POLICY BRIEF

Water Use and Agricultural Productivity Growth in sub-Saharan Africa

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October 2023 / No.794

Abstract

Today, we are confronted with one of the greatest challenges of the 21st century: meeting the increasing needs of the population while reducing the damage caused by agriculture to the natural resources, namely water and land. To date, the empirical literature on the estimation of productivity in agriculture, has disregarded water as an input. Given that it constitutes a necessary input, then its efficient use becomes a prerequisite condition. The main objective of this study was to investigate productivity growth in agriculture in sub-Saharan Africa, considering water as an input. The Stochastic Frontier Approach (SFA) was used to estimate the agricultural production function incorporating water as an input and to derive the total factor productivity (TFP) using a sample of 19 countries for the period 1991–2014. The results of the SFA model showed that the classical coefficients of the production function, including water endowment as an input, have a significant and positive impact on agricultural production growth after correction for the potential endogeneity bias. The average growth rate of TFP considering water as an input was estimated at 0.045% per year for the full sample period, a figure considerably lower than classical TFP estimated at an average rate of 1% per year. For the period 1991–2001, the rate was negative and estimated at -0.44% and 0.36% for the period 2002–2012. The higher performance in 2002–2012 may be due to the significant adoption of good agricultural practices along with technological advances that allowed for saving water (between -0.08% and -0.05% on average per year). Therefore, it would be advisable to focus more on good practices in water saving which are key to an efficient use of water in agriculture.

Introduction

In future sub-Saharan Africa will have to contend with one of the greatest challenges of the 21st century: meeting the increasing food needs of the population while reducing the damage caused to natural resources (i.e., water and land) by agriculture. The continent faces several challenges, among which the most important are persistence of pollution, environment degradation and climate change. The green growth model offers a way that allows agriculture to be more resilient to the effects of climate change and population growth. The world demand for natural resources increased by 240% between 1961 and 2008 and, at the same time, deforestation and bad agricultural practices represented 65% of carbon emission in Africa (BAD and WWF, 2012). According to the sixth assessment Report of the Intergovernmental Experts Group on Climate Change (IEGCC) published in 2021, the African continent, which is the lowest contributor to climate degradation, is among of the regions in the world that are most vulnerable to climate change, causing uncertainties about the availability of water. Water is an essential input in agricultural production and hence plays an important role in food security. According to "The State of Food and Agriculture (SOFA)" report (FAO, 2020), available freshwater resources have decreased by 20% during the two last decades, underlining the importance to produce more with less water, especially in the agriculture sector which uses significant quantities of available water (70% of all water withdrawals globally). The "zero hunger" objective of sustainable development cannot be achieved without careful use of water in the food production process. The SOFA Report (FAO, 2020) stresses the importance of a more productive and sustainable use of freshwater and rainfall water in the agriculture sector to achieve that objective. This study considered water endowment of each region as an input factor in the agricultural production function. What then would be the agricultural productivity growth be when water is integrated in the production function? And what is the difference compared with traditional measurement of productivity?

