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Impacts of agricultural water interventions on farm income: An example from the Kothapally watershed, India

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ABSTRACT

Agricultural water interventions (AWI), e.g. in-situ soil and water conservation strategies, irrigation, and damming of rivers to increase groundwater recharge, have been suggested as important strategies to improve yields in tropical agriculture. Although the biophysical implications of AWIs have been well investigated, the coupling between the biophysical changes and the economic implications thereof is less well understood. In this study we translate the results from a hydrological model, SWAT, on crop yields for different cropping systems with and without agricultural water interventions, to hypothetical farm incomes for a watershed, Kothapally, located in Andhra Pradesh, India. It was found that on average, AWI significantly improved farm incomes by enabling the cultivation of a high value crop during the monsoon season (cotton), supplementary irrigated to bridge dry spells and replacing a traditional crop (sorghum), and also by enhancing the capacity to produce dry season, fully irrigated vegetable crops, in this case exemplified by onion. AWI combined with cotton resulted in more than a doubling of farm incomes compared to traditional sorghum-based systems without AWI during normal and wet years (i.e. for 75% of the years). Interestingly, we observed that the difference between the AWI system and the no intervention system was larger during years of high average rainfall compared to dry years. It was also found that access to irrigation was more important for farm income than crop choice and AWI *per se*, and thus farms with access irrigation benefitted more from AWI compared to farmers lacking access to irrigation. In conclusion, we suggest that in order to assess equity aspects in terms of farm income generation following the implementation of an AWI project, there is a need for income analyses at the farm level, since income estimates at the watershed level may mask important differences in economic benefits between farms.

1. Introduction

Agricultural water interventions (AWI) have been described as key strategies to reduce inherent risks in tropical dryland agriculture, because of its capacity to bridge droughts and dry spells (e.g. Rockström et al., 2010). Multiple factors contribute to locking rural livelihoods into poverty in subsistence and semi subsistence smallholder framing systems in South Asia and sub-Saharan Africa (e.g. Carter and Barrett, 2006; Enfors, 2013; Hussain et al., 2007; Tittonell and Giller, 2013). There are several examples of where improved water management has, at least partly, been able to unlock this trap and place the farmers on a new path onto which farm economies continue to improve (e.g. Hanumantha Rao, 2000; Li et al., 2000; Kerr et al., 2000, 2002; Tilman et al., 2002; Fox and Rockström, 2003; Antle et al., 2006; Barron, 2004; Joshi et al., 2004; Sreedevi et al., 2004; Wani et al., 2012; Singh et al., 2014). Evaluations of AWI programmes conclude that the principal objectives of soil and water conservation, generating employment and raising incomes were successfully met (e.g. Hanumantha Rao, 2000; Joshi et al., 2004; Kerr et al., 2000, 2002; Sreedevi et al., 2004). However, the long-term sustainability of these projects was sometimes found to be unsatisfactory, and was also found to affect people unequally (Kerr et al., 2000).

Alterations of hydrological processes, sediment transport and crop yields as a result of AWI have been described previously, both at the watershed scale and at the larger meso-scale (e.g. Garg et al., 2011, 2012). Similarly, the socio-economic aspects of concurrent agricultural transformations have been documented (Hanumantha Rao, 2000; Hope, 2007; Joshi et al., 2004; Kerr et al., 2000; Sreedevi et al., 2004). However, the coupling between the biophysical changes and the economic implications thereof is less well understood. In particular, there is a lack of quantifications of the variations in farming

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incomes between different cropping systems combined with AWI, which is likely to be very variable in the semi-arid and dry sub-humid zone due to large differences in climate between years. In addition, the importance of farm heterogeneity on the actual outcome of AWI at the farm level, from interventions targeting a whole watershed, is also not well understood.

In this study we analyse the potential of AWI to improve farm incomes, using a watershed in Andhra Pradesh, India, as an example. More specifically, we assess the impact of AWI and crop choice on hypothetical farm incomes under different hydro-climatic and environmental conditions such as rainfall and soil depth.

2. Methods

2.1. Agricultural water interventions in the Kothapally watershed

Agricultural water intervention activities in the Kothapally village, Andhra Pradesh, India, and the surrounding watershed, begun in 1999. Kothapally is situated upstream the Osman Sagar drinking water reservoir that supplies the city of Hyderabad with drinking water, and the watershed is 450 ha in size (Fig. 1). The Kothapally watershed was selected for agricultural water interventions for several reasons: (i) more than 90% of the cultivable area was rainfed,

