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ROOT CHARACTERISTICS OF INDIVIDUAL TILLERS AND THE RELATIONSHIPS WITH ABOVE-GROUND GROWTH AND DRY MATTER ACCUMULATION IN SUGARCANE

JIDAPA KHONGHINTAISONG[1,2], PATCHARIN SONGSRI[1,2] AND NUNTAWOOT JONGRUNGKLANG[1,2*]

[1]Department of Agronomy, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand
[2]Northeast Thailand Cane and Sugar Research Center, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand
[*]Corresponding author's email: nuntawootjrk@gmail.com

Abstract

The expansion of sugarcane production areas is limited, therefore, the improvement of yield components of sugarcane might be a strategy to enhance cane production. Hence, the aim of this study was to identify the relationship between roots in each tiller and their above-ground parts during the tillering phases. This research was carried out at the Agronomy Research Station in Khon Kaen University, Thailand, using a completely randomized design with four replications. Six sugarcane cultivars, namely KK3, KPS01-12, KKU99-02, KKU99-03, UT12 and UT13, with different drought resistance levels, were assigned as treatments. Above-ground growth traits such as height and tiller number were collected at 100-175 days after planting as intervals of 15 days. Leaf dry weight, stalk dry weight and biomass were measured at 175 days after planting. Root traits, i.e. root/shoot ratio, root surface area, root length, root volume, and root number were observed at 175 days after planting. The number of roots from the main to the seventh tillers of six sugarcane cultivars followed a tiller order; all root traits were highest in the main tiller. In some cultivars, root length followed the order (from high to low) of the tiller sequence. There was a positive correlation between the sum of the roots in all tillers per hill and shoot dry weight. In terms of root traits of individual tillers, for almost all cultivars, root volume, root surface area, root length, and root number were positively correlated with biomass and stalk dry weight, except for genotype KK3. These root characteristics can potentially be used as criteria to assess shoot performance. In contrast, the root to shoot ratio may not be an appropriate characteristic to assess shoot growth, and the root dry weight varied between cultivars.

Key word: Tillering phases, Each tiller, Rooting traits, Below-ground, Top growth.

Introduction

Sugarcane is the main industrial crop for sugar production (Seema *et al*., 2014) and an important economic crop in many sugar-exporting countries such as Brazil, Thailand and Australia (Anon., 2017). Currently, the global demand for sugar is increasing, necessitating both horizontal and vertical yield expansions for to meet these requirements (Anon., 2017). However, production areas can only be limited to a certain extent, mainly due to competition with other crops as well as the residential and the industrial sectors (Manimaran *et al*., 2009). Yield increases might therefore be possible mainly by using more effective crop management techniques or high-yield cultivars (Manimaran *et al*., 2009).

Yield components, namely millable cane number and stalk weight, are the key factors and indicators of sugarcane productivity (Kapur *et al*., 2011). Stalk weight is positively correlated with cane height and stalk diameter (Samiullah *et al*., 2015). Stalk elongation represents the increasing stalk fresh and dry weight under suitable growth conditions (Rostron, 1971). In addition, stalk diameter is also related to the final sugarcane yield (Bajelan and Nazir, 1993; Yadav *et al*., 1997; Kumar *et al*., 2 012). Thus, the enhancement of yield productivity is connected with a number of components such as the number of millable canes, cane diameter and cane length (Samiullah *et al*., 2015) as well as the growth and yield of individual tillers. However, information on the relationships between tiller initiation and subsequent loss and the compensation between number of stalk and dry weight is lacking (Bell & Garside, 2005).

Tillering is a process of underground branching by which number of shoots are produced ultimately contribute for the number of millable canes in sugarcane (Vasantha *et al*., 2012). The yield of sugarcane cultivar was largely determined by tillering ability (Joshi *et al*., 1996).The tillering phase is particularly important for determining the millable cane number and sugar content (Buenaventura & Rosario, 1978), as the tillering sprout develops into millable cane and represents a sucrose sink (Kapur *et al*., 2011). However, increased stalk population densities at harvest without enhanced dry matter accumulation do not represent increased yields (Bell & Garside, 2005). Hence, dry weight accumulation may become a key factor for improving yield at elongation and final development stages. The accumulation of organic matter via photosynthesis depends on a variety of growth-related parameters.

