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Accumulation and partitioning of nitrogen, phosphorus and potassium in different varieties of sweet sorghum

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ABSTRACT

This study investigated changes in accumulation and partitioning of nitrogen (N), phosphorus (P), and potassium (K) with harvest dates of early, middle, and late maturity sweet sorghum varieties in 2006 and 2007 in North China. All the varieties exhibited an obvious trend of decrease in concentrations of N, P and K in aboveground plants from elongation to 60 days after anthesis (DAA). The reduction in nutrient concentrations was found in the order of K ($14.5 - 4.5\,g\,kg^{-1}$) > N ($13.3 - 7.4\,g\,kg^{-1}$) > P ($2.40 - 0.96\,g\,kg^{-1}$). Conversely, N, P, and K accumulation significantly increased from elongation to anthesis, and continued to increase until 40 DAA. The accumulation of N, P, and K at maturity (40 DAA) was 128–339 $kg\,ha^{-1}$, 30–75 $kg\,ha^{-1}$ and 109–300 $kg\,ha^{-1}$, respectively. Between elongation and anthesis, the middle and late maturity varieties had a higher ratio of N (50–82%), P (55–83%), and K (62–88%) accumulation than the early varieties (51–64% for N, 40–62% for P, and 55–75% for K). Sweet sorghum exhibited only one important K uptake stage from elongation to thesis according to the accumulation ratio (percentage of the nutrient accumulated at a given stage relative to that at physiological maturity) and rate (kilogram of nutrient accumulated per day per hectare). The stage from anthesis to grain maturity was the second important N and P uptake period. During the delay harvest period between 40 and 60 DAA, the early varieties exhibited significant increases in N accumulation; and the late varieties exhibited the reverse. P accumulation did not decrease significantly, whereas K accumulation decreased for all varieties in both years. Although of the N and P concentrations in straw were significantly lower than in grains, the N, P and K accumulation in straw was 2.2–9.3, 1.7–7.7, and 8.1–30.5 times higher than in grains, respectively. The concentrations of N and P in leaves were higher than in stems after anthesis. We found significantly higher accumulation of P and K in stems than in leaves, with a comparable N accumulation. The findings are helpful to make a fertilization regime recommendation for sweet sorghum production as a bioethanol crop in North China. It also suggests a further genetic improvement for optimizing nutrient use.

1. Introduction

Sweet sorghum (*Sorghum biocolor* (L.) Moench) is a C_4 plant characterized by high biomass and sugar yield (Amaducci et al., 2004; Antonopoulou et al., 2008; Gnansounou et al., 2005; Zhao et al., 2009). The high carbohydrate content of its stalk is similar to sugarcane, but its water requirement is much lower (Almodares and Hadi, 2009). Its wide adaptability (Gnansounou et al., 2005; Kangama and Rumei, 2005) and resistance to salinity and drought (Tsuchihashi and Goto, 2004; Rajagopal, 2008; Wortmann et al., 2010) indicate less competition with food security for human beings, as a result of the possibility to exploit less resources such as productive land and irrigation water for food crops. Sweet sorghum therefore has been widely considered a feedstock for producing fuel ethanol (Buxton et al., 1999; Liu et al., 2008; Almodares and Hadi, 2009; Yu et al., 2008; Liu and Lin, 2009) and biodiesel (Gao et al., 2010). China is not only currently facing an energy shortage, but is also pressured to reduce CO_2 emission from the international community. Sweet sorghum plantations are among the most promising solutions (FAO, 2002; Cheng et al., 2009; Li and Chan-Halbrendt, 2009; Tian et al., 2009).

Although the dry matter and chemical composition, particularly soluble and insoluble carbohydrates, have been well documented in sweet sorghum, little is known about its mineral nutrient accu-

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mulation. Sorghum has been recognized as a "nutrient depletion crop" by farmers, compared with cereals in China. The dynamics of mineral element uptake and partitioning are essential for forming a high biomass yield, and are closely related to nutrient cycling in the soil–plant-processing system (Epstein and Bloom, 2005). For the most field crops, some organs (e.g. grains, tuber, etc.) are harvested and the field residues are possibly incorporated into soils and compensate partially the nutrient losses. It is different that the entire aboveground part of sweet sorghum, as a bio-fuel feedstock, are considered to be harvested for ethanol production from sugar, starch, and cellulosic materials. The understanding of nutrient dynamics of the energy crop will be helpful to maintain soil nutrient balance via genetic improvement or/and fertilization. Of the essential mineral nutrients, nitrogen (N), phosphorus (P), and potassium (K) are the most important macro-nutrients affecting crop yields on one hand, fertilization for the three elements constitutes a considerable proportion of production cost on the other. It is essentially important for bio-ethanol production to reduce its feedstock cost. Information of N, P, and K uptakes and partitioning of sweet sorghum could serve for optimizing fertilization application for a high biomass yield.

In our previous study we investigated the dynamics of biomass and chemical composition of sweet sorghum varieties differing in physiological maturity in North China during in growth (Zhao et al., 2009). In the present study we tested the N, P, and K contents in five sweet sorghum cultivars with a crop cycle length that varied between 111 and 165 days (the same field experiment as our previous study) in North China. The objectives of this study were: (1) to investigate the changes in accumulation and partitioning of N, P, and K with the harvest date of sweet sorghum varieties; and (2) to determine the differences in accumulation and partitioning of N, P, and K in sweet sorghum between early, middle, and late maturity varieties.

