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Water Productivity of Irrigated Agriculture in Different Irrigation Environments of Tamil Nadu: Potential Areas for Improvement

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ABSTRACT

Water Productivity (WP) refers to the efficiency with which water resources are utilized to achieve desired outcomes, such as agricultural production, industrial processes, or domestic use. Irrigated agriculture in World Cropland is accounted as only 16 per cent but those lands yield some 36 per cent of the total world yield water supply for use in irrigated lands may be limited as a result of increased water use. The objective of the study is to explore the scope for water productivity enhancement in irrigated agriculture of different irrigation environments in Tamil Nadu. Purposive and multi-stage sampling technique is followed for the selection of study area and sample respondents. The Physical Water Productivity (PWP) and Economic Water Productivity (EWP) of a purely irrigated crop are estimated under different irrigation methods/ technologies. In order to know the potential of water control in improving crop water productivity, the incremental changes in crop yield and crop water productivity to irrigation were analyzed. The results indicates that PWP are 0.4 kg of paddy, 0.45 of groundnut and 0.5 kg of black gram in tank irrigation environment, 1.7 kg of maize, 5.26 kg of tapioca, 0.26 kg of sorghum in well irrigation environment, 0.2 kg of paddy, 0.35 kg of turmeric, 5.16 kg of sugarcane and 1.04 kg of banana in canal irrigation environment. The EWP are Rs. 1.61 for paddy, Rs. 2.98 for groundnut and Rs. 18.42 in black gram in tank irrigation environments, Rs. 5.78 in maize, Rs. 4.69 in tapioca and Rs. 9.03 in sorghum in well irrigation environments and Rs. 0.98 in paddy, Rs. 9.69 in turmeric, Rs. 1.66 in sugarcane and Rs. 3.43 in a banana crop of canal irrigation environments. The regression values for the yield response to irrigation dosage are quite tiny. It is possible to claim that irrigation alone cannot fully account for fluctuations in yield. There are three basic types of irrigation dose responses for yield and water production. In the first instance, the yield and applied water have a positive but shaky connection, while the reaction of the WP to applied water is inverse and exponential. The second scenario is one in which there is a substantial and positive correlation between applied water and yield, with the majority of farmers applying water under a regime of water scarcity and

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relatively few under a regime of water excess. In the third scenario, the yield and applied water have a "polynomial" relationship, shows that the yield rises with irrigation dose up to a certain point and then starts to fall. In this scenario, WP quickly decreases the point that corresponds to the maximum yield as the water dose is increased.

Key words: *Water Productivity (WP), Physical Water Productivity (PWP), Economic Water Productivity (EWP), irrigated agriculture, irrigation environment.*

Introduction

India ranks second worldwide in farm output with 2.4 per cent of the world's land area (FAO, 2023). Agriculture and allied sectors accounted 20.2 per cent of total economy GVA (Gross Value Added) in 2021 and employed 54.6 per cent of the workforce as of census 2011. Irrigation is the most important activity in raising crops and obtaining optimum output (TPP). Irrigation water requirement will vary among crop wise and region wise. Indian farmers undergone in cultivating high water required crops like paddy, sugarcane, cotton etc. The sources from where water withdrawal for agriculture, i.e irrigation infrastructure includes canals, wells and tank-based systems and other rain water harvesting systems for agriculture activities. Total net area sown is 139.35 million hectares (2018-19) with net irrigated area of 71.55 million hectare (16 per cent by canals and 33.81 per cent by tube-wells). In Tamil Nadu, total net area sown is 4.58 million hectares (2018-19) with net irrigated area of 2.56 million hectare (24.79 per cent by canals and 20.12 per cent by Tube wells).

World agriculture consumes approximately 70 per cent of the fresh water withdrawn per year (FAO AQUASTAT, 2022). Worldwide, the amount of irrigated land is slowly expanding, even though salinization, water-logging, and siltation continue to decrease its productivity (Gleick, 2002). Despite a small annual increase in total irrigated area, the irrigated area per capita has been declining since 1990 because of rapid population growth (Postel 1999; Gleick 2002). Specifically, global irrigation per capita has declined nearly 10 per cent during the past decade (Postel 1999; Gleick 2002). Water supply for use in irrigated lands may be limited as a result of increased water use. Because of this, it is crucial to enhance irrigation management among users in order to make more efficient use of water.

The term "Water Productivity" generally refers to the amount of production or benefits that results from the input quantity of water when applied on a unit base. It is defined as the net consumptive usage efficiency in terms of yield per unit depth of water utilized per unit area of cultivation in the context of agriculture. It would be referred to as the gross irrigation water use efficiency if the field water conveyance, application, storage and distribution efficiencies were taken into account to depict the seepage, runoff, and deep percolation losses (not consumed by plants; evapo-transpiration loss is included as an implicit component of field water balance). However, the term water use efficiency is a manifestation of integrated physical or economic land and water productivity as the numerator is the yield or equivalent income and the denominator is the depth of water consumed per unit land area used (tonnes per hectare per cm of water).

