
Lindane	Tetrachloroethene	Perchlorate
Orange II	Trichloroethene	Nittrate

Conclusion

This chapter has been written with an intention to aware or make familiar our readers with the term Nanotechnology. It is clear from the above literature that while much attention has been focused on the development and potential benefits of nanomaterials in water treatment processes, concerns have also been raised regarding their potential human and environmental toxicity. However, it is difficult to assess the effect of nanomaterials on health and the environment because the methods and tools for such a task have not been well developed yet. It is extremely important that these processes be developed and investigated to ensure that nanomaterials are as safe as possible, while reaching their full potential. Once these information gaps are clear, it is certain that new nanomaterials, in water environment treatment, will play key roles in ensuring sufficient and good quality water and soil to meet the ever-increasing demand for potable water and safe soil in the agriculture.

Soil Genomics

Shree Prasad Vista, Ph.D (Soil Fertility)
Senior Soil Scientist

Background

Genomics is the study of an organism's genetic makeup and how all its genes work together to make an organism function. We use scientific techniques like recombinant DNA (combining different genes together in various arrangements) and gene sequencing (analysing which genes are present and how they can be turned on and off) to understand which organisms are present in soils and how they perform different functions at a genetic level. Leonardo da Vinci wrote, "We know more about the movement of celestial bodies than about the soil underfoot." This statement is just as true today, 500 years after it was written, and is particularly applicable to the microorganisms that inhabit the soil as the identities and roles of most of these microorganisms remain a mystery; even the relevance of microbial diversity to the functioning of soils remains obscure. The complete sequencing of a soil metagenome (i.e., the genomes of all microorganisms inhabiting the soil environment) is now an achievable objective that requires a strong international and interdisciplinary collaboration. The purpose of the TerraGenome network is to facilitate activities that will increase our knowledge and understanding of the soil metagenome. This chapter highlights basic of the state-of-the-art of omic applications in soil science, a field that is advancing rapidly on many fronts. Distinguished authors describe the application of metagenomics, metatranscriptomics and proteomics to soil science. In particular this chapter covers the current and emerging omics techniques and the contribution of these approaches to a better assessment of soil functionality. This is just an attempt to explore the application of various omics technologies to soil science and the future research requirements necessary to overcome the current limitations in this area.

Technological advances in sequencing technologies and bioinformatics analysis tools now enable the generation of a metagenome from soil, although the ultimate goal of obtaining the entire complement of all genes of all organisms in a given sample of soil still lies in the future. The rich information obtained from a soil metagenome will undoubtedly provide new insights into the taxonomic and functional diversity of soil microorganisms; the question is whether it will also yield greater understanding of how C, N, and other nutrients cycle in soil.

Soil microbial communities are known to be incredibly diverse, harboring tens of thousands of species of bacteria and thousands of species of fungi in a gram of soil. This knowledge is based primarily on recent advances in DNA sequencing, which have made it possible to generate millions of sequence reads quickly and economically. The initial application of this high-throughout sequencing technology explored the taxonomic diversity and composition of soil microbial communities using a polymerase chain reaction (PCR)-based approach that focused on phylogenetically informative ribosomal genes. Targeted pyrosequencing has the advantage of being able to focus on a gene, or a few genes, of specific interest; however, for some applications, such as the interaction among multiple community members or their collective response to environmental perturbations, a more comprehensive and complete inventory of microbial genes is desired—a “metagenome”.

Goal of Metagenomics

A major goal of soil metagenomic studies is to identify the functional potential of the complex microbial communities, whether using individual reads or assembled contigs. As might be expected, greater success in assigning functions has been obtained with the longer reads generated with 454 sequencing: 20 to 60% assignment depending on the databases used. In contrast, only 10 to 25% of the shorter Illumina reads have been successfully assigned, although the 10-fold greater number of sequences resulted in more total functional gene assignments.