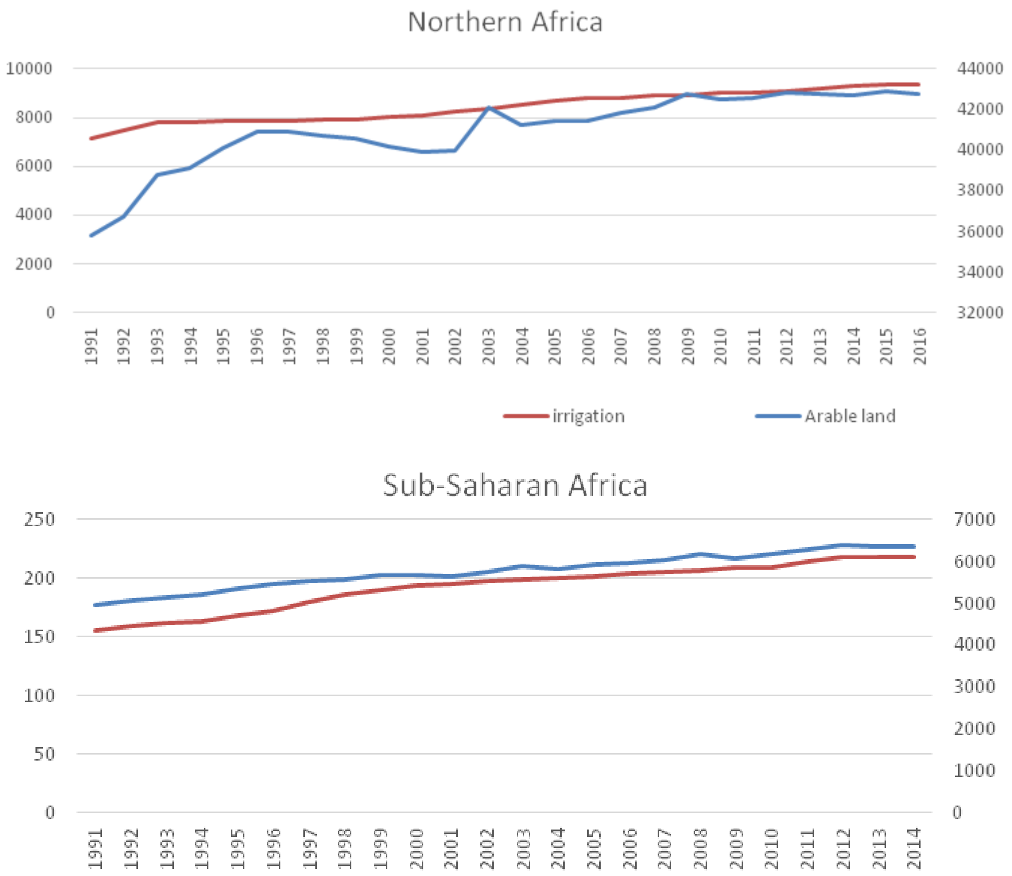
During the 20 last years, water use increased considerably because of population expansion and irrigated agriculture. The use of freshwater by agriculture accounts for 70% of all freshwater withdrawals globally. In Africa, water use by agriculture increased by 90%, on average. In the Sahel countries, according to statistics from FAO (2015), the use of water for agricultural purposes amount to 93% of the available quantities of freshwater.

The water used for agricultural purposes comes mainly from rainfall, surface water sources and underground water. Rainfed agriculture, that is non-irrigated agriculture, depends entirely on rainfall water stored in the soil. This kind of agriculture is only possible in regions where the distribution of rain allows the soil to keep enough moisture during the critical periods of crop growing. According to FAO statistics (2013), rainfed agriculture accounts for about 60% of total production in sub-Saharan Africa. In this kind of agriculture, land management considerably conditions agricultural productivity. However, the ways to improve productivity of rainfed agriculture are limited to the extent that precipitation is subject to important seasonal variations, which is aggravated by climate change.

The main climate change effects on water include the volume, intensity, and variabilities of precipitation. Changes in the timing and distribution of the precipitation are associated with problems of more frequent and more severe floods and drought, depending on the region. Areas where precipitation is expected to occur, are exposed to more frequent and severe floods and to increased erosion and reservoir sedimentation, while regions with lower precipitation face a decrease of water availability and severe drought (Bartes et al., 2008). Even though there exists a high degree of uncertainty in forecasting future precipitation, increases in precipitation are mainly expected in high latitudes and reductions are expected in sub-tropical regions and lower latitudes. Similarly, environmental damage caused by irrigation raises serious concerns and create doubts in many regions of the world about the sustainability of the practice.

