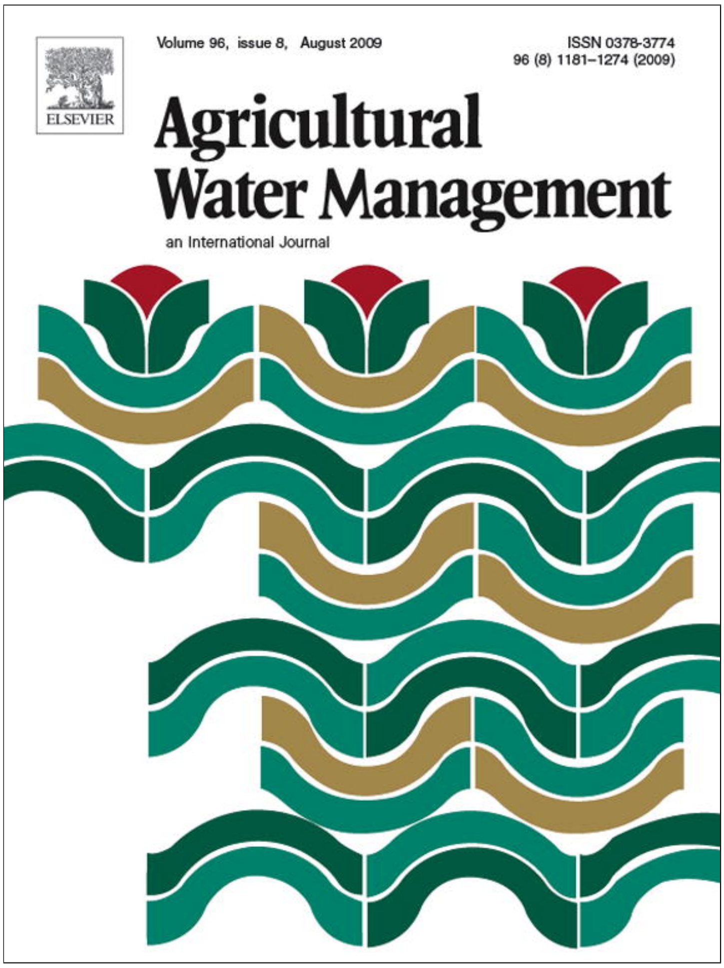
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Water productivity in smallholder irrigation schemes in South Africa

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ABSTRACT

This study investigates the productivity and value of water in two smallholder irrigation schemes (Zanyokwe and Thabina) in South Africa. We apply the residual valuation method (RVM), willingness to pay (WTP) and cost-based approaches (CBA) (i.e. accounting costs of operation and maintenance) to evaluate water productivity and values per crop, per farm, and by scheme. In both schemes, water value estimated by the RVM for vegetables (cabbage, tomatoes and butternuts) is greater than water value for dry maize. At the farm and scheme levels, a comparison was made between gross margin per m^3 of water, WTP per m^3 and accounting cost per m^3 to estimate the relative value of water productivity. The active farmers in the Zanyokwe scheme have lower WTP per m^3 (R0.03) than the gross margin of output (R0.69). Also, the accounting cost (R0.084) per m^3 of water is less than the gross margin. In the Thabina scheme, active farmers are willing to pay (R0.19) per m^3 of water. Hence farmers in Thabina are ready to pay as much as three times the proposed costs of O&M (R0.062) per m^3 of water used. Both the accounting cost and willingness to pay are less than the gross margin per m^3 of water in the Zanyokwe scheme. Our findings indicate that extension and training may be required to improve the productive use of water for those farmers whose returns are insufficient to cover the cost of supply.

1. Introduction

This study is motivated by two main concerns: the economic and financial viability of the South African smallholder Irrigation Management Transfer (IMT) program, and the feasibility of water markets in South Africa.

1.1. The economic and financial viability of the South African IMT program

South Africa has an estimated 1.3 million ha of irrigated land for both commercial and subsistence agriculture (Perret, 2002a; Bembridge, 1996). Irrigated agriculture consumes more than 60% of the groundwater, surface water and recycled water (Backeberg, 1997) and contributes almost 30% of total agricultural production (Backeberg and Groenewald, 1995). According to Perret (2002a) the smallholder irrigation sector (SIS) alone accounts for about 4–5% of irrigated areas in South Africa. About two thirds of the South African SIS are dedicated to food plots that support the livelihood of 300,000 black people (Perret, 2002a). Most SIS, however, have been inactive for many years (Bembridge, 1986; Crosby et al., 2000). Major problems include infrastructure deficiencies emanating from inappropriate planning and design (Perret and Touchain, 2002), poor operational and management structure, inappropriate land tenure arrangements and lack of technical knowledge (Bembridge, 2000).