Whether using individual reads or assembled contigs, the studies to date have been effective in understanding the functional potential of microbial communities in soil and in distinguishing among soils and treatments. For practical reasons, such as cost and computational constraints, many studies have not had true biological replication. In Nepal, the term soil Genomics is not much well understood. However, the application of genomics is practiced unknowingly.

One goal of soil metagenomic studies is to gain insights into soil C, N, P, S, and other elemental cycles. In a comparative metagenomic study to focus on responses of soil metagenomes to N fertilization using two long-term experiments in the Upper Midwest of the United States, consistent responses to N fertilization were observed at the two sites, including: increased relative abundance of genes associated with respiration, protein metabolism, and nucleic acid metabolism; and decreased abundances of genes associated with urea decomposition and tricarboxylate transporters. They did not specifically report on changes in genes associated with classic N cycling processes of N_2 fixation, nitrification, or denitrification. Based on assumptions that assign bacterial phyla into copiotrophic and oligotrophic life histories, they suggested that N fertilization causes a shift toward more copiotrophic phyla.

Obtaining a Representative Sample

Collecting a sample that is representative of a soil is a long-standing challenge for any type of soil study because soils are by nature heterogeneous and vary both spatially and temporally. Often stratified sampling, taking composite samples, and the use of replicated designs can help in obtaining representative samples appropriate for addressing the objective of an experiment, at least when the cost of analyses is not a major limitation. Working with a soil from a single location, DNA extraction protocols display greater variation in metagenomic composition than either soil depth or season of sampling. Current metagenomic sequencing typically requires a few hundred nanograms of DNA. Soils that yield small amounts of DNA, such as permafrost soils, may require additional DNA amplification, a step that may introduce some bias The difficulty in adopting standard methods in soil microbiology is not unique to DNA extraction and a perfect extraction method is unlikely to be developed. Nevertheless, it is likely that the community will select one as a common protocol, as has been done by the Earth Microbiome Project (http://press.igsb.anl.gov/earthmicrobiome/).

Metagenome Interpretation

Even if well-assembled, unbiased soil metagenomes are obtained, there are challenges in how these data will be integrated and synthesized into a coherent representation of the potential functioning of the microbial community. A variety of analytical methods are used, and are being developed, to provide insights into these complex systems and their emergent properties, such as clustering, ordination, and artificial neural networks, are few of them.

Conclusion

This is clearly an exciting time for soil microbial ecology as advances in sequencing technologies generate huge amounts of information about microbial communities. At present, the metagenomics of soils is transitioning from studies about how to do it to those that focus on what can be done with it. Soil metagenomics has already provided insight into the long-standing questions of “who’s there?” and is making inroads into the question of “what are they doing?” Progress will require further developments related to metagenomics combined with knowledge about the spatial and temporal variability of the soil habitat and its influence on microbial activities. This, as well as the integration with other “omics” methods, promises to enhance our understanding about the functioning of soil ecosystems.

Chapter 6: GIS and Remote Sensing Applications

Application of GIS and Remote Sensing in Agriculture and Food Security

Sushil Lamichhane, M.Sc. (Applied GIS)
Kamal Sah, M.Sc.

What is GIS?

Using geographic knowledge in making decisions is basic to human thinking. Where we go, what will it be like, and what shall we do when we get there are applied to the simple events of going to the store or to the major events of planning at regional, national and global scales. By understanding geography and people's relationship to place, we can make better informed decisions about the way we live on our planet. A geographic information system (GIS) is a technological tool for understanding geography and making smart decisions. GIS organizes geographically referenced data so that a person reading a map can select data necessary for a specific objective. A thematic map has a table of contents that allows the reader to add layers of information to a base map of real-world locations. For example, a social analyst might use the base map of topographic survey, and select datasets from the Central Bureau of Statistics to add data layers to a map that shows residents' education levels, ages, employment status, agricultural production, livestock density etc. With an ability to combine a variety of datasets in an infinite number of ways.It is assumed that about 80 percent of data in an organization has some kind of geographic reference.That is why, GIS is a useful tool for nearly every field of knowledge.

