14

Sustainable Irrigation Practices in India

Rajapure V. A.[1] and Kothari R. M.[2]
[1]*Dept. Of Microbiology, Sikkim University, Sikkim*
[2]*Rajiv Gandhi Institute of IT and BT, Bharati Vidyapeeth Deemed University, Pune*
India

1. Introduction

During 1940-50's, water was amply available, its table was hardly 10-15 ft below the surface and needs of water were indeed meager due to simple life-style for India's population of 350 million. Therefore, with limited education, scanty knowledge of agronomic practices, insufficient financial resources and poor market information, nobody applied mind as to what should be done to make agriculture a sustainable profession, especially when water for irrigation from local rivulets, reservoirs and wells was available in the desired quantity. A few resourceful farmers used galvanized iron (GI) pipes for creating a network on the farm for carrying water from the source to different places. At that time, many considered this achievement a significant technological revolution, as it permitted to use the same quantity of water to take 2-3 crops per year by minimizing evaporational losses during the conveyance. This arrangement appeared to give a ray of hope to reduce total dependence on rain god *Varun*, who has not been kind enough in subsequent years for providing desired quantum of rain, at desired frequency and for the desired crop. Since then, GI pipes are totally replaced by economical PVC pipes to irrigate small or large farms economically and most practicably.

Table 1 has summarized the percentage of area brought under irrigation as a function of years. The kinetics of growth in irrigation may appear impressive at the first glance. However, a closer look reveals that it took 40 years (see data of 1990-91) to double the acreage of land under irrigation. The momentum picked up for irrigation since then is impressive and projected area under irrigation by 2010-11 is tentatively 47.5%.

Year	Area under irrigation (%)
1950-51	18.1
1960-61	19.1
1970-71	24.1
1980-81	29.7
1990-91	35.1
2000-01	43.4
2010-11	47.5

*Source: Dept. of Agriculture and Cooperation, Agricultural Census Division, 2010.

Table 1. Post-independence percent area under irrigation*

A closer look from a different angle summarized in Table 2 clearly points out that marginal land holders have mustered the courage, meager resources and efforts to bring maximum acreage under irrigation, no matter which was the source of water. This was probably for their sustainable livelihood without which food/financial security was almost impossible. This rationale appears holding true from the acreage brought under irrigation by large size land holders too, who had an alternative source of livelihood and agriculture was just another avenue of supplementary income.

Size Class	Canals	Tanks	Wells	Tube-wells	Others	Total
Marginal	3405	855	1296	5419	1409	12384
Small	2929	587	1971	4335	1069	10891
Semi-medium	3219	463	2500	4740	1010	11932
Medium	3447	276	2511	4502	811	11547
Large	1578	77	952	1715	550	4872
Total	**14578**	**2258**	**9231**	**20711**	**4849**	**51627**

All figures in `000 ha.
*Source: Dept. of Agriculture and Cooperation, Agricultural Census Division, 2000-2001.

Table 2. Distribution of irrigation sources for various classes of land holdings*

At this juncture, it was considered worthwhile to take a stock of different water resources.

1.1 Monsoon – A sustainable source of water

Presently, India cultivates annually 1-3 crops on its 125 million hectares of agricultural land, solely depending upon the availability of water for irrigation. Majority of the farmers undertake a single crop under rain-fed conditions using monsoon rain, generated by vast aerial circulations over the Bay of Bengal and Arabian Sea, facing east and west coast of India. These monsoon-generated rains, precipitated over 52-72 days from the last week of June until the last week of October, not only irrigate the crops, but they also replenish in a large measure sustainable source of surface and sub-surface water.

1.2 Surface sources of water

The surface source comprises thousands of small rivulets (locally known as *nullahs*), which merge in locally flowing minor rivers, turning into major rivers, which provide throughout yearly source of water for drinking, irrigation and industry. These major rivers are Sutlej, Ganga, Yamuna in north India, Teesta and Brahmaputra in N-E India, Narmada and Tapti in central India and Krishna, Godavari and Kaveri in peninsular India. The availability of water from these major rivers is guaranteed for the whole year for drinking, industry and hydroelectricity; for irrigation, it is available only to a section of farmers who have abundant resources to generate capital-intensive infrastructure for pumping water over 1-10 km distance.

Surplus water flowing through the above mentioned major rivers is diverted and collected in major dams like Bhakra-Nangal, Saradar Sarovar, Hirakud, Nagarjun Sagar, Koyna, Damodar Valley and several locally constructed minor dams for supply to urban settlements, local industry and canal irrigation for agriculture.

1.3 Harvested sources of water

Rain water harvesting is not a new concept in India as historical excavations confirm the existence of village tanks, *bandharas*, bench terraces etc. to retard the flow rate of water and channelize it for storage. Water harvesting, which has been re-discovered and popularized, is borne out of sheer necessity.

It is on record that millions of Rajasthani families migrated to different parts of India due to chronic hardships experienced by them as a result of continued water scarcity. The grandma used to tell us the story as to why there was no alternative to migration, leaving farms, homes and immovable hereditary property behind. Water was so scarce that a child used to get 2-3 liters water for bath, while the elders were getting about 5 lit. Turn-by-turn, all family members used to take bath in a shallow stone tub with a small outlet at the bottom for the collection of used water in an underlying drum for its subsequent use in washing the clothes. The effluent after clothe washing was once again used for wiping the floor in the home and after that it was finally used in the evening for either spraying on the terrace to render it cool for over-night sound sleep in the absence of electricity or surplus effluent used for deficit irrigation. Thus, each drop of water was recycled 4 times and when availability of rains and harvested little water was in question, a momentous decision was taken to migrate (Jain, 2003).

The success of watershed and irrigation depends largely on 2 factors: (i) to harvest water and store it by constructing economical earthen percolation reservoirs or dams and (ii) to use it effectively through micro-irrigation system (MIS) displayed on demonstration farms for the cost and benefits to the farmers, who have a faith in 'seeing is believing', rather than a faith in formal agriculture education in universities.

