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ON-FARM WATER MANAGEMENT FOR HIGHER CROP WATER PRODUCTIVITY IN TUBE WELL COMMANDS OF LOWER INDO-GANGETIC PLAINS

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ABSTRACT

With the background of an alarming draw down of ground water table 3-12 m bgl or more during summer, farm-level interventions on water delivery, allotment, method of application and crop selection were made at deep tube-well commands (40 ha) in the lower Indo-Gangetic plains of West Bengal, India for 10 years during 1999 - 2009. On-farm adaptive research revealed that in summer paddy spout-wise alternate wetting and drying (AWD) at 1-3 days after disappearance of ponded water saved 25-40 % of irrigation water over continuous submergence (5±2 cm). Conveyance efficiency was remarkably improved up to 95% by using polythene delivery pipes in rice as well as non-rice crops. Water distribution efficiency was improved by furrow irrigation, raised bed furrow water application in non-rice crops. Inclusion of vegetables in rice based crop sequences increased the water productivity by 2-3 times as compared to other non-rice crop sequences. In terms of benefit-cost ratio, winter rice-tomato sequence recorded the highest value followed by winter rice-cabbage-summer rice sequence. Inclusion of summer rice increased precious irrigation water expenditure and water cost many folds in the tube well commands.

Key words: *Crop water productivity, Tube-well commands, Rice based crop sequences,*

INTRODUCTION

With the rapid development of irrigation technology, cropping intensity has been reached to > 250% in the lower Indo-Gangetic Plains of West Bengal, India. Rice is the main food grain and it is extensively grown during wet and dry seasons in tube well commands occupying medium and low land ecosystem of alluvial Lower Gangetic Plains Region while vegetables, oil seeds, pulses and wheat occupy the upland and medium lands. Crop intensification has been possible as the area is blessed with fertile soil and ample reserves of good quality ground waters. Summer rice cultivation has been very popular to the farmers of rural Bengal, Bihar and Orissa since 1970s with the introduction of high yielding varieties like TN 1, IR 8, Jaya, Ratna and later IR 50, IR 64 and IR 36, IET 4094 and IET 4786 in irrigated ecosystem. With the rapid development of tube well irrigation technology in 1980s coupled with chemical fertilization and higher profit margin pushed up the summer rice areas of West Bengal to 1.6 million hectare during 2004 AD from 0.76 million hectare in 1989 - 90. Tube well density is maximum to the tune of 1717 to 2412 tube wells /100 sq. km in lower Gangetic plains of West Bengal (Rawal, 2001). The rapid increase of summer rice (*boro*) area to the tune of 5 - 10 % annually over the last decade is only possible with indiscriminate ground water pumping mostly from unconfined aquifer, close to earth surface (12 to 35 m deep) through private shallow tube wells. As a result the alarming magnitude of lowering of ground water table (0.5 to 16 m) has caused many tube well systems to go dry or deliver pulsating discharges during summer months. As in Midnapore, Hooghli and Burdwan districts, farmers have been faced to go for deeper and deeper under ground pump chamber for centrifugal pumps. Shallow tube wells with submersible pumps have been abandoned. Drinking water crisis has been serious concern to summer rice growing areas and arsenic contamination is now reported in 134 blocks of West Bengal. Inclusion of summer rice and high yielding vegetable crops increases the ground water tapping for irrigation. Alarming draw down of ground water table (3-12m or more) during summer is a common phenomenon in most of southern part of West Bengal. Under such situations a farm house hold has to choose crops and crop sequences of high water productivity (Tuong 1999 and Wichelns, 2003) particularly, when water is the binding constraints in tube-well commands. The lot of works are available on water saving and increasing water use efficiency through reducing ponding depth and widening irrigation interval in summer rice (Sarangi and Lenka 2000, Das et al 2000) in India and abroad (Guerra *et al*. 1998, Bouman and Toung 2001 and Molden *et al* 2001). Hence, an attempt was made to find out crops and crop sequences of high water productivity for the tube-well commands of this area so that 'more crops per drop' or 'more food with less water' could be achieved in future.