To summarize, previous water productivity studies focused on analyzing average physical productivity of water for specific crops, including fluctuation due to climate. The economic implications of water productivity, however, were not examined. No attempts were made to analyze incremental changes in agricultural water productivity in economic terms in response to changes in irrigation water dose, or ET. It is critical to examine the potential for increasing water productivity of a certain crop and to decide on crop allocation priorities. The objective of the study is to explore the scope for water productivity enhancement in irrigated agriculture of different irrigation environments in Tamil Nadu.

Approach and Methodology

For each irrigation environment, three districts were purposively selected such as Pudukottai, Salem and Erode. The details of districts and blocks selected for study are shown in Figure.1. As of 2020-21 data, Pudukottai district is named for tank irrigation consisting of 5451 tanks which is the highest compared to other districts in Tamil Nadu. Salem district is selected for well irrigation environment which has the highest number of irrigation wells of 108745.

Erode district is selected for canal irrigation which covers 690 km length of canal length. Multi-stage sampling technique is followed for the selection of blocks, villages and respondents in each irrigation environment.

Physical and Economic Water Productivity

The Physical Water Productivity (PWP) and Economic Water Productivity (EWP) in a purely irrigated crop are estimated as:

$$\text{PWP (kg/m}^3) = \frac{\partial \text{ (kg/ha)}}{\Delta \text{ (m}^3\text{/ha)}}$$

$$\text{EWP (Rs./m}^3) = \frac{\text{NR (Rs./ha)}}{\Delta \text{ (m}^3\text{/ha)}}$$

Δ and ∂ are the irrigation water used (m^3/ha) and yield of the crop (Kg/ha.) for purely irrigated crop. NR is the net return per unit area of the crop (Rs. / ha.). All crops selected for the study are purely irrigated crops, and the green water used for the crop is not considered. The crops considered are sugarcane and turmeric in canal irrigation environment, sorghum and groundnut in well irrigation environment and groundnut, black gram and paddy in tank irrigation environment were treated as irrigated crops, and therefore the water productivity estimated for them are irrigation water productivity.

In order to know the potential of water control in improving crop water productivity, the incremental changes in crop yield and crop water productivity to irrigation were analyzed. The analysis included the following:

