RUFORUM Working Document Series (ISSN 1607-9345), 2021, No. 19 (1): 43-51.
Available from http://repository.ruforum.org

Research Application Summary

Effect of nitrogen and irrigation management on potato (*Solanum tuberosum* L.) yields

Satognon, F.,* Lelei, J.J. & Owido, S. F. O.

Department of Crops, Horticulture and Soils, Faculty of Agriculture, Egerton University
P. O. Box 536-20115, Egerton, Njoro, Kenya
***Corresponding Author:** felixsatognon@gmail.com

Abstract

Nitrogen is the major element that limits potato growth and yield under dry and saturated water stress condition. This study evaluated the effect of nitrogen and irrigation management on potato (*Solanum tuberosum* L.) yields. Potato has a relatively shallow root system with most roots located in the top 50 cm of soil and an application of fertilizer under and/or 5-10 cm of potato root zone may not be efficient. The highest amount of N is needed for the period of tuber bulking that is the stage at which about 58–70% of the total N is taken up. Supplemental irrigation of 55 mm could increase potato yield up to 50.8%. Application of irrigation water beyond the limit may result in nitrogen losses and hence low nitrogen use efficiency (NUE). Based on this fundamental knowledge, a potato farmer may choose the correct type, time and amount of fertilizer to be applied. The supplementary irrigation is also recommended for farmer experiencing drought effects to increase their productivity.

Key words: Irrigation, Nitrogen, Nitrogen Use Efficiency, *Solanum* potato, yield

Résumé

L'azote est le principal élément qui limite la croissance et le rendement de la pomme de terre en condition de stress hydrique sec et saturé. Cette étude a évalué l'effet de la gestion de l'azote et de l'irrigation sur les rendements de la pomme de terre (Solanum tuberosum L.). La pomme de terre a un système racinaire relativement peu profond, la plupart des racines étant situées dans les 50 premiers centimètres du sol, et une application d'engrais sous et/ou à 5-10 cm de la zone racinaire de la pomme de terre peut ne pas être efficace. La plus grande quantité d'azote est nécessaire pendant la période de grossissement des tubercules, stade auquel environ 58 à 70 % de l'azote total est absorbé. Une irrigation supplémentaire de 55 mm peut augmenter le rendement des pommes de terre jusqu'à 50,8 %. L'application d'eau d'irrigation au-delà de la limite peut entraîner des pertes d'azote et donc une faible efficacité d'utilisation de l'azote (NUE). Sur la base de ces connaissances fondamentales, un cultivateur de pommes de terre peut choisir le type, le moment et la quantité d'engrais à appliquer. L'irrigation supplémentaire est également recommandée aux agriculteurs qui subissent les effets de la sécheresse afin d'augmenter leur productivité.

Mots clés : Irrigation, azote, efficacité de l'utilisation de l'azote, pomme de terre *Solanum*, rendement

Introduction

Food insecurity remains a major worldwide problem. In 2019, 11.11% of the world population (820 million) experienced hunger (FAO *et al.,* 2019). According to Devaux *et al*. (2020) food security exists when most people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. This can only be achieved by increasing agricultural production. The potato (*Solanum tuberosum* L.*)*, the third worldwide staple food after wheat (*Triticum* spp) and rice (*Oryza* spp), is one of the crops that have potential to alleviate food insecurity due to its productivity in a short time (Campos and Ortiz, 2020). In 2018, potato production was estimated at 36.8 million tonnes on 17.6 million hectares (FAOSTAT, 2020). This shows a diminution of its production that was estimated at 39 million tonnes in 2017 (FAOSTAT, 2020). This decline in production is attributed to the effects of climate change that leads to poor soil fertility management, appearance of pests and disease under potato production (Pradel *et al.,* 2019). Potato production will be more affected by the growing population which will reduce its production on the same resources. African potato sector will be more exposed to the African growing population estimated at 37% of the worldwide population by 2050 since its increased production in Africa relies on increase harvested area (Campos and Ortiz, 2020). Potato production has increased from 13.36 to 18.70 million tonnes with an increased harvested area ranged from 0.15 to 0.22 million hectares and a decreased yield from 9.15 to 8.61 tonnes/hectare between 2016 and 2018, respectively (FAOSTAT, 2020).

