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Economic Importance, Ecological Requirements and Production Constraints of Potato (*Solanum tuberosum* L.) in Kenya

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ABSTRACT

In Kenya, potato production is done mainly by smallholder farmers as a key food and cash crop. About 83% of the country's crop production is mainly in highland areas with an altitude of between 1,200 and 3,000 m above sea level. The country's average potato yield ranges from 8 to 15 t ha^{-1}, 2 to 3 times below the achievable yield of 40 t ha^{-1}. The production is mainly limited by unavailability of certified seeds, increased pests, diseases, decreased soil fertility and erratic rainfall. The current work reviews the current status of potato production in Kenya with emphasis on its importance, ecological requirements and constraints.

HIGHLIGHTS

- Potatoes require a minimal of 750 – 1000 mm rainfall with altitude of 1500-4200 m.a.s.l and temperature range of 15-20°.
- Potato plants have a higher nutrient requirement, for macronutrients for optimal growth and profitable production.
- Factors affecting potato production include inadequate fertilization, seeds quality, pesticides and herbicides high pricing, pests and diseases and climatic variations.

Keywords: Potato, production constraints, certified seeds, soil fertility

The first domestication of potato (*Solanum tuberosum* L.) was around Lake Titicaca located between Peru and Bolivia in the Andes mountain of South America, approximately 3800m above sea level (Jong *et al*. 2011). Presently, potato production has been embraced in over 158 countries in the sub-tropical, tropical and world's most temperate areas (FAO, 2010; FAOSTAT, 2019). The potato crop was first introduced to East Africa and specifically Kenya by British farmers in the 1880s (Wachira *et al*. 2014). Its value has increased over the years to being the most utilized staple food and source of income, particularly for small-scale farmers in the country, ranking second after maize with quantity production of up to 800,000 t by 2010 (FAO, 2010). Since the 1920s and beyond, potatoes have been populated with aboriginal farmers in Kenyan highlands. For instance, in 1923, a yield of 22.5 ha^{-1} was attained and farmers sold all their products; however, in subsequent years since 1930,

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they've been grappling with economic drawbacks due to pests, diseases and universal despondency (Kaguongo *et al*. 2010).

Potato crops, same as others such as tomato and peppers, belong to the Solanaceae family. Majorly regarded as a perennial crop due to its vegetative breed for merchandising purposes. However, it's a yearly dicotyledonous crop when planted to get botanical seeds (Mosley *et al*. 2000). It has leaflets arranged on either side of the stem, typically in pairs opposite above-ground stem with below-ground storage tubers (Decoteau, 2005).

Potato contains a fibrous rooting system that is relatively shallow and which goes beneath ground up to 30 cm in depth (Gitari *et al*. 2018a, b). During early growth stages, the roots rapidly grow and by maximum mid-season development is achieved (Nyawade *et al*. 2019b; Gitari *et al*. 2020). Hence, root length, density and root mass reduce towards crop maturity (Anonymous, 2004; Nyawade *et al*. 2018). Potatoes can also stay in the field as tubers from one season to another as it is a specialized underground stem that has a possibility of growing above ground (Anonymous, 2013).

Tubers have all the features of regular stems such as rudimentary leaves, lenticels and dormant buds arranged to assume the spiral shape and mostly placed on the apical end of the tuber. The main stem is removed from flower clusters, containing white, red, blue, pink or purple flowers with yellow stamens (Thomas *et al*. 2006). Branching also occurs commonly at the crop base and any node, making it difficult to differentiate with little soil disturbance from stems arising from different nodes. In yield potentiality determination of potato, extend of auxiliary branching both sympodial and basal play a significant role in potato yields.

Potatoes are moderately tolerant to rime ice and their C_3 crops have a dimmed radiance saturation point (Hausler *et al.* 2001). They've characteristically 5 different levels of growth which include; development of sprout, vegetative growth, formation of tubers, bulking and maturation of tubers, which has undefined growth design and produce adventitious rooting system (Dwelle and Love, 1993). Tubers are not only for potato seed propagation but are now majorly embraced as human food sources. Vegetative propagation provides a similar growth pattern of the crop in contrast to sexual propagation, only possible by producing its true seed. However, there's very high variability making it unsuitable for use. In zones having challenges with pests and diseases, the sexual seed has been more adopted. (Mosley *et al.* 2000). Tubers are altered stems of about 70-75 percent water and 25-30% dry matter and contain nodes where growth starts and each growing stem forms sprouts which continue to grow after dormancy, which also dramatically varies with the type of cultivar. Sprouts continue to grow, which gives rise to the crop stems when planted and stolons from underground from which they give rise to new tubers (Burke, 2016; Mosley *et al.* 2000).