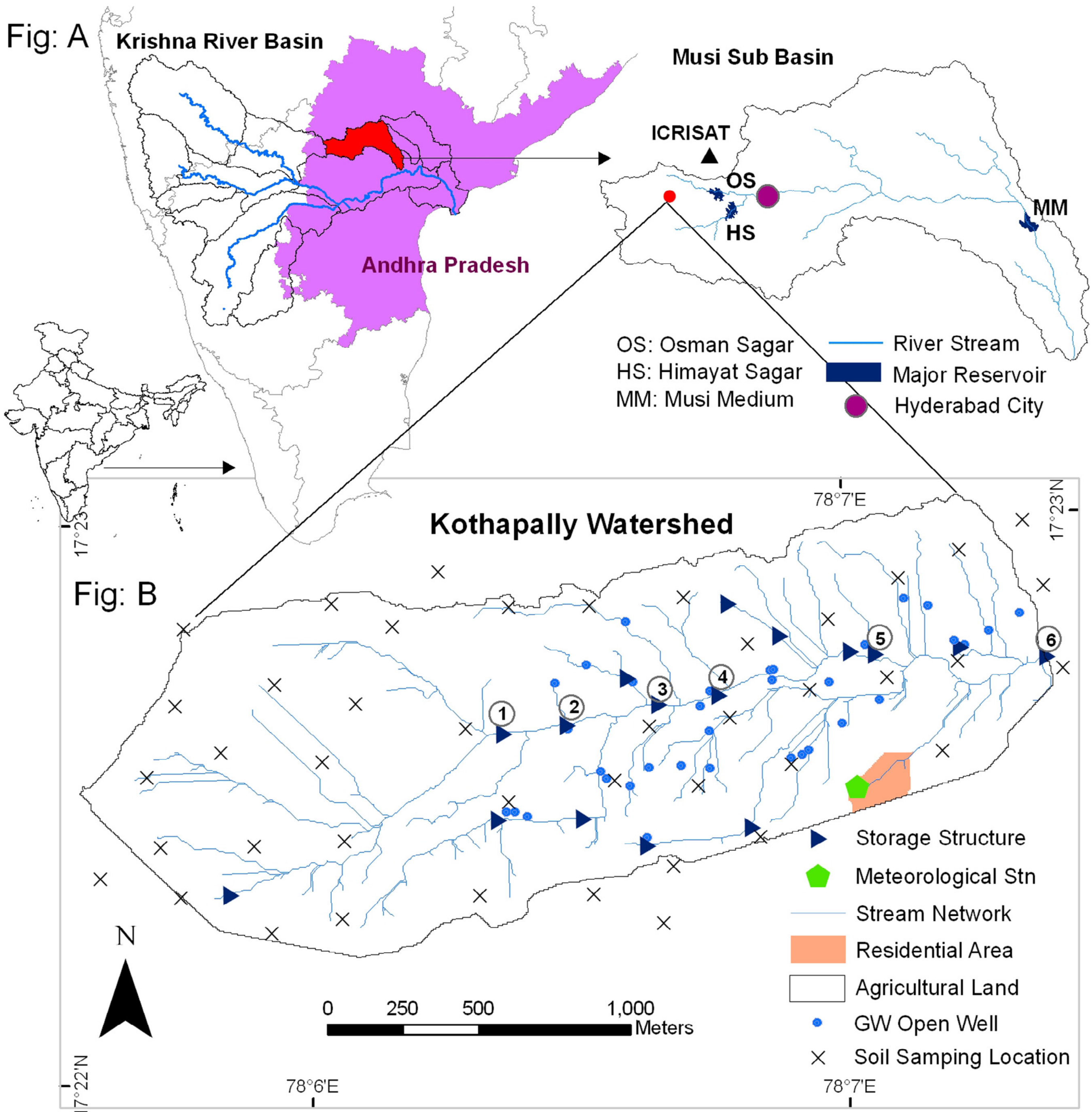


Fig. 1. (A) Location of Kothapally watershed in Musi sub-basin of Krishna river basin, including main reservoirs and Hyderabad city; (B) Stream network, location of storage structures, open wells, meteorological station, soil sampling locations and residential area in Kothapally watershed.

characterised by water scarcity; (ii) crop productivity was below 0.5–1.0 ton/ha; (iii) many open wells were defunct and the community experienced acute water shortage for drinking purposes, especially during the summer period; (iv) the non-existence of water harvesting structures and the potential for minimum interventions to conserve soil and water.

Through implementation of a wide range of water harvesting and rainwater infiltration enhancing technologies, local runoff is being captured and soil loss prevented. Water storage structures further enhance the use of water, with the largest being masonry check-dams constructed on the main river. The water trapped in these structures is not used to irrigate fields, but only to infiltrate to the shallow groundwater at less than 12 m depth. *In-situ* soil and water conservation is now practised on the fields (field bunding, cultivation across the slope, broad bed and furrow practices). As a result, both the infiltration capacity and the organic content of the soil have increased (Wani et al., 2012), thereby contributing further to increasing the groundwater table as well as improving the soil water holding capacity. Groundwater is then pumped from dug wells to irrigate the surrounding fields, which means that only parts of the fields have access to irrigation. In the area surrounding the study site, cotton or sorghum/chickpea is grown, depending on water availability. The latter crops give smaller economic returns, but are more drought tolerant, which thus is the logical choice for a risk minimizing farmer, while an income maximizing approach would be to cultivate cotton with higher average economic returns which renders the farmer more vulnerable to market prices for cotton. Because of the agricultural water interventions, the traditional sorghum based cropping system in Kothapally was replaced by cotton on more than 70% of current croplands. During the dry season, a fully irrigated vegetable crop is also grown on parts of the fields, depending on water availability in the wells.

After the interventions, the average household income in the Kothapally watershed is about 50% higher compared to adjoining villages without AWI (Sreedevi et al., 2004). In Kothapally, average cotton yields are around 2 ton/ha (Garg et al., 2011), which can be compared with an average seed cotton yield of 1.4 ton/ha in India, and close to the world average of 2.2 ton/ha (FAOStat, 2007).