In finding ways to mitigate these problems, both the central and provincial governments have developed ambitious reform programs aimed at revitalizing the SIS and reducing the financial burden of their operation and maintenance costs. Smallholder irrigation farmers are now exposed to the Irrigation Management Transfer program, which includes a cost recovery and institutional change principle in South Africa (DWAF, 1999b; NWA, 1998). This supposes that irrigation water is to be priced, and farmers must pay for the cost of water supply and related services through water user associations (WUA). While such arrangements are important, crucial questions remain: What are these costs? Do the farmers' production systems allow them to pay? If so, are they willing to pay? It is important to have an idea of the value smallholder irrigation farmers assign to water.

1.2. The feasibility of water markets in South Africa

Demand for water is increasing worldwide, especially in developing countries. Increasing water scarcity implies that options for water resource development are becoming limited. Apportioning water resources among different sectors has become a critical issue. Such is the case in South Africa, where many sectors such as domestic users, industry, mining and agriculture require a share of the country's water resources (Olbrich and Hassan, 1999).

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This increased demand on water supply is due to population and economic growth, industrialization, urbanization, provision of water and sanitation services to previously disadvantaged people, and environmental requirements (DWAF, 1999a; Perret, 2002b). Hence, there is a pressing need to address both equity in water allocation (social justice) and water use efficiency (environmental integrity).

To satisfy these needs, the National Water Act of 1998 provided a broad policy framework for measures to finance the provision of water resource management services and the development of water resources, as well as financial and economic measures to support the implementation of strategies aimed at water resource protection, conservation and the best use of water. The Act also provided for water marketing (NWA, 1998; Armitage, 1999; Louw and Van Schalkwyk, 2000). Although stated vaguely, it makes provision for water rights trading (the legal transfer of water use licenses) as an option for water allocation (Armitage, 1999; Farolfi and Perret, 2002). Under previous legislation, water rights trading between sectors did occur and still occurs between commercial farmers. It has proved efficient in certain instances (Armitage, 1999; Farolfi and Perret, 2002). It appears that water rights trading may also be easily implemented within the water user associations. Since the majority of the rural poor in South Africa depend on water for irrigation, and even more for subsistence farming, water marketing remains a contentious issue.

Several authors (Armitage, 1999; Louw and Van Schalkwyk, 2000; Farolfi and Perret, 2002) have proposed that implementing water markets may cause water re-allocation from agriculture to non-agricultural uses (low value to high value uses). Irrigated agriculture and especially smallholder irrigation is a high-volume water user, but with low return, whereas mining and industry use water at low volume, but with high returns. According to Farolfi and Perret (2002) the productivity of water (WP) in mining is much greater than in smallholder irrigation. Therefore, in a scenario where a water rights market is established, total re-allocation of water from smallholder irrigation to the mining sector may occur, as happened in Chile (Gazmuri and Rosegrant, 1994).

Our goal, therefore, is to examine the productivity of water and its value in smallholder irrigation contexts in South Africa. We assess water productivity by crop, farming system and scheme level in two irrigation schemes. We compare water productivity with supply costs and willingness to pay; and we evaluate the implications, especially in terms of water charges/cost recovery, and competition between sectors. The following hypothesis guides our analysis: there is variation in water productivity and value according to evaluation methods, crops, farmer strategies and irrigation scheme.

1.3. Conceptual framework

The concept of water productivity can be defined at different levels and in different contexts. In agronomic terms, it is defined as crop yield (dry matter of the crop produced) per average unit of water consumed (Van der Hoek et al., 2001). Further consideration includes improving non-water inputs in association with irrigation strategies that can increase the yield per unit of water consumed (Molden et al., 2001). These definitions refer to a crop response to water application. However, from an economic point of view, "crop per drop" may be transformed into a "gross margin of output per drop", by monetizing the crop through marketing or self-consumption. In both cases one must evaluate properly water consumption or demand, and evaluate properly the contribution of water to yield or gross margin, given that water is one of many inputs.