Potato production and distribution in Kenya

Potato production in Kenya has contributed to the generation of income and employment among smallholder farmers in the country's highlands, thus serving a significant role in human nutritional management and food security in general (Gitari *et al*. 2018a; Muthoni *et al*. 2013). Desirability appraisal needs eco-friendly complementation for potato production with good fertile land considering prevailing economic and social circumstances (Nyawade *et al*. 2021). Possible large-scale production of potatoes is done under good climatological conditions receiving between 800-1200 mm of annual rainfall (MoALF, 2016). Altitudes of between 1400 and 3000 m above sea level are also required. Areas with these specifications are adequate for potato production and are predominantly in the Central, Coastal, Western, Upper Eastern, Nyanza and Rift Valley regions of Kenya (MoALF, 2016; Obare *et al*. 2010; Gildemacher *et al*. 2009). The major potato varieties widely grown in the country include Destiny, Asante, Dutch Robijn, Kenya Baraka, Shangi, Desiree and Tigoni (NPCK, 2017). Regardless of the variety, farmers are encouraged to use certified seeds to achieve optimal yield (Aktas *et al*. 2019; MoALF, 2016).

In Kenya, potato production is done in the highlands having high altitudes of 1500-2500, where there is a relative advantage over the other food crops such as maize (Nyawade *et al*. 2019a; Abong *et al*. 2010). Development of new potato varieties has been restarted again after successful trials were done, which have paved the way for the new technology adoption and allowed the incorporation of superior clones developed by the International Potato Center (CIP) for tropical regions in Africa (Aktas *et al*. 2019). National potato program researchers conducted adaptive research which involved exposing clones tolerant to various potato viruses and blight to stress, from which the successful ones are certified for regular use in the country by Kenya Plant Health Inspection Services (KEPHIS) (GoK, 2010).

Economic importance of the crop

Potatoes are primarily consumed across the globe as human food in different forms such as boiled, French fries flakes, chips, powder (Araújo *et al*. 2016; Pandey *et al*. 2009). Compared to other tuber crops produced in Kenya, potatoes have the highest nutrient with approximately 2.1% of fresh weight and are also highly rich in fiber content. Also, potato contains potassium and ascorbic acid in high quantities as per the human nutritional requirements (Aktas *et al*. 2019).

In similarity with cereals and comparison with other roots and tubers, potato contains very high nutrient content with low-fat content but rich in micronutrients. These vitamins are vital in providing adequate nutrition to families (Lutaladio and Castaldi, 2009). In the early years before the agricultural revolution, people chose to consume potatoes based on traits such as tuber color, shape, size and skin elegance in the market. However, due to the increasingly sharp rise in chronic degenerative diseases such as cancers, diabetes, asthma, cardiovascular disorders, tuberculosis, among many others, epidemiological studies stress the use of nutrient-rich potato and its critical role in diet (in mineral malnutrition) as part of lifestyle change on consumers (Andre *et al*. 2007). According to Suszkiw (2007), potato contains phytochemicals that help in neutralizing cancer cells and cell-damaging molecules.

To actively utilize the nutritional value of potatoes and to break down its starch, it's not taken raw but cooked and its nutritive value is of great benefit to man since it also protects against not only numerous cardiovascular disorders and cancers but also in reduction of blood cholesterol levels (Astley, 2003). They also contain antioxidants whose importance traverses by reducing heart diseases and eye cataracts (Brown and Brown, 2005).

To maintain the normal growth pattern of a healthy human being free from diseases, a total of not less than twenty-five minerals are required. According to White *et al*. (2009) and White and Brown (2010), these nutrients get to the food chain through plants, making potatoes rich in most such elements. Trace elements, which include iodine and selenium, are also found rich in potatoes except for calcium; hence, in this regard, each cultivar of potato has its characteristic appearance of tubers and nutrient composition (Karenlampi and White, 2009).

In the family of tubers and root crops, potatoes are key energy sources with high protein, approximately 2.1% on fresh weight and medium-size single tuber contains the adequate requirement of vitamin C, B, iron, K and Zn. However, their essential role as tuber vegetable is mostly not appreciated in the world's food system (FAO, 2014). According to FAO (2019), potato can be used as a food security crop, feed for animals, cash crop and other industrial needs and due to its nutritional nature and value, the United Nations named 2008 the International Year of the Potato, which was a celebration of world's most favorite staple food. Therefore, potato is regarded as the most suitable crop to curb food insecurity in developing countries such as Kenya.

