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RESEARCH ARTICLES

Investigation of a simple method to estimate daily crop water requirement and crop coefficient of sugarcane

Thai Hoang Dinh[1] · Trong Lu Le[2] · Hiroo Takaragawa[3] · Yoshinobu Kawamitsu[4]

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Abstract

Upgrading the crop coefficient from FAO-56 is strongly recommended for locally determining crop water requirements. A low-cost and simple method should be practiced in place of a costly lysimeter. The trial was conducted under glasshouse conditions to estimate daily crop water requirements and create the crop coefficient based on water balance under the small pot scale. Soil pots with and without plants were daily weight to calculate soil evaporation, water loss, and transpiration. Reference crop evapotranspiration was computed based on meteorological data following Penman-Monteith equations. The result showed similar trends in crop water requirements and crop coefficient compared to that under the actual field conditions with the highest values at the grand growth phase. To apply the result from the pot experiment, the plant density could be involved in the crop coefficient corrected formula. The extra water estimated based on plant height increasing rate (6 g cm^{-1} for the establishment phase and 12 g cm^{-1} for the later phase) should be a component of crop water requirement.

Keywords Crop coefficient · Sugarcane · Transpiration · Water needs

Abbreviations

ET	Crop evapotranspiration
ET_o	Reference evapotranspiration
EW	Extra water
k_c	Crop coefficient
MAT	Months after transplanting
SE	Soil evaporation
TE	Transpiration

✉ Thai Hoang Dinh
dthoang@vnua.edu.vn

1 Faculty of Agronomy, Vietnam National University of Agriculture, Hanoi 131000, Vietnam

2 Faculty of Biotechnology – Environment, Yersin University, Lam Dong 66100, Vietnam

3 Japan International Research Center for Agricultural Sciences, Okinawa 903-0213, Japan

4 Faculty of Agriculture, University of the Ryukyus, Okinawa 903-0213, Japan

Introduction

Sugar cane is one of the most important crops contributing to global sugar and biofuel production. Annually, to produce an average yield of 70 tons ha^{-1}, sugar cane needs about 1,500 to 2,000 mm of water throughout its growing period (Carr and Knox 2011; Shrivastava et al. 2011; FAO, n.d). Water shortage may lead to revenue failure because of productivity reduction, but water excessive does not bring any more advantages even increasing the production cost. An economic irrigation strategy to compensate for the water shortage from rainfall should be practiced to meet the crop water requirements.

Crop water requirement or crop evapotranspiration (ET) is defined as the depth of water needed to meet the water loss through soil evaporation (SE) and crop transpiration (TE) to achieve full production potential (FAO, n.d). ET is often calculated by reference evapotranspiration (ET_o) and crop coefficient (k_c). There are some methods to calculate ET_o such as pan evaporation or based on meteorological data such as Blaney-Criddle, Radiation, and Penman-Monteith (Doorenbos and Pruitt 1977). K_c mainly depends on crop type. The reference k_c for sugarcane was suggested by Doorenbos and Pruitt (1977), but because of the gene-environment interaction, it is strongly recommended to locally calibrate for each growing region (Cardoso et al. 2015; Dingre and Gorantiwa, 2020).

The soil water balance method using the lysimeter, with high precision to obtain the actual ET of sugarcane, was applied in many previous studies (Inman-Bamber and McGlinchey 2003; Jyothy et al. 2011; Cardoso et al. 2015; Dingre and Gorantiwa, 2020; Yadeta et al. 2021). However, investigating a lysimeter system is costly leading difficult to build up in poor and developing countries. Although the accuracy is not as high as using lysimeters and getting some limitations in the soil available for root and plant growth, the pot experiment is a low-cost and easy solution and has been widely used to study soil evaporation and plant growth activities. Moreover, Ray and Sinclair (1998) and Wu et al. (2011) revealed that the relationship between plant growth and transpiration was not influenced by soil volume or crop type. Silva et al. (2018), and Octura et al. (2020) succeeded in using small pots to evaluate the ET and k_c of vegetable crops. Lu et al. (2018) indicated the availability of using pot experiments to estimate the field crop ET in maize and wheat. These raise the question that whether the ability to apply the balance method on the small pot scale to estimate field ET and k_c of sugarcane. Fortunately, Hossain et al. (2005) based on more than twenty years of data from a field water balance lysimeter created monthly ET and k_c of sugarcane growing locations in Okinawa prefecture, Japan. In this study, we aimed to apply the balance method to determine the ET of sugarcane under pot conditions. The result from the small pot was mainly collated with Hossain et al. (2005) to estimate the field ET and k_c.

Materials and methods

The study consisted of four experiments. The first experiment was the main trial to determine daily water loss from small pots and estimate ET and k_c of sugarcane for the field condition. Other three extra experiments were conducted to support information to fill the gap from experiment 1.

All experiments were conducted under glasshouse conditions at the University of the Ryukyus, Okinawa, Japan (26°25' N, 127°45' E; altitude 126 m). Glasshouse is designed with a semiautomatic controlled roof and surrounding windows to protect from rain, strong wind, and heat. The climatic condition during the experimental period was a typical climate in a subtropical region with the highest temperature and solar radiation values in summer and the lowest values in winter.

The two-month-old seedlings of the commercial sugarcane variety NiF8 were prepared to transplant into Wagner pots (one seedling per pot). The mixture of Shimajiri Mahji red soil: sea sand: peat moss (1:1:1, v v^{-1}) was used as the experimental substrate. The substrate properties were pH = 7.1, electronic conductivity = 153.1 mS m^{-1}, total N = 0.07%, P = 0.1 ppm, and K = 12.2 ppm, bulk density = 0.9 g cm^{-3}. Because sugarcane has huge biomass, keeping the tiller is heavy to lift for determining the whole pot's weight. Plant with more tiller requires more water, limited condition of the small pot is not able to support plant growth. As suggested in previous studies (Jaiphong et al. 2016; Watanabe et al. 2016) tillers were removed immediately after emergence. From 2 weeks after transplanting, each plant was weekly fertilized by replacing irrigation with 500 mL of the modified Hoagland's nutrient solution (6mM $Ca(NO_3)_2.4H_2O$, 4mM KNO_3, 2mM KH_2PO_4, 2mM $MgSO_4.7H_2O$, 25μM H_3O_3, 10μM $MnSO_4.5H_2O$, 2μM $ZnSO_4.7H_2O$, 0.5μM $CuSO_4.5H_2O$, and 0.1mM $C_{10}H_{12}FeN_2NaO_8.3H_2O$).

