Original Research Article

Role of air flow on changing soil properties and plant nutrition in Egyptian alluvial soil

Abstract

Study the effect of air flow on changing some soil properties and plant nutrition is highly important to increase crop quality and productivity. The pot experiment was carried out focusing on Agric faba bean C.V. Giza 2 in Egyptian alluvial soil (clay) during 2017/2018 season. The results revealed that hygroscopic water (HW), saturation percentage (SP) and real density (RD) have not affected by air flow, while organic matter (OM), hydraulic conductivity (HC) and bulk density (BD) have remarkable increase with air flow. The available macro and micronutrients concentrations in soil and plant are also discussed where different results have been obtained depending upon type of nutrient. The total count of bacteria (TCM) is found to be affected with air flow than without aeration techniques. The ~~toll~~ results of this experiment show that aeration or air flow promotes healthy levels of soil gases and has an important role in plant.

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Keywords: Agric faba bean; air flow; nutrients contents; bacteria count; biological process.

Graphical abstract

1. Introduction

Air movement within the profile of the soil is significant because soil air content in the root zone is dependent on air exchanges between the air in the soil surface and the atmosphere, microbial and plant root air respiration, and water gas solubility (Ben-Noah and Friedman, 2018, Bouwer, 1966). In particular, photosynthesis and respiration, carbon dioxide and oxygen play an essential role in the plant biological process (Xu, et al., 2015). Oxygen levels in ground-air must be maintained at or above the level of 50 % or greater than oxygen in the atmosphere to prevent oxygen shortcomings and excess carbon dioxide levels in most plants (Long, et al., 2004). Air penetration refers to the distribution of pored size and the root zone mix retention capacity and depends in particular, on the rooting medium's air-filled porosity (Ahmadi, et al., 2011). In soil air transport two major mechanisms are involved; mass flow and broad flow (Shi, et al., 2012). The mass flow is mainly induced by temperature changes, fluctuations in barometric pressure, wind speeds on the turf surface and water infiltrated (Tyagi and Tripathi, 1983). Diffusion is generally caused by differences in concentration between gasses but can also be influenced by differences in air pressure at temperature (Colmer, 2003). Cultivation may improve the soil aeration and improve the interests of soil gases, but aeration must be continued on a regular schedule or its benefits may decrease over time (Li, et al., 2016). The excessive water and slow exchange of gas with atmosphere decreases the aeration in soil (Colmer, 2003). The main way of exchanging gas is by diffusion, with gases moving from higher to lower partial pressure down a part of the pressure gradient (Hutchinson and Livingston, 2002). Oxygen is essential for aerobic respiration in soil. Flow of O_2 is due to difference of air pressure between atmospheric (high) to soil (low). For CO_2 and H_2O, the opposite is true (Hutchinson and Livingston, 2002). A soil could be seen as healthy when the air filled pore regions represent approximately 50% of the total porosity and the soil air composition is similar to atmospheric air (Tuli, et al., 2005). Plant roots, including soil fauna and flora, require air for respiration which has the major effect on chemical reactions (Millar, et al., 2011). Water and air both pass through the pores in the soil occupying the same areas, whereas some air can be dissolved in soil. Water and air can also be contained in larger pores that aren't filled by water, such as those caused by macro fauna or root decay (Dasberg and Bakker, 1970). The objective of this research is to verify the role of air flow in soil change and plant nutrition in Egyptian alluvial soil.

2. Material and methods

2.1. Experiment design

Pot experiment was carried out during 2017/2018 season using the Agric faba bean C.V. Giza 2 in Egyptian alluvial soil (clay) at Agriculture Experimental Station, Mansoura University, Mansoura, Egypt. Two treatments with three replicates were included in the experiment. During the first treatment, the air flow was pumped through the ground using the vacuum pump, while no air supply in other treatments. This was performed for two weeks (4 h/day) and faba bean was cultivated for three week. The plant and soil samples were selected and analyzed. Figure1 showed the schematic diagram for experimental design and Figure 2 showed the view of plants cultivated with and without air flow.