The share of the total household income derived from agriculture is dependent on farm economy. Studies in the nearby villages of Aurepalle and Dokur have shown that after a number of consecutive drought years, farmers diversify their livelihood strategies through increased off-farm activities (Bantilan and Anupama, 2002). The result from this shift in income source was that the share of agricultural incomes to the total household income was halved or more than halved, while the total household income actually increased. Before 1999, most of the farmers were solely dependent on agriculture. With the introduction of the agricultural water interventions, however, farmers were motivated to do other job activities and services along with cultivating crops, which together with improved yields, led to a substantial change in their livelihood in recent years. Currently, off-farm activities in Kothapally account for around 50% of the total household income, both during normal years and for drought years (Shiferaw et al., 2005).

2.2. Modelling the impact of water interventions and crop choice on farm income

Process based crop growth and hydrological modeling of the Kothapally watershed from 1978 to 2008 was conducted using the Soil Water Assessment Tool (SWAT) to investigate hydrological impacts of different agricultural water interventions (Garg et al., 2011, 2012). In this paper, we run two of the water management scenarios described in Garg et al., (2011, 2012) ("no intervention" and "max intervention", representing the soil- and water-management practices before and after the implementation of the agricultural water interventions, respectively), for two cropping systems (a traditional sorghum based system and a cotton based system), to estimate crop yields. Results from three combined scenarios of soil- and water-management practices and cropping systems are used in this paper: one traditional sorghum based system without AWI ("S no int."), one cotton based system without AWI ("C no int."), and finally one cotton based system with AWI ("C max int."). While cotton based systems without AWI cannot be found in the case-study region, it was included in the study to enable an assessment of the effect of AWI on income for the same cropping system. All three scenarios included a fully irrigated onion crop during the dry season.

In previous studies we found that AWI resulted in higher groundwater levels and seasonal soil moisture availability compared with no interventions (Garg et al., 2011, 2012). While all croplands enjoy the benefits of higher soil moisture availability, only the farms in close proximity to the wells can utilize groundwater for irrigation also after the implementation of AWI. Thus, even with AWI, not all farms have access to irrigation, and similarly, even without AWI, some farms have access to irrigation even if the amount of irrigation water may be more limited than under AWI. In the model we assume that all sub-basins (i.e. hydrological response unit, HRU) closer than 300 metres from a well have access to irrigation (see Fig. 1 for location of wells) in all three scenarios, corresponding to around 50% of all croplands. Specific analyses were made on the role of irrigation by sub-dividing the results for areas with and without access irrigation, for all scenarios.

To replicate regional cropping patterns in the model scenarios, we assumed that during the monsoon season (June–Oct) either sorghum or cotton was grown. This monsoon crop was irrigated twice per season with a maximum of 75 mm of water, depending on water availability in the wells, on all crop-lands with access to irrigation, in all three scenarios. Based on crop specific characteristics for sorghum and cotton, actual crop seasonal evapotranspiration (ET) was estimated in the SWAT model. Crop yields were subsequently calculated from actual ET by assuming a linear relationship between the ratio of actual and potential ET (water stress index) and yields (Stewart et al., 1977) according to crop specific production functions. These production functions were used as an alternative to estimate yields with the SWAT tool, since many of the parameters required by the model to simulate crop growth were unknown, and the parameters in the in-built crop database in SWAT representing sorghum and cotton are not applicable to the Indian context.

To derive production functions for sorghum and cotton it was assumed that they vary with season. In order to account for this seasonal variation, the maximum ET under non-limiting conditions (ET_{max}) was first determined by running the SWAT model between 1974 and 2010, and was found to be 461 mm/yr and 640 mm/yr for sorghum and cotton, respectively. The minimum seasonal ET determining crop failure (ET_{thres}) was assumed to correspond to 40% of ET_{max} based on literature values (around 200 mm for sorghum (Tolk and Howell, 2009) and 385 mm for cotton (DeTar, 2008; Howell et al., 2004)). Thereafter, actual ET without meeting maximum crop water needs was simulated for the same period (ET_{act}). To estimate actual crop yields (Y_{act}) a linear relationship between ET_{act}/ET_{max} and Y_{act}/Y_{max} was assumed, subtracting the amount of ET below ET_{thres} from both ET_{act} and ET_{pot}, according to:

$$\frac{Y_{act}}{Y_{max}} = \frac{ET_{act} - ET_{thres}}{ET_{max} - ET_{thres}}$$

Maximum crop yields under non-limiting water condition (Y_{max}) were assumed to be 3.0 ton/ha for both crops based on field experiments and farmers' participatory research trials conducted at the Kothapally watershed (Wani et al., 2012). Finally, the average crop yield per specific amount of ET was calculated and plotted