Some above-ground traits directly contribute to sugarcane yields, e.g. leaf area, which is an important characteristic to maximize interception of solar radiation and is directly associated with carbon fixation (Sinclair *et al*., 2004). However, root is the first organ to indicate water dehydration in soil (Ferreira *et al*., 2017), and root traits may also determine stalk dry weight in sugarcane due to their functions in nutrient and water uptake. Sugarcane root system includes two root types i.e. sett root and shoot root. The first, it is set root or cutting root, also called temporary root, there provide during 6-15 days after planting. The roots reproduce from sett namely root primordia (Glover, 1967). At 3 months, the sett roots are decreased less than 2 percent of root dry weight (van Dillewijn, 1952). The second, the roots which emerged from the base of shoot 5-7 days after planting (Smith *et al*., 2005). It is thicker than sett root and function as a main root system for sugarcane (Glover, 1967). In general, the development stage of the root strongly contributes to the total above-ground growth of plants, and the size of both parts might be inter-related (Gregory, 2006). Roots may involve with corresponsive stalk growth. In sugarcane, the relationship between root and shoot growth was investigated under diverse conditions, as occurring positive correlation (Smith *et al*., 1999). Increased root traits of sugarcane might lead to increased shoot growth (Smith *et al*., 2005). Moreover, large root systems support physiological and morphological traits of the above-ground parts under early drought stress (Khonghintaisong *et al*., 2018). In this context, an improved understanding of root growth and functioning in sugarcane might be a strategy to improve productivity (Smith *et al*., 2005).

To date, the relationship between dry matter accumulation in cane stalks and root expression is not clearly understood. It is still unclear whether each tiller is directly promoted by its roots. In addition, the relationships between individual stalks and the corresponding below-ground parts have not been studied in detail. Therefore, the aim of this study was to investigate root characteristics of individual tillers of different sugarcane cultivars and their relationship with above-ground plant parts. This information might represent a key factor for improving sugarcane yields in selection breeding programs.

Material and Method

Experimental design and cultural practices: This research was carried out at the Agronomy Research Station in Khon Kaen University, Thailand (lat 16° 28´ N, long 102° 48´ E, 200 m asl), in 2015. A completely randomized design with four replications was used. Six sugarcane cultivars (KK3, KPS01-12, KKU99-02, KKU99-03, UT12 and UT13) commonly used in Thailand, with different drought-resistance levels, were assigned as treatments. Cultivars KK3, KPS01-12 and UT13 were identified as highly tolerant to water stress, whereas cultivars KKU99-02, KKU99-03 and UT12 were susceptible to drought. First, one sugarcane sett was planted into a plastic bag for a uniform germination of sugarcane seedlings, which were then transplanted to pots (50 cm diameter, 50 cm height) at 30 days after planting. Each pot was filled with soil from the Yasothon series (fine-loamy; siliceous, isohypothermic, Oxic Paleustults) up to a height of 40 cm. The soil was uniformly packed from the top to the bottom of the pot. Water was applied to meet the requirements of sugarcane as described in Jangpromma *et al*., (2010). Fertilizer was applied separately as basal fertilization at the time of transplanting and as top dressing at the tillering stage (around 3 months after transplanting). Weeds were controlled manually. In the tillering phase, every germinated tiller was tagged to define a tiller sequence.

Data collection

Above-ground parameters: Immediately after transplanting, we measured plant height from the soil surface to the dewlap of the first tiller and counted the number of tillers. Both characteristics were measured at intervals of 15 days from 100 to 175 days after planting (DAP). At 175 DAP, the above-ground plant parts from each pot were collected for determination of green leaf number, dry leaf number, stalk and leaf weight. From the stem and leaf samples, we randomly removed 10 % and oven-dried them at 80°C for 72 h or until constant weight. Stem and leaf dry meter were determined separately.

Root traits: Root samples were collected at the end of the tillering phase (175 DAP). Root samples were washed manually with tap water to remove soil. Each sequence of tiller was counted to determine root number; subsequently, we measured root volume (RV), root surface area (RSA), and root length (RL) using a root scanner (Perfection, Epson V700) and Winrhizo Pro (s) (V. 2004a, Regent Instruments, Inc). We then determined root dry weight after oven-drying at 80^{o}C for 72 h or until constant weight. Root to shoot ratio was calculated as root dry weight per unit total stem and leaf dry weight.

Statistical analysis: The measured data were subjected to analysis of variance using statistic 8 following a completely randomized design. Comparison of parameters was performed using the Least Significant Difference (LSD) test. The correlation between above-ground and root traits of the total tiller as well as the correlation between with top growth and root characteristics of individual tillers were performed using simple correlation (Gomez & Gomez, 1984).