A GIS program is able to process geographic data from a variety of sources and integrate it into a map project. Many countries have an abundance of geographic data for analysis, and governments often make GIS datasets publicly available. However, data sharing policies of different governments may vary. For example, in the USA, the data held by government are free to use by public, except for some data held confidential due to security reasons.On the other hand, in the UK, the government has the policy to sell the data for recovering the cost of data generation.Map file databases often come included with GIS packages; others can be obtained from both commercial vendors and government agencies. Some data is gathered in the field by global positioning units that attach a location coordinate (latitude and longitude) to a feature such asan agriculture service centre.

As GIS maps are interactive, users can observe a GIS map on the computer screen in any direction, zoom in or out, and change the nature of the information contained in the map.

They can choose whether to see the roads, how many roads to see, and how roads should be depicted. Then they can select what other items they wish to view together with these roads such as soil types, land cover, terrain, storm drains, gas lines, rare plants, agro-vets, banks or hospitals. Some GIS programs are designed to perform sophisticated calculations for tracking storms or predicting erosion patterns. GIS applications can be embedded into common activities such as verifying an address. From routinely performing work-related tasks to scientifically exploring the complexities of our world, GIS gives people the geographic advantage to become more productive, more aware, and more responsive citizens of planet Earth.

GIS in agriculture

GIS has a significant role to play in agriculture at several scales from local to global. The development of several new digital databases at regional and larger scales, the advent of new continuous data collection and remote sensing techniques at the farm scale, and the continued migration of GIS to more and more powerful desktop, laptop computers and hand held devices have caused an explosive growth in the number and variety of agricultural applications during the past few years. The most important applications are probably those connected with precision or site specific farming, which aims to direct the application of seed, fertiliser, pesticide, and water within fields in ways that optimise farm returns and minimise chemical inputs and environmental threats.

Balancing the inputs and outputs on a farm is fundamental to its success and profitability. The ability of GIS to analyze and visualize agricultural environments and workflows has proved to be very beneficial to those involved in the agri-business industry.

From mobile GIS in the field to the scientific analysis of production data at the farm manager's office, GIS is playing an increasing role in agriculture production throughout the world by helping farmers increase production, reduce costs, and manage their land more efficiently. While natural inputs in farming cannot be controlled, they can be better understood and managed with GIS applications such as crop yield estimates, soil amendment analyses, and erosion identification and remediation.

Agriculture is an inherently geographical practice and it is not surprising that this, together with the extremely large sums of money involved make it a natural application for GIS. Many site-specific farming systems utilise GIS and several related technologies (global positioning system, receivers, continuous yield sensors, remote sensing instruments) to collect spatially referenced data, perform spatial analysis and support decision making, and apply variable rate treatment. Two other related technologies, namely, global positioning systems (GPS) and remote sensing technologies offer numerous advantages at scales ranging from the farm field to the entire globe because they can be used to: generate and synthesise new information cheaply and quickly; document data sources and methods of integration; provide diagnostics for error detection and accuracy assessments; provide input data for a variety of crop yield and non-point source pollution models; and prepare maps and tables that meet specific needs. However, these advantages are currently limited by: our lack of knowledge of statistical methods for summarising spatial patterns; the difficulty of moving geographical data and model results between different scales and resolutions; and the cost and difficulty of field validation. Finding ways to advance our knowledge in these areas is vital because the continued development of new GIS and related technologies will only improve food and fibre production systems to the extent that we can utilise this information to build sustainable agricultural production systems which match land use with land capability.

GIS is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes. Application of GIS is revolutionizing planning and management in the field of agriculture. The technology that has given vast scope to the applicability of remote sensing-based analysis is ‘Geographic Information System (GIS)’. GIS provides ways to overlay different ‘layers’ of data: the ecological conditions, the actual physiognomy and human pressure indices. Agriculture always plays an important role in economies of both developed and developing countries. The ability of GIS to analyze and visualize agricultural environments and work flows has proved to be very beneficial to those involved in the farming industry. Balancing the inputs and outputs on a farm is fundamental to its success and profitability. More accurate and reliable crop estimates help to reduce uncertainty in the grain industry. Spatial data are commonly in the form of layers that may depict topography or environmental elements. Nowadays, GIS technology is becoming an essential tool for combining various map and satellite information sources in models that simulate the interactions of complex natural systems and human interventions. GIS can be used to produce images, not just maps, but drawings, animations, and other cartographic products.