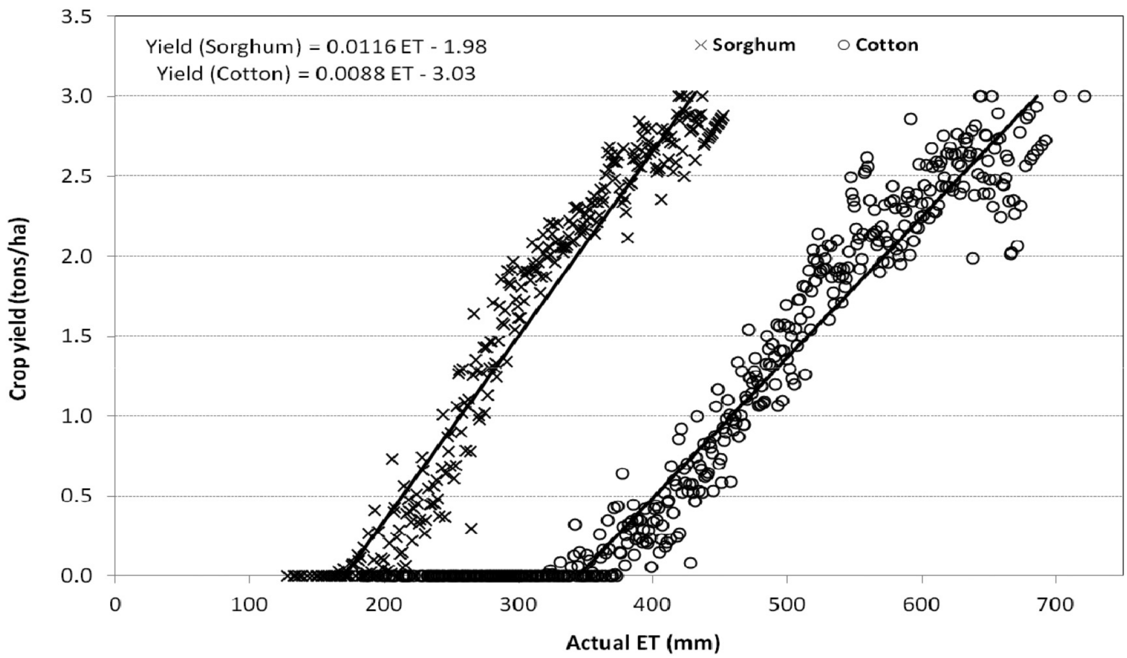


Fig. 2. Production functions for sorghum and cotton respectively used to estimate yields from actual ET.

against ET (Fig. 2), and these resulting production functions were then used in the study to estimate yields from simulated ET_{act} in SWAT, for the monsoon crops. Simulated yields, Y_{act}, were found to correlate well with observations in the field (Garg et al., 2011).

During the dry season that follows the monsoon, a fully irrigated cash crop is commonly grown at the study site. Based on the estimated water level in the wells in the beginning of the dry season as provided by the model for the different scenarios, we estimate the size of the area that can be used to grow a fully irrigated vegetable crop (onion), and which thus varies between scenarios and years. Annual crop water requirements for onion were estimated to 600 mm (assuming 70% irrigation efficiency) (National Water Development Agency (NWDA), 2003). An onion yield of 8.7 ton/ha is thereafter assumed in all scenarios (Government of India, 2008). Thus, while the yields are the same in all three scenarios, the area under cultivation varies between scenarios depending on water availability, and hence the total production.

Total yield (wet and dry season) per sub-basin (HRU) were then converted to farm income using marketable values for cotton, sorghum and onion for year 2008–2009 (Table 1). Thereafter, the cost of production is deducted from the gross income (Table 1). We assume that one sub-basin (HRU) represents one farm in this case, since the number of farms in Kothapally village and the number of sub-basins in the model is the same, or to put it differently, the average HRU was 2.7 ha in size, while most farms are around 2–3 ha each. This assumption was necessitated because of lack of data on farm boundaries in the study area. While this may exaggerate the difference in production between farms if fields belonging to one farm are in reality spread over the watershed, it may on the other hand underestimate differences between farms if individual farms vary significantly in size. Thus, while the results are presented as "farm incomes", they should be interpreted as incomes per sub-basin as a proxy for per farm unit.

Table 1
Cost of production and market price for the different crops in the study area during 2008 (Directorate of Economics and Statistics, Andhra Pradesh, India).

	Sorghum	Cotton	Onion
Cost of production (US$/ha)	300	580	1040
Market price (US$/ton)	170	600	230

Incomes from crop yields will impact on the economic status of the farms. We analyse the results according to the following annual farm income classes: 0–500 US$, 500–1000 US$, 1000–1500 US$ and >1500 US$. To provide a point of reference, in the study area it is estimated that below an annual average income of 500 US$, farmers have to rely predominantly on alternative non-farming livelihoods (year 2008) (Government of India, 2011). Also, at an income level above an annual average income of 1200 US$ (year 2008), farms derive enough incomes to start investing in the agri-business, resulting in a situation where the farm economic status is gradually improving (Government of India, 2011). It should be noted that these numbers refer to total incomes and not only to farm incomes specifically, meaning that incomes from off-farm activities need to be added to farm incomes in order to make comparisons with these figures. In addition, these figures are given for an average household and therefore vary with the number of people in the household.

Results were analysed separately for different hydroclimatic years where relevant, due to large inter annual variations in rainfall. Each year was classified as dry, normal or wet, according to the following criteria: rainfall less than 20% of the long-term average = dry; rainfall between −20% and +20% of the long-term average = normal; rainfall greater than 20% of long-term average = wet. The total number of dry, normal, and wet years included in the simulation was 7, 16, and 8 years, respectively.

