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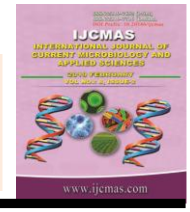

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Effect of Subsurface Drainage System on Maize Growth, Yield and Soil Quality

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A B S T R A C T

The treated industrial wastewater has been, continuously used for crop production in the water scares region of our country. Irrigation with agro-based industrial wastewater (treated paper mill effluent) though it initially increased the yield of many crops, over a period; it deteriorates the soil quality by addition of soluble salts in soil profile results in deflocculating of soil structure, reduced infiltration and waterlogging leads to yield reduction in some crops under poor management condition. A subsurface drainage experiment conducted with different (15, 20 and 25 m) lateral spacing in waterlogged saline-alkali soil revealed that, drainage system improves the soil quality parameters, like soil pH, soil EC, reduction in exchangeable cation, and reduction in exchangeable sodium percentage and increased the maize yield under different lateral spacing under treated effluent irrigation.

Introduction

The water required for meeting agriculture, domestic, industrial and other demand indicates the need for regeneration of municipal and industrial wastewater, which is a cheap and attractive alternative to the dry areas for irrigating crops to sustain productivity. The Indian pulp and paper industry on an average, it uses 143 m^3 of water to produce one ton of paper and this amount will reappear as wastewater. After proper treatment, effluent water safely used for crop production with the addition of suitable organic amendments (Udayasoorian *et al.*, 2004; Hazarika *et al.*, 2007). The main problems associated with irrigation using wastewater is an increase in soil exchangeable Na, as Na is present in high concentrations in wastewater. The monovalent Na ion and its large hydration sphere further facilitate dispersion of the clay, which leads to a reduction in hydraulic conductivity, decrease in permeability, poor drainage and poor soil aeration (Halliwell *et al.*, 2001 and Oliveira *et al.*, 2016) will leads to waterlogging in the soil. An estimated 30 million ha area in the world was affected by waterlogging and salinization, while approximately an additional 80 million ha are affected to some extent (Bakker *et al.,* 2010). The maintenance of adequate soil physical and chemical properties in waterlogged saline and alkali environment achieved by using good quality water, proper choice and the combination of soil ameliorants, good drainage and appropriate cultural practices (Grattan and Oster, 2003). The subsurface drainage system is underground artificial channels through which excess water may flow to a suitable outlet. Subsurface drainage maintains the productive capacity of soil by removing excess water, improving soil moisture, air circulation and reducing salt content and soil erosion (Chahar and Vadodaria, 2008 and Ritzema, 2009). It provides agronomical and environmental benefits, in terms of soil trafficability, field operation, prevents sediment and phosphorus loss from an agricultural field, and improves plant growth and yield in problematic soils (Ambast *et al.,* 2007; Prasad *et al.,* 2007; Ritzema and Schultz, 2011). Waterlogging in the field considered as one of the most important parameter, because it influences the other soil quality parameters (soil aeration, microbial activity, and nutrient availability). The unavailability of other source of good quality water necessitate the farmers to use treated wastewater and limit the choice of crop selection thereby forcing them to go for deep rooted and salt tolerant crop like coconut. The farmers now switched over to coconut based intercropping with CN hybrid and animal husbandry activities (Balusamy *et al.,* 2013). Waterlogging above certain period leads to build up anaerobic condition in soil and it will deter the growth and yield of plants. So, in order to solve the problem of waterlogging and salinity in the crop root zone, the subsurface drainage system been installed at different lateral spacing's in a waterlogged saline-alkali soil in Karur District of Tamil Nadu, India.