Despite, the potato potential yield (80 tonnes/hectare), this has not been fully reached in natural production systems due to the negative interference between the biotic and abiotic factors and the plant growth and tuber development. Thus yields remain low compared to 45 tonnes/hectare obtained by French farmers (FAOSTAT, 2020). Potato is water demanding crop due to its sensitivity to water stress (Nowacki, 2018). Water is needed for plant transpiration which is an important phenomenon for photosynthesis activities during the plant cycle.

Nitrogen is the most often limiting nutrient for potato growth if its quantity and availability are compromised. Nitrogen is a vital nutrient for potato due to its positive effect on the photosynthetic activities, chlorophyll concentration, plant height, rate of dry matter accumulation and tuber yields (Goffart *et al.,* 2011). For a mature potato crop to yield 25–30 t/ha, it depletes about 165–200 kg N, 14–17 kg P and 185–225 kg K/ha from soil (Baishya *et al.,* 2010). Nitrogen is very important nutrient in potato production as the value of the other inputs cannot be fully realized unless N is applied to the crop in an optimum amount (Ruza *et al.,* 2013). Because of its short cycle, mineral nitrogen is necessary to ensure the productivity of potato since soil nitrogen is largely tied-up in an organic matter that cannot readily be available with the potato cycle (Koch *et al.,* 2019). There is a need review the research that have been done for water and fertility management under potato production. This study aimed to evaluate the effect of nitrogen and irrigation management on potato yields, especially in terms of Kenya context.

Findings and Discussions

Potato nutrient requirement. Potato crop requires more primary elements (Nitrogen (N), phosphorus (P) and potassium (K)) during its cycle. Calcium and magnesium are also important for potato production (Koch *et al*., 2019) (Figure 1). To optimize fertilizer use efficiency, potato farmers need a good understanding of: (i) potato nutrient uptake patterns associated with sufficiency levels for soil and plant tissue nutrient concentrations, (ii) cultural and environmental factors that influence plant nutrient availability, and (iii) agronomic fertilizer management practices that optimize nutrient use efficiency (Stark *et al*., 2004). The amount of each element depends on the environment, the weather and the soil type. The table below provides an overview of different fertilizers recommendation based one the nutrient requirement of the area.