1) The crop yield to irrigation water applied

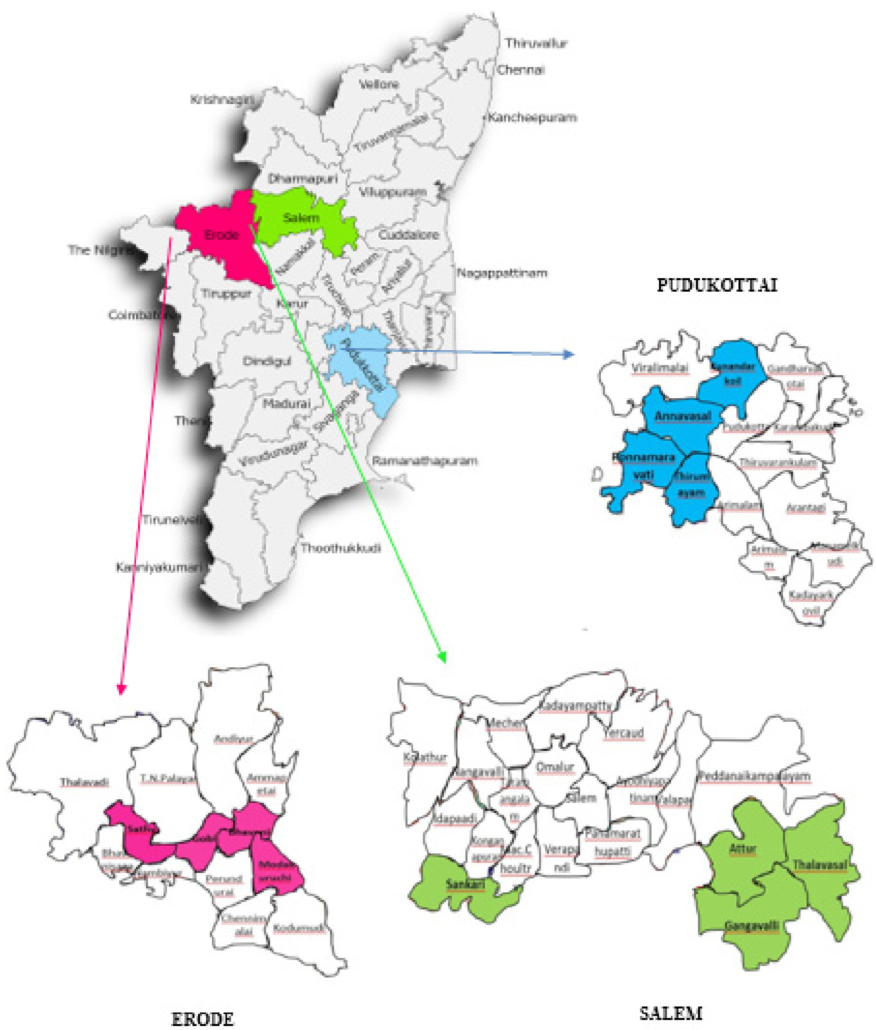

Fig. 1. Selected Districts and Blocks in Tamil Nadu

2) The economic water productivity to irrigation and
3) The yield to fertilizer use.

Results and Discussion

The PWP and EWP of crops of different irrigation environments is given in Table 1. The results from the table indicates that the quantity produced per cubic meter of water consumed in different irrigation environments of Tamil Nadu i.e., PWP are 0.4 kg of paddy, 0.45 of groundnut and 0.5 kg of black gram in tank irrigation environment, 1.7 kg of maize, 5.26 kg of tapioca, 0.26 kg of sorghum in well irrigation environment, 0.2 kg of paddy, 0.35 kg of turmeric, 5.16 kg of sugarcane and 1.04 kg of banana in canal irrigation environment.

The net production value per cubic meter of water consumed in different irrigation environments i.e., EWP are Rs. 1.61 for paddy, Rs. 2.98 for groundnut and Rs. 18.42 in black gram in tank irrigation environments, Rs. 5.78 in maize, Rs. 4.69 in tapioca and Rs. 9.03 in sorghum in well irrigation environments and Rs. 0.98 in paddy, Rs. 9.69 in turmeric, Rs. 1.66 in sugarcane and Rs. 3.43 in a banana crop of canal irrigation environments.

In the case of tank irrigation environment for both paddy and groundnut, the regression analysis showed that the relationship between irrigation water dosage and yield is linear. The R^2 value here is only 0.13 and 0.26, and hence the relationship is not strong. As shown in figure —2 and 3, the paddy and groundnut yield responded to increase in irrigation water applied. However, for the same level of irrigation, the yield differences across farmers are quite substantial. This can perhaps be explained by the difference in the water quality and soil quality, variation in crop variety, fertilizer usage by these farmers and date of sowing.

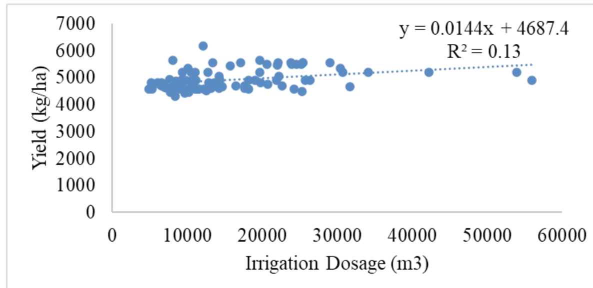

Fig. 2. Yield vs. Irrigation of Paddy in Tank Irrigation Environment

The graphical representation of economic water productivity response to irrigation dosage for paddy and groundnut in tank irrigation environment is given in Figure 4 and 5. The relation between them

Table 1. Irrigation Water Productivity of Different Production Environments in Tamil Nadu

Irrigation environment	Crop	Irrigation methods/technologies	PWP(kg/m³)	EWP(Rs. /m³)
Tank	Paddy	Flood	0.4	1.61
		Alternate wetting and drying	0.61	3.06
	Groundnut	Check basin	0.45	2.98
		Flood	0.38	2.79
	Black gram	Check basin	0.5	18.42
		Flood	0.33	15
Well	Maize	Check basin	1.7	5.78
		Drip/Micro	2.9	7.2
	Tapioca	Check Basin	5.26	4.69
		Drip/Micro	5.8	5.22
	Sorghum	Check basin	0.26	9.03
		Drip/Micro	0.4	11.2
		Open/flood	0.23	6.39
Canal	Paddy	Flood	0.2	0.98
	Turmeric	Furrow	0.35	9.69
		Drip	0.43	13.33
	Sugarcane	Furrow	5.16	1.66
		Drip	7.2	2.01
	Banana	Flood	1.04	3.43

