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Photopedogenesis: Concept and application

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Soil is a soul of infinite lives, but its science is still at youthful stage. Photopedogenesis is a new emerging chapter in Soil Science that opens wide range of its applicability in order to expose the inherent behaviour of soil system for better crop production. The concept of photopedogenesis has come into existence with the advancement of the Theory of Photopedology and deserves appreciation in terms of both short and long wavelength solar radiations

Soil is a sandwich between lithosphere and atmosphere. It forms the upper boundary as well as lower boundary of lithosphere and atmosphere, respectively. Soil is formed on the lithosphere under the influence of many factors including atmosphere as we call climate. The contribution of climate is devoted mainly to rainfall and temperature. Light is seldom referred as a source of heat energy contributing to soil genesis and characterization. In the application of satellite remote sensing, soil is often considered to be the effective lower boundary particularly for visible and near infrared wavelength radiations.

The incoming solar radiation on earth surface (soil) often includes visible, infrared, microwave and radiowave radiations. Only a small fraction of visible (500-1000 candle) radiation is being consumed for photosynthesis by green plants and remaining part of visible, infrared, microwave and radiowave radiations are underemphasized in relation to their contributions to soil, though they are interacting to each other in the environment as well as with matters. Arguments are forwarded that the incoming solar radiation beyond 700 nm predominantly contribute to thermal manipulation in the environment. Even with regard to the visible radiation, it is often advocated that about 60% of it is consumed during photosynthesis and remaining 40% is virtually a strange.

The history of soil has come into existence with the work of Russian scientist, Dockuchaev, who started systematic research on soils and so it's history is hardly older than 150 years. Within such short period, lot of commendable findings have been brought into existence for exploiting soil scientifically for crop production followed by first green revolution. However, its history is still at youthful stage and much of the works are yet to be accomplished for further manipulation of soil on sustainable basis. Soil is a resource and we have to preserve this resource within the natural framework without any scope of degradation. Science is nothing but a key to the natural system to exploit and that too for the welfare of mankind. Obviously, science has no end and we have to look forward for better future by knocking the clues of the natural system like soil, which is virtually a non-renewable natural resource.

In one study, a thin layer of soil (2 mm) on glass slide appeared white when dry; but it looks black when it is moist particularly in black and white photograph taken from the front side of the light source. In another study, light source was fixed opposite to the camera and photograph was taken in both dry and moist conditions of soil. It was observed that the dry soil on photograph was white (bright). Such bright colour of moist soil was due to light entry through the soil in presence of moisture. Such simple experimentation indicated that the light moves to soil in presence of moisture (Fig. 1). Evidence of phototrophic bacteria and even blue green algae in soil may be the indicator of the existence of light at least into some shallow or thin soil layers.

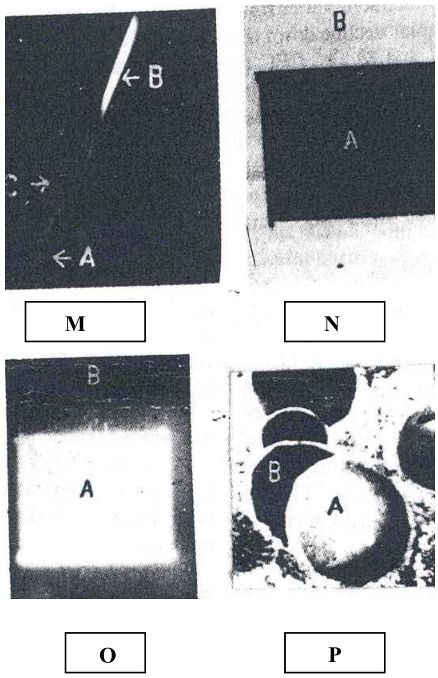

Figure 1. M: Photograph of moving water (A: illumination at the point of striking surface, B: lighted plastic transparent tube, and C: reflected light of shining tube on cemented floor), N: Photograph of soil from front side (A: dark shade in moist portion of soil, and B: white shade in dry portion), O: Photograph of soil from opposite side of light source (A: white shade due to penetration of light in moist portion of soil, and B: dark shade in dry portion of soil) and P: photograph of disturbed soil from opposite side of light source (A: white shade due to moisture, and B: dark shade in dry condition).

