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Research Article

Performance of water table management system for alleviating sodic soil reclamation at Kumulur farm, Trichy District, Tamil Nadu

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Abstract
Waterlogging and sodicity is common problem in many irrigation canal command areas. The water table management system is the next level of improving water management in irrigated agriculture. In the present study, the water table management system was designed to work effectively in the monsoon season as a controlled drainage system and sub-irrigation system during summer. The field evaluation of drain water quality analysis was carried out from the water table management system installed at A-block of Eastern Farm, Agricultural Engineering College and Research Institute, Kumulur farm, Trichy, Tamil Nadu during 2015-2016. The experiment was laid out in a split plot design with three replications. Four levels of drain spacing of drain pipes (7.5, 10, 12.5 and 15m) were the main plot treatment and two levels of depth and diameter of drain pipes (75 cm, 60 cm & 75 mm, 63 mm) were the sub plot treatments. The results showed that the recommended quality of press mud 2 t ha^{-1} was a help to reduce the Exchangeable sodium percentage (ESP) level of 33 to 28 percent when compared to other ameliorants. It was concluded that solubilization should be removed by providing drainage and brought to ESP level of less than 16 percent and 15 m drain spacing to adapt to reduce the ESP level below the critical.

Keywords: Controlled drainage, Drainpipes, Exchangeable Sodium percentage, Pressmud, Sodicity, Subirrigation

INTRODUCTION

Waterlogging and sodicity is common problem in many irrigation canal command areas. Some of the districts in Tamil Nadu are frequently under the problem of waterlogging during heavy rainfall periods. At the time, the same areas are under the problem of water scarcity for a few months during canal non-supply periods. The CD & SI system, synonymously termed as Water Table Management System (WTMS), is mainly adapted in waterlogged areas. Controlled Drainage-Subirrigation (CD-SI) system operates like a conventional drainage system. During wet periods excess water is removed from the field through underground pipes. During times of water scarcity, the same system can furnish water to plants due to upward flux. (Bjonmeberg, 2013). Controlled drainage has been proposed, and is being held in the United States, as a beneficial management practice (BMP), focusing on the reduction of loads and the nutrient concentration in drainage ditches that feed into river networks due to reduction of total drainage outflows and promoting higher nutrient-use efficiency

(Wesstrom, 2006), increased N retention and NO_3-N attenuation. Other benefits accrue from using controlled drainage, e.g. improved water use efficiency (especially with sub-irrigation) and increased crop productivity. With these facts in mind, an attempt was made to study water table management system performance for alleviating sodic soil reclamation. Elmi et al. (2002) reported that water table management is thought to reduce N loads by enhancing denitrification with higher water tables and yielding lower outflow volumes. In another study, a controlled drainage subirrigation system effectively reduced total nitrate loss and improved yields of both processing tomatoes and grain corn on sandy loam soil (Tan et al. 2000). Controlled drainage has more potential for reducing drainage water quantity and improving drainage water quality. Overall, the use of controlled drainage increased crop yield by 0.11% and decreased drainage volume by 19.23%.while maintaining crop yield (Zhiyu Wang et al.2020). With these facts in mind, an attempt was made to conduct a study on water table management system performance for alleviating sodic soil reclamation at Kumulur farm, Trichy District, Tamil Nadu

MATERIALS AND METHODS

The experiment was laid out in A-block of Eastern farm, Agricultural Engineering College and Research Institute, Kumulur, Tamil Nadu. The project site had the problem of waterlogging due to seepage of water from the lake located adjoining the study area. The soil type of the experimental area is Sandy loam. The soil is sodic in nature with a pH of 9.1, electrical conductivity is 0.14 dS m^{-1} and Exchangeable Sodium Percentage is 28 per cent.

The quality of irrigation canal water with pH of 7.56 and electrical conductivity of 0.57dS $m^{-1}$was observed. The quality of irrigation water of the experimental field is presented in Table 1.