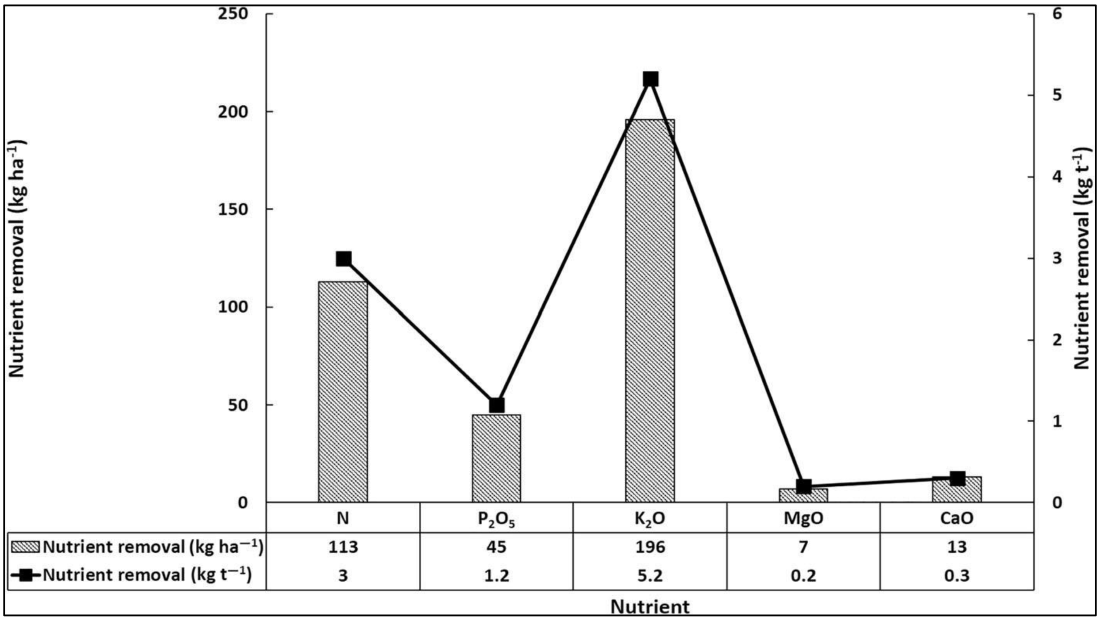

Figure 1. Removal of N, P2O5, K²O, MgO and CaO by potato tubers

Table 1. Fertilization recommendations of different production areas in Europe, South Africa and India

Country/region	Soil type	Recommended fertilization dose (kg ha^{-1})				
		N	P2O5	K_2O	MgO	CaO
Germany	Varying	120–160	-	150–300	70	–
UK	Varying	40–270	0–250	0–360	0–120	–
Netherland	Varying	0-140	20-185	0-440	0-200	-
Indian (North Western hill zone)	Acidic hill soil	120-150	100-150	120	-	-
India (North-eastern hill zone)	Acidic hill soil	100–120	120–150	60	–	–
India	Alluvial	180–240	80–100	100–150	–	–
India (Plateau zone)	Black	100–120	60	60	–	–
India (Nilgiri zone)	Acidic hill	90–120	135–150	90	–	–
South Africa	Varying	110-130	70-300	60-340	0-105	0-1125

Source: Koch *et al*. (2019)

These recommendations are not adopted by most developing because of the cost of fertilizer. Despite the Kenya Government's position (ranked 78th and second after South Africa globally and in sub-Saharan Africa (SSA), respectively) in fertilizer use, the application rates remain low compared to the recommended rate (Jane, 2016). The rates used were on average less than half of the recommended amounts of N and P of 90 and 230 kg ha^{-1} in the form of di-ammonium phosphate (18:46) (Jane, 2016). Potato has a relatively shallow root system with most roots located in the top 50cm of soil and an application of fertilizer under and/or 5-10cm of potato root zone may not be efficient (Rosen, 1988). The different potato nutrient requirements widely vary and differ within the growth stages (Figure 2). Therefore, a split application method is seen as the best way to increase fertilizer use efficiency under potato production.

Nitrogen and potassium are needed by potato plant throughout the growth and mostly at the bulking stage. Potato crop accumulates N in the leaves during the growth stage which is used for bulking. The N requirement of the potato crop is relatively low within the first 4 to 5 weeks of growth and tuberization can even be inhibited or delayed by high N supply during the vegetative stage (Jackson, 1999; Zebarth and Rosen, 2007). The highest amount of N is needed for the period of tuber bulking that is the stage at which about 58–70% of the total N is taken up (Ojala *et al*., 1990). Knowing the different potato growth stages may enable the farmers to obtain higher yield through fertilizer management.

Effect of organic and biological nitrogen on potato yield. For sustainable agriculture, most research focused in finding out the biological system that can replace the conventional potato production without affecting the farmers' income. Such research was done by El-Sayed *et al*. (2014) in Egypt who found out that organic production of potato using 23.8 Mt/ha of compost could be an alternative to conventional production without significant reduction in yield and quality. The most limited organic fertilizer use is the threshold allowable nitrogen level per day. However, the study conducted by Nyiraneza and Snapp (2007) showed that the integrated nitrogen management enhances the potato tuber yield compare to the biological production. The potato tuber yield and N uptake in the integrated system (organic matter plus mineral fertilizer) were 14 to 33% higher than the fertilized unamend treatment.

