Soil Biology and Ecological Farming

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Emerging as an effective alternative to the agro-chemical-based modern or conventional agriculture, the detrimental impact of which is evident both on human health and the environment, ecological farming, based on sound scientific principles, has yielded rich harvests while maintaining the micro-nutrients, microorganisms and macro-fauna of the soil—the Source of Infinite Life (SOIL)

India's growing population needs a proportional increase in food production. Much of the land is already under agriculture and, therefore, the required increase in production has to primarily come from increased productivity (yield per unit of land) and reduced pest damage. For at least five decades, India's agricultural research and education has focussed on agro-chemicals—Green Revolution (GR) technologies, and the development of genetically modified (GM), or transgenic crops. This has, in turn, influenced the agricultural research for development (AR4D) paradigm and the resultant policies.

In the initial years, GR-based agriculture led to a substantial increase in productivity and helped India overcome the low-yield phase. It led the country to being food secure. Over the past decade or so, however, the increase in productivity has essentially been stagnant. In addition, the use of GR technologies over 30 years has caused concern about the impact of agro-chemicals on human health and on the environment.

If in the 1970s, India was importing food grains, today it is importing much of the fertilizers (about 60 per cent of the nitrogenous, 80 per cent of the phosphatic and 100 per cent of the potassic fertilizers) needed for producing this food grain. Contrary to the impression being created, India is not yet a food secure nation.

In the past 20 years or so, organic or ecological farming has emerged as an effective alternative to the agro-chemical-based modern or conventional agriculture. Ecological farming is based on sound scientific principles. Several farmers, using good agricultural practices (without agro-chemicals), have claimed harvesting yields comparable to those of neighbouring farmers, who use agro-chemicals. Several review papers and publications including some from the UN-FAO, have reported results in favour of this type of farming.

This article discusses the plausible explanations on how such farms (without agro-chemicals) may have yields comparable to farms where agro-chemicals are used by enhancing soil fertility and plant nutrition.

SOIL—A STOREHOUSE OF PLANT NUTRIENTS

A crop needs several organic elements such as vitamins and growth hormones and inorganic (or atomic) elements, and these constitute its cells (constitutive) or participate in its metabolism (non-constitutive). Four of the vital constitutive elements are carbon (C), oxygen (O), hydrogen (H) and nitrogen (N). Thirty elements may come from the soil and they form only two to eight per cent of the body dry mass of a plant. Most of these names can be found in books on soil science and plant nutrition. Claude Bourguignon has listed 12 of these as vital or essential elements for plant growth. If the concentration of these in the soil is below a threshold limit (as studied and reported by several research publications), their deficiency in the soil shows up readily through characteristic symptoms on different parts of the plant. Two of the 12 elements, potassium (K) and chlorine (Cl), are non-constitutive. The other 10 elements are constitutive—phosphorus (P), boron (B), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), molybdenum (Mo), copper (Cu) and zinc (Zn). Eighteen other elements, also called the secondary micro-nutrients or trace elements, are required in very small quantities.

The function of some of these is not fully understood. Four of the 18—lithium (Li), sodium (Na), rubidium (Rb) and cesium (Cs) are non-constitutive. The other 14 are constitutive. These are fluorine, (F), silicon (Si), selenium (Se), cobalt (Co), iodine (I), strontium (Sr), barium (Ba), aluminium (Al), vanadium (V), tin (Sn), nickel (Ni), chromium (Cr), beryllium (Be) and bromine (Br). Significantly, only three of the over 30 elements—nitrogen (N), phosphorus (P), and potassium (K), widely known as major elements, are readily available in the market and are proactively promoted by the AR4D system globally.