Reports reveal that root proliferation is much greater during rainy season when soil is moist and light must have worked in some way or the other as it may be apprehended and postulated. Light can enter into the soil when it is moist, ionization in soil solution seems also to be controlled by such radiations and importantly, the nutrient status can safely be promoted by irradiating the soil with low wavelength radiations. The increase of available phosphorus just by increasing the soil moisture status also relates to the role of light in increasing the P-availability in soils. Using such high energy radiation like X-rays, soil nitrogen level in soil can be enhanced remarkably as a result of nuclear transfer reaction between $^{12}C_6$ and $^{16}O_8$ stable isotopes already present in soil system. The X-ray irradiated soils indicated loss of organic carbon with subsequent gain of total N content. Such findings support the phenomenon of the nuclear transfer reactions in which one atom each of stable carbon and oxygen reorient under the energy level induced by X-rays to form two atoms of stable nitrogen. Such dramatic changes were puzzling to understand when the soils were first treated with X-rays. However, the subsequent tests of two different soil types derived from basalt and limestone in Ethiopian ecosystem (sub-humid and sub-temperate) validated the phenomenon for subsequent quantification. The forwardal of photopedogenesis, thus, forms a new chapter in soil science and needs appreciation from different groups of scientific communities in order to quantify the mechanisms comprehensively for practical purposes in better crop production.

Light as a source of energy is often referred to in Soil Science in terms of inflow of energy particularly in the process of soil genesis. In general term, light is accepted merely as a means of heat energy as indicated by temperature change. Black plastic sheet or some organic residues, for example, are used as mulches to absorb light, which on interaction yields heat to the soils. Another study indicates that the deep placement of urea sub-granules could significantly enhance both fertilizer efficiency and plant growth particularly in rice under intense light. In line with this, the electrical conductivity of soil is high during day time as compared to night due to accelerated ionizations induced by heat at elevated temperature of the soil system through sunlight. The significant impact of incoming sunlight was recorded on diurnal change of soil temperature up to the depth of at least 50 cm, wherein soil moisture again plays some role of relevance. Our concern to this has been confined to temperature change vs. electrical conductivity in soil and hardly correlates to incident light.

One distinct possibility of phosphorus availability in soil with increasing soil moisture contents (Fig. 2) seems to be associated with the role of photopedogenesis, in which increasing soil moisture content would have allowed more incoming light to enter into the soil. The light within the soil in presence of moisture would subsequently have promoted the existing ionization state of soil solution, in which phosphate might have been one of ions. The phosphate in the process of ionization could likely have appeared available at the neutral to almost neutral pH of the soil solution following the trend as below:

$$PO_4^{-3} \xrightarrow{H_2O} HPO_4^{-2} \xrightarrow{H_2O} H_2PO_4^{-1}$$

Light intensity required for photosynthesis is often much lower than the total intensity of incoming sunlight. Densely planted crop stands appear to be taller at the centre of the field plot, where soil receives minimum or very restricted incoming light due to dense canopy. But, the stands at the corner or border allow light to approach soil obliquely from the surrounding. At the corner, vertically incoming light benefits the plant canopy for photosynthesis, whereas obliquely incoming light activate soil photopedogenetically. The plant stands at the centre get light only on canopy, which restricts light entry towards bottom on the soil. This induces only photosynthesis on the green parts of the plants and they tend to grow upward and appear taller than the plants at the corner. The reproduction followed by flowering and fruiting is often weak and shriveled in such tall plants. However, the plants at the corner grow well with better growth performance and fruit setting, though they were comparatively shorter in height (Fig. 3). At the corner, both plant as well as soil received light and the crop growth performance in terms of number, size and quality of pods was much better at the corner, though the density of plants were almost identical to central part of the tray. Plant roots at the corner could not have received more nutrients from surrounding due to restriction imposed by plastic border. Such simple experiment also indicated qualitatively the role of light in promoting the soil productivity. This further suggests that light is vital not only for crop plants, but equally good for soil to induce productivity, though this chapter has been hidden and strange until recently. Quantification of such emerging scientific facts in soil science needs to be initiated and forwarded.