Potato ecological requirements

Potatoes grow well in excellent climatic conditions where a temperature range of 15-20° is good for optimal growth and yield (Nyawade *et al*. 2019b). Potatoes require ideally 750 – 1000 mm rainfall at a minimum; however, they can withstand drought though productivity is drastically reduced if it's within 6 weeks after planting and during root formation and development (Gitari *et al*. 2018a; Hijmans, 2003). According to FAO (2011), an altitude of (1500-4200) or lower is the most appropriate for potato crop production in tropical lands as long as it's within the cool season. For tuberization to effectively happen, it does best with the night temperature of 16°C and regular irrigation. The crop thrives in well-drained soils with an optimal pH of 4.8-5.8 and has a maximum tolerated salinity threshold of 1.7ds/m (Haverkort and Verhagen, 2008). Adequate farm preparation is essential in potato production, which should be done with minimal disturbance of the soil ecosystem. Sandy-loam and loam soils are highly fertile and mostly preferred for crop production (FAO, 2008).

To ensure good crop growth and productivity, agronomic practices such as weeding should be done immediately after the plant emerges on the ground and when crops are 20cm high. Shallow ridging should frequently be done to limit conversion of stolons to aerials and also prevent attack by insects, pests, bacterial, viral and protozoan infections and greening of tubers. Correct herbicide application (selective and non-selective) in low lethal dosage forms and crop rotation help in controlling weeds which is manually done in most developing countries.

Potato plants have a higher nutrient requirement, especially for macronutrients (Gitari *et al*. 2020; Nyawade *et al*. 2019a, c). For optimal growth and profitable production, they require the supply of adequate essential nutrients for quality and good growth performance (FAO, 2019). Nitrogen (N) is an essential macronutrient required in high quantities to achieve higher yields and vegetative growth (Gitari *et al*. 2018b). However, if applied in excess, it may cause excessive foliar growth in expense to tuber formation (Moore *et al*. 2011). Fayera (2017) confirmed that an increase in N application has led to increased tuber yield and yield components of potato. Phosphorus (P) is needed in large quantities, especially during the early growth to encourage rooting and tuber growth and in the late season during bulking (Burton, 2018; Gitari *et al*. 2019a). According to Trehan *et al*. (2009), potassium (K) requirement in potato production is more than 50% at tuber initiation and is essential for fundamental metabolic processes and disease prevention. Subsequently, its deficiency results in decreased yield production. Sulfur (S) is required for protein and helps to activate enzymes that regulate potato growth (Burke, 2016). Other micronutrients such as Soil organic matter (SOM), Calcium (Ca), Magnesium (Mg), among others, help in the growth and development of the crop.

Factors affecting potato production

Fertilizer, seeds quality, pesticides and herbicides price are amid the aspects affecting potato production. Pests, diseases and climatic variations are the major factors affecting the potato production industry (Stewart and Bradshaw, 2001; Andy *et al*. 2017; Mutegi *et al*. 2021; Nyawade *et al*. 2021). Several factors have been discussed here with relevance on how to improve productivity. According to Haverkort and Verhagen (2008), increased levels of carbon (IV) oxide (CO_2) in the atmosphere have been seen to favor the production of potato plants and their crop yield productivity. This results in increased photosynthetic rates, thus improving crop growth and performance (Nasar *et al*. 2021; Seleiman *et al*. 2021). The authors further argue that higher concentration levels of CO_2 result in potatoes having less open stomata, which prevent loss of water through transpiration and hence allow adequate uptake amount of CO_2 for photosynthesis (Nyawade *et al*. 2021).

Potato tuber growth is highly affected by temperature fluctuations between 5-30° (Hijmans, 2003). According to Levy and Veilleux (2007 and Nyawade *et al*. (2019b, 2020), the impact of increased temperature on potato production may widely depend on the location of the plantation. However, temperatures above 30° will negatively impact potato production, especially by reducing tuber growth starch partitioning, increasing disease incidences such as brown spots and reducing tuber dormancy. Such factors adversely reduce growth performance, the yield of crops and the weight of tubers. At shallow temperatures, potatoes are susceptible to frost damage and this causes reduced growth and damage to tubers (Haverkort *et al*. 2012).

According to IPCC (2007), it is predicted that there will be changes in water resource availability across the globe. A decrease is predicted to occur in semi-arid lands and adverse weather conditions such as flash flooding are expected to rise in areas even where rainfall is projected to decrease (Raza *et al*. 2021; Haverkort *et al*. 2012). The deficiency of soil moisture negatively impacts potato production due to their high sensitivity compared to cereal crops such as wheat; therefore, frequent irrigation is required to aid in tuber growth and development (FAO, 2012).

Colorado potato beetle and potato tuber moth are pests that spread in too cold areas to survive (Haverkort *et al*. 2012). Aphids also act as vectors of many potato viruses and are suited in high-temperature locations (Pandey, 2012). Pathogens such as dickeya cause potato blackberg disease.

These grow and reproduce faster at higher temperatures, causing economic losses to the farmer (Czajkowski, 2012). Bacterial infections such as *Ralstonia solanacearum* cause infections at high temperatures and spread quickly during flush flooding (Haverkort *et al*. 2012; Brown and Brown, 2005). Potato late blight (*Phytophthora infestans*) is also a threat at high temperatures and wetter conditions (Forbes, 2011; Andy *et al*. 2017).