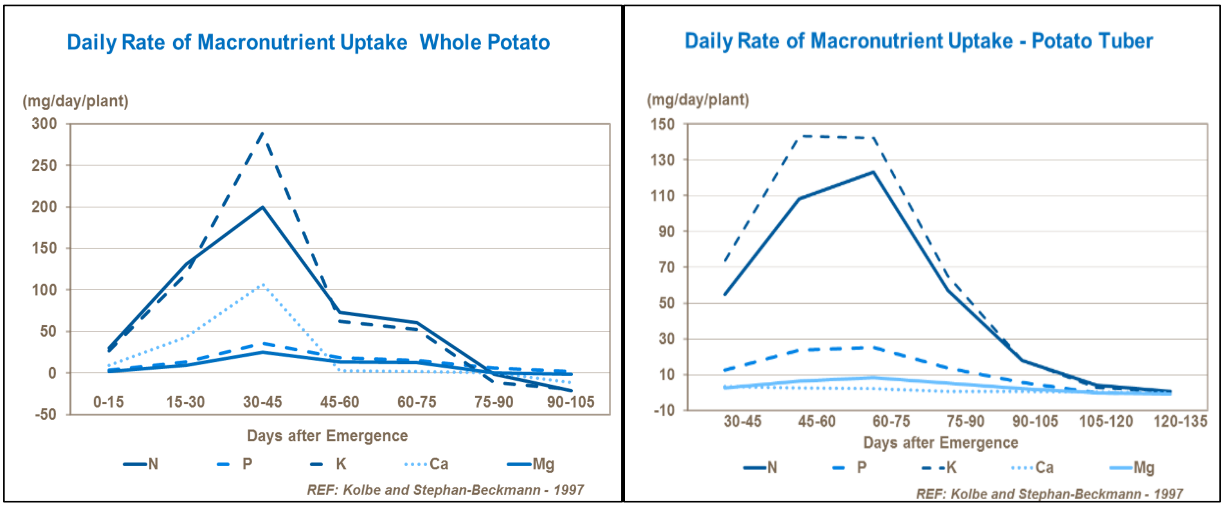

Figure 2. Potato nutrients requirement at its different stages

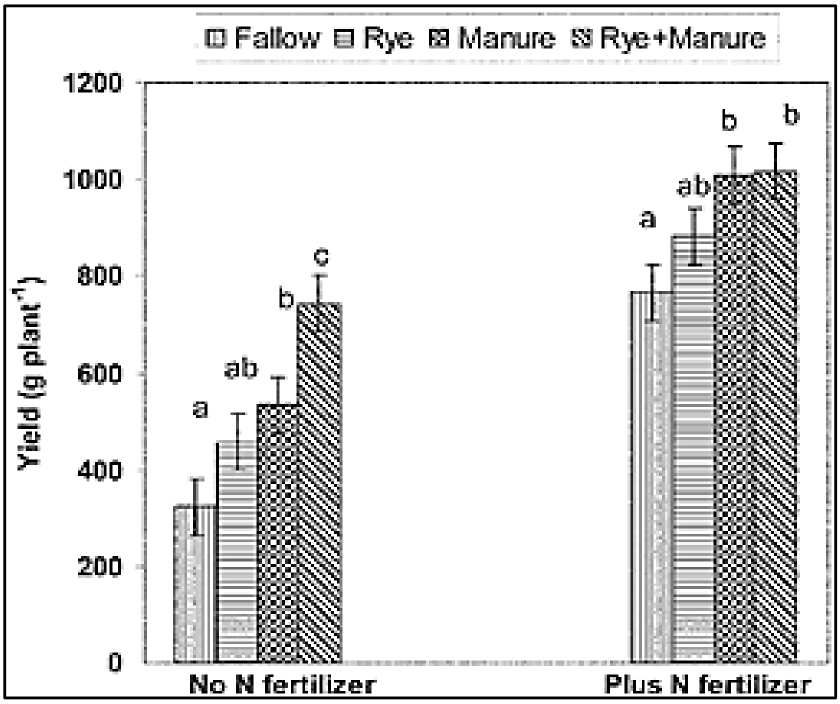

Figure 3. integrated management of inorganic and organic Nitrogen in potato systems (Nyiraneza and Snapp, 2007)