Materials and Methods

An experiment conducted in waterlogged saline-alkali soil at Pandipalayam Village, Karur District of Tamil Nadu, India to assess the effect of different (15, 20 and 25 m) lateral spacing on growth, yield and soil quality of maize grown field. The lateral spacing was arrived using the Hooghouts formula based on the depth of water table, amount of water needs to be removed, hydraulic conductivity of soil, and depth to impervious layer. The subsurface drainage system installed in an area of 1.20 ha with different lateral spacing. The perforated corrugated flexible PVC pipes with a diameter of 80 mm used as a lateral and placed at a depth of 1.1 to 0.9 m from the surface. Before installation of it, the lateral covered with coconut fiber to allow the passage of water through the perforation and avoid clogging of the pores. The blind PVC pipe with a diameter of 110 mm has used in the main drainage, which connected with laterals to remove the water from the field. The zero chips (blue metals) were also used to as bedding material and to cover the laterals, finally the mains and laterals filled with dig out soil.

Field preparation and sowing of maize

The individual plots of 15, 20 and 25 m lateral spacing ploughed ridges and furrows formed by adopting a spacing of 60 cm between the two ridges. Maize seeds (var. M 900 Gold) sown in the side of the ridges by adopting 25 cm spacing. The cultural practices including gap filling, thinning, weeding and plant protection measures carried out for the entire crop growth period as recommended by Tamil Nadu Agricultural University, Coimbatore.

Details of standardization experiment with maize crop (Non-replicated trail)

T_1 : 15 m lateral spacing
T_2 : 20 m lateral spacing
T_3 : 25 m lateral spacing
T_4 : Control (undrained field)

The representative soil samples were collected at different crop growth stages *Viz.*, vegetative (30 DAS), heading (60 DAS) and at harvest stage at 0-15 cm depth. The collected samples were analyzed for soil pH by potentiometry soil water suspension of 1:2.5 ratio (Jackson, 1973), electrical conductivity by conductimetry soil water suspension of 1:2.5, exchangeable sodium and potassium by a flame photometer and exchangeable calcium and magnesium by versanate titration method. The exchangeable sodium percentage worked out by using the formula given by Saxena *et al.,* (1978).

Results and Discussion

Effect of lateral spacing on soil characteristics

The different drain spacing of 15, 20 and 25 m influenced the soil reaction (pH), electrical conductivity, exchangeable cations *viz.*, Ca, Mg, Na, K, and ESP of soil. Overall the drainage system influenced the soil physicochemical properties positively, thereby yield and growth of maize under different lateral spacing.

Soil reaction (pH)

The soil pH plays an important role in the availability of plant nutrients in saline-alkali soils. The presence of common acid forming cations ions *viz.,* H^+, Fe^{2+}or Fe^{3+} and Al^{3+} and base forming cations like Ca^{2+}, Mg^{2+}, Na^+ and K^+ are influencing the soil pH. In the present study, the soil pH decreased towards crop advancement due to the removal of some of the base forming cations from the soil by drainage effluent and addition of H^+ in the form of HCO_3 (Fig.1). Similarly, Bharambe *et al.,* (2001), Rakesh *et al.,* (2005) and Pradeep *et al.,* (2005) also reported that the reduction in soil pH due to the removal of sodium and bicarbonate ions along with leachate water. Towards the end of the maize field experiment, the lowest soil pH of 8.88 was observed in the drained field with 15 m lateral spacing possibly as a result of the removal of much ions through drainage effluent compared to other drain spacing and undrained field.

Soil Electrical conductivity (EC)

Soil EC is a measure of the amount of salts in the soil solution, which affects crop yield, plant nutrient availability and activity of soil microorganisms. In the present study, the soil EC showed a decreasing trend (to a tune of 14.7, 14.2 and 14.0 percent in 15, 20 and 20 m lateral spacing's, respectively compared before installation of drainage system) towards crop advancement (Fig. 2) and in undrained field it showed an increasing trend (1.29 per cent). The decrease in soil EC noticed in the drained field due to the removal of soluble salts through drainage water at different lateral spacings (Bharambe *et al.,* (2001), Pradeep *et al.,* (2005) and Rakesh *et al.,* (2005). Similarly, Bahceci and Nacar (2009) reported 80 percent decrease in soil salinity within a period of 4 years and more reduction in soil salinity in top 30 cm of soil profile was reported by Yu *et al.,* (2016). In the present investigation, an increase in soil EC observed in the undrained field due to the addition of a considerable quantity of soluble salts through effluent water. This was in line with the finding of several workers (Udayasoorian *et al.,* 2003; Kumar and Chopra, 2011; Sharma *et al.,* 2014) where they reported that effluent irrigation increased EC of the soil.