Nutrient leaching, poor cropping system, increased rate of eroded soil and inflated prices of chemical fertilizer have been related to the low yields (Maitra *et al*. 2020; Cheptoek *et al*. 2021; Faridvand *et al*. 2021). The application rate of fertilizer in Kenya has always been below the recommended application rates, which directly results in less supply of essential nutrients required to meet the minimal crop growth performance and yield productivity (Koch *et al*. 2021; Mugo *et al*. 2021; Ochieng *et al*. 2020; Muthoni and Nyamongo, 2009; Nduwimana *et al*. 2020; Kaguongo *et al*. 2008). It was, however, noted by Muthoni (2016) and Nyawade *et al*. (2021) in their studies that small-scale farmers in Kenya are prone to applying Di-ammonium phosphate (DAP) fertilizer during the planting period and rarely do top-dress with N fertilizer (Mugo *et al*. 2020) hence, are common tradition related to low soil pH. An increase in soil acidity has resulted in the loss of nutrients and toxic accumulation of aluminum and manganese toxicities and reduction in potassium, calcium, phosphorus and magnesium quantities in the soil (Fageria, 1998; IPNI, 2010). However, Westermann (2005) noted that the problem doesn't prevail in the whole field but occurs mostly in smaller portions of land, which contain high sand compared to organic matter (OM).

Prolonged crop production on unfertile soils is associated with loss of both macronutrients such as P, N and K (Mugo *et al*. 2020) and micronutrients such as Ca^{2+}, Zn^{2+} and Mg^{2+} (Michelle *et al*. 2021; Otieno *et al*. 2021), which has resulted in diminished nutrient supply. Potatoes require high quantities of potassium than usual, however, their levels have been depreciating over time due to land overutilization with no nutrient nourishment (Wekesa, 2014; Kihara, 2017). For optimum potato production, recommended nutrients need to be added to the soil in the right quantities and the proper methods of application in designated seasons of application (Rosen and Bierman, 2008). Potatoes are large consumers of primary nutrients (NPK). For example, for a farmer to produce a maximum yield of 48 t ha^{-1}, potato tubers use 24kg P, 47.6kg N, 103.8kg K and 5kg S (Mugo *et al*. 2020); as the stem takes 82kg P, 31.8 kg N, 47.6kg K and 3.2kg S (Burton, 2018). It is also worth noting that the largest nutrient requirement for potatoes occurs between 6 and 10 weeks after emergence Kolbe and Stephan-Beckmann (1997). However, the optimum amount of nutrients required for potato production in achieving the required maximum yield is only through fertilizer application, which has proved to economically disadvantage small scale farmers (Gitari *et al*. 2018a; Obare *et al*. 2010).

Tuber quality in potato production can only be established in the field. However, some of the abiotic factors such as season variability, tuber maturity and cultivar have a significant effect on the final quality (Alamar *et al*. 2017). The synergistic application of chemical and organic fertilizers is recommended (Nesbit and Adl, 2014). Appropriate farming practices include applying recommended rates of fertilizer to improve the tuber growth and market value (Gitari *et al*. 2019b; Tan *et al*. 2016; Maitra and Gitari 2020). Desiccation of vines affects the quality of tubers as it triggers stolon production and causes maturity of tuber periderm, which significantly controls tuber production. To overcome the impact and prevent compromise on the tuber quality (Alamar *et al*. 2017), a multifactorial approach is required to manage these variables (De Meulenaer *et al*. 2007). To control sprouting, cold storage is required depending on farmer's choice to the market, freshly produced tubers ready for market can be stored at a temperature of 7° or below and those to be processed for value addition can be stored to a bit higher temperatures of 8-13° to maintain their quality (Alamar *et al*. 2017).

CONCLUSION AND RECOMMENDATIONS

This review has indicated that the unavailability of certified seeds, increased pests and diseases, decreased soil fertility and erratic rainfall is the principal factors hindering potato productivity in Kenya. Suboptimal application of essential soil nutrients and their availability due to high cost are key factors contributing to low yields. The high cost of accessing certified seed potatoes has resulted in the replanting of already harvested seed potatoes or those purchased from either the local open-air markets or other farmers, resulting in low crop productivity. Therefore, there is a dire need for capacity building of farmers on the production, access and importance of using certified seed potatoes and its proper agronomic practices to bridge the existing yield gap.

