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# Assessment of Brackish Water Usability for Irrigating the Coastal Sugarcane Fields under the Background of Saline Intrusion

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## ABSTRACT

**Background:** Globally, irrigation water deficit (IWD) due to saline intrusion and decreased rainfed continues to affect coastal cultivation regions (CCRs). Coastal lowland regions have increasingly frequent saline intrusion, resulting in the IWD as a part of climate variability. Cu Lao Dung Isle, a terrain-low coastal plain in Vietanm is facing revenue loss due to adverse cultivation conditions in recent years.

**Methods:** The objective of this study was, therefore, to assess the effectiveness of the mixture of brackish and freshwater (MBF) for irrigating the spring crop sugarcane in the 2019/20 season grown in a household farming in Cu Lao Dung Isle. An experiment was exploded with the MBF varying from 1.5 to 5.0 dS $m^{-1}$ corresponding to 100 and 120% of the crop evapotranspiration (ETc). Determination of daily ETc was conducted simulating the FAO-Penman Monteith model based on the weather data obtained using an automatic weather station, locating in the study area.

**Result:** Based on the findings, the MBF at 3.0 dS $m^{-1}$ levels corresponding to 120% of ETc was stated to be suitable for normal growth of sugarcane Khonkaen III variety. The results showed that the MBF of increasing levels varying from 3.5 to 5.0 dS $m^{-1}$ significant influenced the growth process and yield of sugarcane. In general, the utilization of brackish water for irrigating in the CCRs is a suitable solution for economic efficiency.

**Key words:** Brackish, Climate variability, Mixture, Revenue reduction, Saline instruction.

## INTRODUCTION

Globally, coastal cultivation regions (CCRs) have been facing challenges from saline intrusion due to rising sea levels as a consequence of global warming, resulting in the irrigation water deficit (IWD) (Dang *et al.,* 2021; Silva *et al.,* 2019). Global warming contributes to increasing the frequency and intensity of extreme disaster events and has significantly affected all aspects of people's lives, especially agricultural production in coastal lowland regions (Pipitpukdee *et al.*, 2020). In addition, the unfavourable weather due to the impacts of climate variability (ICV) such as temperature and evapotranspiration increase trend while the rainfed trend to decrease have contributed to exacerbating disadvantages in farming practices (Dwivedi and Shrivastava, 2022). According to Everingham *et al.* (2015), the ICV on sugarcane production would be from the increase in rising sea level due to a significant proportion of sugarcane being grown along with CCRs. It is, therefore, a large increase in sea level would enhance these areas difficult to farm (Singels *et al.*, 2013). Rising sea levels are seemly increasing the IWD problems and therefore, saline intrusion in the CCRs will also be exacerbated (Baez-Gonzalez *et al.*, 2018).

In the context that freshwater for irrigation is increasingly scarce, seeking remedial solutions have recently been received the attention of scholars around the world (Chandiposha, 2013; Xue and Ren, 2017; Sudrajad *et al.*, 2022). The remedial solutions have proposed recently include growing drought-tolerant varieties and improving irrigation efficiency using brackish water (Everingham *et al.*, 2015; Olivier and Singels, 2015). In recent years, the MBF for irrigating in agriculture, especially the CCRs has become one of the encouraging solutions to alleviate the IWD (Al-Dalain, 2020; Khandakar *et al.*, 2018). As one of the abundant water resources, brackish water has become an important irrigation source in various coastal regions of the world (Anízio *et al.*, 2020). The utilization of brackish water resources is, therefore, considered an important solution to alleviate the shortage of freshwater (Anízio *et al.*, 2020; Lira *et al.*, 2018). Currently, there are three main approaches to utilizing brackish water for irrigating include all brackish water irrigation, the MBF and alternating fresh-brackish water irrigation (de Carvalho *et al.*, 2015; Wang *et al.*, 2019).

As a recognition of the importance of using brackish water for irrigation in the CCRs where freshwater is becoming scarce (Knox *et al.*, 2010; Vu *et al.*, 2018), scholars have explored the studies regarding the utilization of brackish water for agricultural irrigation (Farid *et al.*, 2017; Rahman *et al.* 2015). For example, Anízio *et al.* (2020) studied the

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relationship between biochemical indicators and the yield of sugarcane RB 92579 variety in Recife, Brazil. A study on the MBF to irrigate sugarcane was explored at the Lysimetric Station of Irrigated Agriculture by Lira *et al.* (2018). Wang *et al.* (2019) conducted a study on the MBF for irrigating winter wheat in the Yellow River Delta, China. Farid *et al.* (2017) conducted an experiment to determine the effects of the MBF on the growth of sorghum crops.

