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Water Productivity of Agricultural Crops in Upper Manair Catchment

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Abstract:
Water use in agriculture is highest among other water users and economically far less efficient. The production per unit water consumed, the water productivity, must be increased to increase its economical efficiency. Knowledge about water resources availability and crop water productivity with high spatial and temporal resolution is necessary for water productivity improvement analyses. Therefore, the study has been taken up to characterize the hydrologic processes of the Upper Manair catchment and assess crop water productivity using Soil and Water assessment tool (SWAT) to evolve irrigation management plans to sustain the use of groundwater resources for irrigation. The biological and economical yield of different field crops, viz. Rice, Maize, Cotton, Sugarcane and sunflower were predicted successfully. Water productivity for Rice, Maize, Cotton, Sugarcane and sunflower were estimated at 0.61, 1.27, 0.41, 8.04 and 1.05 kg /m^3, respectively, which were significantly lower than the potential. SWAT model predicts crop yield, biomass and water productivity temporally and spatially which will help to finalize the management practices to sustain ground water resources. In addition to adopting water saving technologies, reliable quality and hours of supply of power is extremely important for achieving higher water productivity in ground water irrigation.

1. Introduction

Land and water resources are finite and their management is crucial for improving food security in the country. The pressure on land and water resources is increasing due to the rapid growth in population. Water use in agriculture is rated as high among other water users. The share of water available for agricultural production will be reduced in future due to competition from the industrial and domestic sectors, while at the same time food production must be increased to meet the food grain requirement of the growing population. Together, the increasing food demand and decreasing water allocation suggest that the agricultural sector has to produce more food with less water, that is, to increase agricultural water productivity (Cai and Sharma 2010). It is inevitable that the production per unit water consumed, the water productivity (WP), must be increased to meet this challenge. Knowledge about water resources availability and crop water productivity with high spatial and temporal resolution is necessary for water productivity improvement analyses. Process--based models provide an opportunity to lay the basis for further analysis of WP.

Basin-wide WP analyses (Molden 1997) are required to measure the effectiveness of these interventions through analysis of system water demand-supply and its relation to agricultural outputs.

Barron et al. (2010) assessed the impact of different agro eco systems productivity, water balance, water productivity and biomass productivity in relation to dry spells occurrence in Goulbi N'Kaba river basin in South east Niger. With marginal inputs of fertilizer, millet yield increased from 2.0-2.4 t/ha, water productivity, improved from 6,000 to 12,000 m^3 and actual evapotranspiration (ETa) t^{-1} grain, has increased from 1,700 to 3,000 m^3 ETa t^{-1} grain.

Bhaskaran et al. (2010) used SWAT to model the production of Switch grass for current landscapes at a regional scale in the Arkansa White Red river basin (5, 00,000 ha), England. Average yield reported in field trials tended to be higher than average SWAT predicted yield, which may nevertheless be more representative of production scale yield. It was inferred that differences between SWAT flow predictions and field data increased in downstream sub basin with higher percentage of water.

Hydrologic budget and crop yield simulation was done without calibration for the Upper Mississippi river basin (UMRB) by Srinivasan et al. (2010). Compared with three calibrated SWAT models developed in previous studies of the entire UMRB, the uncalibrated SWAT model also presented similar results. Hence, the SWAT model can provide satisfactory predictions on hydrologic

budget and crop yield in the UMRB without calibration. It can reliably predict monthly stream flows on any other agricultural watershed in tropical climates with conditions similar to the watershed (Phomcha et al., 2011).
The impact of climate on hydrology and rice yield in Bhavani basin (3246 km^2) of India was assessed by Lakshman et al. (2011). The SWAT model predicted paddy crop yield successfully and the yield of paddy is more during Kharif season compared to Rabi season due to change in rain fall, temperature and photo periods between the two seasons and the simulated yields were comparable with recorded yields. SWAT can be an effective tool for developing adaption strategies to sustain paddy production under changing climate.
Kaushal et al. (2012) used the SWAT model to characterize the hydrologic processes and assess crop water productivity of the Upper Bhima River Basin (46,066 km^2) in India. Agricultural water productivity for sugarcane, sorghum and millet were as 2.90, 0.51 and 0.30 kg m^{-3} respectively, which were significantly lower than the potential and global maximum in the basin and warrant further improvement. Analysis suggested that maximization of the area by provision of supplemental irrigation to rain fed area as well as better on farm water management practices can provide opportunities for improving water productivity.
Prasad and Mani (2013) used the SWAT model to simulate crop yield and productivity of different crops in the Kothakunta subwatershed, Wargal village, Medak district of Andhra Pradesh. It was noticed that the simulated maize crop yield and biomass has shown great harmony with field observations compared to other crops.
Hence, hydrological model integrated with crop growth simulation model and geographic information system (GIS) has been applied to analyze water productivity, which is an indicator of water use efficiency, at the basin scale in order to evolve operational plan for sustainable use of ground water resources.
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2. The Study Area