METHODS

Farm-level investigations were conducted at 5 deep tube-well (DTW) commands located in Lower Indo-Gangetic Plains Haringhata and Chakdaha Block of Nadia district (23^0 N latitude and 85^0 E longitude, 8.75m above mean sea level) by All India Coordinated Research Project on Water Management, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India during 1999-2009. Deep tube well commands were 40 ha each having 10 spouts, discharge capacity 80-100 m^3 $hour^{-1}$. The soils of the command were sandy loam in upland, and clay loam in low land with bulk density 1.42 - 1.58 g cm^{-3} and infiltration rate 8-12 mm hr^{-1} and pH 6.5 - 6.8, organic carbon 0.54 - 0.61%, total nitrogen 0.059-0.063%, available P 7-10 kg ha^{-1} and available K 127-146 kg ha^{-1}. The climate of this region is humid tropical, average temperature ranges from 25 to 36^0 C during summer and at winter it lies between 25 to 12^0C. The average annual rainfall of this region is 1500 mm. The variation of rainfall was 1244 - 1862mm with season-wise break up of summer (February – May)- 114.7 - 251.7 mm, rainy (June-September)- 1373.4 & 1159.6 mm and winter (October- January)- 156.2 & 450.7 mm during 1999-00 and 2008-09. Crop water productivity of rice-based viz. winter rice-tomato (R-T), winter rice potato-sesame (R-P-S), winter rice -wheat-jute (R-W-J), winter rice-cabbage- summer rice (R-C-R), winter rice-mustard – summer rice (R-M-R), winter rice-summer rice (R-R) were under taken for on-farm water management studies. Crop sequences were raised with recommended agronomic practices. Water productivity (WP) of various crops and its sequences were worked out following Kijne (2002) and Barker *et al.* (2002). For computation of land productivity rice equivalent yield was computed on the basis of prevailing market price after Tomar and Tiwari (1990), and Choudhury *et al,* 2000.

FINDINGS AND DISCUSSION

Status ground water irrigation

In lower Gangetic plains of ground water has been extensively used for irrigation by more >80%. The 3^{rd} Minor Irrigation Census Report (2000-2001) of Government of West Bengal, India revealed that ground water use was maximum in Murshidabad district (1.92 lakh ha) followed by Medinipur (1.88 lakh ha ha), Bardhaman, Nadia, North 24 Parganas and Hoogly. Total culturable command area (CCA) was 14.09 lakh ha out of which shallow tube well 11.7 lakh ha and deep tube well 1.8 lakh ha (Table 1). The ground water irrigation potential was 23.56 lakh ha i.e. 59% of created potential has been utilized. The boro rice (summer rice) area irrigated by tube well wells has also been increased at an alarming rate (10% annually) over the last decade, whereas, canal irrigated area stagnated and the area irrigated by tanks and other sources has declined steadily reducing the recharge of the ground water. Ground water mining in the Gangetic basin was mainly for seasonal irrigation only. Ground water over draft mainly occurred in extreme summer months in summer rice growing area, which was totally fed by ground water. In West Bengal 6.0 lakh ha summer rice was grown under ST and DT commands i.e. 40 % of total boro rice area (15 lakh ha). Ground water fed summer area was maximum in Midnapore (1.08 lakh ha) followed Burdwan (0.99 lakh ha). Over exploitation of ground water for summer rice caused drinking water crisis and arsenic contamination to the aquifer leading to environmental and health hazards in 138 blocks of eight districts.

Table1. Ground water irrigation scenario of some districts of lower Gangetic plains of West Bengal during 2000-01

District	Tube well structures			CCA ('000 ha)		Summer rice area ('000 ha)		Actual GW irrigated ('000ha)
	Number ('000)		Density					
	ST	DT	No./100Sq. km)	ST	DT	ST	DT	
Maldah	36.8	0.32	969	83.9	13.5	45.9	2.7	99.6
Murshidabad	83.2	0.59	1717	148.9	21.8	56.7	2.6	191.7
Nadia	94.1	0.75	2412	92.1	27.8	43.8	6.4	155.8
North 24 Pgs	63.2	0.32	1982	72.8	12.2	45.7	4.0	113.8
Burdwan	50.7	0.60	950	144.7	23.6	91.1	8.3	183.2

Hoogly	20.3	0.51	855	72.8	20.5	32.0	6.8	107.6
Medinipur	77.4	0.77	727	180.1	24.5	99.5	8.3	188.8
Bankura	27.6	0.74	574	43.4	4.3	16.2	0.2	56.5
West Bengal	596.6	4.99	952	1169.9	183.1	555.0	46.3	1409.7