REFERENCES

1. Abong, G., Okoth, M., Imungi, J. and Kabira, J. 2010. Evaluation of selected Kenyan potato cultivars for processing into potato crisps. *Agric. Biol. J. North America*, **1**: 886–893.
2. Aktas, E., Topaloglu, Z., Irani, Z., Sharif, A. and Huda, S. 2019. Food provision to food security: How can we reduce waste on the supply side? *Qatar Foundation Annual Research Conference Proceedings*): pp. 23–42.
3. Alamar, M.C., Tosetti, R., Landahl, S., Bermejo, A. and Terry, L.A. 2017. Assuring potato tuber quality during storage: A future perspective. *Front Plant Sci.*, **8**.
4. Andre, I., Bradley, P., Wang, C. and Baker, D. 2007. Prediction of the structure of symmetrical protein assemblies. *Proc. Natl. Acad. Sci.*, **104**: 17656–17661.
5. Andy, R., Secor, G., Gudmestad, N. 2017. Late Blight in Potato. NDSU/University of Minnesota.
6. Anonymous. 2004. Directory of released crop varieties and their recommended cultural practices. Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.
7. Anonymous. 2013. Potato's production guide. Agriculture, Forester and Fisheries, Republic of South Africa.
8. Araújo, T.H., Pádua, J.G., Spoto, M.H., Ortiz, V.D., Margossian, P.L., Dias, C.T. and Melo, P.C. 2016. Productivity and quality of potato cultivars for processing as shoestrings and chips. *Hortic. Bras.*, **34**: 554–560.
9. Astley, S.B. 2003. Dietary antioxidants—past, present and future? *Trend Food Sci. Technol.*, **14**: 93–98.
10. Brown, R.I. and Brown, I. 2005. *The application of quality of life*, **49**: 718–727.
11. Cheptoek, R.P., Gitari, H.I., Mochoge, B., Kisaka, O.M., Otieno, E., Maitra, S., Nasar, J. and Seleiman, M.F. 2021. Maize productivity, economic returns and phosphorus use efficiency as influenced by lime, Minjingu Rock Phosphate and NPK inorganic fertilizer. *Int. J. Biores. Sci.*, **8**: 47–60.
12. Czajkowski, R. 2012. Why is *Dickeya* spp. (syn. *Erwinia chrysanthemi*) taking over? The ecology of a blackleg pathogen.
13. De Meulenaer, B., De Wilde, T., Mestdagh, F., Govaert, Y., Ooghe, W., Fraselle, S. and Verhé, R. 2007. Comparison of potato varieties between seasons and their potential for acrylamide formation. *J. Sci. Food Agric.*, **88**: 313–318.
14. Decoteau, R. 2005. Principles of plant science. Educational factors and technology in growing plants. Pearson education; Inc. New Jersey. **412**.
15. Dwelle, R. and Love, S. 1993. Potato growth hand development. Assessed on December 14, 2020, from http://www.cals.uidaho.edu.potato.
16. Fageria, N.K. and Zimmermann, F.J.P. 1998. Influence of pH on growth and nutrient uptake by crop species in an Oxisol. *Comm. Soil Sci. Plant Anal.*, **29**: 2675–2682.
17. FAO-Food and Agriculture Organization of the United Nations. 2008. AGP – International Year of the Potato. Available at: http://www.fao.org/agriculture/crops/core-themes/theme/hort-indust-crops/international-year-of-the-potato/en/.
18. FAO-Food and Agriculture Organization of the United Nations. 2019. The state of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns. Rome, FAO.
19. FAO-Food and Agriculture Organization of United Nation. 2012. Crop Water Information: "Potato" Water Development and Management Unit.7 November 2012.
20. FAO-Food and Agriculture Organization. 2014. Food and Agricultural Organization of the United Nations. /The potato sector Potato pro.com/ http://www.potatopro.com/ethiopia/ potato-statistic.
21. FAOSTAT- Food and Agriculture Organization, Statistics Division of the United Nations. 2019. Potato production in 2018; Region/World/Production Quantity/Crops from pick lists".
22. Faridvand, S., Rezaei-Chiyaneh, E., Battaglia, M., Gitari, H., Raza, M.A. and Siddique, K.H.M. 2021. Application of bio and chemical fertilizers improves yield and essential oil quantity and quality of Moldavian balm (*Dracocephalum moldavica* L.) intercropped with mung bean (*Vigna radiata* L.). *Food Energ. Secur.*, DOI: 10.1002/fes3.319.
23. Fayera, W.N. 2017. Yield and yield components of potato (*Solanum tuberosum* L.) as influenced by planting density and rate of nitrogen application at Holeta, West Oromia Region of Ethiopia. *African J. Agric. Res.*, **12**: 2242–2254.
24. Forbes, G.A. 2011 Implications for a warmer, wetter world on the late blight pathogen: How CIP efforts can reduce the risk for low-input potato farmers CIP.
25. Gildemacher, P.R., Demo, P., Barker, I., Kaguongo, W., Woldegiorgis, G., Wagoire, W.W. and Struik, P.C. 2009. A Description of Seed Potato Systems in Kenya, Uganda and Ethiopia. *Am. J. Potato Res.*, **86**: 373–382.
26. Gitari, H.I., Gachene, C.K.K., Karanja, N.N., Kamau, S., Nyawade, S., Sharma, K., Schulte- and Geldermann, E. 2018a. Optimizing yield and economic returns of rain-fed potato (*Solanum tuberosum* L.) through water conservation under potato-legume intercropping systems. *Agric. Water Manag.*, **208**: 59–66.
27. Gitari, H.I., Karanja, N.N., Gachene, C.K.K., Kamau, S., Sharma, K. and Schulte-Geldermann, E. 2018b. Nitrogen and phosphorous uptake by potato (*Solanum tuberosum*