Source: Author's estimation

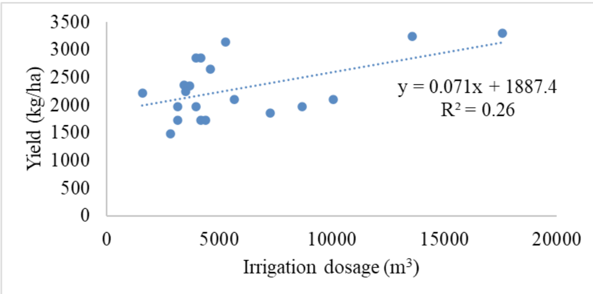

Fig. 3. Yield vs. Irrigation of Groundnut in Tank Irrigation Environment

is exponential and inverse. Lower economic water production was associated with higher water dosages (R^2=0.41). In general, those who used more irrigation had lower productivity levels, while many farmers who applied less irrigation also had lower water productivity levels. Many farmers that maintained a comparable irrigation dose at the same period saw great water yield. This can be as a result of agricultural yields being lower due to lower input amounts of fertilizer. The absence of a corresponding rise in yield, the rising cost of Fertilizers, which lowers net returns, and the rising volume of water used, which raises the value of the denominator are possible causes of the decreased water productivity at increasing dosages of irrigation.

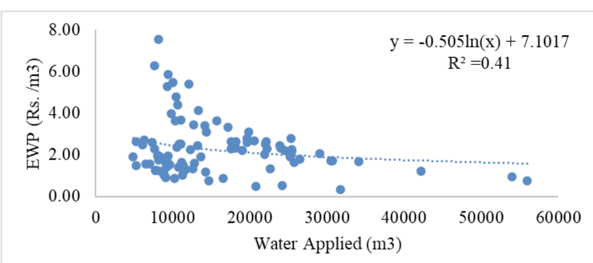

Fig. 4. WP vs. Irrigation Dosage of Paddy in Tank Irrigation Environment

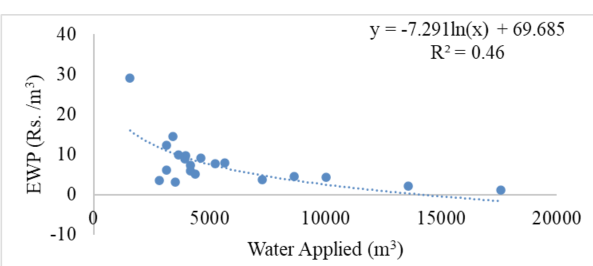

Fig. 5. WP vs. Irrigation Dosage of Groundnut in Tank Irrigation Environment

Figure 6 and 7 shows the graphical representation of the variation in yield with different levels of fertilizer dosage of paddy and groundnut in tank irrigation environment. It shows a slightly stronger relationship between fertilizer use and crop yield (R^2=0.30). The relationship between them is inverse and exponential. The overuse of fertilizer use beyond the optimum level in paddy crop decreases the yield. This shows that, increase in fertilizer use doesn't increase the yield of paddy beyond the optimum level.

In the case of well irrigation environment for both maize, tapioca and sorghum, the regression analysis showed that the relationship between irrigation water dosage and yield is linear in maize and sorghum. The R^2 value here is only 0.14 and 0.17, and

