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INTENSIVE CASSAVA PRODUCTION: CROP FOR THE FUTURE

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Abstract
Cassava (*Manihot esculenta* Crantz) is a major staple food in sub-Saharan Africa (SSA), providing an important source of calories and options for food security for the increasing population. It is a warm season crop, with unique and useful environmental physiological traits, including the ability to produce in marginal soils, and yield even under conditions of extreme drought. Analysis of literature was carried out to understand the crop's yield potential, since there is wider recognition of cassava as a crop of choice for climate change adaptation strategies and to increase food security in the near future, particularly in (SSA). Literature study includes: cassava physiology, yield potential, crop characteristics for potential yield, understanding the nutrient dynamics, and modelling of cassava growth and yield. The study indicates that cassava has a high yield potential of over 90 tons ha^{-1} of fresh storage roots (32 t DM ha^{-1}) in a year, and high nutrient use efficiency. This suggests that some crop parameters used currently in cassava growth simulation models require modification. Good estimates of potential yields provide important benchmarks for realistic yield targets and understanding of yield gaps with local relevance. The increasing demand for cassava offers farmers the opportunity to intensify production, earn higher incomes, and boost their food supply. Therefore, the use of inorganic fertilizers, following 4R nutrient stewardship (right amount, right time, right place and right source), is inevitable to sustainably improve productivity in the future. Also, understanding the dynamics of nutrient requirements and the impact of uptake limitations of cassava during the growth cycle enables prediction of cassava yields under nutrient limited conditions, and may provide insight in best management practices to improve nutrient use efficiency. Knowledge of nutrient (N, P and K) demand and uptake patterns under deficient conditions in cassava can be used to develop a simulation model. After testing the model, it may be used for many purposes, including: generation of crop responses for series of years in order to characterize cassava growth and nutrient uptake, provide location-specific fertilizer recommendation, and extrapolate from the studied area to other areas where less detailed information is available. Increasing cassava yield requires an in-depth understanding of limitations in growth. Therefore, researchers need to adopt a wholesome approach in developing useful technologies for good agronomic practices that will support sustainable cassava production and bridge the large yield gap.

Keywords: Potential yield, food security, nutrient dynamics and modelling

Introduction
Food demand is predicted to increase substantially in Sub Saharan Africa (SSA) where more than half of the anticipated growth between now and 2050 is expected to occur, with most of the projected increase concentrated in Nigeria (UNDESA, 2017). The current world population of 7.8 billion is expected to reach 8.5 billion by 2030, 9.7 billion in 2050 and 11.2 billion in 2100 (Worldometers, 2020). In SSA, children under the age of 15 account for 41% of the population, while young persons between 15 and 24years account for a further 19% (UNDESA, 2017). With such young growing population and over 54% of the work force based on the agricultural sector for livelihoods, income and employment (FAO-DG, 2018), the need to increase crop productivity for food, industrial uses and other purposes that will improve the living standard becomes important. However, only a small proportion of the required increase in food production can come from expansion of the area cultivated (Koning *et al*., 2008; Hall and Richards, 2013; Barnosky *et al*., 2016). There is increased awareness of the impacts of CO_2 release and decrease in biodiversity, resulting from the conversion of grassland or forest to arable lands (Haberl, 2015). Moreover, it is expected that there will be losses of good quality agricultural lands for urban development and

other non-agricultural uses. In addition, the likelihood of expanding irrigated agriculture in Africa is limited (Viala, 2008; Strzepek and Boehlert, 2010). Therefore, 90 % of the increase in crop production will have to be from improved crop varieties and management (Hall and Richards, 2013; Ray *et al*., 2013).

The ultimate challenge becomes to provide the growing population in SSA with a sustainable, secure supply of safe, nutritious, and affordable high-quality food; using less land, with lower inputs, in the context of global climate and environmental changes. Sustainable agricultural intensification especially in SSA, resulting in increased yields per unit of land has been identified as the most promising approach towards food security (Godfray *et al*., 2010; Tscharntke *et al*., 2012). The food scarcity of 2008 may be a warning of what is to come. Staple food prices increased rapidly and caused unrest in 36 countries (BBC-News, 2008; Mittal, 2009). Therefore, food self-sufficiency has become a necessity. Cassava is a major staple food in SSA and has been vital to food security in SSA despite the low productivity in the area (Howeler *et al*., 2013; Senkoro *et al*., 2018). There is a large potential to sustainably increase the crop's productivity; subsequently, increasing food availability and provision of other by-products for industrial uses.