Water harvesting has been made successful at the foot of hillocks in a totally degraded land by creating a reliable, captive and sustainable water storage and recharge mechanism through open larger reservoirs, which came into existence on the basis of topography of land. Water transiently collected in them was gradually transferred in the dug-out open wells for recharge by virtue of slope and seepage. This system has enabled to harvest and store about 1200 million liters of water under the scheme Watershed Development.

In simple terms, watershed development comprises of (i) allowing sufficient percolation of rain water in the catchment areas (recharge zone), (ii) permitting its further percolation in the command area (transition zone) and (iii) collecting flowing water at safe flow rate for judicious use in the delta area (discharge zone) (Jain 2003). This has been made possible by creating a network of terraces and trenches in the hilly region so that soil erosion is controlled, water percolation enhanced on the terraces for useful plantation to stabilize the soil strata and extra water harnessed through the network for the year-round use. Its pictorial presentation is depicted in Fig. 1-4.

This strategy has enabled Jain Irrigation Systems to convert barren hilly wastelands into irrigated, lush green, high yielding and sustainable farms through recharge and recovery of the ground water through 25 dug-out wells and 33 bore wells (Fig. 4).

Fig. 1. Hill terracing undertaken at the Jain watershed

Fig. 2. Jain Sagar reflecting the efforts in watershed development

Contour trenches are useful for increasing soil moisture and impounding the run-off surplus water over the slopes (Fig. 1). During bench terracing, small streams generated in the direction of the slope are diverted by a technique known as gully plugging, by using rubble structure of locally available stones or earthen embankment. The rain water allowed to percolate on bench terraces increases its agro-potential, yields more crop and surplus water is collected in the vast open reservoirs and percolation tanks (Fig. 2) to help natural recharge of under-ground aquifers (wells) through pumping or overflowing to fall in the well. There is a criticism that watershed development is problem-centric and location-specific. However, this has little merit, if its transplantation is done with modification(s) of design and structures for water harvesting, storage and use for benefit under altered conditions.

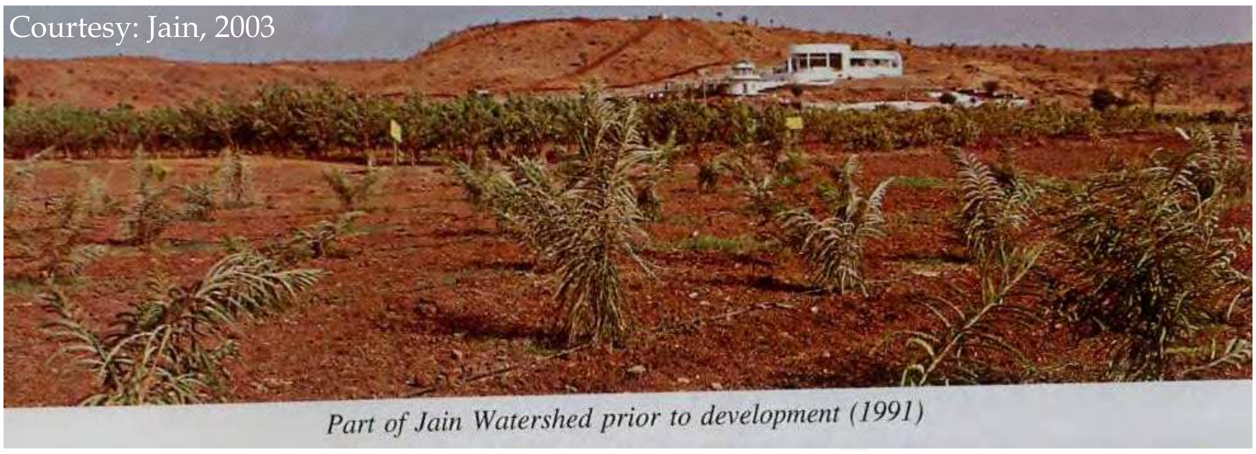


Fig. 3.

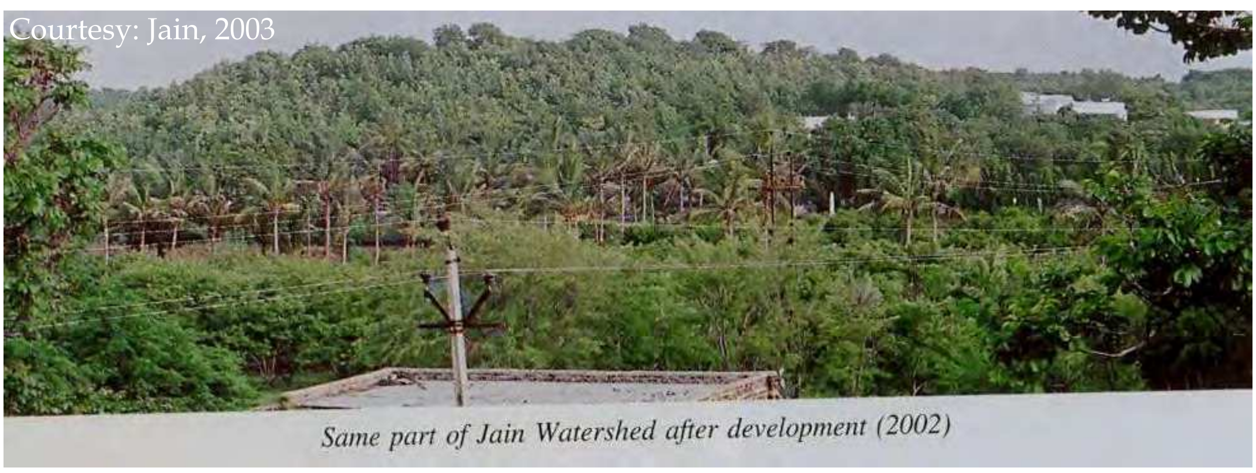


Fig. 4.

