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Soil Aeration under Different Soil Surface Conditions

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With 6 tables

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Abstract

The assessment of the importance of soil aeration for various plant characteristics and environmental conditions is necessary to evaluate the oxygen relations to the crops. The root environment as a solid–liquid matrix depends upon soil structure and moisture condition. A limited oxygen supply restricts the root development and also reduces the nitrogen fixation in peanuts. Soil surface conditions can be altered by mulching and plays a significant role in protecting the plants against deficient aeration during critical periods of growth phases. The effects of eight mulching treatments (rice husk, rice husk-incorporated, paddy straw, sawdust, water mulch, clear polyethylene, black polyethylene and control) on the soil oxygen diffusion rate (ODR) during the various growth phases of peanut crop (*Arachis hypogaea* L.) were investigated on a lateritic sandy loam soil (ultisols). These experiments were conducted for two consecutive seasons. ODR values were higher in mulched plots. With the progress of growth stages and also in deeper soil depths, the differences between the values of ODR among treatments narrowed down. The influence of mulches on other physical edaphic properties like bulk density, aeration (non-capillary) porosity and soil temperature were also studied. Mulches reduced the surface crusting and thereby soil bulk density; and increased the aeration porosity and ODR. Soil temperature was higher under plastic mulches whereas vegetative mulches suppressed it.

Key words: aeration — aeration porosity — bulk density — mulch — oxygen diffusion rate — peanut

Introduction

Soil aeration is one of the most important determinants of soil productivity. As soon as the oxygen supply in the soil is limited, the rate of growth of most crop plants slows down and stops entirely when the oxygen concentration sinks below two per cent. The composition of soil air is subject to rapid fluctuations since it is the resultant of two dynamic properties; the change of oxygen to carbon dioxide by roots and microbes and the renewal of soil air by atmospheric air. Another interesting difference between the atmosphere and soil air is that the latter is characterized by high relative humidity, which nearly always approaches 100 % except at the soil surface during prolonged dry spells.

Of particular importance is the presence of adequate amounts of oxygen, as it is constantly exhausted by roots and microbes. Without sufficient oxygen in the soil the normal functions of most crop plants and of the aerobic microbes come to a standstill. Anaerobic bacteria use oxygen in organic and inorganic compounds, reducing them to sulfides, nitrites, ferrous compounds, and other reduced compounds that are toxic to the plants. An excess of oxygen in the soil is also undesirable because the organic matter would be oxidized too rapidly. Semi-aerobic decomposition is best for the production of the largest amount of true humus and for the steady supply of organic compounds that serve to stabilize soil aggregates. Since diffusion is the main agent of air renewal, the methods of soil–air management have to be such that they affect potential diffusion rates through changes in structure, moisture content and temperature. A more open structure, a lower moisture content, and a higher temperature will increase diffusion rates.

Soil surface conditions can be altered by mulching. Mulch can be defined as a material used at the surface of the soil primarily to prevent the loss of water by evaporation. Other soil properties and soil surface conditions that are affected directly or indirectly by mulches are soil water through increased infiltration, favourable water storage, soil temperature through radiation shielding, heat con-

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duction and evaporation cooling, soil temperature moderation, soil nutrient mobility, soil salinity control, soil biological regime through organic matter addition, soil structure improvement, weed control and soil aeration.

In addition to the above factors, plants are sensitive to the aeration status of the soil. It is generally agreed that gaseous exchange between soil atmosphere and the aerial atmosphere is primarily accomplished by the process of diffusion. Oxygen diffusion rate (ODR) is used as an index of the soil aeration status in the cropped field. Mulching also alters soil temperature (Khan 1998b). ODR is temperature dependent and an increase in temperature decreases the solubility of oxygen and increases the diffusion through both gas and liquid (Letey and Stolzy 1964, and Khan and Mohsin 1976). Elaborate reviews have been produced about the influences of aeration under varying physical edaphic properties affecting the plant growth (Letey and Stolzy 1964, Grable 1966, Currie 1961, and Mohsin and Khan 1977).

Research information on the soil oxygen flux under varying mulching conditions is limited. The objective of the experiment reported here was to determine the ODR of the soil as influenced by varying mulching treatments during the growth period of peanut crop.