Results and Discussion

Sugarcane growth patterns: The six sugarcane cultivars had different tiller generation patterns, since the peaks of tiller production varied with the time series. Cultivars KK3 and KKU99-02 showed maximum tiller emergence during the initial stage of 3–4 months or 130 DAP; after that, tillers were reduced gradually due to the deterioration of the late tiller generation. The tiller numbers for KKU99-03 were highest during the initial stage of 3–4 months, but the reduction in the tiller number was lower. In contrast, KPS01-12 and UT13 showed a slightly increased tiller production until the end of the tillering phase and had no tillering deterioration. Cultivar UT12 had consistent tiller numbers during the initial tillering phase, and the tillers were maintained until the end of the developmental stage. However, KK3 had the highest tiller number during the peak period and thereafter, but showed high tiller deterioration (Fig. 1). At 175 DAP, three drought tolerant cultivars: KK3, KPS01-12 and UT13 had rather high tiller numbers, whereas UT12, KKU99-02 and KKU99-03 which were defined as drought susceptible cultivars, were 4^{th}–6^{th} in tiller numbers, respectively.

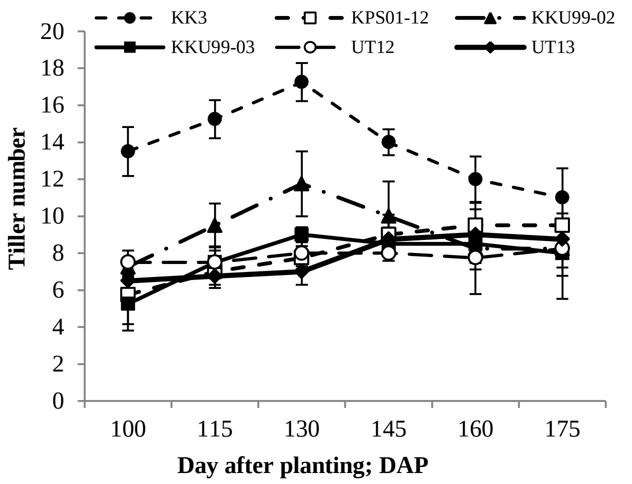

Fig. 1. Tiller numbers of the six sugarcane cultivars KK3, KPS01-12, KKU99-02, KKU99-03, UT12 and UT13 in the tillering phases.

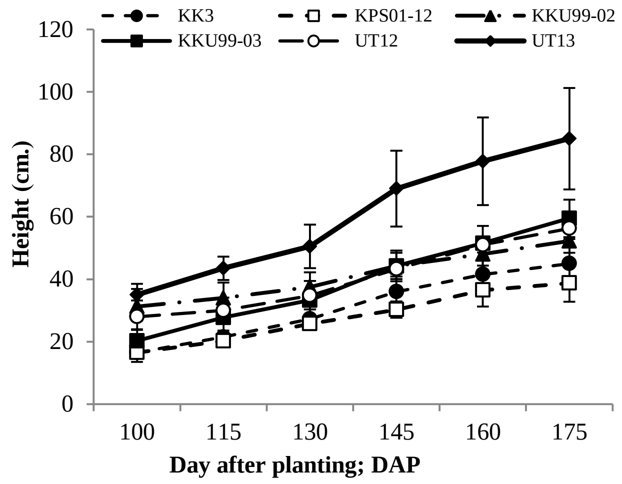

Fig. 2. Height of six sugarcane genotypes; KK3, KPS01-12, KKU99-02, KKU99-03, UT12 and UT13 in tillering phases.

High tiller numbers indicate high initial growth, which is a basis for high productivity (Guruprasad *et al*., 2015; Samiullah *et al*., 2015; Khan *et al*., 2018). In our study, the tiller numbers of KK3, KKU99-02 and KKU99-03 were decreased due to tiller mortality after the maximum tiller phase. The maximum number of sugarcane tillers was produced 2–3 months after planting; after this, tiller death began, which varied with genotype, tiller class, time of planting and cultural conditions (Vasantha *et al*., 2012; Vasantha *et al*., 2014). Most of the dead stalks tended to be young tillers, which were damaged because of competition with stronger tillers (Buenaventura & Rosario, 1978). The yields of sugarcane cultivars have been determined to be largely related to their tillering abilities (Joshi *et al*., 1996).

Six sugarcane varieties had a similar height patterns that gradually increased over time. However, KKU99-03 exhibited a high stem growth rate, while UT13 had the tallest stem height when compared to the other cultivars (Fig. 2). Height increase depends on the genotype and the environmental conditions (Khonghintaisong *et al*., 2018). Cane height can therefore be seen as a combination between environmental conditions and cultivar characteristics; height plays an important role in the final yield (Samiullah *et al*., 2015).

Above-ground dry matter: Stalk dry matter was highest in the main tiller when compared with other tillers. We observed different patterns in the stalk dry weights of the different varieties. Cultivars KK3, UT12 and UT13 could separate into two groups consisting of: 1) the first to the fourth tillers having a high stalk dry weight and 2) the fifth to seventh tillers being smaller (Fig. 3a). The stalk dry weight of KKU99-03 was gradually reduced following the tiller order. For cultivars KPS01-12 and KKU99-02, there was no clear stalk dry weight pattern, while KKU99-02 lost three tillers (Fig. 3a).