Watershed management in practice involved:

- Controlling, channelizing and collecting the surface run-off water
- Reducing the impact of more rainfall on soil erosion
- Decreasing the speed of flowing water by increasing its local infiltration
- Enhancing the moisture-holding capacity of soil
- Improving the soil texture and fertility
- Minimizing the chance of over-irrigation
- Arresting the ecological degradation and
- Increasing the productivity through crop intensity per unit area, per unit time and per unit of water utilized

This success of watershed development has been put to use and practiced on a large-scale by banana growers in Jalgaon region of Maharashtra who initially thought that there is no alternative to flood irrigation. However, watershed development and its imaginative conveyance for drip irrigation and ultimate use for tissue-cultured banana has doubled the acreage as irrigation by Micro-irrigation systems (MIS) requires almost 50% less water and secondly, maturity (harvesting) period of banana crop reduced from 18 to 12 months.

Presently, 90 million hectares of land is totally dependent upon annual rainfall to grow any crop, which provides livelihood to about 65% of our rural population. Rain water harvesting has the potential to add 30 million hectares to the irrigated area which ranges in 38-42% of the total land under irrigation.

1.4 Sub-surface sources of water

In the process of water percolation, seepage in short term might appear as wastage of water, but due to deeper penetration it is a safe storage of water, recharging the ground aquifers for long term usage. Therefore, another major source of water for irrigation has been underground reservoirs (wells and tube-wells) which are largely created by self-financing by the farmers and have their huge regional significance for enabling the farmers to take as many as 3-4 crops, the fourth crop being short duration vegetables, spices and condiments. Such artificial recharge by first obstructing the flow of water and then injecting in the wells/tube-wells merely by gravity has the following advantages:

- Creates reliable source of water
- Minimizes depth of water to pumping level
- Increases discharge rates
- Prevents decline of water table in the region
- Maintains safe ground water balance for future use

1.5 Recyclable sources of water

Vast stretches of land are irrigated to produce substantial amount of vegetables throughout the year in urban India, using unprocessed municipal waters, leaving the quality of vegetables doubtful in nutrition, due to contamination of pesticides and heavy metals. Precise quantum of this effluent, acreage under it and quantum of vegetables produced are not known as this work is being undertaken by the unorganized sector.

Thus, through these four resources, Indian farmers undertake about 39-43% of cultivable area into irrigation to generate about 225 million tons of cereals, 15 million tons of pulses, 337 million tons of sugar, almost equal quantity of oilseeds, besides vegetables, spices, fruits and medicinal plants. Among the commercial water guzzling crops are rice, sugarcane, banana, jute, bamboo etc.

2. Objectives of irrigation systems

The type of irrigation undertaken has largely depended on the physical texture of soil, climatic conditions (high/low temperature, rainfall, relative humidity, nearby vegetation, photo-period), suitability of soil for cultivating a particular crop and objectives for which irrigation is sought. To illustrate these factors, following examples are given.

2.1 Rice nursery

While monsoon rains start in the last week of June, major requirement of irrigation arises for preparing rice plantlets in the middle of scorching heat of May, to be ready for large scale cultivation almost throughout India, especially in Punjab, Haryana, Western Uttar Pradesh (Rice bowl of India), coastal regions and other high yielding provinces. Irrigation at this juncture is highly critical when sun is scorching and yet, production of rice plantlets is utmost necessary. Any failure in irrigation during this period or subsequent late arrival of rains generates not only hardships for farmers, but also radically alters the prosperity of rural India and their purchasing power, promoting higher growth rate of Gross Domestic Product (GDP), due to partial loss of rice yields.

2.2 Nursery for horti-/floricultural crops

The cultivation of nurseries is not only imperative for rice, but it is equally imperative for sugarcane, banana, horticultural crops and floriculture, both for local consumption as well as value-added exports. The crops raised under nurseries include green bell pepper, black pepper, cardamom, several vegetables such as ochre, brinjal, capsicum, garlic, onion, potatoes, variety of high yielding grafts of several fruit species (mango, sapota, pomegranate, lemon, pineapple, oranges, etc.), flowers such as marigold, variety of cut roses, tuberose, gerbera and ornamental plants etc. (Singh *et al.*, 2002). Production of seeds for vegetable crops and raising tissue culture derived plantlets of fruit crops like banana need huge amount of water for irrigation (Fig.5).

Fig. 5. Greenhouse depicting nursery operations

2.3 Wheat farm irrigation

After rice, the second major consumed cereal is wheat, which too requires at least 4-6 irrigations during 120-135 days crop cycle for quality and quantity of yield. Since wheat cultivation is undertaken during November-April period, contribution of rain-fed irrigation is almost nil to minimal (except for the residual moisture in the soil). Therefore, vast stretches of wheat irrigation largely depend upon canal network, wells/tube-wells and percolation tanks, frequency of irrigation being dependent upon temperature, photoperiods, evapo-transpiration rate and quality of soil as well as variety of seeds sown. Being the second largest cultivated cereal crop after rice, irrigation requirement is huge.

2.4 Value-added crop cycle

A highly value-added crop such as saffron is cultivated throughout its crop duration either in green houses or under extremely cold climate where irrigation is minimally required.

However, farmers do not take any chance due to unpredictable frequency of raining and at times extreme precipitations, thereby creating a necessity of foggers, sprinklers or drip irrigation.

2.5 Fruit crops

While India has legitimate claim to be world's number one or two producer and processor of several fruit crops, it is not without huge investment in drip irrigation, where the frequency, quantum and duration of irrigation is largely determined by the climatic conditions and sustainability of the crop without compromising with the quality and quantity of output. For example, different types of berries are 4-5 months duration crop and yet they require regular irrigation for optimal yields. Similarly, banana crop yield suffers due to either scorching heat or extremely windy climate inducing high rate of evapo-transpiration (Allen *et al.,* 1998) prior to onset of rainy season, thereby requiring protection through not only irrigation or mulching (Fukuoka, 1978), but also through shade imparted by rapidly growing leguminous bushy plants (wind breakers). This is applicable in equal measure for commercially grown crops like grapes, oranges, guava, pomegranate etc.