Experiment 1: estimation of crop water requirement and crop coefficient of sugarcane from pot scale

Experimental design

From Nov 2016 to Jun 2018, the trial was conducted. On 19 Nov 2016, 30 seedlings were transplanted into pots 1/2000a (actual size of upper diameter x lower diameter x height: 250 × 234 × 264 mm) filled with 8 kg of experimental substrate. The daily average air temperature and relative humidity ranged from 11.3 to 33.6°C and from 43.1 to 92.7%. It was higher at 2.7 ± 1.2 °C and 9.1 ± 7.3 than outside temperature and humidity, respectively. Average daily solar radiation ranged from 7.0 to 193.3 W m^{-2} which was 0.52 ± 0.05 times the outside's solar radiation (Fig. 1). Three sample pots were randomly selected and marked as Su1, Su2, and Su3 to determine pot weights. A bare pot was also prepared as a control pot to determine soil surface evaporation. Two months after transplanting (MAT), a soil matric potential sensor (pF sensor, MPS-6, Decagon Devices Inc., USA) was installed in each plant pot at 10 cm depth. The water potential of the experimental substrate ranged from pF values of 2.00 (field capacity) to 4.20 (permanent wilting point).

As soon after transplanting, water was fully irrigated, and the redundant water was drained from the hole at the pot bottom. The initial weight of each pot was determined. The daily irrigation was done by applying daily water loss from each pot. From Apr 2017, irrigation was done twice a day at noon and 6 pm on sunny days. Because of the occurrence of drought stress symptoms in plants and soil, from mid-May to mid-Jul 2017, besides the amount of daily water loss, an extra amount of water was added until the pot weight of 11.700 g. In mid-Jul 2017, the early and mid-Aug, the extra

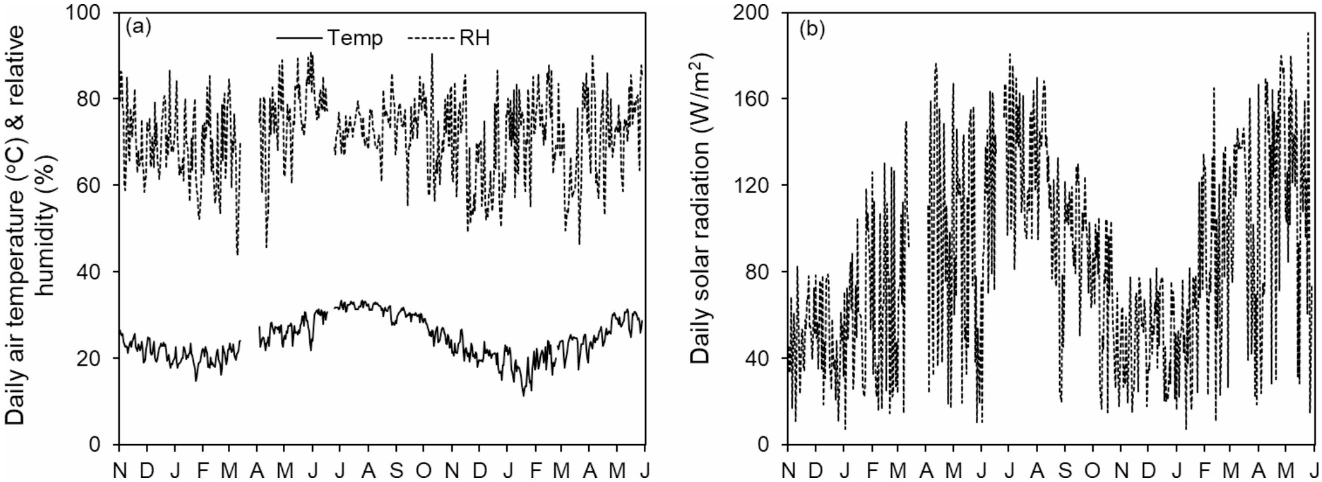

Fig. 1 Weather conditions of daily air temperature and relative humidity (**a**), and daily solar radiation (**b**) during the experimental period. Note: the capital letters on the horizontal axis are in turn abbreviations of months from November 2016 to June 2018

water amounts of 700, 300, and 700 g were in turn added. From mid-Aug until the end of the experiment, each pot was monthly added with an extra water amount of 120 g.

Data collection

The daily outdoor and indoor climatic data were recorded 60 min intervals for air temperature, relative humidity, and solar radiation from the weather system (Harusa View, ADS) which is installed beside and inside the glasshouse. The reference evapotranspiration (ET_o) was calculated according to the Blaney-Criddle method (Doorenbos and Pruitt 1977). Soil moisture was automatically recorded at intervals of 10 min.

An electronic digital scale was used to weigh the experimental pot every day at 6 pm. The pot weight before and after irrigation was recorded. The daily soil surface evaporation and total water loss were calculated according to the formulas:

$$\mathrm{SE} = \mathrm{PS}_1 - \mathrm{PS}_2$$

Where, SE: soil surface evaporation (g day^{-1}) from bare pot; PS_1: the weight of pot after irrigation on the day before; PS_2: the weight of pot before irrigation on the day after.

$$\mathrm{ET_p} = \mathrm{PC}_1 - \mathrm{PC}_2$$

Where, ET_p: total water loss or crop water requirement (g day^{-1}) from planted pot; PC_1: the weight of pot after irrigation on the day before; PC_2: the weight of pot before irrigation on the day after.

The transpiration rate (g day^{-1}) was calculated by:

$$\mathrm{TE} = \mathrm{ET_p} - \mathrm{SE}$$

Where, TE: transpiration rate of the plant.

The field crop water requirement (mm m^{-2} day^{-1}) was calculated by :

$$\mathrm{ET_a} = \frac{\mathrm{ET_p}}{1000 \times \mathrm{A_p}}$$

Where, ET_a and ET_p: the crop water requirement in the actual field and pot, respectively; A_p: pot surface area (m^2); 1000: conversion factor from g m^{-2} day^{-1} to mm m^{-2} day^{-1}.

The crop coefficient (k_c) was calculated as follows:

$$\mathrm{k_c} = \frac{\mathrm{ET_a}}{\mathrm{ET_o}}$$

Where, k_c: crop coefficient; ET_o: reference crop water requirement (mm m^{-2} day^{-1}).

Growth parameters including plant height, total leave number, and SPAD were determined weekly from 1 week after transplanting until the end of the experiment. Plant height was measured from the soil surface to the top visual dewlap on the main stem. The leaf number was marked and counted from the start to the end of the experiment. SPAD was measured by a SPAD 502-Plus (Minolta, Japan) at the first fully expanded leaf.

Experiment 2: estimating the increasing rate of stalk weight during the sugarcane life cycle

Water uptake from the root system is mainly used for transpiration, and less than 5% is used in chemical reactions and stored in plant tissues (McElrone et al. 2013). Sugarcane produces huge biomass compared to other annual crops. Depending on growth stages, sugarcane's green tissues contain from 60 to 80% water. This might cause errors when weighing the pot to determine ET_p by balance method. Although the daily errors are negligible, over time they become considerable and induce water shortage, especially in the elongating phase when the plant has high growth rates. Therefore, irrigation by only daily water loss in experiment 1 is not enough to balance crop water requirements. To avoid errors as well as water stress, besides the water loss from evapotranspiration, extra water should be a part of ET. Formation of the stalk and storing water in the stalk might be the reason for the difference. The trial was conducted to determine the amount of extra water (EW) that should be added to protect from water stress.

