Cassava Productivity Linked to Potassium's Influence on Water Use Efficiency

By Kodjovi S. Ezui, Angelinus C. Franke, Peter A. Leffelaar, and Ken E. Giller

Adequate K supply is requisite for increasing cassava productivity and enhancing resilience to water stress.

Sustainable intensification of cassava production depends largely on maintaining proper soil K fertility.

Low soil fertility is recognized as an underlying factor to poor crop productivity in sub-Saharan Africa. This is associated with sub-optimal agricultural practices including low and unbalanced fertilizer application. Continuous cultivation of cassava without fertilizer application causes severe nutrient depletion, especially for K (Howeler, 2002). This situation of poor crop production is worsened by erratic rainfall patterns under rain-fed conditions with up to 60% yield losses experienced due to drought (Alves, 2002).

Potassium plays key roles in stimulating the photosynthetic activity of leaves, increasing the translocation of photosynthates to the roots, and regulating stomatal aperture and closure (Chérel et al. 2014). However, the influence of K on water use efficiency (WUE) and water transpiration is poorly documented. The focus of this study was to assess the effect of K on cassava yield, WUE, and water transpiration as affected by N and P availability under rain-fed conditions in West Africa.

On-farm experiments were conducted at two sites with contrasting soil K concentrations in southern Togo for two consecutive seasons (**Table 1**). At each experimental site, 15 nutrient combinations of N, P, and K at the rates of 0, 50, and 100 kg N and K/ha, and at 0, 20, and 40 kg P/ha were laid out in a randomized complete block design with three replicates (Ezui et al., 2017). Plot sizes were 5.6 m x 8 m (44.8 m^2) and cassava was planted at the recommended density of 0.8 m x 0.8 m (15,625 plants/ha). Mineral N fertilizer was applied as urea, P fertilizer as triple superphosphate, and K fertilizer as potassium chloride. Sequential harvests were carried out at 4, 8, and 11 months after planting (MAP) on both sites, except in year 1 in Djakakope where the trial was only harvested at 11 MAP.

Table 1. Soil physical and chemical characteristics (0 to 20 cm depth) before crop establishment on the fields in Sevekpota and Djakakope, Togo.

	Sevekpota		Djakakope	
Soil property	Field 1 (2012)	Field 2 (2013)	Field 1 (2012)	Field 2 (2013)
Org. Carbon, g/kg	11.5	12.2	6.2	4.7
Org. Nitrogen, g/kg	0.9	0.8	0.4	0.3
Sodium, mmol/kg	1.2	0.4	0.1	0.1
Potassium, mmol/kg	3.5	1.4	0.4	0.7
Calcium, mmol/kg	18.1	13.6	18.2	17.3
Magnesium, mmol/kg	5.3	4.5	7.1	7.0
Sand, g/kg	536	680	835	858
Silt, g/kg	163	150	52	45
Clay, g/kg	301	170	113	97
pH (H_2O), 1:2.5	6.5	6.5	6.5	6.5
Bray-P1, mg/kg	1.9	3.2	4.5	10.4
Total Phosphorus, mg/kg	189	202	155	194

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Water use efficiency [g dry matter (DM)/kg water] was estimated for each treatment as the weight of the biomass produced over the cumulative amount of water potentially transpired from planting to harvest. Potential transpiration (PTRAN) was based on the Penman equation (Penman, 1948). Cumulative PTRAN was obtained by integrating PTRAN over time, between planting and the different crop harvests. The cumulative PTRAN at each harvest was plotted against the amount of biomass produced at that harvest. The slope of the regression line of this graph is taken as the overall WUE for cassava.

Gross margin for different fertilizer treatments were calculated by subtracting the cost of fertilizers from the value of the cassava produced. We used national average values (± standard deviation) of fertilizer prices in Togo: US$1.72 ± 0.10 per kg N, $3.48 ± 0.37 per kg P, and $1.82 ± 0.19 per kg K (http://africafertilizer.org); and fresh cassava root prices at the farm gate of $0.118 ± 0.040 per kg (CountrySTAT, 2015).

