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Enhancing Coastal Saline Soil Productivity: Innovative Irrigation and Mulch Strategies for Improved Chili Cultivation

Rahul Adhikary[1*], Dwity Sundar Rout[2], Avisweta Nandy[3], Basanta Kumar Samal[4]

[1]*Department of Soil Science, M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha, India-761211*
[2]*Department of Agricultural Extension Education, M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha, India-761211*
[3]*Department of Agricultural Economics, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India*
[4]*Department of Nematology, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India*

**Corresponding author's E-mail: rahul.adhikary@cutm.ac.in*

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Abstract

Coastal saline soils in the West Bengal region present intricate challenges to agricultural productivity, primarily stemming from the limited availability of high-quality irrigation water. To address this issue, potential solutions encompass the utilization of saline water through appropriate irrigation techniques and schedules. This study investigates the synergistic effects of combining saline and fresh water via tillage practices and the selection of salt-resistant crop varieties. The experiment comprises eight treatment combinations, each replicated four times, involving the application of both saline and fresh water using 10-liter capacity pitchers placed strategically between four plants. Additionally, two distinct tillage methods, conventional and mulch, are employed. The chosen crop variety for experimentation is Bullet lanka-3 variety. The results underscore substantial enhancements in both soil physicochemical properties when implementing diverse pitcher irrigation methods alongside varying tillage strategies. These improvements contribute to ameliorated soil conditions and heightened nutrient accessibility, consequently fostering crop growth and yield. Noteworthy gains are observed in chili production, with yields ranging from 4.04 t ha^{-1} to 8.81t ha^{-1} across the initial seven harvesting intervals, in comparison to the control plot. This research sheds light on innovative techniques to mitigate the challenges posed by coastal saline soils, paving the way for improved agricultural sustainability and productivity.

Keywords: *Pitcher irrigation, chili, saline water, soil properties*

1. Introduction

Coastal regions, characterized by their unique ecosystems and climatic conditions, have long played a pivotal role in global agricultural productivity. However, the persistent challenge of saline soils in these areas has posed significant obstacles for both farmers and researchers. In the Indian state of West Bengal, the proximity to the Bay of Bengal has led to the prevalence of extensive saline soil areas (Bhowmick et al., 2020). Salinity stress not only diminishes soil fertility but also impedes crop growth, resulting in reduced yields and economic instability (Hailu and Mehari, 2021). Amidst these challenges, the cultivation of chili (*Capsicum annuum* L.) emerges as a particularly important endeavor due to its economic significance, culinary value, and its ability to thrive in diverse conditions.

Given the urgency of addressing these issues, this research endeavors to comprehensively investigate methods to enhance coastal saline soil productivity in West Bengal, with a specific focus on innovative irrigation and tillage strategies to improve chili cultivation. With the global population steadily increasing, ensuring food security and promoting sustainable agricultural practices is of paramount importance. Thus, developing methodologies that facilitate efficient crop production in challenging environments like saline soils becomes a critical area of exploration.

The pitcher water system, believed to have originated in Northern Africa and Iran (Soomro et al., 2018; Stein, 1997), has been utilized for irrigation purposes. This technique has been reported to have been employed in watering watermelons in India and Pakistan, horticultural crops in Brazil, Germany, and Indonesia as well as corn, chili, and okra in Zimbabwe (Adhikary et al., 2022). Chili (*Capsicum annuum* L.) holds a prominent position among the most widely consumed vegetables in India, with an estimated annual production of approximately 17.64 lakh tons (Olatunji and Afolayan, 2018; Singh et al., 2010). Incorporating the pitcher pot irrigation method, a combination of traditional wisdom and modern innovation, holds the potential to revolutionize water management in coastal saline areas. This method not only conserves water but also minimizes soil salinity, addressing two significant challenges in agricultural sustainability (Jena et al., 2023). Particular note are the nutritional benefits associated with chili consumption. Rich in vitamins, minerals, and bioactive compounds, chilies contribute to a balanced diet and have been linked to potential health advantages (Hernandez et al., 2020). The fruits also contain various antioxidant compounds, including phenolic compounds, metabolites, and phytochemicals, renowned for their positive impact on human health. Incorporating chili cultivation within the framework of innovative agricultural strategies not only addresses food security concerns but also promotes nutritional well-being on a broader scale (Materska and Perucka, 2005).

