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Aeration of clayey soils by injecting air through subsurface drippers: Lysimetric and field experiments

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ABSTRACT

We examined the effects of air injection into clayey-soil, with and without a perforated sphere around the dripper, on oxygen concentrations and pepper yields in a barrel experiment, and on soil oxygen concentrations and stem growth of young mango trees in a field experiment. The perforated sphere was intended to reduce soil resistance to air flow and to enhance the efficiency of air spreading in the soil. The main findings were that injecting atmospheric air did not contribute much to aeration of soils with high existing oxygen concentrations, i.e., about 80% of the atmospheric 21%, in the barrel experiments, and did not contribute at all in the field experiment, where oxygen concentration was about 95% of atmospheric. Furthermore, it was found that an oxygen concentration of about 80% did not decrease pepper yield in the absence of other stresses such as salinity or nutrients deficiency. A perforated sphere increased soil oxygen concentration when both water and air were applied through the sphere. A positive effect of air injection on pepper yields was found in soils with high volumetric water contents, i.e., average above 0.4 throughout the growth period. Conversely, air injection decreased pepper yields in barrels where water contents were lower.

1. Introduction

1.1. Oxygen deficiency and methods for improving soil aeration

Oxygen deficiency in agricultural soils under intensive irrigation is a well-known phenomenon, especially in fine-textured, clayey (heavy) soils, with slow internal drainage (Drew and Lynch, 1980; Friedman and Naftaliev, 2012). This phenomenon intensifies when treated waste water or saline water is used for irrigation, mainly because of the increased irrigation doses used to ensure leaching of salts (Assouline and Narkis, 2013). High temperatures also may induce oxygen deficiencies (Asplund and Curtis, 2001; Ityel et al., 2014). Oxygen deficiency decreases the root membrane exclusion capabilities, and thereby intensifies plant sensitivity to salt stress. Many studies have demonstrated the strong effects on plant metabolism, of oxygen concentration and supply rates in the root zone: they affect respiration, root elongation, transpiration, and nutrient absorption. Also, previous studies revealed the harmful effect of anoxia (total lack of oxygen) and hypoxia (low oxygen concentrations) on various physiological processes and on root resistance to diseases (Armstrong, 1979; Bhattarai et al., 2006; Glinski and Stepniewski, 1985; Grable, 1966).

Nonetheless, today there are only a few agricultural means of improving soil aeration, and some of them, e.g., deep tillage, destroy soil structure and induce erosion. Others, such as digging trenches and filling them with coarse-textured material are expensive and irreversible. Oxygen deficiencies are usually avoided by choosing a crop compatible with soil aeration capability. Thus, developing an efficient and simple technique for soil aeration could increase the variety of permissible crops in fine-textured soils and also increase the yields of currently grown crops.

Air injection was found fairly effective in aerating the rhizosphere (Bhattarai et al., 2006; Niu et al., 2012). Other methods such as adding hydrogen peroxide (Bhattarai et al., 2004; Melsted et al., 1949), other peroxides (Bryce et al., 1982; Herr and Jarrel, 1966), or air bubbles (Bhattarai et al., 2004, 2006; Goorahoo et al., 2002; Abuarab et al., 2013) to subsurface drip irrigation, and digging feeding trenches along the tree rows and filling them with highly water-

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Table 1
Previous aeration studies and their main results.

