A Study on Irrigation Water Productivity Under Different Irrigation Environments of Tamil Nadu, India

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ABSTRACT

The world is attempting to increase water efficiency in all activities, especially in irrigation, which consumes three-fourths of total available water. Concerning the near future food demand and sustainability issues, views are directed to reduce the usage of water or increase the efficiency of water use. India is a major contributor to the agricultural production and food supply to many countries. Irrigated agriculture is being followed by the many farmers in India which consumes huge amounts of water. Considering the monsoon failure and increased water demand, one must find solutions for retaining water in an available manner. The focus is on finding major water-consuming crops and irrigation methods under different irrigation environments of Tamil Nadu. Pudukottai, Salem and Erode are the districts of Tamil Nadu state selected as a study area. In each district, blocks, villages and respondents are selected through multi-stage random sampling. This study is entirely based on primary data which is collected using a well-structured interview schedule. The collected data is used to estimate the Physical Water Productivity (PWP) and Economic Water Productivity (EWP). The results show that PWP and EWP are variable across crops under different irrigation environments. In a tank environment, the alternate drying and wetting method of irrigation in paddy is effective and saves around 39 per cent of water compared to the conventional method by flooding. For Groundnut crops, drip irrigation is more effective than check basins which are better than the flood irrigation method. We can conclude that the farmers should follow water-saving irrigation methods/technologies and cultivate crops that show less demand for water during the season when the water is scarce and turn to cultivation of crops like sugarcane and banana in water surplus season.

Keywords: Irrigated agriculture, Irrigation methods, Physical Water Productivity (PWP), Economic Water Productivity (EWP).

1. INTRODUCTION

Water, a renewable natural resource, is becoming increasingly scarce in India due to intensive consumption in water-dependent sectors. Agriculture is no exception, consuming most of the water just for crop irrigation. India, being an agricultural country, consumes an extremely high amount of water.. The absence or delay of monsoons, cultivation of crops with high water requirements in water deficit regions, and rising temperatures that increase crop water demands are some of the major causes for the prevailing water problems in India, and in the agricultural sector. Irrigated agriculture, the major contributor to agricultural production, poses the issue of optimizing irrigation water usage efficiency and simultaneously ensuring food security (Kang *et al.*, 2017, Zwart and Bastiaanssen, 2004).

Irrigation is the most important element affecting agricultural productivity in subhumid and arid regions (Oweis & Hachum, 2003). Irrigation water productivity (IWP), defined as the yield per unit of irrigation water used (Molden, 1997), has become an essential criterion that considers both agricultural production and water use efficiency. It is a comprehensive indicator showing the extent of irrigation and crop management (Seckler et al., 2004, Abdullaev and Molden, 2004, Zoebl, 2006). Increasing the IWP value would not only relieve scarce water resources but also ensure food security (Ali & Talukder, 2008, Molden, 1997). Understanding the impact of driving variables on IWP helps in exploring strategies to improve IWP, which is important for effective water use and sustainable agricultural development.

Food demand will increase substantially with population growth. At the same time, water demand from non-agricultural sectors will continue to increase in both developed and developing countries. According to a recent FAO survey (Bruinsma, 2017) of 93 developing countries, agricultural production will increase by 49 percent in rain-fed systems and 81 percent in irrigated systems between 1998 and 2030. As a result, much of the additional food production will be produced on irrigated land, three-quarters of which is in developing countries. The International Food Policy Research Institute (IFPRI) recently conducted a study of water productivity based on somewhat different assumptions than FAO (Cai and Rosegrant, 2003). According to this analysis, between 1995 and 2025, the average water productivity of rice would increase from 0.39 to 0.53 kg per m3 in developing countries and from 0.47 to 0.57 kg per m3 in developed countries. According to IFPRI, the average water productivity of all other cereals would increase from 0.56 to 0.94 kg per m3 in poor countries and from 1.00 to 1.32 kg per m3 in rich countries over the same period. Achieving the expected water productivity to feed the growing world population will therefore be a challenge for breeders, agronomists and irrigation specialists in the coming years.