Cassava: a crop of hope for meeting the food needs of sub Saharan Africa

Cassava is extensively cultivated for its edible storage roots, which is rich in starch and has high energy content of about 16.5 MJ kg^{-1} DM (Montagnac *et al*., 2009). It is more resilient to adverse conditions and climate change than other crops, like grains (Rosenthal and Ort, 2012; De Souza et al., 2017) or other cereals, and seems a better option for various reasons. It has the ability to survive on poor soils, with a high yield per hectare. The flexibility of planting and harvesting times makes it a farmer's friendly crop, reduces cost and price risks (Fresco, 1986). Cassava could provide sub-Saharan Africa with options for food security in the face of increasing population, dwindling resources, and changing climate. The global area cropped with cassava has expanded considerably over the past decades (Howeler, 2017; Shackelford *et al*., 2018), with over 26 million hectares of land cultivated in 2017, of which approximately 78% is in Africa (FAOSTAT, 2020a). Nigeria is the largest cassava-producing country in the world with about 60mt of fresh cassava roots produced yearly from 2015 to 2018 (FAOSTAT, 2020a). Therefore, an in-depth study of the crop is essential to understand its growth and yield potentials in the region, to explore ways of maximizing its benefits for food security and economic growth.

Cassava physiology

Cassava is propagated from the stems. Emergence of new sprouts from the stem cuttings begins at 5-15 days after planting (DAP), and is fully achieved at 30 DAP. Until 30 DAP, shoot and root growth depends on the reserves of the stem cutting. The first adventitious roots are replaced by fibrous roots (Cock *et al*., 1979; Alves, 2002). These new roots take up water and nutrients, only a few of them (between 3 and 14) become storage roots, which can be distinguished from the fibrous roots from 60 to 90 DAP (Alves, 2002). Cassava shows simultaneous shoot and storage root development in which photo assimilates are partitioned between shoots and storage root growth (Fukai *et al*., 1984; Alves, 2002). However, photo assimilates are preferentially partitioned to shoot until 6 months after planting (Fig. 1). Maximum growth rates of stems and leaves are achieved within 90–180 DAP, which is the most active vegetative growth stage for cassava. In the absence of Western Africa (WA) seasonal dry period, cassava leaf area index (LAI) attains its peaks at 120 to 150 DAP, when senescence of lower leaves begins to counteract further leaf production at the top of the canopy. LAI typically begins to decline at 270 DAP when senescence outpaces new leaf production (El-Sharkawy *et al*., 1990; El-Sharkawy and De Tafur, 2010). The fastest rates of dry matter (DM) accumulation in storage roots occur from 180–300 DAP. At 300–360 DAP (referred to as the dormancy period or end of a growth cycle), the leaf production decreases, while starch accumulation in storage roots continues (Alves, 2002). The plant completes its 12-month cycle, and this could be followed by a new cycle (Fig. 1). To obtain high storage root yield, the crop should reach a leaf area index (LAI) of 3–3.5 as quickly as possible, and maintain that LAI for as long as possible (El-Sharkawy, 2003). Leaf life varies between 60-80 days during the first four months of growth and increases to about 120 days at later plant stage (El-Sharkawy, 2003). However, patterns of dry matter partitioning among the plant's organs are affected by growth conditions and could show different trends, particularly with changes in soil nutrient level, water regime, solar radiation, length of the day (photoperiod), and temperature.