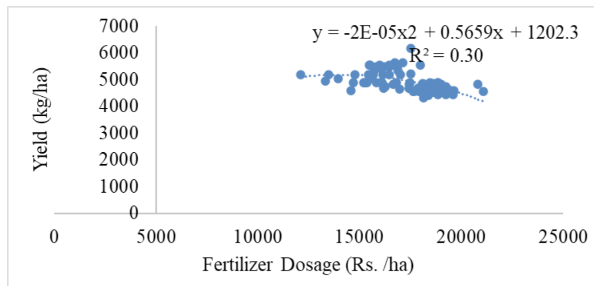

Fig. 6. Yield vs. Fertilizer Dosage of Paddy in Tank Irrigation Environment

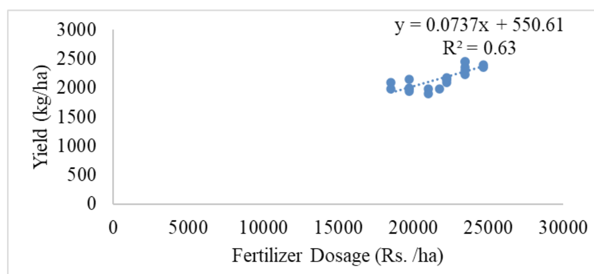

Fig. 7. Yield vs. Fertilizer Dosage of Groundnut in Tank Irrigation Environment

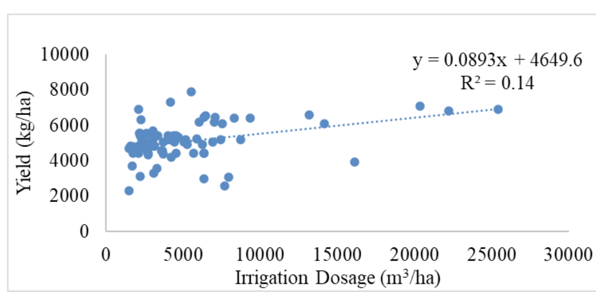

Fig. 8. Yield vs. Irrigation Dosage of Maize in Well Irrigation Environment

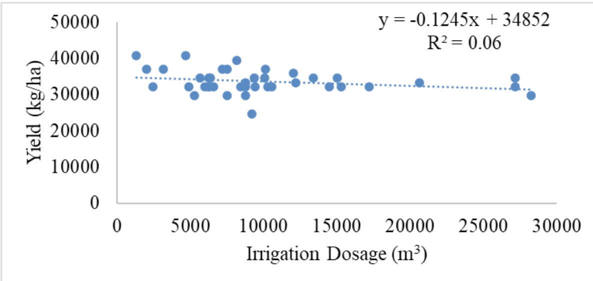

Fig. 9. Yield vs. Irrigation Dosage of Tapioca in Well Irrigation Environment

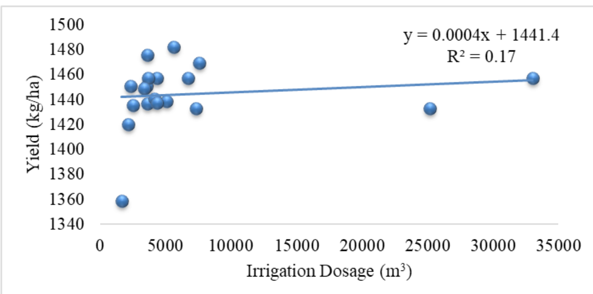

Fig. 10. Yield vs. Irrigation Dosage of Sorghum in Well Irrigation Environment

hence the relationship is not strong. As shown in figure —-8 and 9, the maize and sorghum yield responded to increase in irrigation water applied. Whereas, the relationship between irrigation dosage and yield response is negative in tapioca crop (R^2=0.06). However, for the same level of irrigation, the yield differences across farmers are quite substantial. This can perhaps explain by the difference in the water quality and soil quality, variation in crop variety, fertilizer usage by these farmers and date of sowing.

The graphical representation of economic water productivity response to irrigation dosage for maize and tapioca in well irrigation environment are given in Figure 11 and 12. The relation between them is logarithmic and inverse. Lower economic water production was associated with higher water dosages (R^2=0.48 for maize and R^2=63 for tapioca). A lot of farmers who applied less irrigation also had lower water productivity levels, whereas those who utilized more irrigation generally had lower production levels. Many farmers who kept up a similar irrigation dosage throughout the same time period had excellent water yields. This may be a result of reduced agricultural yields brought on by less fertilizer input. Possible explanations of the decreasing

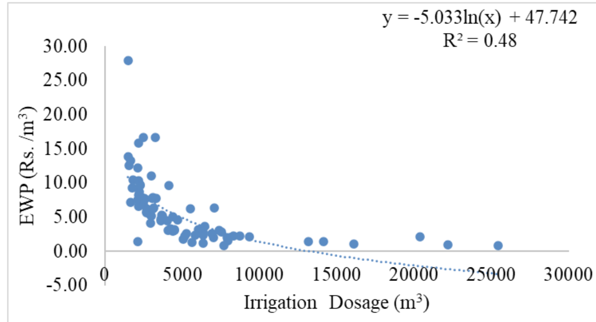

Fig. 11. WP vs. Irrigation Dosage of Maize in Well Irrigation Environment

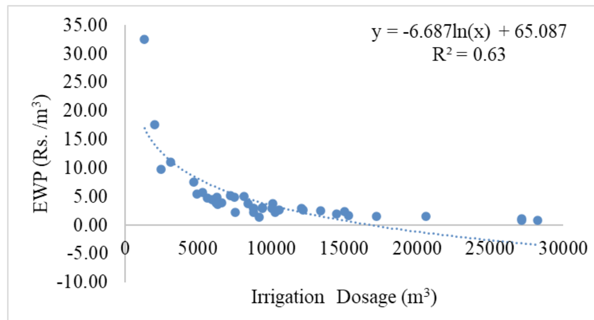

Fig. 12. WP vs. Irrigation Dosage of Tapioca in Well Irrigation Environment

water productivity with higher doses of irrigation include the absence of a comparable increase in yield, the rising cost of Fertilizers, which reduces net returns, and the rising volume of water utilized, which increases the value of the denominator.