From the above narration, it is abundantly clear that no matter which crop, soil texture and unpredictability in the climate, irrigation should be the mainstay of supplementing necessary moisture for keeping the plants turgid, healthy and photosynthetically active for partitioning nutrients from the soil, its micro-flora, soil conditioners and soil moisture into higher yields of cereals, legumes, tubers, roots, fibers etc. Therefore, suitability of a particular type of irrigation as a function of crops needs consideration.

3. Types of irrigation

Irrigation already accounts for about 55-70% use of water in India. Due to unawareness of the cost: benefit ratio in using modern irrigation practices, out of available water, almost 60% used in irrigation is wasted. According to WHO estimate, in India agriculture uses as much as 70-90% of all renewable water resources that are now gradually diverted to human use. Following types of irrigation are used in India.

3.1 Rain-fed irrigation

Rain-fed irrigation accounts for 75-90 million hectares of land in India. Limitations of rain-fed irrigation are highlighted through the following illustration of different leguminous crops of which India is the largest producer, processor, consumer and importer.

While some of the leguminous crops like Mung (*Vigna radiata*), Urad (*V. mungo*) are totally depending on rainfed irrigation, soybean needs intense irrigation for at least one month, cowpea (*Vigna unguiculate*) requiring for 2-3 months and arhar (*Cajanus cajan*) requiring for 4-5 months. A myth that semi-arid crops do not need much irrigation has always given sub-optimal yields and at times poor quality. It is on record that India produced about 12 million tons of pulses during 1950-60 when its population was between 350-450 million and due to myths associated with irrigation, it has never crossed the mark of 150 million tons production when its population has crossed 1210 million (2011 census). The reason behind such poor performance in yield of pulses was primarily due to poor (70%) germination rate, thereby losing the productivity by 30% from the beginning of cultivation. Another reason has been lack of irrigation during flowering and seed-bearing period due to which flowers either withered or seed formation was sub-optimal, substantially reducing the yield. The notable example is soybean which is produced at the rate of 1.8 tons per acre in USA, whereas it ranges between 0.6-0.9 tons in India (Patil *et al.*, 2003).

3.2 Surface/flood irrigation

This is the most common method used worldwide with certain modifications like furrow irrigation or terrace irrigation (Fig. 6a). In both cases, water control is manual and therefore it induces large variations in volumes of water applied per unit area. Under such situation, moisture distribution is uneven and deep percolation unavoidable (Jain, 2003). This is most undesirable during the period of water shortage.

Until 1970s, rains were abundant, timely and surface as well as underground reservoirs remained replenished giving the false hope that while flood irrigation is sufficient at little cost, why to resort to modern methods of irrigation which are capital-intensive. However, this myth has slowly vanished when farmers realized that flood irrigation, though economical in short term, has transformed productive soils into saline, alkaline, acidic and non-productive soils due to huge accumulation of salty, acidic and alkaline ingredients in the soil (Patil *et al.*, 2001; 2002a; 2002b).

A closer look at the soil texture revealed that it is not only the salt content, but organic carbon content in the soil and useful micro-flora totally dependent on carbon content was almost extinct from the soil, thereby substantially eroding its self-fertilization capacity (Ramamurthy *et al.*, 1996). This problem was compounded further by indiscriminate and prolonged use of pesticides of increasing toxicity to control pests of increasing virulence, which has diminished useful micro-flora (N_2-fixers, phosphate solubilizers, sulphur oxidizers, carbon composters, ecto-/endo-mycorrhizae etc.) (Chaudhari *et al.*, 2008). Therefore, to enhance the fertility of soil and commensurate productivity, farmers resorted to increasing use of chemical fertilizers, which were not only cost-intensive, but also energy- and pollution-intensive, perforce dictating an increase in the quantum and frequency of irrigation for sustenance of crops.

Over-irrigation, has suffocated ramified root system, microbial flora and earthworms with the resulting hypoxia affecting a cascade of growth-specific physiological processes and ultimately causing fungal infection not easy to overcome, thereby adversely affecting the fertility of soil, microbial flora in rhizosphere, root system and productivity. Typical examples are green bean (*Vigna radiata)*, black gram (*V. mungo*), banana etc.

When surface irrigated areas are supplied water from public network of canal system (Santhi and Pundarikanthan, 2000), irrigation scheduling depends upon water delivery, its rate of discharge, duration and frequency. Since the farmer is not sure as to when he will have the next opportunity to irrigate his crop, he often indulges in over-irrigation, thereby defeating the purpose of conserving the water (Unger and Howell, 1999). This objective could be achieved with the guarantee of frequency so that irrigation is received in time and over-irrigation is curbed.

Flood irrigation, practiced on large scale, is almost abandoned, except for water guzzling monocot crops like rice (*Oryza sativa*), sugarcane (*Saccharum officinarum*), bamboo (*Bambusa* *arundinacea*), banana (*Musa paradisiaca*) etc . However, in view of colossal loss of water, problems created by flood irrigation and scarcity of water resources, drip irrigation (DI) has become the mainstay of moisturizing root system of plants. Its underutilization, merely to save crops, has desiccated the plants without alleviating heat stress and providing substandard productivity in quality and quantity.