The experiment was laid out in split plot design with three replications. Four levels of drain spacing of drain pipes (7.5, 10, 12.5 & 15m) were the main plot treatment and two levels of depth and diameter of drain pipes (75 cm, 60 cm &75 mm, 63 mm) were the sub plot treatments. Treatments details are presented in Table 2. Cheap acidic industrial wastes pressmud may be available, which can be profitably used for sodic soil improvement. Pressmud contains gypsum depending on whether the Kothari sugar factory is adopting carbonation or a sulphatation process for the clarification of juice.

Drain water quality analysis

Drain water samples were collected manually. About five hundred milliliter drain water samples were taken in the experimental site during the crop period of paddy.

Table 1. Quality of Irrigation water

Quality of irrigation water	Value
pH	7.56
EC (dS m^{-1})	0.57
Bi-carbonate (HCO_3) (mg l^{-1})	110
Carbonate (CO_3) (mg l^{-1})	12
Chloride (Cl_2) (mg l^{-1})	35
Sodium (Na) (mg l^{-1})	37
Potassium (K) (mg l^{-1})	5
Sulfate (SO_4) (mg l^{-1})	106

The drain water samples flowed into 5 liter plastic container. Drain water sample analysis were done 60 and 120 days after transplanting (DAT). Drain water quality analysis made on controlled drainage under the following sections were:

i) Effect of water table management system on cation (sodium, potassium, calcium and magnesium) removal in drain water at various times of planting from the soil system and

ii) Effect of water table management system on anion (bicarbonate, chloride, carbonate, sulphate, nitrate and phosphate) removal in drain water at various time of planting from the soil system. The methodology of all cations and anions are presented in Table 2.

Ions concentration

It is the amount of solute lost in tile drainage divided by the total flow during the time period and it is expressed in mg l^{-1} or ppm

Flow weighted Ions concentration

Flow weighted ion concentration was calculated by multiplying the ion concentration in (mg l^{-1}) with the drainage effluent (mm) and dividing by 100 (unit conversion) for each interval of sampling

RESULTS AND DISCUSSION

Effect of drain spacing, drain depth and drain diameter on cation removal

Drainage structure efficiency

The highest drainage structure efficiency (38.00 per cent) was recorded in 15 m spacing + 75 cm drain depth + 75 mm drain diameter (S_4D_1), whereas the lowest value (29.71 per cent) was in 7.5 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_1D_4). Drainage structure efficiency in reducing the Exchangeable Sodium Percentage (ESP) level of sodic soil is presented in Table 3.

The result shows that the recommended quantity of pressmud was a help to reduce the ESP level of 33 to

Table 2. Methodology of drain water quality analysis

Drain water quality analysis	Methods	Reference
EC (ds m^{-1})	Conductometry	Jackson (1958)
pH	Potentiometry	Hesse (1971)
Nitrate (meq l^{-1})	UV spectrophotometric	Jackson (1958)
Total Phosphorous (meq l^{-1})	Digestion and ascorbic acid spectrophotometric	Jackson (1958)
Potassium (meq l^{-1})	Flame emission photometer method	Jackson (1958)
Calcium (meq l^{-1})	Versanate titration method	Jackson (1958)
Magnesium (meq l^{-1})	Bray's versanate method	Jackson (1958)
Sodium (meq l^{-1})	Flame emission photometric method	Jackson (1958)
Chloride (meq l^{-1})	Mohr's titration method	Jackson (1958)
Sulfate (meq l^{-1})	Nephelometry	Hart (1961)
Carbonate (meq l^{-1})	Titration method USDA handbook 60 (1954)	Piper (1966)
Bicarbonate (meq l^{-1})	Piper (1966) titration with 0.01 N H_2SO_4 by methyl orange indicator	Piper (1966)

Table 3. Treatment details.

