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Exploring the yield gap of orange-fleshed sweet potato varieties on smallholder farmers' fields in Malawi

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ABSTRACT

Orange-fleshed sweet potato (OFSP) can contribute to combating vitamin A deficiency and establishing more resilient cropping systems in sub-Saharan Africa. There is limited understanding of the factors that affect yield and quality of OFSP on smallholder farmers' fields. This study aimed to assess the performance of six OFSP varieties, identify factors limiting productivity and explore options to close the gap between actual and attainable OFSP yields on fields of smallholder farmers. Data were collected in the 2015/16 growing season from 221 on-farm variety demonstrations in seven districts in Central and Southern Malawi. Dependent variables of interest included crop establishment, vine yields, storage root formation, root yields, percentage of marketable root yield, and weevil infestation. Using linear mixed models, a range of biophysical, climatic, management and socio-economic factors and variables was used to identify associations with these dependent variables. The root yield gap was explored using a multivariate boundary line model to identify the most yield limiting factors. Results show a large variability across farmers' fields and a wide range of interacting factors affecting the variables of interest. Varieties Chipika and Kadyaubwerere attained good yields and were preferred by farmers in terms of taste. Varieties Zondeni and Anaakwanire gave a poor root yield, but a good vine yield. Timely planting is crucial to attain good root yields by making better use of the available rainfall. There was a varietal effect on weevil infestation and Kaphulira was most affected. Weevil control is required for market-oriented producers to enhance the percentage of marketable roots. The average attainable fresh root yield ranged from 18 t ha^{-1} for Zondeni to 32 t ha^{-1} for Mathuthu, against actual yields of 5–9 t ha^{-1}. Elevation, planting date, rainfall and crop establishment could explain only 28 percent of the average yield gap, while 49 percent was explained for Mathuthu. Other factors that may explain the yield gap, but were not included in the model are: tillage methods and soil nutrient limitations. Male host farmers received better quality cuttings and planted in better soil moisture conditions, resulting in better establishment and vine yields. OFSP productivity can be enhanced through gender-sensitive extension, by ensuring male and female farmers can plant clean planting material of a suitable variety early in the rainy season. This requires additional efforts in vine multiplication of the required variety prior to the onset of the rains.

1. Introduction

The population in sub-Saharan Africa is expected to increase 2.5-fold and the demand for cereals to triple by 2050, indicating a pressing need to close yield gaps and increase cropping intensity to reduce future dependence on food imports (van Ittersum et al., 2016). At the same time food systems should not only feed the population, but also provide affordable nutritious diets (Haddad et al., 2016). Micronutrient deficiencies are a major health concern in Sub-Saharan Africa caused by a lack of crop diversity, limited access to markets with nutritious food and consequently limited dietary diversity (Luckett et al., 2015). Sweet potato (*Ipomoea batatas* [L.] Lam) fits well in this context, since it is widely produced and rich in carbohydrates, protein, calcium, iron, potassium, carotenoids, dietary fiber, and vitamins (especially C, folate, and B_6), and very low in fat and sodium (Bovell-Benjamin, 2007). Sweet potato production in Africa has doubled from 1.0 to 2.0 million tons between 2002 and 2012 (FAO, 2017). Predominantly white or yellow fleshed varieties are cultivated, while orange-fleshed sweet potato (OFSP) is rich in beta-carotene which is converted into vitamin A in the human body (Low et al., 2017). Vitamin A is an essential nutrient that

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prevents blindness in children and pregnant women. It is deficient among people in most sub-Saharan African countries, which results in increased risks of severe infections and even death from common diseases such as diarrhea and measles (WHO, 2017). Promotion of OFSP has proven to be an effective food based approach to increase vitamin A intake and serum retinol concentrations in young children in rural Mozambique (Low et al., 2007). As a result of a growing evidence base on the effectiveness of OFSP to improve nutritional status (Tanumihardjo et al., 2017), to date 42 OFSP varieties have been bred in Africa (Low et al., 2017). Sweet potato in Africa is perceived as a drought tolerant food security crop (Motsa et al., 2015). Mass relief distributions of planting material to drought-, flood- or conflict-affected households are common (Kapinga et al., 2005). There is limited awareness on the potential of sweet potato as a viable cash crop. Consumers that were well informed about the nutritional benefits were willing to pay 51% more for OFSP than for white-fleshed sweet potato in Mozambique (Naico and Lusk, 2010) and 25% more in Uganda (Chowdhury et al., 2011), while without prior nutritional information this is not the case. This corresponds with results of a meta-analysis of 23 studies that shows consumers are willing to pay 21% more for biofortified crops (De Steur et al., 2017).

Better OFSP yields will enable smallholder farmers to harvest more beta-carotene per ha for home consumption or market sales to the wider rural and urban population. Breeding programs continue releasing new OFSP varieties in Africa (Andrade et al., 2016). Besides good potential yields, traits of particular importance include storability, sweet and dry taste, early maturity, drought tolerance and high beta-carotene content (Laurie et al., 2004). The actual yields of sweet potato in Southern Africa are estimated to be as low as 3 t fresh root ha^{-1} in the period 2010–2014 (FAO, 2017) compared with attainable yields of 27 t ha^{-1} reported in Mozambique (Andrade et al., 2016) and 35 t ha^{-1} in Malawi (Chipungu, 2015). This shows that despite breeding efforts, smallholder farmers are often unable to benefit from yield gains from genetic improvement (Tittonell and Giller, 2013) due to other yield reducing factors.