Soil exchangeable cations

Exchangeable cations are those, which exchanged by a cation of an added solution. The soil exchangeable cations Ca^{2+}, Mg^{2+}, K^+ and Na^+ often called the exchangeable bases, commonly occur in the soil in the order listed above (Thomas, 1982). In the present investigation, before the start of the experiment it was in the order of $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. In drained field, the exchangeable sodium showed a decreasing trend and other cations like Ca, Mg and K observed an increasing trend (Fig.3a to 3d). The paper mill effluent added a considerable amount of exchangeable cations like Ca, Mg and K in soil and the content increased towards crop advancement (Hameed and Udayasoorian, 1998; Udayasoorian *et al.*, 2003; Sharma *et al.*, 2014 and Kumar *et al.*, 2015). The decreasing trend of exchangeable Na^+ (which is basically monovalent cation) easily leached through drainage effluent under subsurface drainage system (Bharambe *et al.*, 2001; Pradeep *et al.*, 2005) and it showed a decreasing trend in the drained field. In the undrained field, the exchangeable cations like Ca, Mg, Na and K showed an increasing trend due to salt-laden effluent (Kumar *et al.*, 2015).

Exchangeable sodium percentage (ESP)

The ESP is the amount of adsorbed sodium on the soil exchange complex expressed in percent. The monovalent nature of Na^+ does not attach to any nearby particle resulting in dispersion and tight arrangement of dispersed soil particle with sodium greatly reduce the infiltration and drainage in such soil. The subsurface drainage system decreased the soil exchangeable sodium percentage at the different lateral spacing in the drained field, whereas it increased in undrained filed (Fig. 4). The decrease in ESP of 15.1, 13.8 and 11.8 percent recorded at 15, 20 and 25 m lateral spacing, respectively during the experimental period and whereas in undrained filed it increased 15.4 percent compared to initial value. The highest decrease in ESP at 15 m lateral spacing was recorded as a result of higher leaching of soluble salts especially Na through drainage water (Bharambe *et al.*, 2001 and Pradeep *et al.*, 2005), otherwise would have been concentrated in the soil solution and accumulated in soil layers. Similarly, Ramana Rao and Bhattacharya (2001) also reported that the effect of salt leaching is better in smaller spacing. Balusamy and Udayasoorian (2017a) observed a decrease in ESP by 42 percent over control in the drained field that received organic amendments and gypsum.

Effect of lateral spacing on maize growth and yield

The provision of subsurface drainage system in waterlogged saline-alkali soil increased the germination percentage, plant height, leaf length, leaf width and leaf area index of maize crop, due to removal of a large amount of soluble salts, waterlogging free condition and increased nutrient availability in drained field, favored the plant growth and development (Kolekar *et al.*, 2011; Balusamy and Udayasoorian, 2017b). Similarly, Sousa *et al.*, (2011) reported that 80 percent increase in coconut plant height after 8 months in drainage system installed field, whereas it was only 50 percent in the undrained field. The mole drainage system with 4 m lateral spacing increased the plant height, number of branches per plant, number of pods per plant, weight of pods per plant in groundnut (Kolekar *et al.*, 2011).

The presence of high concentration of soluble salts in the soil, poor aeration, and poor nutrient availability at high pH except for specific nutrients like P, coupled with poor quality effluent water in undrained field limits the growth and development of maize leading to poor germination and growth characteristics. This was supported by Kumar *et al.*, (2010), who observed that high concentration of Na, CO_3, HCO_3 in the paper mill effluent decreased the bulk density, water holding capacity due to deflocculation of soil by the high concentration of sodium and it adversely affect the germination and plant growth.