In irrigated agriculture (non-rainfed), the water used to grow crops is partially or totally provided by man. Indeed, during rain seasons people use several methods to store runoff water in the soil, in lakes or retention dams, for use during dry seasons. In general, water for irrigation is withdrawn from water points (rivers, lakes, or aquifers) and driven to crop area using appropriate transport infrastructure. To meet their needs of water, irrigated crops benefit from reliable rainfall water and irrigation. Irrigation is an efficient management tool against uncertain precipitation. According to Fox and Rockström (2003) and Pathak et al. (2009), relying on irrigation as a complementary tool would be an interesting alternative option to reduce water deficits for rainfed crops in semi-arid areas.

Figure 1: Trends of irrigated and arable lands (in hectares)



Northern Africa

Sub-Saharan Africa

Sub-Saharan Africa alone accounts for 99% (3,884 km3) of the renewable water resources of the continent, but with a lower efficient utilization rate of 30%, compared to northern Africa where this rate is 69 % with only 1% of the renewable water resources. Only 3% of this water is used for irrigation in sub-Saharan Africa, compared to northern Africa where this rate is 170% (FAO, 2015). Historically, the increase in irrigated agriculture land followed the same growth pace as the arable lands in sub-Saharan Africa. In contrast, in northern Africa, the increase of irrigated agricultural land was faster, meaning more important needs of water. The fact that the increase in irrigated agricultural land has the same growth pace as that of arable land shows the importance of water in the agricultural production process. The important shares of irrigated lands demonstrate the need to improve the use of water as an input in agriculture. Rhoades (1997) concluded that the increase of food production in developing countries should essentially come from irrigated agricultural lands.

However, water is a complex resource, it is unlike a stable resource like land. Water is produced in a dynamic cycle of rain-runoff water-evaporation, with important time and spatial variations, and quantity of water variations that condition African production systems. Even though this could be a nuisance (in case of floods) for certain crops, efficient use of water remains a challenge for sustainable agriculture in Africa. A wide empirical review assessing agricultural productivity growth (Irz et al., 2001; Devkota and Upaghyay, 2013; Djoumessi, 2021, 2022) disregarded water endowment as an input in agricultural production. Very few studies (Wallace, 2000; Howell, 2001; Zwart and Bastiaanssen, 2004; Fereres and Soriano, 2007) have attempted to analyse the role of water use in agriculture. To the best of our knowledge, no study has so far attempted to analyse agricultural productivity growth, considering water endowment as an input, which was the main objective of this study.

Data source

The study sample comprised 19 sub-Saharan African countries with data covering the period 1991–2014. In this study, the output (represented by the agricultural production index) and the inputs (labour, cultivated land, agricultural machinery and tractors, fertilizers, and water endowment) used to estimate production function and TFP, were drawn from World Bank and the Food and Agriculture Organization of the United Nations (FAO, 2015) statistical databases. The construction of the variable representing water endowment for agriculture was defined as a combination of the *available water index* and the *irrigated agricultural lands*. The index of available water was estimated using the principal component approach (PCA) based on three variables: the average annual rainfall, superficial waters, and renewable water resources.

The data used for this analysis were collected as follows: *Agricultural production index* = the index of crop production represents the agricultural production of each year compared to the reference period of 2004 to 2006. This index reports data on the total set of crops, except forage crops. The groupings by regions and income of the production indices from FAO were calculated based on underlying values in dollars and normalized regarding the reference period of 2004 to 2006. A rapid production growth was observed for most of the countries since the 2000s. *Labor:* corresponds to active population working in agricultural activities for each year and for each country. *Lands:* agricultural lands represent the share of the territory that is arable, and which is cultivated or in pasturage on a permanent basis.