Agricultural sustainability has the highest priority in all countries, whether developed or developing. Aero-space Remote Sensing and GIS technology are gaining importance as useful tools in sustainable agricultural management and development. The solution for providing food security to all people of the world without affecting the agro-ecological balance lies in the adoption of new research tools, particularly from aerospace Remote Sensing, and combining them with conventional as well as state-of-the-art technologies like Geographic Information Systems (GIS). Sustainable agricultural development is one of the prime objectives in all countries in the world, whether developed or developing. The broad objective of sustainable agriculture is to balance the inherent land resource with crop requirements, paying special attention to optimisation of resource use towards achievement of sustained productivity over a long period.

Remote sensing and GIS technology are being effectively utilized in some countries in several areas for sustainable agricultural development and management. The areas of sustainable agricultural development/ management that utilize such technologies include cropping system analysis; agro-ecological zone based land use planning; quantitative assessment of soil carbon dynamics and land productivity; soil erosion inventory; integrated approaches for monitoring agricultural droughts etc.

GIS and remote sensing technologies can be very effective tool for suggesting action plans /management strategies for agricultural sustainability of any region.

GPS in agriculture

The global positioning system (GPS) makes possible to record the in-field variability as geographically encoded data. It is possible to determine and record the correct position continuously. This technology considers the agricultural areas, fields more detailed than previously; therefore, a larger database is available for the user. The accurate yield data can be reported only in the points where GPS position recording has happened. GPS receivers coupled with yield monitors provide spatial coordinates for the yield monitor data. This can be made into yield maps of each field. Information collected from different satellite data and referenced with the help of GPS can be integrated to create field management strategies for chemical application, cultivation and harvest. The development and implementation of precision agriculture or site-specific farming has been made possible by combining the Global Positioning System (GPS) and geographic information systems (GIS). These technologies enable the coupling of real-time data collection with accurate position information, leading to the efficient manipulation and analysis of large amounts of geospatial data. GPS-based applications in precision farming are being used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping. GPS allows farmers to work during low visibility field conditions such as rain, dust, fog, and darkness.

Basics of remote sensing

Definition

Remote sensing means acquiring information about a phenomenon, object or surface while at a distance from it. This name is attributed to recent technology in which satellites and spacecraft are used for collecting information about the earth’s surface. This was an outcome of developments in various technological fields from 1960 onward.

Principle of Remote Sensing

Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material. Different objects return different amount and kind of energy in different bands of the electromagnetic spectrum, incident upon it. This unique property depends on the property of material (structural, chemical, and physical), surface roughness, angle of incidence, intensity, and wavelength of radiant energy.

The Remote Sensing is basically a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computer, electronics and telecommunication, satellite launching etc. All these technologies are integrated to act as one complete system in itself, known as Remote Sensing System. There are a number of stages in a remote system, working as links in a complete and each of them is important for successful operation.

Stages in remote sensing

1. Emission of electromagnetic radiation or EMR (sun/self-emission).
2. Transmission of energy from the source to the surface of the earth, as well as absorption and scattering.
3. Interaction of EMR with the earth's surface reflection and emission.
4. Transmission of energy from the surface to the remote sensor.
5. Sensor data output.
6. Data transmission, processing and analysis.

What we see?