The patterns of leaf dry weights in relationship to tiller order were different for each sugarcane cultivar. Cultivars UT12 and UT13 had large leaf dry weights for early tillers (from the first to the fourth tillers), and smaller leaf dry weight were shown for late tillers (from the fifth to the seventh tillers), whereas other cultivars tended to sort from large to small with early to late tillers (Fig. 3b). In contrast, the biomass of the tiller series showed the same pattern as stalk dry weight, since stalk weight contributed more than leaf dry weight to biomass (Fig. 3c).

Tillering capability and consequent growth efficiency determine sugarcane yields (Joshi *et al*., 1996; Tahir *et al*., 2014). Vasantha *et al*., (2012) reported that the tillers formed up to 90 days represented 90% of millable canes. It is obvious that higher numbers of millable canes lead to higher total volumes of stalks per hill and, thus, higher productivity (Matsuoka & Stolf, 2012). The differences in mortality and shoot dry matter accumulations of tillers might be a result of characteristics related to water and nutrient uptake. The cultivars that are competitive for water and nutrients would have higher growth efficiencies (Buenaventura & Rosario, 1978)

Root trait patterns: The root length patterns of cultivars KK3, UT13 and KKU99-02 did not follow the order of tillers, but the main tiller had the greatest length. In cultivars KPS01-12, KKU99-03 and UT12, root length followed the order (from high to low) of the tiller sequence (Fig. 4a). However, cultivars KK3 and KPS01-12 which were defined as drought tolerant cultivars, had higher root length for the 4^{th}–7^{th} tillers, and thus might have maintained a high tiller number at 175 DAP (Fig. 1). Obviously, the susceptible cultivars, namely KKU99-02 and KKU99-03 had short roots on younger tillers (4^{th}–7^{th} tillers). In addition, root surface area and root volume showed the same patterns as root length (Fig. 4b and 4c). The primary tiller represented most of the root surface area and the root volume. In the six sugarcane cultivars, root patterns were different, while all root traits were highest for the main tiller.

Six sugarcane cultivars were different for root dry weight, as revealed by the low dry weights in KKU99-02 and KKU99-03. Cultivars KK3, KPS01-12, UT12 and UT13 showed no decreases for root dry weight with tiller order. In all six cultivars, root dry weight was highest for the main tiller (Fig. 5a). Similarly, the maximum numbers of roots were presented in the main tillers. Root number followed the order (from high to low) of the tiller sequence, except for cultivars KKU99-02 and UT12 (Fig. 5b).