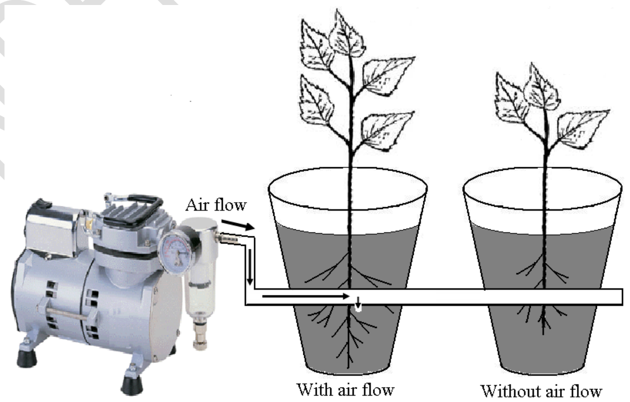

Fig.1. Schematic diagram for experimental design

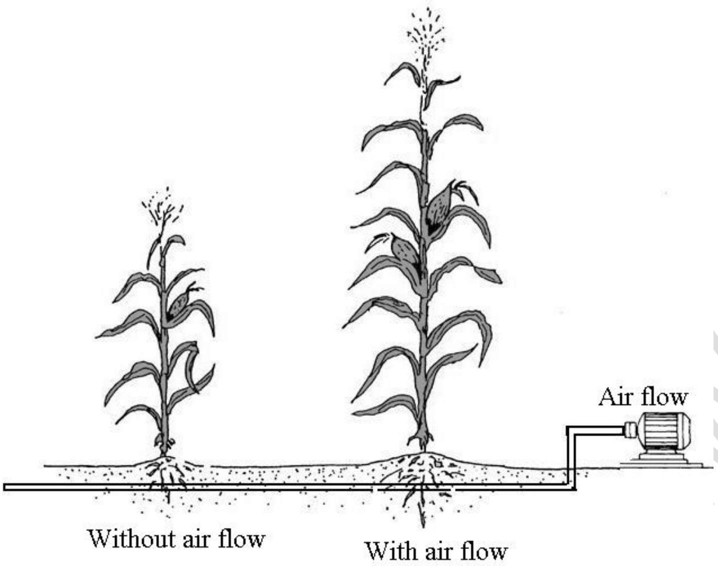

Fig. 2 View of plant cultivated with and without air flow

The soil characterization were conducted in Table 1 as follows:

Table 1 Physical and chemical properties of soil

Physical properties								
Soil texture	Fine sand %	Coarse sand %	Silt %	Clay %	EC (ds/m)	HW %	Bulk density (g/cm^3)	
Clay	17.31	9.33	22.32	51.04	1.72	6.61	35.4	
Chemical properties								
pH Soil paste	Organic matter (OM %)	Available nutrients (ppm)						
		N	P	K	Fe	Mn	Zn	Cu
7.70	1.86	91.0	226.3	347.0	14.5	12.1	1.4	0.75

EC: Electric conductivity; HW: Hygroscopic water

2.2. *Soil analysis*

~~PH~~ value was determined in the soil paste using a Gallenkamp pH meter (A. Gallenkamp Co.& Ltd., UK) and electric conductivity (EC) in 1: 2.5 soil: water extract was determined according to the reported procedures (Sahlemedhin and Taye, 2000). Particle size distribution was determined following the international pipette method (Wirth, 1946). Available K was extracted using 1.0 N ammonium acetate (pH 7) and determined by flame photometer (Hesse, 1971). Available micronutrients in soil samples were extracted by DTPA solution and determined using the atomic absorption spectrophotometer (Haluschak, 2006, Reeuwijk, 2002). Organic matter was determined using chromic acid wet oxidation method and multiplying the resultant values by 1.724 (Hesse, 1971). Available micronutrients in soil samples were extracted by diethylene triamine pentaacetic acid (DTPA) solution and determined using the atomic absorption spectrophotometer (Lindsay and Norvell, 1978). Hydraulic conductivity (K) values of the soil samples columns were determined using the constant head permeameter in disturbed soil (Eq. 1) (Smith, 2000).

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$$K = QL/HAT \qquad \text{Eq. 1}$$

Where: K: hydraulic conductivity coefficient (cm/sec); Q: the volume (cm^3) of water being passed through the soil column at time (T); A: cross section area (cm^2); L: length of soil column (cm); H: hydraulic head (cm).

Bulk density was determined by using paraffin wax method (Wilke, 2005). Saturation (SP %) was determined according to reported procedure (Rawal, et al., 2019). Total bacteria were counted (TCM) using a soil dilution plate technique involving inoculation of replicate plates containing nutrients agar at 30 $^{\circ}$C in dark. Evaluation is performed after 48 h (Martin, 1975).