Materials and Methods

The field study was conducted for two consecutive seasons on lateritic sandy loam soil (typic, acrorthox, kaolinitic, ultisols) in the Coastal belt of eastern India. The experimental soil is well drained, acid (pH 5.50) and has low natural fertility, cation exchange capacity and lime content in the soil. Three replications of eight mulch treatments were combined in a randomized block design. Erect bunch type peanuts (*Arachis hypogaea* L.) cultivar SB'XI were hand dibbled at a spacing of 30 cm × 15 cm. The recommended agronomic practices for the optimum peanut yield in this agro-climatic region were followed (Khan and Datta 1982).

Physical edaphic properties of the soil were studied with the objective of determining the changes brought about in the soil environment by the use of various mulches and their effects on the performance of peanut crop. Undisturbed core samples were taken for determining the bulk density and the same cores were saturated and kept at 60 mb tension to determine the aeration (noncapillary) porosity (Kohnke 1968). Soil temperature was measured at 5, 10, 15 and 20 cm depths in the plant rows by thermocouples. Temperature readings were taken at all four depths at 8 am and 3 pm throughout the growth phases of peanut (Viz., from sowing till harvest). One shaded thermocouple was placed at a height of 100 cm in the centre of the experimental area for measurements of air temperature. Temperatures were measured by instrumentation described by Khan et al. (1977).

ODR measurements were made using the platinum microelectrode technique (Letey and Stolzy 1964). Measurements were taken at depths of 5, 10, 15 and 20 cm below the soil surface by inserting the electrodes to the proper depth each time just prior to reading. Observational data were recorded five times daily at 4 h intervals throughout the growth phases of peanut crop. Three observations were made for each plot and five electrodes were used for each site to avoid variability from location to location. The treatment details are presented in Table 1.

Results and Discussion

Influence of mulch treatments on physical edaphic properties of the soil (bulk density and aeration porosity) during different growth stages of peanut are presented in Tables 2 and 3. The data reveal that relatively higher values of bulk density occurred in bare as compared to mulch plots but among the latter treatment there were no marked differences. However, plastic mulches maintained minimum values of bulk density during both years of experimentation. Hazra et al. (1973) also reported a lower bulk density under vegetative and polyethylene mulches. Mulches reduce the surface crusting and thereby soil bulk density (Lyford and Qashu 1969, and Khan 1984). Aeration porosity is inversely related to the bulk density. As the former increases, there will be a decrease in the latter. The measurements of soil temperature and ODR at four depths were taken throughout the growth phases of peanut (namely, seedling emergence stage, flowering stage, pegging stage, pod formation stage and at harvest) but for the sake of brevity, temperature readings during seedling emergence stage are presented in Table 4. The mean ODR values during seedling emergence stage (initial crop growth phase), and during pod formation stage and at harvest (final crop growth phase) are presented in Tables 5 and 6. The mean ODR values of initial and final growth phase are presented to show the effect of mulching on its value.

While soil temperature was higher under polyethylene sheets, the vegetative mulches in general suppressed it. Amongst the plastic sheets clear polyethylene recorded higher soil temperatures in comparison to black polyethylene and the water mulch. Vegetative mulches do not allow the radiant energy to contact the soil directly. The radiation interception due to shading and evaporative cooling were responsible for lower soil temperature under veg-

Table 1: Treatment details

Serial No.	Treatment symbol	Treatment abbreviation	Description of treatments
1.	M_1	Rice husk	Rice husk spread on the soil surface @ 6 tons per hectare
2.	M_2	Rice husk incorporated	Rice husk mixed into the surface soil (5 cm) @ 6 tons per hectare
3.	M_3	Paddy straw	Paddy straw spread on the soil surface @ 6 tons per hectare
4.	M_4	Saw dust	Saw dust spread on the soil surface @ 6 tons per hectare
5.	M_5	Water mulch	Layers of water (up to a height of 15 cm) contained in polyethylene envelopes placed between the rows & plants on the soil surface
6.	M_6	Clear polyethylene	Transparent polyethylene (thickness 30 gauge) spread on the soil surface
7.	M_7	Black polyethylene	Black polyethylene (thickness 30 gauge) spread on the soil surface
8.	M_8	Bare (control)	Normal cultivation practice followed