Experimental design

On 4 Jul 2017, 20 seedlings were transported into Wagner pot 1/2000a (actual size of upper diameter x lower diameter x height: 250×234×264 mm) filled with 8 kg of the substrate. From transplanting to finishing of the experiment (3 Apr 2018), water was supplied fully to the pots until the water was released from the draining hole.

Data collections

At intervals of 2 months from transplanting, 3 plants were randomly collected to determine stalk diameter (on the plant's top, middle, and bottom), stalk height, and total fresh weight of the sample plant. Stalk volume was calculated based on stalk diameter and stalk height.

Experiment 3: effect of water schedules on crop water requirement of sugarcane

The experiment was conducted to check the effectiveness of adding extra water from experiment 2 to reduce the effect of water shortage.

Experimental design

On 1 Apr 2018, 20 seedlings were transported into Wagner pot 1/2000a filled (actual size of upper diameter x lower diameter x height: 250×234×264 mm) with 8 kg of the substrate. The experimental design was a completely randomized design with three replications. Two irrigated schedules included S1 – irrigated by daily water loss only for 16 weeks (same as experiment 1), after that rewatering until full capacity, then irrigated by daily ET plus with EW according to suggestion from experiment 2, and S2 – irrigated by daily ET plus with EW from the start until the end of the experiment (3 Jan 2019). Three planted pots were prepared for each treatment and one bare pot was prepared to estimate SE. Each plant pot installed a soil matric potential sensor (pF sensor, MPS-6, Decagon Devices Inc., USA) at 10 cm depth.

Data collections

The daily indoor climatic data were recorded to calculate ET_o. Soil moisture (pF) was recorded automatically at intervals of 10 min. Experimental pots were weighed daily to calculate ET. The plant height of sample plants was measured weekly to calculate the increasing rate and EW adding for each treatment.

Experiment 4: effect of the pot sizes on crop water requirement of sugarcane

The experiment was conducted from 16 Jun 2018 to 3 Jan 2019 to determine the effects of pot surface area on the daily ET of sugarcane.

Experimental design

The experimental designs were completely randomized designs with three replications. The 20 two-month-old sugarcane seedlings were transplanted into Wagner pot 1/5000a (actual size of upper diameter x lower diameter x height: 158×150×170 mm) filled with 2.5 kg substrate (A1), and Wagner pot 1/2000a filled (actual size of upper diameter x lower diameter x height: 240×234×170 mm) with 6.25 kg substrate (A2). Three planted pots were prepared for each treatment. The irrigated schedule was practiced by daily ET plus with EW according to the suggestion from experiment 2.

Data collections

The plant height of sample plants was measured weekly to calculate the increasing rate and EW adding for each treatment. Experimental pots were weighed daily to calculate ET_p.

Data analysis

The data were analyzed and graphed by Microsoft Excel 2016. Analysis of variance (ANOVA) according to a completely randomized design was analyzed using Statistix 8 package. Means were compared by Tukey multiple comparisons test $p \leq 0.05$. Correlation coefficients were determined from the graph and verified.

Results and discussion

Experiment 1

Pot weight and soil moisture management

The pot weight of the plant pots was initially recorded as 11.250 g, then maintained at the beginning during the first six months until mid-May 2017 (establishment phase) with some days from Feb to mid-Mar at 11.500 g to test the change of soil moisture (Fig. 2a). The pF was stable at around 2.1 until mid-Apr 2017, then increased to around 4.0 with a higher increasing rate of Su2 compared to other pots (Fig. 2b). It means that irrigation by only ET was not enough when the plant was in start the grand growth phase (from Apr 2017). Hence, from mid-May to mid-Jul 2017, we tried to add extra amounts of water until the pot weight of 11.700 g, but the pF values still maintained at 4.1 in Su2, and increased to 4.0 in Su1 and Su3. From mid-Jul to mid-Aug 2017 when the extra water amounts were in turn added, the pF values of Su1 and Su3 were dropped and bottomed out at 2.1, meanwhile the pF of Su2 just decreased to 2.1 at the last added amount. This indicated that a total of 1.700 g of water seemed enough to compensate for the water shortage. From mid-Aug 2017 when 120 g of water was monthly added the pF was maintained at 2.1 for one month, then increased and stable at around 3.0 from Sep to Nov 2017 (start maturing phase) before having different changes among the three pots. The pF of Su2 had the largest change with an upward trend to the peak of 4.3 in mid-Mar before declining to 3.0 at the end of the experiment. The pF of Su1 and Su3 had upward trends alternated with downward trends during the period from mid to end of Dec 2017 and from late Mar to early May 2018. The variation in pF among experimental pots could be from the difference in the growth of sugarcane plants. Plants in Su2 seemed growth better (Fig. 3) and required higher water than other plants in Su1 and Su3. Su2, therefore, absorbed more water, leading to the pF in this pot being higher than others.

Growth of sugarcane

Plant height increased slightly during the first four months (establishment phase), and it rapidly increased (with a ceasing growth period from mid-Jun to mid-Jul) until the end of Nov 2017 (end of grand growth phase). After that, plants were in maturing phase thus very slow growth rates were recorded (Fig. 3a). SPAD surged from 30 to 50 after the first three weeks, then stable at around 45 for 4 months before plunging from mid-Apr to mid-Jul 2017. It recovered, maintained the same values for 2 months, and fell until mid-Mar 2018. Since then, it again recovered until the finish of the experiment (Fig. 3b). Total leaf numbers (TLNs) gradually went up until the end of Nov 2017, but also flattened off during the same period as shown in plant height. Afterward, the TLNs of Su1 and Su3 slowly rosed before a faster increase from early Mar 2018, whist, water stress from Dec 2017 to Mar 2018 might lead the TLNs of Su2 to increase at a slow rate until the end of the experiment (Fig. 3c). There was an upward trend in green leaf numbers (GLNs) from the beginning to Dec 2017, then maintained at around 20 leaves until mid-Apr 2018. During the last two months of the experiment, GLNs of Su1 and Su3 increased stable while the falling of old leaves lead to that of Su2 being stable.

During the cycle, the growth rate of sugarcane is slow in the establishment, it is faster and strongest during vegetative stages, becomes slower in yield formation, and stops in the ripening stage. Leaf nitrogen, corresponding to leaf chlorophyll or SPAD, also reduces along with plant age (Sage et al. 2014). Essentially, the growth of plants in this