The implications of this research transcend immediate economic gains. As the specter of climate change looms, coastal regions are becoming increasingly vulnerable to rising sea levels and heightened salinization. Consequently, the findings of this study hold the potential to serve as a model for addressing similar challenges in coastal areas worldwide, safeguarding the sustainability of agricultural systems amidst evolving environmental dynamics.

In subsequent sections, we delve into the methodologies deployed, the outcomes achieved, and the tangible implications of the proposed innovative irrigation and tillage strategies. In doing so, we contribute to the ever-expanding knowledge base dedicated to enhancing agricultural resilience and propelling the boundaries of sustainable crop production in saline-affected regions.

2. Materials And Methods

The experiment was conducted during the rabi seasons of 2018-19 and 2019-20 within the agricultural fields of Simabandh village, situated in Kakdwip, South 24 Parganas, under the Coastal Saline Zone of West Bengal, India. The geographic coordinates of the area are approximately 21°05'8" N latitude and 88°11' E longitude, with an elevation of 1.21 meters above mean sea level. The experimental study took place during the summer season. The chosen location serves as a representative example of coastal saline soil, characterized by a substantial presence of salinity in the field. These soils exhibit elevated electrical conductivity due to their salt content. Originating in the alluvial deposits of the deltaic plain of the Ganges River, these soils possess a gentle slope of 1-2%. They are deep and imperfectly drained, displaying a whitish sandy clay loam texture. The A horizon is gray and mildly alkaline, while the B horizon shows distinct mottling. In terms of soil characteristics, the electrical conductivity in a 1:2.5 water extract ranges from 2.0 to 4.40 dS m^{-1}, and the pH level measures 7.53. Initial soil properties recorded are as follows: organic carbon content at 0.58%, available nitrogen at 148 kg ha^{-1}, available phosphorus at 22.63 kg ha-^{1}, and available potassium at 120 kg ha-^{1}.

The experiment was conducted with the factorial RBD growing of chili (*Capsicum annum*. L) variety Bullet lanka-3 during the summer seasons, citing years of experimentation. The treatments were:

T_1 = Sweet water + Conventional tillage
T_2= Sweet water + Mulch tillage
T_3= Sweet water (25%) + saline water (75%) + Conventional tillage
T_4= Sweet water (25%) + saline water (75%) + Mulch tillage
T_5= Sweet water (50%) + saline water (50%) + Conventional tillage
T_6= Sweet water (50%) + saline water (50%) + Mulch tillage
T_7= Sweet water (75%) + saline water (25%) + Conventional tillage
T_8= Sweet water (75%) + saline water (25%) + Mulch tillage

Traditional tillage refers to a method of preparing the seedbed and managing weeds through cultivation in agriculture. Conservation agriculture commonly employs mulch tillage, a practice where crop residues are retained on the surface, and subsurface tillage is performed with minimal disruption to these residues. A diverse range of cultivator implements are utilized for mulch tillage operations. The experimental setup featured plot dimensions of 5 x 3 square meters, utilizing a split plot design with four replications. Water-filled pitchers were employed on a weekly basis, and manual observations were made on randomly selected plants. Soil moisture readings, spanning a depth of 0-15 cm, were taken at seven-day intervals, encompassing the period from seeding to harvesting for each individual plot.

Laboratory analysis:

The pH and Electrical conductivity (EC) of soil samples were assessed using 1:2.5 soil water suspensions, employing a glass electrode pH meter in accordance with the methodology outlined by Jackson (1973). Organic carbon (OC) content was determined using the rapid titration method prescribed by Walkley and Black method (Walkley and Black, 1934). Available nitrogen (N) content was measured using the alkaline permanganate method (Subbiah and Asija, 1956), while available phosphorus content was determined as per the soil with 0.5M $NaHCO_3$ (Olsen and Sommer, 1982). Available potassium content was extracted using 1 N ammonium acetate at pH 7, following the protocol established by Jackson (1973). The soil data was collected and subsequently analyzed within a laboratory setting. Data generated from this investigation were subjected to statistical analysis, utilizing the methodology proposed by Gomez and Gomez (1984).