The Upper Manair Catchment (UMC) of Andhra Pradesh was selected for the study. The UMC is located between the latitudes 17.65^0 and 18.50^0 N and longitudes 78.15^0 and 78.85^0 E which comprises parts of the Medak, Nizamabad and Karimnagar districts of Andhra Pradesh. The catchment area is 2, 20,173.1631 ha. Two rivers namely Kudlair river of Medak district and Manair river of Nizamabad are flowing through the catchment and contributing the flows to Upper Manair reservoir.
The physiography of the area is undulating having a slope of 1-6%, slightly eroded, and moderately drained. The mean elevation of catchment is 456.5 m. The Upper Manair catchment consists of mainly two types of soils. Clay loam soils occupy an area of 92% in the catchment. Remaining 8% soils are Clay. Climate of the study area is semi-arid with distinct summer, winter and rainy seasons. The average annual rainfall of 21 years from 1992 to 2012 was 777.8 mm. The highest amount of rainfall was recorded in 1995 as 1143.8 mm and lowest amount of rainfall was recorded during the year 2009 as 536.01mm. The average maximum and minimum temperatures ranged between 33 and 19.6^0C and the average relative humidity was 59.3%

3. Crops and Cropping Pattern of Study area

The major cropping systems followed in the study area are paddy - paddy, maize-maize, paddy-maize, cotton-maize and maize-sunflower. The major crops grown during kharif and rabi are paddy, maize and cotton respectively. Sugarcane, sunflower and vegetables are also grown but not in significant area. The primary source of water for irrigation is ground water. The data on application of irrigation water to different crops has been obtained by conducting farmer's survey in the catchment area on different aspects of cultivation.

4. Hydrological Model -Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds. It predicts the effect of management decisions on water, biomass and crop yields with reasonable accuracy on large, ungaged river basins. A more detailed description of the model is given in Neitsch et al. (2005). ARCSWAT 2009 was used in the present study. It requires geo spatial layers of DEM, drainage network, LULC and soil.

5. Preparation of Geospatial layers

The Digital Elevation Model was prepared by downloading Cartosat DEM of catchment area from Bhuvan web site provided by NRSC with a resolution of 30 m x 30 m. The projection UTM, the spheroid type (WGS 1984) and Datum of WGS 84 and 44 N zone has been applied to DEM. The mask area of the catchment has been created by drawing the polygon which is the area of interest to generate stream network on DEM. The Arc SWAT interface automatically generated stream network, flow direction and accumulation by taking into consideration the elevation values of DEM and masked area on the DEM. The outlet points have been added based on the flow from Kudlair river and Palvancha vagu (Manair river) reaching to Upper Manair reservoir. The delineation of watershed was completed based on the added outlet points. The reservoir point has also been set at the outlet of the watershed.
The LULC was prepared for the study area of 2,20,289.5 ha using IRS P_6, LISS III image of December, 2011 and September, 2012. The information from LISS III image and toposheets were utilized for classification of land cover generation of training sets. Major portion of the study area was covered with agricultural crops viz. paddy, maize and cotton. The areas of different land uses of the study area are presented in percentage in Table 3. The soil map (1.250,000) developed by NBSS & LUP has been taken as

reference map and clipped to the catchment area. The soil textural classes were identified. One is clay loam soil and another one is clay soil. In addition to that the soil map prepared by SWAT group for India was also considered to ascertain the types of soils.