Water productivity is calculated using the total gross margin of output (Fig. 1), given that smallholder farmers do not account for external factor costs, such as taxes, land fees, interest rates, depreciation of capital and the like, when calculating farm income or budgets. It is thus assumed that an increase in farm gross return may positively affect both water value and a farmer's willingness to pay (both represented by positive signs), and conversely that a decrease which may occur due to lack of a farmer's skill or other inputs, may have a negative effect.

2. Materials and methods

2.1. Data collection

We collected data from the Thabina and Zanyokwe irrigation schemes between February and May 2003. These schemes were chosen because they are representative of the diversity of smallholder irrigation schemes (SIS) in South Africa. The schemes encompass a diversity of farming systems and management approaches from subsistence to commercial production, and the most common sources of bulk water supply, rivers and dams (Table 1).

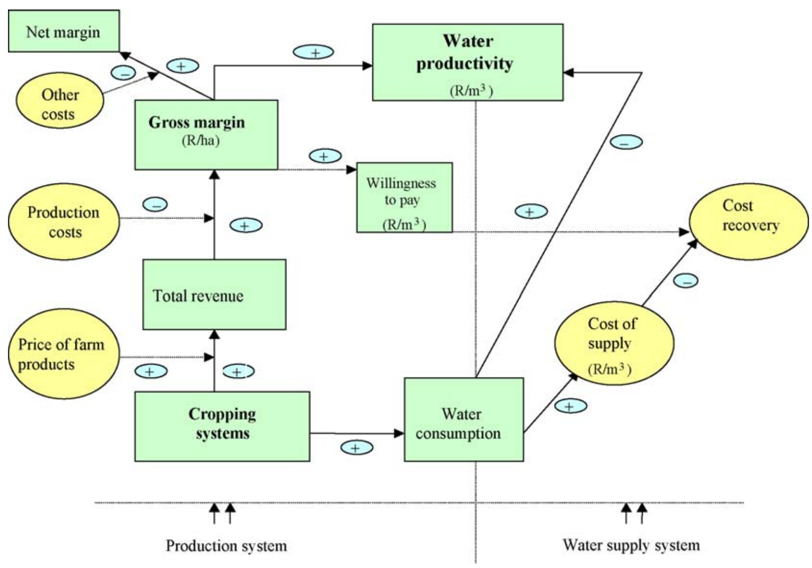

Fig. 1. Conceptual framework for evaluating water productivity and value in SIS context.

Table 1
Descriptive statistics of the Zanyokwe and Thabina smallholder irrigation schemes in South Africa.

Irrigation scheme	Zanyokwe	Thabina
Annual rainfall (mm)	590	790
Altitude (m)	540	560
Irrigated area (ha)	535	234
Number of farmers	66	149
Irrigation system	Dragline sprinkler	Gravity-based system
Water supply system	Dam with piped irrigation	River with a dam and canal

Before interviewing individual farmers, we conducted group discussions with scheme management committees, staff members of WUAs and the Limpopo provincial department of agriculture staff to obtain background information about each of the schemes. We then designed a questionnaire for interviewing the farmers. We use a stratified sampling technique to obtain a representative sample of 124 farmers (60 in Thabina and 64 in Zanyokwe). We collected annual data for the period from summer of 2001/02 and 2002/03. We assigned monetary values to all variables (even those used for family consumption) at the market prices for equivalent products (Statistics South Africa, 2003). The conversion rate for the South African Rand at the time was R6.5 to 1 US dollar.

2.2. Method employed in data analysis

We used the residual valuation method (adapted from Young, 1996) to measure the residual return to water in the Zanyokwe scheme, which had production data for both irrigated and rain-fed situations. The residual return to water is determined by subtracting the gross margin (total revenue less variable production costs) of rain-fed crops from the gross margin of irrigated crops and then dividing the residual gross value of output by the quantity of water used (m^3) (Young, 1996). The residual valuation method is based on the premise that the residual value obtained as total revenue minus total production cost, excluding the compensation for capital assets and management, is attributed completely to irrigation water.