This paper aims to discuss water productivity (physical and economic) in different irrigation environments such as canals, tanks and wells in Tamil Nadu. Farmers apply different technologies or methods to irrigate crops. Therefore, water productivity under different irrigation methods in three irrigation environments is analyzed.

2. LITERATURE REVIEW

Arun S. Patel (1981) notes the extent to which irrigation and new technologies have expanded in his paper entitled Irrigation: Its Employment Impact in the Command Areas of Medium Irrigation Projects in Gujarat" This expansion has also helped raise living standards and set in motion an employment drive that falls short of desired productivity levels. Irrigation has led to significant changes in cropping patterns. Specifically, (i) a shift from low-value cereals and pulses to higher-value cereals, (ii) a shift from food grains to non-food grains (both long and short duration crops), (iii) a shift from crops with indigenous (desi) varieties to HYVs in both food grains and non-food grains, and (iv) a shift from food grains to non-food grain crops.

Himanshu Takkar (1999) in his research states that irrigation is becoming increasingly important in agriculture. This has been evident worldwide over the past two decades as the steady expansion of irrigation began to decline between 1979 and 1982. Between 1982 and 1994, irrigated acreage worldwide increased by 13% annually, whereas previously it had grown by 2% annually. Even if the prediction is correct, it is unlikely that global irrigated area will grow faster than 0.6% per year over the next 25 years. Since 1980, irrigated per capita cropland has declined, leading to stagnation in per capita cereal production and adding a new dimension to global food security.

According to Lekhi R. K. (2004), irrigation is the most important factor for agricultural development in India. He states that irrigation enables multiple crops and increases crop yields, which makes it useful for agriculture. This goal can only be achieved if farmers are provided with reliable irrigation infrastructure. Even after the recent implementation of nine five-year plans, Indian agriculture remains a game of monsoon. People have experienced drought in many regions of the country due to difficulties such as the absence of the monsoon for almost two consecutive years. Several places have experienced famine or near-famine as a result. It is believed that irrigation systems can free farmers from total dependence on nature while maintaining their reliance on it.

The Food and Agriculture Organization of the United Nations (2003) defines water productivity as the amount or value of a product compared to the volume or value of water consumed by the crop, where the value of the product can be expressed in different terms (biomass, grain, money).

WP is most commonly measured as crop output per cubic meter of water. Partial water productivity can be expressed in physical or economic terms as follows (Seckler *et al.,*):

1. Pure physical productivity is defined as the quantity of the product divided by the quantity of the input. Examples include crop yield per hectare or cubic meter of water either diverted or consumed by the plant. For example, the International Water Management Institute (IWMI) sees as one of its primary objectives 'increasing the crop per drop'.

2. Productivity, combining both physical and economic properties, can be defined in terms of either the gross or the net present value of the product divided by the amount of water diverted or consumed by the plant.

3. Economic productivity is the gross or net present value of the product divided by the value of the water either diverted or consumed by the plant, which can be defined in terms of the value or opportunity cost in the highest alternative use.

Hussain et al. (2005) point out that the most meaningful measure is the threshold value, i.e., the additional value created when water is added (or lost when water is not available). WP valuation is more directly related to problems in situations of water scarcity or cost than in systems supplied with abundant water of low value. WP is most meaningful as an indicator when water resources are increasingly scarce.

Molden et.al. (2007) defined water productivity as the relationship between the net benefits of crop production, forestry, fisheries, livestock, and mixed agricultural systems and the amount of water required to produce those benefits. In its broadest sense, it reflects the goal of producing more food, income, livelihoods, and environmental benefits at a lower social and environmental cost per unit of water consumed, where water consumed means either water made available for use or water consumed by use. In simple terms, this means growing more food or producing more benefits with less water. Physical water productivity is defined as the ratio between the mass of agricultural production and the amount of water consumed, and economic productivity is defined as the value obtained per unit of water consumed. Water productivity is also sometimes measured specifically for crops (crop water productivity) and livestock (livestock water productivity).