L.) and their use efficiency under potato-legume intercropping systems. *Field Crop Res.*, **222**: 78–84.

28. Gitari, H.I., Nyawade, S.O., Kamau, S., Gachene, C.K.K., Karanja, N.N. and Schulte-Geldermann, E. 2019b. Increasing potato equivalent yield increases returns to investment under potato-legume intercropping systems. *Open Agric.*, **4**: 623–629.
29. Gitari, H.I., Shadrack, N., Kamau, S., Gachene, C.K.K., Karanja, N.N. and Schulte-Geldermann, E. 2020. Agronomic assessment of phosphorus efficacy for potato (*Solanum tuberosum* L) under legume intercrops. *J. Plant Nutr.*, **43**: 864–878.
30. GoK-Government of Kenya. 2010. Strategy for developing potato Industry in Kenya. Ministry of Agriculture.
31. Hausler, R., Hirsch, H., Kreuzaler, F. and Peterhan, C. 2001. Over expression of C4-cycle enzymes in transgenic C3 plants. *J. Exp. Bot.*, **53**: 369. 170–197.
32. Haverkort, A.J., van Koesveld, M.J., Schepers, H.T. A.M., Wijnands, J.H.M., Wustman, R. and Zhang, X. 2012. Potato prospects for Ethiopia: On the road to value addition. Lelystad, PPO-AGV.
33. Haverkort, A.J., Verhagen, A. 2008. Climate change and its repercussions for the Potato Supply Chain. *Potato Res.* **51**: 223–237.
34. Hijmans, R. J. 2003. The effect of climate change on global potato production. *Am. J. Potato Res.*, **80**: 271–280.
35. IPCC- Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.]. IPCC, Geneva, Switzerland.Crop Water Information: Potato (2012). FAO Water Development and Management Unit.7 November 2012, pp. 104.
36. IPNI-International Plant Nutrition Institute. 2010. Soil pH and the availability of plant nutrients. Fall 2, 3535.
37. Jong, H.D., Jong, W.D. and Sieczka, J.B. 2011. The complete book of potatoes is what every grower and gardener needs to know, 259.
38. Kaguongo, W., Ng'ang'a, N., Muthoka, N., Muthami, F. and Maingi G. 2010. Seed Potato Subsector Master Plan for Kenya (2009–2014). Seed potato study sponsored by GTZ-PSDA, USAID, CIP and Government of Kenya, Ministry of Agriculture.
39. Kaguongo, W.P., Gildemacher, P., Demo, P., Wagoire, W., Kinyae, P., Andrade, J., Forbes, G., Fuglie, K. and Thiele, G. 2008. Farmer practices and adoption of improved potato varieties in Kenya and Uganda. Social Sciences. International Potato Center (CIP), Lima, pp. 15–16.
40. Kärenlampi, S.O. and White, P. J. 2009. Potato Proteins, Lipids and Minerals. *Adv. Potato Chem. Technol.*, pp. 99–125.
41. Kihara, J., Sileshi, G.W., Nziguheba, G., Kinyua, M., Zingore, S. and Sommer, R. 2017. The application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa. *Agron. Sustain. Dev.*, **37**.
42. Koch, M., Naumann, M., Pawelzik, E., Gransee, A., Thiel. H. 2020. The importance of nutrient management for potato production, Part I: Plant nutrition and yield. *Potato Res.*, **63**: 97–119.
43. Kolbe, H. and Stephan-Beckmann, S. 1997. Development, growth and chemical composition of the potato crop (*Solanum tuberosum* L.). I. leaf and stem. *Potato Res.*, **40**: 111–129.
44. Levy, D. and Veilleux, R.E. 2007. Adaptation of potato to high temperatures and salinity-a review. *Am. J. Potato Res.*, **84**: 487–506.
45. Lutaladio, N.B. and Castaldi L. 2009. Potato: The hidden treasure. *Food Compost Anal. J.*, **22**: 491–493.
46. Maitra, S. and Gitari, H. 2020. Scope for adoption of intercropping system in Organic Agriculture. *Indian J. Nat. Sci.*, **11**(63): 28624–28631.
47. Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., Brahmachari, K., Shankar, T., Bhadra, P., Palai, J.B., Jena, J., Bhattacharya, U., Duvvada, S.K., Lalichetti, S. and Sairam, M. 2020. Intercropping system – A low input agricultural strategy for food and environmental security. *Agron.*, **11**: 343.
48. Michelle, A.O., Gitari, H.I., Danga, B., Raza, M.A., Kisaka, O.M., Elbeltagi, A., Singh, R.J., Soratto, R.P. 2021. Application of GIS in land evaluation and development of Suitability Map for capsicum production in Nairobi Peri-Urban Counties. *J. Remote Sens GIS.*, **10**: 290.
49. MoALF–Ministry of Agriculture Livestock and Fisheries. 2016. The Kenya national potato strategy 2016–2020.
50. Moore, A., Olsen, N., Frazier, M. and Carey, A. 2011. Organic potato production: Nitrogen Management and Variety Trials. Presented at the Idaho Potato Conference on January 20, 2011.
51. Mosley, A., Vales, I. and McMorran, Y.J.S. 2000. Principles of potato Production. http://oregonstate.edu/potatoes/CSS322WebNotes.Html.
52. Mugo, J. N., Karanja, N.N., Gachene, C.K, Dittert, K, Gitari, H.I and Schulte-Geldermann, E. 2021. Response of potato crop to selected nutrients in Central and Eastern highlands of Kenya. *Cogent. Food Agric.*, **7**: 1898762.
53. Mugo, J.N., Karanja, N.N., Gachene, C.K., Dittert, K., Nyawade, S.O. and Schulte-Geldermann, E. 2020. Assessment of soil fertility and potato crop nutrient status in central and eastern highlands of Kenya. *Sci. Rep.*, **10**.
54. Mutegi, J., Muthamia, J., Kathuku-Gitonga, A., Mukami, C., Mutuma, E., Esilaba, A. and Gikonyo, E. 2021. Potato production in Kenya: A guide to good agronomic and plant nutrition practices. African Plant Nutrition Institute (APNI), Nairobi, Kenya.
55. Muthoni, J. 2016. Soil fertility situation in potato producing Kenyan Highlands Case of KALRO-Tigoni. *Int. J. Hortic.*, DOI: 10.5376/ijh.2016.06.0025.
56. Muthoni, J. and Nyamongo, D.O. 2009. A review of constraints to ware Irish potatoes production in Kenya. *Forest*, **1**: 98–102.