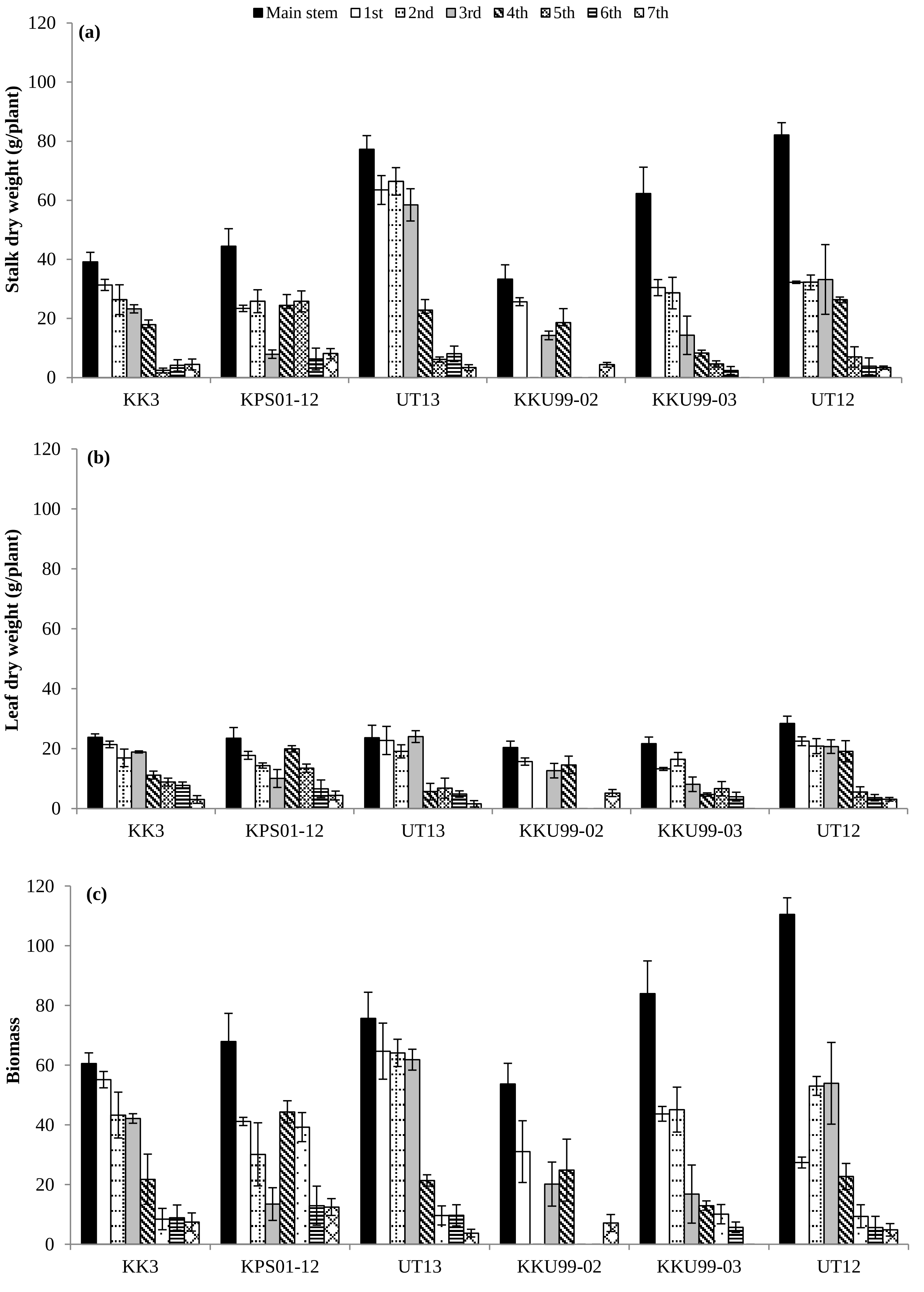

Fig. 3. Stalk dry weights and leaf dry weights for the six sugarcane varieties: KK3, KPS01-12, KKU99-02, KKU99-03, UT12 and UT13 in the tillering phases of eight tillers: main stem, 1st, 2nd, 3rd, 4th, 5th, 6th and 7th.