As a crucial crop, sugarcane is commonly grown in Cu Lao Dung Isle with a total area approximately of 6500 hectares (Lee and Dang, 2019) based on suitable environmental conditions as high temperature, abundant rainfed and solar radiation to bring income to local growers and ethnic minorities (Dang *et al.*, 2021). However, global warming has strongly affected sugarcane cultivation households across the area by rising saline intrusion and decreasing rainfed, leading to the IWD in recent years (Vu *et al.*, 2018). For instance, in 2016, sugarcane growers in the Cu Lao Dung Isle have lost their income due to a severe drought and saline intrusion damaged more than 30% of the sugarcane area (RCSA, 2016). Recently, in 2019 the drought and saline intrusion continued to record across the area. The IWD caused nearly 100 ha of damaged sugarcane (Dang *et al.*, 2021). According to sugarcane growers, great variation in sugarcane yields exists in the area with rising sea level, leading to saline intrusion, decrease rainfed and drought, resulting in the IWD (Lee and Dang, 2019). In the context of water scarcity, it is necessary to seek adaption solutions, to limit the effects caused by lack of water for irrigation on the sugarcane crops. This study is, therefore, to assess the utilization of the MBF to irrigate sugarcane fields across the study area as an adapted solution to adverse ICV.

## MATERIALS AND METHODS

### Study area

The experiment was conducted at a household farming, located in Cu Lao Dung Island, Vietnam (Fig 1). Weather across the study area is characterized by tropical monsoon climate with an average monthly temperature was 26.8°C, average daily sunshine of around 6.6 hours and total annual rainfall of up to 1900 mm and 95% of rainfall mostly occurred from May to November (Dang *et al.*, 2021). During the growing season of sugarcane across the study area, the average monthly rainfall is approximately 160 mm and other characteristics of weather are illustrated in Fig 2.

### Weather data

The reference evapotranspiration (ETo) is calculated using the Penman–Monteith method. Specifically, ETo is defined by Eq. (1).

$$ETo = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T + 273}\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \quad ......(1)$$

Where

$R_n$ is the net radiation at the soil surface (MJ $m^{-2}$ $day^{-1}$); G is soil heat flux density (MJ $m^{-2}day^{-1}$); T is mean daily air temperature (°C); $u_2$ is wind speed at 2.0 m height (m $s^{-1}$); $e_s$ is the saturation vaporpressure (kPa); $e_a$ is actual vapor pressure (kPa); Δ is the slope of the vapor pressure curve (kPa °$C^{-1}$); c is psychrometric constant (kPa °$C^{-1}$).

ETo was simulated based on the daily weather data, which obtanied from an automatic weather station, closing to the experimental farm.

While the irrigation water demand (IWD) for sugarcance crop is difined using the Eq.(2). In the AquaCrop model, the crop evapotranspiration (ETc) is caculated based on the product between ETo and the crop coefficient (Kc) for hydrological week (10-day) and is presented by Eq.(2).

$$ETc = ETo * Kc \quad .......(2)$$

Where

$K_C$ in the (2) equation is defined based on each growth stage of sugarcane crop.

### Soil data and fertilizer rates

Soil samples were randomly colected in the experimental field at depth varying from 0 to 60 cm and were divided into three layers based on an international soil texture classification software (Oyeogbe and Oluwasemire, 2013). Specifically, at 0-20 cm layer from surface, coarse sand = 214 g $kg^{-1}$, fine sand = 397 g $kg^{-1}$, silt = 249.2 g $kg^{-1}$, clay = 139.8 g $kg^{-1}$, bulk density = 1.37 g $cm^{-3}$, field capacity = 22.8%, porosity = 47.56%, particle density = 2630 kg $m^{-3}$ and textural class is sandy loam (Table 1). At 20-40 and 40-60 cm from surface, the same physical properties are described in Table 1.

