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Water conservation and management technologies for its efficient utilization

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ABSTRACT

Water is one of the important finite natural resources and due to increased industrialization, urbanization and domestic use; its diversion to agricultural sector is reducing. With reduced water availability, it is also expected that agricultural production should increase to meet the food requirement in future. In order to achieve this, one of the possible options is to utilize the available water more efficiently, judiciously and equitably so that wastage or inefficiency is minimized. The present paper discusses various technologies/practices related to rainwater management, ground water management, canal water management, on-farm water management, in-situ and ex-situ water conservation, water harvesting, lining effect to minimize conveyance losses, efficient irrigation application systems, multiple uses of water, conjunctive use of rain, surface and ground water, and measures to reduce losses. In addition to this, it also throws light on some well adopted agronomic practices like zero tillage, Furrow Irrigation Raised Bed (FIRB), Bed Planting method, and irrigation scheduling techniques and their role in water saving as compared to conventional methods. This paper also highlights the importance of water productivity as an indicator and pathways to improve water productivity. Lastly, paper suggests some future challenges to be addressed in order to achieve efficient conservation, management and utilization of water.

Keywords: Rainwater management, Canal water management, Ground water management, On-farm water management, multiple uses of water, conjunctive use of water

INTRODUCTION

Water is one of the most critical inputs for life on this earth. But due to indiscriminate and unscrupulous exploitation by users, its availability and accessibility in terms of quantity is reducing. If this trend continues, affordability of water will be a great challenge in future. An overview of water availability and utilization as well as water requirements in various sectors in the year 2050 as discussed by (Upadhyaya and Singh, 2019) are presented in Table 1.

When annual per capita water availability becomes less than 1700 m^3, it is categorized under water stressed condition and by the year 2025, India will become water stressed country. If it declines further to around 1,000-1,100 m^3, it will become more serious water scarce condition. (The Hindu, 2019).

The present status of efficiencies of various irrigation systems shows that conveyance efficiency of surface water through unlined canal and through lined canal vary from 55 to 60% and 70 to 75%, respectively. Conveyance efficiency of the canal depends on many factors such as length of the canal, type of soil, material used for lining etc. The efficiencies of flood, furrow, sprinkler and drip irrigation systems reported in literature are 65%, 80%, 85%, and 90%, respectively. Presently, the surface water efficiency is 35% and can be improved up to 65%; ground water efficiency is 55% and can

Table 1. Water availability, utilizable water and requirement in India

Sl. No.	Water resources	Amount
1.	Annual rainfall (including snowfall)	4,000 km^3
2.	Rainfall during Monsoon season	3,000 km^3
3.	Evaporation and soil water	2,131 km^3
4.	Annual average runoff in rivers	1,869 km^3
5.	Utilizable water resources	1,123 km^3
6.	Water requirement estimates projection in the year 2025	1,093 km^3
7.	Water requirement estimates projection in the year 2050	1,450 km^3
8.	Annual per capita water availability in India in the year 1951	5,177 m^3
9.	Annual per capita water availability estimated in the year 2025	1,465 m^3
10.	Annual per capita water availability estimated in the year 2050	1,235 m^3

be improved up to 75%; urban water efficiency is 60% and can be improved up to 90%; rural water efficiency is 70% and can be improved up to 90%; and industries including power is presently 80% and can be improved up to 95%. This indicates that scope of improvement in efficiency exists and efforts should be made in developing adopting technologies/practices/strategies enhancing efficiency.

As of now irrigation sector consumes about 80% of the total water use, which may reduce to about 70% by 2050 due to competing demands from other sectors. Most of the irrigation projects are very old and have become less efficient. Given the quantum of use in this sector, it is needless to emphasize that it has tremendous potential for water saving on efficient irrigation water use.

Factors to be considered for better water management

In order to develop a better water management plan, the factors essentially required to be considered are: source of water availability, water supply, irrigation methods and scheduling, social and economic conditions of water users, drainage facilities, water loss hotspots, shape, size and slope of field, Indigenous Technical Knowledge (ITK) and superstitions/ blind belief of farmers, cost effectiveness and sustainability of various technologies, relation between water users and water managers, type of soil, crops to be grown and their crop water requirements, training and exposure of farmers to recent water management practices and level of farmers' participation in on-farm water management activities etc.

Water Conservation Technologies in Agriculture

Water conservation in agriculture can be achieved by adopting efficient management of rainwater, ground water, and canal water as well as adopting on-farm water management practices.

Rainwater Management

Rainwater is very precious input for crop and it can be stored in the field as much as possible. By creating bund around rice field and storing rainwater in it, runoff as well as soil and nutrient loss reduces, crop water demand to be met out from other sources of irrigation reduces and ground water recharge increases. The amount of storage depends upon the quantum of rainfall and its distribution, height of bund around the rice field, and the soil and varietal characteristics. At Patna 20 to 25 cm bund height around rice fields has been reported to arrest maximum rainwater in fields and minimize runoff (Upadhyaya, 2015).

Water Harvesting

Water harvesting is one of the best methods of rainwater storage either above the soil surface (ex-situ) or below the soil surface (in-situ). Deep ploughing, profile modification and vertical mulching help in keeping rough soil surface and increase infiltration rate of soil. The criteria for in-situ rainwater harvesting technique to be adopted, depend on the rainfall intensity, slope and texture of the soil. For lands with slope upto 1-2 per cent, field bunding, land leveling, contour ditching, and cultivation along contour can be good water conservation measures, whereas for the lands having 2 to 6 per cent slope graded contour bunds and for the lands having slopes ranging from 6 to 33 per cent bench terraces can be appropriate (Upadhyaya, 2015). There is a need to explore and promote rain water harvesting, ground water recharging techniques and watershed management in rainfed areas (Upadhyaya and Singh, 2019)

Ex-situ storage is suitable in arid and semi-arid areas, where low and erratic rainfall normally occurs with high intensity of short duration resulting in high runoff and poor soil moisture storage. If this surface runoff is harvested/stored over a large area, it can yield considerable amount of water for providing life saving irrigation to the crop during the dry spells in the monsoon season and also for growing a second crop in rabi season. The ex-situ rain water harvesting technologies include roof top collection, dug out ponds/ storage tanks, nala bunding, gully control structures/check dams/ bandharas (weirs), water harvesting dams, percolation tanks/ponds, subsurface dams/ barriers etc.(Upadhyaya, 2015)

Ground Water Management

Unlike canal water or rainwater, ground water is an assured source of water supply but it consumes energy for withdrawal and it is very costly as compared to rainwater or canal water. Though good quality shallow ground water aquifers are available, but farmers give least preference and avoid using it due to its high cost. Small and fragmented land holdings and absence of land consolidation at many places also discourage farmers to use ground water. Some of the important technologies developed for attaining better ground water management are development of rigid PVC tube wells, improved propeller pumps, improved foot valve, chain pumps for water lifting in tribal areas, efficient reflux valve, safety device against overheating of diesel engines, low cost well screens for shallow tube wells, Krishak Bandhu pumps, Solar pumps, Treadle pumps etc. Many types of pumps like centrifugal pump, turbine pump, submersible pump, propeller pump and mixed flow pumps are available in the market for irrigation. Centrifugal pump is the most commonly used pump. It works efficiently when total head is more than 4 m. Turbine and submersible pumps are used when water is lifted from more depths. Propeller pumps are suitable when water is lifted from the depth less than 4 m. Proper selection and timely maintenance of pump, motor or engine, suction and delivery pipes and other accessories/ attachments (foot valve, bends etc.) not only improves the efficiency of the system but life of the system also increases (Upadhyaya, 2015). Ground water may seem costly affair, but it can be economical if used conjunctively with canal water and rainwater for irrigation of rice. It is discussed in detail in conjunctive use section.

Canal Water Management

Earlier, canal water was treated as protective measure against drought and purpose was to provide life saving irrigation to crops, but later on there was a paradigm shift in thinking and water suppliers started treating it as productive measure. A major shift has taken place in cropping pattern, groundwater development, cropping intensity, irrigation intensity etc. In canal commands, there are many problems like (i) large gap in supply and demand and no attention on adequacy, equity and timeliness issues, (ii) poor maintenance of canal and its' distribution network resulting in lot of wastage of water, (iii) poor communication and linkage among water suppliers/managers and water users, which leads to low reliability, (iv) poor collection of revenue etc.

In order to efficiently utilize canal water, some practices like (i) formation of Outlet Management Group (OMG) at outlet level, Water users Associations (WUAs) at distributary level and Federation of Water Users at Canal level, (ii) frequent meetings and dialogues among water suppliers and users and strengthening of communication facilities in order to address issues related to adequacy, equity and timeliness, increasing reliability, maintaining regularity and flexibility in flow rate, frequency and duration, (iii) training through communication product, and awareness campaigns (iii) staggering of paddy transplantation period, (iv) crop diversification, (v) revision in crop planning from head to tail reach, seem quite promising. Participatory Irrigation Management (PIM) has been identified as one of the potential interventions to efficiently utilize canal water.

Radha Krishan *et al.*(2014) reported that there are technical, managerial, hydraulic, socio-economic, institutional, financial and administrative problems related to water release, distribution, allocation and utilization in Vaishali Branch Canal under Gandak canal system and need attention of water users and canal managers. Canal water release is inadequate, irregular, untimely and unreliable. In order to decrease the gap between irrigation requirement and water supply by developing an optimal as well as equitably water allocation plan OPTALL model based on quadratic programming technique was employed. The optimal water allocation schedule was found much better than actual release and in no case supply demand ratio was more than 1.0, whereas in case of actual release it is excessively higher than 1.0 in many distributaries showing inequitable water distribution. This study could be useful to water suppliers to allocate water adequately and equitably among more number of water users in canal command. Similar types of findings were reported by Upadhyaya (2016a) when OPTALL model was employed on Patna Main Canal under Sone Canal System.

One of the possible ways to reduce gap between supply and demand may be storage of excess water by the side of canal, which goes as waste during rainy/lean period and can be used for rearing fish as well as to provide irrigation during peak demand period as reported by Upadhyaya (2016a,b).

On-Farm Water Management

The efficiency of irrigation water can be increased by its judicious use on the farm. The on-farm water management includes (i) improving the conveyance efficiency of irrigation channels, (ii) improving application efficiency, (iii) scheduling of irrigation, (iv) change in crop establishment and other management practices, (v) soil health management, (vi) soil moisture conservation, (vii) various resource conservation techniques, (viii) multiple use of irrigation water, (ix) conjunctive use of water etc. All these practices help in increasing the water use efficiency and agricultural production.

Reducing conveyance losses

Water is lost during conveyance through seepage from main canals, branches, distributaries, minors, watercourses and field channels. Conveyance loss accounts for 40 to 50 per cent of the water delivered into a canal. Almost half of these losses occur in field channels. While the seepage is a net loss of water in areas with poor quality groundwater, it can be retrieved for irrigation in areas having good quality ground water. The farmers at their convenience may withdraw this water as and when needed. In order to reduce these losses lining of canal network should be done selectively based on these factors together with economic considerations. However, watercourses, which contribute very little to groundwater, should be lined for efficient conveyance and distribution of water.

Reducing application losses

Most of the area in the country is irrigated by surface application methods such as check basin, border strip and furrow irrigation. The application efficiency of these methods have been found to be only 30 to 50 per cent as compared to attainable level of 60 to 80 per cent. This is due to the fact that these methods are not designed to match the stream size, soil type, slope etc. by adopting efficient irrigation practices, deep percolation losses can be reduced. Considerable savings in water can also be achieved by adoption of sprinkler, drip/micro-sprinkler irrigation in water scarcity areas, having conditions conductive to their application. Actual field studies indicated water saving of 25 to 33 per cent and increased yield upto 35 per cent with sprinkler system compared with surface irrigation method.

Drip irrigation saved 25 to 60 per cent water and increased yield of crops upto 60 per cent compared with surface irrigation methods. Singh *et al.* (2015) reported that one of the water application device developed at ICAR Research Complex for Eastern Region, Patna is Low Energy Water Application (LEWA) device, which operates at 0.4-0.6 kg cm^{-2} pressure and can be used for irrigating rice, wheat and other close growing crops. The cost of LEWA system is less and it saves water, time and energy. So this is very efficient, effective and beneficial irrigation system for small and marginal farmers having fragmented land holdings. Low Energy Water Application (LEWA) device gives throw diameter of 6-8 m, application rate 2.6-3.1 cm h^{-1}. The surface uniformity is observed greater than 70% when operated at an operating pressure of 0.5 kg cm^{-2} or above and sub-surface uniformity is greater than 90%. It has a great role in improving yield and water productivity. It was found that there is 45% and 10% water saving as well as 50% and 55% energy saving over surface and sprinkler irrigation system, respectively. Yield values vary as 3.775, 3.581 and 3.525 t/ha and water productivity values as 1.91, 1.62 and 0.95 kg m^{-3} in LEWA, sprinkler and surface irrigation system, respectively.

Irrigation scheduling

Irrigation scheduling is also one of the important techniques, which may contribute in efficient utilization of irrigation water. Basically, irrigation scheduling can be done by three methods i.e. (i) critical crop growth stage, (ii) soil moisture availability between field capacity and wilting point, and (iii) evapotranspiration estimated from temperature, relative humidity, wind velocity, sunshine hours, solar radiation etc. Depending on availability of water, farmers generally prefer first method for deciding irrigation. Where irrigation water supplies are plentiful, irrigation must be repeated before a yield or quality reducing water stress develops in the fields.

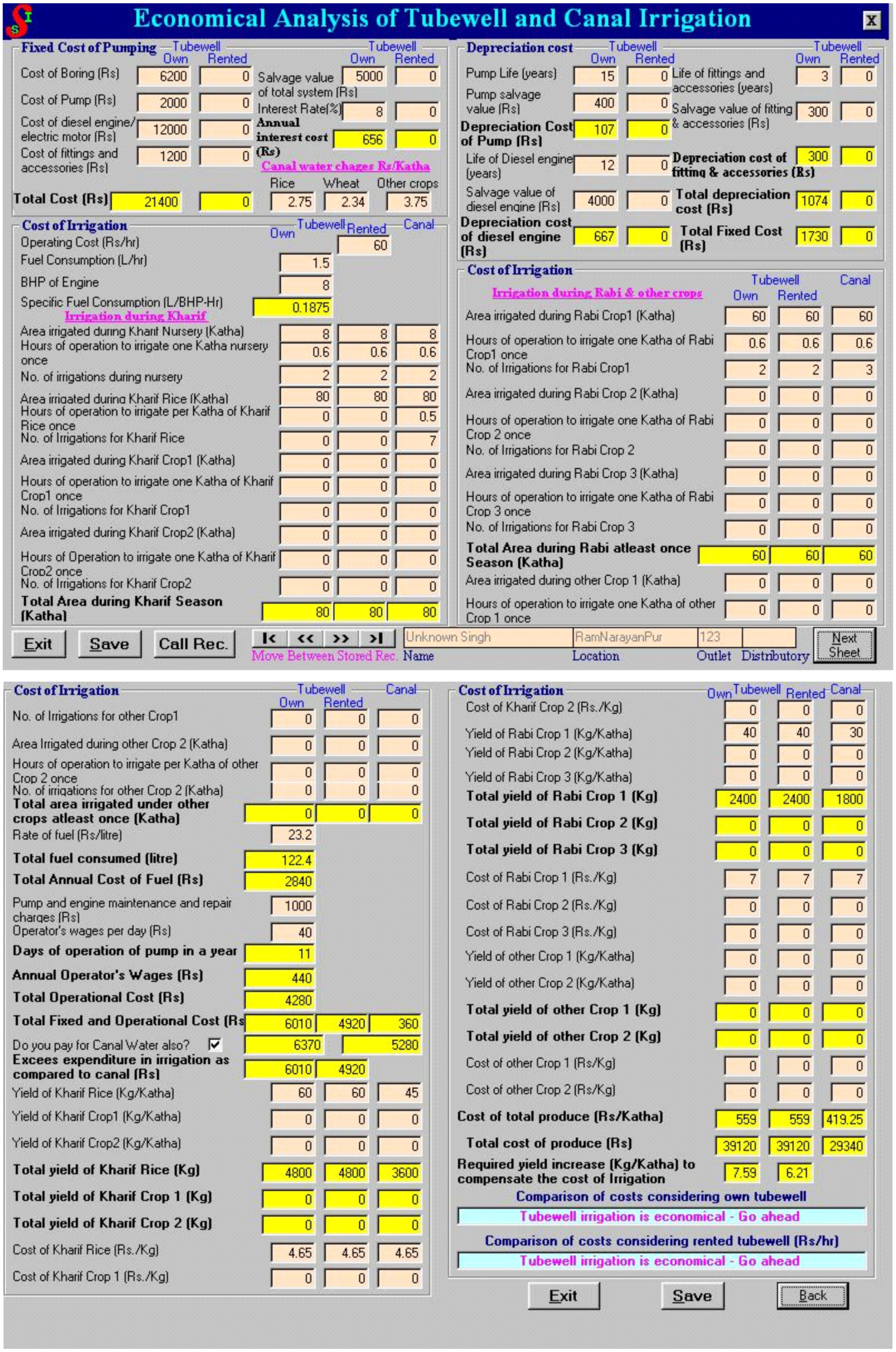
Multiple Use of Irrigation Water

Upadhyaya (2015) discussed that the productivity of canal/ground water can be increased by routing it through a fish pond-cum-secondary reservoir and planting vegetable or fruit plants on the bunds. By weekly exchange of water, fish harvest upto 10 t/ha as additional income can be obtained. If an integrated farming system is followed in which output of one system (like excreta of animals and birds) is input to other system (fish in the pond), the nutritional value of water for fish, crops, fruits and vegetables increases resulting in increase in production and income many folds. Experience on multiple uses of water, which was adopted by the Self Help Groups (SHGs) and farmers of the project area under four situations i.e. (i) Pan culture for fish cultivation in waterlogged areas, (ii) Rice-fish cultivation in seasonally waterlogged areas, (iii) Rice-fish cultivation in irrigated areas, and (iv) fish cultivation in local depressions/ pits showed that this technology not only helped the SHGs and farmers in improving their income and livelihood but their understanding about the beneficial uses also developed.

Conjunctive Use of Water

Conjunctive use of rain, surface and ground water has potential to efficiently utilize water for crop production. In canal command area, where water is very cheap, farmers don't prefer to use ground water because it is very costly as compared to surface water. In Sone Canal Command system, Bihar, the canal water charges are Rs 88/- per acre for Rice, Rs 75/- per acre for wheat, and Rs 150/- per acre for sugarcane crop, irrespective of volume of water or number of irrigations, whereas tube well water charges vary from Rs 120/- to Rs 150/- per hour or in other words Rs 1200/- to Rs 1500/- for one irrigation of an acre area (if 10 hours are considered to irrigate an acre area). Assuming that $1/10^{th}$ area is used to grow nursery of rice and during nursery period maximum 3 irrigations are provided, so expected expenditure on irrigation through tube well comes out to Rs 360/- to Rs 450/-. A good learning experience from farmers suggests that timeliness is very important in agriculture. If rice nursery is established during *Rohni Nakshatra* (i.e. 25^{th} May to 6^{th} June) than it can be transplanted in the field and the crop can efficiently utilize rain water in succeeding months. Due to timeliness, not only rain water utilization efficiency, rice production and recharge increases, but also runoff, soil erosion and irrigation requirement from canal reduces. At the same time rice is harvested timely and next crop gets opportunity to be sown in the vacant field. Experiments conducted in farmers field showed that the farmers who established rice nursery during *Rohini Nakshatra* (i.e. 25^{th} May to 6^{th} June) produced about 0.4 t/acre more yield as compared to those farmers who established rice nursery during or after *Adra Nakshatra* (i.e. 22^{nd} June to 5^{th} July). In monetary terms, farmers who established nursery timely got a benefit of Rs 6000/- (assuming price of rice @ Rs 15 per kg). In order to demonstrate and convince farmers about conjunctive use and its economical benefits, a decision support tool was developed in English using Visual Basic platform. This interactive tool calculates (i) annual fixed and operational costs of irrigation from tube well and canal, (ii) yield and total cost of produce, (iii) excess expenditure incurred in tube well irrigation over and above the canal water charges, and (iv) required yield increase needed to compensate for the additional cost of irrigation from tube well. A pictorial view of decision support tool as presented by Upadhyaya (2017) is reproduced for ready reference.

This Decision Support Tool (DST) was found quite convincing and effective to farmers in exploring and promoting conjunctive use options. This DST is based on economic criteria i.e. increase in yield due to additional investment in irrigating crops with tube well water. It informs the decision after comparing the additional income from increase in yield of crops and additional investment in irrigation through tube well. If income from increased yield is more than additional investment on irrigation through tube well, the DST displays the decision as 'Tube well irrigation is economical - Go ahead'. Similarly, if income from increased yield is less than additional investment on irrigation through tube well, the DST displays the decision as 'Tube well irrigation is not economical – Think again'. The results reveal that conjunctive use of tube well and canal water has tremendous scope in canal command and it can be


Economical Analysis of Tubewell and Canal Irrigation
Fixed Cost of Pumping
Tubewell Own Rented
Cost of Boring (Rs) 6200 0
Cost of Pump (Rs) 2000 0
Cost of diesel engine/ electric motor (Rs) 12000 0
Cost of fittings and accessories (Rs) 1200 0
Total Cost (Rs) 21400 0
Salvage value of total system (Rs) 5000 0
Interest Rate(%) 8 0
Annual interest cost (Rs) 656 0
Canal water chages Rs/Katha
Rice 2.75 Wheat 2.34 Other crops 3.75
Depreciation cost
Pump Life (years) 15 0
Pump salvage value (Rs) 400 0
Depreciation Cost of Pump (Rs) 107 0
Life of Diesel engine (years) 12 0
Salvage value of diesel engine (Rs) 4000 0
Depreciation cost of diesel engine (Rs) 667 0
Life of fittings and accessories (years) 3 0
Salvage value of fitting & accessories (Rs) 300 0
Depreciation cost of fitting & accessories (Rs) 300 0
Total depreciation cost (Rs) 1074 0
Total Fixed Cost (Rs) 1730 0
Cost of Irrigation
Tubewell Own Rented Canal
Operating Cost (Rs/hr) 60
Fuel Consumption (L/hr) 1.5
BHP of Engine 8
Specific Fuel Consumption (L/BHP-Hr) 0.1875
Irrigation during Kharif
Area irrigated during Kharif Nursery (Katha) 8 8 8
Hours of operation to irrigate one Katha nursery once 0.6 0.6 0.6
No. of irrigations during nursery 2 2 2
Area irrigated during Kharif Rice (Katha) 80 80 80
Hours of operation to irrigate per Katha of Kharif Rice once 0 0 0.5
No. of Irrigations for Kharif Rice 0 0 7
Area irrigated during Kharif Crop1 (Katha) 0 0 0
Hours of operation to irrigate one Katha of Kharif Crop1 once 0 0 0
No. of Irrigations for Kharif Crop1 0 0 0
Area irrigated during Kharif Crop2 (Katha) 0 0 0
Hours of Operation to irrigate one Katha of Kharif Crop2 once 0 0 0
No. of Irrigations for Kharif Crop2 0 0 0
Total Area during Kharif Season (Katha) 80 80 80
Cost of Irrigation
Tubewell Own Rented Canal
Irrigation during Rabi & other crops
Area irrigated during Rabi Crop1 (Katha) 60 60 60
Hours of operation to irrigate one Katha of Rabi Crop1 once 0.6 0.6 0.6
No. of Irrigations for Rabi Crop1 2 2 3
Area irrigated during Rabi Crop 2 (Katha) 0 0 0
Hours of operation to irrigate one Katha of Rabi Crop 2 once 0 0 0
No. of Irrigations for Rabi Crop 2 0 0 0
Area irrigated during Rabi Crop 3 (Katha) 0 0 0
Hours of operation to irrigate one Katha of Rabi Crop 3 once 0 0 0
No. of Irrigations for Rabi Crop 3 0 0 0
Total Area during Rabi atleast once Season (Katha) 60 60 60
Area irrigated during other Crop 1 (Katha) 0 0 0
Hours of operation to irrigate one Katha of other Crop 1 once 0 0 0
Exit Save Call Rec.
Move Between Stored Rec.
Unknown Singh RamNarayanPur 123
Name Location Outlet Distributory
Next Sheet
Cost of Irrigation
Tubewell Own Rented Canal
No. of Irrigations for other Crop1 0 0 0
Area Irrigated during other Crop 2 (Katha) 0 0 0
Hours of operation to irrigate per Katha of other Crop 2 once 0 0 0
No. of irrigations for other Crop 2 (Katha) 0 0 0
Total area irrigated under other crops atleast once (Katha) 0 0 0
Rate of fuel (Rs/litre) 23.2
Total fuel consumed (litre) 122.4
Total Annual Cost of Fuel (Rs) 2840
Pump and engine maintenance and repair charges (Rs) 1000
Operator's wages per day (Rs) 40
Days of operation of pump in a year 11
Annual Operator's Wages (Rs) 440
Total Operational Cost (Rs) 4280
Total Fixed and Operational Cost (Rs 6010 4920 360
Do you pay for Canal Water also? 6370 5280
Excees expenditure in irrigation as compared to canal (Rs) 6010 4920
Yield of Kharif Rice (Kg/Katha) 60 60 45
Yield of Kharif Crop1 (Kg/Katha) 0 0 0
Yield of Kharif Crop2 (Kg/Katha) 0 0 0
Total yield of Kharif Rice (Kg) 4800 4800 3600
Total yield of Kharif Crop 1 (Kg) 0 0 0
Total yield of Kharif Crop 2 (Kg) 0 0 0
Cost of Kharif Rice (Rs./Kg) 4.65 4.65 4.65
Cost of Kharif Crop 1 (Rs./Kg) 0 0 0
Cost of Irrigation
Own Tubewell Rented Canal
Cost of Kharif Crop 2 (Rs./Kg) 0 0 0
Yield of Rabi Crop 1 (Kg/Katha) 40 40 30
Yield of Rabi Crop 2 (Kg/Katha) 0 0 0
Yield of Rabi Crop 3 (Kg/Katha) 0 0 0
Total yield of Rabi Crop 1 (Kg) 2400 2400 1800
Total yield of Rabi Crop 2 (Kg) 0 0 0
Total yield of Rabi Crop 3 (Kg) 0 0 0
Cost of Rabi Crop 1 (Rs./Kg) 7 7 7
Cost of Rabi Crop 2 (Rs./Kg) 0 0 0
Cost of Rabi Crop 3 (Rs./Kg) 0 0 0
Yield of other Crop 1 (Kg/Katha) 0 0 0
Yield of other Crop 2 (Kg/Katha) 0 0 0
Total yield of other Crop 1 (Kg) 0 0 0
Total yield of other Crop 2 (Kg) 0 0 0
Cost of other Crop 1 (Rs/Kg) 0 0 0
Cost of other Crop 2 (Rs/Kg) 0 0 0
Cost of total produce (Rs/Katha) 559 559 419.25
Total cost of produce (Rs) 39120 39120 29340
Required yield increase (Kg/Katha) to compensate the cost of Irrigation 7.59 6.21
Comparison of costs considering own tubewell
Tubewell irrigation is economical - Go ahead
Comparison of costs considering rented tubewell (Rs/hr)
Tubewell irrigation is economical - Go ahead
Exit Save Back

propagated in the area provided water users are convinced about yield improvement resulting in economic benefits, which compensate the additional cost of irrigation. Analysis showed that compared to owning tube well, water purchasing is the most economical option followed by getting only pumping sets on rent basis to run tube wells for irrigation.

Measures to reduce water loss

Some of the measures for efficient and optimal use of scarce water resources are: (i) reduction in water losses in conveyance and distribution system through periodic maintenance, (ii) applying the right quantity at right time, (iii) effective involvement of farmers in water management, (iv) right cultivation and irrigation practices including increased use of water saving devices like sprinkler and drip, precision leveling, (v) provision of effective drainage channels, (vi) conjunctive use of surface and ground waters, (vii) reuse of seepage waters, (viii) recycling of domestic & industrial waste water, (ix) demand management through mass awareness and proper water pricing. Further, reforming irrigation institutions is central to increasing the productivity and the efficiency of irrigation systems in a transparent and accountable manner with increased participation by the users. Water use efficiency/ Performance evaluation studies along with water audit and benchmarking have an important potential to contribute to improve the services and the efficiency of the operations. Within the general efforts of reforms, these can provide essential input.

Water Productivity - an indicator showing impact of present water use and improved water use

Upadhyaya and Sikka (2016) discussed the concept of land, water and energy productivity in agriculture and usefulness of this concept in assessing the present status of resource utilization as well as possible pathways to enhance productivity after applying certain technical interventions/improved agricultural practices/strategies. This indicator was found quite capable of studying loop holes or the hotspots of inefficient use of water and suggesting the suitable pathways to improve it. Upadhyaya (2018) studied Rice and Wheat water productivity at various locations in the country and reported that Rice water productivity varies between 0.394 to 0.446 kg m^{-3} under various crop establishment and water application treatments at Almora. Two irrigations at Pre-sowing and tillering stages gave maximum water productivity. It indicates that Pre-sowing and tillering stages are very sensitive stages and under the situation of limited water availability irrigation should be provided at these stages of crop growth. When four irrigations at Pre-sowing, tillering, panicle initiation and grain formation stages were applied, it gave the minimum water productivity because amount of water applied was more but yield was less. Water productivity was found marginally lower in zero tillage treatment compared to conventional tillage method. It indicates that under limited water availability, zero tillage method should be preferred over conventional tillage method. Rice water productivity values at Kurukshetra, Haryana was found more under Bed Planting method of crop establishment as compared to conventional tillage. Though yield was more in conventional tillage but water used was much less in bed planting method leading to higher water productivity under the treatment of bed planting. Compared to continuous submergence, saving in irrigation water when desaturation/drainage period was 3 days, varied in the range of 23 to 55% at various locations in India. As compared to continuous submergence, rice water productivity was found higher under the cases when irrigation was applied after different days of drainage period and rice water productivity value increased when drainage period increased from 1 to 5 days. So it may be concluded that continuous submergence in Rice doesn't enhance water productivity and water is not efficiently utilized by the crop leading to more water losses and this practice should be discouraged.

Water productivity and wheat yield analysis under various resource conservation techniques such as Furrow irrigation raised bed (FIRB) planting, zero tillage and conventional tillage at Patna indicated that though wheat yield was more in zero tillage method followed by FIRB planting method as compared to conventional tillage method but water productivity was higher in FIRB followed by zero tillage method as compared to conventional tillage method. Results also indicated that irrigation at most critical crop growth stages gave better water productivity compared to irrigation at all the stages or less sensitive stages. Resource conservation techniques indicated that bed planting method of wheat crop establishment yielded marginally better water productivity values compared to zero tillage and conventional tillage method.

Some important and useful water management and water saving well tested technologies, which may be adopted at wider scale are-

(i) Zero-till direct seeded rice for water saving upto 50% without yield reduction as compared to conventional puddle transplanted method

(ii) Zero tillage for wheat establishment saves 25 to 30% of water in first irrigation as compared to conventional method of wheat sowing. It also saves time, energy and money.

(iii) Raised bed furrow method of wheat establishment in water scarcity area as it saves 40-45% of water compared to conventional method of wheat establishment with only 10% reduction in yield.

(iv) Polythene-lined small rainwater harvesting structure (Doba) for establishment of agro - forestry in uplands.

(v) Integrated Farming System models including agriculture, horticulture, vegetables, medicinal and aromatic plantation, agro-forestry, livestock, fisheries, duck, pig and, got rearing for different category of land holders with a view to improve agricultural water productivity, income, employment and livelihood of poorest of the poor.

(vi) Application of limited irrigation water at the critical crop growth stages (Upadhyaya, 2016b), when water is essentially required, lot of water can be saved without adversely affecting the crop yield and thus enhancing water productivity.

(vii) Upadhyaya (2016c) suggested integrated water resources management and climate change adaptation strategies to identify low lying areas of small size having dykes around, so that excess runoff as a result of high intensity rainfall of less duration can be captured and stored for future use. When runoff is essential, safe disposal of excess runoff through well connected drainage network into the river needs to be assured. Since climate change is being realized more frequently occurring phenomenon, strategies to minimize the adverse impact of frequent floods, droughts and other calamities should be chalked out and implemented.

FUTURE CHALLENGES

Since water is a diminishing resource, the need of the hour is to conserve and utilize it effectively and efficiently. Only then it will be possible to produce more food from the available land and water resources. To achieve this goal our research efforts should focus on the following issues.

- Development of cost effective and energy efficient pressurized irrigation systems to be operated by solar energy, wherever possible and their promotion.
- Development of Decision Support Tool for optimal release, allocation, distribution and utilization of water to improve water use efficiency and decision making process.
- Minimizing gap between water supply and water demand by establishing linkage between water suppliers and water users.
- Water budgeting and water auditing in order to know the loopholes or hotspots having high water loss and promote efficient use of water.
- Review of Irrigation water price and its revision so that farmers may realize its value and utilize it efficiently.
- Minimize the gap between water availability, water accessibility and water affordability.
- Development of implementable flood and drought management strategies for minimizing the adverse impact on crop.
- Revival of old indigenous water storage or use technologies and their integration with latest technologies.
- Decision making about water harvesting structures or soil and water conservation measures in a watershed employing modern techniques like GIS, remote sensing, Artificial Neural Network (ANN), Fuzzy Logic or Internet of Things (IOT).
- Development of cost effective water use efficient and management technologies/practices suitable for small landholders.
- Crop water productivity enhancement, which can be achieved either by improving yields without increasing water consumption or sustaining yield and reducing water consumption.
- Exploring opportunities for reuse and recycling of water to the extent possible because this promotes multiple uses of water and improves water productivity. This is also effective in combating floods and droughts.

- Capacity building and training of water users and water suppliers to create awareness about use of this precious resource.
- Development and transfer of socially acceptable and economically viable self sustaining water conservation and management technologies in farmers field for effective implementation and up scaling in participatory mode.

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