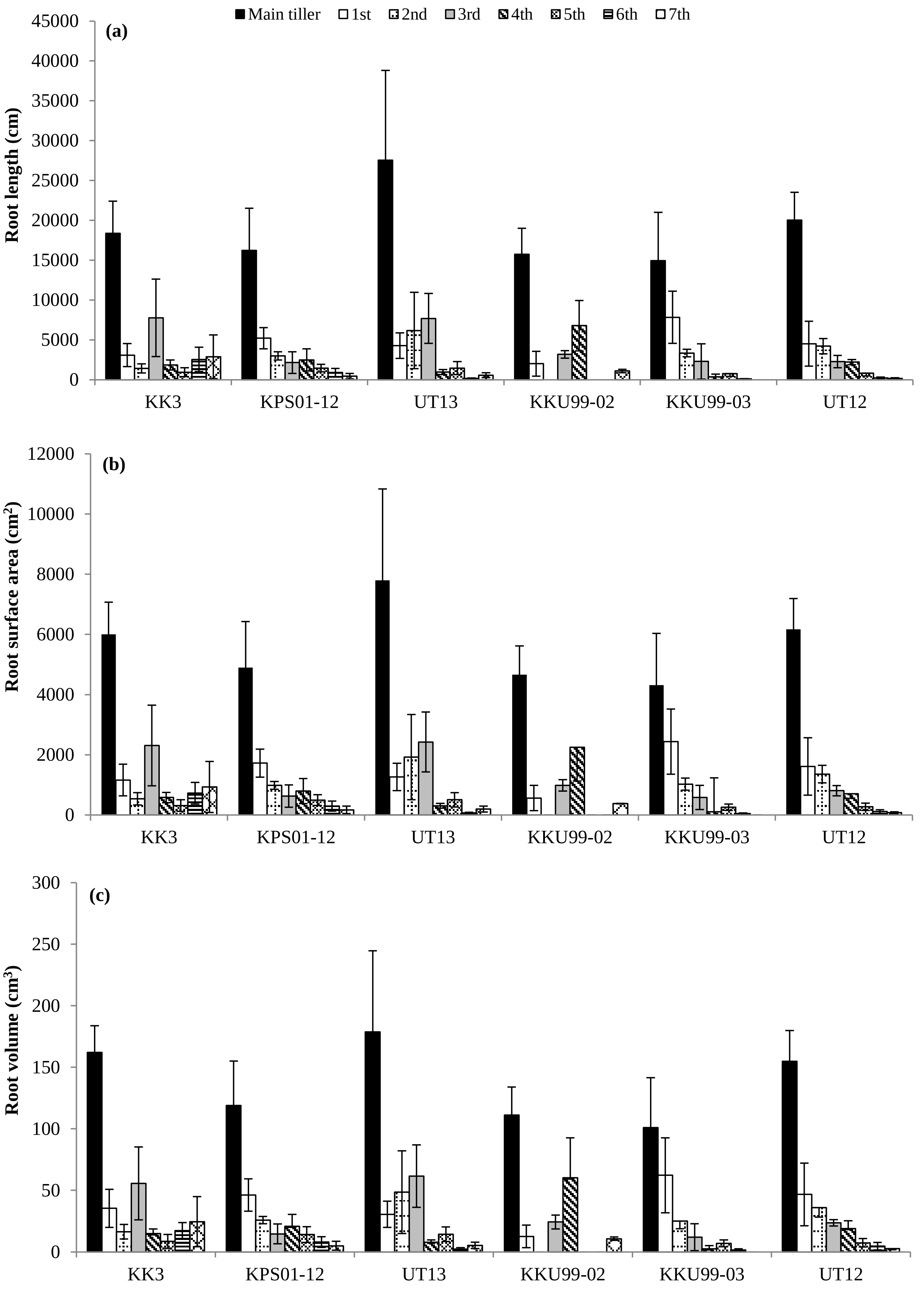

Fig. 4. Rooting traits; root length, root surface area, root volume of eight tillers; maim stem, 1st, 2nd, 3rd, 4th, 5th, 6th and 7th of the six sugarcane varieties in the tillering phases.