Following local cultivation practices, farmers used 10-20 tons per hectare of manure fertilizers including manure, sludge and ash to fertilize sugarcane in the stage of land preparation. In addition, fertilization rates with N, P and K were provided 250, 100 and 200 kg $ha^{-1}$ of N, $P_2O_5$ and $K_2O$, respectively. Specifically, 10 days before sowing, basal fertilization was manually conducted using 800 kg $ha^{-1}$ of CaO and 1000 kg $ha^{-1}$ of manure. At 30 days after sowing (DAS), first top-dressing fertilization was performed using 80, 30 and 60 kg $ha^{-1}$ of N, $P_2O_5$ and $K_2O$, respectively and at 60 DAS, a second top-dressing was performed with 80, 30 and 60 kg $ha^{-1}$ of N, $P_2O_5$ and $K_2O$, respectively. Finally, a third top-dressing was deployed on the 120$^{th}$ DAS with a ratio of N, $P_2O_5$ and $K_2O$ include 90, 40 and 80 kg $ha^{-1}$, respectively (Table 2).

### Crop cultivation data

At the experimental farm, a sugarcane Khonkaen III variety was sown as the test crop with a depth of 25 cm from the soil surface (Fig 3A). Sugarcane growing season is around 15 to 30 January and is harvested varying from 10 to 30 October. That is, Khonkaen III variety, which is known high sugar level, reaching from 13-15 CCS and the average yield is up to 120 tons $ha^{-1}$ (Kamwilaisak *et al.*, 2021). In addition, sugarcane cuttings can pullulate up to 7 tillers/bush and the average stem diameter can reach 2.74 cm (Kamwilaisak *et al.*, 2021). The sugarcane cuttings were randomly sown in eight rows at a distance of 75 cm row spacing and 30 cm between cuttings, as illustrated in Fig.3B. Treatments consisted of the MBF of eight levels: FS1 = 1.5; FS2 = 2.0; FS3 = 2.5; FS4 = 3.5; FS5 = 4.0; FS6 =4.5; FS7 = 5.0 and FS8 = 6.5 dS $m^{-1}$, respectively corresponding to 100% and 120% of ETc during the growth period of sugarcane (Fig 3C). The experimental farm was randomly designed, in a scheme of 8 rows x 2 plots with a drip irrigation system so that the amount of irrigation water is equivalent to 100% of ETc for the first plot and 120% of ETc for the second plot (Fig 3B).

## RESULTS AND DISCUSSION

### Relationship between stem diameter and mixed brackish water levels

The experimental results show that there was a close link between the stem diameter, sugarcane yield and the MBF levels. The analysis of the relationship for these factors of the stem diameter, sugarcane yield was presented in Table 3.

The treatments of the MDF levels corresponding to 100% and 120% of ETc, in general, there was no significant difference in stem diameter. Specifically, the stem diameter of MDF4 was 2.67 and 2.70 cm, respectively corresponding to 100% and 120% ETc slightly lower than that of MDF1, MDF2 and MDF3 while the salt concentration of MDF4 was higher than that of MDF1, MDF2 and MDF3 (Table 3). Specifically, the stem diameter of the MDF1, MDF2 and MDF3 treatments were overtopped by 0.75%, 0.37% and 0.19%, respectively, for irrigation depth 100% ETc and by 1.11%, 1.48% and 0.16%, respectively, for irrigation depth 120% ETc compared with the MDF4 treatment (Table 3; Fig 4). However, for MDF levels higher than 3.0 dS $m^{-1}$, the decrease in stem diameter were 4.12, 6.74, 8.24 and 10.86 for irrigation depth of 100% ETc and 3.37, 5.24, 6.74 and 8.24 for irrigation depth of 120% ETc compared with the MDF4 treatment.

Generally, there was no significant difference in stem diameter among irrigation treatments as well as different irrigation depths across the study area. In a study on the effect of brackish water on the growth stages of sugarcane, Souto Filho (2013) stated that the effect of brackish water on stem diameter of sugarcane, SP813250 and RB 92579 varieties was not affected.

### Relationship between sugarcane yield and mixed brackish water levels

For sugarcane yield, sugarcane irrigated with an MDF level of 3.0 dS $m^{-1}$ corresponding to 120% ETc, showed a

**Table 1:** Soil physical properties across the experimental farm.

| Soil depth (cm) | Bulk density (g $cm^{-3}$) | Field capacity (%) | Porosity (%) | Silt (%) | Sand (%) | Clay (%) | Texture class |
|---|---|---|---|---|---|---|---|
| 0-20 | 1.37 | 22.8 | 47.56 | 24.89 | 61.17 | 13.94 | Sandy loam |
| 20-40 | 1.45 | 23.5 | 45.92 | 26.15 | 59.38 | 14.47 | Sandy loam |
| 40-60 | 1.38 | 25.1 | 46.27 | 19.87 | 60.37 | 19.76 | Sandy loam |