3. Results and Discussion

Yield and Yield Attributes

Table 1 presents the recorded data and subsequent analysis concerning yield-related attributes of chili. Among the various treatments, treatment T_8 exhibited the highest number of fruits per plant (326), a result that was on par with the findings from treatment T_7. Treatment T_8 also demonstrated the maximum fruit weight (2.73g). The fruit yield data was notably affected by different treatments involving salt and sweet water. The combination of blending saline and sweet water in pitcher pots for pitcher irrigation, in conjunction with various types of tillage, led to a considerable increase in chili yield and its associated attributes compared to treatment T_3. Specifically, treatment T_8 emerged as the most effective in enhancing parameters such as the number of fruits per plant, fruit length, fruit diameter, fruit weight, and overall chili yield when compared to the other treatments.

Bulk density, porosity and water holding capacity

The outcomes concerning alterations in various physical soil properties resulting from the implementation of a combination of blended saline and sweet water in pitcher pots for pitcher irrigation, along with different tillage methods, are outlined in (figure 1). Across each pitcher irrigation treatment, the values of bulk density demonstrated a decrease in comparison to the control (T_3). The sequence of bulk density changes followed this order: (T_2) > (T_8) > (T_1) > (T_7) > (T_6) > (T_5) > (T_4) > (T_3). This decline in bulk density throughout the year suggests potential improvements in subsequent years due to the application of varied tillage methods combined with the use of blended saline and sweet water in pitcher irrigation. The reduction in bulk density can likely be attributed to higher levels of organic carbon content in the soil.

Soil pH, EC and Organic carbon

The analyzed data evaluated over a span of two years, a distinct pattern emerges in the soil's chemical properties, specifically its pH and Electrical Conductivity (EC). These properties exhibit significant fluctuations as a direct result of introducing a blend of saline and sweet water into pitcher pots for irrigation, coupled with the utilization of various tillage methods. Across each treatment involving pitcher irrigation and specific tillage, the recorded pH and EC values consistently demonstrate a decrease compared to the control plot (T_3). Notably, the combination of sweet water and mulch tillage (T_2) (7.77 and 2.10 dsm^{-1}) yields the lowest values. Furthermore, the data reveals a subtle downward trend in subsequent years, attributed to the varied tillage practices employed. The decline in EC values implies a concurrent reduction in soil salt concentration. This observation aligns with a study conducted by Bhingardeve et al. (2006), which explored the effects of saline and sweet water, along with differing levels of fertilizer through drip irrigation, on soil pH and EC during distinct growth stages of chili. Shifting the focus to organic carbon content within the soil, marked fluctuations are evident in response to the pitcher irrigation method and diverse tillage approaches. The dataset also demonstrates variations stemming from treatment application within each year. Particularly noteworthy is the superior performance of organic carbon content in the second year across all treatments (figure1), with the most noteworthy organic carbon content observed in plots subjected to (T_2). These findings resonate with outcomes presented in the studies conducted by (Himabindul et al.,2019; Adhikary et al.,2020).

Available soil nutrients

The results concerning the impact of diverse tillage methods on pitcher irrigation and its effects on the availability of nitrogen, phosphorus, and potassium post-harvest, recorded annually, are depicted in Figure 2. Nitrogen, phosphorus, and potassium availability were notably higher in soils treated with T_3 than in other treatments. The highest availability of these nutrients was observed in T_8. Across the various types of pitcher irrigation, available nitrogen exhibited a consistent increase when compared to the control (T_3). This observation aligns with the findings reported by (Yihenew et al., 2015; Pal et al., 2020).