At temperature above absolute zero, all objects radiate electromagnetic energy by virtue of their atomic and molecular oscillations. The total amount of emitted radiation increases with the body's absolute temperature and peaks at progressively shorter wavelengths. The sun , being a major source of energy, radiation and illumination, having a sharp power peak around 0.5 µm, allows to capture reflected light with conventional (and some not-so-conventional) cameras and films.The basic strategy for sensing electromagnetic radiation is clear. Everything in nature has its own unique distribution of reflected, emitted and absorbed radiation. These spectral characteristics, if ingeniously exploited, can be used to distinguish one thing from another or to obtain information about shape, size, and other physical and chemical properties. In so far as we know the spectral characteristics, we can pick an appropriate detector to make the desired measurement, remembering that for a given collector's diameter we get our greatest spatial resolution where wavelengths at longer are shortest and energies greatest, and that these energies decrease at longer wavelengths and distances.

Modern remote sensing technology versus conventional aerial photography

The use of different and extended portions of the electromagnetic spectrum, development in sensor technology, different platforms for remote sensing (spacecraft, in addition to aircraft), emphasis on the use of spectral information as compared to spatial information, advancement in image processing and enhancement techniques, and automated image analysis in addition to manual interpretation are points for comparison of conventional aerial photography with modern remote sensing system. During early half of twentieth century, aerial photos were used in military surveys and topographical mapping. Main advantage of aerial photos has been the high spatial resolution with fine details and therefore they are still used for mapping at large scale such as in route surveys, town planning, construction project surveying, cadastral mapping etc. Modern remote sensing system provide satellite images suitable for medium scale mapping used in natural resources surveys and monitoring such as forestry, geology, watershed management etc. However the future generation satellites are going to provide much high resolution images for more versatile applications.

Remote sensing in agriculture

When farmers or ranchers observe their fields or pastures to assess their condition without physically touching them, it is a form of **remote sensing**. Observing the colours of leaves or the overall appearances of plants can determine the plant’s condition. Remotely sensed images taken from satellites and aircraft provide a means to assess field conditions without physically touching them from a point of view high above the field.

Most remote sensors see the same visible wavelengths of light that are seen by the human eye, although in most cases remote sensors can also detect energy from wavelengths that are undetectable to the human eye. The remote view of the sensor and the ability to store, analyse, and display the sensed data on field maps are what make remote sensing a potentially important tool for agricultural producers. Agricultural remote sensing is not new and dates back to the 1950s, but recent technological advances have made the benefits of remote sensing accessible to most agricultural producers.

Remote sensing: How you can use it on your farm

Remotely sensed images can be used to identify nutrient deficiencies, diseases, water deficiency or surplus, weed infestations, insect damage, hail damage, wind damage, herbicide damage, and plant populations. Information from remote sensing can be used as base maps in variable rate applications of fertilizers andpesticides. Information from remotely sensed images allows farmers to treat only affected areas of a field. Problems within a field may be identified remotely before they can be visually identified. Ranchers use remote sensing to identify prime grazing areas, overgrazed areas or areas of weed infestations. Lending institutions use remote sensing data to evaluate the relative values of land by comparing archived images with those of surrounding fields. Using remote sensing based crop forecasting methods, traders who deal in grains may anticipate the status of potential supply in the market in the upcoming time periods.

The Electromagnetic spectrum

The basic principles of remote sensing with satellites and aircraft are similar to visual observations. Energy in the form of light waves travels from the sun to Earth. Light waves travel similarly to waves traveling across a lake. The distance from the peak of one wave to the peak of the next wave is the wavelength. Energy from sunlight is called the electromagnetic spectrum. The wavelengths used in most agricultural remote sensing applications cover only a small region of the electromagnetic spectrum, measured in micrometers (µm) or nanometers (nm). One µm is about 0.00003937 inch and 1 µm equals1,000 nm. The visible region of the electromagnetic spectrum is from about 400 µm to about 700 µm. The green color associated with plant vigour has a wavelength that centers near 500 µm. Wavelengths longer than those in the visible region and up to about 25 µm are in the infrared region. The infrared region nearest to that of the visible region is the near infrared (NIR) region. Both the visible and infrared regions are used in agricultural remote sensing.