Figure 13 and 14 shows the graphical representation of the variation in yield with differential levels of fertilizer input. This shows a slightly stronger relationship between fertilizer use and crop yield which has a R^2 of 0.13 and 016 for maize and tapioca crop respectively. This does not necessarily imply that the increased fertilizer dosage led to the higher

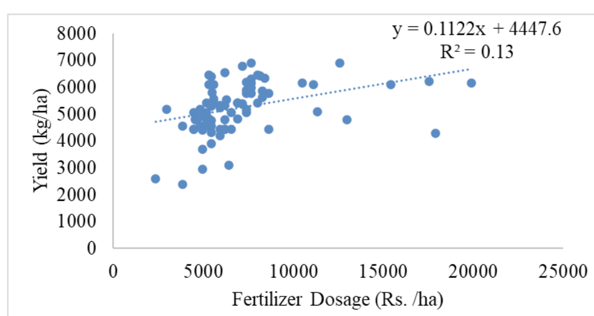

Fig. 13. Yield vs. Fertilizer Dosage of Maize in Well Irrigation Environment

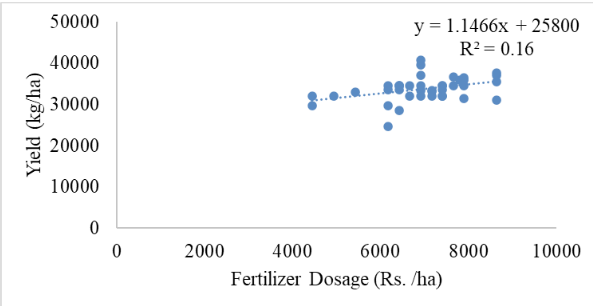

Fig. 14. Yield vs. Fertilizer Dosage of Tapioca in Well Irrigation Environment

yield. Farmers with superior irrigation systems and those that utilize more irrigation water tend to use proportionately greater doses of fertilizer. The increase in production cannot be attributed to a greater fertilizer dose due to the co-linearity between irrigation and fertilizer dosage. Therefore, a more extensive analysis of the data was done in order to separate the influence of fertilizer dosage on crop output.

In the case of canal irrigation environment for both paddy, turmeric and sugarcane, the regression analysis showed that the relationship between irrigation water dosage and yield is linear in maize and

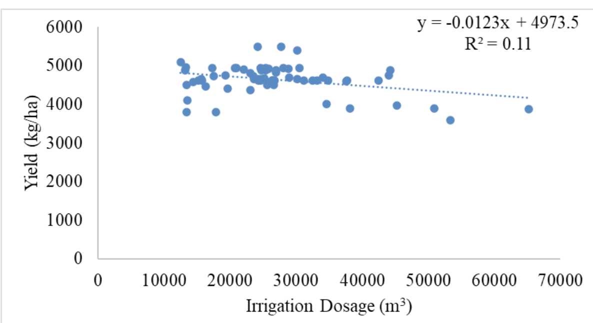

Fig. 15. Yield vs. Irrigation Dosage of Paddy in Canal Irrigation Environment

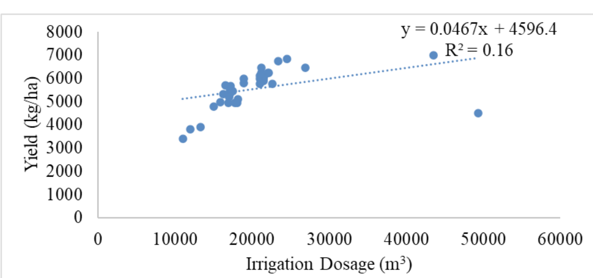

Fig. 16. Yield vs. Irrigation Dosage of Turmeric in Canal Irrigation Environment

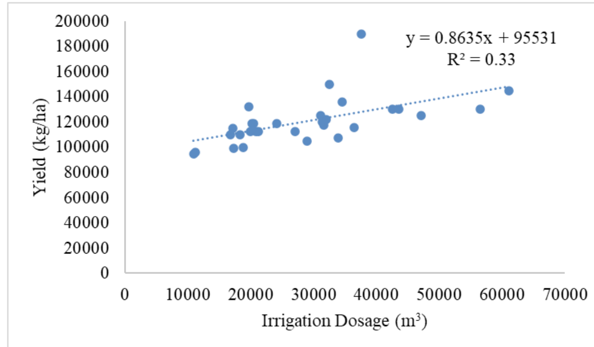

Fig. 17. Yield vs. Irrigation Dosage of Sugarcane in Canal Irrigation Environment

sorghum. The R^2 value here is only 0.16 for turmeric and 0.33 for sugarcane, and hence the relationship is slightly strong. As shown in figure —-16 and 17, the turmeric and sugarcane yield responded to increase in irrigation water applied. Whereas, the relationship between irrigation dosage and yield response is negatively linear in paddy crop (R^2=0.11). However, for the same level of irrigation, the yield differences across farmers are quite substantial. This may be explained by the various crop varieties, non-availability of water from canal systems, variations in soil and water quality, the use of fertilizer by these farmers, and the timing of sowing.

