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Nitrogen and phosphorous uptake by potato (*Solanum tuberosum* L.) and their use efficiency under potato-legume intercropping systems

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A B S T R A C T

Competition for nitrogen (N) and phosphorous (P) under potato-based intercropping systems decreases the level of nutrients available for potato and subsequently influences nitrogen and phosphorous use efficiency. A field trial was conducted for four consecutive seasons between 2014 short rains and 2016 long rains to assess the effect of incorporating legumes as intercrops into potato cropping systems on N and P uptake and uptake efficiency by the potato crop and nutrient use efficiency. The treatments included potato intercropped with either dolichos (*Lablab purpureus* L.) (PD), garden pea (*Pisum sativum* L.) (PG) or climbing bean (*Phaseolus vulgaris* L.) (PB), and a pure stand of potato (PS). Intercropping potato with beans and peas significantly reduced its N uptake by 22 and 27% relative to PS, but the N uptake was not affected under PD. Phosphorous uptake was 2, 8 and 11 kg P ha^{-1} lower in PD, PB and PG, respectively compared with PS. Nitrogen use efficiency (NUE) was significantly higher in PD, PB and PG by 30, 19 and 9% compared with PS. Similarly, P use efficiency (PUE) was 6, 14 and 21% higher in PG, PB and PD, respectively than PS. The highest tuber yield recorded in PS (36 t ha^{-1}) did not significantly differ from PD (34 t ha^{-1}) whereas tuber yield was significantly lower in PB and PG as compared with PS. The study shows the great potential of dolichos as a promising intercrop that could be integrated into potato cropping systems without negatively affecting potato yield.

1. Introduction

Potato cultivation under intercropping systems has been practised globally due to its effectiveness in soil and water conservation resulting in increased yield and economic returns compared with monocropping (Hinsinger et al., 2011; Gericke et al., 2012; Nyawade, 2015; Zhang et al., 2016b). High productivity in potato production systems has been achieved by incorporating crops such as radish, maize and bean (Mushagalusa et al., 2008; Singh et al., 2016; Zhang et al., 2016b). However, competition between companion crops for the available resources such as moisture, light and nutrients like nitrogen (N) and phosphorous (P) is a common occurrence (Gitari et al., 2017). These two elements are essential nutrients that are important in potato production and their deficiency may result in yield losses (Fernandes and Soratto, 2012; Hopkins et al., 2014; Sandana, 2016; Musyoka et al., 2017). Nevertheless, these mineral elements are inherently low in most tropical soils such as Nitisols (Alfisols), which dominate potato-growing areas in Kenya (Jaetzold et al., 2006; IUSS Working Group WRB, 2015). The low available P is also due to its adsorption onto soil constituents such as organic matter, clays and sesquioxides (Hinsinger et al., 2011; Hopkins et al., 2014; Gitari, 2013; Hill et al., 2015).

Nitrogen and phosphorous are usually supplied to crops mainly through inorganic fertilizers, and this takes about 20% of operating costs in potato production (Stark et al., 2004; Rens et al., 2018). In Kenya, as many other sub-Saharan countries, potato growers are mainly small-scale farmers who primarily use the government-subsidised ammonium-based fertilizers such as di-ammonium phosphate and calcium ammonium nitrate. Adding P to a low pH soil renders it unavailable through fixation by Fe and Al. In addition, its uptake by most crops largely depends upon root interception due to its low mobility (Hill et al., 2015). However, the potato has a shallow rooting system to exploit fully such P and N hence; they are susceptible to loses principally through immobilization, volatilization, leaching and runoff under poor agronomic management (Hopkins et al., 2014; Rens et al., 2018). This

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results not only in yield losses but also adversely affect the environment through processes such as eutrophication of surface water bodies (Zhaohui et al., 2012; Jones et al., 2013). This is an indication that potato-based cropping systems are still vulnerable to nutrient loss pathways resulting in poor crop growth and low tuber yield. For instance, the average tuber yield in Kenya is 8–15 t ha^{-1}, which is more than three times lower than the 30–40 t ha^{-1} that are achievable under field conditions (Muthoni et al., 2013; Gitari et al., 2016). Therefore, identification and integration of suitable intercrops in potato cropping systems could be a potential strategy to curb such losses.

A number of strategies have been proposed to reduce N and P losses from cropping systems such as the use of crop-specific fertilizers, synchronizing fertilizer application with the crop nutrient demand and use of slow N-releasing fertilizers (Abalos et al., 2014; Venterea et al., 2016; Lam et al., 2017; Rens et al., 2018). Although such strategies have been shown to be viable in developed countries, most farmers in sub-Saharan Africa are reluctant to adopt them because of incomplete or unclear information and most cannot financially afford to apply these strategies. Thus, research on nutrients use efficiency is imperative for feasible potato production systems, especially in tropical soils, which usually are low in N and P. Development of innovative strategies that would enhance availability of N and P from fertilizers applied to a potato crop would contribute greatly to easing the burden of increased cost of production to the resource-poor farmers who are dependent on agriculture for their livelihood.

One potential strategy that could be easily adopted by resource-poor potato growers is identification and integration of suitable intercrops in potato cropping systems. Intercropping is one of the cultural practices that improve nutrient uptake and use efficiency without requiring an increase in fertilizer inputs (Hinsinger et al., 2011; Gitari et al., 2016; Nyiraneza et al., 2017). Better nutrient utilization under intercropping can be achieved through niche facilitation and complementarity occurring in the rhizosphere of the companion crops, hence minimizing competition for nutrients thus increasing nutrient use efficiency (Richardson et al., 2009; Zhang et al., 2017). This is mainly possible when legumes are integrated since they have the ability to fix atmospheric N for their own utilization and subsequently transfer the surplus directly making it accessible for uptake by companion crops (Ojiem et al., 2007; Hauggaard-Nielsen et al., 2009; Sitienei et al., 2017). The roots of legumes can also produce exudates that can solubilize P by competing with phosphate ions for exchange sites, hence making it available for uptake by the non-legume crops in the intercropping system (Hinsinger et al., 2011; Postma and Lynch, 2012; Wang et al., 2015; Zhang et al., 2016a; Giles et al., 2017).