It is postulated in the "Theory of Photopedology" (Mishra, B.B. 1996. J. Indian Soc. Soil Sci. 44, 541-543) that the core electron of water molecules gets loosely bound with incident light (photon) to form photoelectron, which in contact with negatively charged colloidal particles of soil (clays and humus) induces photo-ionization. In presence of water, light interacts with soil and forms a soil-water-light system in continuum, which appears to be darker or grayer shade of characteristic nature (Fig. 1).

In soil fertility management for crop plants, the greatest problem being encountered is the nitrogen unavailability. Most of the soil nitrogen contents are either in organic or gaseous forms that can not be utilized by plants directly. Even the inorganic forms of plant utilizable nitrogen are subject to loss either due to denitrification or leaching or even volatilization. Hardly 30-40% N-efficiency has been often recorded in the best managed soils and remaining 60-70% of applied N is normally the wastes. Our atmosphere is rich in gaseous nitrogen (around 79%) and this nitrogen undergoes some exchange with soil atmosphere under well tilled condition. Only some selective microorganisms are capable of changing either gaseous or organic forms of nitrogeto

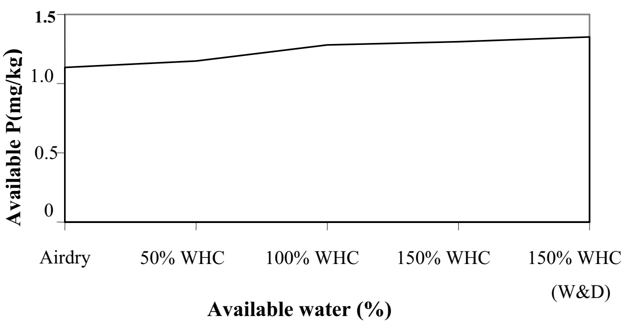

Figure 2. Available phosphorus of soil as affected by soil moisture levels.

Table 1. Effect of X-rays on some soil fertility parameters.

Soil fertility parameter	Basalt derived soil			Limestone derived soil		
	Untreated	X-ray treated	Gain (+) or loss (-)	Untreated	X-ray treated	Grain (+) or loss (-)
Organic carbon, %	1.82	1.69	-0.13	4.12	3.97	-0.15
Total nitrogen, %	0.106	0.134	+0.028	0.322	0.340	+0.018
Available P, mg kg^{-1}	21.69	23.19	+1.500	14.38	16.81	+2.43
NH_4-N, mg kg^{-1}	3.81	6.72	+2.910	6.49	6.72	+0.23

the plant utilizable form, but such transformations suffer from a number of abiotic and biotic factors, of which many are not easily manageable. Soils developed on basalt and seldom on limestone under sub-humid and sub-temperate climates often show high C: N ratio. Such high C: N ratio soils, although have appreciable amount of organic carbon, indicate the tendency of immobilization or the organic compounds or molecules remain protected physically as well as chemically restricting further decomposition. In this soil, the total N content was appreciably high (>1%), but the soils suffer from N-deficiency. To tackle such limitation, we irradiated the air-dry soil samples (<2 mm) with X-rays. The present analysis followed the data generated earlier during different sets of preliminary experimentation. The results obtained are surprising in disclosing the truth related to the nuclear transfer reaction (Table 1).

The information on the impact of low wavelength EM radiation on soil features is least discovered. It is evident that irradiation of soils with identical low wavelength radiation often influenced the microorganisms. Earlier works also revealed that the soil irradiated with gamma radiation indicated increase in the available nitrogen and phosphorus contents. Such findings support the present hypothesis, but fail to disclose the scientific clues behind the process.