The graphical representation of economic water productivity response to irrigation dosage for paddy and turmeric in canal irrigation environment is given in Figure 18 and 19. The relation between them is logarithmic and inverse. Lower economic water production was associated with higher water dosages (R^2=0.55 for paddy and R^2=70 for turmeric). A lot of farmers who applied less irrigation also had lower water productivity levels, whereas those who utilized more irrigation generally had lower production levels. Many farmers who kept up a similar ir-

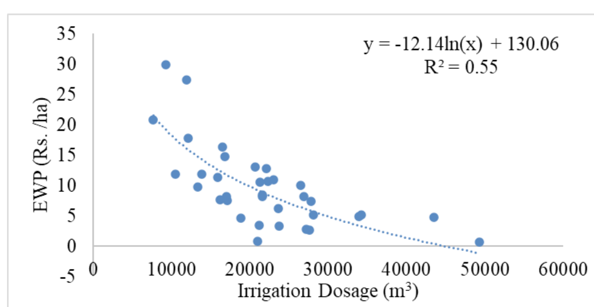

Fig. 18. WP vs. Irrigation Dosage of Paddy in Canal Irrigation Environment

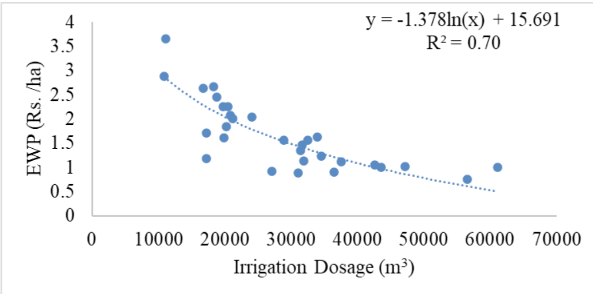

Fig. 19. WP vs. Irrigation Dosage of Turmeric in Canal Irrigation Environment

rigation dosage throughout the same time period had excellent water yields. This may be a result of reduced agricultural yields brought on by less fertilizer input. Possible explanations of the decreasing water productivity with higher doses of irrigation include the absence of a comparable increase in yield, the rising cost of fertilizers, which reduces net returns, and the rising volume of water utilized, which increases the value of the denominator.

Figure 20, 21 and 22 shows the graphical representation of the variation in yield of paddy, turmeric and sugarcane crops with differential levels of fertilizer input. This shows a slightly stronger relationship between fertilizer use and crop yield which has a R^2 of 0.44, 0.19 and 013 for paddy, turmeric and sugarcane crop respectively. This does not necessarily suggest that the higher yield was caused by the increased fertilizer dosage. Farmers that use more irrigation water and/or have better irrigation systems typically require proportionally higher dosages of fertilizer. Due to the co-linearity between irrigation and fertilizer dosage, the increase in yield cannot be attributed to a higher fertilizer dose. To disentangle the impact of fertilizer dose on crop yield, a more thorough examination of the data was conducted.