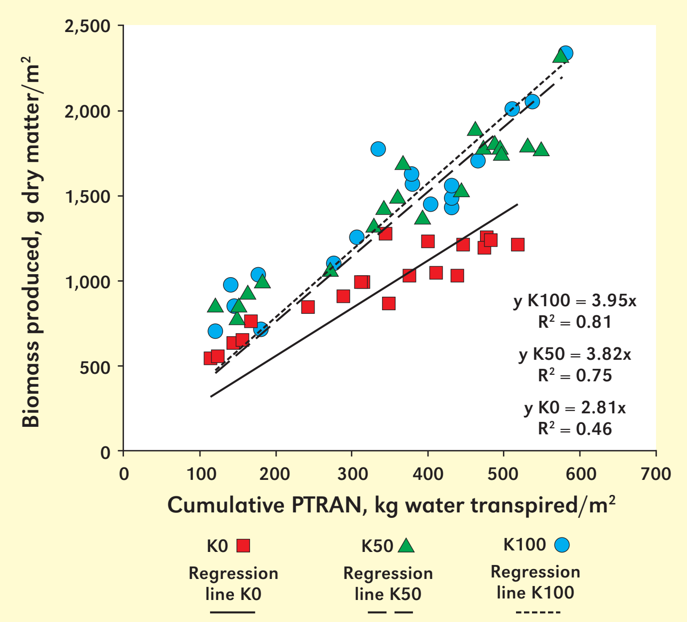

Figure 1. Response of cassava biomass production to PTRAN as affected by K rates in Djakakope, and the related WUE as indicated by the slopes of the regression lines. Each point corresponds to the average of a fertilizer treatment at a given harvest, time, and year.

Table 2. Yield (t root DM/ha) and WUE (g biomass DM/kg water transpired) as affected by N, P, and K fertilizer applications and their significant interactions with harvest time in Djakakope and Sevekpota. For each fertilizer rate of a given nutrient, all rates of the two other nutrients are included.

	Djakakope		Sevekpota	
Factors	Yield	WUE	Yield	WUE
N effects				
0 N	5.59	3.73	6.70	3.99
50 N	7.45	4.11	8.23	3.70
100 N	7.28	3.81	8.39	3.44
p value	*0.006*	*0.051*	*<0.001*	*0.021*
P effects				
0 P	6.30	3.73	7.63	3.68
20 P	7.34	4.13	7.65	3.49
40 P	6.68	3.83	8.03	3.85
p value	*0.089*	*0.296*	*0.094*	*0.277*
K effects				
0 K	4.87	3.14	7.71	3.74
50 K	7.74	4.22	8.56	3.77
100 K	7.71	4.26	7.05	3.51
p value	*<0.001*	*<0.001*	*0.048*	*0.162*
Harvest x N				*0.092*
Harvest x K	*<0.001*			
Harvest x N x K		*0.024*		
P x K				*0.062*

TAKE IT TO THE FIELD

The effects of K on water use efficiency (WUE), root yield, and profitability in cassava are heavily influenced by its balance with N.

Effect of K on WUE and Yield

Overall response of cassava WUE and storage root production to fertilizer applications was higher at Djakakope (**Table 2**) due to the lower soil N and K concentrations compared to Sevekpota (**Table 1**). Potassium application increased WUE over the cropping season in Djakakope (**Figure 1; Table 2**). The application of K also improved root DM at both locations. The positive effect of K on WUE could be ascribed to the ability of K to regulate stomatal aperture and closure (Chérel et al., 2014), given the high sensitivity of cassava to a leaf-to-air vapor pressure deficit. This mechanism allows the crop to transpire the limited amount of available water slowly during the dry season, resulting in greater DM gain and larger WUE over the cropping season. In our study, however, the effects of K on WUE can be attributed to enhanced biomass production. At Sevekpota, K fertilizer did not show significant effects on WUE nor on PTRAN and PET due to the high soil K status of this site. A critical soil K range of 0.08 to 1.8 mmol/kg is generally associated with cassava response to K applications (Howeler, 2002).