3. 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.

3.1 Cost and Returns Analysis

The different items of variable costs such as labour cost, seed cost, fertilizer cost, plant protection cost, and irrigation cost; and fixed cost items viz., rental value land, land revenue, and interest and depreciation on farm buildings and implements were worked out as per the methodology defined by Government of India (1990) to analyze the profitability of rice production.

3.2 Physical and Economic Water Productivity

The water flow is measured using the float method in each respondent's farm and the water flow rate is collected. The other data for such operational expenses, fixed expenses and yield are collected from respondents through a well-structured interview schedule. A total of 360 respondents are interviewed for my research purpose. Based on the primary data collected, analysis of Physical and Economic Water Productivity are worked out using the following methodology:

The physical water productivity PWP (kg/m^3) and water productivity in economic terms, EWP (Rs. /m^3) in a purely irrigated crop are estimated as:

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

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

Δ and ∂ are the irrigation water used (m^3/ha) and yield of the crop (Kg/ha.) for purely irrigated crops. NR is the net return per unit area of the crop (Rs. /ha.). Cost and returns are worked out for each crop to derive the NR. All crops selected for the study are purely irrigated crops, and the green water used for the crop is not considered.

Float method is a used to measure water flow rate. It is a method for measuring small to large water flow with medium accuracy. This method is best used in streams with calm water and during periods of good weather for if there is too much wind and the surface of the water is rough the float may not travel at the normal speed.

To calculate the water flow (in m^3) multiply the average water velocity (in m/s) by the average width (in m) and by the average depth (in m).

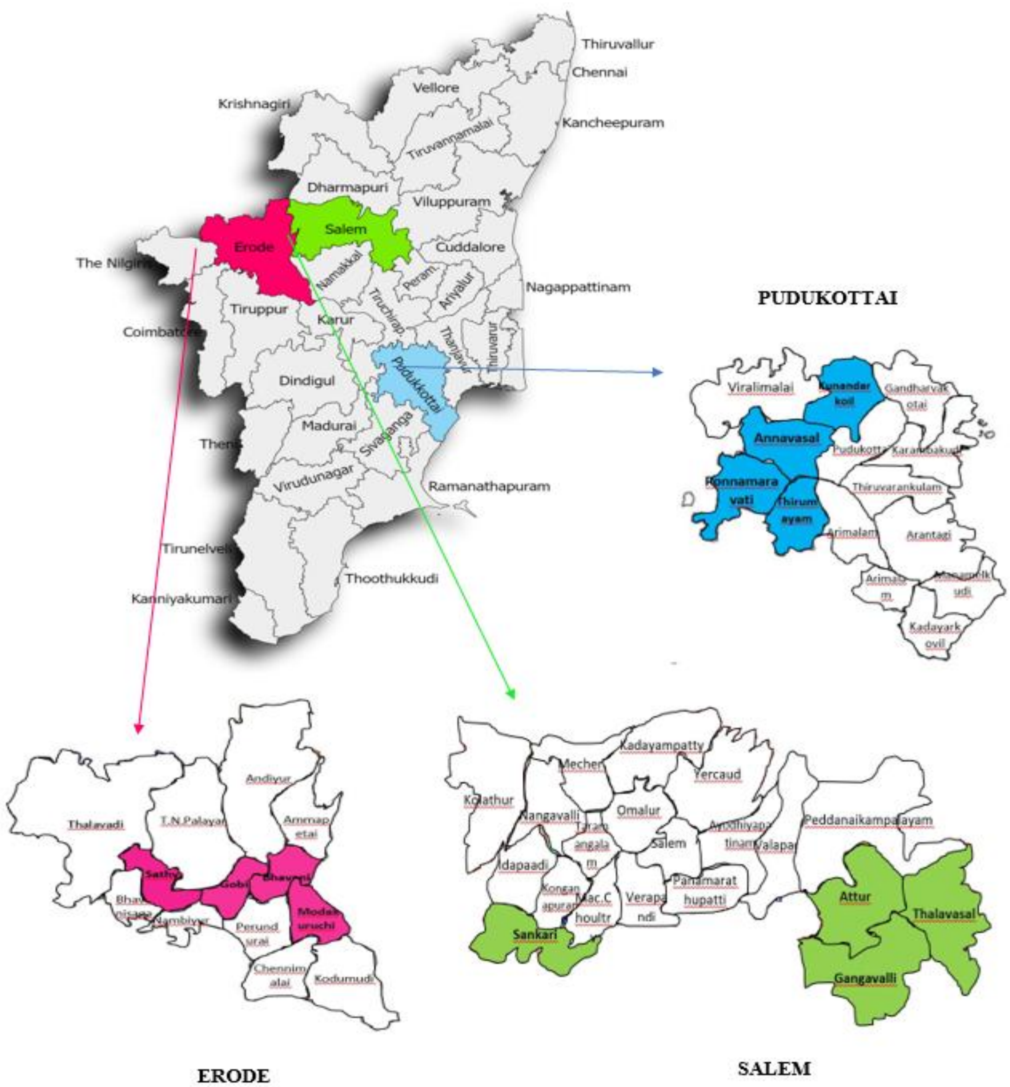
Surface water velocity (in m/s) is estimated by dividing the distance from AA to BB (in meters) by the average time (in seconds) and multiply this result by 0.85 (a correction factor) to estimate the average water velocity of the stream.