2.3. Plant analysis

Faba bean plant was oven dried at 70 $^{\circ}$C till constant weight, grained and 0.2 g from each sample was then wet digested (Wirth, 1946). Micronutrients were determined in whole plant according to reported method (Mertens, 2005, Mertens, 2005).

3. Results and Discussion

3.1. Soil characterization

3.1.1.Physical properties of the soil

The physical characteristics of soil under consideration are affected by air flow as presented in Table 2 and Figure 3.

Table 2 Soil physical properties

Treatments	HW %	SP %	OM %	BD g/cm^3	RD g/cm^3	Porosity %	HC (cm/h)
With air flow	6.38	62.1	1.79	1.04	2.1	50.48	110.3
Without air flow	11.0	71.8	0.82	1.02	2.4	57.5	66.2

HW: Hygroscopic water; SP: Saturation percentage; OM: Organic matter content; BD: Bulk density; RD: Real density; HC: Hydraulic conductivity

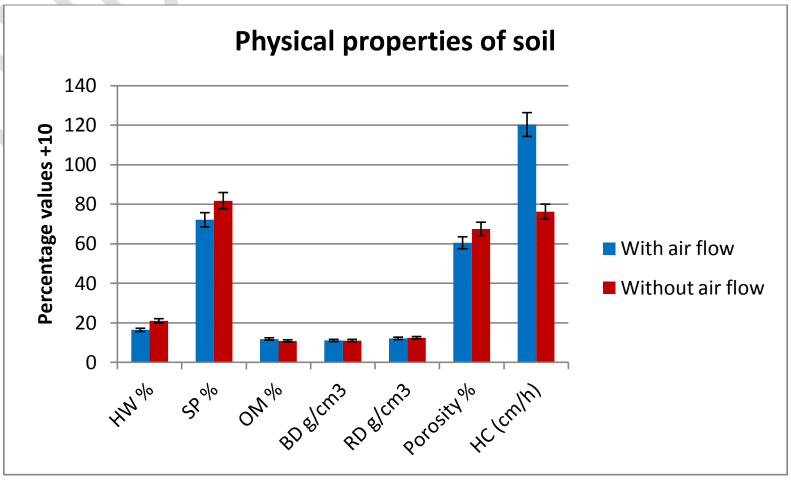

Fig. 3. Physical properties of soil used in experiments

The data revealed that the HW, SP and porosity percentages are found to be higher in absence of air flow than in case of its presence. The OM content and HC values are highly increased in presence of air flow compared with the other treatment without air flow. On the other hand, the RD and BD values have no remarkable change in both treatment methodologies.

Soil is considered healthy if porosity is around 50 % of the total porosity filled up by air, including plant roots and plays an important role in chemical reactions for the breathing of soil fauna and flora (Moldrup, et al., 2004). When water, oxygen and nutrients consume less than the plant needs, plant growth becomes limited. Soil compaction is one of the factors which lead to limited soil supply to the root system (Tracy, et al., 2011). The functioning of roots developed in soil compaction conditions can be restricted by either mechanical impedance or poor soil aeration due to low porosity (Unger and Kaspar, 1994). The roots can suffer from a lack of water, good nutrition and oxygen when the land becomes compacted. All growing media constitute constantly changing environment with movement of nutrients, constant gas exchange and constant flux of water. Any factor influencing one of these processes will have a serious impact on plant growth. The compaction of the soil can seriously affect the fertile triangle (Air- water- nutrition) (Lal, 2000). Low ground aeration or a deficit in oxygen is a major limiting factor for planting. The soil may be oxygen deficient by management of the pores such as compaction (Crawford, 1992). The airflow used to provide good aeration and to prevent a compaction effect was therefore considered in this study. Soil compaction increases bulk density and changes the distribution of soils pores, air movement, water and nutrients (Hoffmann and Jungk, 1995). Water infiltration may flush or move air, thereby triggering airflow in the profile. Additionally, dissolved oxygen may come to the root zone through irrigation. Similarly, air will replace water when excess water is drained (Lambers and Oliveira, 2019). The composition of soil air is determined by the rate of oxygen removal and its replenishment rate; with all changes in soil structure, humidity content and temperature, the production rate of carbon dioxide and oxygen refreshment fluctuates continuously. The concentrations of carbon and oxygen in the soil air are fluctuating. The soil air's carbon dioxide content increases and its oxygen content decreases at depth that can be highly pronounced in dried soil during wet periods (Buchmann and Ehleringer, 1998).