Main plot treatments: (at 4 levels of drain spacing)	Subplot Treatments: (at 2 levels of drain depth and diameter)
S_1 = 7.5 m spacing	D_1= Depth at 75 cm + 75mm dia
S_2 = 10 m spacing	D_2 = Depth at 75 cm + 63mm dia
S_3 = 12.5 m spacing	D_3 = Depth at 60cm + 75 mm dia
S_4 = 15.0 m spacing	D_4 = Depth at 60cm + 63mm dia

28 per cent compared to other ameliorants. It suggested that the solubilize sodium should be removed by providing drainage and brought to ESP level of less than 16 per cent. Drainage structure efficiency in reducing the ESP level of sodic soil are presented in Table 4. The succession migration intensity of soil elements as sodium and potassium was as follows.

Sodium ion and flow weighted ion concentration

The highest sodium ion concentration (66.50 mg l^{-1}) was recorded in 15 m spacing + 75 cm drain depth + 75 mm drain diameter (S_4D_1) whereas lowest value (52.00 mg l^{-1}) in 7.5 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_1D_4). The interaction effects, i.e. when an interaction effect was present, the impact of one factor depended on the level of the other factor in ANOVA, were significant. A similar trend was observed during all days of observation at 60 DAT and 120 DAT.

The highest drainage coefficient (2.28 kg ha^{-1}) was recorded in 7.5 m spacing + 75 cm drain depth + 75 mm drain diameter (S_1D_1), whereas the lowest value (1.07 kg ha^{-1}) in 15 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_4D_4). Ion and flow weighted concentrations of sodium are presented in Fig. 1 and 2. Yukio et al. (2020) was found that the subsurface drainage could decrease accumulated sodium, removing 14 Mg ha^{-1} of sodium in net mass, down to approximately between one-third and one-fourth of the remaining sodium of the control field

Potassium ion and flow weighted ion concentration

The highest potassium ion concentration (5.50 mg l^{-1}) was recorded in 15 m drain spacing + 75 cm drain depth + 75 mm drain diameter (S_4D_1), whereas the lowest value (3.30 mg l^{-1}) was recorded in 7.5 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_1D_4).

Table 4. Drainage structure efficiency in reducing the ESP level of sodic soil

Treatment imposed	ESP status of experimental soil	Reduction in ESP
Green manure, press mud, farm yard manure and gypsum - Best treatment : pressmud	33 per cent	28 per cent
After Organic amendments (pressmud)	28 per cent	23 per cent
Pressmud + Drainage structure	23 per cent	15 per cent

The highest flow weighted potassium ion concentration (0.1394 kg ha^{-1}) was recorded in 7.5 m spacing + 75 cm drain depth + 75 mm drain diameter (S_1D_1), whereas lowest value (0.0918 kg ha^{-1}) in15 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_4D_4). Ion and flow weighted concentrations of potassium are presented in Fig. 3 and 4. Vigovskis et al. (2015) reported that paddy more influenced the content of phosphorous in drain water and agriculture practice, including the climatic condition of the year, than the used fertilizer rate. They also suggested that exchangeable potassium in soil has increased more than 4 times and significantly affected drain water content of potassium.

Bicarbonate ion and flow weighted ion concentration

The highest bicarbonate ion concentration (427 mg l^{-1}) was recorded in 15 m drain spacing + 75 cm drain depth + 75 mm drain diameter (S_4D_1) whereas lowest value (408 mg l^{-1}) in 7.5 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_1D_4).

The highest flow weighted bicarbonate ion concentration (16.87 kg ha^{-1}) was recorded in 7.5 m spacing + 75 cm drain depth + 75 mm drain diameter (S_1D_1), whereas the lowest value (7.59 kg ha^{-1}) in 15 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_4D_4). Ion and flow weighted concentrations of bicarbonate are presented in Fig. 5 and 6. Naeem Khan et al. (2019) reported that bicarbonate is a significant anion present in all surface and ground waters and it's normally ranging from 25 to 400 ppm. The high level of bicarbonates in groundwater has deep soil high in carbonaceous minerals.