Fig.1 Effect of lateral spacings on soil pH in the subsurface drainage system

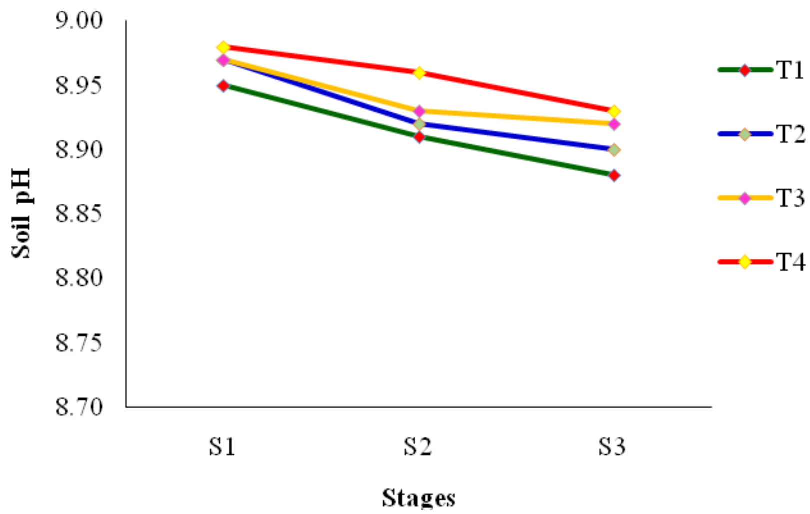
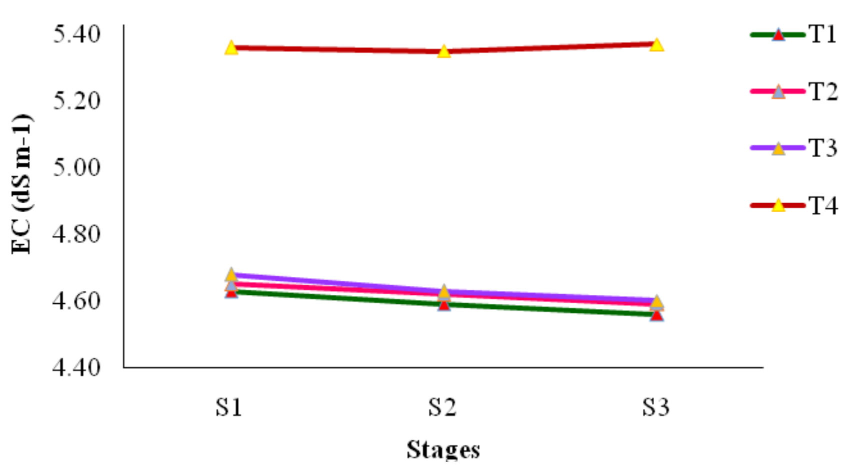


Fig.2 Effect of lateral spacing on soil EC (dS m^{-1}) in the subsurface drainage system



(S_1: 30 DAS; S_2-60 DAS; S_3-at harvest stage)

Fig.3 Effect of lateral spacing on soil exchangeable Na, Ca, Mg and K in the subsurface drainage system

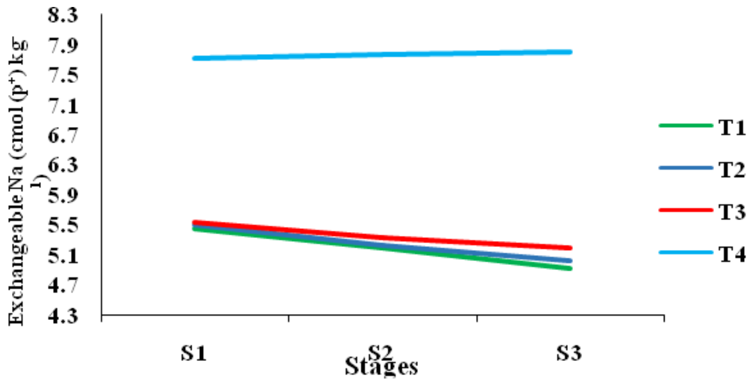


Fig.3a Exchangeable Na (cmol $(p^+)kg^{-1}$)