**Table 2:** Fertilization rates provided for growth stages of sugarcane.

| DAS | N (kg $ha^{-1}$) | $P_2O_5$ (kg $ha^{-1}$) | $K_2O$ (kg $ha^{-1}$) | CaO (kg $ha^{-1}$) | Manure (kg $ha^{-1}$) |
|---|---|---|---|---|---|
| -10 | - | - | - | 800 | 1000 |
| 30 | 80 | 30 | 60 | - | - |
| 60 | 80 | 30 | 60 | - | - |
| 120 | 90 | 40 | 80 | - | - |

DAS = Day after sowning; N = Nitrogen fertilizer; $P_2O_5$ = Phosphate fertilizer; $K_2O$ = Potassium fertilizer; CaO = Quicklime.

**Table 3:** Stem diameter and yield of sugarcane observed corresponding to the mixed brackish and freshwater levels under different irrigation depths.

| Location | Irrigation depths | Mixed brackish and freshwater levels (dS $m^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | % ETc | MBF1 | MBF2 | MBF3 | MBF4 | MBF5 | MBF6 | MBF7 | MBF8 |
| **Stem diameter of sugarcane (cm)** | | | | | | | | | |
| Zone I | 100 | 2.69A | 2.68B | 2.67A | 2.67A | 2.56A | 2.49B | 2.45A | 2.38A |
| Zone 2 | 120 | 2.73B | 2.74A | 2.73B | 2.70A | 2.58B | 2.53B | 2.49B | 2.45A |
| **Sugarcane yield observed (Mg $ha^{-1}$)** | | | | | | | | | |
| Zone I | 100 | 100.9B | 98.4A | 96.9A | 93.7A | 88.5A | 83.9A | 79.3A | 76.1A |
| Zone 2 | 120 | 116.6A | 115.9B | 113.8A | 112.4B | 107.9A | 101.8B | 96.2A | 89.7B |

Noted: Uppercase letters in the columns and in the rows within each variable are not significantly different according to Student's t-test ($p \leq 0.05$).

significantly high yield in comparison to the treatments of the MDF levels varying from 3.5 to 5.0 dS $m^{-1}$. Corporeality, sugarcane irrigated with the MDF levels varying from 1.5 to 2.5 dS $m^{-1}$ obtained average yield around 98 Mg $ha^{-1}$ for irrigation depth 100% of ETc and enhance 115 Mg $ha^{-1}$ for irrigation depth 120% of ETc. It means that the average yield of sugarcane irrigated with 1.5, 2.0 and 2.5 dS $m^{-1}$ was averagely higher 5.4% compared to the MDF level of 3.0 dS $m^{-1}$ for irrigation depth 100% of ETc and 2.4% compared to the MDF level of 3.0 dS $m^{-1}$ for irrigation depth 120% of ETc (Fig 5). The analysis also pointed out that there was a decline in sugarcane yield on the order from 5.5 to 18.8% for irrigation depth 100% of ETc while for irrigation depth 120% of ETc, the yield of sugarcane reduced from 4.0 to 20.2% corresponding to an increase from 3.5 to 5.0, in dS $m^{-1}$ (Table 3). Based on the findings, it can be asserted that sugarcane yield is significantly influenced by the source of irrigation brackish water.