Water Flow Rate = Width of the channel $\times$ Depth of the channel $\times$ Average Water Velocity

Average Water Velocity = (Distance travelled/Time taken) $\times$ 0.85

The crops considered are sugarcane and turmeric in a canal irrigation environment, sorghum and groundnut in a well irrigation environment and paddy and groundnut in a tank irrigation environment were treated as irrigated crops, and therefore the water productivity estimated for them is irrigation water productivity.

Figure 1: Selected Districts and Blocks In Tamil Nadu



4. RESULTS AND DISCUSSION

The concept of PWP is important as it shows what it costs to make the water available for use in agriculture. Hence, PWP, considering the crop output produced per unit of irrigation water applied in the field, gives more accurate economic picture, especially for water-intensive crops like paddy and sugarcane. Thus, PWP and EWP are worked out for three major crops in the tank irrigation environment – paddy, groundnut and black gram, which occupy about 47 per cent of the gross cropped area in Tamil Nadu. The cost and returns of crops in different irrigation environments are given in Table 1. The estimated PWP and EWP of major crops in a tank irrigation environment was provided in Table 2.

Table 1: Cost and Returns of Crops in Different Irrigation Environments

Irrigation Environment	Crops	Fixed Cost (Rs. /ha)	Variable Cost (Rs. /ha)	Gross Returns (Rs. /ha)	Net Returns (Rs. /ha)
Canal	Paddy	11577	50540	92708	30591
	Turmeric	11900	177558	361429	171971
	Sugarcane	27013	69444	131250	34793
	Banana	18347.38	113279.81	234000	102372
Well	Maize	9028.92	59179	127490	59282
	Tapioca	13393	107686	268736	147657
	Sorghum	10328.50	19479.89	87120	57311
Tank	Paddy	10888.05	53064.37	86480	22527
	Groundnut	22147.25	79617.98	118905.8	17140
	Black gram	16955.26	46817.61	77805	14032

Source: Author's estimation

The paddy farmers in a tank irrigation environment report the highest land productivity of paddy (4.9t/ha). The PWP is also high to the tune of 0.40 kg/m^3 respectively whereas the EWP is 1.61 Rs. /m^3 in flood-type irrigation method, whereas in alternate wetting and drying method, the paddy farmers obtain more PWP and EWP of 0.61 kg/m^3 and 3.06 Rs. /m^3. Through the water-saving technology used by the farmers, 39 per cent of the water is saved compared to conventional methods of irrigation. The PWP and EWP of Groundnut are 0.45 kg/m^3 and 2.98 Rs. /m^3 respectively in the check basin method of irrigation, whereas in flood or open type irrigation, farmers availing 0.38 kg/m^3 of PWP and 2.79 Rs. /m^3 of EWP which is lesser than the check basin type of irrigation. The PWP and