Electromagnetic energy and plants

When electromagnetic energy from the sun strikes plants, three things can happen. Depending upon the wavelength of the energy and characteristics of individual plants, the energy will be reflected, absorbed, or transmitted. Reflected energy bounces off leaves and is easily identified by human eyes as the green color of plants. A plant looks green because the chlorophyll in the leaves absorbs much of the energy in the visible wavelengths and the green color is reflected. Sunlight that is not reflected or absorbed is transmitted through the leaves to the ground. Interactions between reflected, absorbed, and transmitted energy can be detected by remote sensing. The differences in leaf colors, textures, shapes or even how the leaves are attached to plants, determine how much energy will be reflected, absorbed or transmitted. The relationship between reflected, absorbed and transmitted energy is used to determine spectral signatures of individual plants. Spectral signatures are unique to plant species. Remote sensing is used to identify stressed areas in fields by first establishing the spectral signatures of healthy plants. The spectral signatures of stressed plants appear altered from those of healthy plants. Interpreting the reflectance values at various wavelengths of energy can be used to assess crop health. The comparison of the reflectance values at different wavelengths, called a vegetative index, is commonly used to determine plant vigour. The most common vegetative index is the normalized difference vegetative index (NDVI). NDVI compares the reflectance values of the red and NIR regions of the electromagnetic spectrum. The NDVI value of each area on an image helps identify areas of varying levels of plant vigour within fields.

How does remote sensing work?

There are several types of remote sensing systems used in agriculture but the most common is a passive system that senses the electromagnetic energy reflected from plants. The sun is the most common source of energy for passive systems. Passive system sensors can be mounted on satellites, manned or unmanned aircraft, or directly on farm equipment. There are several factors to consider when choosing a remote sensing system for a particular application, including spatial resolution, spectral resolution, radiometric resolution, and temporal resolution. **Spatial resolution** refers to the size of the smallest object that can be detected in an image. The basic unit in an image is called a pixel. One-meter spatial resolution means each pixel image represents an area of one square meter. The smaller an area represented by one pixel, the higher the resolution of the image. **Spectral resolution** refers to the number of bands and the wavelength width of each band. A band is a narrow portion of the electromagnetic spectrum. Shorter wavelength widths can be distinguished in higher spectral resolution images. Multi-spectral imagery can be measure several wavelength bands such as visible green or NIR. Landsat, Quick bird and Spot satellites use multi-spectral sensors. Hyper spectral imagery measures energy in narrower and more numerous bands than multi-spectral imagery. The narrow bands of hyper-spectral imagery are more sensitive to variations in energy wavelengths and therefore have a greater potential to detect crop stress than multi-spectral imagery. Multi-spectral and hyper-spectral imagery are used together to provide a more complete picture of crop conditions. **Radiometric resolution** refers to the sensitivity of a remote sensor to variations in the reflectance levels. The higher the radiometric resolution of a remote sensor, the more sensitive it is to detecting small differences in reflectance values. Higher radiometric resolution allows a remote sensor to provide a more precise picture of a specific portion of the electromagnetic spectrum. **Temporal resolution** refers to how often a remote sensing platform can provide coverage of an area. Geo-stationary satellites can provide continuous sensing while normal orbiting satellites can only provide data each time they pass over an area. Remote sensing taken from cameras mounted on air planes is often used to provide data for applications requiring more frequent sensing. Cloud cover can interfere with the data from a scheduled remotely sensed data system. Remote sensors located in fields or attached to agricultural equipment can provide the most frequent temporal resolution.

Remote sensing: The complete process

The following figure illustrates a satellite remote sensing process as applied to agricultural monitoring processes. The sun (A) emits electromagnetic energy (B) to plants (C). A portion of the electromagnetic energy is transmitted through the leaves. The sensor on the satellite detects the reflected energy (D). The details then transmitted to the ground station (E). The data is analyzed (F) and displayed on field maps (G).