Legumes have received considerable attention due to their N fixation ability through the biologically N fixation. The total N contents of legume crops grown in potato rotations can be as high as 240 kg N ha^{-1}. The possible benefits of growing legumes prior to potatoes include improved soil physical properties, N contributions to subsequent crops, contributions of biologically fixed N to the cropping system, suppression of soil-borne potato diseases (Stark and Porter, 2005). This N accumulation in crop residues may reduce the N fertilizer application and then its cost for the next production. However, the N released from the rotation or green manure may delay the bulking stage of the crop leading to low yield since excessive nitrogen stimulates biomass production. The synchronization of N mineralization and plant N uptake is important but this seems complicated due to its presence in the soil. Hence, this method may be more applicable based on the choice of the legume species since the nitrogen fixation depends on the crop species. A study has been done on a pure stand of potato (PS) and a potato intercropped with either garden pea (*Pisum sativum* L.) (PG), dolichos (*Lablab purpureus* L.) (PD) or climbing bean (*Phaseolus vulgaris* L.) (PB). Intercropping potato with PB and PG significantly lowered its N uptake by 22 and 27% relative to PS, but N uptake was not affected under PD (Gitari *et al*., 2018). Nitrogen use efficiency (NUE) was significantly higher in PD, PB and PG by 30, 19 and 9% compared with PS. Dolichos lablab has been seen as a most promising legume that could be integrated into potato cropping systems to improve NUE without compromising the tuber productivity (Gitari *et al.,* 2016; Gitari *et al.,* 2018).

Effect of irrigation and irrigation method on yield and water use efficiency of potato. On average, potato requires 65% moisture content during its growth cycle (Leal Filho *et al.,* 2015; Kingori *et al.,* 2016). Potato requires between 350 to 450 mm of water to produce dry matter tuber of 1 kilogram, but this depends on the soil type and cultivar, growing period, environmental and field conditions (Kingori *et al.,* 2016). The plant is very susceptible or sensitive to water stress compared to many other crops. Tuber initiation to maturity growth period forms the critical water requirement period where water deficits affect productivity (Salter and Goode, 1967; Sasani *et al.,* 2006; Ahmadi *et al.,* 2010). If the moisture stress prevails at tuber initiation stage, the yield loss is greater (31%) than at tuber development stage (21%). Rain-fed potato growing areas demand additional water supplement through irrigation for uniform wetting to a depth of at least 10-15 cm for bumper harvests (Yactayo *et al.,* 2009). Due to irregular rainfall patterns, additional water needs to be supplemented to meet the crop water demand. Tang *et al*. (2018) found out that potato yield water productivity could be increased by 18.3% to 23.3% compared with the local rain-fed condition. Supplemental irrigation of 55 mm could increase potato yield up to 50.8%. Combining the optimal planting date with better irrigation scheduling have increased the potato yield by 64.3% compared with the local normal planting dates and rain-fed condition. Irrigation water is very important for potato production due to the high yield of potato in a short time If shortage of readily available water in the soil is eliminated by irrigation it is possible to achieve high and stable yields of potatoes, at the level of 40-50 t ha^{-1}. Among the different irrigation methods tested by Ati *et al*. (2012), drip irrigation has shown the higher water saving amount with high yield. The high cost of irrigation water brought scientists to develop many irrigation techniques including deficit irrigation (DI), partial root-zone drying irrigation (PRD) and full irrigation (FI). However, study so far conducted in irrigated potato indicates that DI (irrigated water below the maximum crop evapotranspiration) and PRD (alternated irrigation of the root-zone by watering of one furrow and maintaining dried the adjacent one until the next watering cycle) are two promising irrigation techniques to save water with a WUE increase and no yield reduction (Xie *et al.,* 2012). In several experiments, PRD has shown better results than DI and FI, allowing for 39–50% of water saving, while an increase of WUE without significant tuber yield reduction (Table 2) (Jovanovic *et al.,* 2010; Xie *et al.,* 2012).