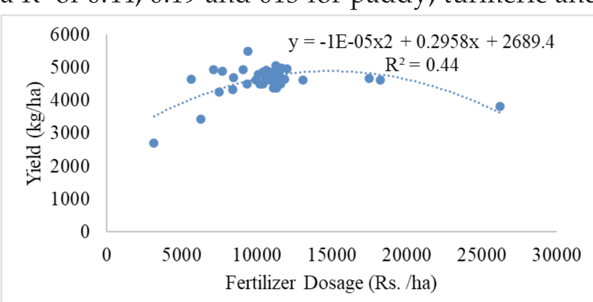

Fig. 20. Yield vs. Fertilizer Dosage of Paddy in Canal Irrigation Environment

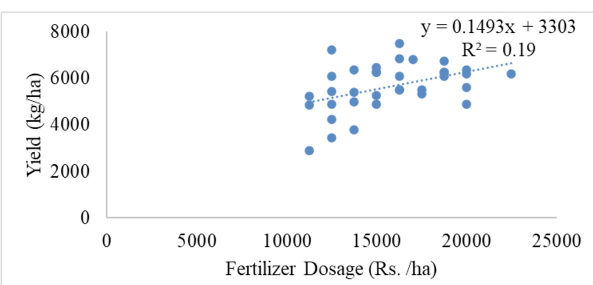

Fig. 21. Yield vs. Fertilizer Dosage of Turmeric in Canal Irrigation Environment

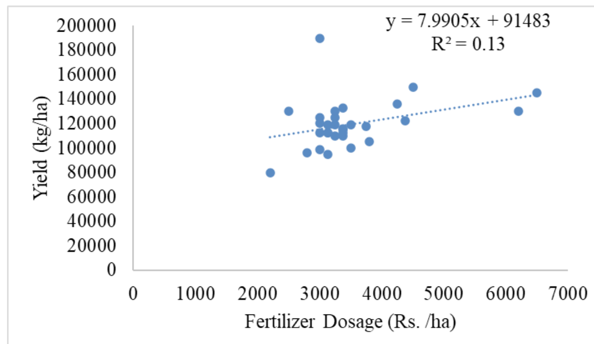

Fig. 22. Yield vs. Fertilizer Dosage of Sugarcane in Canal Irrigation Environment

At this point, the regression values for the yield response to irrigation dosage are quite tiny (Figures 10 and 15). Therefore, it is possible to claim that irrigation alone cannot fully account for fluctuations in yield. The association and regression coefficient, however, are significant because the data reported here are for diverse farmers, who represent varied soil types, planting dates, and seed kinds, all of which have the ability to affect crop production. Additionally, Figure 3's yield curve has a relatively moderate slope, which is extremely different from what is often seen given the considerable variation in irrigation water dosage among the sample farms.

There are three basic types of irrigation dose responses for yield and water production. In the first instance, the yield and applied water have a positive but shaky connection, while the reaction of the WP to applied water is inverse and exponential. In such cases, reducing the irrigation water dosage would not have a substantial impact on the output, and frequently it wouldn't even have a negative impact. Similar improvements would greatly improve WP. This tactic, meanwhile, would only be effective if there was enough arable land, which is uncultivated owing to a lack of water. Farmers want to increase the area under irrigation and use the water they save from irrigation on fields to irrigate more land in order to sustain financial returns.

The second scenario is one in which there is a substantial and positive correlation between applied water and yield, with the majority of farmers applying water under a regime of water scarcity and relatively few under a regime of water excess (Figures 17). It is possible that if irrigation dose is increased, water productivity physically may also somewhat rise. However, the response of water production to applied water is "inverse-logarithmic" in terms of economic value (Rs/m^3). The majority of farmers' best course of action in this situation would be to use the least amount of irrigation possible, since this would result in the maximum water production possible. To maintain the net returns, the farmers may need to slightly increase the area irrigated in this situation.

In the third scenario, the yield and applied water have a "polynomial" relationship, meaning that the yield rises with irrigation dose up to a certain point and then starts to fall (Figure 7). In this scenario, water productivity quickly decreases past the point that corresponds to the maximum yield as the water dose is increased. As a result, connection between applied water and water productivity may be described as "polynomial" in economic terms. Farmers who are losing money on yield and income returns have the most motivation to cut back on irrigation in this scenario. They raise output and water productivity in this way.

Due to the flat rate structure of power pricing in the research areas, the rationale for overwatering crops beyond the point of maximum return is zero marginal cost of energy utilized for groundwater pumping. In such circumstances, farmers may maximize their overall benefits from farming without even expanding the area irrigated. Due to insufficient irrigation dose, many farmers are not receiving their maximum yield and water output. To conserve water, it's crucial for them to increase irrigation dose while decreasing the area under irrigation.

Farmers hesitate to apply sufficient amounts of Fertilizers when irrigation schedules and water delivery are unclear, as is the case with canal irrigation, which reduces productivity. When the water supply is unpredictable compared to a water supply that is guaranteed (well water), the depth of each application is sometimes substantially higher than the optimal dosage. After harvest, there is a lot of residual moisture and significant percolation losses as a result. These result in an increase in crop ET depletion that is not helpful. Increased irrigation rates may also result in more fertilizer leaching and less effective nutrient usage.

Conclusion

Regions that receive intense canal irrigation should be prioritized for water productivity improvements because: 1] water-intensive crops are cultivated in these regions; 2] there is poor control over water supply; and 3] irrigation quality and dependability is low. Semi-arid and dry environments with deep water tables are appropriate for increasing water production (reducing non-beneficial evaporation and non-recoverable deep percolation). Following canal-irrigated regions, areas that rely on well irrigation and where a significant amount of land remains uncultivated due to water constraint should be prioritized. The rationale for this is that in such cases, farmers may boost aggregate returns by expanding the area under irrigation.

We conclude that the irrigation departments may be encouraged to work on increasing the quality and dependability of irrigation water, as well as "water control." Because there is limited potential for expanding groundwater-irrigated territory, groundwater draught would be reduced as well.

Acknowledgment

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