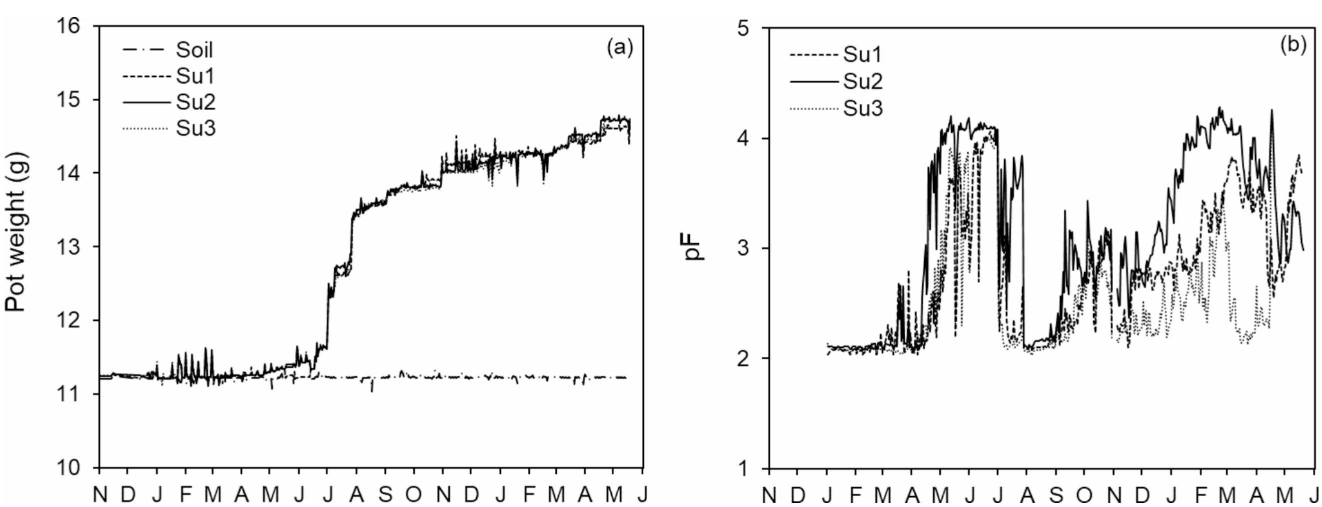

Fig. 2 Pot weight (**a**) and soil moisture (**b**) during the experimental period. Note: Soil and Su1, 2, 3 mean pots of no-plant soil and plant number 1, 2, 3; the capital letters on the horizontal axis are in turn abbreviations of months from November 2016 to June 2018

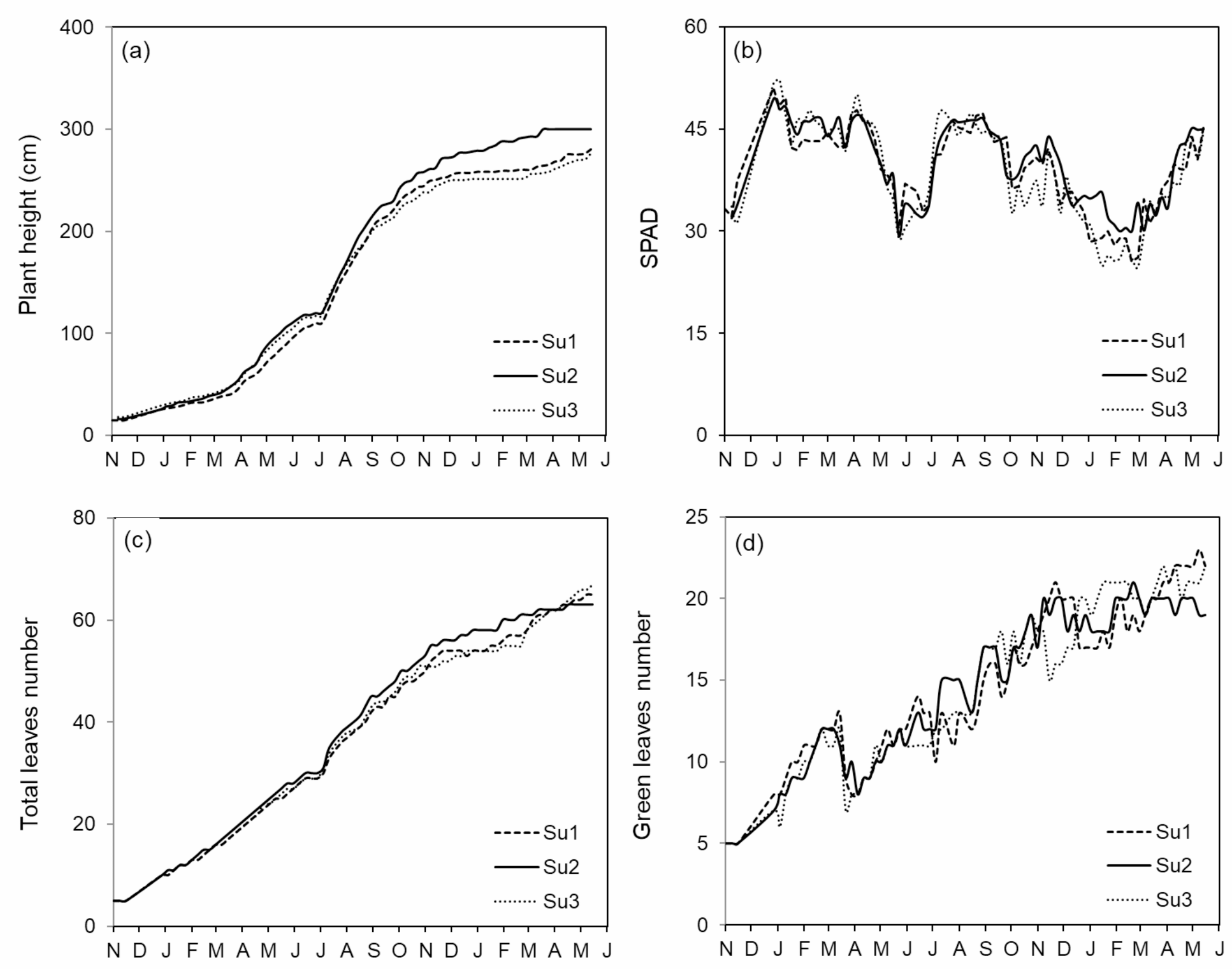

Fig. 3 Growth parameters of sample plants for plant height (**a**), SPAD (**b**), total leaves number (**c**), and green leaves number (**d**). Note: Su1, 2, 3 means plant number 1, 2, 3; the capital letters on the horizontal axis are in turn abbreviations of months from November 2016 to June 2018

experiment is similar to normal plants under field conditions. Water deficiency is the reason for growth reductions in sugarcane. Vegetative is the most susceptive stage (Ferreira et al. 2017) meanwhile water shortage in the ripening phase is negligible (Doorenbos and Kassam 1979). Dinh et al. (2019) reported a pF of 2.8 was the withdrawal threshold for water stress. Under field conditions, Dinh et al. (2020) observed the reductions in plant height increasing rate and SPAD when soil pF reached over 3.0. Therefore, ceasing in plant height and total leaves number and decline in SPAD during mid-season (Apr to Jul and Sep to Oct 2017) is mainly affected by water stress.