6. Application of Model

A base SWAT model has been created with the dataset of upper manair catchment and simulated total water yield, reservoir levels, reservoir discharge and reservoir volume for the period 1992 to 2012. Since the model is physically based and has been developed to simulate the ungauged catchments, it is not necessary to calibrate the model (Srinivasan et al. 2010). But for accuracy in simulation, the model was calibrated and validated against the measured reservoir volumes. The results obtained in the present study were in good agreement with R^2 =0.85. The Nash-Sutcliffe efficiency (NSE) criteria were also used to calibrate and validate the model.

7. Simulation of Yield of Different Crops

A simplified version of the EPIC crop growth model is incorporated into SWAT and can effectively estimate crop yields. It has been applied to assess crop water productivity at watershed level. SWAT allows representation of a wide variety of crops and management combinations for evaluation and provides reasonable estimate of crop yield and biological yield. Another added advantage of SWAT model is that it can predict the crop yield with minimum input data. The simulated yield obtained from the model is furnished below in the Table 1. The biomass and economical yield was simulated for different crops grown in the watershed for three management practices namely amount of irrigation, tillage operation and fertilizer respectively.

Crop	Type of soil	Irrigation + Fertilizer applied	
		Yield (kg ha^{-1})	Biomass(kg ha^{-1})
Paddy	Clay loam	3580	7200
	Clay	2850 2850	5865
Double crop Maize	Clay loam	6291	13342
	Clay	5970	12588
Cotton	Clay loam	1924	9052
	Clay	2506	10025
Sugarcane	Clay loam	84325	95625
	Clay	83125	94527
Sunflower	Clay loam	3836	8006.2

`Table 1: Estimated Biomass and Economical yield of different crops

The model has predicted the yield sufficiently well during normal years that received rainfall close to the average and without any extreme events. The simulated yield of paddy was presented in Fig. 1. The economical yield of paddy varied from 2850 to 3580 kg ha^{-1} with irrigation. The biological yield of paddy varied between 5865 to 7200 kg ha^{-1}. The yield of rice is more during Kharif season compared to Rabi season. Most of the sub basins recorded more than 3 t ha^{-1} during Kharif season while during Rabi season more than 50% of the sub basins in the study region recorded yield levels lesser than 3 t ha^{-1}. This must be due to the change in rainfall, temperature and photo periods between the two seasons and the simulated yields were comparable with the yields obtained from farmers' response. Lakshmanan et al. (2011) also simulated crop yield of rice in Bhavani basin and confirmed that SWAT can be used very well for simulation of rice yields.

The maize crop was grown under two different types of soils and maximum yield was simulated in clay loam soil which was shown in Fig. 1. The yields varied from 5970 to 6291 kg ha^{-1} for irrigated corn. The maize yields were in good agreement with simulated yields reported by R Srinivasan et.al (2010). The biological yields of maize were in the range of 12588 to 13342 kg ha^{-1}.

The highest yield was obtained for cotton from clay soils (Fig.1). The yields ranged from 648.2 to 1412.3 kg ha^{-1} for irrigated cotton. Cotton also showed influence of fertilizer on yield. The cotton yields with the application of fertilizer varied from 1924 to 2506 kg $ha^{-1.}$Similarly, the biomass yield was also increased to 10025 kg ha^{-1}.