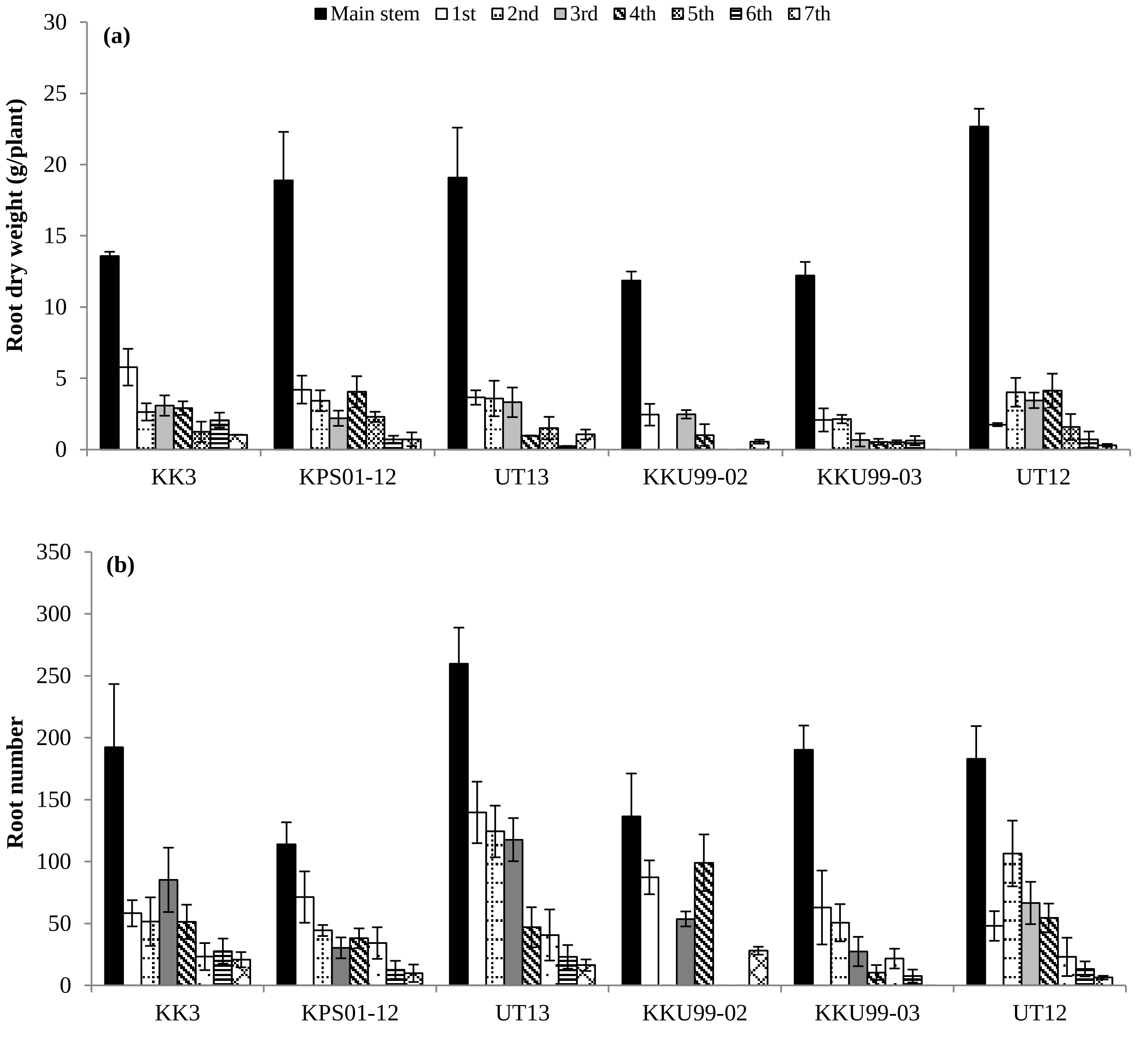

Fig. 5. Root dry weights and root numbers of the six sugarcane varieties: KK3, KPS01-12, KKU99-02, KKU99-03, UT12 and UT13 for eight tillers: main stem, 1st, 2nd, 3rd, 4th, 5th, 6th and 7th in the tillering phases.

The root system plays a key role in shoot development and sugarcane productivity (Smith *et al*., 2005). Large root systems with high root surface areas and deeper roots increase water and nutrient uptake (Wood & Wood, 1967; Inman-Bamber *et al*., 2012). Moreover, a reduction in upper soil layer moisture content increases the root activity of sugarcane at a deeper soil layer (Inman-Bamber *et al*., 2003). Good root performance, which included good responses in root volume, root surface area and root length to early drought stress, also maintains the morphological and physiological traits of the above-ground parts (Khonghintaisong *et al*., 2018). The developmental stage of the root strongly determines the growth of above-ground plants, and there is inter-relation between the sizes of both parts, as large shoots are linked to large root systems (Gregory 2006). In sugarcane, the root system could closely correlate with biomass (Jangpromma *et al*., 2012)

In this report, drought tolerant cultivars had high tiller numbers in the tillering phase due to the good root performance of individual tillers, especially the younger tillers. Moreover, there were parallel expressions between shoot and root traits of sugarcane cultivars, i.e., in terms of maximum height and above-ground dry weight, with the maximum values of root traits present in the main stem. In addition, root length, root volume and root surface areas were possibly correlated.

Relationships between root traits and above-ground characteristics: In the tillering phases, the correlation coefficients between the sum of root characteristics for all tillers, i.e. root surface area, root volume and root length, and above-ground characteristics, such as shoot dry weight, corresponded significantly and positively (Table 1). Obviously, the root characteristics contributed to the accumulation of above-ground dry matter in sugarcane.

Table 1. Correlation coefficients (N = 24) between root traits (root length, root surface area and root volume) and above-ground plant characteristics (shoot dry weight, leaf dry weight, leaf area and tiller number) of the sum of all tillers.

	Shoot dry weight	Leaf dry weight	Leaf area	Tiller number
Root length	0.707 **	0.295	0.128	-0.265
Root surface area	0.707 **	0.303	0.146	-0.267
Root volume	0.790 **	0.648 **	0.550 **	0.017

**Significant at a 0.01 probability level

Table 2. Correlation coefficients (N = 48) between root traits (root length, root surface area, root volume, root number, root dry weight and root/shoot ratio) and aboveground plant characteristics (shoot dry weight, leaf dry weight, biomass and leaf area) of the main to the seventh tillers.