Despite the relative drought tolerance of sweet potato compared to cereal crops (Motsa et al., 2015), water limitations greatly affect crop development. Root formation on freshly planted cuttings is optimal at a soil water content of 80% of field capacity, though even at 40% of field capacity considerable root formation still occurs (Belehu, 2003). Crop water use of sweet potato under full irrigation in Mozambique was 800 mm with root yields of 33 t ha^{-1} compared to 360 mm and 15 t ha^{-1} in the same site under rain fed production (Gomes and Carr, 2001, 2003). Other studies confirmed that irrigation can enhance yields (Ghuman and Lal, 1983) and total nitrogen concentration, but can reduce dry matter concentration in the roots (Ekanayake and Collins, 2004). Despite common low-input cultivation practices, sweet potato shows a large yield response to nutrient input application via fertilizer and manure (Agbede, 2010). Potassium enhances root yields and quality by increasing the root: top ratio, dry matter concentration and beta-carotene and anthocyanin contents (George et al., 2002). Phosphorus and nitrogen application also enhance yields (Dumbuya et al., 2016) (Ankumah et al., 2003). Tillage benefits root yield by reducing the bulk density of the soil (Agbede, 2010), while production on ridges may result in better yields than production on mounds (Dumbuya et al., 2016).

The most serious sweet potato disease in Africa is the sweet potato virus disease (SPVD) which is caused by combined infection with sweet potato chlorotic stunt virus by whiteflies and sweet potato feathery mottle virus by aphids (Karyeija et al., 1998; Gibson et al., 2004). Sweet potato weevil (C. *formicarius* complex) is worldwide considered the biggest pest attacking both cultivated and stored sweet potatoes (Chalfant et al., 1990; Allemann et al., 2004). Severity of weevil infestation depends on variety (Stathers et al., 2003b) and increases with delaying the harvest of mature roots (Smit, 1997). Both SPVD and weevils can infect new fields via planting material. Timely access by farmers to sufficient quantities of clean planting material is a challenge in areas with a long dry season due to limited knowledge of technologies to conserve vines (Okello et al., 2015). A final challenge affecting smallholder sweet potato producers is poor storability of roots compared to grain crops (Abidin et al., 2016).

Low crop yields are usually caused by a multitude of interacting biophysical, socio-economic and management constraints that determine final production on farmers' fields (Fermont et al., 2009). Production ecology concepts (Van Ittersum and Rabbinge, 1997) are often used to quantify the yield gaps between potential, water- or nutrient-limited and actual yields. The extent to which biotic stresses such as pests, diseases and weeds or abiotic stresses such as nutrient deficiencies and drought affect the yield gap can vary across regions (Wairegi et al., 2010). To target interventions that aim to improve OFSP productivity on smallholder farmers' fields we need to identify the main factors contributing to the yield gap. This study reports on data collected in on-farm variety demonstration plots in seven districts in Central and Southern Malawi in the 2015/16 rainy season. We aimed to (i) assess the performance of six released OFSP varieties on a large number of farmers' fields in different agro-ecological conditions; (ii) identify important varietal, abiotic, biotic and crop management factors limiting smallholder OFSP production; (iii) discuss opportunities to enhance OFSP productivity for smallholder farmers, and; (v) draw lessons on the conditions under which OFSP planting material distributions to smallholder farmers will be most beneficial.

2. Materials and methods

2.1. Location and approach of the study

The study was conducted under the project 'Feed the Future Malawi Improved Seed Systems and Technologies' which aims to scale out seed and other crop technologies of various crops to > 280,000 rural households in seven districts (Mchinji, Lilongwe, Dedza, Ntcheu, Balaka, Machinga and Mangochi) in Central and Southern Malawi. This target area represents three agro-ecological zones (AEZ) as defined in Malawi (Saka et al., 2006): AEZ 1 represents the lake shore, middle and upper Shire at an elevation of 200–760 m above sea level (masl), AEZ 2 the mid-elevation upland plateau at 760–1300 masl, and AEZ 3 the highlands at > 1300 masl (Fig. 1).

Malawi has a unimodal rainfall distribution with rains from December to April, followed by a long dry season. Long term average total rainfall in the research sites ranges from 801 to 1000 mm with 1001–1200 mm in the higher elevation areas of Dedza and Ntcheu (METMALAWI, 2017). On farm demonstrations were established in 390 sites in the 2015/16 rainy season. Eleven project partners including government and NGO's were responsible for implementation of the field activities and data collection. Each demonstration site consisted of six plots each planted with a different OFSP variety. *Zondeni* is a local variety that was recommended by the Department of Agricultural Research Services (DARS) in 2008 for scaling out, because there were no released OFSP varieties in Malawi yet. It matures late in 5–6 months and has a yield potential of only 16 t ha^{-1}. Five other varieties were released by DARS in 2011 (Chipungu, 2015). These are *Anaakwanire* with a 5–6 months maturity period and yield potential of 25 t ha^{-1}, *Chipika* and *Kadyaubwerere* with a medium maturity period of 4–5 months and 35 t ha^{-1}, *Mathuthu* with 4–5 months and 25 t ha^{-1} and *Kaphulira* which is the earliest maturing variety with a growing period of 3–4 months and a potential yield of 35 t ha^{-1}. Each demonstration served as a learning site for fifty farmers who also received one bundle of planting material to plant in their own fields to apply what they learnt.

2.2. Trial design and data collection

The field study was considered as a variety trial with 390 blocks that