Crop water requirement factors

The daily ET_o and SE changes look similar to the happens in air temperature and solar radiation. In the winter months (Nov to Jan), ET_o and SE fluctuated around 1 mm day^{-1} and 70 g day^{-1}, respectively, then reached their peaks in the summer months from May to Aug before dropping until the end of the year (Fig. 4a, b). The daily TE and ET_p remained constant during the first two months. They grew more and more rapidly and reached a peak in the period of mid-Aug to mid-Oct, then declined during the last months of the year 2017. From Jan to Jun 2018, the TE and ET_p changes were similar to ET_o and SE trends. The flattened-off of TE and ET_p was also recorded during the period of mid-May to mid-Jul 2017 (Fig. 4c, d). In the grand growth phase, sugarcane requires the largest water for leaf expansion and stem elongation. High temperature and light intensity coincided with this phase is also the reason for the highest transpiration. Under moderate water stress, a decrease in TE is mainly due to stomatal limitations (Ferreira et al. 2017). Dinh et al. (2019) reported stomatal conductance maintained at the

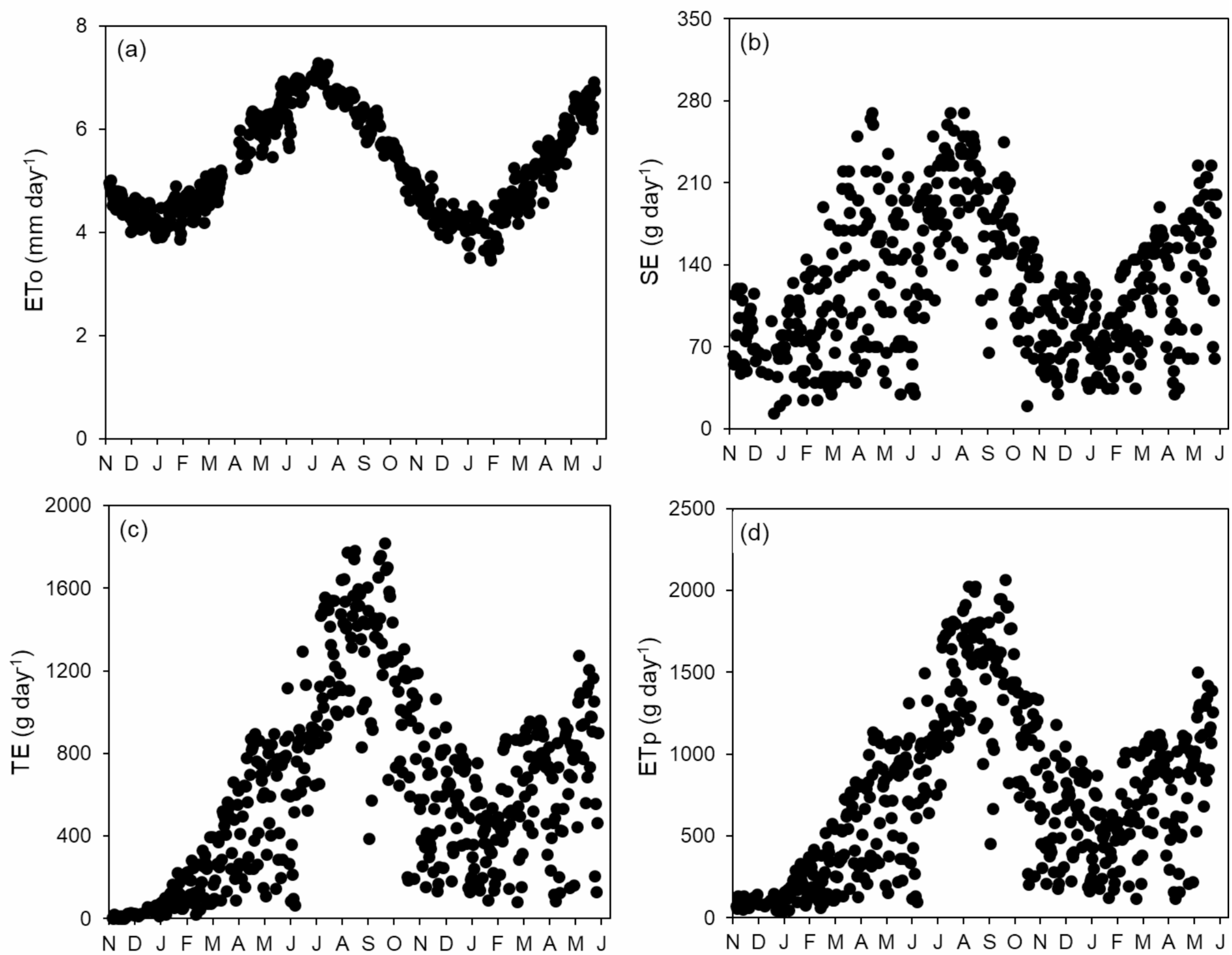

Fig. 4 Reference evapotranspiration (**a**), soil evaporation (**b**), transpiration (**c**), and total water loss of plant (**d**). Note: the capital letters on the horizontal axis are in turn abbreviations of months from November 2016 to June 2018

same levels in ranges of pF from 2.8 to 3.8. This experiment could explain the flattened-off in changes TE and ET_p from May to Jul 2017.

Transpiration is mainly the driving force for water uptake into the plant. The contribution to ET_p almost came from TE with a very strong linear correlation ($R^2 = 0.9951$) (Fig. 5). Endres et al. (2010) reported a close regression in the relation between photosynthesis and TE in sugarcane. Different sugarcane varieties perform different photosynthesis and transpiration (Silva and Costa 2009; Vasantha et al. 2010). Based on this relationship, the daily transpiration rate or the daily photosynthetic ability of different sugarcane varieties could be estimated from daily water loss.

The daily ET_a ranged from 0.7 to 41.3 mm m^{-2} day^{-1} (Fig. 6a). It had a similar trend with the change of daily and monthly k_c shown in Fig. 6b and c. They remained at the lowest levels during the first two months and climbed to the peak from mid-Aug to mid-Oct (9 to 11 MAT). There was a notice period with the stop increasing of k_c from mid-Apr to mid-Jul 2017 by the effects of severe stress. Then k_c had a downward trend until mid-Jan, fluctuating around 3 during the next 3 months before rising again in the last months (Fig. 6b). The k_c of the three plants were most similar except for the different increasing rates among Su1 and Su3 with Su2 in the last two months (Fig. 6c). It could be because higher GLNs of Su1 and Su3 involved higher leaf transpiration in comparison with Su2.

Our study result is in line with previous studies on the change of k_c with the highest values in the mid-season (Inman-Bamber and McGlinchey 2003; Silva et al. 2013; Cardoso et al. 2015) or grand growth phase (Win et al. 2014; Yadeta et al. 2021). Compared to the reports of Hussain et al. (2005), there was a correspondence of investigated k_c in this experiment to reference k_c under field conditions, especially