		Shoot dry weight	Leaf dry weight	Biomass	Leaf area
KK3	Root length	0.441	0.627	0.5148	0.765 *
	Root surface area	0.468	0.643	0.5383	0.775 *
	Root volume	0.492	0.657	0.5597	0.781 *
	Root number	0.611	0.772 *	0.6794	0.875 **
	Root dry weight	0.650	0.758 *	0.7001	0.829 *
	Root/shoot ratio	-0.536	-0.274	-0.4534	-0.300
KPS01-12	Root length	0.821 *	0.746 *	0.8141 *	0.700
	Root surface area	0.830 *	0.756 *	0.8230 *	0.716 *
	Root volume	0.840 **	0.768 *	0.8345 *	0.735 *
	Root number	0.885 **	0.864 **	0.8980 **	0.691
	Root dry weight	0.845 **	0.758 *	0.8346 **	0.856 **
	Root/shoot ratio	0.569	0.618	0.5989	0.528
UT13	Root length	0.720 *	0.660	0.7114 *	0.594
	Root surface area	0.733 *	0.678	0.7257 *	0.607
	Root volume	0.746 *	0.695	0.7397 *	0.619
	Root number	0.882 **	0.830 *	0.8764 **	0.764 *
	Root dry weight	0.669	0.595	0.6565	0.556
	Root/shoot ratio	-0.260	-0.263	-0.2623	-0.175
KKU99-02	Root length	0.824 *	0.802 *	0.8197 *	0.752 *
	Root surface area	0.819 *	0.805 *	0.818 *	0.758 *
	Root volume	0.812 *	0.806 *	0.8137 *	0.764 *
	Root number	0.951 **	0.961 **	0.9599 **	0.947 **
	Root dry weight	0.808 *	0.746 *	0.7879 *	0.674
	Root/shoot ratio	0.782 *	0.783 *	0.7865 *	0.720 *
KKU99-03	Root length	0.969 **	0.874 **	0.9538 **	0.796 *
	Root surface area	0.967 **	0.877 **	0.9526 **	0.795 *
	Root volume	0.961 **	0.875 **	0.9474 **	0.791 *
	Root number	0.968 **	0.884 **	0.9556 **	0.793 *
	Root dry weight	0.921 **	0.808 *	0.9004 **	0.706 *
	Root/shoot ratio	0.262	0.268	0.2660	0.081
UT12	Root length	0.947 **	0.709 *	0.901 **	0.769 *
	Root surface area	0.951 **	0.724 *	0.9088 **	0.782 *
	Root volume	0.956 **	0.740 *	0.9168 **	0.795 *
	Root number	0.967 **	0.854 **	0.9568 **	0.872 **
	Root dry weight	0.923 **	0.657	0.8689 **	0.691
	Root/shoot ratio	0.387	0.044	0.2985	0.174

*, ** Significant at 0.05 and 0.01 probability levels, respectively

For roots of individual tillers, the correlation coefficients between above-ground parts and root traits of sugarcanes differed between cultivars. Cultivar KK3 showed positive relationships between leaf dry weight and root number, leaf dry weight and root dry weight, and all root traits excluding the root to shoot ratio were positively correlated with leaf area. For KPS01-12, biomass, leaf dry weight and shoot dry weight were significantly correlated with the root traits, i.e. root length, root surface area, root volume and root number, and only root surface area, root volume and root dry weight were correlated with leaf area. For KKU99-02, almost all root traits and above-ground parts were related, apart from root dry weight and leaf area. Cultivar KKU99-03 showed a positive correlation between below-ground and above-ground plant characteristics for almost all root traits except the root to shoot ratio. Root length, root surface area, root volume and root number of UT12 were associated with all shoot characteristics, which was also the case for shoot biomass and root dry weight. However, there were no correlations between the root to shoot ratio and all above-ground plant characteristics for UT12. For cultivar UT13, we observed positive correlations for root length, root surface area, root volume and root number with shoot dry weight and biomass; there was also a relationship between leaf dry weight and area as well as root number (Table 2).

Increased stalk numbers in the late growth period of sugarcane did not contribute to increased yields, whereas stalk dry matter accumulation in this period significantly affected yields (Bell & Garside, 2005). In general, the development stage of the root strongly contributes to the total above-ground growth of plants, and root size and shoot systems may be inter-related (Gregory, 2006). In sugarcane, the relationship between shoot and root growth has been investigated under diverse conditions and has shown a positive correlation (Smith *et al*., 1999). However, there are no reports about the relationship between root characteristics and the individual associated tiller. In our research, root length, root surface area, root volume and root numbers were positively correlated with biomass and stalk dry weight for almost all cultivars, except for the cultivar KK3. These root characteristics have the potential to be used as criteria to assess shoot performance. In contrast, the root to shoot ratio might not be an appropriate characteristic to assess shoot growth, and the root dry weight response varied between cultivars.

Conclusion

The six sugarcane cultivars showed different patterns of tiller generation. Cultivar KK3 had the highest tiller number at the peak and after the peak periods, although it had a high tiller deterioration. All sugarcane varieties had a similar height pattern; height gradually increased over time. However, KKU99-03 had a high growth rate, while UT13 had the highest stem height. The different cultivars differed in root trait patterns, and all root traits were highest in the main tillers. In some cultivars, root length followed the order (from high to low) of the tiller sequence. The correlation coefficients between the sum of roots in all tillers and the shoot dry weight were significantly positive. In almost all cultivars, root length, root surface area, root volume and root number were positively correlated with biomass and stalk dry weight, except for genotype KK3. These root characteristics can potentially be used as criteria to assess shoot performance. In contrast, the root to shoot ratio might not be an appropriate characteristic to assess shoot growth, and the root dry weight varied between cultivars.

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