EWP of Black gram are 0.50 kg/m^3 and 18.42 Rs. /m^3 respectively in the check basin method whereas in the open/flood type method of irrigation, farmers obtaining 0.33 kg/m^3 of PWP and 15.00 Rs. /m^3 of EWP. The results indicate that the farmers following open or flood-type methods of irrigation use high water volume while getting lower productivity. The reason being an uneven distribution of water throughout the field which in turn causes lesser nutrient uptake by the crop, it causing crop productivity decline The high land productivity owing to assured irrigation, added with an effective and assured procurement policy for paddy further encourages farmers to cultivate this crop despite the rising water sustainability issues. Considering the other two crops, Black gram, has the highest EWP compared to the other crops. Overall, the obtained net income was higher for paddy. The farmers must concentrate on pulses cultivation concerning water sustainability issues and better technology must be provided to the farmers to increase the yield of pulses without an increase in water requirement.

Table 2: Irrigation Water Productivity of Different Crops in Tank Irrigation Environment of Tamil Nadu

(In Numbers)

Name of the crop	Irrigation Methods/Technologies	PWP (Kg/m^3)		EWP (Rs. /m^3)	
		Average	Range	Average	Range
Paddy	Flood	0.40	0.08-0.94	1.61	0.32-7.55
	Alternate wetting and drying	0.61	0.21-0.78	3.06	2.89-3.26
Groundnut	Check basin	0.45	0.09-1.41	2.98	1.23-29.15
	Flood	0.38	0.26-0.45	2.79	2.62-2.89
Black gram	Check basin	0.50	0.38-0.88	18.42	13.30-23.55
	Flood	0.33	0.29-0.40	15.00	13.90-16.12

Source: Author's estimation

Irrigation Water Productivity for different crops in the well irrigation environment of Tamil Nadu is given in Table 3. The maize farmers in a well irrigation environment report the highest land productivity of maize (5.79t/ha). The PWP is also high to the tune of 1.70 kg/m^3 respectively whereas the EWP is 5.78 Rs. /m^3 in the check basin method, 2.90 PWP and 7.20 EWP in drip irrigation or micro irrigation method. Farmers obtained better results in the drip irrigation method than in the check basin method. Comparing the PWP of three major crops in a good irrigation environment, Tapioca has the highest PWP of 5.26 kg/ m^3 in the check basin method and 5.80 kg/ m^3 in the drip irrigation method whereas the PWP of sorghum is 0.26 kg/m^3, 0.40 kg/m^3, 0.23 kg/m^3 in check basin, drip and open method of irrigation respectively. EWP is high in sorghum crop which accounts that 9.03 Rs. /m^3, 11.20 Rs. /m^3 and 6.39 Rs. /m^3 in check basin, drip and open methods of irrigation, whereas the for maize crop are 5.78 Rs. /m3 in check basin method and 7.20 Rs. /m3 in drip irrigation method and for tapioca crop, are 4.96 Rs. /m^3 and 5.22 Rs. /m^3 respectively. The crop Sorghum has the lowest PWP of 0.26 kg/m^3 and the highest EWP of 9.03 Rs. /m^3 which is considered an efficient crop in terms of water sustainability issues.