3. Results

3.1. The impact of AWI on livelihoods in Kothapally

AWI combined with cotton resulted in more than a doubling of farm incomes compared to traditional sorghum-based systems without AWI during normal and wet years (i.e. for 75% of the years), which is due to a combination of higher incomes from the main crop (cotton) and higher yields from the fully irrigated, vegetable crop (onion) (Fig. 3a). Inter annual variations in income was also found

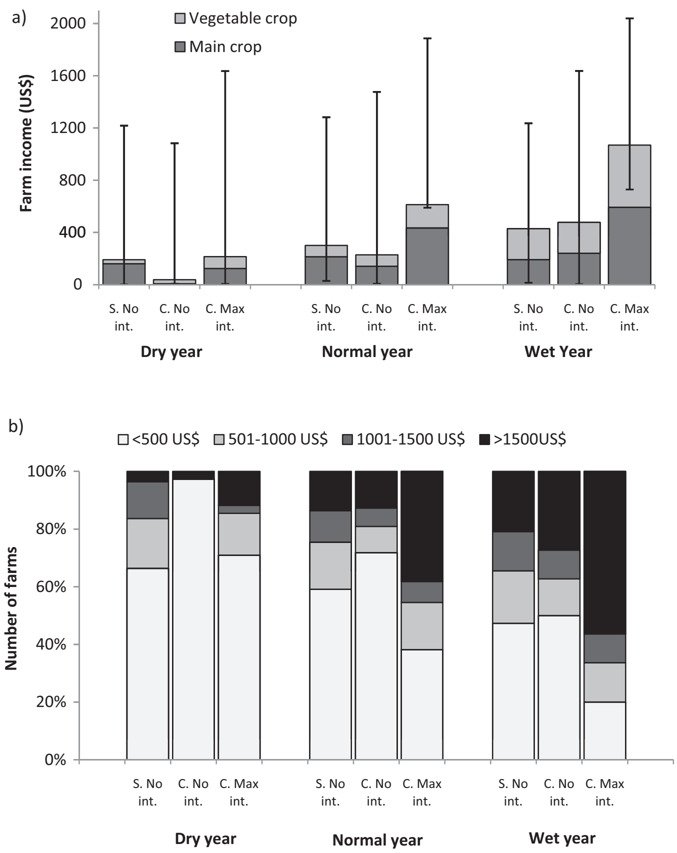


Fig. 3. (a) Farm income from main crops and vegetable crops for different cropping systems, with and without AWI, illustrated for different hydroclimatic years. (b) Number of farms per income category for different cropping systems, with and without AWI, illustrated for different hydroclimatic years. "S no int." = sorghum based system, no AWI; "C no int." = cotton based system, no AWI; "C max int." = cotton based system, with AWI.

to be large. During dry years both the traditional sorghum based system without AWI (S no int.) and the cotton based system with AWI (C max int.) had an average income around 200 US$/yr, while during wet years, the corresponding figure is more than twice as large for the traditional sorghum based system without AWI (S no int.), and five times as large for the cotton based system with AWI (C max int.).

During wet years, yields from the fully irrigated, vegetable crop (onion) constituted around 50% of total farm incomes for all systems, while during drier years, this fraction was slightly lower. Only a small amount of water was available for irrigation of a vegetable crop without AWI during dry years, while with AWI, the income derived from vegetable cropping during dry years was more than 40% of total farm incomes, which makes up for low incomes from cotton.

The impact of AWI on farm income is seen clearly when comparing the cotton-based systems with and without AWI. A cotton/vegetable system without AWI (C no int.) basically resulted in complete crop failure during dry years, and average farm incomes were generally found to be lower than for the traditional sorghum/vegetable crop rotation without AWI (S no int.).

Average farm incomes in the Kothapally area varied between different hydro-climatic years, cropping systems and AWI (Fig. 3b). In general, within a cotton-based system with AWI (C max int.), around 60% of the farmers have an income above 500 US$ during normal years, ranging from 30% during dry years to around 80% during wet years. The corresponding figure for the traditional sorghum based system (S no int.) was found to be 40% for normal years. Interestingly, looking only at dry years, more farms have an income below 500 US$ with the cotton based system with AWI (C max int.), compared with the traditional sorghum based system without AWI (S no int.); however, this picture is reversed for normal and wet years. The figure also illustrates that even during wet years nearly 20% of the farms with AWI have an income below 500 US$. This gives an indication of the potential spatial heterogeneity in the area in terms of access to irrigation and soil depth that may have a large influence on farm incomes, and which we will examine in the following sections.

3.2. Who benefitted from AWI?

We now turn to the spatial variability in farm income within the Kothapally village for different hydroclimatic years. The traditional sorghum-based system without AWI (S no int.) generated stable incomes on most farms for all years (Fig. 4a-c). On the other hand, in a cotton-based system with AWI (C max int.) (Fig. 4g-i), the difference between farms with higher and lower incomes is apparent, in particular during dry years. During dry years, only 35% of the total area in the watershed was predicted to generate higher incomes under the AWI system with cotton (C max int.) compared to the sorghum based system without AWI (S no int.), excluding non-productive areas of the study area. Even when considering all years, 15% of the watershed area still reached higher average incomes with the sorghum based system without AWI (S no int.) compared to the cotton based system with AWI (C max int.), again only considering productive areas. Between 10 and 15% of the study area (in particular in the north western part of the watershed) was non-productive, i.e. farm net incomes were negative (i.e. costs exceeded gross incomes) irrespective of season in all scenarios. This heterogeneity in farm income generation suggests that several factors that varied in the Kothapally watershed, such as access to irrigation (i.e. proximity to the irrigation wells) and soil depth, could be important determinants of farm income, and thereby influence the choice of cropping system and water management intervention.

So under which conditions can we expect that AWI would result in desired outcomes in terms of higher farm incomes? Analyzing farm incomes for areas with and without access to irrigation from the open wells in all scenarios for varying amounts of rainfall, two important observations could be made. First, it was found that AWI had a larger impact on net incomes at high rainfall amount compared with low rainfall amounts (Fig. 5). This analysis also revealed that access to irrigation was in fact found to be more important than crop choice or AWI *per se*, for income generation (Student's t-test, $p < 0.005$). In most cases, irrigated fields performed better than non-irrigated fields irrespective of crop choice. Similarly, in most cases, irrigated fields performed better than non-irrigated fields irrespective of whether AWI was practised or not ($p < 0.001$).