Fig. 6. Types of irrigation; (a) Flood/furrow irrigation; (b) Drip irrigation; (c) Sprinkler irrigation; (d) Mist irrigation

3.3 Micro-Irrigation Systems (MIS)

This type of irrigation guarantees higher water use efficiency (WUE) at a greater benefit: cost ratio to the user (Zhang *et al.*, 1998). In this system, water is directly applied at the root zone of the plants or plantlets and in controlled quantities through a low pressure network and at desired intervals as per the requirements of the crops (Vasane and Kothari, 2006). In case, the land is at different heights, irrigation could be beneficially provided by the construction of distribution tanks at strategic locations (Jain, 2003). This permits minimizing evaporational losses, seepage and therefore provides most efficient use of water. Computation of the cost of MIS per hectare is about USD 2000 per hectare (Jain, 2003). It includes the cost of construction of water distribution tanks, cost of installing MIS and cost of replacing old material from time to time. This cost may appear a bit on higher side for the poor farmers of India. However, upon implementation in a step-wise manner, neither the capital investment is beyond the reach, nor repentance occurs for the loss of crop. In fact, from the total cost and total income, the pay-back period is about 7.5 years, in the total lifespan of MIS for 12-15 years. During this period, the farmer is assured of adequate food grains, vegetables, fruits, spices for quality life, while preserving fertility of the land and hope for a prosperous future as it permits re-growth of local micro-flora and fauna changing the ecology for better, useful to the farmer, village and nearby region (Vasane and Kothari, 2008).

Depending upon the texture as well as fertility of the soil and duration of the crop, Drip Irrigation (DI) systems (Fig. 6b) have become more sophisticated in terms of irrigating the desired volume of water required for the crop, without increasing the consumption of either electricity or manpower (Ayars *et al*., 1999). Basically, the principle underlying DI has been (i) to generate about 50% moisture in the rhizosphere for keeping the root system efficient for partitioning moisture along with locally available macro- and micronutrients into the shoot system, (ii) to help soil microbial flora colonize the rhizosphere so that dependence of soil solely on chemical fertilizers is reduced to the tune of 10-40% for a comparable crop yield, (iii) to permit the availability of adequate oxygen for the respiration of the root system, local micro-flora and earthworms, (iv) to allow maximum root ramification by softening the soil to increase surface area of the root system for the absorption of adequate moisture and nutrients and (v) to sustain the growth of ecto- and endo-mycorrhizae, which are inherently well-equipped to overcome the adverse effects of heavy metals, xenobiotics and agro-chemicals which are inhibitory to microbial and plant growth.

The sophistication of DI has substantially enhanced in the last five years by reducing the evaporation of moisture so that one could undertake at least 25-40% increased acreage under irrigation in the quantity of water saved and without compromising with the soil texture, microflora and sustainability in yields (Brats *et al*., 1987).

Indeed this system has been a harbinger of another revolution in irrigation as it brings several advantages to the farming viz., saving of water, reducing soil erosion, directed use of fertilizers and saving of energy, labor and finance with an added advantage of early harvesting period and 10-25% higher yield (Vasane and Kothari, 2008). This system has the potential to arrest dwindling levels of underground water table. A major step in this direction is taken by many state governments by subsidizing MIS to undertake 3-4 crops per annum, subject to availability of adequate water and electricity for pumping it to surface level.

From the above narration, it is abundantly clear that no matter which crop, soil texture and unpredictability in the climate, micro-irrigation should be the mainstay of supplementing necessary moisture for keeping the plants turgid, healthy and photosynthetically active for partitioning a variety of nutrients, plant protection agents and moisture into higher yields of cereals, legumes, tubers, roots and fibers.

Optimal utilization of DI as a function of texture of soil, quality of seeds and duration of crops has provided plant systems at its optimal growth, physiological functions and ultimate productivity. Vegetables (*Solanum melongena*), cereals (*Zea mays*), pulses (*Pisum sativum, V. mungo),* oilseeds *(Arachys hypogaea*), cotton (*Gossypium* spp.) and fruit crops (*Ficus carica, Vitis vinifera, Psidium spp.*) are typical examples.

3.4 Sprinkler irrigation system

Sprinkler irrigation system includes a set of traveling rain guns and continuous transfer of lateral system to the places where irrigation is required (Seginer, 1987). This type of irrigation has the merit of high application rate in shortest period, which is desired to save desiccating crop. However, it requires higher water pressure to improve the reach of water over larger surface area and therefore not appropriate for smaller fields, a reality in Indian scenario where an average farmer holds 0.5-2.5 acre of land. Secondly, sprinkler irrigation is not suitable for slopping farms, degraded land, heavy soils and windy conditions. Thirdly, during water scarcity, high water pressure is not feasible at many places in India. It is only an ideal system when application rates are high and farms are large. From field evaluation studies, a major disadvantage of sprinkler irrigation has come to our knowledge that farmers really do not control the depth of irrigation; therefore, problems of scarcity of water aggravate (Capra and Scicolone, 1998). On the contrary, since water is scarce, hence expensive, if farmers adapt to under-irrigation uniformly, they may accept potentially low yield instead of having no yield at all.

To overcome the problems of sprinkler irrigation using rain guns, micro-sprinkling has been designed for smaller farms with an irrigation frequency depending on the availability and quality of water (Fig. 6c). With this system, farmers attain improved irrigation efficiency merely by adapting irrigation schedules at desired frequency depending on the turgidity of the foliage of the crop (Pereira, 1999).

3.5 Mist irrigation

This type of irrigation has been prerequisite for tissue culture derived crops at primary hardening (Vasane and Kothari, 2008; Vasane *et al.*, 2010) when the plantlets were indeed tender, required higher humidity level to overcome 'heating' which was equally necessary for rapid growth of plantlets and bio-acclimatization (Vasane *et al.*, 2010) (Fig. 6d). Misting in secluded areas is also accorded to saffron crop; it is necessary for delicate ornamental plants and cut flowers prior or during the transit so that their flower/foliar conformation is retained without loss of freshness. Misting has helped fruit crops to delay maturation, to arrest over-sweetening of grapes, to overcome heat stress to banana under scorching period and to retain freshness of vegetables, fruits, sprouts etc. prior to auctioning or for enhancing the shelf-life.

3.6 Deficit or supplementary irrigation

Acute water scarcity enforces either deficit irrigation or supplementary irrigation (SI), not to the liking of the farmers, but by perforce of circumstances, they have to consider water scarcity in totality in terms of drinking for human beings and cattle, household purposes for hygienic living, economic purposes for optimizing agricultural/industrial output and environmental benefit to render life of farmers livable by improved irrigation management (English and Raja, 1996).