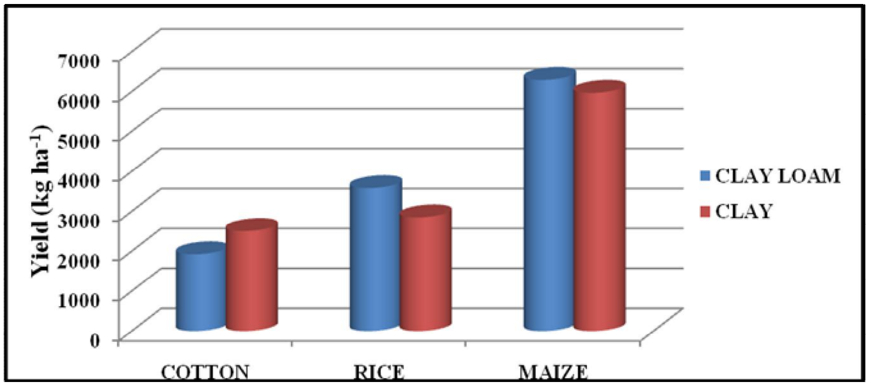

Figure 1: Economic yield of crops under different soil types in catchment

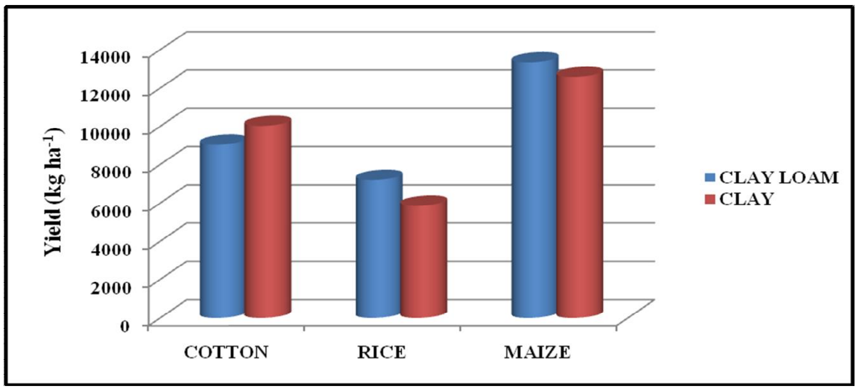

Figure 2: Biological yield of crops under different soil types in catchment

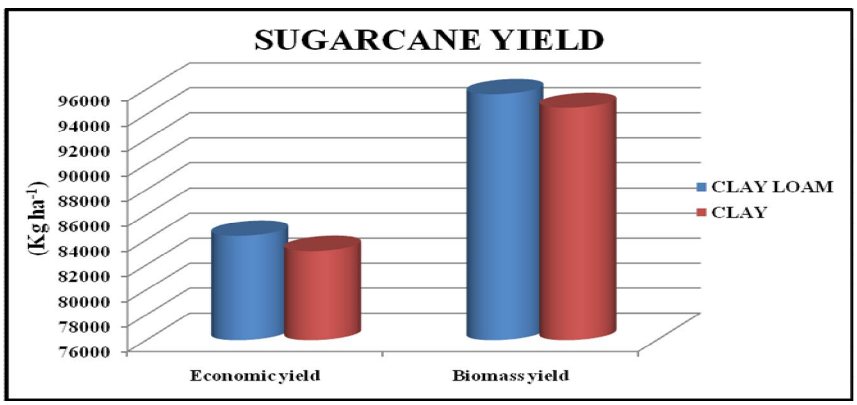

Figure 3:Economic and biological yield of Sugar cane under different soil types in catchment

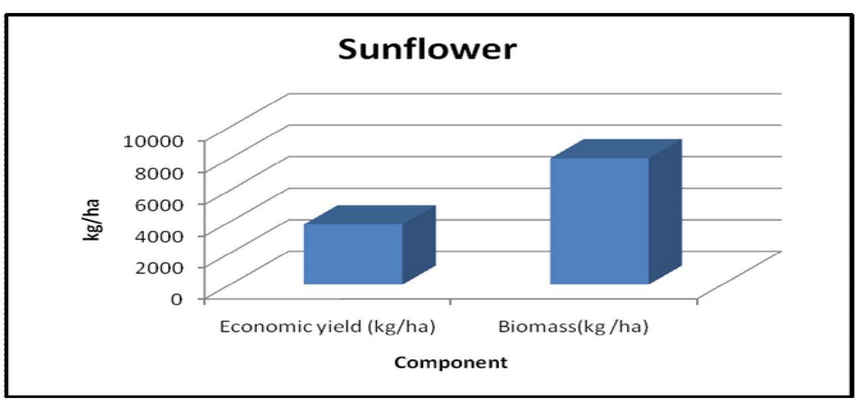

Figure 4: Economic and biological yield of Sunflower under different soil types in catchment

The simulated yield of sugar cane was ranged from 83125 to 84325 kg ha^{-1} (Fig. 3). Only two basins of catchment have area under sugar cane and irrigation has been applied through reach. The sugarcane yields were as high as 70–90 t ha^{-1} during wet year. In case of dry year, the range of crop yields reduced to 45–60 t ha^{-1} in the catchment. Kaushal et al (2012) also reported that sugar cane yields in Upper Bhima irrigated command areas were as high as 45–90 t ha^{-1} during 1999 (wet year). There is little variation in yield with respect to soil type. Sunflower was grown in Clay loam soil only. The simulated yield of sunflower was 3836 kg ha^{-1}(Fig. 4) and biomass was 8006.2 kg ha^{-1}.