The arable lands include lands defined by FAO as lands with temporary crops (lands containing two crops are counted only once), temporary meadows for mowing and grazing, farmlands or vegetable gardens, and temporary fallow lands. The abandoned lands used for shifting cultivation are excluded from this evaluation. *Agricultural machinery and tractors* = the agricultural machinery refers to the number of tracked and wheeled tractors (excluding garden tractors) used in agriculture at the end of the year concerned or at the end of the first term of the subsequent year. *Fertilizers* = the consumption of fertilizers (100 g per hectare of arable land) measures the quantity of nutrients used per unit of arable land. The fertilizers included nitrogen, potassium, or phosphate (notably natural lime phosphate fertilizers). *Irrigation* = the total fully irrigated agricultural lands. *Precipitations* = average annual rainfall within the country. *Surface waters* = total volume of surface waters within the country. *Renewable waters* = total volume of renewable water resources within the country.

Conclusion

To sum up, the main objective of the study was to examine the agricultural productivity considering water endowment as an input for a sample of 19 sub-Saharan African countries with a panel data set covering the period 1991–2014. The results of the SPF model show that the estimated values of the output elasticities regarding the traditional production factors and water endowment in agriculture, have a positive and significant effect on the agricultural production growth after correction for the indigeneity bias. The average growth rate of TPF considering water endowment as an input is estimated at 0.045% per year, which is considerably lower than the traditional TPF growth (amounting to 1%). From 1991 to 2001, the average annual growth rate of the TPF with water endowment as a production factor has been estimated at -0.44%, mainly due to the poor management of crops. In the subsequent period of 2002–2012, the agricultural productivity growth rate has registered a fast increase estimated at 0.36 %. The average growth rate of the TFP with water endowment during 2002–2012 is due to the significant increase of agricultural best practices followed by technological advances that led to water savings. The average water savings in agriculture amounted to -0.08% per year between 1991 and 2001; this rate stood at -0.05% between 2001 and 2012. These results show the significant impact of water efficiency per unit of agricultural production. Therefore, this study recommends that public or private decision makers focus more on an efficient management of water resources to support sustainable agriculture. This includes improved irrigation technology which leads to water savings. Among those innovations, the following can be mentioned: the pipeline distribution systems, the adoption of pressure systems for sprinklers, and drip irrigation or a system that delivers water directly to plant roots. In each case, the aim is to substitute the wasteful traditional irrigation system using new technologies that maximize the benefit of water use for each crop.

References

Alene, A.D. (2010), “”Productivity growth and the effects of R&D in African agriculture”, *Agricultural Economics, Wiley* Online Library, Vol. 41 No. 3–4, pp. 223-238.

Bates, B., Kundzewicz, Z. et Wu, S. (2008), *Climate Change and Water*, Secrétariat du Groupe d'experts intergouvernemental sur l'évolution du climat.

Bierkens, M.F., Reinhard, S., de Bruijn, J.A., Veninga, W. et Wada, Y. (2019), “The shadow price of irrigation water in major groundwater-depleting countries”, *Water Resources Research*, Wiley Online Library, Vol. 55 No. 5, pp. 4266–4287.

Churchill, A., and J. Behan. 2010. “Comparison of methods used to study consumer emotions associated with fragrance”. *Food Quality and Preference*, 21(8): 1108–13.

Coelli, T. and D. Prasada Rao. 2003. “Total Factor Productivity Growth in Agriculture: A Malmquist Index Analysis of 93 Countries, 1980–2000”. Durban, Afrique du Sud.

Datt, G. and M. Ravallion. 1998. “Farm productivity and rural poverty in India”. *Journal of Development Studies*, 34(4): 62–85.

Devkota, S. and M.P. Upadyay. 2013 “Agricultural productivity and poverty reduction in Nepal". Working Paper. Faculty Research and Creative Activity.

Diewert, W. 1992. “The Measurement of Productivity”. *Bulletin of Economic Research*, 44(3): 163–98.

Djoumessi, Y., Afari-Sefa, V., Kamdem, C.B. et Bidogeza, J.-C. (2018), “Socio-economic and institutional factors underlying efficiency of smallholder vegetable farms in Southwest region of Cameroon”, *International Journal of Social Economics*, Vol. 45 No. 1, pp. 93–106.