57. Muthoni, J., Shimelis, H. and Melis, R. 2013. Potato Production in Kenya: Farming Systems and Production Constraints. *J. Agric. Sci.*, **5**.
58. Nasar, J., Khan, W., Khan, M.Z., Gitari, H.I., Gbolayori, J.F., Moussa, A.A., Mandozai, A., Rizwan, N., Anwari, G. and Maroof, S.M. 2021. Photosynthetic activities and photosynthetic nitrogen use efficiency of maize crop under different planting patterns and nitrogen fertilization. *J. Soil Sci. Plant Nutr*. DOI: 10.1007/s42729-021-00520-1.
59. Nesbitt, J.E. and Adl, S.M. 2014. Differences in soil quality indicators between organic and sustainably managed potato fields in Eastern Canada. *Ecol. Indic.*, **37**: 119–130.
60. NPCK-National Potato Council of Kenya. 2017. Potato Variety Catalogue.
61. Nyawade, O.S., Gitari, H.I., Karanja, N.N., Gachene, C.K.K., Schulte-Geldermann, Parker, M. 2018. Intercropping potato with grain legumes for enhanced productivity and climate change adaptation in smallholder farms, Kenya. RUFORUM Working Document Series, **17**: 377–381.
62. Nyawade, S., Gitari, H.I., Karanja, N.N., Gachene, C.K.K., Schulte-Geldermann, E. and Parker, M. 2021. Yield and evapotranspiration characteristics of potato-legume intercropping simulated using a dual coefficient approach in a tropical highland. *Field Crop Res.*, **274**:
63. Nyawade, S.O., Gachene, C.K.K., Karanja, N.N., Gitari, H.I., Schulte-Geldermann, E. and Parker, M. 2019a. Controlling soil erosion in smallholder potato farming systems using legume intercrops. *Geoderma Reg.*, **17**: e00225.
64. Nyawade, S.O., Karanja, N.N., Gachene, C.K.K., Gitari, H.I., Schulte-Geldermann, E. and Parker, M. 2020. Optimizing soil nitrogen balance in a potato cropping system through legume intercropping. *Nutr. Cycling Agroecosys.*, **117**: 43–59.
65. Nyawade, S.O., Karanja, N.N., Gachene, C.K.K., Gitari, H.I., Schulte-Geldermann, E. and Parker, M. 2019b. Intercropping optimizes soil temperature and increases crop water productivity and radiation use efficiency of rainfed potato. *Am. J. Potato Res.*, **96**: 457–471.
66. Nyawade, S.O., Karanja, N.N., Gachene, C.K.K., Gitari, H.I., Schulte-Geldermann, E. and Parker, M.L. 2019c. Short-term dynamics of soil organic matter fractions and microbial activity in smallholder legume intercropping systems. *Appl. Soil Ecol.*, **142**: 123–135.
67. Obare, G., Nyagaka, D., Nguyo, W. and Mwakubo, S.M. 2010. Are Kenyan smallholders allocatively efficient? Evidence from Irish potato producers in Nyandarua North District. *J. Dev. Agric. Econ.*, **2**: 78–85.
68. Ochieng', I.O., Gitari, H.I., Mochoge, B., Rezaei-Chiyaneh, E. and Gweyi-Onyango, J.P. 2021. Optimizing maize yield, nitrogen efficacy and grain protein content under different N forms and rates. *J. Soil Sci. Plant Nutr.*, **21**: 1867–1880.