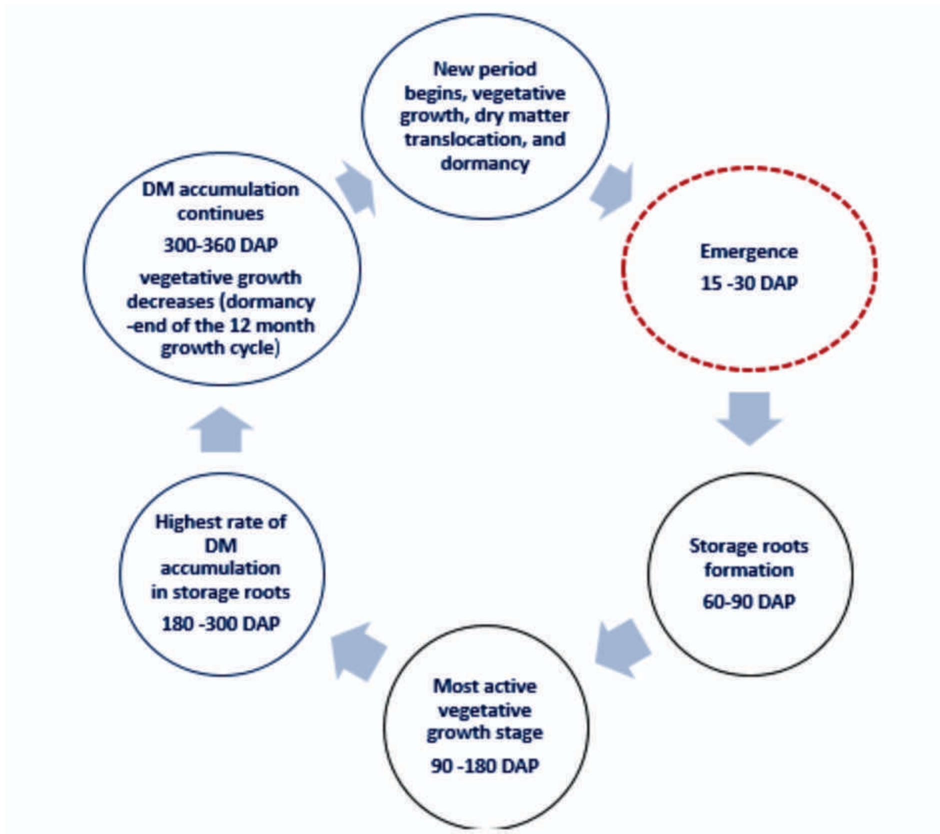

Fig. 1: Cassava growth cycle begins with emergence at 15-30 DAP and matures 300-360 DAP, depending on variety, environment and climatic conditions

Attaining cassava yield potential

Cassava, though grown mostly as a subsistence crop by smallholder farmers is becoming increasingly important as a commercial crop, and now cultivated on large scale in order to meet the growing demand. Average fresh storage root yield of cassava varies between 1.1 and 32.1 t ha^{-1} fresh roots with a global average yield of 11.3 t ha^{-1} fresh roots among 104 cassava growing countries. Current average root yield in smallholder farmers' fields in SSA is estimated at only 7.2 t ha^{-1} fresh roots (FAOSTAT, 2020b). Yields in research trials varied from 8.6 to 55.5 tons ha^{-1} of fresh root yield (Fermont *et al*., 2009; Eke-Okoro and Njoku, 2012; Howeler, 2017). These values are far below the potential yield of 80–100t ha^{-1}(Cock *et al*., 1979; El-Sharkawy *et al*., 1990; Byju and Suja, 2020), when growth conditions and management are optimal. Hence, it is possible to further increase cassava yields through improved fertilizer management.

Improving crop yield with fertilizers must be considered alongside nutrient use efficiency (NUE) (Janssen, 2011; Norton, 2014), for sustainable crop production. NUE is an important concept for evaluating crop production systems and depends on fertilizer management (Norton, *ibid*; Fixen *et al*., 2015). However, if the pursuit of improved NUE impairs current or future productivity, the need for cropping fragile or preserved lands will likely increase. At the same time, as nutrient rates increase towards an optimum, productivity continues to increase but at a decreasing rate, and NUE typically declines (Barbieri *et al*., 2008). Though, the extent of the decline will be determined by factors including soil, and climatic conditions. Improvements in agronomic practices including balanced fertilizer (N, P and K) application can markedly improve NUE, and when implemented concurrently with increased nutrient rates, can result in simultaneous increase of both crop yields and NUE (De Wit, 1968; Fixen *et al*., 2015). Yield response, nutrient uptake, agronomic efficiency, internal utilization efficiency, apparent recovery efficiency, and nutrient harvest index are used in agronomic research to assess the efficiency of fertilizer application and such studies should be included in cassava production for better understanding of the system.

Cassava crop characteristics for potential yield

The physiological and phenological traits of a crop determine its potential yield. These traits are influenced by genotype, environment and management (Byju and Suja, 2020). In cassava, some variables related to the canopy, such as LAI, leaf retention etc, are strongly positively correlated with storage root yield (El-Sharkawy and De Tafur, 2010). Improvement of resource use efficiency is an important approach towards achieving the potential yield. It depends on the efficiencies with which the crop converts intercepted light into biomass over the course of the growing season (De Souza *et al*., 2017). Light interception is affected by canopy size, duration and speed of ground coverage after planting. Values of intercepted light from improved cassava cultivars ranged between 52.3-64.1%. These are below values recorded from modern cultivars of major grains and seed crops, and the theoretical limit of 100% (De Souza *et al*., 2017). Therefore, increasing seasonal light interception of cassava to approach theoretical maximum could greatly improve cassava storage root yield. Further, improving the radiation use efficiency appears to present the greatest opportunity for improving cassava yield potential. For instance, average RUE of 1.16 g DM MJ^{-1} IPAR (Ezui *et al*., 2017) recorded from experiments in West Africa is only 36% of the RUE of other C_3 plants such a potato (Rezig *et al*., 2013; Zhou *et al*., 2017). Understanding the basic physiology of cassava and relations among or between parameters and crop growth rate (CGR) will enable us to optimize crop management and improve crop growth simulation models (Kiniry *et al*., 1999; De Souza *et al*., 2017).