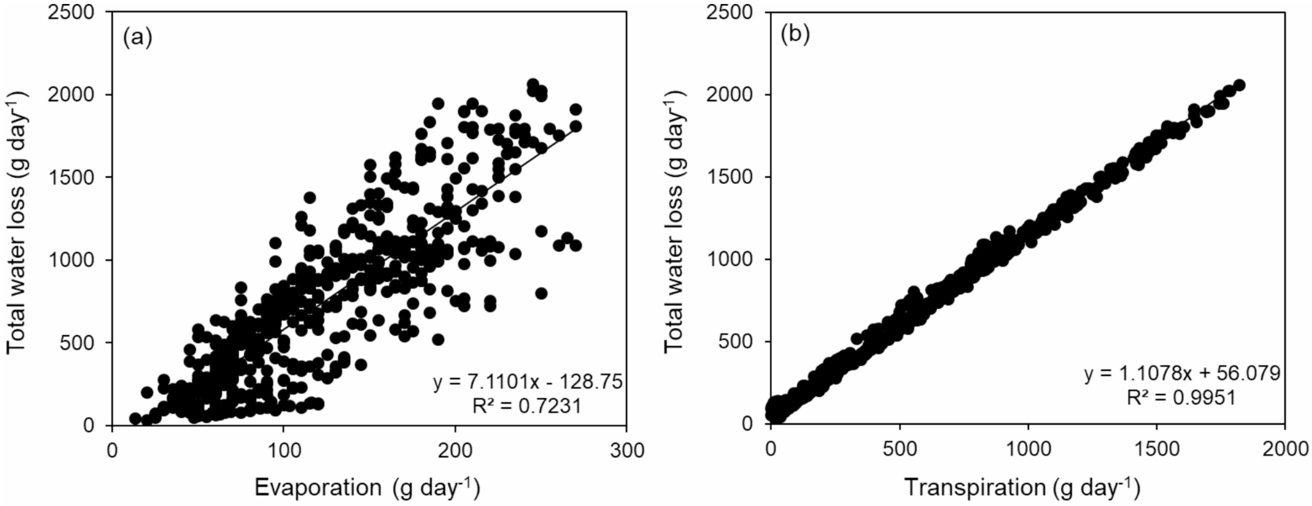

Fig. 5 Contribution of evaporation (**a**) and transpiration (**b**) to total water loss

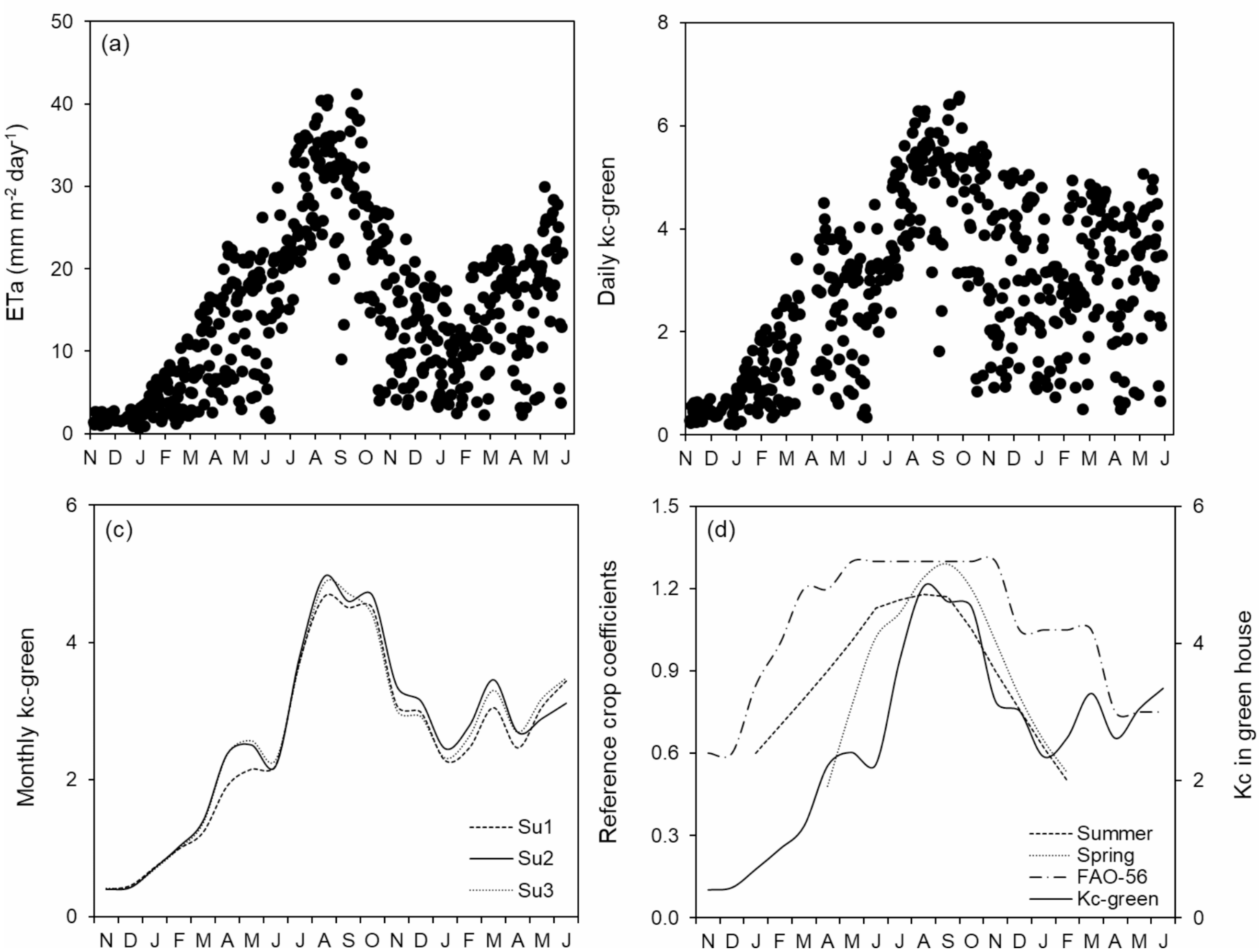

Fig. 6 Daily field crop water requirement - ET_a (**a**), daily (**c**) and monthly (**b**) crop coefficients in greenhouse conditions - k_c green, and comparison with field reference crops coefficient from FAO-56 and Hussain et al. (2005) in summer - k_c summer and spring - k_c spring cropping seasons (**d**)
Note: Su1, 2, 3 means plant number 1, 2, 3; the capital letters on the horizontal axis are in turn abbreviations of months from November 2016 to June 2018

for Spring k_c (Fig. 6d). However, the k_c of pot condition was rough as higher 4 times as reference k_c. The most variation may come from differences in plant density in the actual field and plant density calculated from pot surface area. Lu et al. (2018) had the same consideration to correct ET based on the plant density in pot and lysimeter conditions. Plant density calculated from pot surface area was 20 plant m^{-2}, but in the actual field, sugarcane is often grown at a plant density of 3.3 plant m^{-2} and the remained part is bare soil. Thus, the calculation for field ET should consider water loss from both the transpiration of plants with their density and the evaporation of bare soil. In case of this reason, we suggest an adjusted formula to calculate ET as follows:

$$\mathrm{ET}_{\mathrm{a}}^{\mathrm{d}} = \frac{\mathrm{ET}_{\mathrm{p}} \times \mathrm{D}_{\mathrm{a}} + \left(\frac{1}{\mathrm{A}_{\mathrm{p}}} - \mathrm{D}_{\mathrm{a}}\right) \times \mathrm{SE}}{1000} \quad (1)$$

Where, $\mathrm{ET}_{\mathrm{a}}^{\mathrm{d}}$: adjusted crop water requirement in the actual field; ET_p: crop water requirement in the pot; SE: soil evaporation; D_a: the plant density in the actual field; A_p: pot surface area; 1000: conversion factor from g m^{-2} day^{-1} to mm m^{-2} day^{-1}.