Deficit irrigation mode is designed (Shangguan *et al.*, 2001) when water is scarce and yet a purposeful strategy is adapted to sustain the crop under increasing degree of water deficit; at the cost of yield, irrigation is adopted by many farmers in the case of *Jatropha curcus,* a source of non-edible oil for biodiesel production. These authors have proposed a model for regional optimal allocation of water under deficit irrigation and have illustrated the model by suitable application.

3.7 Simulation-based irrigation: A concept

In all the modifications suggested to overcome water deficit and yet sustain the crop, several computerized simulation models are available (Endate and Fipps, 2001). However, they are of little use since the farmers are neither aware of simulation concept, nor they practice such models of varying irrigation frequency. Farmers' orientation to understand this concept is a prerequisite before their application could be considered. At best, they could cultivate crops robust to sustain water scarcity by adopting minimal irrigation and other cultural practices (viz. mulching) so that they have good chance to maximize the crop yield per unit area of land per unit time (Fukuoka, 1978).

4. Problems of water scarcity during the farm management

Semi-aridity, aridity, drought and desertification are both, natural and man-made contributions arising out of increasing water scarcity over increasing duration. Under these conditions water conservation and water use efficiency needs to be considered on a priority basis, since water scarcity implies that locally available water of inferior quality (viz., municipal effluent) has to be relied upon for irrigation in an increasing manner. In addition, water distribution uniformity (WDU) would be a fundamental measure to reduce water demand for under-irrigation, scarcity irrigation, deficit irrigation, contingency irrigation etc. Therefore, regardless of the quality of water or its quantum, strategies for sustainable water management will have to be put into practice so that water scarcity in future could be readied presently and meaningfully.

4.1 Contingency irrigation

Water shortage may appear due to natural imbalance in the quantum of rainfall and its use; however, in a large measure, it is due to short-sighted human practices which indulge into its over-exploitation and reduced land use, propagating water shortage years after years. While water tables are falling, while water demand is dramatically growing at an unsustainable rate for additional food production. This situation of increasing water demand will continue to increase in the coming decades as style of living and income enhances their consumption of food. This situation invites consideration for moderate, immediate and permanent contingency irrigation models or practices.

To address this problem, large scale development of surface and underground resources is increasingly getting unacceptable due to environmental concerns. Compounding this problem, water delivery infrastructure built in recent decades is becoming obsolete due to silting of reservoirs and lack of repair in the irrigation network. The net result is falling levels of the water table by every passing day by providing water on demand to millions of farmers who tapped it using tube-wells to grow the crops. These developments clearly point towards increasing scarcity of water.

During irrigation, no matter it is deficit or contingency, the following factors need utmost consideration:

- Water harvesting and creation of water reservoirs on farm.
- An increased storage capacity on farm for local absorption of precipitated water.
- Minimization of evaporation in water reservoirs/canal networks through the use of eco-friendly chemicals (Unger and Howell, 1999).

- Farmers' orientation in thinking to take cognizance of agro-meteorological/hydro-meteorological predictions so that water scarcity does not aggravate its wasteful use, detrimental to local population.
- Agro-meteorological predictions should, enable planning for drought-tolerant crops to reduce the impact of water scarcity through mere irrigation scheduling.
- Drip irrigation is preferred to sprinkler irrigation to minima moisture evaporation.
- Uniformity of water distribution as a function of farm topography for minimal wastage and productivity variation per unit land area.
- Deep percolation of water beyond rhizosphere avoided by controlling the greed of farmers regarding uncertainty of quantity and frequency of next irrigation.
- Due to inter-dependence between supply and demand, wherever feasible, water of inferior quality used.
- Shortage of electricity and its availability at odd hours for irrigation circumvented to activate pumping from wells/tube wells by remote control, so that farmers are spared from snake/scorpion bite while trading long distances merely to start the pumps for timely irrigation.

In nutshell, outcome of irrigation is always determined by the availability of quality and quantity of water, quantum and frequency of irrigation, respiration of soil life and compositing of organic matter for plant growth promotion and protection, ultimately providing quality and quantity of food, fodder, fiber and pharma ingredients output.

4.2 Sustainable water management

It considers conservation of all water resources using appropriate technologies and their use with social acceptability, economic viability, and eco-friendliness. Under the head of social acceptability, cross subsidization of available water needs to be made into legitimate inter-regional (rural versus urban) and inter-sectoral (agricultural versus industrial) needs. Such considerations ahead of the scarcity will provide flexible practices in irrigation management. Otherwise, politically oriented and ill-considered decisions tend to aggravate human sufferings, cattle perishing, agricultural stagnation or decline and reduced industrial output, cumulatively affecting GDP adversely.

In semi-arid zones, tillage practices to control the run off of water, vegetation management to limit evaporation from plants and use of mulches for retaining moisture in the soil has the potential to play a central role. The preferred mulches are biodegradable (viz., bagasse) so that in the first season they serve as mulch and in the next season, they serve as compost. Synthetic mulch is the next alternative.

Under aridity, consideration of low moisture carrying capacity of the ecosystem in right perspective needs irrigation in small dosages and at higher frequency so that immediate hardships out of aridity are minimized (Sarwar and Bastiaanssen, 2001). This is a case of moderate contingency arising out of water scarcity.

Drought being a natural, but temporary imbalance in the availability of moisture caused by lower than the average rainfall over the years, its uncertain frequency, limited duration and severity of sunlight aggravate the rate of evapo-transpiration, resulting into diminished moisture availability for plants to sustain (Pereira, 1989). Severity of such situation needs application of soil conditioner (Chaudhari and Kothari, 2009) and DI at night time so that due to water-holding capacity of the soil conditioner, crop is sustained at a minimal loss due to evapo-transpiration, providing the hope of livelihood, especially for rural and economically weaker population. This is a case of immediate contingency due to acute water scarcity (Pereira, 1999).