In a similar way, we analysed the impact on soil depth on income for areas with and without access to irrigation separately for all scenarios. In all rainfed systems, there seems to be a sharp decline in income below 250–300 mm of soil for systems with and without AWI ($p < 0.001$, Fig. 6a). For irrigated systems, however, no such sharp decline in income at a certain threshold level of soil depth was observed in either of the scenarios (Fig. 6b). The layered pattern observed for the irrigated systems (Fig. 6b) is a modelling artefact explained by assumptions made about the extent of the irrigated area for dry, normal and wet seasons respectively.

4. Discussion

AWI was predicted to improve farming incomes in a cotton based system during normal and wet years compared to a traditional sorghum-based system without AWI, in the Kothapally village on average. This is similar to results reported for other studies

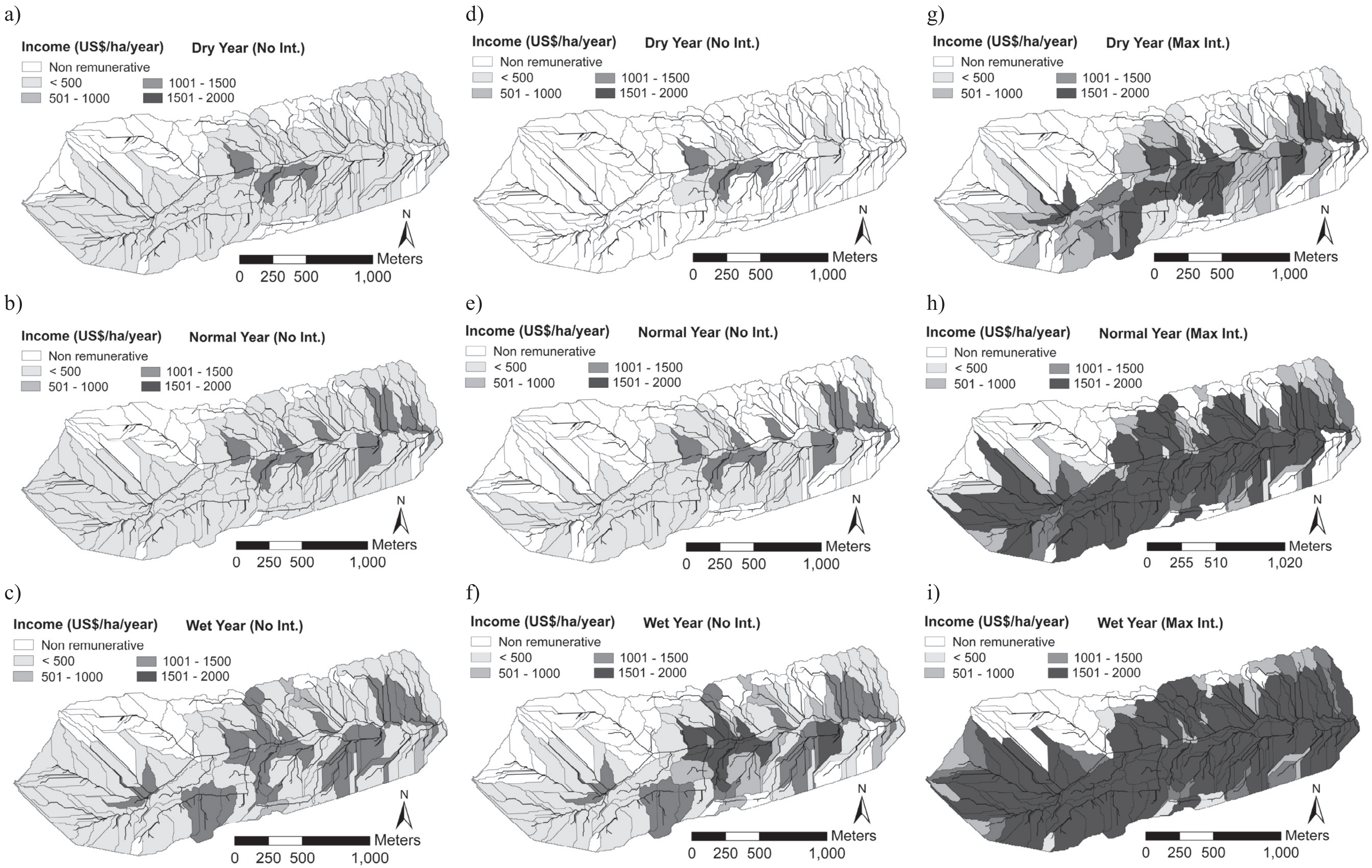
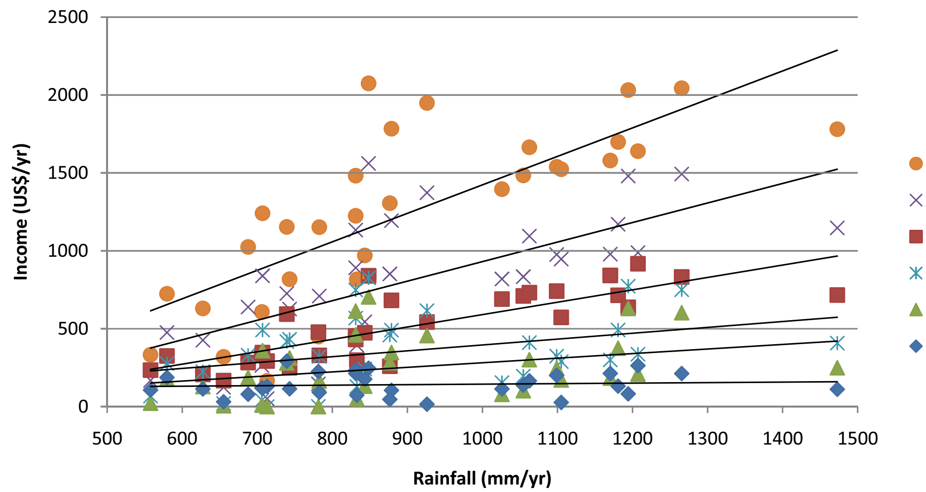


