SHORT COMMUNICATION

IMPLICATIONS OF WATER AND ENERGY ACCESS ON AGRICULTURAL PRODUCTION AMONG SMALLHOLDER FARMERS IN KWAZULU-NATAL, SOUTH AFRICA

Kaula A[1], Mudhara M[1], Senzanje A[2] and Mukwedeya B[1]

[1]School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa.
[2]School of Engineering, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

aphiwetkaula@gmail.com

Abstract

Resource-intensive farming systems that have caused water scarcity and significant deforestation cannot deliver sustainable agricultural production and food, as they negatively affect the efficient management of these resources. The balance between the three components of Water, Energy and Food (WEF) needs sustainable and efficient management to ensure effective synergy between them and assist in resource security and productivity. The WEF resources must be balanced by acknowledging that they are unique and different in their behaviour, properties, nature and cycles. Smallholder irrigated schemes lack knowledge of how water and energy interact, and how access to them, or the lack of access to them, affects their food production. A structured questionnaire was administered to 345 randomly selected smallholder irrigation farmers, a mix of sugarcane growers and vegetable farmers in the rural areas of the KwaZulu-Natal Province, South Africa. A Cobb-Douglas production function examined how access to water and energy resources affects food production. The results revealed that factors, such as energy input costs, increase the gross revenue of food production by 0.228%, that the minutes it takes to fetch water decreases the gross revenue of food production by 0.313%, and that the synergy between irrigated cultivated area and the energy input costs increases the gross revenue of food production by 0.099%. The study concludes that the availability of water, as well as the accessibility to it, significantly affects the gross revenue in food production. These findings advocate for policy options that will address the improved availability of water and access to it for households and irrigated plots on smallholder farms.

Keywords: Food production, smallholder irrigation, resource security, trade-offs, WEF nexus, gross revenue

Introduction

Smallholder farmers in Africa face a critical challenge with regards to ensuring sustainable agricultural production, due to their limited and irregular access to water resources, which is exacerbated by climate change, as well as a lack of reliable energy sources (Villamor, 2018). The nexus of water and energy access emerges as a central predicament that influences the crop yields, economic viability and overall livelihoods of these farmers (Tälle *et al*., 2019). Farmers have exacerbated these challenges by partaking in unsustainable farming practices that have harmed the environment (Simpson *et al*., 2020). Waterways have been contaminated by the excessive and improper application of pesticides and fertilisers (FAO, 2017), groundwater levels have dropped because of extensive and inefficient irrigation techniques, while soil degradation and biodiversity loss have resulted from intensive cultivation and overgrazing (Rapsomanikis, 2015). Simpson *et al*. (2020) posit that these complex challenges require comprehensive investigation and targeted interventions in order

to develop resilient and sustainable solutions that enhance agricultural productivity while ensuring the long-term well-being of smallholder farmers in the region.

Resource scarcity and food insecurity are a significant problem in smallholder irrigation schemes. Understanding the interconnection of the WEF resources will create an opportunity to combat the food and nutrition security issue, whilst encouraging the better management of WEF and the avoidance of undesirable trade-offs. This study seeks to explore the implications of water and energy access on agricultural production among smallholder farmers in KwaZulu-Natal (KZN). This study aims to contribute not only to the regional understanding of these issues, but also to the global dialogue on creating resilient and sustainable agricultural systems in the face of evolving environmental and socio-economic dynamics. In doing so, the study aspires to foster resilience, to enhance food security and to promote the long-term sustainability of agricultural livelihoods in the smallholder farming sector.

Methods

Study area description

The data were collected from four irrigation schemes in the KZN Province, namely, the Makhathini Flats (MFIS), which is dominated by sugarcane growers. Ndumo B (NIS), Tugela Ferry (TFIS) and Mooi River (MRIS), which are dominated by cash-crop farmers. MFIS and NIS are situated in the Umkhanyakude District under the Jozini Local Municipality in north-eastern KZN. The MFIS has 538 hectares and is comprised of individuals (mostly males) and cooperative irrigating farmers (mostly women) (Njoko and Mudhara, 2017). The individual farmers operate on land that is provided by the land trusts (under tribal authorities), and the cooperative farmers operate on state-owned land (Muchara *et al*., 2014). A structured questionnaire was used to collect data from the farmers and it was administered through face-to-face interviews. The questionnaire included the households water accessibility (e.g. the water source and distance to the water source) and the energy costs (e.g. access to electricity and an energy source). In order to calculate the production of different farmers and their different produce, the gross revenue was calculated by using their yields over the current season in 2021.