Chloride Ion and flow weighted ion concentration

The highest chloride ion concentration (284 mg l^{-1}) was recorded in 15 m drain spacing + 75 cm drain depth + 75 mm drain diameter (S_4D_1), whereas the lowest value

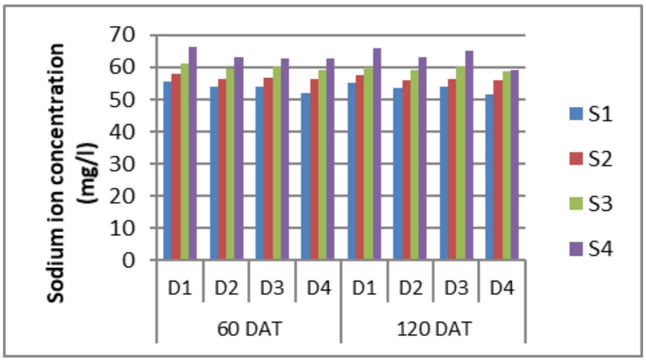

Fig. 1. *Sodium ion concentration*

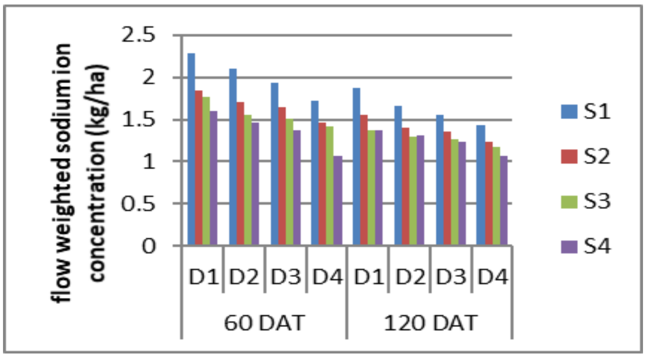

Fig. 2. *Flow weighted sodium ion concentration*

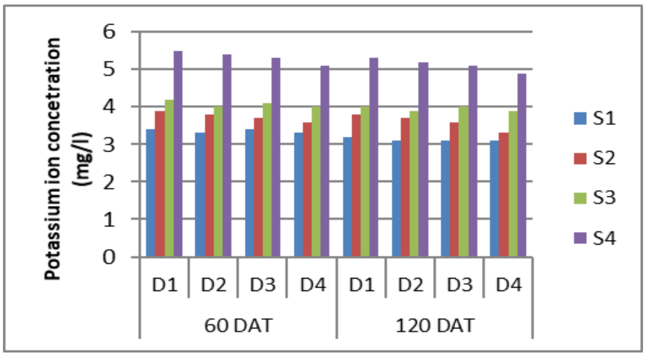

Fig. 3 *Potassium ion concentration*

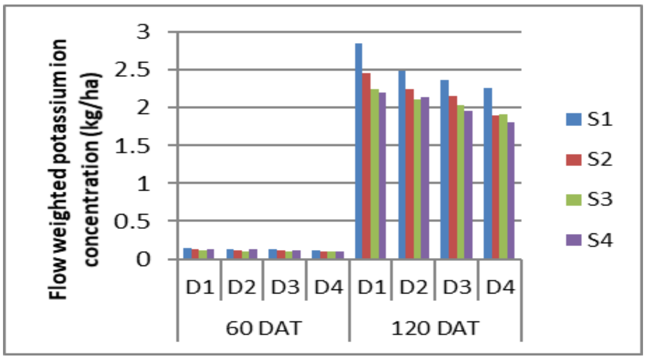

Fig. 4. *Flow weighted potassium ion concentration*

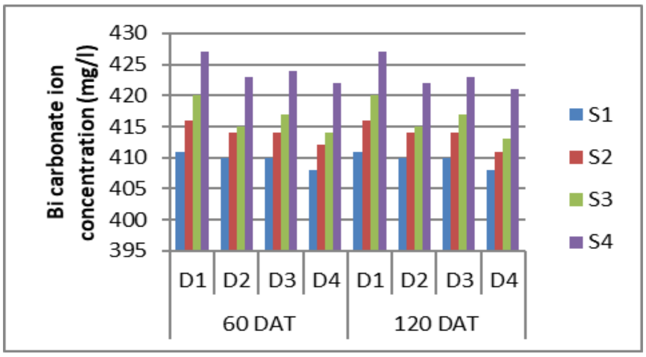

Fig. 5. *Bicarbonate ion concentration*

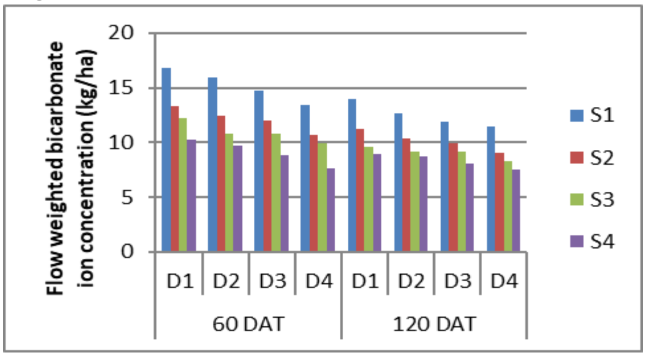

Fig. 6. *Flow weighted bicarbonate ion concentration*

(259 mg l^{-1}) was recorded in 7.5 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_1D_4).

The highest flow weighted chloride ion concentration (10.75 kg ha^{-1}) was recorded in 7.5 m spacing + 75 cm drain depth + 75 mm drain diameter (S_1D_1), whereas the lowest value (4.91 kg ha^{-1}) was recorded in 15 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_4D_4). Ion and flow weighted concentrations of chloride are presented in Fig 7 & 8. Verma and Ratan (2020) discussed that the chlorides are very common water pollutants. The contamination of chlorides in surface water may appear due to salty rocks and chlorides have mild effects on living organisms. Their excessive intake may cause some serious damage or poisoning to the living body. The recommended limit of chloride in water is <250 mg/L.

Nitrate ion and flow weighted ion concentration