3.1.2. *Chemical properties of the soil*

The effect of air flow treatment on the chemical properties of the soil can be summarized in Table 3 and Figures 4 and 5.

Table 3 Average available nutrients concentration in soil

Treatments	Macronutrients *Av. Conc. (ppm)*			Micronutrients *Av. Conc. (ppm)*	
	N	P	K	Zn	Fe
With air flow	68	5.4	425	2.9	9.5
Without air flow	72	4.9	440	1.8	7.2

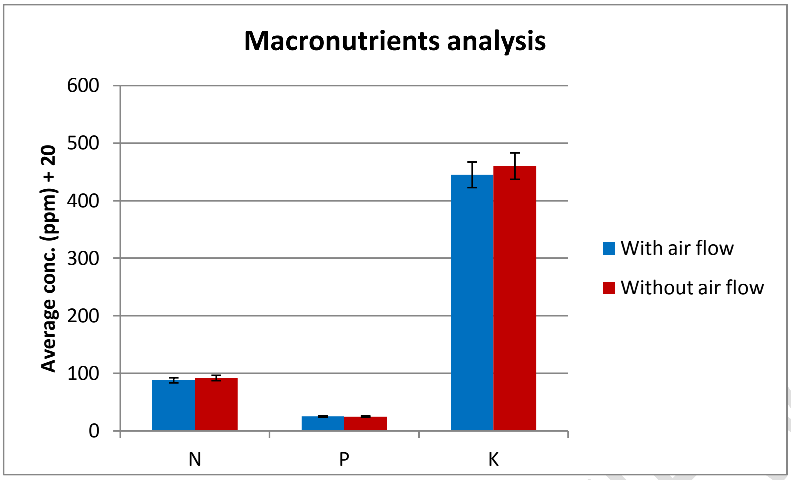

Fig. 4. Effect of air flow treatments on available macronutrients concentrations (ppm)

The available N and K concentrations are decreased with air flow treatment, while P concentration is increased in the same condition (Table3 and Figure 4).

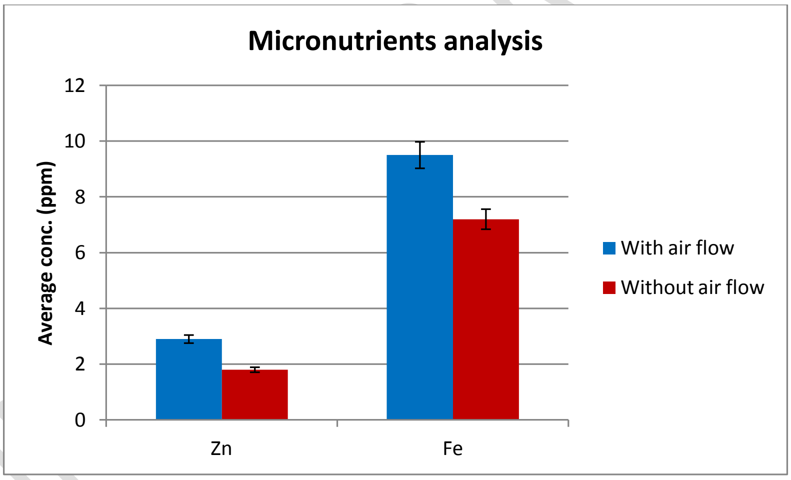

Fig. 5. Effect of air flow treatments on available micronutrients concentrations (ppm)

Concerning the micronutrients, the available concentrations of Zn and Fe are increased with air flow condition as indicated by data tabulated in Table 3 and plotted in Figure 5.

The concentration of oxygen in water outside the roots may be much higher than the minimum amount of that needed inside the cells to keep its metabolism aerobic, since it must spread to every cell outside the root and this needs an oxygen gradient. Zinc deficiency may also induce the compacting of the soil by affecting the root system. Anaerobic conditions imply the reduction of accessible ferric iron into ferrous and insoluble manganese oxidant into manganese ions, which are much more moving than oxidized ions in the soil (Buchmann and Ehleringer, 1998).