Note – All the treatments were maintained just after sowing except M_2.

etative mulches, whereas incident short wave radiation is transmitted through clear polyethylene and absorbed directly by the soil causing higher soil temperature. Soil temperatures were not as high under black plastic because the soil received only a portion of the incoming energy absorbed by the black film. Similar results were reported by Adams (1962), Burrow and Larson (1962) and Revut (1973) and Khan (1998b). ODR was also found to be significantly higher under vegetative mulches followed by plastic mulches in comparison to that in bare plots. There is a gradual decrease in ODR under all the treatments with lapse of time. It may also be seen from the table, that as the soil depth increases, the ODR decreases. The decrease in ODR values with the lapse of time in all treatments is attributed to a general increase in bulk density and resultant decrease in aeration (noncapillary) porosity (Khan 1998a). The values of ODR also decrease with increased bulk density at constant moisture (Mohsin and Khan 1977). It was also observed from the data that ODR decreased with increasing soil depth. ODR values were reduced at deeper soil depth due to increase of resistance components (Letey and Stolzy 1964). ODR is also temperature dependent. An increase in temperature decreased the solubility of oxygen and increased the diffusion coefficient through both gas and liquid (Stolzy and Letey 1964). An increase of 1.4 per cent $^{\circ}C^{-1}$ ODR in sandy loam soil was reported (Mohsin and Khan 1977).

An improved soil physical environment and retention of greater amount of water under mulched condition for a longer period of time gave a better crop yield. The most noticeable influence was the favourable (lower) bulk density under mulches which might have allowed the roots to grow and penetrate the soil to a greater depth than the bare plots. Better root penetration under mulches is because of the improvement in the soil structure and good aeration. Under nonmulched treatments, bulk density increased abruptly which might offer resistance to root growth causing a restricted area and volume of the soil for moisture, aeration and nutrient absorption. Khan and Datta (1983) observed that for a particular soil there was a maximum bulk density for root growth. When the soil exceeded that maximum value, root proliferation was adversely affected. Hillel (1971) reported the reduced soil water availability under increased bulk density. Drying takes place very rapidly after irrigation in non-mulched treatments and that moisture depletion from the active root zone occurs at a faster rate than replenishment of moisture from lower layers (Lemon 1956, and Khan 1986).

Studies relating crop production to soil temperature have caused wide acceptance of the value of mulches for providing a favourable crop environment for increasing crop yield in cold temperate climates. Adams (1962) reported a significant increase in pod yields with the use of a plastic mulch, which was attributed to the warmer soil temperatures. Warmer temperature may increase the absorption of nutrients and water as well as the production and translocation of carbohydrates. Soil temperatures affect other factors which influence growth, such as nitrification, P-mineralization,

Table 2: Bulk density as influenced by varying mulch treatments at different growth stages of peanut

	Bulk density (g cm^{-3})									
	0–7.5 cm soil depth					7.5–15 cm soil depth				
Treatments	Seedling emergence stage	Flowering stage	Pegging stage	Pod formation stage	At harvest	Seedling emergence stage	Flowering stage	Pegging stage	Pod formation stage	At harvest
M_1	1.30	1.35	1.40	1.42	1.49	1.38	1.43	1.43	1.44	1.49
M_2	1.33	1.38	1.43	1.49	1.55	1.43	1.46	1.44	1.45	1.49
M_3	1.31	1.34	1.46	1.50	1.56	1.39	1.44	1.44	1.46	1.50
M_4	1.29	1.36	1.42	1.48	1.53	1.41	1.44	1.45	1.48	1.53
M_5	1.28	1.34	1.42	1.46	1.51	1.40	1.44	1.40	1.45	1.49
M_6	1.26	1.32	1.41	1.47	1.52	1.41	1.44	1.42	1.47	1.48
M_7	1.27	1.33	1.40	1.46	1.53	1.40	1.43	1.43	1.45	1.47
M_8	1.40	1.43	1.47	1.51	1.58	1.42	1.45	1.44	1.49	1.52
L.S.D. ($P = 0.05$)	0.0142	0.0153	0.0176	0.0154	0.0156	0.0157	0.0157	0.0158	0.0170	0.0142

