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Water and radiation use efficiencies explain the effect of potassium on the productivity of cassava

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ABSTRACT

We studied the effects of potassium (K) and its interactions with nitrogen (N), phosphorus (P) and harvest time on the productivity, water use efficiency (WUE) and radiation use efficiency (RUE) of cassava under rain-fed conditions. A field experiment was conducted during two consecutive years on K-deficient soils in Djakakope and on relatively K-rich soils in Sevekpota in Southern Togo, West Africa. Fifteen fertiliser combinations involving K and N rates of 0, 50 and 100 kg ha^{-1} each, and P rates of 0, 20 and 40 kg ha^{-1} were tested. Monthly measurements of leaf area index from 3 to 11 months after planting and daily weather data were used to estimate light interception, RUE, potential water transpiration and WUE of cassava. Overall WUE was 3.22 g dry matter kg^{-1} water transpired and RUE was 1.16 g dry matter MJ^{-1} intercepted photosynthetic active radiation (PAR). On the K-deficient soils, application of K increased WUE and RUE by 36–41% compared with 2.81 g dry matter kg^{-1} water transpired and 0.92 g dry matter MJ^{-1} intercepted PAR achieved without K, respectively. However, the effect of K on cassava growth depended on N availability. Applications of N had relatively weak effects on RUE and WUE, but induced a positive correlation between RUE/WUE and K mass fractions in the plant, and increased the cumulative amount of light intercepted by 11–51%, and the cumulative amount of water transpired through increased leaf area by 13–61%. No significant effect of P on WUE and RUE was observed. Increased cassava yields could be achieved under rain-fed conditions in West Africa through enhanced K management to increase RUE and WUE, along with sufficient N supply for improved light interception and water transpiration by the crop.

1. Introduction

Potassium is a key determinant of the productivity of root crops, including cassava (*Manihot esculenta*, Crantz). It plays many roles such as stimulating the photosynthetic activity of leaves, increasing the translocation of photosynthates to the storage roots (Hillocks et al., 2002), and regulating stomatal aperture and closure (Chérel et al., 2014), which helps to minimise water losses during drought. Potassium deficiency can lead to reduced yield and starch content of storage roots (Nair, 1986). A lack of K can also lead to an increased hydrogen cyanide (HCN) content of cassava roots, especially when N supplies are inadequate (Marschner and Marschner, 1995). High HCN content in storage roots constitutes a serious health hazard, since fresh cassava roots are popular food in West Africa.

Cassava productivity can be measured as function of the radiation use efficiency (RUE) and the amount of light intercepted (Pellet and El-Sharkawy, 1997). It can also be expressed as the product of water use efficiency (WUE) and the amount of water transpired (El-Sharkawy and Cock, 1986). Thus, a linear relationship is assumed under favourable conditions between biomass production and light interception, which defines RUE (Pellet and El-Sharkawy, 1997; Sinclair and Muchow, 1999; Veltkamp 1985), and between biomass production and water consumption by the crop, which determines WUE (Yao and Goué, 1992). The amount of water consumed by the crop can be calculated as the amount of rainfall received during the growing season (generally unreliable method, as it neglects

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drainage, run-off, and changes in soil moisture), or as the amount of water evapo-transpired, or transpired during the growing season. When WUE is based on water transpiration, it is also referred to as transpiration efficiency (Siahpoosh and Dehghanian 2012; Zhang et al., 1998). El-Sharkawy and Cock (1986) reported WUE value of 2.9 g total biomass DM per kg of water transpired for cassava. Reported values of WUE based on evapo-transpiration range from 0.4 to 4.8 g DM per kg water (Lemon (1969) as cited by Yao and Goué (1992)). Thus, it is important to define the units used to assess WUE. Pellet and El-Sharkawy (1997) obtained RUE values between 1.15 and 2.30 g DM per MJ intercepted light under a high rainfall regime of 1800 mm per year. Both light interception and water transpiration depend on the dynamics of the leaf area index (LAI) of the crop, highlighting the importance of LAI in assessing RUE and WUE. We are not aware of any studies to the RUE and WUE dynamics of cassava cultivars commonly promoted in West Africa such as TME 419 (highly promoted in the cassava belt in Nigeria, and referred to as “Gbazekoute” in Togo) and TMS 30572 (“Afisiafi” in Ghana, also grown in Nigeria). Assessing these parameters will inform cassava growth models simulating potential and water-limited yields of cassava in West Africa.

The application of K fertilisers increases cassava productivity on K-deficient soils (Ezui et al., 2016; Howeler 1991; Kang 1984; Sogbedji et al., 2015). It is however poorly documented how K affects the interaction between RUE, light interception and cassava productivity. Similarly, information on the effect of K on WUE and water transpiration by cassava productivity is scarce. It is unclear whether K is most active in light interception or in efficient use of light or in both. Moreover, the dynamics of K impacts on RUE and light interception as well as on WUE and water transpiration during cassava crop life as affected by the availability of N and P is poorly reported. This hinders our ability to improve K management in relation to N and P availability, needed to increase cassava productivity in West Africa. In this paper, we address these knowledge gaps.