The nuclear transfer reaction involves the transfer of a nucleon (neutron and proton) from one nucleus to the other. In a simple manner, for example, the bombardment of nitrogen target would lead to the transfer of either neutron or proton from the nucleus as shown below:

$^{14}N_7 + ^{14}N_7 \longrightarrow ^{13}N_7 + ^{15}N_7$ (transfer of neutron)

and,

$^{14}N_7 + ^{14}N_7 \longrightarrow ^{13}C_6 + ^{15}O_8$ (transfer of proton)

Identical to the above, when carbon ($^{12}C_6$) and oxygen ($^{16}O_8$) are targeted by high energy X-rays, the reaction seems to lead the formation of two atoms of stable nitrogen isotope as follow:

a). $^{12}C_6 + ^{16}O_8 \longrightarrow ^{13}C_6 + ^{15}O_8$ (transfer of neutron)

b). $^{13}C_6 + ^{15}O_8 \longrightarrow ^{14}N_7 + ^{14}N_7$ (transfer of proton)

c). $^{12}C_6 + ^{16}O_8 \longrightarrow ^{14}N_7 + ^{14}N_7$ (overall reaction)

In the first transfer reaction, the neutron of oxygen atom is transferred to the carbon nucleus, whereas in the second transfer, proton of the oxygen nucleus is transferred to form two atoms of stable nitrogen isotope. The above postulated reactions are obviously induced by the energy level received from X-rays. Both organic carbon and oxygen are present in the well aerated soil samples used for treatments. The total nitrogen build-up was likely at the expense of the loss of organic carbon as evident from the data (Table 1). We have not virtually studied the released energies from X-rays and such investigation needs to be followed systematically in order to validate and generalize the present findings for technology mission.

The tremendous benefits in respect particular of total nitrogen build-up of soils in the present study have led to further large scale experimentation with compost and farm yard manures being irradiated to X-rays before using them to soils for nitrogen fertilization. Stepwise findings would help to develop suitable technology for soil fertility management in a big way. The trend of decline in the organic carbon content in the X-ray treated basaltic soil samples was much lower than that of limestone. Higher organic carbon content in soil derived from limestone was due to interaction of humic materials with calcium forming Ca-humate that contributes black color to soil. The total nitrogen content was very high in both soil types after X-treatments, but comparatively higher in basaltic soils. The build-up of NH_4-N content indicated that the nitrogen build-up was of inorganic form that is utilizable to plants. The enhancement of available phosphorus content was likely due to release of organically occluded phosphorus present in the soils, since organic carbon underwent declining due to irradiation with X-rays.

We have thus concluded that soils need to be critically investigated in relation to photopedogenesis, wherein both short as well as long wavelength radiations contribute significantly in relation to plant growth and development. If the upper atmosphere is the huge photonuclear as well as photo-electromagnetic laboratory, the soil surface acts as a sink to equilibrate the ecological senescence in order to balance the healthy environment for our survival. This is one reason that we call "soil" as an abbreviated "SOIL" meaning thereby the "soul of infinite lives". Photopedogenesis thus seems to be integral part of soil so long as soil is a resource to plants and plant products for survival of human beings. In order to address the food security, such inherent soil characteristics need to be quantified for better scientific exploitation of soil resource in days to come.

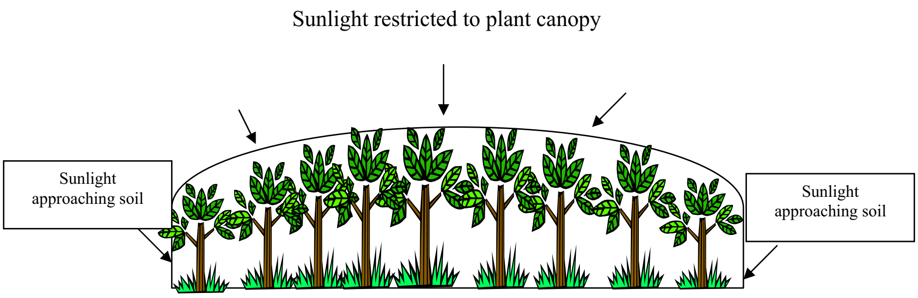

Figure 3. Generalized view of densely planted crop vegetative cover showing tall growth at center and short but matured growth at boarder, where incoming light is distributed both for photosynthesis as well as photopedogenesis.