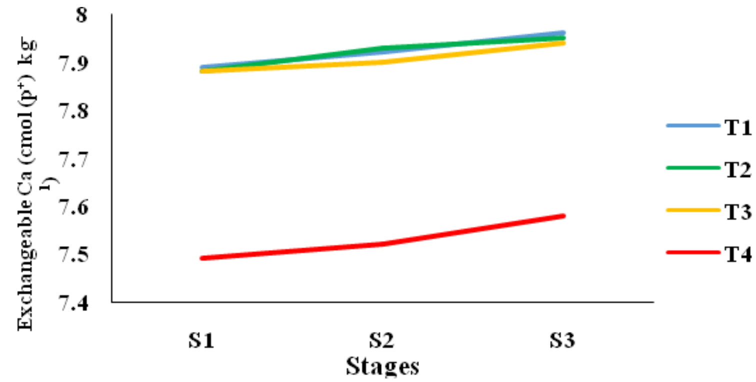


Fig.3b Exchangeable Ca (cmol $(p^+)kg^{-1}$)

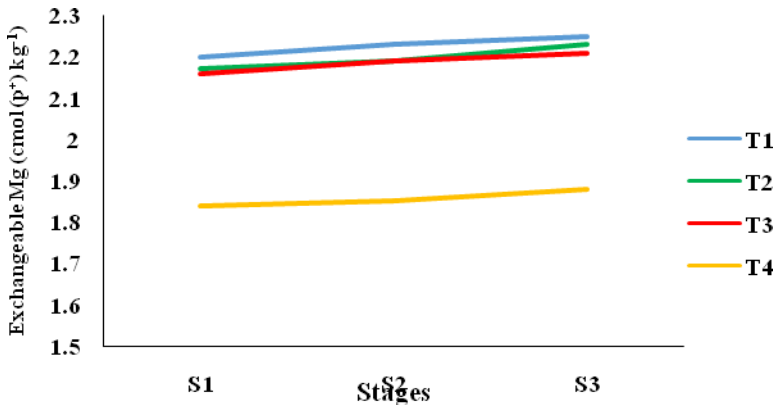


Fig.3c Exchangeable Mg (cmol $(p^+)kg^{-1}$)

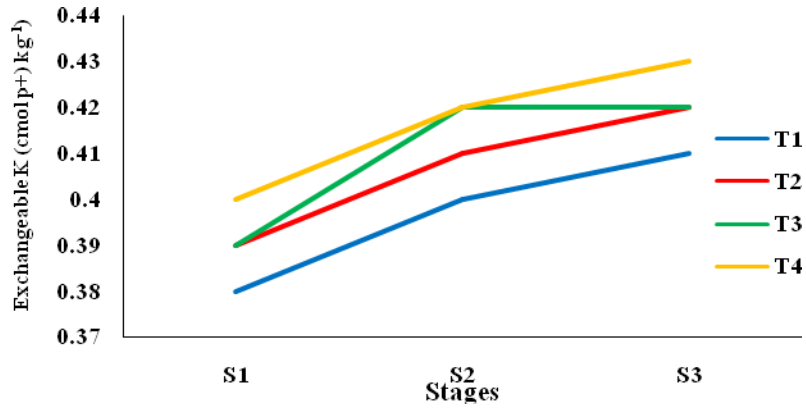
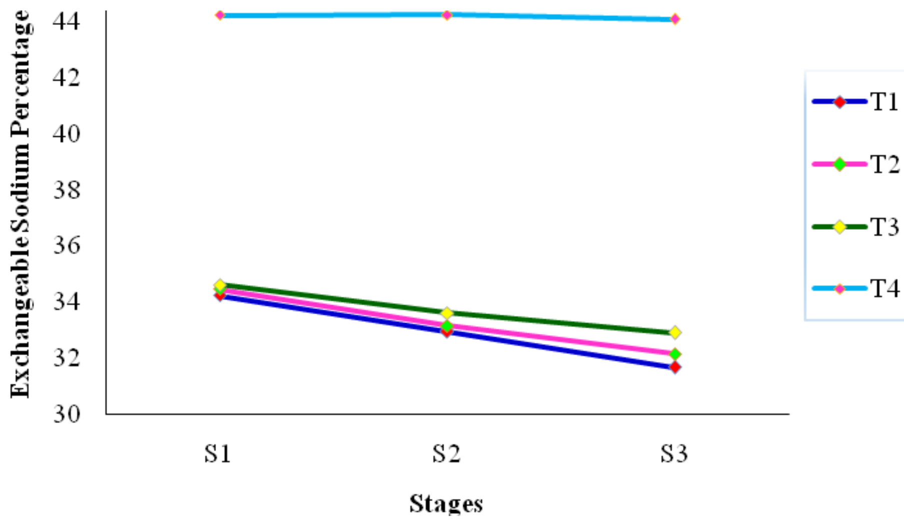