Interaction Effect of Nitrogen and Irrigation on Potato Yield. In the subtropical plains, potato, a short duration heavy feeder crop takes between 90 to 100 days to produce 25–30 t/ha tubers. Efficient and balanced use of water and nutrients results in increased potato yields. A monitored drip system that allows nutrigation is the preferable method of potato irrigation on sandy soil. That helps to split nitrogen to plant according to its needs in order to avoid intoxication of the nitrogen; the balance of water supply makes the nutrients readily available for crop uptake (Shahnazari *et al.,* 2007; Yactayo *et al.,* 2009). Integrating nitrogen with irrigation water significantly affects

Table 2. Total and marketable yield, amount of applied irrigation water (AIW) during treatments and irrigation water-use efficiency (IWUE) of potato under full irrigation (FI) and partial root-zone drying (PRD) in 2007 and 2008 seasons

Water treatment	Yield (t ha^{-1})	Marketable yield (t ha^{-1})	AIW (mm)	IWUE (kg ha^{-1} mm^{-1})
FI-2007	45.31 AB	43.10	188	241.00 A
PRD-2007	41.78 A	40.00	125	334.27 B
FI-2008	53.19 C	42.52	225	236.40 A
PRD-2008	50.46 BC	41.28	130	380.14 C

Different letters mean significant difference at 0.05 level. Sources (Jovanovic *et al.,* 2010).

Nitrogen Use Efficiency (NUE). Application of irrigation water where a low nitrogen rate of 0 kg N/ha is supplied leads to zero NUE. NUE increases with irrigation water and nitrogen rates. High irrigation water application results in better NUE compared to low irrigation water. Increasing irrigation rate from 40 to 100 % increases NUE by 14.42 and 13.3 kg/kg. Generally, the application of nitrogen beyond 112.5–150 kg N/ha decreases NUE by 1.95 and 14.48 kg/N kg (Koch *et al.,* 2019). Water and nitrogen are two critical factors in potato production. Potato being sensitive to water deficit, even slight water stress causes a reduction in leaf number and size, canopy radiation interception and photosynthesis, which consequently affects the tuber number, size, and yield. In agricultural production, influences of water and nitrogen on plant growth are not independent of each other, and they often interact. Water stress reduces nitrogen uptake as a result of the decreased water uptake and transpiration rate. In the absence of proper management, the high amount of nitrogen and gravitational water increases the nitrogen losses under potato irrigation (Cambouris *et al.,* 2008; Vos, 2009; Giletto and Echeverría, 2013; Giletto *et al.,* 2019). The control environment production with the specific water and nutrient requirements for specific potato varieties is seen to be the best way to increase potato productivity in order to meet the food demand of the growing population.

Conclusion

Use of Nitrogen and water management under potato production is the best way to increase potato yield, NUE and WUE. This study reviewed previous studies on soil water and fertility management under potato production to give an overview of the application of the results obtained. In this review, we found that the nitrogen application on time with the recommended rate based on the soil type can increase potato yield. Extreme N uptake caused by excess fertilization favors vegetative growth at the cost of tuber growth. The additional irrigation is very necessary to increase potato yield. The proper management of nitrogen and water in time is very important for potato production. Application of irrigation water beyond the limit may result to nitrogen losses and then the low NUE. Based on this fundamental knowledge, a potato farmer may choose the accurate type, time and amount of fertilizer application.

Acknowledgement

This paper is a contribution to the Seventh Africa Higher Education Week and RUFORUM Triennal Confernce held 6-10 December 2021 in Contonu, Benin.