An important fact that is overlooked, even by a large number of agricultural scientists, but which is essential to understand, is that the major part (92 to 98 per cent) of the body mass (dry and not wet mass) of a plant is made of carbon, nitrogen, oxygen and hydrogen. All the four are gases. One can confirm this from the fact that when the bio-mass of any plant is burnt, we get only two to eight per cent of the original weight of the burnt bio-mass as 'ash'. The rest goes into the air because they were gases. When we burn rice or wheat straw, we generally get about two per cent of the original mass as 'ash' whereas it is about eight per cent in the case of woody plant parts, for example, stems of pigeon pea plants. These four elements also occur in other forms in the soil. Carbon molecules can also reach the plant through the breakdown products of proteins and amino acids through the carbon skeleton. Nitrogen exists in several forms in the soil—ammonium ions, nitrates, amines, etc.—and can be taken up by plant roots. Hydrogen and oxygen are part of a water molecule. A plant assembles these elements during the photosynthetic process while growing under favourable conditions.

Micro-nutrients also include some plant growth factors such as vitamins and enzymes, which are organic compounds and are required in tiny amounts as nutrients. These are present in soils due to micro-organisms and macro-fauna (such as earthworms), resident in soils and are either excretory products of these living beings due to their normal life-cycle in soils, or are available after their death. Most of these growth factors are also available on the surfaces of roots, where populations of micro-organisms are abundant.

All the 30 mineral elements described above are available in most of the soils where crops are grown and in the plant bio-mass (leaves, branches, flowers, fruits) of every plant, but their composition/proportions differ between soil types, fields and from one plant part to another. Each of the 30 mineral elements exist in at least two forms—available, or water soluble, form and non-available, or bound, form. Much of the concentration of each of these nutrients in the soil and in the plant bio-mass is in the non-available form and only a small fraction (usually one to eight per cent of the total concentration) is present in the available form.

Micro-organisms and macro-fauna, resident in agricultural fields, keep converting the non-available form of nutrients to available forms, as part of their daily life, provided the conditions are favourable for their survival and functioning. This activity happens continuously throughout the day and night. Successful farmers (organic farmers producing yields comparable to chemical farms) practice a set of good agricultural practices (GAP) to create such conditions. These include on-farm production and the use of plant bio-mass as a source of crop nutrients, the maximum possible plant bio-diversity on the farm, integration of trees and animals on fields growing annual crops, recycling of crop residues, and soil and water conservation in a scientific manner.

SOIL: A SOURCE OF INFINITE LIFE

Soil is a source (S) of (O) infinite (I) life (L). It houses and supports several different forms of life, starting from photo-synthesizers (plants and their roots — 'First Trophic Level' — the primary food formers in the soil) to animals (predators and burrowers — 'Fifth and Higher Trophic Level'). In-between are the mutualistic de-composers and the root feeders (bacteria, fungi, nematodes — 'Second Trophic Level'), shredders and graders (protozoa, arthropods — 'Third Trophic Level'), and predatory nematodes and arthropods — 'Fourth Trophic Level'. All these different forms of life in the soil are intricately woven as a food-web and make it 'Living'. One cup of undisturbed native soil may contain up to 200 billion bacteria, 20 million protozoa, 100,000 m of fungi, 100,000 nematodes and 50,000 arthropods.

All these life forms need a lot of food and, as indicated above, plants are the basic food material for them. But soils of most agricultural farms today are heavily degraded biologically and lack life, and, therefore, lack the capacity to produce high yields without agro-chemicals.

To grow plants without fertilizers and harvest a high yield, one needs to recycle all crop residues or their converted form after their economic use, back to the soil. For example, if one has grown sorghum—the grains are usually for human consumption and the stalks for cattle. The changed form of stalks (that is, cattle dung) should be applied to farms. If cattle dung is needed for cooking food, however, its changed form, ash, should be evenly applied to the fields.

In addition, one needs to grow fast-growing trees as a source of bio-mass (food for the living beings in the soil) and fruit trees (as a source of both human and soil nutrition) on field boundaries and/or farm boundaries. All these form a local natural resource for a high yield without fertilizers. It is important to note that one does not need a large tonnage of cattle-dung (a myth among many farmers and even scientists) for a high yield without fertilizers. Cattle-dung is needed in small quantities as a source of agriculturally beneficial micro-organisms, in the same way as we need only one spoon of old but good quality curd to prepare curd out of 10 or even 100 litres of milk.