Status of ground water table (GWT)

Periodical piezometric observations revealed that rise and fall of ground water table (GWT) varied depending on the topo-sequence, cropping pattern and climatic season. Water depth reached maximum to the extent of 5-6 m bgl during May and June in high land situation and 1.5 – 5 m bgl in low land situation depending upon the extent of ground water abstraction for summer rice (Fig 1). Fall of GWT on monthly basis was much faster in shallow tube well than deep tube well irrespective of land situation. Fall generally started from October 2^{nd} part and continued up to June 1^{st} part. The pattern of fall was very distinctive in different tube wells commands. Fall was faster in winter months (November – February) while in low land situation it occurred during pre-monsoon period (February May) due to tapping of much water for summer rice cultivation. The daily rate of fall in low land was maximum to the tune of 5.1 to 6.6 cm day^{-1} during January – February. In post monsoon months (November to January) was 1.65 to 2.50 cm day^{-1} in upland situation. In summer months GWT falling rate was minimum due to no water mining for irrigation and dry earth surface acts as insulating agent against surface evaporation.

GWT started rising with the onset of monsoon and it continued up to middle of October. Rising of GWT was faster to the tune of 3.1 to 6.2 cm on daily basis during June, July and August and this rate slowed down gradually from September. The lowest recharge rate (0.5 to 1.2 cm day^{-1}) was seen in early October. The rising rate also varied depending upon land situation. The rising of GWT was much faster in upland during monsoon months than low land in DT commands, whereas, rising was much faster in low land in early monsoon months due to much draw down caused by summer rice cultivation.

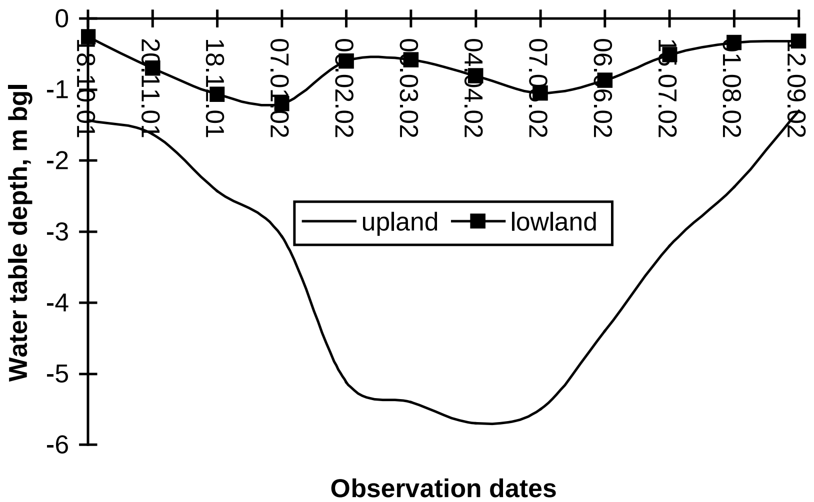

Fig. 1 Ground water table (GWT) fluctuation in deep tube well (DT) of alluvial Gangetic basins

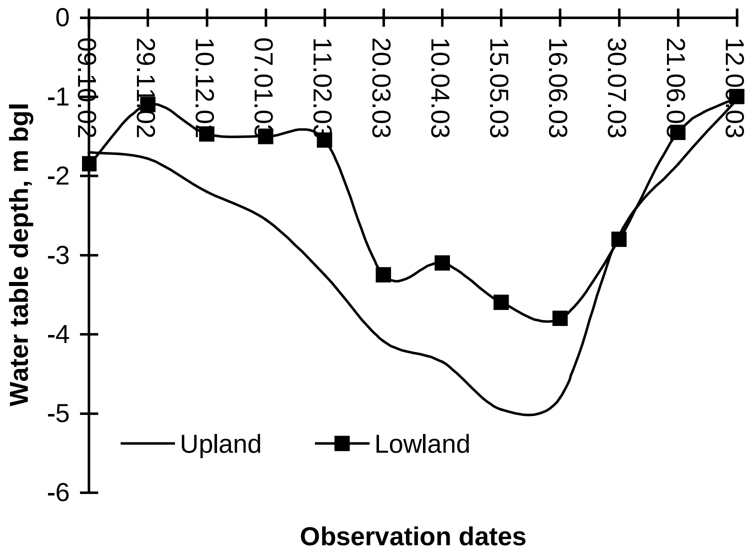

Fig 2. Ground water table (GWT) fluctuation in shallow tube well (ST)of alluvial Gangetic basins