The highest nitrate ion concentration (18.39 mg l^{-1}) was recorded in 15 m drain spacing + 75 cm drain depth + 75 mm drain diameter (S_4D_1) whereas lowest value (9.60 mg l^{-1}) in 7.5 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_1D_4).

The highest flow weighted nitrate ion concentration (0.459 kg ha^{-1}) was recorded in 7.5 m spacing + 75 cm drain depth + 75 mm drain diameter (S_1D_1) whereas lowest value (0.286 kg ha^{-1}) in 15 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_4D_4). The ion and flow weighted concentration of nitrate is presented in Fig 9 and 10. Similar results were found by Kladivko (2005), who reported that an approximate balance between increasing drainage intensity (narrower spacing) to improve drainage and decreasing drainage intensity to reduce Nitrate N losses need to be found in order for the surface water quality. Lu et al. (2016) reported that nitrate concentration in surface water was reduced effectively when proper subsurface drainage rate in the paddy field was maintained in the waterlogging condition at Nanjing Hydraulic Research Institute in China. The reasons for the decline in nitrate concentration included volatilization, nitrification, soil adsorption, crop absorption, and migration into the depth of the soil.

Phosphate ion and flow weighted ion concentration

Ion concentration

The highest phosphate ion concentration (0.65 mg l^{-1}) was recorded in 15 m drain spacing + 75 cm drain depth + 75 mm drain diameter (S_4D_1) whereas lowest value (0.21 mg l^{-1}) was recorded in 7.5 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_1D_4).

The highest flow weighted phosphate ion concentration (0.0168 kg ha^{-1}) was recorded in 7.5 m spacing + 75 cm drain depth + 75 mm drain diameter (S_1D_1), whereas lowest value (0.0079 kg ha^{-1}) was recorded in 15 m drain spacing + 60 cm drain depth + 63 mm drain diameter (S_4D_4). Ion and flow weighted concentrations of nitrate are presented in Fig. 15 and 16. Similar results were found by Culley *et al.* (1983), who reported that the dissolved and total P from tile positioned at 1.0 m

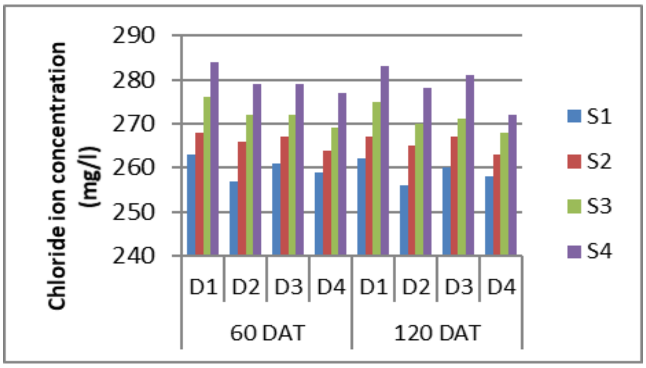

Fig. 7. *Chloride ion concentration*

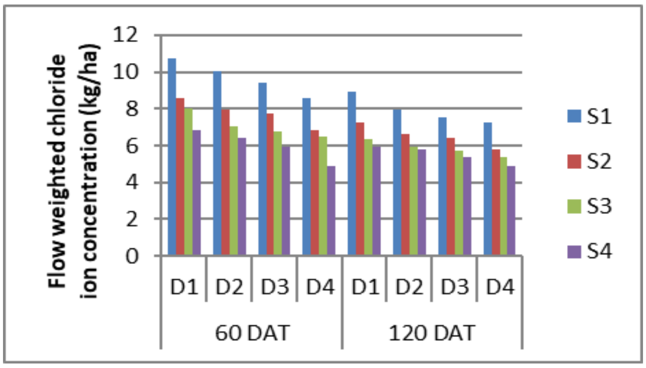

Fig. 8. *Flow weighted chloride ion concentration*

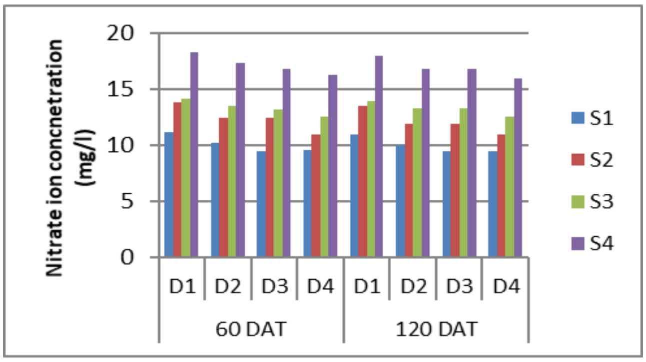

Fig. 9. *Nitrate ion concentration*

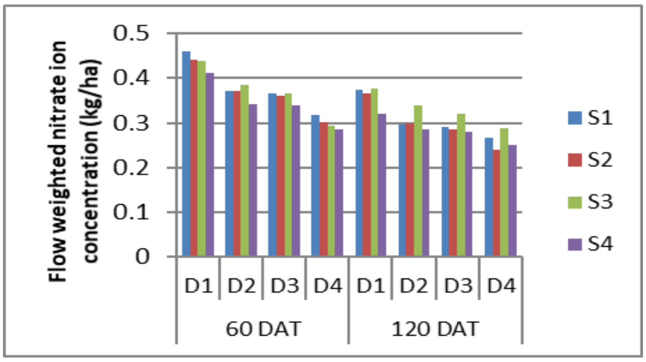

Fig. 10. *Flow weighted nitrate ion concentration*

depth showed approximately 50 per cent less concentration when compared to 0.6 in deep tile. Valero et al. (2007) reported that controlled drainage resulted in increased P loads in pipe drainage when compared with free-draining plots, most likely caused by an increase in phosphorous solubility due to the shallow water table. Of the total dissolved phosphorous (TDP) concentration, dissolved reactive phosphorus (DRP) represented 80 percent for the controlled drainage system compared with 67 percent for the free-draining system. P removal processes are predominantly biogeochemical. Phosphorus sorption to sediments is one of the main P removal mechanisms (Kroger et al. , 2011). Studies have shown that there can be significant losses of the dissolved reactive form TDP through pipe drainage controlled drainage systems compared with free-draining systems (Guo et al. 2011), caused by a reduction of Fe^{3+} to Fe^{2+} in