Fig. 4. Farm incomes in the Kothapally water-shed for different management systems and hydroclimatic years. (a–c) sorghum based system, no AWI; (d–f) cotton based system, no AWI; (g–i) cotton based system, with AWI. Top row – dry years; middle row – normal years; bottom row – wet years.



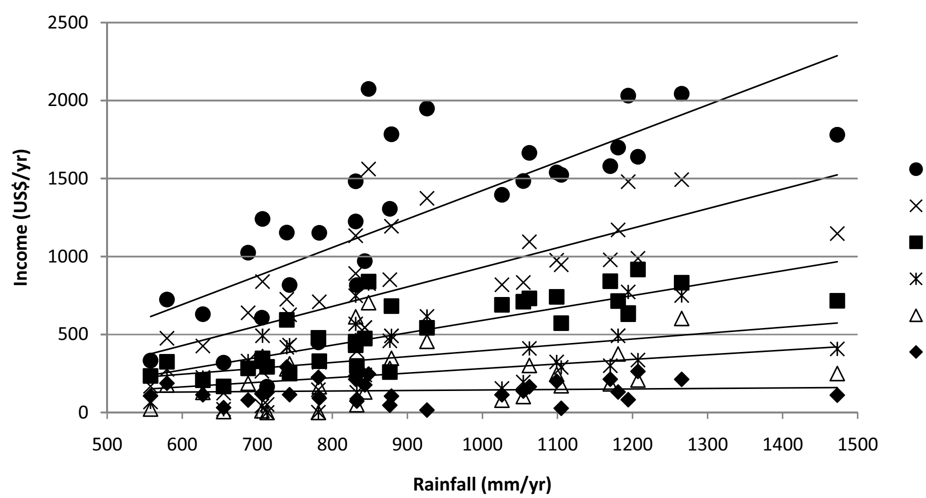


Fig. 5. Variation of net incomes with rainfall for different cropping systems with and without AWI ("S no int." = sorghum based system, no AWI; "C no int." = cotton based system, no AWI; "C max int." = cotton based system, with AWI). These scenarios were further sub-divided into irrigated and non-irrigated croplands. "irr" = access to irrigation; "no irr" = no access to irrigation.

relating farm incomes to AWI (e.g. Singh et al., 2014). Because cotton is more sensitive to drought compared to sorghum, the economic return is larger for sorghum during dry years. It thus appears that from a farm income generation perspective, sorghum is the most rational crop choice without AWI, and that large income improvements when shifting from sorghum to cotton based systems cannot be expected if not combined with AWI. However, it should be noted that from a food security point of view, a cotton-based system increases the vulnerability of the farmer to changes in market prices of cotton, and could thus result in food insecurity since cotton is not a food crop.

The results also highlighted the spatial heterogeneity of the study area in terms of farm income generation. This is due both to physical conditions such as soil type and topography (e.g. soil depth), but predominantly to access to wells for irrigation. In fact, it turns out that access to irrigation from the open wells is the single most important factor determining farm income in the Kothapally village. This is an important finding that could be missed if only analysing average incomes at the watershed scale. Our results also indicate that farmers with access to irrigation benefitted more from AWI than those who did not have access to irrigation, which clearly has equity implications that needs to be taken into account when planning to implement an AWI project at the watershed scale.

A common perception about AWI is that it is most effective in areas with low annual average rainfall amounts by bridging droughts and dry spells. Interestingly, we observed that the difference between the AWI system and the no intervention system was larger during years of high average rainfall compared to dry years, i.e. it seems that the largest economic gains with AWI is actually during the wet years and not the dry years. This is because more water could be stored in the agricultural system during wet years, which enabled growing a larger off-season crop (the vegetable crop).

The results of the study are influenced by the shape and slope of the production functions. It is clear that with different values for the minimum crop water requirements for sorghum and cotton, the results on yields and subsequently incomes would have been different. No yield data for individual farms and years were available, and therefore it is not possible for us to validate these results. Neither did we have data on farm boundaries and household sizes. The results for the scenarios are therefore hypothetical, and should be interpreted as examples of how farm incomes could vary under different cropping systems with and without AWI.