Aeration technique	Yield effect	Aeration rate (O_2 added)	Crop	Soil	Reference
Adding H_2O_2 to irrigation	+ 50%		Corn	"excellent tillage" 6% organic material	(Melsted et al., 1949)
H_2O_2	+ 20%		Soya bean	"	"
Air injection	+ 53%		Corn	"	"
Air injection	No influence		Soya bean	"	"
Urea peroxide	Leaf area + Plant mass +		Chrysanthemum	peat + perlite	(Herr and Jarrel, 1966)
Urea peroxide	+ 20% above-ground mass	$CH_6N_2O_3$ at 40 ppm = O_2 at18.5 mgL^{-1}	Tomato	Flooded peat + sand	(Bryce et al., 1982)
Air injection	+ 150% + 100% No influence	0.5 to 24 h/d aeration	Tomato Eggplant Common bean	Silt-clay loam daily irrigation	(Busscher, 1982)
Air injection	+ 33% No influence	0.5 to 24 h/d aeration	Pepper Soya	Sand daily irrigation	"
Adding air bubbles to irrigation	+ 39%	12% (v/v) air	Pepper	Sandy loam	(Goorahoo et al., 2002)
H_2O_2	+ 25%	Two treatments with 50% H_2O_2 at5 L/Ha	Squash (field)	Vertisol (field capacity to saturation)	(Bhattarai et al., 2004)
H_2O_2	+ 82%	500 ppmH_2O_2 = O_2 at 30 mg/L	Soya (flower pot)	"	"
H_2O_2	+ 14%	"	Cotton (flower pot)	"	"
Air bubbles	+ 6%	12% (v/v) air	Soya (flower pot)	"	"
Air bubbles	+ 28%	12% (v/v) air	Cotton (flower pot)	"	"
Air bubbles	+ 21% + 28% (high salinity)	12% (v/v) air	Tomato (flower pot)	"	(Bhattarai et al., 2006)
Air bubbles	+ 35%	12% (v/v) air	Soya bean	"	(Bhattarai et al., 2008)
Air bubbles	+ 15%	12% (v/v) air	Pumpkin	"	"
Air bubbles	+ 11%	12% (v/v) air	Chickpea	"	"
Air bubbles	+ 70%	12% (v/v) air	Melon	"	(Bhattarai et al., 2010)
Air bubbles	+ 4%	12% (v/v) air	Pepper	"	"
Air bubbles	No influence	12% (v/v) air	Tomato	Rockwool, waste water (greenhouse)	Bonachela et al. (2010)
Air bubbles	No influence Longer shelf life	O_2 at 2–40 $mg\,L^{-1}$	Cucumber	Sawdust (greenhouse)	Ehret et al. (2010)
Air bubbles	No influence Longer shelf life	O_2 at 2–40 $mg\,L^{-1}$	Pepper	Sawdust or perlite (greenhouse)	"
H_2O_2	Delay in flowering and fruit formation	H_2O_2 at 600, 800 ppm	Pepper (barrel) screen house	Vertisol	Ben-Noah (2012)
Air bubbles	+12 to +38%	12% (v/v) air	Corn	Sandy clay loam	Abuarab et al. (2013)
Air injection	+ 22% (subsurface drippers) + 12% (furrows)	Volumes up to 100% of root area porosity after irrigation	Cucumber	Sandy loam (greenhouse)	Niu et al. (2013)
Air bubbles	+ 10% boll weight	12% (v/v) air	Cotton	Vertisol	Pendergast et al. (2014)
Air injection	Increased yield at 0.5 $L\,min^{-1}$; decrease at higher discharge rates	Air at 0–2 $L\,min^{-1}$	Cucumber (flower pot)	Perlite	Lee et al. (2014)
Air bubbles	+ 33% (on-surface drippers) + 13% (subsurface drippers)	12% (v/v) air	Potato	Sandy clay loam	Shahien et al. (2014)
Air bubbles	No influence	12% (v/v) air	Sugar beet	Clayey loam	Vyrlas et al. (2014)

and air-conductive materials such as gravel, tuff, perlite, or compost (Ben-Gal et al., 2004; MacDonald et al., 2004), were tested and found to be variously effective. For example, in a sandy soil, where aeration problems are not very common, injection of air bubbles via shallow (15 cm deep) subsurface drippers induced a 39% increase in pepper yield (Goorahoo et al., 2002). However, despite many attempts, only a handful of studies reported improvement of soil