Experiment 2

The correlation coefficient between stalk height and plant weight was stronger than that between stalk volume and plant weight (Fig. 7a, b). There was an error in stalk diameter because of the effect of the thickness of leaf sheaths which cover the stalk at measurement time. The stalk diameter was smaller by the senescence of the leaf. Therefore, the increasing rate of plant weight during the crop cycle could be easier to estimate by increasing the rate of stalk height. The pot ET should be re-calculated as follows:

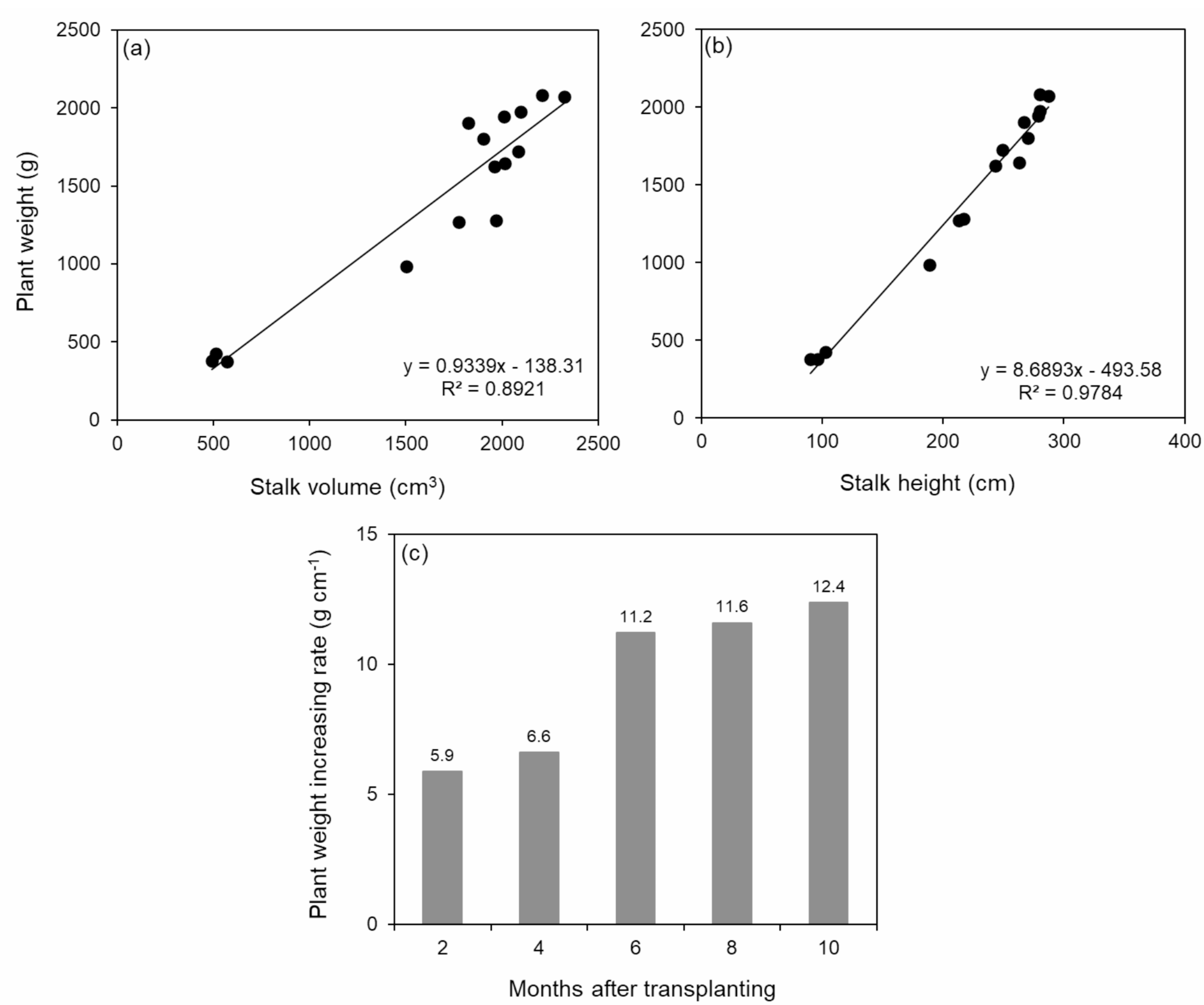

Fig. 7 Correlations of plant weight with stalk volume (**a**) and stalk height (**b**), and increasing rate of plant weight (**c**)

$$ET_p^e = ET_p + EW \quad (2)$$

Where, ET_p^e: adjusted crop water requirement; EW: extra water for 1 cm of plant height increase.

From our investigation, we suggest the EW is an average of 6 g cm^{-1} of stalk height increased rate during the establishment phase (first 4 MAT) and 12 g cm^{-1} during grand growth phase (since 4 MAT) (Fig. 7c).

Experiment 3

The results from Fig. 8 showed no difference in change of ET_p between the two irrigation schedules during the first 2 months when the plant was in the establishment phase. The difference was clearer from early Jun 2018 (the beginning grand growth phase) with lower values of ET_p in S1. It corresponds to the change of pF when the pF value reached over 3.0 in S1 at that time. In Jul 2018 when pF maintained around 3.9, the ET_p of S1 treatment was not changed. It increased in early Aug 2018 when re-irrigated by recommended irrigation schedule as S2. The ET_p of S1 was recovered and reached the same values as S2 in early Oct 2018. This change was similar to the ET_p of the plant in Fig. 4d (experiment 1). The results of this experiment confirmed the result in experiment 1 that irrigated only daily water loss is not enough to balance crop water needs when plants are in the grand growth phase. The shortage of water daily accumulated leads to a decrease in soil water (an increase in pF values) and a reduction in stomatal conductance resulting in lower ET_p of S1. Dinh et al. (2018) reported that stomatal conductance was diminished by water shortage but recovered when rewatering. Therefore, when the shortage was refilled, the ET_p of S1 recovered equally to that of S2.

Based on the corrected formulas for ET_a in (1) and (2), the re-calculated crop requirement factors were shown in Table 1. After correcting, ET_a^d and k_c^d became closer to the reference k_c of the spring cropping season in Hossain et al. (2005). The difference might be because k_c in Hossain et al. (2005) was averages of many different years and varieties. Lu et al. (2018) also found differences in ET among wheat and maize varieties.

Experiment 4

There were similar trends in the fluctuation of daily ET_p of A1 and A2 treatment with an increase to peak during the period from Jun to Sep 2018, then a decrease until the end of the experiment (Jan 2019). However, the daily ET_p in the A2 treatment (with an average of 409.1 g day^{-1}) was significantly higher than that in the A1 treatment (492.8 g day^{-1}) (Fig. 9a). Limitation in soil volume might be the reason for lower values of ET_p in A2 compared to A1. Ray and Sinclair (1998) agreed that pot size had a large effect on plant growth and transpiration, but no significant effect on the normalized transpiration ratio. In fact, in our study, the daily ET_a of the two treatments was mostly not different during the experimental period, except for the period from Aug to Sep 2018 ET_p when the plant reached the peak of growth (Fig. 9b). This result supports using small pots to estimate ET in sugarcane. However, it should consider the daily irrigation schedule to avoid the effect of daily water shortage when using a smaller pot.