Water distribution system

There were 10 spouts distributed in three directions viz. East, North and South or West. Water was delivered from source to the crop fields with the help of earthen channel. From each spout two main irrigation channel of opposite direction stretch out the spout command. Generally channel dimension varied from sprout to spout and narrowed down at the tail end. Sub irrigation channels are distributed according to the land situation in a zigzag fashion. Most of the channels are along the boundary of plot. Channel density differs from spout to spout and the nature of cropping i.e. for rice crop channel density varied from 169 m length per spout. The average channel density within the command area is 42.2 m ha^{-1}. The tube well has a discharge rate of 80-100 m^3 $hour^{-1}$. The average discharge of spout was 18.1 and 14.8 lit sec^{-1} at head and tail reach of the spout system respectively. The average seepage rate of channel for dry crops like sunflower, mustard and wheat was high ranging from 0.133 to 0.233 lit $sec^{-1}m^{-1}$. Water distribution of deep tube well was based on demand driven basis i.e. water was allotted to the field as per demand of farmers and according to the need of the crop or growing season. Deep tube well water was mainly used for winter crops like wheat, mustard and vegetables like tomato, brinjal, cabbage, cauliflower, potato, pointed gourd and *boro* rice (January-April) during dry months; and some times it was used for *aman* rice (July –October) transplanting or flowering if drought occurs.

Table 2. Mondalhat deep tube well (108 N) water supply schedule for rice and non-rice crops during 2000-01

Month	Operation schedule			Crops irrigated
	Hours day^{-1}	Days $month^{-1}$	Hours $month^{-1}$	
October	7	4	28	Vegetables
November	4	3	12	Vegetables
December	6	18	108	Vegetables
January	8	22	176	Rice + Vegetables
February	11	24	264	Rice + Vegetables
March	10	29	290	Rice + Vegetables

April	9	14	126	Rice + Vegetables
May	4	4	16	Rice + Vegetables
June	-	-	-	
July	11	10	150	Rice
August	6	8	48	Rice
September	-	-	-	

Existing operational policies of the command

- Water users committee (WUC) was not well functioning in the command area.
- Deep tube well operator allotted the water without considering the actual irrigation requirement.
- General tendency of the farmers was to take more water for the crop
- Irregularities and uncertainties in water supply specially power cut off and defunct deep well

Constraints in agricultural production found in the command

- High seepage loss in the earthen channel due to cracking.
- Absence of irrigation land layout system
- Leakage of discharge around the spout
- Failure of pump due to much draw down
- Tube well density was much higher at the Gangetic plains
- Sinking of tube well without safe distance
- Increased summer rice area in the Gangetic plains
- Absence of crop planning and crop substitution as per water availability
- Farmers' reluctantance to save water

Crop water demand and supply

Reference crop evapotranspiration (ET_c) computed (Table 3) for the sub-humid Gangetic plain region revealed that winter growing vegetables, wheat and mustard crops had low crop water demand (87-157 mm) while the summer grown crops like jute, summer rice and sesame had about 2-3 times higher evaporative demand (326--344 mm). On sequence basis inclusion of summer rice, sesame and jute during summer months increased the reference ET (784-833 mm); while rice- winter vegetable crop sequences had lower crop water demand (434- 715 mm). Total crop sequence water use (Table 4) covering irrigation water application plus the annual effective rain called here water supply (WS) was maximum in winter rice-cabbage- summer rice sequence (2090 mm) and the lowest noted in autumn rice-tomato crop sequence (870 mm). Growing summer rice in sequence required huge irrigation water use of 850-1120 mm depending on land situation and soil type. There was wide gap between demand and supply of water in rice-rice or rice-cabbage-rice due to higher amount of percolation losses in rice ecosystem in sandy loam soil of Lower Gangetic Plains Region of West Bengal (Goswami 2006).