References

Ahmadi, S. H., Andersen, M. N., Plauborg, F., Poulsen, R. T., Jensen, C. R., Sepaskhah, A. R. and Hansen, S. 2010. Effects of irrigation strategies and soils on field grown potatoes: Yield and water productivity. *Agricultural Water Management* 97 (11): 1923-1930.

Ati, A. S., Iyada, A. D. and Najim, S. M. 2012. Water use efficiency of potato (*Solanum tuberosum* L.) under different irrigation methods and potassium fertilizer rates. A*nnals of Agricultural Science* 57 (2): 99-103.

Baishya, L., Kumar, M. and Ghosh, D. 2010. Effect of different proportion of organic and inorganic nutrients on productivity and profitability of potato (*Solanum tuberosum*) varieties in Meghalaya hills. *Indian Journal of Agronom*y 55 (3): 230-234.

Cambouris, A., Zebarth, B., Nolin, M., and Laverdière, M. (2008). Apparent fertilizer nitrogen recovery and residual soil nitrate under continuous potato cropping: Effect of N fertilization rate and timing. *Canadian Journal of Soil Science* 88 (5): 813-825.

Campos, H. and Ortiz, O. 2020. The Potato Crop: Its agricultural, nutritional and social contribution to humankind. Springer Nature. 518pp.

Devaux, A., Goffart, J.-P., Petsakos, A., Kromann, P., Gatto, M., Okello, J. and Hareau, G. 2020. Global food security, contributions from sustainable potato agri-food systems. pp. 3-35. In: The Potato Crop: Springer, Cham.

El-Sayed, S. F., Hassan, H. A., El-Mogy, M. M. and Abdel-Wahab, A. 2014. Growth, yield and nutrient concentration of potato plants grown under organic and conventional fertilizer systems. *Am. Eurasian J. Agric. Environ. Sci.* 14 (7): 636-643.

FAO, WFP and UNICEF. 2019. The state of food security and nutrition in the world 2019: safeguarding against economic slowdowns and downturns.

FAOSTAT. 2020. http://www.fao.org/faostat/en/#data/OA.

Giletto, C. M., and Echeverría, H. E. 2013. Nitrogen balance for potato crops in the southeast pampas region, Argentina. *Nutrient Cycling in Agroecosystems* 95 (1): 73-86.

Giletto, C. M., Calvo, N. R. and Echeverría, H. 2019. Predicting Nitrogen losses in potato crop with soil Nitrogen and plant tests. *Agronomy Journal* 111 (5): 2493-2503.

Gitari, H., Gachene, C., Karanja, N., and Schulte-Geldermann, E. 2016. Evaluation of potato (*Solanum tuberosum* L.) nutrient use efficiency under legume intercropping systems. Annual Conference proceedings of Tropical and Subtropical Agricultural and Natural Resource Management (TROPENTAG), organised by the University of Natural Resources and Life Sciences. BOKU Vienna, Austria.

Gitari, H. I., Karanja, N. N., Gachene, C. K., Kamau, S., Sharma, K. and Schulte-Geldermann, E. 2018. Nitrogen and phosphorous uptake by potato (*Solanum tuberosum* L.) and their use efficiency under potato-legume intercropping systems. *Field Crops Research* 222: 78-84.

Goffart, J.-P., Olivier, M., and Frankinet, M. 2011. Crop nitrogen status assessment tools in a decision support system for nitrogen fertilization management of potato crops. *HortTechnology* 21(3): 282-286.

Jackson, S. D. 1999. Multiple signaling pathways control tuber induction in potato. *Plant Physiology* 119 (1): 1-8.

Jane, M. 2016. Soil fertility situation in potato producing kenyan highlands—case of KALRO-tigoni. *International Journal* 6 (24): 1-11.

Jovanovic, Z., Stikic, R., Vucelic-Radovic, B., Paukovic, M., Brocic, Z., Matovic, G. and Mojevic, M. 2010. Partial root-zone drying increases WUE, N and antioxidant content in field potatoes. *European Journal of Agronomy* 33 (2): 124-131.