Djoumessi, Y.F. 2022. “New trend of agricultural productivity growth in Sub-Saharan Africa”. *Scientific Africa*, 18: 1–12.

Djoumessi, Y.F., Kamdem, C.B. and L. Ndeffo Nembot. 2020. “Moving off agrarian societies: Agricultural productivity to facilitate economic transformations and non-agricultural employment growth in sub-Saharan Africa”. *Journal of International Development*, 32(3): 324–41.

Djoumessi, Y.F. 2021. “What innovations impact agricultural productivity in Sub-Saharan Africa?”. *Journal of Agriculture and Food Research*, 6, 100228.

FAO (Food and Agriculture Organization of the United Nations). (2020). *Situation mondiale de l'alimentation et de l'agriculture 2020 (SOFA): Relever les défis de l'eau dans l'agriculture.* Rome, Italy: FAO.

Fereres, E. and M.A. Soriano. 2007. “Deficit irrigation for reducing agricultural water use”. *Journal of Experimental Botany*, 58(2): 147–59.

Fox, P. and J. Rockström. 2003. “Supplemental irrigation for dry-spell mitigation of rainfed agriculture in the Sahel”. *Agricultural Water Management*, 61(1): 29–50.

Gallup, J.L., Radelet, S. et Warner, A. (1998), “Economic Growth and the Income of the Poor”, *Manuscrit, Harvard Institute for International Development*, Citeseer.

Gallup, J.L. et Sachs, J.D. (2000), “Agriculture, climate, and technology: why are the tropics falling behind ?”, *American Journal of Agricultural Economics*, Vol. 82 No. 3, pp. 731–737.

Gedefaw, M., Wang, H., Yan, D., Qin, T., Wang, K., Girma, A., Batsuren, D., et al. 2019. "Water resources allocation systems under irrigation expansion and climate change scenario in Awash River Basin of Ethiopia". *Water*, 11(10): 1966.

Gleeson, T., Wada, Y., Bierkens, M.F. et Van Beek, L.P. (2012), "Water balance of global aquifers revealed by groundwater footprint", *Nature*, Nature Publishing Group, Vol. 488 No. 7410, pp. 197–200'

Greene, W. 2005b. "Reconsidering heterogeneity in panel data estimators of the stochastic frontier model". *Journal of Econometrics*, 126(2): 269–303.

Headey, D., Alauddin, M. and D. Prasada Rao. 2010. "Explaining Agricultural Productivity Growth: An International Perspective". *Agricultural Economics*, 41(1): 1–14.

Howell, T.A. 2001. "Enhancing water use efficiency in irrigated agriculture". *Agronomy Journal*, 93(2): 281–89.

Irz, X., Lin, L., Thirtle, C. and S. Wiggins. 2001. "Agricultural productivity growth and poverty alleviation". *Development Policy Review*, 19(4): 449–66.

Kannan, N. et Anandhi, A. (2020), "Water Management for Sustainable Food Production", *Water*, Vol. 12 No. 3, p. 778.

Lachaud, M.A. et Bravo-Ureta, B.E. (2021), "Agricultural productivity growth in Latin America and the Caribbean: an analysis of climatic effects, catch-up and convergence*", *Australian Journal of Agricultural and Resource Economics,* Vol. 65 No. 1, pp. 143–170

Lachaud, M.A., Bravo-Ureta, B.E. and C.E. Ludena. 2017. "Agricultural productivity in Latin America and the Caribbean in the presence of unobserved heterogeneity and climatic effects". *Climatic Change*, 143(3–4): 445–60.

Lachaud, M.A., Bravo-Ureta, B.E. et Ludena, C.E. (2022), "Economic effects of climate change on agricultural production and productivity in Latin America and the Caribbean (LAC)", *Agricultural Economics*, Vol. 53 No. 2, pp. 321–332.