Desertification in a large measure is man-made problem over longer duration, carried forward from the past in the availability of water. While drought aggravates desertification, recycling of water for human and cattle consumption and recycling for irrigation provides a workable strategy to arrest the rate of desertification and thereby human hardships. This appears an extremely difficult contingency, being permanent in nature and scope, requiring irrigation scheduling (Teixiera *et al.*, 1995). This is a case of chronic contingency.

4.3 Demand management of water

This aspect needs holistic approach during the period of water abundance. This statement apparently appears as paradox. However, it provides time to conserve water, so that scope, duration and intensity of scarcity in future is minimized and more awareness created in the local population for water scarcity, that the available water has to be used for minimizing human/cattle hardship and economic use in agriculture/industry. This has been illustrated by Goyal *et al*. (2001) through an integrated approach for sustainable improvement in agro-forestry systems where demand of water is initially high for high success rate.

In fact, the forgotten merits of practicing crop rotation (Fukuoka, 1978, Patil *et al.*, 2003), vermin-compost application (Chaudhari and Kothari, 2009), organic manuring (Ramamurthy *et al.*, 1998) and green farming (Vasane and Kothari, 2009) have the potential to reduce the impact of water scarcity by virtue of their moisture holding capacity of the soil at no compromise with the potential of the standing crop.

4.4 Use of municipal effluent for irrigation during water scarcity

The municipal effluents generally contain carbohydrates, proteins, fats, lignin, soaps, synthetic detergents and miscellaneous products of common household usage, which are susceptible to biodegradability. Effluent with such composition can be ensured if an effluent containing chemicals from the process industry is released through the separate discharge lines so that domestic municipal wastewater could be readily utilized with either minimal treatment or without costly or time-consuming pre-treatment to minimize phytotoxic levels and health risks associated with it. Typical industrial effluents rich in pesticides, heavy metals, carcinogens, xenobiotics and extreme acidity/alkalinity have relatively less volume and industries are encouraged to treat it at the point of origin so that larger volume of industrial effluent has minimal contaminants, with enhanced suitability and feasibility of use only as a last resort when plant life is at a stake due to persistent droughts (Teixeira *et al.*, 1995). In fact, waters contaminated with worms like ascaris, enteric bacteria and enteric viruses could be either decontaminated in shallow water ponds exposed to scorching sunlight or subjected to methanogenesis for biogas production (Suryavanshi *et al.*, 2009) so that useful product is obtained, attainment of temperature beyond 40°C during biogas generation period has the chance of water disinfection and its use for irrigation. Thus, water treated through natural system of solarization or after biogas production could spare the field workers from direct contact with microbial infections and allow the soil to retain its useful micro-flora so that salad crops which are eaten uncooked and green fodder crops for cattle upon solarization are within the safety zones. Any other treatment prescribed in the literature does not sound logistically and economically feasible. However, monitoring of (a) microbial contamination in water to be used for irrigation upon solarization and (b) surface contamination of food and fodder is essential to minimize health and ecological risks, as prescribed by the WHO guidelines.

While the above irrigation practices provide a short term succor to make the life of a farmer livable, use of such sub-standard quality water needs to be monitored for long term effects by monitoring (a) dispersion of soil particles, (b) stability of soil aggregates, (c) permeability or infiltration rate of water, (d) exchangeable ions and (e) total dissolved solids. These measures have the potential to maintain osmotic pressure exerted by water within the limits on the growth and yield of plants, failure to which has potential of progressive decline in the yield (Sarwar and Bastihaassen, 2001).

5. Practicable measures to alleviate the water scarcity

The use of following adjuvant could be considered to retain moisture in the soil/plant.

5.1 Use of soil conditioners

As the availability of water for irrigation becomes scarce and concurrently the need for taking 3 crops per annum enhances to meet the needs of ever-increasing population, several adjuvant have been conceived, experimented, produced and used to find if the quantum and frequency of irrigation per crop could be reduced by their judicious use. Among these adjuvant, soil conditioners are at the forefront by virtue of their (a) moisture-holding capacity, (b) micro-flora propagating nutritive attribute, (c) fertilizing ability and (d) capacity to impart soft soil texture for permitting optimal germination of seeds as well as subsequent ramification of root system (Ramamurthy *et al.*, 1998). Traditionally, night soil and cattle dung were used for this purpose. With the advent of chemical fertilizers, farmers have forgotten the merits of keeping cattle as a source of soil conditioners and supplementary source of income to tide over adverse situations created by the scarcity of water (Chaudhari and Kothari, 2009). However, the use of cattle dung has steadily been substituted by biodegradable waste from household, agricultural operations, industrial processing/municipal collections, which are now being subjected to hydrolysis, acidification and methanogenesis to provide biogas for agricultural operations, arrest the release of methane and CO_2 generated during the process and thereby minimize warming impact of greenhouse gases and at the same time use the solids as organic manure and its supernatant as plant growth promoter, thereby reducing the consumption of water through irrigation (Suryavanshi *et al.*, 2009). The exploratory use of poly-acrylamide (*Jalshakti*) to hold moisture in rhizosphere did not succeed due to its exorbitant cost, potential to release carcinogenic monomers and inability to impart physical, chemical and microbial advantages imparted by the locally generated low cost soil conditioners and FYM (Ramamurthy *et al.*, 1998). In fact, the soil conditioners have become vital inputs in raising the nurseries and ornamentals/floricultural crops for export, as soil conditioner takes care of plants' requirement of moisture from the time of packaging, quarantine inspection at the point of export, aerial transport, quarantine at the port of destination, auctioning market, until the ornamentals or the cut flowers reach the homes of consumers for sustained life up to two additional weeks (Singh *et al*., 1995, Sharma *et al*., 2004).

Soil conditioners derived out of barks of *Eucalyptus*, *Acacia*, Raintree etc. have not only imparted the attributes of soil conditioners, but also retarded the incidence of pests, presumably due to presence of terpenoids, alkaloids and flavonoids in the bark (Yadav *et al*., 2002).