Cow-dung has been reported to contain five of the total six functional groups of agriculturally beneficial micro-organisms. These are nitrogen fixing micro-organisms, phosphate solubilizing micro-organisms, plant-growth promoting micro-organisms, cellulose degrading micro-organisms and antagonists of disease causing micro-organisms. The sixth functional group —entomo-pathogenic micro-organisms (those with the ability to kill insects)—may also be present in cow-dung, and are known to be present in soils of most agricultural fields (for example, the bacterium Bacillus thuringiensis). Because fresh cow-dung is an important ingredient in many liquid types of manure, all these agriculturally beneficial micro-organisms are present in these manure and in larger numbers than in cow-dung itself. Eventually, these become a part of the soil in large numbers and are not needed from market sources.

There are many recipes for liquid manures used by organic farmers in which fresh cow-dung is recommended to be used as inoculum for their preparation, for example, *Amrit Jal* or *Jeev Amrit* and *Gur-Jal Amrit*. The quantity of dung needed to prepare 100 litres of manure is only 10 kg and is enough for use in an area of one acre. The frequency of application may be three to four times in a crop cycle of about 120 days. One can thus manage to produce enough fertilizer for up to ten acres of land with just one cow. Like cow-dung, compost should also be viewed as a source of agriculturally beneficial micro-organisms and not as a source of N, P, K, and be evaluated accordingly.

Unfortunately, the agriculture education system has not internalized this knowledge of soil biology and the experience of ecological farming; therefore, it still calculates the nitrogen needs of a crop per hectare (if through compost) by measuring the N concentration in compost.

Chemical fertilizers, when applied to soils, negatively affect the population and the functions of the agriculturally beneficial micro-organisms. For example, the effectiveness of 'rhizobia'—known to convert inert nitrogen in the air to the plant utilizable form of nitrogen (called nitrogen fixation) is adversely affected by the use of nitrogenous fertilizers. The same is true with the use of synthetic pesticides and herbicides. Several publications report that fertilizers such as nitrogen and micro-nutrient mixtures can be applied by spraying these on plant surfaces to be absorbed by plants, perhaps through the stomata on the leaves. If applied through sprays, one would perhaps need one-fifth of the levels of fertilizers recommended for soil application. It is unfortunate that this mode of meeting plant nutrient needs is not researched sufficiently and wherever known, for example, as in the case of nitrogen, it is not promoted pro-actively, either by the industry or agricultural institutions or universities and extension agencies.

The plant root system may not differentiate whether a mineral element in the soil (for example, nitrogen) is from a bag of fertilizer or from the degradation of plant bio-mass. Cow-dung and compost are merely changed forms of plant bio-mass.

It is not only the soil of a farm but also all the plants (including weeds) growing on a farm that may have all the 30 mineral elements. Weeds are a menace but have some positive aspects as well. Some weeds are known to be rich in a particular mineral element. For example, Bathua, or Chenopodium album, has been reported to be rich in iron.

Some weeds may be rich in some other mineral elements. Up to 1.8 tonnes of dry weed bio-mass per ha has been measured in rain-fed areas in a long-term study by the International Crops Research Institute of the Semi-Arid Tropics (ICRISAT). Weeds are thus a potential source of several mineral elements needed for plant growth. Other noted uses of weeds are (a) enriching plant bio-diversity on a farm, and (b) serving as habitat for agriculturally beneficial insects and, thus, helping manage insect-pests on a farm. However, we need to manage weeds appropriately because they compete with crop plants for sunlight and soil moisture. They are best removed manually or mechanically and not by the use of herbicides. Herbicides, like other agro-chemicals (fungicides, insecticides), are poisons and adversely affect the various forms of soil life listed above, and should not be used.

Innovative farmers in Punjab are experimenting with soft options of managing weeds—spraying with undiluted cow-urine and soap powder (two per cent) solution (with two eggs as sticker for every 15-litre spray tank). Spraying can be done on weeds growing between two plant rows (at least one foot apart), using nozzles with hoods.

All these are the basic facts of agricultural science and also form the core of the science and the practice of organic or ecological farming.

The regular addition of plant bio-mass, as surface mulch, and microbial agents results in high organic matter in the soil, leading to better soil health, making plants tolerant to drought and pests, and eventually resulting in a high yield.