Kingori, G. G., Nyamori, A. J., and Isutsa, K. D. 2016. Improving seed potato leaf area index, stomatal conductance and Chlorophyll accumulation efficiency through irrigation water, Nitrogen and Phosphorus Nutrient management. *Journal of Agricultural Studies* 4 (1): 127-141.

Koch, M., Naumann, M., Pawelzik, E., Gransee, A. and Thiel, H. 2019. The importance of nutrient management for potato production Part I: Plant nutrition and yield. *Potato Research* 63 (1): 97-119.

Leal Filho, W., Esilaba, A. O., Rao, K. P. and Sridhar, G. 2015. Adapting African agriculture to climate change. Springer.

Nowacki, W. 2018. Water in potato production, problems and challenges. *Ynieria Ekologiczna*

19 (6): 14-25.

Nyiraneza, J. and Snapp, S. 2007. Integrated management of inorganic and organic nitrogen and efficiency in potato systems. *Soil Science Society of America Journal* 71 (5): 1508-1515.

Ojala, J., Stark, J. and Kleinkopf, G. 1990. Influence of irrigation and nitrogen management on potato yield and quality. *American Potato Journal* 67 (1): 29-43.

Pradel, W., Gatto, M., Hareau, G., Pandey, S., and Bhardway, V. 2019. Adoption of potato varieties and their role for climate change adaptation in India. *Climate Risk Management* 23: 114-123.

Rosen, C. J. 1988. Potato fertilization on irrigated soils. University of Minesota Extension.

Ruza, A., Skrabule, I. and Vaivode, A. 2013. Influence of nitrogen on potato productivity and nutrient use efficiency. *Proceedings of the Latvian Academy of Sciences* 67 (3): 247-253.

Salter, P. J. and Goode, J. E. 1967. Crop responses to water at different stages of growth, 1st Edn. Commonwealth Agricultural Bureaux, Farnham Royal, U.K, 1967.

Sasani, G., Patel, C. K., Patel, R., Patel, N. and Patel, S. 2006. Efficient use of water and fertilizers through drip fertigation in potato. *Potato Journal* 33 (3-4): 131-133.

Shahnazari, A., Liu, F., Andersen, M. N., Jacobsen, S.-E. and Jensen, C. R. 2007. Effects of partial root-zone drying on yield, tuber size and water use efficiency in potato under field conditions. *Field Crops Research* 100 (1): 117-124.

Stark, J., and Porter, G. 2005. Potato nutrient management in sustainable cropping systems. *American Journal of Potato Research* 82 (4): 329-338.

Stark, J. C., Westermann, D. T. and Hopkins, B. 2004. Nutrient management guidelines for Russet Burbank potatoes: University of Idaho, College of Agricultural and Life Sciences.

Tang, J., Wang, J., Fang, Q., Wang, E., Yin, H. and Pan, X. 2018. Optimizing planting date and supplemental irrigation for potato across the agro-pastoral ecotone in North China. *European Journal of Agronomy* 98: 82-94.

Vos, J. 2009. Nitrogen responses and nitrogen management in potato. *Potato Research* 52 (4): 305-317.

Xie, K., Wang, X.-X., Zhang, R., Gong, X., Zhang, S., Mares, V. and Quiroz, R. 2012. Partial root-zone drying irrigation and water utilization efficiency by the potato crop in semi-arid regions in China. *Scientia Horticulturae* 134: 20-25.

Yactayo, W., Gutiérrez, R., De Mendiburu, F., Mares, V. and Quiroz, R. 2009. Effect of partial root-zone drying on the growth of potted potato plants under greenhouse conditions. Paper presented at the 15th Triennial Symposium of the International Society for Tropical Root Crops (ISTRC), International Potato Center, Lima, Peru.

Zebarth, B. and Rosen, C. J. 2007. Research perspective on nitrogen BMP development for potato. *American Journal of Potato Research* 84 (1): 3-18.