3.1.3. Total count of bacteria

Soil textures differ in many ways than heap of inert rock particles. One of the more important is the presence of microorganisms and their energy which is driven by organic oxidation residues left behind (Baldock and Skjemstad, 2000). The micro-organisms have continuously oxidized and leave the dead plant behind in a form that the plant can afford. All organisms have to breathe to live, but different breathing methods have been developed. The majority of the soils of all fungi and actinomycets are subject to conditions of good aeration and few, if any outside the yeasts, are anaerobic. On the other hand, the soil bacteria are groups which appear to be tolerant to progressive oxygen deficiencies in different grades. If they fix nitrogen and therefore oxygen for oxidation of the carbohydrate, the bacteria in legume nodules must be supplied with energy (Buchmann and Ehleringer, 1998). The effect of air flow treatment on total count of bacteria (TCB) has represented in Figure 6, where a remarkable increase in TCB compared with no air flow treatment.

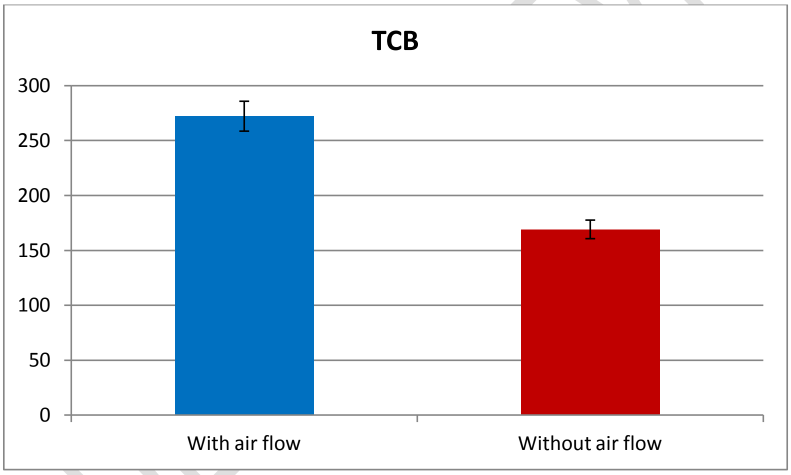

Fig. 6. Effect of air flow on Total count bacteria x 10^6 (TCB)

3.2. Plant characterization

3.2.1. Macro- and micronutrients as affected by air flow Macronutrients:

Assessment of macro- and micronutrients on plant was performed in both treatment conditions (with/ without air fow) as depicted in Table 4 and Figures7 and 8.

Table 4 Plant analysis (bean)

Treatments	N %	P %	K %	Zn %	Fe %
With air flow	3.28	0.395	2.08	63	98
Without air flow	2.76	0.312	1.69	68	109