The crops used in the analysis, maize, potatoes and butternuts, are the most common crops grown in the Zanyokwe SIS (Nstonto, 2003, personal communication). Water volumes were determined using the SAPWAT computer program, which uses data from the closest weather station. SAPWAT is a Southern Africa computer program used to calculate crop water requirements (Crosby, 1994). In calculating water volumes, SAPWAT accounts for season length and irrigation system efficiency.

We evaluated water productivity by crop type in the two irrigation schemes, but using data for the most common crops grown under irrigation only. This was required because some of the major crops grown in the Thabina scheme lacked information for rain-fed situations. In the data collected from two schemes, crops are classified as high yield or low yield or as intensive or extensive on the basis of the average yield and the level of inputs for a given crop and crop budget (Yokwe, 2005; Lavigne and Stirer, 2003; Perret et al., 2003). We also applied the RVM in this step, based on the premise that water is paid after all other inputs are paid (excluding capital assets).

Finally, we used the Contingent Valuation Method (CVM) to estimate farmers' willingness to pay per m^3 of water used (Young, 1996). CVM does not rely on market data, but asks individuals about the value they place on something, in this instance by asking them how much they would be willing to pay for water (Lange and Hassan, 2006). In the survey, we asked farmers to evaluate and disclose the financial contribution they might be willing to make for water supply and related services. Respondents were given a choice to indicate how much they are willing to pay. Based on the data collected, respondents were categorized as being subsistence farmers, specialised growers of specific crops only, pensioners who sell produce for income, transition farmers who are moving from subsistence to commercial production, and commercial farmers. These classifications were based on the following criteria: (i) the level of marketing (as opposed to subsistence with virtually no marketing of produce), (ii) the level of diversification (number of crops sold) and (iii) the livelihood system (source of income) (Yokwe, 2005; Lavigne and Stirer, 2003; Perret et al., 2003). Our goal was to reflect the different opportunities and constraints facing various smallholder farmers in South Africa. We used the data obtained from the survey to determine the average value of water in Rand per m^3 (i.e. average Rand per ha per year divided by total irrigation water demand per ha) for each of the farmer categories. Such figures are important for investigating the link between consumption for particular cropping and farming systems and possible charges for irrigation (cost-based approach).

3. Results and discussions

3.1. The residual return to water

Total revenue from irrigated maize was estimated at R6370 per ha, while total revenue for rain-fed maize was estimated as R5460 per ha (Table 2). Thus, irrigation enables the farmer to increase total revenue from high-yield maize production by R910 per ha. In addition, the cost of inputs including fertilizer, pesticide, seeds, labor, equipment, water and marketing, is smaller by R663 per ha for irrigated dry maize compared with rain-fed maize. Hence the estimated residual gross margin benefit from irrigation is R1573 per ha.

The estimated irrigation water requirement for maize in the semi-arid region of Eastern Cape is 515 mm (source: SAPWAT, 1999), or 5150 m^3 ha^{-1}. Thus, the estimated return to water for dry maize in Zanyokwe is R0.31 per m^3 (Table 2; R1 573.32/5150 m^3 used). Similarly, the estimated returns to irrigation for potatoes and butternut are R0.37 per m^3 and R0.72 per m^3, respectively.

The estimated returns to irrigation represent a large portion of the gross margins for these crops: 87%, 89%, and 97% for dry maize, potatoes and butternut, respectively. These proportions are somewhat higher than one might expect. Such results can be

Table 2
Estimates of the residual return to irrigation water (Rand per m^3) in Zanyokwe scheme, South Africa.

	Grain maize*			Potatoes*			Butternuts*		
	Irrigated	Rain-fed	Δ	Irrigated	Rain-fed	Δ	Irrigated	Rain-fed	Δ
Total revenue (Rand/ha)	6370	5460	910	11985	3630	8354	11655	3495	8160
Production costs (Rand/ha)	4569	5232	−663	9630	3360	6270	8145	3374	4770
Gross margin (Rand/ha)	1800	227	1573	2354	270	2084	3510	120	3389
Irrigation water used (m^3/ha)**	5150	0	5150	5670	0	5670	4700	0	4700
Return to water (Rand/m^3)		0.31			0.37			0.72	

Δ = Change in output (irrigated minus rain-fed). All figures are expressed as per ha. All figures are average obtained from both rain-fed and irrigated (data collected in summer and winter of 2002–2003 excepted ** from SAPWAT). * Summer high yield crop types. The current conversion rate for South African Rand (ZAR) to US dollar = R6.5 per US dollar.