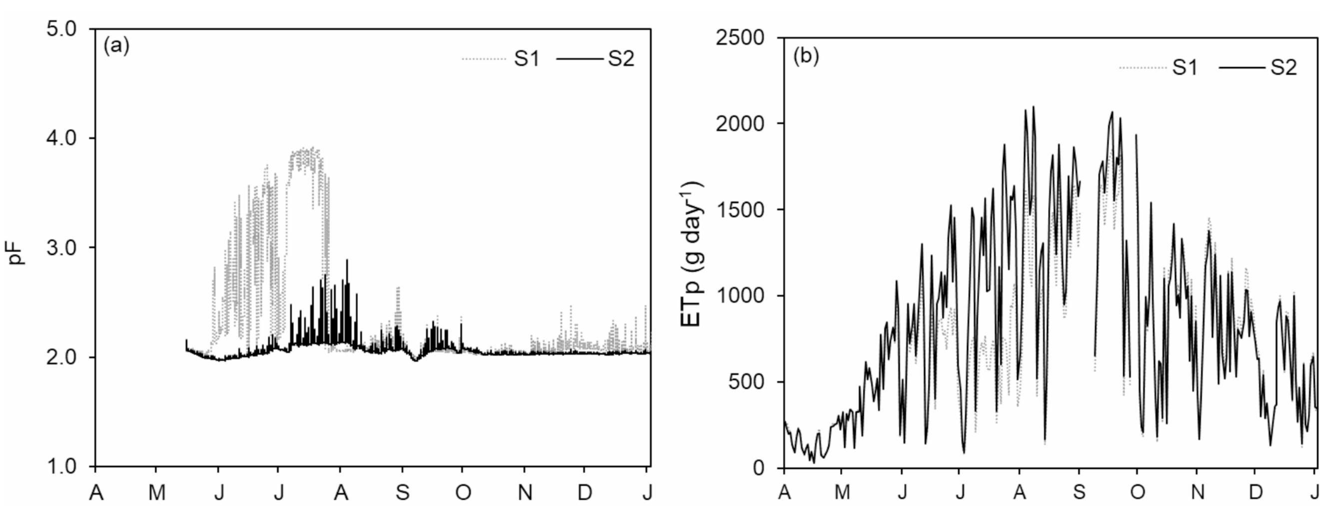

Fig. 8 Soil moisture (**a**) and daily crop water loss (ET_p) during the experimental period
Note: S1 and S2 mean water schedule 1 and 2; the capital letters on the horizontal axis are in turn abbreviations of months from 2 April 2018 to 3 January 2019

Table 1 Crop water requirement and crop coefficient from the pot and reference field conditions

Month	ET_a	ET_a^d	*Ref.ET	k_c	k_c^d	*Ref. k_c
April	3.21	2.75	1.70	0.64	0.55	0.48
May	9.92	4.82	3.20	1.69	0.83	0.77
June	16.59	5.37	4.70	2.63	0.85	1.02
July	22.03	6.17	5.90	3.45	0.97	1.11
August	27.35	7.05	6.40	4.57	1.18	1.24
September	30.67	7.59	5.40	5.30	1.31	1.29
October	17.70	4.53	4.20	3.68	0.94	1.20
November	15.17	3.91	2.50	3.37	0.87	1.01
December	10.59	2.79	1.80	2.69	0.71	0.81
January	8.99	2.31	1.80	2.39	0.61	0.65

Note: ET_a and ET_a^d mean uncorrected and corrected crop water requirements from the pot experiment; k_c and k_c^d mean uncorrected and corrected crop coefficient from the pot experiment; Ref. ET and Ref. k_c mean reference crop water requirement and coefficient calculated from lysimeter by Hossain et al. (2005)

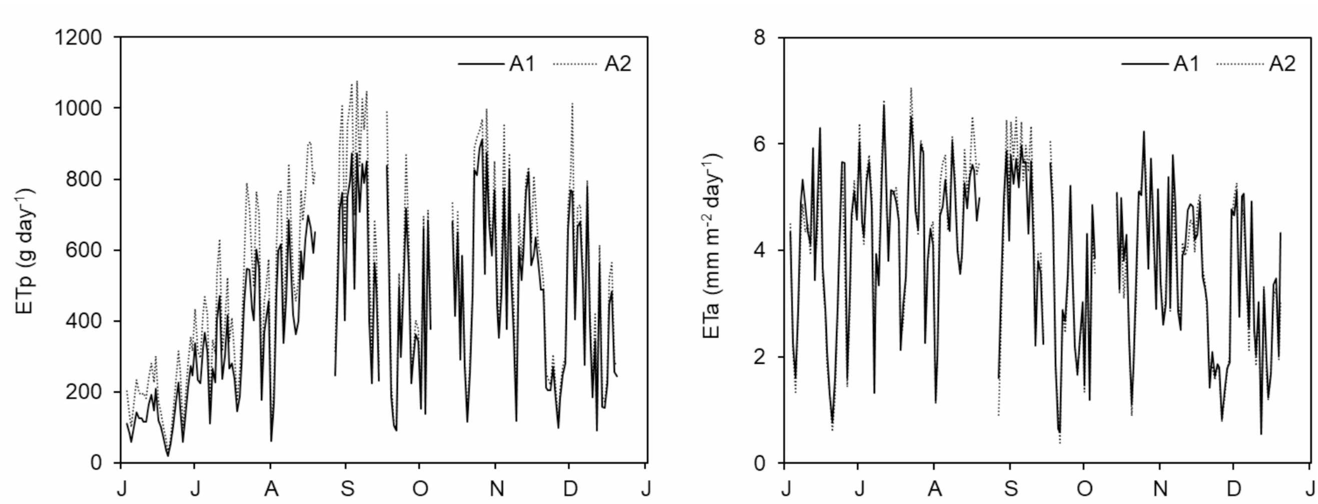

Fig. 9 Daily pot - ET_p (**a**) and field - ET_a crop water requirement (**b**) of different soil volume treatments during the experimental period. Note: A1 and A2 mean soil volume treatment; the capital letters on the horizontal axis are in turn abbreviations of months from 16 June to 3 January 2019

Conclusion

In conclusion, the change in k_c in our pot experiment is homogeneous with the previous investigation in k_c under field conditions using a lysimeter system. The balance method on a small pot scale could be a feasible way of estimating ET and k_c in the field instead of building a costly large-scale lysimeter system. To apply k_c from the pot to the field conditions, the plant density and evaporation of bare soil should be considered as the component to convert. The extra water from increasing plant growth (6 g cm^{-1} for the establishment phase and 12 g cm^{-1} for the later phase) should be a part to calculate ET along with water loss from crop evapotranspiration.

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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