Cobb-Douglas function

The Cobb-Douglas production function was the best fit for analysing the relationship between water, energy use and the farm's gross revenue (to quantify the various products farmers produce and be able to analyse the data, the produce was converted to monetary quantification. This method derived the potential gross revenue). Several authors have used the Cobb-Douglas production function for examining food production (Zhang *et al*., 2020; Biam *et al*., 2016; Okoye *et al*., 2016; Moghaddasi and Pour, 2016), as well as the relationship between energy inputs and food production or yield (Hatirli *et al*., 2006). The Cobb-Douglas function is expressed as:

$$InY_i = \beta_0 + \sum_{j=1}^{n} \beta_j In(X_{ij}) + e_i \quad i = 1, 2, \ldots n \qquad (1)$$

Where:

Y_i = farm gross revenue, X_{ij} = the vector of inputs used in the production processes, β_0 = constant term in the model, β_j = coefficients of inputs that are estimated from the model and e_i = error term. This study assumes that the food output is zero if there is no energy and water input, as in Hatirli *et al*. (2006). This assumption requires excluding the constant term (β_0) from Equation (1), which was reduced to:

$$InY_i = \sum_{j=1}^{n} \beta_j In(x_{ij}) + e_i \quad (2)$$

Table 1 shows the description of explanatory variables. The water sector has three variables, namely, the water source, the distance to the water source from the household, and the time it takes to fetch it. The energy sector has four indicators, namely, the energy costs (the cost of fertiliser application, human labour, seeds and machinery), access to electricity, agricultural assets i.e. the machinery used on the farm, and the energy sources. The indices of synergy include interactive variables between the size of the irrigated plots the energy input costs, and access to water. The household characteristics include their marital status, education, household income and expenditure on food.

Table 1. Description of explanatory variables

WEF sector	Name of variable	Definition of measurement	Expected Sign
Water	Water source	Household's primary source of water (1 = Piped (tap) water in dwelling; 2 = Piped (tap) water on-site or in yard; 3 = Public tap; 4 = Water-carrier/tanker; 5 = Borehole; 6 = Borehole off site/communal; 7 = Rain-water tank on site; 8 = Flowing water/stream; 9 = Dam/pool/stagnant water; 10 = Well; 11 = Spring; 12 = Neighbour 13 = Other	+
	Water source distance	Distance of water source from dwelling (1 = Less than 100 m; 2 = 100 m - less than 200 m; 3 = 200 m - less than 500 m; 4 = 500 m - less than 1 km; 5 = 1 km or more; 6 = water on site; 7 = Don't know)	-
	The time it takes to fetch water	The minutes it takes to fetch water (minutes)	_
Energy	Energy cost	The amount of money paid for the energy sources implemented in growing the crops (ZAR)	_
	Access to electricity	Days per week that the household has access to electricity (days)	+
	Agricultural assets	Number of types of machinery and livestock that the farmer has	+
	Energy source	Households primary source of energy (0 = other; 1 = Electricity from mains)	+
Synergy	Index of synergy irrigated plot x energy input costs	Area under Irrigation multiplied by energy cost (interaction variable).	+
	Index of synergy access to water x energy input cost	Access to water was measured by the number of days the households had access to water in a week, multiplied by the energy costs (interaction variable).	+
Household characteristics	Marital status	Marital status of household head (1= single; 2 = Married; 3 = Widowed, 4 = Divorced)	+/-
	Education	Highest level of education of household head (0 = non-formal education; 1 =	+

		Primary education (Grade 1-6); 2 =Secondary education (Grade 7-12); 3 =Tertiary education (Certificate/Diploma/Degree)	
	Household income	Average monthly income (ZAR)	+
	Food expenditure	Prices of food bought in the last month (ZAR)	-

Results and Discussion

Factors influencing gross revenue among irrigation farmers

The econometric analysis used the general multivariate linear regression model, to estimate the factors influencing the farm's gross revenue. Table 2 indicates the relationship the dependent variable has with the independent variables. The multiplicative index of the synergy between irrigated plots and input energy costs was statistically significant ($p<0.01$), while the marital status was statically significant ($p<0.05$). The coefficient of determination (R-squared) shows that about 85% of the total variability in the gross revenue is explained by the explanatory variables in the model.

Table 2 shows that marital status had a positive and statistically significant effect on the gross revenue. Single irrigation farmers produced 0.276% less than their married counterparts. The results are in line with those of Irianti *et al*. (2016), who found that married farmers are more likely to be productive, compared to their unmarried counterparts.

Table 2. Effect of water and energy on food production

Independent Variable	Coefficients	Level of Sig.	VIF
Constant	9.518	0.000***	
Education	-0.307	0.695NS	1.21
Marital status	0.276	0.019**	1.17
Household income	-0.187	0.007***	2.39
Food expenditure	0.062	0.564NS	1.91
Water source	-0.193	0.322NS	2.19
Distance to water source from HH	0.148	0.494NS	1.98
Minutes to fetch water	-0.313	0.011**	1.68
Agricultural assets	0.036	0.652NS	1.57
No access to electricity	-2.423	0.007***	1.15
Source of energy	0.787	0.000***	1.87
Energy input costs (plot)	0.228	0.000***	1.92
Index of synergy irrigated plot size x energy input costs	0.099	0.000***	3.38
Index of synergy access to water x energy input costs	-1.65e-08	0.732NS	1.78