Table 3
Summary of irrigation water productivity for various crops in Zanyokwe and Thabina smallholder irrigation schemes, South Africa.

Crop type	Zanyokwe scheme			Thabina scheme		
	Gross margin (Rand/ha)	Water consumption (m^3/ha)**	Gross margin (Rand/m^3)	Gross margin (Rand/ha)	Water consumption (m^3/ha)**	Gross margin (Rand/m^3)
Dry maize-high yield*	1800	5150	0.35	1162	5840	0.20
Dry maize-low yield*	211	5150	0.04	−374	5840	0
Tomatoes-intensive	–	–	–	8455	3910	2.16
Tomatoes-extensive	–	–	–	1957	3910	0.50
Cabbage-intensive	5155	3140	1.64	4208	3700	1.14
Cabbage-extensive	409	4610	0.09	3377	3700	0.91
Butternut-high yield	3510	4700	0.75	–	–	–
Butternut-low yield	101	4300	0.02	–	–	–

Data collected in summer and winter 2001–2002. All figures are averages obtained from different farmers (except ** from SAPWAT). * Summer crops. The current conversion rate for South African Rand (ZAR) to US dollar = R6.5 per US dollar.

explained by the very arid conditions of the scheme, which make irrigation a crucial input of production. Also, the estimated production cost for dry maize in rain-fed conditions is rather high (Table 2), perhaps because the data have been collected directly from farmers who might have over-estimated some of the input costs. Thus, it would be helpful to analyse cost and returns information for more than one year.

3.2. Water productivity of crops under irrigation

Intensively irrigated cabbage generates a larger gross margin per m^3 than dry maize in both schemes (Table 3). This is partly a consequence of different irrigation systems – dragline sprinkler for cabbage compared with gravity based systems for maize. As expected, higher gross margins and higher water productivity are observed for irrigated crops using sprinkler systems compared to gravity-based systems, which have higher water losses due to evaporation and infiltration from earthen irrigation channels. In Zanyokwe, irrigated dry maize and irrigated potatoes generate smaller gross margins per m^3 than cabbage and butternuts. In Thabina, cabbage and tomatoes outperform dry maize (Table 3). There is a greater potential return in more intensive vegetable crop production than in food grain crops and in more intensive high input and high productivity cropping systems. This measure of water productivity and high gross margins however may not necessarily correspond with the highest economic returns, as we have not accounted for higher capital requirements and opportunity. Low yield and extensive cropping systems generate very low gross margins per ha and low irrigation water productivities (gross margins per m^3). Opportunities for producing higher yielding crops using intensive cropping systems should be investigated.

3.3. Farmers' willingness to pay and the costs of supply

In the Zanyokwe scheme, specialized farmers are willing to pay R0.03 per m^3 of water used, while transition farmers are willing to pay R0.02 per m^3 and full-time commercial farmers are willing to pay R0.01 per m^3 (Table 4). Specialized farmers are willing to pay at least R0.03 per m^3. By comparison, the estimated operation and maintenance costs of supply are almost three times what farmers are willing to pay per unit of water, more than R0.08 per m^3. If the operation and maintenance costs are to be covered by the gross margin m^{-3}, these costs can form only a small portion of the gross margin. For specialized farmers, the operation and maintenance costs of the Zanyokwe scheme will form only a small portion (12%) of the gross margin of output per m^3. Hence in the Zanyokwe scheme farmers do not realize a direct link between the water they use and the returns they generate from farming. In other words, farmers are not aware of how much water they use or the value they obtain from its use. In the Zanyokwe scheme, the accounting cost and the willingness to pay are less than the gross margin.

In the Thabina scheme, the situation is somewhat different. Subsistence farmers indicate they are willing to pay R0.02 per m^3 for the cost of supply (Table 4). Specialized farmers indicate they are willing to pay R0.03 per m^3. Pensioner farmers (commercial) are willing to pay R0.19 per m^3, whereas full-time commercial farmers are willing to pay R0.03 per m^3 (Table 4). The most active and willing farmers in the Thabina scheme are the pensioners who sell some of their produce to provide some income. If farmers are required to pay for the costs of supply (O&M costs), these costs will be about 44% of what the pensioner commercial farmers are willing to pay. Farmer willingness to pay in Thabina is about 63% of the gross margin (R0.30 per m^3) gained from irrigation water.