Materu, S., Shukla, S., Sishodia, R., Tarimo, A. and S. Tumbo. 2018. "Water use and rice productivity for irrigation management alternatives in Tanzania". *Water*, 10(8): 1018.

Mellor, J.W. 1963. "The use and productivity of farm family labor in early stages of agricultural development". *Journal of Farm Economics*, 45(3): 517–34.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M.A. et Kijne, J. (2010), "Improving agricultural water productivity: Between optimism and caution", *Agricultural Water Management,* Elsevier, Vol. 97 No. 4, pp. 528–535.

Nin-Pratt, A. et McBride, L. (2014), "Agricultural intensification in Ghana: Evaluating the optimist's case for a Green Revolution", *Food Policy*, Vol. 48, pp. 153–167.

Njuki, E., Bravo-Ureta, B.E. et O'Donnell, C.J. (2019), "Decomposing agricultural productivity growth using a random-parameters stochastic production frontier", *Empirical Economics*, Vol. 57 No. 3, pp. 839–860.

Pathak, P., Sahrawat, K.L., Wani, S.P., Sachan, R.C. and R. Sudi. 2009. "Opportunities for water harvesting and supplemental irrigation for improving rainfed agriculture in semi-arid areas", CAB International Publishing.

Perry, C., Steduto, P. et Karajeh, F. (2017), "Does improved irrigation technology save water? A review of the evidence", *Organisation des Nations unies pour l'alimentation et l'agriculture, Le Caire*, vol. 42.

Rhoades, J.D. 1997. “Sustainability of irrigation: An overview of salinity problems and control strategies”, *Footprints of Humanity: Reflections on Fifty Years of Water Resource Development, Proceedings of the Canadian Water Res. Assoc. 1997 Annual Conference, Lethbridge, Alberta.*

Seckler, D., Molden, D. and R. Sakthivadivel. 2003. “The concept of efficiency in water resources management and policy". *Water Productivity in Agriculture: Limits and Opportunities for Improvement,* 1: 37–51.

Tuong, T.P. 1999. “Productive water use in rice production: opportunities and limitations”. *Journal of Crop Production*, 2(2): 241–64.

Turral, H., Wood, M., and C. Fitzpatrick. 2017. “Macalister Land and Water Management Plan”.

Van Beek, L.P.H., Wada, Y. et Bierkens, M.F. (2011), “Global monthly water stress: 1. Water balance and water availability”, *Water Resources Research*, Wiley Online Library, Vol. 47 No. 7.

Von Cramon Taubadel, S, Anriquez, H et Nivievskyi, O (2009), Investment in Developing Countries’ Food and Agriculture: Assessing Agricultural Capital Stocksand Their Impact on Productivity.

Wada, Y., van Beek, L.P. et Bierkens, M.F. (2012), “Nonsustainable groundwater sustaining irrigation: A global assessment”, *Water Resources Research,* Wiley Online Library, Vol. 48 No. 6.

Wada, Y., Van Beek, L.P., Van Kempen, C.M., Reckman, J.W., Vasak, S. et Bierkens, M.F. (2010), "Global depletion of groundwater resources”, *Geophysical Research Letters*, Wiley Online Library, Vol. 37 No. 20.

Wada, Y., Wisser, D. et Bierkens, M.F. (2014), “Global modeling of withdrawal, allocation and consumptive use of surface water and groundwater resources”, *Earth System Dynamics,* Copernicus GmbH, Vol. 5 No. 1, pp. 15–40.

Wallace, J.S. 2000. “Increasing agricultural water use efficiency to meet future food production”. *Agriculture, Ecosystems & Environment,* 82(1–3): 105–19.

Ziolkowska, J.R. 2015. “Shadow price of water for irrigation—A case of the High Plains”. *Agricultural Water Management*, 153: 20–31.

Zwart, S.J. et Bastiaanssen, W.G. (2004), “Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize”, *Agricultural Water Management,* Elsevier, Vol. 69 No. 2, pp. 115–133.

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