Mean VIF	1.86
R^2	0.849
F	78.08***
n	195

*Note: ***, **, NS = significant at 1%, 5%, Not Significan*t

The time it takes to fetch water from the water source to the household has a negative and statistically-significant effect on the gross revenue. Thus, if the minutes to fetch water increases by 1%, the gross revenue decreases by 0.313%. Ningi *et al.* (2021) posit that access to water is crucial for various farming activities, and delays, or inefficiencies, in obtaining water can impact the overall productivity and profitability of a farm. If farmers spend a significant amount of time on fetching water, it can reduce the time that is available for essential farming activities. Delays in obtaining water can lead to suboptimal irrigation schedules, which affects the health and productivity of the crop. Furthermore, the time spent on water-related tasks reduces the available time for other productive activities, which can lead to a lower overall labour productivity on the farm. Efficient water supply systems, such as an irrigation infrastructure or access to nearby water sources, are essential for optimising the utilisation of labour and increasing the gross revenue.

Table 5 shows that having no access to electricity had a negative and statistically-significant influence on the gross revenue. Thus, the gross revenue decreases by 2.423% for every percentage increase in the household's days without access to electricity, *ceteris paribus (all other things being equal)*. Simpson *et al*. (2020) are of the view that the availability of electrical power influences various aspects of farming operations and can enhance productivity, efficiency and income. Electrically-powered irrigation systems, such as pumps and sprinklers, enable farmers to manage their water resources effectively. Reliable access to electricity for irrigation contributes to better crop yields, it improves the quality of the crop, as well as the ability to cultivate throughout the year, which positively impacts the overall revenue. In some cases, electricity is crucial for post-harvest activities, such as sorting, cleaning and packaging.

The household energy source had a significantly-positive (p<0.01) relationship with the gross revenue. The results showed that a percentage change in the type of energy that the household utilises is accompanied by an increase of 0.787% in the gross revenue, *ceteris paribus (all other things being equal)*. The results imply that farmers with electricity from the national grid attain more gross revenue, compared to those who use alternative energy sources, such as gas, paraffin, wood, coal, candles, animal dung and solar energy.

Energy input costs had a positive and statistically-significant effect on the gross revenue, which means that a one-percent increase in such costs results in a 0.228% increase in the gross farm revenue. This result contradicts that of Bashira and Schilizzi (2013), who found that input costs had a negative effect on farm productivity. They argued that the high cost of fertiliser prevented farmers from applying the required amounts to their fields. However, the results of this current study are inconsistent with the above findings, since farmers in the irrigation schemes received the Presidential Employment Stimulus Initiative (PESI), which provides financial support for subsistence producers. The PESI alleviated some of the farmers' input costs so that they could acquire adequate quantities of fertiliser and pay for irrigation water. Using fertiliser increases crop production and achieves optimum yields (Sinyolo *et al*., 2014).

The index of synergy between the size of the irrigated land that is cultivated and the input energy costs had a positive and statistically-significant effect on the gross farm revenue. A percentage increase in a combination of the size of irrigated land and the input energy cost would increase the gross farm revenue by 0.099%. The positive relationship between the

gross revenue and the index of synergy between the size of the cultivated irrigated land and the input energy costs suggests that there is synergy between the WEF resources for the smallholder farmers in the KwaZulu-Natal irrigation schemes. The relationship means that enlarging the size of the irrigated land that is cultivated, as well as an increase in the energy inputs, is associated with increased production.

Conclusion and Recommendations

Resource-intensive farming is detrimental to the environment. It is exacerbated by the lack of knowledge on how the resources can be utilised efficiently. This study was designed to investigate the implications of water and energy access on agricultural production among smallholder farmers in the KwaZulu-Natal Province of South Africa. Data were analysed by using the Cobb-Douglas function. The study concludes that water availability and accessibility significantly affects food production, as the minutes that it takes to fetch water have a negative impact in the study areas. Furthermore, the synergy index of the size of the cultivated irrigated land and the energy input costs positively affected food production. This evidence suggests that water is a vital resource in food production for smallholder farmers. The household income, the minutes it takes to fetch water, as well as the lack of electricity, affect food production negatively. In line with the recent debate on this subject, it is evident that farmers should maximise the synergy of the irrigated land and the purchasing of inputs, in order to attain a relatively-high level of food production. Strategies must be implemented to optimise water-use efficiency, since entrance barriers include the cost and dependability of access to both water and energy. Strategies for optimising water-use efficiency must be implemented, since entrance barriers include the cost and dependability of access to both water and energy. Improved water-use management can achieve a more sustainable scale of agricultural production, which will reduce the need for energy and water resources. As a result, smallholder farms will be able to develop access to resources and to turn a profit.

Acknowledgements

The authors acknowledge the Water Research Commission, for funding and supporting this study.

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