Table 3. Crop water demand (Etc) and supply, yield and water productivity (WP) of rice and vegetables in the tube well commands (mean of 2000-01 and 2001-02)

Crop	Demand (ETc, mm)	Irrigation water (mm)	Total Water supply (WS, mm)	Yield ($t\ ha^{-1}$)	WP_{WS} ($kg\ m^{-3}$)
Summer rice	343	1120	11355	5.8	0.43
Wheat	152	150	276	3.2	1.15
Mustard	99	100	205	1.0	0.48
Potato	121	180	231	22.7	9.82
Tomato	157	220	301	22.4	7.44
Cabbage	94	240	296	21.5	7.26
Sesame	326	180	430	1.5	0.34
Jute	344	120	585	2.6	0.44

CD (P=0.05)	36.06	108.60	120.20	3.24	1.28

Crop water productivity

Crop water productivity in terms of land and water productivity of individual crops (Table 3) revealed that winter vegetable crops like tomato, cabbage and potato had significantly higher land productivity (21.5 - 22.7 t ha^{-1}) as well as water productivity values (7.6 – 9.82 kg m^{-3}) than the summer rice (0.43), mustard (0.48), sesame (0.34) and jute crop (0.44). Rice-based crop sequences in the tube well command revealed that rice equivalent yield (REY) was maximum (24.6 t ha^{-1}) in rice-cabbage-rice sequence (Table 4). Rice-potato and rice potato-sesame and rice cabbage-rice recorded higher water productivity (WP_{WS}) of 1.18 –1.90 kg m^{-3} water that was 42.16 - 128.9% higher than rice-rice sequence. High water requiring crops like summer rice and sesame having their sizable growth period coinciding with hot and high evaporative summer months tend to lower the system productivity in physical and economic term. The least water cost (WC) was noted in winter rice-tomato sequence (US $ 40 ha^{-1}) and the maximum water price was paid for winter rice-summer rice sequence (US $ 187). Growing of summer rice increased the water cost for cultivation (US $ 120-157 ha^{-1}) in the sequence by 2-4 times than the other conservative water use crop sequences. Monetary net return was maximum (US $ 2123 ha^{-1}) in winter rice-cabbage-summer rice (R-C-R) sequence followed by winter rice-tomato (US $ 1471) i.e. inclusion of vegetable crops in rice based sequence increased the economic productivity of the sequence by 2-4 times as compared to winter rice-wheat-jute (US $ 442) / winter rice-mustard-summer rice (US $ 749) and winter rice-summer rice sequences (US $ 836). In terms of benefit-cost ratio, winter rice-tomato sequence recorded the highest value (1.66) followed by winter rice-cabbage-summer rice sequence (1.54). Winter rice-wheat-jute sequence had the least B:C ratio in the tube well commands of lower Gangetic plains.

Table 4. Land and water productivity of rice-based crop sequences in the tube well command (mean of 2000-01 and 2001-02)

Crop sequence	REY (t ha^{-1})	ET (mm)	WS (mm)	WP_{WS} (kg m^{-3})	WC (US $ ha^{-1})	Net return (US $ ha^{-1})	Benefit: cost
R-T	16.6	434	870	1.90	40	1471	1.66
R-P-S	18.1	784	950	1.90	65	1043	0.66
R-W-J	10.3	833	970	1.06	60	442	0.44
R-C-R	24.6	715	2090	1.18	201	2123	1.54
R-M-R	13.0	779	1410	0.92	157	749	0.68
R-R	11.7	681	1400	0.83	187	836	1.01
CD (*P*=0.05)	1.55	47.63	125.7	0.15	23.93	202.07	0.17

On-farm interventions for higher WUE

Interventions	Intervention mode	Water saving %
i) DT operation	Water users committee	20-30
ii) Water distribution	Appointment of *math rakhal* (irrigation care taker) Earthen channel cleaning Use of PVC delivary	10-15 10-20 20-30
iii) Water management aspects	Intermittent ponding in rice Raised bed furrow irrigation in vegetables Ridge & furrow irrigation in vegetables Border strip irrigation in wheat and mustard	30-40 15-20 10-20 10-20

Conclusion

It may be concluded that crop water productivity was much higher in winter rice – vegetables based sequences and inclusion of summer rice increased precious irrigation water expenditure and water cost many folds in the tube well commands. Grow summer rice in low lands only following rotational submergence. Use polythene delivary pipe for water conveyance. Promote water users' body for field irrigation.

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