The enhancement of phosphorus content in soils, relative to the control (T_3), due to each treatment, were as follows: 18.19 kg ha^{-1}, 17.09 kg ha-^{1}, 16.66 kg ha^{-1}, 14.49 kg ha-^{1}, 13.80 kg ha-1, 12.58 kg ha-^{1}, and 11.19 kg ha-1 for T_8, T_7, T_2, T_6, T_5, T_1, and T_4, respectively. The available potassium ranged between 153-288 kg ha-1. Regarding potassium availability, over the control (T_3), the values were 134.34 kg ha^{-1}, 132.88 kg ha^{-1}, 128.89 kg ha^{-1}, 117.48 kg ha^{-1}, 112.38 kg ha^{-1}, 101.13 kg ha^{-1}, and 98.03 kg ha^{-1} for (T_8), (T_7), (T_2), (T_1), (T_6), (T_5), and (T_4) respectively. The data consistently demonstrates that the application of various types of pitcher irrigation, combined with different tillage methods, significantly elevates the availability of nitrogen, phosphorus, and potassium when compared to the control (T_3).

The observed variations in chili yields and attributes due to the application of different irrigation water types and tillage methods can be attributed to favorable alterations in soil conditions, particularly the reduction in soil salinity, which subsequently enhanced nutrient availability within the soil. A similar observation was reported by Tesfaye et al. (2011). According to Setiawan et al. (1998), the pitcher irrigation system employs a bottle-like emitter composed of baked clay, sand, and ash. This emitter maintains a consistent water level within the pitcher and gradually permeates the pitcher wall, thereby providing moisture to crops in the surrounding soil. This irrigation system has demonstrated successful application in cultivating horticultural products, including chili, within field conditions. (Kumari et al., 2009) highlighted that the implementation of varying levels of drip irrigation and mulches significantly augmented the growth, yield, and water use efficiency of chili in comparison to control conditions. This observation aligns with the findings of Hangarge et al. (2002) and Adhikary et al. (2022), which indicated that the incorporation of organic wastes and manures, such as FYM, resulted in lowered bulk density, corroborating the results of this study. Conversely, the porosity results exhibited an opposite trend to bulk density, displaying an increase due to the application of each treatment in comparison to the control. The highest values were consistently observed in (T_2) for chili, annually (Figure 1). This rise in porosity is likely attributed to the higher organic carbon content in the soil, leading to reduced bulk density, increased available space, and enhanced soil aggregation. These fluctuations in porosity findings mirror the observations made by Choudhury et al., (1985) and Orji and Eke, (2018). The water holding capacity of the soil also exhibited significant variation with the implementation of the blended saline and sweet water in pitcher irrigation, coupled with different tillage methods, across both years. The data indicated a tendency toward slight increases in subsequent years due to the utilization of diverse tillage methods. The heightened water holding capacity can be attributed to the increased organic carbon content within the soil. This aligns with the conclusions drawn from investigations conducted by Bhattacharya et al. (2004), which suggested that the application of organic manures contributed to enhanced water holding capacity in comparison to control conditions.

The decline in EC values implies a concurrent reduction in soil salt concentration. This observation aligns with a study conducted by Bhingardeve et al. (2006), which explored the effects of saline and sweet water, along with differing levels of fertilizer through drip irrigation, on soil pH and EC during distinct growth stages of chili.

The available nitrogen significantly increased with the application of each of the different types of pitcher irrigation over control (T_3). Availability of N and P found more in the soils received 75% sweet water + 25% saline water with mulch tillage treatment (T_8), than the application other treatments. The availability of K was maximum in the soils under 75% sweet water+ 25%saline water treatment than others. Changes in the availability of N and P due to application of treatments found more effective than the availability of K. The results corroborate with the findings of Sharma and Bali (2017) and Rao et al. (2020).

4. Conclusion

The findings from this study strongly indicate that the utilization of blended saline and sweet water in pitcher irrigation, combined with diverse tillage methods, leads to notable enhancements in the growth and yield of chili crops during the rabi season. This approach also contributes to the amelioration of soil's physical properties, particularly a reduction in bulk density, and it effectively boosts the water use efficiency of the cultivated crop. Moreover, each treatment employed in the study demonstrates the capacity to decrease electrical conductivity while simultaneously increasing soil organic carbon content, consequently enhancing soil fertility. Among the various combinations of saline and sweet water applied through pitcher irrigation and various tillage methods investigated in this study, the cultivation of chili with a blend of 25% saline water and 75% sweet water, coupled with mulch tillage (T_8), emerges as the most promising strategy for addressing salinity constraints and enhancing soil's physical and chemical properties, thus facilitating chili production in the specific context of coastal saline soil areas.

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