Without access to irrigation farmers become less resilient to drought and dry-spells. Therefore, it raises the question on the local availability of coping mechanisms during years of very low financial returns, such as savings, insurance systems, non-farm incomes,

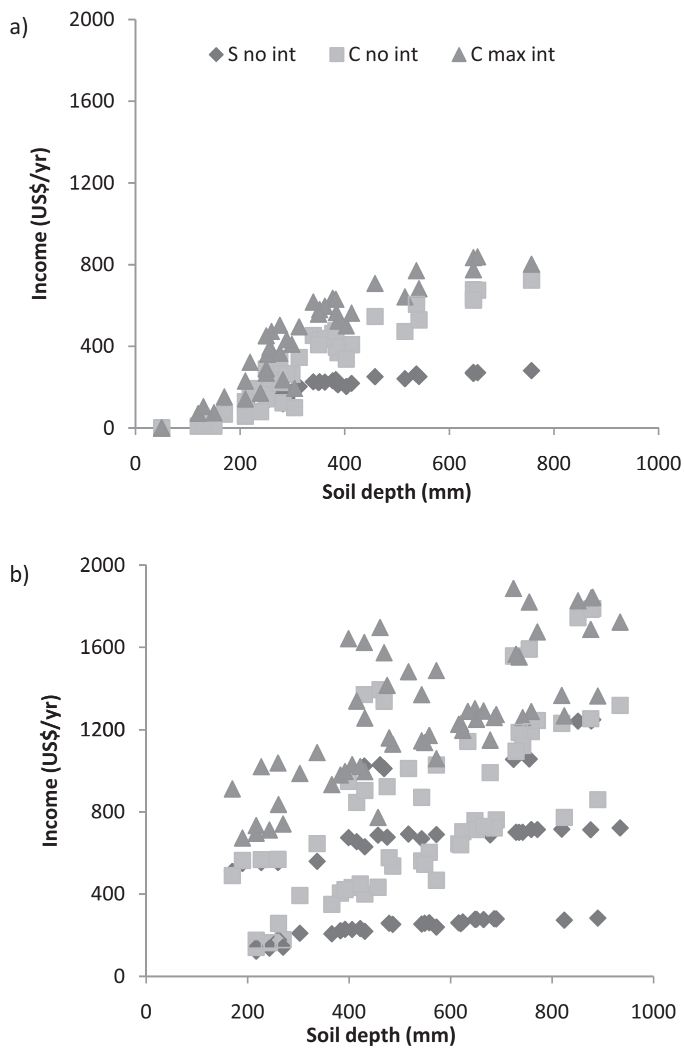


Fig. 6. The impact of soil depth on farm incomes for different cropping systems with and without AWI for (a) non-irrigated croplands, and (b) irrigated croplands. "S no int." = sorghum based system, no AWI; "C no int." = cotton based system, no AWI; "C max int." = cotton based system, with AWI.

and the ability to purchase food at local markets. It also highlights the importance of good weather forecasting systems. If farmers know in advance that the monsoon season is likely to be very dry, this opens up for the possibility of planting more drought tolerant crops that specific year. With good weather predictions farmers can also make a better judgement on the economic returns on their investments in terms of fertilizer use, seed variety, etc.

In Kothapally, easy access and timely advice to farmers are believed to be important factors behind the observed productivity improvements, and has led to enhanced awareness of the farmers and facilitated their ability to consult with the right people when they faced problems (Sreedevi et al., 2004). Generally, villagers have a positive attitude towards AWI, and the local leadership has been critical to lever the implementation and management. Any activity has been consulted upon thoroughly with the villagers before implementation which has resulted in a visible mutual trust and a shared vision among partners. The socio-economic status has improved after introducing AWI in the Kothapally village (Sreedevi et al., 2004). As mentioned previously, most of the farmers were solely dependent on agriculture in 1999 and before. However, as part of AWI, farmers were motivated to do other job activities and services along with cultivating crops. For instance, farmers started doing dairy farming, transport services, labour work for building roads and houses, nursery plantation and engaged with small scale business and local services locally (viz., running small café, saloon shop, stitching clothes at home, selling food and general materials in shops, selling coupons for recharging mobiles, etc.). The ability to shift between farm and non-farm activities strengthens the adaptive capacity of these farming systems (Cooper et al., 2008).

In view of the development needs for rural semi-arid and dry sub-humid sub-Saharan Africa, there is a need to revisit the success story of AWI development in the Indian context to explore relevance of opportunity to outscale. Our study has highlighted the need to assess potential outcomes of AWI implementations at the sub-watershed scale to assess potential equity aspects in terms of who might benefit from AWI. For instance, it appears that differences in infrastructure, such as access to irrigation, might be an important factor to consider. Equally, differences in environmental conditions such as soil depth and rainfall amounts may also have an impact on the outcomes of AWI. Also, large inter-annual variation in rainfall may also change the outcomes of an AWI project.

5. Conclusions

In general, AWI significantly improved farm incomes in the Kothapally village by enabling the cultivation of a supplementary irrigated, high value crop during the monsoon season, and also by enhancing the capacity to produce dry season, fully irrigated vegetable crops. AWI combined with cotton resulted in more than a doubling of farm incomes compared to traditional sorghum-based systems without AWI during normal and wet years (i.e. for 75% of the years). On the other hand, annual incomes generated from farming activities fluctuated less with the traditional sorghum based system without AWI, compared with cotton based systems with AWI. In general, we observed that the difference between the AWI system and the no intervention system was larger during years of high average rainfall compared to dry years, suggesting that the largest economic gains with AWI is actually during the wet years and not the dry years in this region. It was also found that access to irrigation was more important for farm income than crop choice and AWI *per se*, and thus farms with access to irrigation benefitted more from AWI compared to farmers lacking access to irrigation. To assess equity aspects in terms of farm income generation following the implementation of an AWI project, we suggest that there is a need for income analyses at the farm level, since income estimates at the watershed level may mask important differences in economic benefits between farms.

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