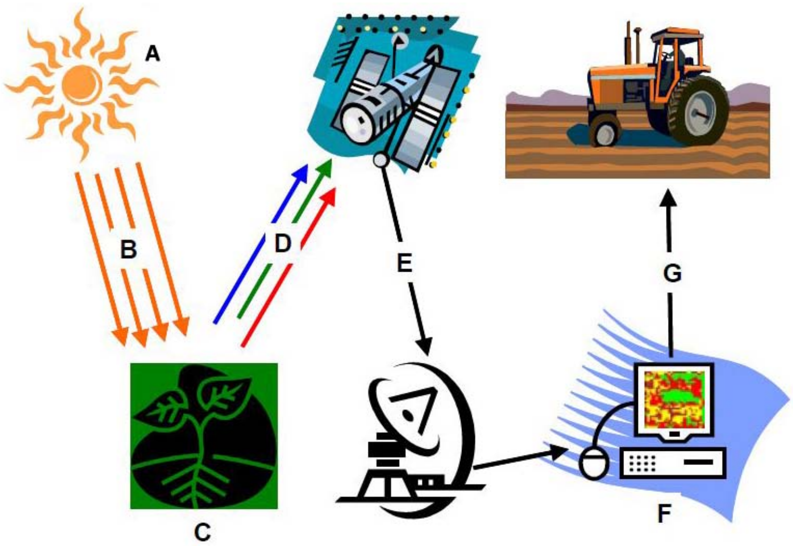


Figure 26: A satellite remote sensing process as applied to agricultural monitoring processes.

GIS and remote sensing applications in food security

Importance of GIS and remote sensing in food security

Food security is defined as a household's availability to healthy food that is consistently accessible in order to sustain an active and healthy lifestyle. This security is threatened on a community and global level by three important factors; the access and availability of food in local environments, the effects of the changing climate on agriculture and natural resources, and the active participation in planning, developing, and managing effective strategies to optimize and sustain food production with the available existing land. Several strategies have been developed using Geospatial Information Systems (GIS) and Remote Sensing techniques, which contribute knowledge and understanding to food security. These strategies include techniques which examine local food environments, assess changes in land use and landcover, identify areas of importance in specific regions to determine the relationships between biophysical and socioeconomic attributes, and the use of 3D models to demonstrate landscape and construct methods to sustain our food sources. GIS and Remote Sensing play significant roles in securing the future of our food production and our population. The importance of food security is directly linked to increases in population density, limitations on agriculture yields, and the spread of food deserts.

Droughts, floods, and erratic weather conditions pose a major threat to food security. A 3-Dimensional modeling GIS tool is a method used to illustrate landscape models that can be easily learned and understood. Collaboration to identify and evaluate targeted areas is made possible, thus enhancing cooperation between communities and institutions. Sustainable development can then be reached in all sectors of the globe, especially in third world countries that need to address these issues to eliminate hunger and optimize land use.

Securing the local food environment

Food outlets such as supermarkets, small grocery stores, restaurants, and fast food restaurants comprise local food environments in urban, sub-urban, and rural communities. Studies have examined spatial and statistical association between access to these food sources and socioeconomic deprivation. Disadvantages that prevent communities from obtaining food security are the theories of Food Deserts and Food Swamps. ‘Food Deserts’ are defined as impoverished areas where it is difficult to purchase fresh affordable food, most often found in urban communities. ‘Food Swamps’ are defined as areas where socially disadvantaged communities are over exposed to unhealthy food, primarily fast food restaurants. Understanding the association between the spatial and statistical location of healthy and unhealthy food outlets in different communities gives a better insight to their local food environments. Food swamps and food deserts have been found in urban communities where access for food trucks may be difficult and fast-food restaurants have rapidly developed. Access to supermarkets, with higher availability and affordable healthy food, are primarily located in suburban and rural communities near major roadways. On a perception-based study, residents of targeted neighborhoods to locations near supermarkets and small grocery stores to have higher variety and availability.