the anoxic, waterlogged conditions, leading to increased P solubility. Bohlen and Villapando (2011) showed that the total Ps were lower in pastures with 'reduced flow', available soil P concentrations were higher, most likely attributable to anaerobic, flooded conditions that stimulate the release of phosphorous. Jia *et al.* (2019) reported that ditches and ponds have significant Pbuffering capacities and can act as sinks of P in the overlying water, as P sorption reactions in sediments are regarded as important mechanismsfor P removal.

Order of anions in mobilizing Na from the soil type

There was no significant difference in drain spacing + drain depth + drain diameter of ESP level. It may be recommended to utilize 7.5 m spacing and 15.0 m based on the pipe materials and installation cost. It was found that 15 m drain spacing was adapted to reduce the ESP level below the critical level. The recommended level of pressmud (2 t ha^{-1}) combined with the water table management system reduced the ESP level. Order of anions in mobilizing Na from soil type are HCO_3^- > Cl^-> $CO_3^=$> $SO_4^=$> $NO_3^=$> PO_4>$^=$ and it is depicted in Fig. 13. Withers et al. (2003) showed that fresh application of P might cause loss of dissolved and particulate of porous forms inland runoff when rainfall interacted directly with fertilizers and manures which were spread on the soil surface. The rate of phosphorous loss was temporarily and spatially varied variable < 1 to 25 per-cent of total P applied. Zhiyu et al. (2020) reported that the application of controlled drainage in clay loam soil would alleviate total P loss in outflow, which may contribute to a cost-saving for the farmer, except for surface drainage showing a 2.66% increase in total P loss.