3.4. Water charges and cost recovery

These results can be used to evaluate whether the estimated costs and gross margins gained from irrigation water are in line with estimates of farmers' willingness to pay. For example, in the Thabina scheme, the estimated O&M costs are R0.062 per m^3, while active farmers are willing to pay R0.19 per m^3, and the estimated gross margin is R0.30 per m^3. However, in the Zanyokwe scheme, the

Table 4
Comparison between gross margin for various types of irrigation farmers, their willingness to pay for irrigation water and the accounting costs for operation and maintenance (O&M) for the irrigation scheme.

Farmers' types	Zanyokwe			Thabina		
	Gross margin (Rand/m^3)	Willingness to pay (Rand/m^3)	Acc. costs of O&M (Rand/m^3)	Gross margin (Rand/m^3)	Willingness to pay (Rand/m^3)	Acc. costs of O&M (Rand/m^3)
Subsistence farmers	–	–	0.084	0.01	0.02	0.062
Specialized farmers	0.69	0.03		0	0.03	
Pensioner farmers (commercial)	–	–		0.30	0.19	
Transition farmers	0.32	0.02		–	–	
Full-time commercial	0.44	0.01		0.29	0.03	

Acc. = Accounting costs of operation and maintenance (figures obtained electricity bills from Eskom and salaries e.g. Thabina). The current conversion rate for South African Rand (ZAR) to US dollar = R6.5 per US dollar.

willingness to pay by active farmers is very low (R0.03 per m^3) in comparison with the estimated gross margin (R0.69 per m^3). Farmers in the Zanyokwe scheme do not fully appreciate the value of the water they use and the gross margin obtained from irrigating, as the gross margin from water use exceeds farmer willingness to pay for water. If subsistence farmers in the Thabina scheme were required to pay for the operation and maintenance costs of water supply, they would need to produce more output per unit of land and water used, probably through intensification (increased use of inputs). Subsistence farmers may also need to become more commercial in their orientation. Even though these data pertain to a single year, our findings indicate that extension and training may be required to improve the productive use of water for farmers whose returns are insufficient to cover the cost of supply.

3.5. Inter-sectoral water rights transfer

In terms of water trading between sectors, the results highlight the risk of a large transfer from smallholder irrigation farmers, who value water at low levels, to sectors with higher water productivity and greater willingness to pay (e.g. mines and domestic users). Competition for water, if left to uncontrolled market forces, may result in smallholder farmers' selling their water rights to sectors which value water at higher levels. Policy intervention might be needed to avoid a "liberal trap" such occurred in Chile, where smallholder farmers sold their water rights "en masse", ultimately resulting in deeper rural poverty (Gazmuri and Rosegrant, 1994). Some form of economic control or regulatory policy, at catchment management agencies level may be required to ensure a more balanced allocation of water when water trading occurs under the proposed water user associations.

4. Conclusions

The value of water in smallholder irrigation schemes varies according to crop type, farmer type, and irrigation scheme. Using the residual valuation method we find a very small difference between the 'return to water' and the 'gross margin of output' when all inputs are considered. The estimated proportion of the return to water for maize in Zanyokwe is less than the return to water obtained from butternuts and potatoes.

We find also that the estimated value of water in producing dry maize is much less than the values estimated for cabbage and tomatoes and for high input (high productivity) or intensive crop types and systems. While the returns from irrigation of maize are much smaller than those obtained from irrigation of vegetable crops, maize is an important source of food supply. Hence it is important to consider the potential impacts on food production of an effort to expand production of high value crops in these smallholder irrigation schemes.

4.1. Limitations and recommendations for further research

- This study highlights the need to improve water productivity in the smallholder irrigation context, but more data are needed regarding actual water consumption and actual capital and maintenance costs. Production and cost data for more than one year would improve the analysis.
- It would be helpful also to monitor gross margins and crop budgets over many years, for both rain-fed and irrigated crops. Such an effort would enhance understanding of the residual return to irrigation water.
- Efficient techniques for investigating water productivity in smallholder irrigation need to be developed, taking into consideration variables such as labour, energy, water and time efficiency.

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