2. Materials and methods

2.1. Study site

A field study was conducted in 2006 and 2007 at the Shangzhuang Experimental Station (39°56′N, 116°20′E) of China Agricultural University in Beijing, China. The site has a continental monsoon type climate, with an average multi-annual solar radiation of 2423 h and average multi-annual temperature of 11.5 °C. Annual mean precipitation is 554.2 mm, falling mostly in July and August. Monthly precipitation and air temperature data during the study period and main physical and chemical properties of the soils in the two years are presented in Zhao et al. (2009).

2.2. Experiment design and crop cultivation

Sweet sorghum hybrid Zaoshu-1 (ZS1), Chuntian-2 (CT2), and inbreed Italy (ITY), Lvneng-3 (LN3), M-81E were tested using a randomized block design with four replications. It was sown on April 26 in 2006 and 2007. The ITY and ZS1 varieties exhibited early maturity (111–116 days), CT2 exhibited middle maturity (138–143 days), and LN3 and M-81E exhibited late maturity (160–165 days). Basal fertilizer of 48 kg N ha^{-1} as urea, 90 kg P_2O_5 ha^{-1} as diammonium phosphate and 50 kg K_2O ha^{-1} as potassium sulfate were applied just before sowing. 48 kg N ha^{-1} as urea and 50 kg K_2O ha^{-1} as potassium sulfate were applied at elongation, and 24 kg N ha^{-1} as urea were applied at anthesis. Sweet sorghum grains matured around 30 days after anthesis (DAA) for the early varieties and 36–44 DAA for the middle and late varieties. Further details of the crop management and the main morphological phases of sweet sorghum were described by Zhao et al. (2009).

2.3. Sampling and measurements

Ten aboveground sweet sorghum plants were taken on the date of elongation and 0, 20, 40, and 60 DAA from each plot. In 2006, each plant was divided into stems, leaves and a panicle for biomass estimation. One internode was taken after every two internodes from the base of each plant and was cut into 10–15 cm long pieces. The grains were threshed and the panicle axis and rachis branches were cut and mixed with stem pieces proportionately on a basis of oven-dried weight. In 2007, apart from grains, the tissues were not separated and a mixed plant sample of the whole plant was made. After being placed in an individual paper bag, it was oven dried at 70 °C to constant weight in order to gravimetrically estimate plant biomass. The changes in biomass with harvest time are presented in Zhao et al. (2009). The dried samples were ground with a Wiley mill to pass through 0.5 mm mesh for nutrient determination. The ground samples were stored at 4 °C for qualitative analyses.

2.4. Chemical analysis

Grains, leaves and stems were separated, oven-dried to constant weight at 70 °C and ground for N, P, and K analyses following Kjeldahl digestion with H_2SO_4–H_2O_2 (Wolf, 1982). N concentration was determined by semimicro-Kjeldahl digestion and distillation (Nelson and Sommers, 1980). P concentration was determined by the vanadomolybdate yellow method (Jackson, 1958). K concentration was measured using a flame spectrophotometer. All analyses were performed in duplicate. The chemical composition of the plant parts is presented as nutrient concentration (g kg^{-1}).

2.5. Calculation and statistical analysis

The nutrient accumulation in grains, leaves and stems was computed as the product of the concentration multiplied by the dry weight of biomass. The nutrient accumulation ratio (%) at different growth stages was the percentage of the nutrient accumulation at a given stage relative to that at physiological maturity (40 DAA). The nutrient accumulation rate (kg ha^{-1} day^{-1}) at each growth stage was obtained from the nutrient accumulation divided by the number of days of the growth stage. Means and standard errors were calculated for the four replicates from each treatment. ANOVA was conducted using SAS (SAS Institute, 1999). The statistical significance of the differences between means was determined by the least significant difference. All significant results are reported at the $P < 0.05$ level.

3. Results

3.1. N, P, and K concentrations

Sweet sorghum exhibited an obvious trend of decrease in N, P and K concentrations in aboveground plants from elongation to 60 DAA across all the early, middle, and late maturity varieties we used in 2006 and 2007 (Fig. 1). N and K concentrations ranged between 23.7–32.4 g kg^{-1} and 19.6–29.7 g kg^{-1} at elongation and were significantly (2.3–3.2 times and 1.6–3.5 times) higher ($P < 0.001$) than at anthesis (0 DAA) on the whole plant basis. The variations in P concentrations between elongation (2.1–3.3 g kg^{-1}) and anthesis (1.5–2.4 g kg^{-1}) were smaller than the N or K concentration (Fig. 1). The N, P, and K concentration in aboveground plants at grain maturity (40 DAA) was 7.5–10.2 g kg^{-1}, 1.4–2.5 g kg^{-1} and 5.0–9.6 g kg^{-1}, respectively. The reduction in nutrient concentrations from anthesis to 60 DAA was in the order of K (14.5 – 4.5 g kg^{-1}) > N (13.3 – 7.4 g kg^{-1}) > P (2.40 – 0.96 g kg^{-1}) for all the varieties in both years. Although the K concentration in