Table 3: Aeration porosity as influenced by varying mulch treatments at different growth stages of peanut crop

Treatments	Aeration porosity (%)									
	0–7.5 cm soil depth					7.5–15 cm soil depth				
	Seedling emergence stage	Flowering stage	Pegging stage	Pod formation stage	At harvest	Seedling emergence stage	Flowering stage	Pegging stage	Pod formation stage	At harvest
M_1	24.31	22.10	20.60	18.30	16.10	22.32	19.35	19.90	15.40	13.50
M_2	23.90	21.30	19.50	17.40	15.60	21.70	20.17	17.30	15.80	13.80
M_3	24.20	22.90	20.10	17.90	15.10	21.90	19.65	17.92	15.30	13.60
M_4	25.83	23.20	21.20	19.80	17.50	22.50	20.10	18.40	16.87	14.10
M_5	25.60	24.07	22.30	20.00	17.65	22.60	19.95	17.50	15.95	14.67
M_6	26.10	24.60	23.37	20.50	17.80	23.10	20.80	18.40	16.60	14.70
M_7	26.00	24.80	23.20	21.97	18.10	23.00	21.20	17.10	16.95	14.75
M_8	23.70	20.90	18.10	16.00	15.07	22.95	20.40	18.93	15.70	13.60
L.S.D. ($P = 0.05$)	1.630	1.767	1.768	1.770	1.769	1.768	1.768	1.952	1.771	1.771

Table 4: Soil temperature influenced by mulching treatments during seedling emergence stage of peanut crop

	Soil Temperature (°C)							
	5 cm soil depth		10 cm soil depth		15 cm soil depth		20 cm soil depth	
Treatments	8 am	3 pm	8 am	3 pm	8 am	3 pm	8 am	3 pm
M_1	28.00	30.00	27.90	29.90	27.50	29.75	27.93	29.75
M_2	27.60	32.00	28.50	32.90	28.90	31.50	30.00	31.60
M_3	27.50	31.75	27.90	30.50	28.00	30.00	28.10	30.25
M_4	26.90	31.25	27.00	30.00	27.50	29.00	28.00	29.40
M_5	27.50	34.50	28.10	32.00	29.00	31.25	29.10	31.75
M_6	28.10	36.00	28.90	34.00	29.90	32.50	30.00	32.50
M_7	27.50	32.50	29.90	32.00	28.00	31.50	28.10	31.40
M_8	29.00	35.00	27.50	33.10	30.00	33.00	28.50	33.00
L.S.D. ($P = 0.05$)	1.811	1.813	1.809	1.812	1.811	1.813	1.753	1.810

Table 5: Mean Oxygen diffusion rate (ODR) values during seedling emergence stage of peanut crop as influenced by varying mulch treatments

	ODR (10^{-8} g cm^{-2} min^{-1})							
	Soil depth (cm)							
	1st Year				2nd Year			
Treatment	5 cm	10 cm	15 cm	20 cm	5 cm	10 cm	15 cm	20 cm
M_1	75.85	67.69	59.36	52.37	81.75	71.06	64.26	59.96
M_2	72.13	66.46	57.50	50.90	79.56	67.33	63.10	58.00
M_3	74.30	67.83	59.00	51.75	81.10	70.67	64.00	59.11
M_4	73.00	66.96	57.90	51.14	80.67	69.39	62.83	58.08
M_5	72.00	64.11	56.72	51.42	77.40	67.10	62.30	58.29
M_6	71.10	63.00	55.87	49.14	75.10	64.00	61.25	56.82
M_7	71.70	63.70	56.95	50.42	76.22	65.87	62.56	57.10
M_8	69.00	61.57	53.10	49.20	74.25	62.00	59.28	52.66
L.S.D.	1.699	1.699	1.697	1.688	1.722	1.599	1.717	1.765

uptake of water, transpiration and respiration. Increasing seed bed soil temperatures during the growing season accelerated growth rates and plant development sufficiently to hasten maturity and increase the pod yield (Khan 1998b).