Fig.3d Exchangeable K (cmol $(p^+)kg^{-1}$)

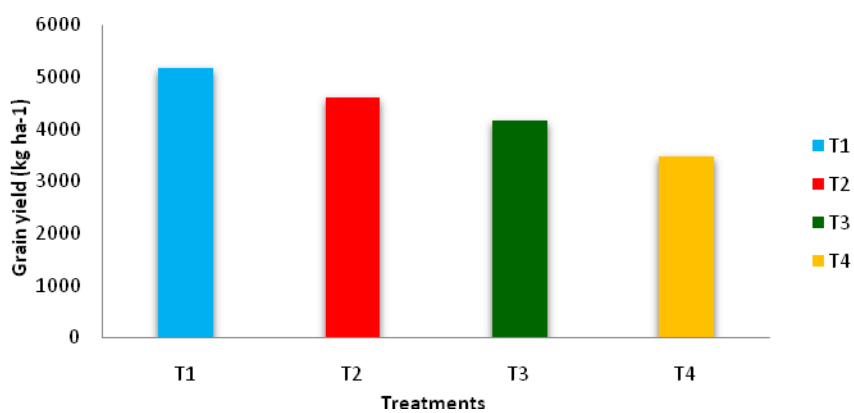
(S_1: 30 DAS; S_2-60 DAS; S_3-at harvest stage)

Fig.4 Effect of lateral spacing on soil exchangeable sodium percentage in the subsurface drainage system



(S_1: 30 DAS; S_2-60 DAS; S_3-at harvest stage)

Fig.5 Effect of lateral spacing on maize yield (kg ha^{-1})



(S_1: 30 DAS; S_2-60 DAS; S_3-at harvest stage)

The highest cob length, maximum test weight, cob yield and grain yield was recorded in the drained field with 15 m lateral spacing followed by 20 and 25 m lateral spacing (Fig. 5). The increase was due to improvement in soil physical properties *viz.,* infiltration rate, porosity and chemical properties (low pH, EC, ESP) and improved nutrient availability in the drained field. Similarly, Abdel-Dayem and Ritzema (1990) reported an increased yield of many crops to a tune of 10 percent for rice, 48 percent for berseem, 75 percent for maize and more than 130 percent for wheat under subsurface drainage system. The increase was because of decreased soil salinity, improved air and water condition in crop root zones. The poor yield of maize in the undrained field due to poor soil physicochemical properties viz., shallow water table depth, high pH, EC and ESP (Stieger and Feller, 1994; Samad *et al.*, 2001 and Zhang *et al.*, 2015), which limits the growth and development of crops in waterlogged saline-alkali soil.

In conclusion, the subsurface drainage system is a highly promising technology to overcome the adverse effect of waterlogging and saline-alkali soil problem in the industrial effluent and canal water irrigated areas. The provision of the subsurface drainage system, readily leach the soluble salts from the soil layer through drainage water, which is a limiting factor for proper growth and development of plants in salt-affected soil. Further, the subsurface drainage system decreases the soil reaction (pH), electrical conductivity and exchangeable sodium percentage under different lateral spacing in the drained field. The overall improvement in the soil physicochemical condition, increase in germination percentage, plant height, leaf length, leaf width and leaf area index of maize crop was observed, due to removal of a large amount of soluble salts, waterlogging free condition and increased nutrient availability in drained field, which favored the plant growth and development.

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