69. Otieno, M.A., Gitari, H.I., Danga, B. and Karuma, A.N. 2021. Soil properties and fertility management with respect to Capsicum (*Capsicum annuum* L.) production in Nairobi Peri-urban Counties. *J. Soil Sci. Plant Nutr.*, DOI: 10.1007/s42729-021-00655-1.
70. Pandey, S.K. 2012. Potato research priorities in Asia and the Pacific Region. FAO.
71. Pandey, S.K., Singh, S.V. and Manivel P. 2009. Genetic variability and causal relationship over seasons in potato. *Crop Res.*, **29**: 277–281.
72. Raza, M.A., Gul, H., Wang, J., Yasin, H.S., Qin, R., Khalid, M.H.B., Naeem, M., Feng, L.Y., Iqbal, N., Gitari, H., Ahmad, S., Battaglia, M., Ansar, M., Yang, F. and Yang, W. 2021. Land productivity and water use efficiency of maize-soybean strip intercropping systems in semi-arid areas: A case study in Punjab Province, Pakistan. *J. Clean Prod.*, **308**, 127282.
73. Rosen, C.J. and ierman, P.M. 2008. Potato yield and tuber set as affected by phosphorus fertilization. *Am. J. Potato Res.*, **85**: 110–120.
74. Seleiman, M.F., Aslam, M.T., Alhammad, B.A., Hassan, M.U., Maqbool, R., Chattha, M.U., Khan, I., Gitari, H I., Uslu, O.S., Roy, R. and Battaglia, M.L. 2021. Salinity Stress in Wheat: Effects, Mechanisms and Management Strategies. *Phyton-Int. J. Exp. Bot.*, DOI: 10.32604/phyton.2022.017365.
75. Stewart, H.E. and Bradshaw, J.E. 2001. Assessment of the field resistance of potato genotypes with major gene resistance to late blight (*Phytophthora infestans* (Mont.) de Bary) using inoculums comprised of two complementary races of the fungus, *European Assoc. Potato Res.*, **44**: 41–52.
76. Suszkiw, J. 2007. Phytochemical profilers: investigate potato benefits. *Agric. Res.*, **55**: 20–21.
77. Tan, B., Huang, Z., Yin, Z., Min, X., Liu, Y., Wu, X. and Fang, M. 2016. Preparation and thermal properties of shape-stabilized composite phase change materials based on polyethylene glycol and porous carbon prepared from potato. *The Royal Society of Chemistry-Advances*, **6:** 15821–15830.
78. Thomas, K., Extension, E. and Dale, M. 2006. Growing potatoes: what is a potato?
79. Trehan, S.P., Pandey, S.K. and Bansal, S. 2009. Potassium Nutrition of the Potato Crop- the Indian Scenario.
80. Wekesa, M.N., Okoth, M.W., Abong', G.O., Muthoni, J. and Kabira, J.N. 2014. Effect of soil characteristics on potato tuber minerals composition of selected Kenyan varieties. *J. Agric. Sci.*, **6**: 163.
81. Westermann, D.T. 2005. Nutritional requirements of potatoes. *Am. J. Potato Res.*, **82**: 301–307.
82. White, P. and Brown, P.H. 2010. Plant nutrition for sustainable development and global health. *Ann. Bot.*, **105**: 1073–1080.
83. White, P.J., Bradshaw, J.E., Finlay, M., Dale, B., Ramsay, G., Hammond, J.P. and Broadley, M. R. 2009. Relationships between yield and mineral Concentrations in Potato Tubers. *Hortic. Sci.*, **44**: 6–11.