Effects of N on WUE and Yield

Nitrogen application decreased WUE in Sevekpota, but increased PTRAN (**Table 2**). Nitrogen additions did increase root DM in Sevekpota and Djakakope. The increase in PTRAN by N application goes along with a rise in plant photosynthetic activity (El-Sharkawy and Cock, 1986) due to the positive effect N has on leaf area development. This results in larger soil coverage by the plant canopy, leading to reduced evaporation from the soil.

The results in **Table 2** reveal that N and K play complementary roles in determining cassava productivity. While N is more active in enhancing water transpiration through larger cassava leaf area development, K plays a role in improving the efficiency of water use by cassava.

Effects of P Application on WUE and Yield

Phosphate fertilizer did not have any significant effect on WUE, or root DM at either site. This weak response of cassava to P fertilizer can be attributed to the crop's strong mycorrhizal associations, which improves cassava's efficiency to extract P from the soil (Sieverding and Leihner, 1984).

Effect of Harvest Time on WUE

Estimated WUE ranged from 1.54 to 7.12 g DM per kg water transpired, with an overall value of 3.22 g biomass DM produced per kg water transpired over the cropping season, and a coefficient of determination (R^2) of 0.64. Water use efficiency was 3.58 and 2.99 g DM per kg water in Djakakope (R^2 = 0.64) and Sevekpota (R^2 = 0.68), respectively. These values are comparable to the 2.9 g total biomass DM per kg of water transpired for cassava reported by El-Sharkawy and Cock (1986).

The variability in WUE within sites can be credited not

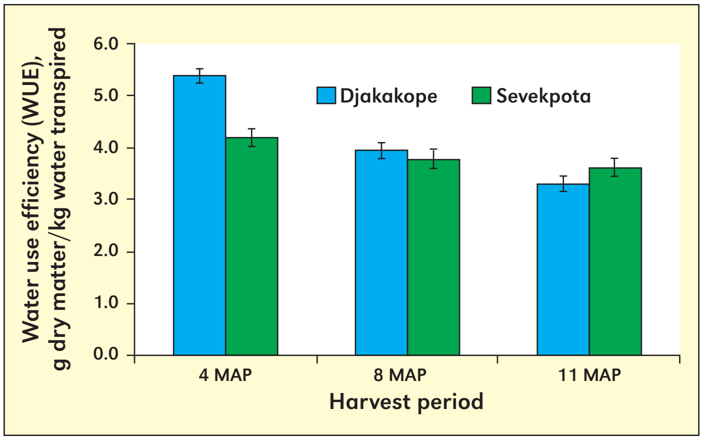

Figure 2. WUE as affected by harvest times in Djakakope and Sevekpota. Error bars indicate the standard error of the mean.

only to response to N and K applications, but also to the effect of harvest time (**Figure 2**). Greater WUE was obtained at 4 MAP harvest, compared to 8 and 11 MAP harvests ($p < 0.001$). Demands for water and light energy are high during the first 6 MAP, which comprises a period of strong vegetative growth, generally from 3 to 6 MAP (Alves, 2002). Fertilizer application should be well timed to ensure nutrient availability at the critical growth period to ensure higher use efficiency. Beyond this phase, the rate of shoot growth is reduced in favor of carbohydrate translocation to the roots.