8. Crop Water Productivity and Field Water Productivity

WP may be measured by a series of indices namely, physical and economic WP, irrigation WP, rainwater productivity, and ET WP. Individual indices serve various purposes. The combined use of irrigation WP and ET WP, help to better understand water uses and associated outputs. However, information on water supply and consumption is often inadequate. This is particularly true when groundwater extraction through private pumps is a common practice, which is the case in Upper Manair catchment. In this context, CWP and FWP is a pragmatic option to assess the effectiveness of basin-wide agricultural water supply and consumption**.** Crop water productivity and Field water productivity of different crops grown in Upper Manair catchment are presented in Table 2.

Crop	Yield (kg/ha)	ET (mm)	CWP (kg/m^3)	FWP (kg/m^3)
Paddy	3215	525.3	0.61	0.49
Double crop Maize	6130.5	483.5	1.27	1.45
Cotton	2215	534.7	0.41	0.39
Sugarcane	83725	1040.9	8.04	7.31
Sunflower	3836	365.1	1.05	1.12

Table 2: Crop water productivity and Field water productivity of different crops in Upper Manair catchment

The CWP of different crops namely, Paddy, double crop maize, cotton, sugarcane and sunflower are 0.61, 1.27, 0.41, 8.04 and 1.05 respectively. The CWP and FWP of paddy were less compared to other crops. Tuong and Bouman (2003) gave a range of 0.4 –1.6 kg m^{-3} for low land rice conditions. Owing to the large share of low land rice in the catchment, increasing the water productivity of rice would increase the water productivity of the whole catchment. WP can be increased with controlled water delivery. “Water control” means supplying water close to the difference between crop water requirement and available soil moisture in the root zone. It ensures greater utilization of applied water for ET, and minimal non-recoverable percolation from the applied water, which is non-beneficial. The measures for this include on-farm water management practices and improving the conveyance of water. The range for cotton seed yield is 0.4-0.6 kg m^{-3} (FAO-33). The WP_{ET} range for maize is 0.8 -1.6 kg m^{-3}, a C4-crop, which is significantly higher than rice and cotton. Excess irrigation of 101.26 MCM was applied in maize fields in the entire catchment which lead to low WP. Irrigation schedules based on real-time crop requirements, soil water monitoring, and short-term forecasts appear to be sound options for increasing water productivity in current irrigated maize fields. The cane yield of sugarcane is more than the national average (66.38 t ha-^{1}). But, WP of sugarcane is less. This can be improved by adopting water saving technologies like, irrigation at critical growth stages, trash mulching and skip furrow irrigation, etc. FWP is less than CWP in paddy, cotton and sugarcane. However, it is more in Sunflower and maize which indicates minimum field losses. In addition to the above, improving power supply conditions – both quality and hours of supply is extremely important for achieving greater control over water delivery in ground water irrigation. Unreliable power supplies and power supply during night time force farmers to apply excess water whenever power supply is available (Kumar and Singh, 2001) instead of application at the critical stages of crop growth that gives higher productivity.

9. Conclusion

SWAT simulated economic and biomass yields accurately using minimum crop management inputs. It has estimated low yields in dry year and more yields in wet year. Agricultural water productivity of all crops was lower in the catchment and warrant further improvement. WP of paddy is less due to high share of soil evaporation into ET, percolation from fields and seepage losses because of continuous flooding. The adoption of on farm water management practices in the cultivation of paddy can not only improve WP of paddy but also conserve energy. Water saving technologies particularly, controlled timely supply of water is important to increase productivity. In addition to adopting water saving technologies, reliable quality and hours of supply of power is extremely important for achieving higher water productivity in ground water irrigation.

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