Understanding cassava nutrient dynamics

The growth rates of cassava are inextricably related to cumulative nutrient uptake (Howeler, 2002; Byju and Suja, 2020), and they determine fertilizer requirements. Nutrients uptake occurs during the entire growth cycle, with the maximum at about 4 MAP (Howeler, 2012). This period corresponds to maximum DM accumulation and uptake rate of cassava (when the canopy is fully developed and vegetative growth has reached its peak). Uptake rate of nutrients decreases after six months, though uptake of nutrients of the plant continues throughout the growth period (Howeler and Cadavid, 1983; Howeler, 2012). Nutrients uptake and growth rates, including the production potential of cassava are influenced by demand from the growing crop, climatic conditions, soil water availability, soil fertility and plant age (Alva *et al*., 2002). Also, nutrient concentration of plants decreases during the growth cycle, even when nutrient supply is sufficient (Justes *et al*., 1994; Lemaire, 2012). The concept of nutrient dilution and nutrition index for nitrogen (N) have been widely used as a diagnostic tool for crop N sufficiency, but only few studies are available for other macronutrients (Zamuner et al., 2016; Gómez *et al*., 2018). To our knowledge, none exists for cassava. Therefore, it becomes important to understand the nutrient uptake of cassava as affected by fertilizer application and establish nutrient dilution curves and nutrition indices for cassava, for improved crop management.

Modelling cassava growth and yield

In order to provide information to farmers, policy makers and other stakeholders on approaches to sustainable agriculture, many researchers and farmers seek to estimate the yield of crops before harvest. On this basis, crop growth simulation models are used to study the system and provide relevant information for planning and managing crop production. Robust simulation models that describe the processes of cassava development and nutrients uptake can help to understand changes in crop growth in response to changes in environmental conditions, and nutrient management (van Ittersum *et al*., 2003). A LINTUL-type of model that simulates dry matter production as a function of the amount of light intercepted and constant radiation use efficiency (*RUE*), can be used for this purpose. LINTUL has been developed to simulate potential and water limited crop growth of cassava (Ezui *et al*., 2018). However, this model has not been tested in Nigeria where cassava is cultivated across a range of environmental and climatic conditions. Further, nutrient limited growth has not been included in the LINTUL model. Hence, the need to develop and test a dynamic model for cassava that simulates N, P, K limited growth in the tropics.

Rationale for a comprehensive study

The potential yield of cassava in SSA is not known. However, if we apply the general rule of thumb in crop production, average daily dry matter yield is about 200 kg DM ha^{-1}, with a harvest index of 0.5, the potential storage root yield of cassava could be about 36 tons ha^{-1}. Disturbingly, annual average yield in SSA has remained poor (FAOSTAT, 2020a). No research has yet investigated the response of cassava to targeted optimized dosages of NPK fertilizer, aimed at potential yields for improved cassava production in Nigeria. Existing crop models on water limited yield (Matthews and Hunt, 1994; Gabriel *et al*., 2014; Ezui *et al*., 2018) have not been tested for cassava in Nigeria. In fact, no crop model has yet been developed to simulate cassava growth under nutrient limited conditions. Cassava simulation model will help to determine potential and economical yields in different agro-ecologies for agro advisory purposes. Also, to improve the existing LINTUL-Cassava model (Ezui *et al*., 2018) to better accurately assess yield gaps under water- and nutrient limited conditions. These findings could inform better practises for increased productivity.

Research focus for the Future

Studies should explore the yield potential of cassava and the dynamics of nutrients limitations in relation to water availability; obtain better insight and a theoretical understanding of how the crop responds to nutrient availability and application of fertilizers in different agro-ecologies. Studies should focus on the following:

- assess cassava yield potential and response to fertilizer application, including the nutrient use efficiency;
- evaluate the temporal dynamics of light interception in cassava and radiation use efficiency under non-water limited conditions, calibrate, evaluate and test existing cassava models;
- understand the biomass growth and nutrient uptake of cassava as affected by fertilizer application and establish nutrient dilution curves and nutrition indices for cassava; and
- develop and test a dynamic model for cassava that simulates N, P and K limited growth.

Conclusion

Many studies have been done to elucidate the relevance of cassava for food security and economic growth. Yet, its potential yield in SSA is unknown and the productivity on a land area basis has remained low. This systemic literature analysis shows that cassava yield can be enhanced tremendously for the future; this is confirmed by large yields reported by scientists from South America, Asia and Australia. Improved crop management practises that improve both NUE and productivity without negative consequences for the long term are essential and a key strategy for food security.

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