In intercropping systems, integrating deep-rooted crops such as dolichos results in better exploitation of soil resources such as water and nutrients (Ojiem et al., 2007; Whitbread et al., 2011; Nyawade, 2015; Gitari et al., 2017). In this regard, dolichos can extract water and nutrients from deeper soil horizons thus reducing competition of these resources from the surface horizon to the benefit of shallow-rooted crops such as potato. Dolichos has been established as a drought tolerant and multipurpose legume cultivated for its green pods and grain, and as fodder (Whitbread et al., 2011; Sennhenn et al., 2017). Despite the potential of dolichos as an intercrop in potato-based intercropping systems, little has been done to assess its effects on nutrient use efficiency. Therefore, this study aimed at assessing the effects of intercropped legumes on N and P uptake by potato and their use efficiency for whole cropping system.

2. Materials and methods

2.1. Site description

A potato-legume intercropping trial was conducted at Kabete Field Station, University of Nairobi, located at 1°15′S, 36°44′E and 1860 m above sea level. The site is a typical Kenyan highland where most of the country's potato cultivation is carried out and is classified as dry sub-humid agro-ecological zone (Jaetzold et al., 2006). The predominant soil type is a Humic Nitisol and is characterized by a homogeneous deep soil profile of up to about 2 m (Jaetzold et al., 2006; IUSS Working Group WRB, 2015). The soil had a bulk density of 1.03 g cm^{-3}, pH of 5.6 (soil to water ratio of 1:2.5), organic carbon of 29 g kg^{-1}, and available N and P of 167 and 53 kg ha^{-1}, respectively. Exchangeable Na, K, Mg and Ca were 1.2, 1.8, 2.5 and 9.0 $cmol_c$ kg^{-1}. The site receives an average annual rainfall of 1000 mm in a bimodal pattern, from March to June, usually referred to as 'long rains', and October to December referred as 'short rains'.

2.2. Experimental design and layout

This study was conducted for four consecutive seasons from 2014 short rains to 2016 long rains. The treatments included potato (cv. Shangi) as a pure stand (abbreviated as PS) and potato intercropped with either garden pea (*Pisum sativum* L. cv. Green feast) (PG), dolichos (*Lablab purpureus* L. cv. Uncinatus) (PD) and climbing bean (*Phaseolus vulgaris* L. cv. Kenya tamu) (PB). The trial was laid out in a randomized complete block design with four replications for each treatment. The dimension of the experimental plot was 6 by 4 m accommodating six potato rows spaced at 0.9 m. At the onset of each growing season, pre-sprouted seed potato tubers (35–55 mm in diameter) were planted in rows at an inter-seed spacing of 0.3 m, a seed rate of 1.8 t ha^{-1} and a plant density of 36,400 plants ha^{-1}. The legumes were planted between potato rows at a rate of 20 kg of seed ha^{-1} with two seeds sown at a spacing of 0.25 m within a row such that the final plant density was 88,000 plants ha^{-1}. Shangi was preferred for its popularity among smallholder farmers in the country. It matures within 90 days with an attainable yield of 40–50 ha^{-1} under field conditions (Muthoni et al., 2013; Gitari et al., 2017). The legume varieties used in this study are the most common ones among the local farmers, hence the high chances of adoption of the proposed potato-legume intercropping systems.

2.3. Agronomic practices

The potato was supplied with 34 kg ha^{-1} of N, 15 kg ha^{-1} of P and 28 kg ha^{-1} of K using NPK (17:17:17) compound fertilizer at planting and 54 kg ha^{-1} of N using calcium ammonium nitrate (CAN) fertilizer 28 days after planting (DAP). Weeding, earthing-up for potato and staking for beans were done manually 28 DAP. To control late blight, the potato was sprayed twice per month starting from 14 days after the emergence with Daconil 720 SC (Chlorothalonil 720 g L^{-1}) alternated with Ridomil Gold MZ 68 WG (Mefenoxam 40 g kg^{-1} + Mancozeb 640 g kg^{-1}). For the control of aphid that infested only dolichos, the crop was sprayed with Bestox 100 EC (Alpha-cypermethrin 50 g L^{-1}) alternated with Duduthrin 1.7 EC (Lambda-cyhalothrin 17.5 g L^{-1}).

2.4. Data collection

Plant canopy cover was measured every seven days starting from 28 to 84 DAP using a sighting frame. The frame was placed between potato rows and the vegetation was observed through each of the ten thin gun sight tubes arranged at fixed intervals along a crossbar. A similar sampling frequency was used for soil moisture content using a digital moisture meter-HSM50 (Omega®). The probe of the meter was inserted at a depth of 0.2 m from different points of the plot. Harvesting was carried out manually from 12 m^2 central area per plot at 65 and 75 DAP for pea, 84 DAP for potato and bean, and 120 DAP for dolichos. From the harvesting area, 10 potato plants were randomly selected and their haulm biomass was harvested, weighed and cut into 5 cm long pieces. The tubers were dug out, weighed and 10 tubers were randomly picked and sliced into 10 mm wide strips. Sub-samples of 500 g for haulm biomass and tubers were oven-dried at 70 °C for 72 h and their weights

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