Table 3. Irrigation Water Productivity of Different Crops in the Well Irrigation Environment of Tamil Nadu

(In Numbers)

Name of the Crop	Irrigation Methods/Technologies	PWP (Kg/m^3)		EWP (Rs. /m^3)	
		Average	Range	Average	Range
Maize	Check basin	1.70	0.24-8.51	5.78	0.77-27.93
	Drip/Micro	2.90	2.64-3.40	7.20	3.45-14.90
Tapioca	Check Basin	5.26	1.04-30.87	4.69	0.84-32.57
	Drip/Micro	5.80	1.60-6.30	5.22	0.98-13.35
Sorghum	Check basin	0.26	0.03-0.57	9.03	-0.13-29.42
	Drip/Micro	0.40	0.21-0.69	11.20	5.40-19.25
	Open/flood	0.23	0.11-0.38	6.39	4.28-8.20

Source: Author's estimation

The PWP and EWP of major crops in the canal irrigation environment are given in Table 4. The sugarcane farmers in the canal irrigation environment report the highest land productivity of paddy. The PWP is also high to the tune of 5.16 kg/m^3 and 7.20 kg/m^3 in furrow and drip irrigation methods whereas the EWP is 1.66 Rs. /m^3 and 2.01 Rs. /m^3 in furrow type and drip irrigation method respectively. The PWP of turmeric is 0.35 kg/m^3 (furrow method) and 0.43 Rs. /m^3 (drip method) whereas farmers availing 9.69 Rs. /m^3 of

EWP (Furrow method) and 13.33 Rs. /m^3 (Drip method) of EWP. The PWP and EWP of banana is 1.04 kg/m^3 and 3.43 Rs. /m^3 respectively in the open/flood irrigation method. Paddy farmers follow flood-type irrigation methods only and they are achieving 0.20 kg/m^3 of PWP and 0.98 Rs. /m^3 of EWP. The results indicate that the farmers following open or flood type methods of irrigation incur high water volume and lower productivity compared to the water-saving irrigation method. The reason is an uneven distribution of water throughout the field which in turn reduce nutrient uptake by the crop and decline in the productivity of the crop. The high land productivity owing to assured irrigation, added with an effective and assured procurement policy for paddy further encourages farmers to cultivate this crop despite the rising water sustainability issues. Considering the water scarcity issues, farmers in canal irrigation environments must cultivate turmeric crops in water scarcity periods/regions to achieve both EWP and PWP and cultivate other crops when water availability is considered plenty.

Table 4: Irrigation Water Productivity of Different Crops in Canal Irrigation Environment of Tamil Nadu

(In Numbers)

Name of the Crop	Irrigation Methods/Technologies	PWP (Kg/m^3)		EWP (Rs. /m^3)	
		Average	Range	Average	Range
Paddy	Flood	0.20	0.07-0.58	0.98	0.22-2.46
Turmeric	Furrow	0.35	0.08-0.93	9.69	0.66-29.84
	Drip	0.43	0.12-0.59	13.33	4.56-21.23
Sugarcane	Furrow	5.16	1.85-10.78	1.66	0.74-3.66
	Drip	7.20	3.25-11.23	2.01	1.00-4.65
Banana	Flood	1.04	0.37-2.63	3.43	0.7-11.20