By understanding the spatial relationship of healthy and unhealthy food outlets, one is better able to examine and interpret factors needed to improve health issues such as obesity, type II diabetes, cardiovascular disease, malnutrition and hunger. Urban cities depend on transportation of food stock to support their communities. If highly populated cities have limited space for supermarkets and accessibility to supermarkets, residents are forced to turn to fast-food restaurants that have become highly available and are more affordable. Accessibility and availability to healthy, affordable food is a major threat to food security if communities are limited to these sources. In rural areas of the third world countries there is limited accessibility to outside food sources. These regions depend highly on their own agriculture production to sustain their populations. With increasing populations, urbanization leads to agriculture land fragmentation. When food security is minimal, residents travel to more secure regions. To optimize food production and create a sustainable region that has so much possibility for productivity, it is vital that proper planning, development, and management strategies be put into place for small farm holders in these rural regions to support their own populations.

Changing food production with the environment

Population trends have increased in all parts of the world. As a result, urbanization leads to fragmentation, primarily in open spaces and agricultural lands with potential to be developed. Safeguarding the source of production is essential to our survival and securing food supply. Coinciding with changes in populations and land use, climate plays an influencing role on food production and biodiversity. GIS and Remote Sensing technologies such as satellites and software can be used to gather and map data concerning soil fertility, elevation models, population, poverty index, food production etc. Correlating these data sets and analysing them with GIS techniques is useful in analysing changes in the climate and their effects on agriculture production. GIS and Remote Sensing systems are also able to monitor changes in climate and demonstrate its effect on soil fertility, rainfall, growing conditions, and approaching food shortages. Remote Sensing systems such as the SPOT-4 and 5 satellites with the VEGETATION instrument create imagery on a global scale that can be used to identify disaster prone regions where changes in vegetation may become insecure. The FAOARTEMIS is a widely used system to monitor food supply and demand conditions for proper preparation for disasters such as food shortages, droughts, and hunger. By monitoring rainfall, soil fertility and vegetation, disasters such as drought can be foreseen and proper planning can be put into action to prevent catastrophic effects.

Conclusion

The past decade has witnessed a tremendous growth in agricultural applications of GIS at a variety of scales. These applications have benefited from technological advances connected with GIS and several related technologies including GPS, remote sensing, continuous data collection techniques, geo-statistics, etc. In addition, the growth in popularity of site-specific farming as away to improve the profitability and/or reduce the environmental impact of modern agriculture has promoted the development of desktop GIS that are customised for these types of application. The use of these advanced technologies in agriculture offers at least four advantages: they provide data cheaply and quickly at a variety of (fine) resolutions; they use repeatable methods (to the extent they generate metadata on data sources and analytical procedures); they provide improved diagnostics for error detection and accuracy (uncertainty) determinations; and they generate information that can be used with the visualisation tools commonly found in GIS to develop customised maps and/or tabular summaries. These advantages may be partially offset to the extent that these technological innovations have outpaced our knowledge of soil/crop (cause-effect) relationships, spatial interpolation techniques, and model/database validation. Further work is urgently needed to improve our understanding of these aspects of science at a variety of scales to confirm the potential use of GIS and related technologies in routine surveillance and assessment activities ranging from site-specific farming systems to global food production and security issues. Precision farming allows the precise tracking and tuning of production. Precision farming makes farm planning both easier and more complex. There is much more map data to utilize in determining long term cropping plans, erosion controls, salinity and acidity controls and assessment of tillage systems. But as the amount of data grows, more work is needed to interpret the data and this increases the risk of mis-interpretation leading to wrong decisions. Farmers implementing precision farming will likely work closer with several professionals in the agricultural, GPS and computing sciences. Hence, the foundation technologies in precision agriculture are GIS, GPS and remote sensing. GIS and Remote Sensing are essential techniques used to better understand the changing relationships between food availability, the accessibility of land mass and the effects of climate change on agriculture production. By better understanding these relationships, proper planning can be made to prevent disasters related to food insecurity and we can strengthen sustainable practices thus securing food supply for future generations. Moving forward, proper planning, development, and management of the existing agriculture lands and the farm holder’s production practices will secure food supply on a regional and global scale. GIS and Remote Sensing applications provide the information and knowledge necessary to adapt sustainable agriculture practices and yield insight to threats caused by climate change and other environmental factors.