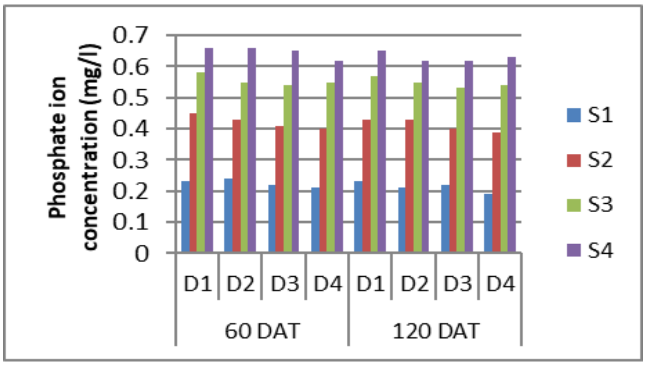

Fig. 11. *Phosphate ion concentration*

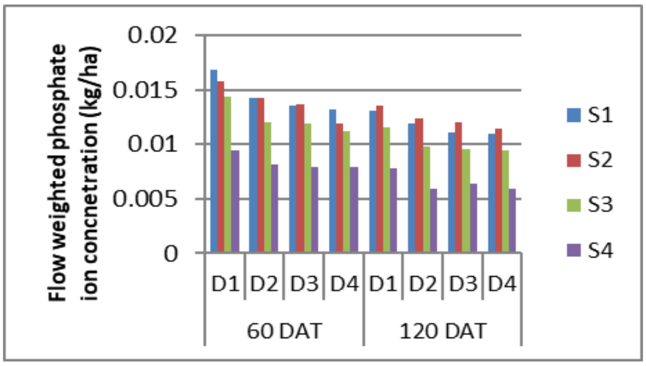

Fig. 12. *Flow weighted phosphate ion concentration*

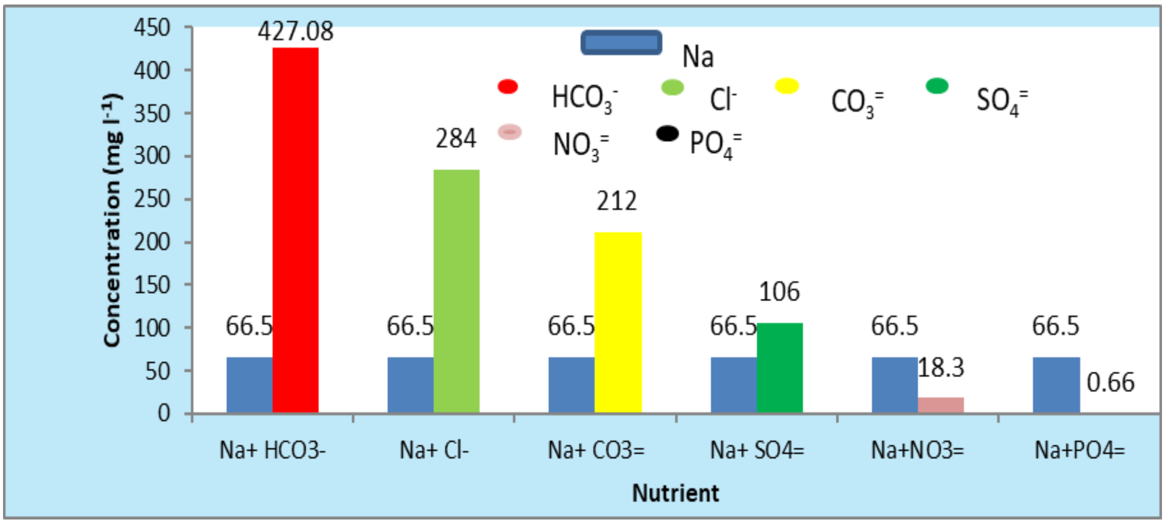

Fig. 13. *Order of anions in mobilizing Na from the soil type*

The implementation of controlled drainage offered some potential with the decline of nitrate loss, which was 18.9% lower in controlled drainage than in control.

Conclusion

The preliminary study conducted using different ameliorants (Gypsum and pressmud) to solubilize sodium showed that the recommended quantity of pressmud helped to reduce the ESP level of 33 to 28 per cent compared to gypsum. Hence, it was concluded that the solubilize sodium could be removed by providing drainage and brought to ESP level of less than 16 per cent. There was no significant difference in drain spacing + drain depth + drain diameter on ESP level. It is recommended to utilize 7.5 m spacing and 15.0 m based on the pipe materials and installation cost. The 15 m drain spacing should be adapted to reduce the ESP level below the critical level. The recommended level of pressmud was 2 t/ha, combined with a water table management system to reduce the ESP level. Implementing a controlled drainage cum sub-irrigation system works effectively in drainage and the sub-irrigation mode and fulfils both the needs. Controlled drainage operated as a traditional drainage system during wet periods removed excess water from the field through a system of underground drain tubes. The same procedure can furnish water to plants through sub-irrigation. Under sub-irrigation mode, the upward flux and the discharge rate must satisfy the plant's lifesaving irrigation needs during summer.

Conflict of interest

The authors declare that they have no conflict of interest.

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