Economic Benefits of K Application

The economic analysis revealed that gross margin of fertilizer use increases as WUE of cassava rises, particularly in Djakakope (**Figure 3**). The largest gross margins were achieved with the application of 50 and 100 kg K/ha in Djakakope, and with 50 kg K/ha in Sevekpota. These results stress the importance of supplying balanced amounts of K on a site-specific basis in order to achieve an optimal return from investment in fertilizer. BC

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Dr. Ezui is a Cropping Systems Agronomist at IPNI sub-Saharan Africa Program, stationed at IITA-HQ at Ibadan, Nigeria; e-mail: gezui@ipni.net. Prof. Franke is a Senior Lecturer at University of the Free State, Bloemfontein, South Africa; e-mail: FrankeAC@ufs.ac.za. Dr. Leffelaar, Plant Production System Group, Wageningen University, the Netherlands; e-mail: peter.leffelaar@wur.nl. Dr. Mando, Soil Scientist, GRAD Consulting Group, Ouagadougou, Burkina Faso; e-mail: amando@gradcg.com. Prof. Giller is Chair, Plant Production System Group, Wageningen University, the Netherlands; e-mail: ken.giller@wur.nl.

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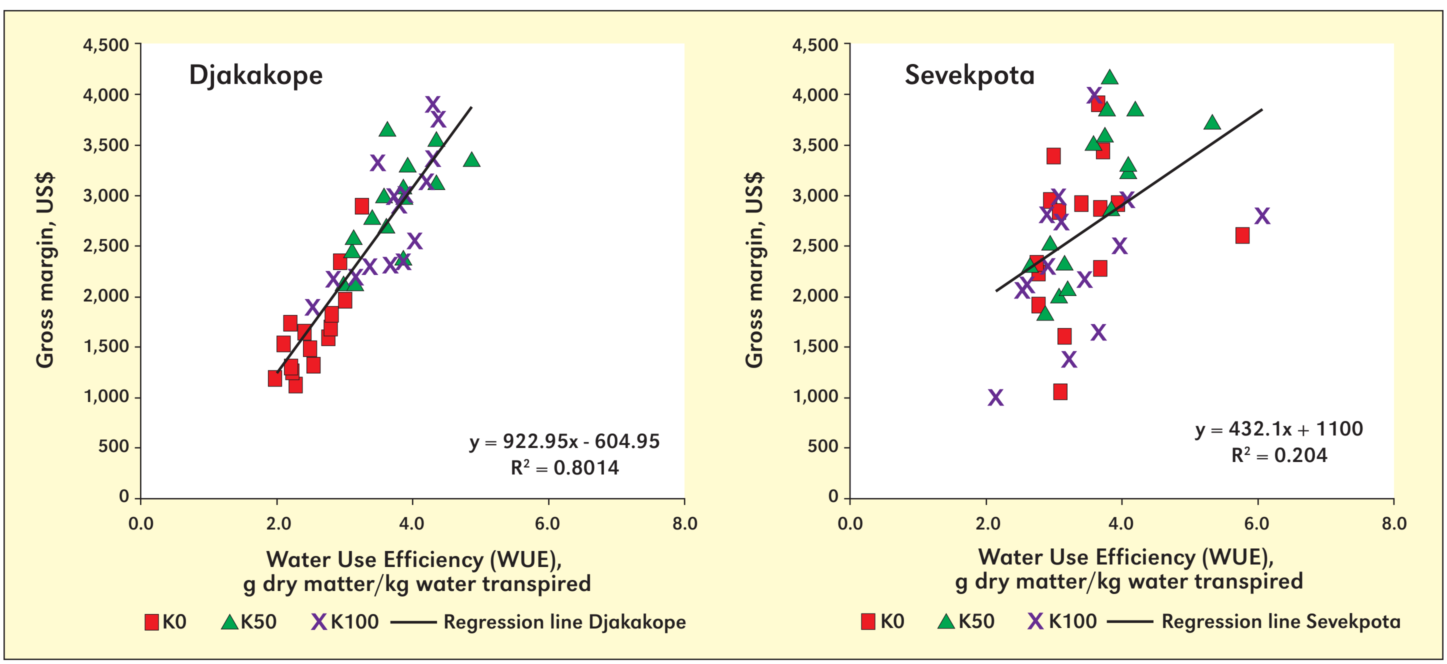

Figure 3. Gross margin of fertilizer use as a function of WUE at different K rates at Djakakope and Sevekpota.