Source: Author's estimation

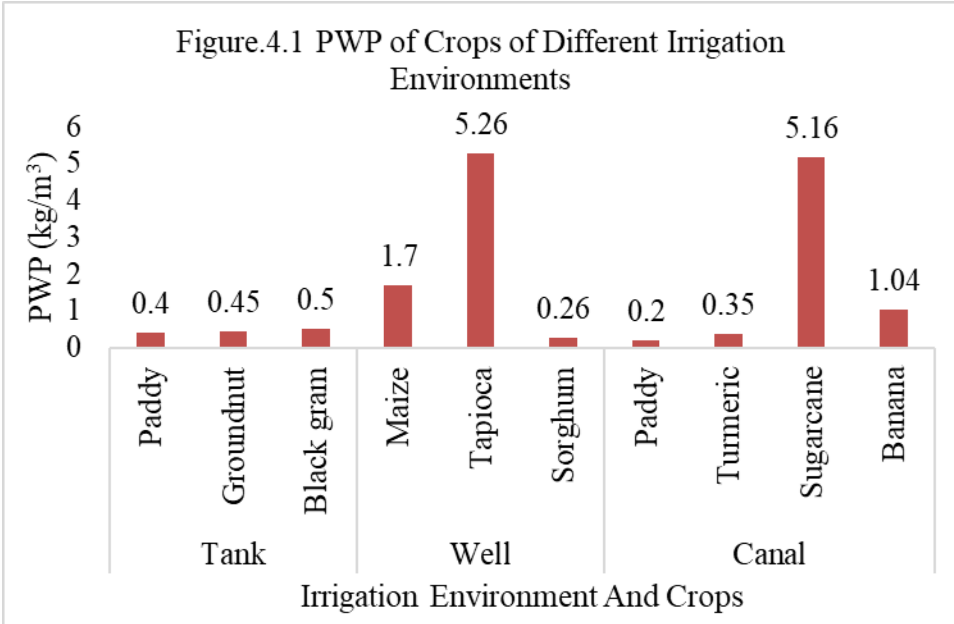


Fig 2: PWP of crops of different irrigation environments

The status of each crop on PWP of crops of different irrigation environments is given in Fig.2. The graph showed that the quantity produced per cubic meter of water consumed in different irrigation environments of Tamil Nadu, 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.

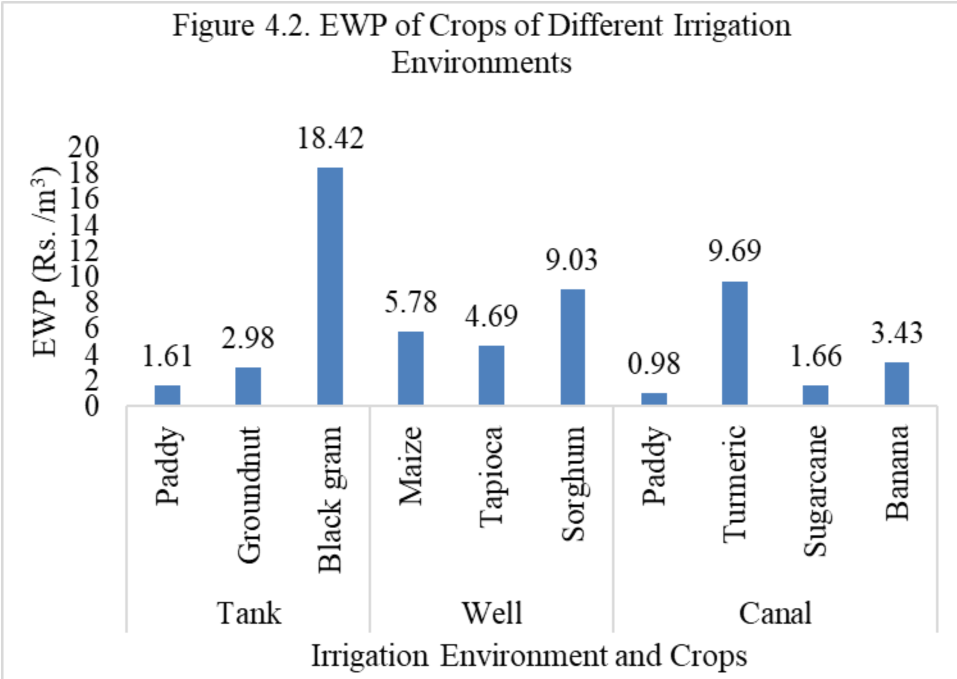


Fig 3: EWP of crops of different irrigation environments

The status of each crop on this indicator is given in Fig. 3. The graph shows that the net production value per cubic meter of water consumed in different irrigation environments, 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.

5. CONCLUSION

To increase WP, it is required to ascertain the maximum or achievable WP that may be attained under particular circumstances as well as the actual WP, which is the baseline or existing state of WP in a given system. When recommending WP improvement methods, it is important to have a realistic understanding of the circumstance. By quantifying the WP gap, the potential for progress may be measured. It is crucial to measure the WP gap for a variety of reasons. The major steps to increase both PWP and EWP are 1. Identify the sources of the WP gaps. 2. Provide management measures to close the gaps.

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