This paper aims to assess the interaction between K and the availability of N and P on the RUE, light interception, WUE, transpiration, dry matter and harvest period of cassava under rain-fed conditions in West Africa. We hypothesised that: i) K increases either RUE or light interception through its interaction with N and P; ii) K increases WUE or water transpiration through its interaction with N and P.

2. Material and methods

2.1. Location, climate and soils

A field experiment was carried out at two locations in the Coastal Savannah agro-ecological zone of Southern Togo: Sevekpota (6.437^{0}N, 0.959^{0}E, with an elevation of 121 m above sea level – masl) and Djakakope (6.464^{0}N, 1.597^{0}E, 86 masl). This agro-ecological zone has a bi-modal rainfall distribution, which favours two growing seasons from mid-March through July and from September through mid-November. The experiment was conducted on Ferralsols (Ferrallitic soil with a depth over 200 cm) with a low exchangeable K capacity in Djakakope and on Acrisols (Ferruginous, shallow soils with a hard pan at about 50–80 cm depth) with a relatively better K supplying capacity in Sevekpota.

2.2. Experimental design

A randomised complete block design was used with three blocks of 15 NPK treatments defined to account for interactions among nutrients (Table 1). In total 45 plots of 5.6 × 8 m (44.8 m^2) were laid out at a planting density of 0.8 × 0.8 m (15,625 plants ha^{-1}) as recommended for cassava production in the area. Spacing was 1 m between plots and 2 m between blocks.

Table 1
N, P and K fertiliser rates in kg ha^{-1} in the experimental treatments.

Treatments	N	P	K
P1	0	0	0
P2	100	0	0
P3	0	0	100
P4	100	0	100
P5	0	40	0
P6	100	40	0
P7	100	40	100
P8	0	40	100
P9	0	20	50
P10	50	0	50
P11	50	20	0
P12	50	40	50
P13	50	20	100
P14	100	20	50
P15	50	20	50

2.3. Crop establishment and management

Gbazekoute (TME 419) was selected for this experiment as the main improved cultivar adopted by farmers in Southern Togo. It is generally grown for 10 to 12 months and yields on average 20–25 Mg ha^{-1} of fresh storage roots (30–40% dry matter content). This variety can produce 56 Mg ha^{-1} under optimal management (Odedina et al., 2009). Healthy cuttings were planted on May 22, 2012 (Year 1) and April 23, 2013 (Year 2) in Sevekpota, and May 25, 2012 and May 03, 2013 in Djakakope. Fertiliser was applied as urea (46% N), triple-super phosphate (TSP: 46% P_2O_5, 20% P) and muriate of potash (MOP: 60% K_2O, 50% K). Triple-super phosphate was given in one application at planting, whereas one-third of the urea and MOP were applied 21 days after planting (DAP). The remaining two-thirds were applied at 60 DAP just after weeding. Weeding was carried out four times during the growing season. Harvests in Sevekpota took place on the following dates: 127, 245 and 317 DAP in Year 1 and 139, 238 and 322 DAP in Year 2; in Djakakope the crop was harvested at 318 DAP in Year 1, and at 136, 231 and 322 DAP in Year 2.

2.4. Data collection

Soil samples were composed of five sub-samples per sampling depth before crop establishment on each site at the following depths: 0–20 cm, 20–40 cm and 40–60 cm. These samples were air-dried and ground to pass through a 2 mm mesh sieve. Particle size was determined using the hydrometer method, pH (H_2O, 1:2.5) using a glass electrode pH meter, organic carbon by the Walkley-Black method, total N using Kjeldahl digestion, and available P by the method of Bray 1. Exchangeable cations (K^+, Na^+, Ca^{2+} and Mg^{2+}) were extracted using a single extraction with dilute Silver-Thiourea (AgTU) solution (0.01 M Ag^+) and measured using an atomic absorption spectrophotometer for Ca^{2+} and Mg^{2+}, and a flame spectrophotometer for Na^+ and K^+. All analyses were conducted by the ICRISAT laboratory, Niamey, Niger.

Daily rainfall was measured on each site using manual rain gauges. Daily minimum and maximum temperatures, air humidity, and wind speed data were provided by the nearest weather station at Lomé (6.167^{0}N, 1.250^{0}E, 19.6 masl) for Sevekpota and Tabligbo weather station (6.583^{0}N, 1.500^{0}E, 40 masl) for Djakakope. Daily solar radiation was not measured in the area and therefore, satellite data provided by NASA were used (http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov).