Field Scale Options for Improving Water Use Efficiency

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ABSTRACT

India is amongst the foremost countries in the world practicing large scale irrigation. In spite of the above facts large part of agricultural land remain dependent on vagaries of rainfall. Most of irrigation projects in India are running with poor water use efficiency in the range 30 to 40 percent. It is estimated that only about three –fourth of cultivable land even after exploitation of ultimate irrigation potential. Hence to cope up with the ever increasing demand and competition from other users it is imperative to harness all the available waters resources including rainwater for augmenting water supplies and supplemental use.. This paper gives a state of the art review of the options for improving water use efficiency in crop production focusing on both irrigated and rain-fed agriculture at farm level. The limits and opportunities for the following options to improve water use efficiency in agriculture are suggested are (i) Augmentation of canal water supplies through conjunctive use of surplus rainwater from small scale reservoirs, enhancing water availability, both, in time and space through rainwater harvesting and its supplemental use for converting rainfed areas to partially irrigated areas for boosting yield, irrigation intensity and ultimately the productivity. RWH through small scale structures/ ponds have potential to contribute about 20 million ha m. additional water. (ii) Introduction of buried pipe below the public outlet replacing water courses and field channels in tertiary /*chak* command having undulating topography with slope >1% (iii) Introduction of improved land and crop management practices such as ridges and furrows, broad-bed and furrows for facilitating improved aerobic conditions, water conservation and recycling, selection of less water sensitive crops and irrigation scheduling in commands. Partial replacement of traditional practice with improved "System of Rice Cultivation (SRI)" for water saving and enhanced water productivity. (iv) Use of pressurised irrigation techniques in undulating topography, marginal lands and areas where conjunctive use of ground water, ponds and canal water to be promoted. (v) Converting intensive irrigation to deficit irrigation supplies up to the limits the marginal return in terms of yield or economics remain positive. Use of both generalised seasonal and growth stage water production functions to predict yield under water stressed environment under changing climate is advocated. Efficient water use and management is indeed an inter- disciplinary subject and requires inputs from engineers, agricultural scientists, economist and water users. Some of options discussed in this article may be location specific, never the less, those can be used with appropriate modification as useful tool in enhancing WUE and productivity in agriculture.

WATER USE EFFICIENCY

Water use efficiency (WUE) in agriculture has been defined in various terms by various people.

In economic term, WUE has been defined as the value of agricultural produce in monitory term per unit of water consumed for the production of said produce, that is,. Rs/ m^3 of water.

In agronomic term WUE has been defined as the ratio of crop yield to per unit of water use (Kg/m^3) of water. This definition is still widely used (Viets 1962; Hatfield et al 2001; Kang et al 2002; Yuan et al 2003; Zhang et al 2004). The only difference in its use lays in the framing of the nominator, whether yield may be crop dry matter, the economic yield (including crop price) etc. For the denominator, evapotranspiration is often taken, since the calculation of transpiration is considered difficult. The "agronomic water use efficiency" is the most simple and straightforward measure to quantify water use efficiency in agriculture. It considers the yield a crop has produced per unit of available water. In a way it refers to what has been stated at the UN Millennium Summit in September 2000, "more crop per drop".

In engineers technical term, as per water use efficiency guidelines developed by CWC India, most widely accepted definition of WUE in irrigation sector is the ratio between the actual volume of water consumed by crop/ plant during evapo-transpiration and the volume extracted or derived from a supply source. Over all project irrigation efficiency or WUE is a product of water conveyance efficiency and water application efficiency. In India, values of Project WUE vary from 30 to 40 percent, accounting for total 60 to 70 percent losses in water conveyance and field application.

Some of the confusion in the definition of 'water use efficiency (WUE)' comes from the fact that the researcher use it interchangeably with 'water productivity(WP)' (Zwart and Bastiaaanssen 2004; Blumling et al 2007). According to Molden (1997) water productivity is the physical mass of production or the economic value of production measured against gross inflows, net inflows, depleted water, process depleted water or available water.

IMPROVING WATER USE EFFICIENCY

The review of literature revealed that WUE and WP could be increased through integrated use of resources at plant, field, system and basin levels, which apply regardless of whether the crop is grown under rainfed or irrigated conditions. Various field scale options for improving WUE are discussed in this paper with the hypothesis that any action for enhancing water availability at field level would scale up WUE and WP in the project scale or in the basin.

Augmentation of Water Supplies and Storage through Rainwater Harvesting

Rainwater harvesting, which is in vogue since time immemorial in India, can be used for enhancing water availability, both, in time and space through augmentation of canal supplies, supplemental use, converting rainfed areas into partially irrigated areas and ultimately for improving the productivity.

The term rainwater harvesting (RWH) is used in different ways and, thus, no universal classification has been adopted. Water harvesting in its broadest sense is defined as the "collection of runoff for its productive use". Runoff may be harvested from roofs and ground surfaces, as well as from intermittent or ephemeral watercourses. A wide variety of water harvesting techniques for many different applications is known.

Rainwater harvesting and management research has received emphasis across the country during the last four decades with the following objectives:

- Ensure maximum *in situ* rainwater conservation.
- Harvest rainwater for recycling as come-up supplemental irrigation and supporting establishment of tree crops.
- Integrate conservation and production technologies considering watershed as a unit of measurement

RWH potential

Region wise preliminary assessment for rainwater storage potential shows that a significant quantity of rainwater is available for harvesting, which through small interventions, could be effectively harvested and recycled for enhancing water productivity (Katyal,1997) . The estimates shown in

Table1 reveal that even with harvesting of 4 to 7 mm rainwater a gain of about 24 million ha m of water can be obtained. The regions associated with annual precipitation range from 750mm to 2500mm are contributing to 62% area of the country and about 263 million ha m of available rainwater and likely to contribute about 18 million ha m of harvestable runoff through small scale runoff management structures(RMS). Major problems of these areas are first flood and second drought under rainfed conditions. Till recently major emphasis on small scale RWH for irrigation or domestic use was concentrated on areas receiving < 750 mm rainfall. RWH potential in regions with annual rainfall >750 mm should also be given due attention.

Computation of rainwater harvesting potential (RWH) potential is complex and difficult as so many variables are involved.

Table 1. Estimated potential volume of rainwater storage for small-scale water harvesting structures

Rainfall zone (mm/yr)	**Geographical area**		**Rainwater availability, M ha m**	**Rainfall for effective surface storage (mm)**	**Harvestable runoff (million ha m)**	**Major problems**
	(million ha)	**% of total**				
>500	**52.07**	**15.9**	**15.6**	**5**	**0.78**	**Drought**
500-750	**40.26**	**12.3**	**25.2**	**6**	**1.51**	**Drought**
750-1000	**65.86**	**20.0**	**57.6**	**7**	**4.03**	**Drought/ flood**
1000-2500	**137.24**	**41.9**	**205.9**	**6**	**14.61**	**Flood/ drought**
>2500	**32.57**	**9.9**	**95.7**	**4**	**3.26**	**Flood/ drought**
Total	**328.00**	**100**	**400**	**-**	**24.19**	

The climatic water balance analysis was carried out using 10-day rainfall at different probability levels and published records of PET to arrive at 10-day values. Cumulative rainwater surplus potential thus estimated at 50 % probability level for some of the locations in India is given in Fig. 1

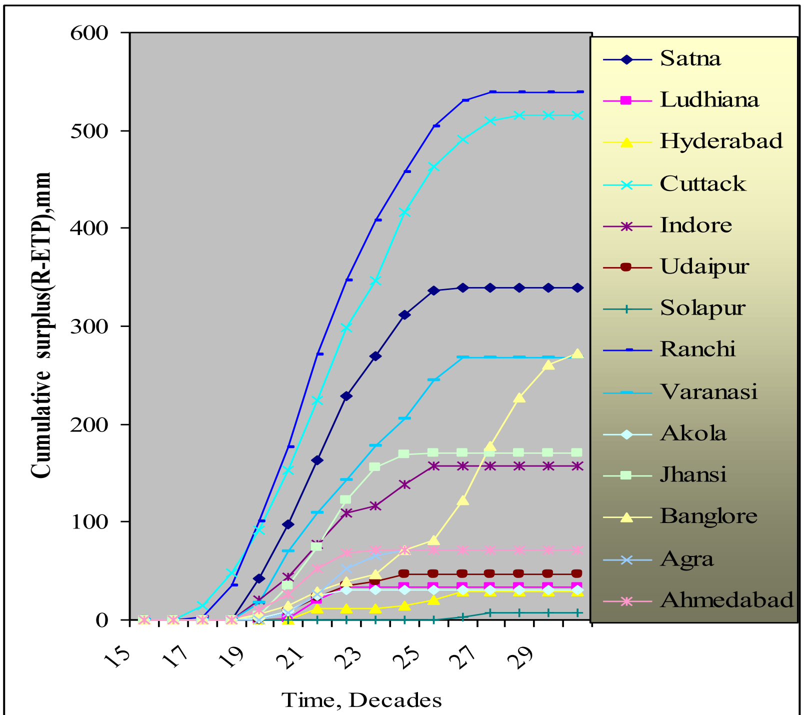

Fig.1 Cumulative rainwater harvesting potential at 50% probability, mm

The analysis show large variation in annual cumulative rainwater surplus in the country. The cumulative surplus rains ranged from mere <50 mm at Solapur, Banglore and Ahmedabad to > 500 mm at Cuttack. The surplus rainwater can either be stored in the soil profile upto the limit of its water holding capacity and part as surface runoff in RMS before it goes to the rivers or big reservoirs.

Scientific field investigations have also demonstrated high potential of RWH (10-40% of annual rainfall) in dryland tracts of the country (Sastry *et al.* 1985; Rajput, 2003). Studies showed that runoff percentage varied not only with Agro-climatic situations but also with changes in topographic, soil, vegetation and rainfall magnitude, intensity and temporal distribution at particular location (Table2) .

Table 2 : Water yield into farm pond recorded under different regions in India

Sl. No.	Research Centre/ Organization	Soil	Land slope (%)	Annual Rainfall (mm)	Expected water yield	
					mm	%
1	CSWCRTI,Dehradun	Silty loam	2 to4	1600	265	16.5
2	CSWCRTI,R.C. Chandigarh	Sandy loam	10 to15	1150	630	55.0
3	CSWCRTI,R.C. Kota	Clay loam to clay	-	787	135	15-20
4	CSWCRTI, R.C. Vasad	Alluvial sandy loam to loamy sand	-	850	142	16.7
5	AICRPDA, Anantpur	Shallow red	5	540	108	20.0
6	AICRPDA, Hyderabad	Red sandy soil	2 to 5	770	77	10.0
7	ICRISAT, Hyderabad	Medium deep black	5	750	75	10.0
8	AICRPDA, UAS Banglore	Red	2 to 3	830	166	20
9	Dry farming res. Station Solapur	Medium black	2 to 3	760	133	15 to 20
10	CSSRI Karnal	Alkali	0 to 2	650	260	40
11	AICRPDA, Ranchi	Sandy loam and sandy clay loam	2 to 2.5	1490	260	15 to 20
12	ORP, Chitradurga, Karnataka	Red loam	5 to 10	612	61	10
13	ORP Banga, Haryana	Silty clay loam-sandy loam	10	1116	558	50
14	ORP Rebari, Panchmahal Gujarat	Sandy loam	-	1000	100	10
15	AICRPDA, JNKVV Indore	(a) Medium black clay (b) Deep black clay	0.5 to1 1 to 2	1053 812	425 102	40 12.5

Pond Design

Sizes of farm ponds were designed using Krimgold equation (Krimgold and Horrold, 1944) of water balancing inputs, viz. the catchment rainfall, surface runoff, seepage and evaporation losses, depth of storage, and out flow from the pond as below:

$$\frac{RA}{a} + P - (E + \frac{U}{a} + S) = d + \frac{W}{a} \qquad .....(1)$$

Where, A = The size of watershed area draining into pond, ha; a = average area of the pond ha; R = Total runoff from the contributing catchment area during the period under consideration (July to September), m; P = Precipitation falling on the reservoir during the storage period, irrespective of whether or not it produces runoff from the drainage area, m; U = Amount of water used during the period under consideration, m; E = Evaporation from pond surface (estimated from pan evaporation data); S=Seepage from July to September, m; d = Depth of water in the pond, assumed 3 m, and W =Amount of water in excess of the capacity of the reservoir which is wasted over the spillway, ha-m. This factor was assumed to be nil

Size of farm pond was designed for different locations in central India. Estimated acreage can be irrigated (ha) once from the dugout ponds under different agro-climatic zones of M.P. at seepage rates of 20mm/day and 50mm/day, pond depth 3m and gross irrigation depth 70mm , are given in Table 3

Table 3. Estimated runoff potential and acreage can be irrigated (ha) once from dugout pond Under different agro-climatic zones of M.P.

Agroclimatic zone	Name of station	Probable rainfall at 50 % probability (July-Sept.)	Probable runoff, m^3 per ha catchment	Area Irrigated once (in ha) through pond with 1ha catchment	
				seepage@ 20mm/day	seepage @ 50 mm/day
Jhabua Hills In MP	Jhabua	606	600	0.53	0.32
	Dhar	748	980	0.91	0.53
Nimar valley	Khargone	570	820	0.74	0.44
	Khandwa	509	640	0.53	0.32
Malwa Plateau	Indore	611	1110	1.04	0.63
	Mandsaur	538	610	0.53	0.32
Gird region	Gwalior	588	700	0.63	0.40
Vindh yan	Bhopal;	888	1960	1.90	1.18
	Sagar	900	1960	1.90	1.18
Central Narmadavalley	Powarkheda	952	2120	2.09	1.25
Keymore plateau & satpura hills	Jabalpur	1029	2310	2.28	1.40
	Satna	792	1440	1.32	0.85
Satpura plateau	Chhindwara	652	1100	1.04	0.63
Chhattisgarh plain	Waraseoni	1086	3220	3.37	1.90

There are enough evidences to prove that conversion of rainfed areas into partially irrigated through recycling of harvested water resulted in to one additional legume crops with presowing or supplemental irrigation and / or 15 to 20 % increase in yield of kharif crops and 40 to 50 man - days of employment generation/ ha/year.

Rainwater harvesting (RWH) is in vogue since time immemorial in arid semi-arid and subhumid and humid climatic regions. Rainwater Cistern, *Khadin, Bhandaras, Anicut, Phad, Haveli, Tankas,* tanks and ponds in many part of India bear proof to this. Comprehensive reviews on Indigenous Technical knowledge(ITK) of rainwater conservation and management are available (Kerr and Sanghi,1992, and Mishra, 2003). In the past no systematic rules were followed for RWH and deciding the catchment-storage area ratio for RMS. In most situations, in addition to reviving traditional water harvesting systems, there is need to have new or modified systems (Sharma and Mishra,1995). It is apparent that the technologies and objectives of RWH are highly location specific and sound RWHM system developed for a particular region can not be applied as such to other areas for technical, physiographical, environmental and socio-economic reasons.

In canal command, depending on the situation the farm ponds or small storage reservoir can be located in vicinity of canal or public outlet, farmers field or in vicinity natural *nallah*, wherever feasible in participatory mode. Those ponds or reservoirs can be fed with surplus rainwater and / or with surplus water supply from canal. Such structures should be provided with water recycling facilities and may be linked with canal supplies or ground water.

Considering the fact that the RWH practices are most effective when implemented on watershed basis and in participatory mode, the Government at National and State level, has promoted number of schemes to promote conservation of this vital resource throughout the country. A number of social activists and voluntary organizations have shown growing interest in local watershed development, either in itself or as part of integrated development of a village or area. Sukhomajri, Tejpura, Nalgaon, Daltonganj, Ralegon Siddhi, Jawaja, Adgaon. Alwar, Chitrakoot, Khandwa, are well known examples and have been widely discussed and written about. Based on economic evaluation of various alternatives of soil and water conservation(SWC) programmes in India, concluded that water harvesting and recycling for productive purposes is the most attractive investment SWC option(Ram Babu et al.(1994). There is need of reorientation of the current approaches of RWH in the light of indigenous technical knowledge (ITK).

It is important to look for complementary opportunities for linkage between **green water** (part of water is consumed in eco-system by vegetation and evaporation from moist surfaces) and **blue water**(the surplus recharge aquifer and rivers) in an integrated manner to improve conservation and productivity of water in the country. Among the alternatives available, combination of the two forms of water are most likely to produce superior results. However suitable combinations of storage types depend on number of factors, including topography, hydrology, and the existence of suitable aquifers. Also, It has become imperative to wove the traditional knowledge into the modern techniques and; physical system into social system to get the maximum benefits and thereby ensuring water security.

On-Farm Water Conveyance

Most of the conveyance losses occur below the public outlet as the watercourse and field channels have more wetted area per unit discharge as compared to main and branch canals. Buried pipe irrigation system offers solution to control distribution losses below public outlet of an irrigation project. The buried pipe system consist of the pipes for carrying water to different points in command and allied structures required for functioning of the system. Provision of buried pipeline below the public outlet offers following merit over open channel distribution system:

- Buried pipe facilitate easy access to farm machinery, suited to undulated topography, fragmented holdings
- Buried pipe minimise water losses, earth work, construction period, maintenance cost, wastage of land, theft and conflict amongst the water users.
- It can easily facilitate 'warabandi' or volumetric supply and equitable distribution.

Buried pipes system is less expensive than open channel distribution system, particularly below public out let / *Colaba* , where discharge is less than 30 litres /sec. and land slope is more than 1 % as evident from experiences in Madhya Pradesh as per old cost estimates given in Table 4.

Table 4. Typical estimated cost for buried pipe system in comparison to open channel irrigation system in Madhya Pradesh (Thaper Hydroconsult, 1991)

Project location	Size of Chak , ha	General land slope, %	Type of disnet system	Cost of the system, Rs/ha*
Gadigaltar (Khargone), MP	33.0	0.36	Cement concret pipe	7900
			Open chanel	12500
Khor(Dhar), MP	20,4	2.0	UPVC pipe lateral system	4978
			Open channel lateral system	7951
Khor(Dhar), MP	20.7	1.0	UPVC pipe loop system	7095
			Open channel loop system	12471

Other utilities of buried pipe are for conjunctive use of ground water, canal water and harvested rainwater; interconnecting various water sources and introduction of drip and sprinkler systems in irrigation command.

Field Water Application

Most of the field crops in command areas are irrigated by wild or free flooding with application efficiency in the range 40 to 60 % . Field studies on mode of surface water application using borders are indicative of potential for improving water application efficiency by 20% simply by grading the field and changing continuous mode of application to surge mode(Pathak and Rajput,1994) as given in Table 5..

Table5 Water application efficiency as affected by mode of water application in borders in light to medium soils

Mode of application	Water application efficiency, %		
	0.3 % slope	0.6 % slope	0.9% slope
Continous mode	64.8	65.8	65.5
Cutoff mode	73.2	67.7	72.4
Surge mode	81.2	82,9	79.8

The pilot action research studies have shown 20 to 30 % water saving through border and furrow irrigation, if supported with land shaping operations. There seems every reason to place emphasis on improvement in surface irrigation in the coming decades with following advances:

- Adoption of improved hydraulic design of the field and precise(laser controlled) land grading
- Use of low pressure gated pipes or siphon tubes in place of head ditches , particularly on rolling topography
- Controlling field runoff at the down stream side of border /furrows by exercising cut-off, water application in alternate furrows/ borders, wide spaced furrows
- Reuse of drainage water for irrigation in lower fields.

Plenty of literature is available to support enhancement in crop productivity and water saving through use of pressurized irrigation techniques, such as sprinkler and micro/drip systems of irrigation(Sivanappan, 1990). Low energy precision application (LEPA) or low cost water and energy efficient water application (LEWA) systems of micro irrigation which can operates under low head of 4 to 6m have been found to be promising to work under low pressure head. Experimental findings on comparative studies under All India Coordinated Project in ICAR and SAUs on drip irrigation techniques are quite encouraging to show enhancement, not only in productivity but also in water saving using drip system in comparison to surface irrigation methods (Table 6)

. **Table 6:** Effect of drip irrigation over to surface irrigation on enhancement in yield and water saving of crops in India (Source: Batta , 2006)

Crop	Experimental Centre	Increase of yield over surface irrigation,%	Water saving over surface irrigation
Sugarcane	Bhawanisagar, Madurai, Rahuri	19.7 to 51.0	22.3 to 43.2
Summer groundnut	Bhavanisagar, Navsari, Madurai	31.5 to 59.0	6.4 to 46.3
Banana	Bhawanisagar, Parvani Rahuri, Navsari	12.0 to 14.6	22 to 42.2
Pomegranate(3yr old)	Belvatgi	71	19.6
Ber(3yr old)	Belvatgi	28.2	18.2
Acid lime	Madurai	5.0	49.4
Curry leaf	Belvatgi, Bhavanisagar	0.0 to 26.0	34.4 to 39.9
Bittergourd	Rahuri, Chalakudy	14 to 23.1	42.0 to 70.6
Ridgegourd	Rahuri	17.1	59.0

Pilot studies on introduction of pressurized irrigation in canal command at a public outlet of minor irrigation project in Orissa (Srivastava et al., 2010) showed its economic and technical viability. The system was designed in such a way that it provided pipe conveyance and surface irrigation for rice cultivation during monsoon period and additionally supported with sprinklers and drip system for rabi and summer non rice crops through a service pond. Problem of water turbidity was solved by using low cost filters to facilitate use of sprinkler and drip irrigation. At Dapoli (Maharashtra) studies on rain water harvesting and recycling through locally developed earthen diffusers resulted in 22.9 % water saving over basin irrigation method.

Sprinklers irrigation system should find its application in (i) undulating sandy terrain which, because of topographic limitations and water availability constraints, remain devoid of canal supplies, and where conjunctive use of ground water and surface water/ rainwater is to be promoted.

Drip or micro sprinklers should initially be promoted fruit orchard and vegetables and in certain areas for sugarcane. Drip has good scope for adoption in culturable wasteland, hilly slopes, coastal sandy areas and in command of perennial flow canal and wells or tube wells.

On-Farm Land and Crop Management:

Practices, such as ridge and furrows, broad-bed and furrows and field drains in ill-drained areas helped in safe disposal of excess water, water conservation under scanty rain fall and efficient management of water. These practices can give boost to grain yield by 10 to 20 % in field crops.It is necessary to draw action plan integrated nutrients and water management for different crops of the commands considering water availability.

"System of Rice intensification (SRI)" involves use of certain management practices, which together provides better growing condition for rice plant than traditional practices. SRI include early planting (12 to14 days old seedlings), limited irrigation with 25 cm X 25 cm grid spacing, limited irrigation (2 - 3 cm depth after appearance of hairline cracks), weeding and application of more compost and building soil organic matter. SRI is another term for sustainable rice intensification offers advantages of less seed rate (5 to 8 Kg /ha), less nursery area, labour saving, water saving (600-700 mm as against 1200 to 1500 mm in traditional system of continuous flooding), improved aeration, enhanced yield by 500 to 1500 kg/ha over traditional system of rice cultivation. SRI, due to intermittent water submergence also helps in control of malaria. The modern rice varieties with use of SRI technique have about two to three fold increase in water productivity compared with traditional varieties. Introduction of SRI alone in rice growing irrigation command can contribute to 30 to 50 percent of water saving over traditional rice cultivation (Swaminathan , 2011).

Genetic engineering, if properly integrated in breeding programmes and applied in a safe manner, can further contribute to the development of drought tolerant varieties and to increasing the water productivity.

Deficit Irrigation

In the past while planning an irrigation project, the supply schedule were based on delta and duty concepts. Limitations of the available water supplies were not given attention. However, in practice the irrigation supplies do not meet the demand during the crop period as planned. Introduction of new cropping pattern with high water demanding varieties and inequality in water distribution are necessitating major changes in irrigation management and scheduling of limited supplies in the command. Tail end deprival and decreased water availability makes it imperative to practice 'deficit irrigation'. The main objective of deficit irrigation is to increase the water use efficiency of a crop by eliminating irrigation that has little impact on yield. The resulting yield reduction may be very small compared with the benefits gained through diverting the saved water to irrigate other crops under water stressed environment. .

Before implementing a deficit irrigation programme, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season (Kirda,2000). Crops and crop varieties that are most suitable for deficit irrigation are those with a short growing season and are tolerant to drought. Under deficit irrigation practices, agronomic practices may require modification, e.g., decreased plant population, lower dose of fertilizer, adoption of flexible planting dates, and selected short season varieties (Kirda, 2000). A seasonal water production function model was developed (Stewart et al, 1977), advocating linear relationship between relative water deficit and relative yield, found wide acceptance in the following form. :

$$[1- Y/Y_m) = k_y \; [I - ET_a /ET_m)] \;...... \;.......... \quad (2)$$

Where, K_y is the yield response factor or sensitivity factor, ET_a is the actual crop evapotranspiration, ETm is the crop evapotranspiration for standard conditions (no water stress), Ya is the crop yield when ET = ETa , and Ym is the maximal crop yield corresponding to ET_m. A better description of ET impacts on yields is obtained when the yield response factors refer to specific crop phases and the history of the crop stresses is taken into consideration as it is largely reported in the literature.

FAO Irrigation and Drainage Paper # 33 (Doorenbos and Kassam ,1979) represented an important source to determine the yield response to water of field ,vegetable, and tree crops through Eq. 1.

Major variation was noticed in physical productivity of water across farmers in the same region, and the same crop has differential water productivity in different regions of India (Dinesh Kumar et al, 2012).

Variation of ky

Moutonnet, P.(2000) compared two series of ky values obtained from FAO data sets an(IAEA).The two data sets whilst showing the same trends, gave neither identical average values for ky International Atomic Energy Agency (IAEA) coordinated research project (CRP) showed a wide range of variation for this parameter 0.2 =< ky =<1.15 (FAO), and 0.08 <= ky<= 1.75 , the yield response factor worked out values. Variation in values of ky could not be explained by FAO or IAEA , and thereby raising generality of the model. Hence, high degree of sophistication and requirement for information, applicability and transferability, existing functions /models restrict their usefulness to different environmental conditions. Equation 2 was verified (Rajput and Singh, 1986) with strong linearity (P<0.01) using data from different site in India for a single variety of wheat(*Triticum aestivum L*). However large variation in Ky was notice from 0.77 to 1.56, Thus, the evidence from this study that a variety differs substantially in its sensitivity to water stress, when it is grown under different environmental conditions, does not support the hypothesis of Eq.2 (Stewart et al ,1977). A useful predictive relationship between ky and soil and climatic factors was established for Indian environment as

$$ky = 12.12 \left[(e_s - e_a / e_s)^4 \; \{(T_s - T_{27})/T_s\} / (CS)^2 \right]^{0.196} \;\ldots\ldots\ldots\ldots(3)$$

where $(e_s - e_a / e_s)$ is relative vapour pressure deficit, Ts is total crop period in days, T_{27} below 27^0C, CS is silt plus clay percentage in the root zone(representing soil moisture retention properties). The coefficient of determination (R^2) = 0.912 was statistically significant at 1% probability level.

A couple of growth stage sensitivity models, on wheat yield response to ET deficit imposed over different stages of wheat growth, were developed (Rajput and Singh,1986 and Rajput, 1993), which have been found to predict wheat yield with high degree of accuracy under water stressed environment in India. Basically two types of approaches have been used based on ET and IW/CPE approach. IW stands for depth of irrigation applied and CPE is cumulative evaporation from USWB Class A pan. As India provides lot of variation environment conditions these models/functions could prove to be useful tool in management of irrigation water. Generalised water productivity models need to be developed for different crops so that the information can be integrated in to 'Decision Support System' tools and optimization of project irrigation schedules.

The management options discussed here should be scaled up to a project or basin level. Accordingly, thev policies and strategies should be developed. Though the options are no matter location specific, never the less, those can be utilized as a single or multiple tools for augmentation of supplies and integrated water resource management. .

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