Mulch protects the soil from the impact of the raindrops and therefore protects its tilth. This favours aeration. On the other hand, it keeps the soil more moist, thus restricting the effective air capacity. During spring and summer when much aeration is needed, it keeps the soil cool thus decreasing diffusion rates. Whether the total result of mulching on diffusion will be positive or negative depends upon the individual case. However, observation indicates that it usually decreases diffusion of oxygen into the soil.

Other means of managing soil aeration include regulation of respiration of roots and microbes by

Table 6: Mean Oxygen diffusion rate (ODR) values during pod formation stage & at harvest of peanut crop as influenced by varying mulch treatments

	ODR (10^{-8} g cm^{-2} min^{-1})							
	Soil depth (cm)							
	1st Year				2nd Year			
Treatment	5 cm	10 cm	15 cm	20 cm	5 cm	10 cm	15 cm	20 cm
M_1	63.10	50.15	47.47	42.51	66.27	54.49	49.11	44.31
M_2	61.56	47.80	45.86	41.15	64.30	51.55	46.00	41.87
M_3	63.00	49.10	47.00	42.00	66.00	53.25	48.00	43.90
M_4	62.93	48.70	46.33	41.77	65.34	52.61	47.32	42.33
M_5	59.51	46.90	45.42	40.52	62.23	51.75	46.00	41.67
M_6	56.90	47.02	44.37	38.92	59.65	51.00	44.11	39.25
M_7	58.09	46.25	45.53	39.34	60.33	51.40	45.53	39.90
M_8	55.25	44.38	42.45	38.00	58.00	49.87	42.33	37.13
L.S.D. ($P = 0.05$)	1.729	1.848	1.700	1.729	1.746	1.614	1.721	1.709

fertilization and cultural practices, density of plant stand, amount and location and time of incorporating residues into the soil, and choosing the degree of decomposition of residues when they are incorporated.

Zusammenfassung

Bodenbelüftung bei unterschiedlichen Bodenoberflächenbedingungen

Die Einschätzung der Bedeutung der Bodenbelüftung für verschiedene Pflanzeneigenschaften und Umweltbedingungen ist notwendig, um die Sauerstoffbeziehung zu Kulturpflanzenbeständen zu bestimmen. Die Wurzelumwelt als eine fest-flüssige Matrix wird von der Bodenstruktur und den Feuchtigkeitsbedingen bestimmt. Eine begrenzende Sauerstoffversorgung schränkt die Wurzelentwicklung ein und reduziert die Stickstoff-Fixierung bei Erdnüssen. Die Bodenoberflächebedingungen können durch Mulchen verändert werden und spielen eine signifikante Rolle in dem Schutz der Pflanzen gegen Mangel an Durchlüftung während kritischer Perioden des Pflanzenwachstums. Der Einfluss von acht Mulchbehandlungen (Reisspelzen, eingearbeitete Reisspelzen, Reisstroh, Sägemehl, Wassermulch, klares Polyethylen, schwarzes Polyethylen und Kontrolle) auf die Boden-Sauerstoffdiffusionsrate (ODR) während der verschiedenen Wachstumsphasen von Erdnüssen (*Arachis hypogeae* L.) wurden auf einem lateritischen, sandigen Lehmboden (Ultisol) untersucht. Die Experimente wurden für zwei aufeinander folgende Anbauperioden duchgeführt. ODR-Werte waren höher in den mulchbehandelten Parzellen. Mit dem Fortschreiten des Wachstums und der Entwicklung in größeren Bodentiefen nahmen die Unterschiede zwischen den Werten der ODR innerhalb der Behandlungen ab. Der Einfluss von Mulchbehandlungen auf andere physikalische edaphische Eigenschaften wie z. B. Bodendichte, Belüftung (nicht kapillar) Porosität und Bodentemperatur wurden ebenfalls untersucht. Mulchbehandlungen reduzierten die Oberflächenverkrustung und damit auch die Bodendichte und erhöhten die Belüftungsporosität und ODR. Die Bodentemperatur war unter Plastikmulch höher, während organische Mulchverfahren die Bodentemperatur erniedrigten.

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