As stated, only a small fraction (about 1 to 4 per cent in case of nitrogen) of all the 30 mineral elements in the soil may occur in the available form, and the rest in bound form. Interestingly, all the soil testing laboratories that are stated to help farmers (but are designed to help industry) measure only the available form of elements. Most, or all such laboratories in India, lack a facility to measure the total or bound form of any mineral element. All these laboratories are designed to promote the use of fertilizers and the soil-test results are used for generating advisories on the quantity of a given fertilizer that a farmer should apply to the soil.

The typical soil of a farm may contain 0.1 per cent of soil mass as total or bound form of nitrogen. The roots of a plant can access nutrients from up to 30 cm of soil depth, and this upper 30 cm layer of soil weighs about four million tonnes (for every hectare) and thus translates to 4,000 kg of bound N in every hectare. And 1.0 per cent of the 4,000 kg (that is, 400 kg) is in available form. The root system of a plant is, therefore, exposed to a large quantity of nitrogen. Typically, less than one per cent of dry mass of a cereal grain is nitrogen. If a yield, say of sorghum, is 3,000 kg per ha, it would remove a maximum of 30 kg of N per ha; but if the yield is 5,000 kg, it will remove about 50 kg N per hectare, and this quantity is much smaller than the high quantity of nitrogen in the soil (400 kg available and 4,000 kg bound form).

The same is true for the other mineral elements. We, however, need to facilitate a plant's access to this small quantity of N (30 to 50 kg) through the use of liquid manures rich in agriculturally beneficial micro-organisms or through making soil—a living soil of the kind indicated above.

A plant accesses nutrients largely through its root system. The micro-organisms and the soil macro-fauna play an important role in this function. Published literature indicates that the roots of a plant play a large role in selecting the microbial life around it. For example, only the rhizobium of chickpea can enter the roots of a chickpea plant and no other type of rhizobium species enters its roots. Some species of rhizobia have been reported to enter the root system of rice, travel to the leaves through its stem and enhance plant growth. The population of micro-organisms in the soil, in the close proximity to the roots (called the root rhizosphere), is about 10 to 100 times bigger than that in the neighbouring soil mass. There is a whole world of endophytic micro-organisms (those living and functioning inside a plant system, rhizobium is only one type) that are expected to help a plant in various ways and are yet to be explored substantially. The GAP promoted under ecological farming helps the plants access adequate nutrients needed for good plant growth and yield.

There is no doubt that conventional agriculture is based on science, but its focus is on developing research outputs that make farmers depend on the purchased inputs. Moreover, these research outputs are tuned mostly to serve the interests of the input-providers and corporate organizations. On the contrary, if we are serious about addressing the distress widely observed in the farm-sector, we need agro-technologies that empower the farmers to produce inputs on-farm, which will help them reduce the cost of crop production. The challenge for us is to make the AR4D cater to this need, and also to ensure that science is articulated to the agri-practices of the organic farmers. This should help in scaling-up with confidence.

The Soil-Health Card programme of the Government of India and of the states working on this programme is at present targeted at analysing pH, electrical conductivity (EC), the organic carbon, the available form of nitrogen, phosphorus and potassium. As stated earlier, this programme too is targeted at promoting the use of fertilizers and only pays lip service to 'soil health'; in practice, it will still harm soil health but at a slower pace than when the fertilizers are used indiscriminately.

CONCLUSION

In the present scenario, wherein the AR4D works more in favour of external input providers and less in the interest of the farmers, every farmer should become an experimenter and grow crops using GAP (all or most of the methods stated earlier), to meet the need for crop nutrients on a small area (say one acre), and compare the results with the neighbouring area where fertilizers have been applied. If the yield in the experimental area without the agro-chemicals is lower, he/she must visit some successful farmer of their area to find out what additional practices the successful farmer of the area is employing to get high yields. The knowledge and confidence that high yields are possible without agro-chemicals lie with successful organic or ecological farmers and not with the agricultural scientists, and agricultural institutions and universities mandated with the AR4D.

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The references for this article are available on request from newsreach@pradan.net