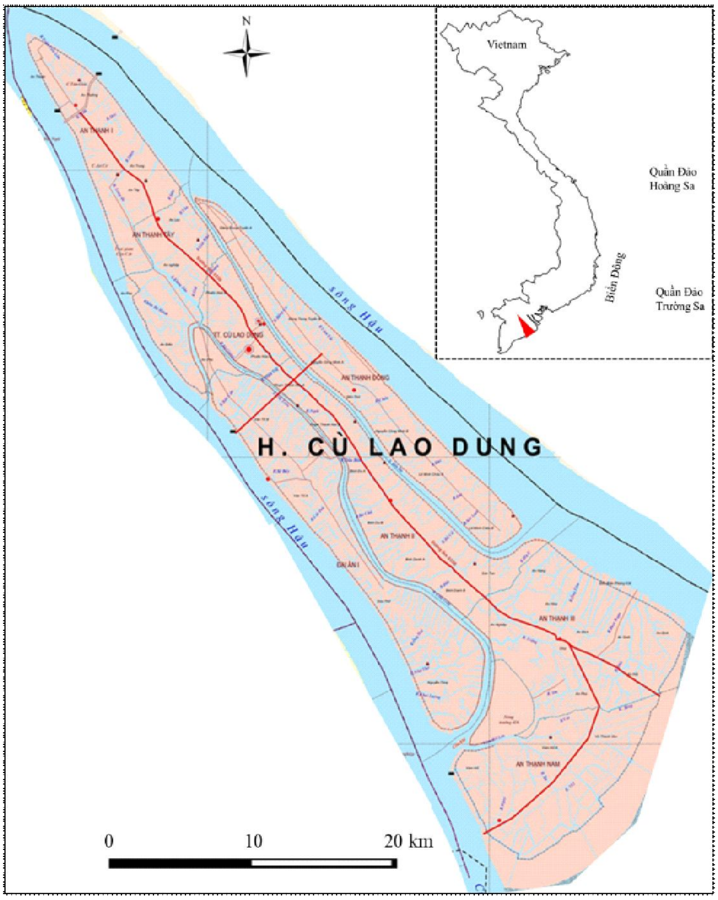


**Fig 1:** Illustration of the study area.

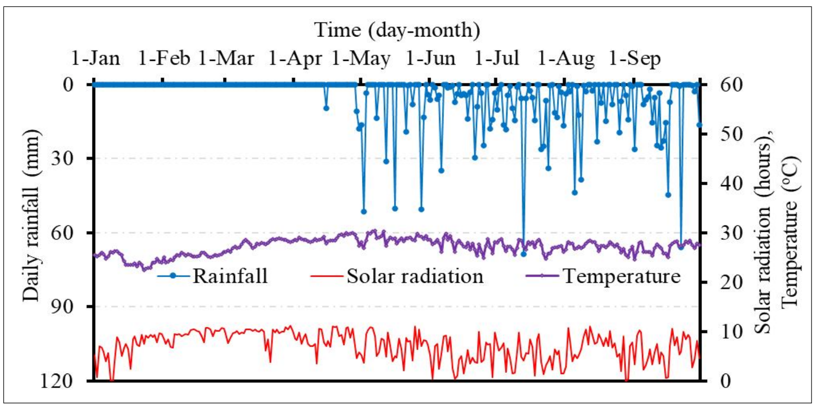


**Fig 2:** Weather factors across the study area during the growing period of spring crop sugarcane.

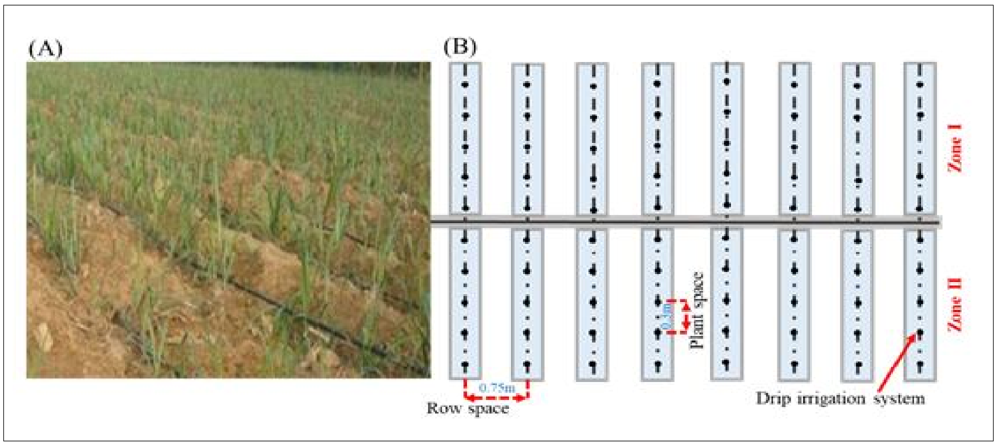


**Fig 3:** Illustration of sugarcane cultivation practice across the household farming.

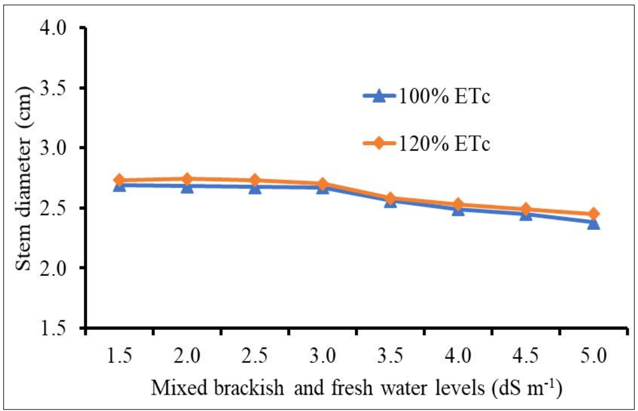


**Fig 4:** Analyzed results of stem diameter corresponding to the mixed brackish and freshwater levels under under different irrigation depths.