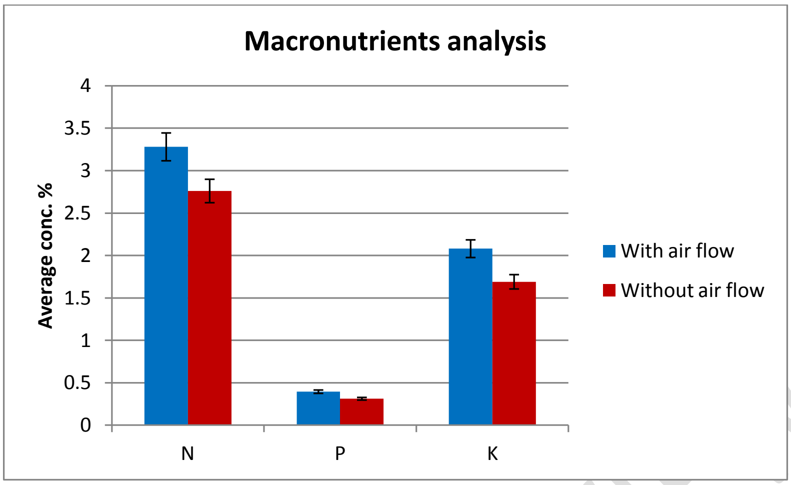

Fig. 7. Effect of air flow treatments on available macronutrients concentrations

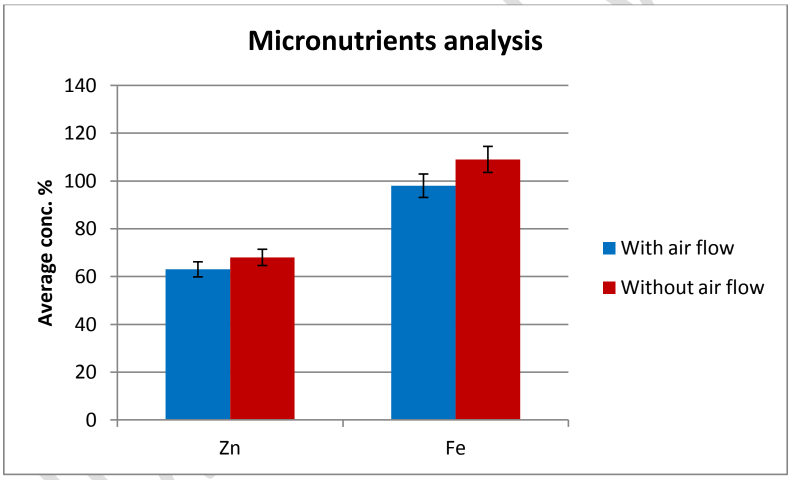

Fig. 8. Effect of air flow treatments on available micronutrients concentrations

The air flow has a highest increase on nitrogen, phosphorus and potassium content in plant with air flow than without air flow in the order N > K > P. While the percentage of Zn and Fe give the high increase with no aeration compared with aeration condition. These data is agreement with previously reported by (Foth, 1978) who found that aeration is a major limiting factor in the achievement of optimal growth with the widespread use of fertilizers and irrigation. The progressive decreases in aeration that occurs in a soil profile appear to restrict root systems to a certain extent. Poor ventilation can lower water consumption and lead to early wilting. The dramatically reduction in root length, leading to a decrease of the surface area for P uptake, could be attributed to lower total P in plants with increasing compaction (no air conditions) (Nadian, et al., 1997). Lower soil aeration actually affects potassium uptake, which is less than 45 % of any major nutrients (Baligar, et al., 2001). Soil anaerobic conditions induce a number of chemical and biochemical reduction reactions. Denitrificaiton is part of the processes by which nitrate is reduced to nitrite then to nitrous oxide and to elemental nitrogen (Peng, et al., 2007). Soil compaction limits the soil supply to the root system. Root functioning can be restricted by mechanical impedance, or poor aeration of soil, due to a low porosity (Yamauchi, et al., 2018). An impaired root system could greatly reduce the consumption of less mobile nutrients such as P by plants, especially on soils with small nutrient levels. The pores of soil not filled with water have gasses, and the soil atmosphere constitutes such gasses. Its composition differs from that of the free atmosphere because the soil-based plant roots and the organisms remove oxygen and breathe into it carbon dioxide, making it richer in carbon dioxide and poorer in oxygen than the free atmosphere. Since most crop roots can only operate if adequate oxygen supply is available, oxygen transfer from soil organisms and plant roots must be made possible in soils or by soil mechanisms or processes (Colmer, 2003). Lack or inadequate soil air (O_2) can result in reduced growth of the plant, photosynthesis and materials for plant development (Fryer, et al., 1998). Because Fe is strongly bound, it is not easy to locate iron and should be considered immobile in plants. The symptoms of deficiency are the intervention of chlorosis in new leaves (Rustioni, et al., 2018). Soils contain about 1 to 5 % of iron, which is much more than necessary for plants, but in aerobic environments Fe is present in the oxidation state of Fe^{+3} as iron oxide [written as $Fe_2O_3.NH_2O$ or $Fe(OH)_3$], which is highly insoluble. High ground stability and high soil porosity are usually linked to high levels of iron oxide. The iron is reduced under poor drainage and mobilized frequently in the presence of organic matter (OM). The main form of iron in soils is hydrated one, but the layer silicate structure of soils 2:1 and 2:2 is freely used for iron (Roosz, et al., 2015).

Conclusions

The effect of air flow on changing some soil properties and plant nutrition is studied. The pot experiment was carried out focusing on faba bean C.V. Giza 2 in Egyptian alluvial soil (clay) during 2017/2018 season. The results revealed that hygroscopic water, saturation percentage and real density have not affected by air flow, while organic matter, hydraulic conductivity and bulk density have remarkable increase with air flow. On the other hand available N and K concentrations are found to be increased in the treatment without air flow as compared with air flow treatment. Available P, Zn and Fe contents have been increased with air flow in the soil . The total count of bacteria is increasingly affected in air flow treatment. Plant nutrition (i.e. N, P and K) are also increased by airflow. On the opposite way Zn and Fe content were not affected by air flow. The results of this experiment show that aeration or air flow promotes healthy levels of soil gases and has an important role in plant. Biological processes especially respiration are reflected on well plant growth, plant nutrition and soil properties.

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COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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