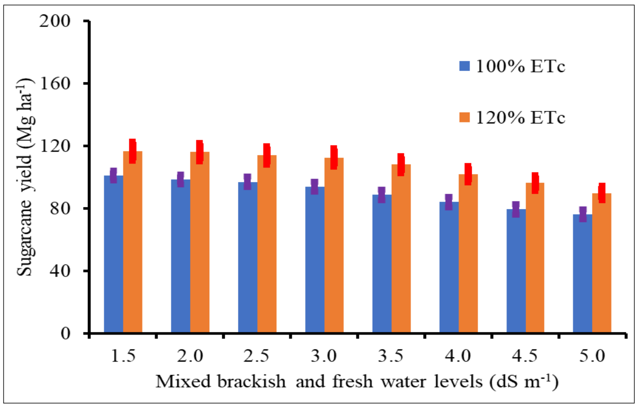


**Fig 5:** Yield of sugarcane irrigated with different levels of brackish and fresh water.

A similar study by CONAB (2016) also stated that the yield of sugarcane declined with the increase of salt concentration in the irrigation water over 3.0 dS $m^{-1}$. Compared with the other MFS levels, 3.0 dS $m^{-1}$ level irrigated corresponding to 120% of ETc had a less negative effect on the growth process of sugarcane as well as yield of sugarcane.

As in the studied results obtained by Lira *et al.* (2018) showed that there was a reduction up to 28.6% in mean sugarcane yield, for the MBF level of 6.5 dS $m^{-1}$ compared with 0.5 dS $m^{-1}$. In a study on brackish irrigation water of 1, 2, 4 and 8 dS $m^{-1}$ for sugarcane CP691062 variety, Nadian *et al.* (2012) reported that reduction in the yield of sugarcane decreased in irrigation water salinity increase and the decline in 4.67% in yield of sugarcane, per unit increase in brackish water, in dS $m^{-1}$. Based on the analysis, there was no significant difference in sugarcane yield among MBF1, MBF2, MBF3 and MBF4 treatments while the yield of MBF4 treatment was only lower than 4.4 for irrigation depth of 100% ETc and 2.7% for irrigation depth of 120% ETc compared to MBF1, MBF2 and MBF3 treatments.

## CONCLUSION

The study assessed the effectiveness of the mixture of brackish and freshwater for irrigating the spring crop sugarcane in 2019/20 across the study area. The utilization of brackish water potential to irrigate the coastal sugarcane fields is adapted as the solution to improve agricultural sustainability.

The results show that a reasonable mixture of brackish and freshwater levels did not reduce the yield of sugarcane but has significantly saved fresh water for irrigation, which is already scarce. Based on the findings, the mixture of brackish and fresh water at a level of 3.0 dS $m^{-1}$ with 120% of ETc to irrigate the spring crop sugarcane across the study area was significantly saved freshwater source but still obtain the optimal sugarcane yield. Especially in the context of global warming, irrigation fresh water is increasingly scarce due to the impacts of saline intrusion.

For other regions, whether brackish water irrigation is applied during the growth process of sugarcane may be dependent on each type of plant, local cultivation conditions and the salinity of irrigation water should be fully considered before implementation. Further investigating of soil saline, plant growth and its production is, therefore, still needed to maintain feasible long-term irrigation with brackish water. On the premise of meeting the irrigation water requirement of sugarcane, sugarcane growers saved the freshwater resource by utilizing the abundant brackish resources.

### Compliance with ethical standards


### Funding

This study was not funded by any agency.


### Conflict of Interest

Authors have not received research grants from any agency. Authors confirm that we have no conflict of interest.

### Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

### Author contributions

Conceptualization, T.K.T. Dinh and T.A. Dang; methodology, T.A. Dang, T.K.T. Dinh analysis the database and prepares the draft. T.A. Dang experimental survey and editing the original draft. T.K.T. Ding and T.A. Dang have read and agreed to the published version of the draft.

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