5.2 Application of press mud

It is a waste product emerging from the sugar industry, which has been extensively analyzed for its physico-chemical and microbiological ingredients for sustainable agriculture (Talegaonkar, 2000). Its inherent soft, spongy and fluffy physical nature provides porous texture to the soil, thereby promoting higher rate of seed germination and subsequent root ramification which provides more surface area and energy available for the adsorption of variety of nutrients from the rhizosphere. Its acidic nature renders press mud suitable for the amendment of alkaline soils, besides contributing the fertilizing value. Its organic nature demonstrates its potential to serve as a matrix for retaining viable counts of microbes in biofertilizers (Talegaonkar, 1999). Its composite nature indicates its utility for water holding and expeditious composting due to its overall growth promoting property. Its minor constituents like wax and sterols render it value-addition for sustained release of growth promoters and plant protection agents as a function of their hydrolysis by soil microbial flora. Its battery of trace constituents induce production of microbial iron chealaters (siderophores), imparting it an additional function of plant protection. Ultimately, its harmless nature and ease of application makes it an attractive candidate for moisture withholding during dry season or farming during rain shortage. In totality, press mud seems to have the potential to provide eco-friendly, cost-effective and sustainable bio-resource for increasing agricultural productivity through its multifaceted characteristics (Talegaonkar *et al*., 2001).

5.3 Application of fly ash

Fly ash, the ultimate combustion product of thermal power stations, has been another soil conditioner and by virtue of its inorganic nature showed an excellent potential to meet micronutrient needs of plants. Apparently, very few have realized that timely availability of the micronutrients reduce the necessity of irrigation up to 10% in eco-friendly manner (Phirke *et al*., 2001a, 2001b, 2004). However, it should also be kept in mind that its non-judicious use has the hazard of compacting the soil and reducing its rate of infiltration as well as availability of air for the respiration of rhizospheric microflora and root system (Phirke *et al*., 2004).

5.4 Application of biofertilizers

High yielding inoculants such as efficient (i) *Azotobacter* for nitrogen fixation for cereal crops (Phirke *et al*., 2001b), (ii) *Rhizobia* for leguminous crops (Talegaonkar, 2000), (iii) *Aspergilli* for phosphate solubilization under varied soil textures, pH and climatic conditions (Patil *et al*., 2005), (iv) *Thiobacilli* for oxidation of elemental sulfur to solubilized sulfate radicals (Phirke *et al*., 2001), (v) different types of bacteria/fungi for transformation of complex organic matter into easily assimilable plant nutrients (Ramamurthy *et al.*, 1998) and (vi) ecto- as well as endo-mycorrhizae to tide over salinity/alkalinity/acidity/heavy metal contaminants in the soil etc. have been the mainstay of providing plant nutrition without requiring colossal quantities of water used during the production of chemical fertilizers (Phirke *et al.*, 2002). Their use certainly supplements fertilizer value to different crops and in different soils to the extent of 20-40%. In spite of their eco-friendly and efficient performance, their use is restricted due to (a) non-familiarity of the farmers with their attributes, (b) conditions required for their sustenance and (c) availability of unethical biofertilizer preparations of doubtful integrity and viable spore count (Patil *et al.*, 2005). However, their use with water holding matrices like press mud, farm yard manure, compost, soil conditioners etc. has been a professionally satisfying experience for enhancing soil fertility and human health as found in soybean crop (*Glycine max*) (Patil *et al.*, 2006). The only limitation biofertilizers impose is that chemical fertilizers still need to be used in harmless concentrations and use of pesticides (Zope *et al.*, 2000) to combat a virulent pest be made as a last resort so that colonization of biofertilizers is retained year after year (Patil *et al.*, 2005).

5.5 Application of plant growth regulators

Plant growth regulators (PGRs), derived out of industrial or agricultural wastes, alcoholic or amino acids in nature, have served for the growth of plants either through supplemental nutrition or affording protection from pests through sustained availability of ingredients for the synthesis of chlorophyll (Sharma and Kothari, 1992, Yadav *et al.*, 1995). They too provide succor to plants for limited period during water scarcity through several mechanisms, including enhanced chlorophyll synthesis, increased root ramification, decreased stomatal opening and regulating several physiological processes to tide over stressful period (Sharma and Kothari, 1993b, 1994, Jolly *et al.*, 2005). While precise mechanism of their working is not clear, they are useful in enhancing productivity of rice (Sharma and Kothari, 1993a) and other crops (Sharma *et al.*, 1994, 1995). Table 3 has summarized outcome of joint application of soil conditioner and PGR.

5.6 Application of siderophores or biopesticides

Alternatively, *Pseudomonas* or its secretions, known as siderophores, have also promoted plant growth, presumably by rendering selective availability of Fe^{3+} to the plants and its concomitant denial to the pests. As pest nuisance arises due to shortage/excess of irrigation, synthesis of siderophores through fermentation and applicability on a large scale has been explored on groundnut crop with 10± 2% increase in the yield and minimal affliction of *A. flavus*. Thus, siderophores could alleviate stressful situation due to water scarcity for some period (Chincholkar *et al.*, 2000).

While chemical pesticides have controlled many pests, their application has enhanced problems rather than solving them. To address this issue, our school has developed a number of strategies using botanicals for preparing biopesticides and exploring their use to pre-empt pest affliction at the cost of crop yield. In principle, the strategy conceived the use of de-oiled cake of neem seeds (*Azadirachta indica*) or jatropha (*Jatropha carcus*) or karanj (*Pongamia pinnata*) or babul (*Acacia arabica*) which not only enriched the soil for nitrogen, but also boost its resistance power to pre-empt likely pests (Patil *et al.*, 2000, Mendki *et al.*, 2000, 2003; Patil *et al.*, 2010).

Crop	Application rate	Qualitative effect	Quantitative effect	
			Control	Experimental
Lawn	0.4 kg.m^2	Reduced water requirement	Greenish	Dark green
Rose	0.5 kg/plant	Longer shelf life	Less & small flowers	More & bigger flowers
Marigold	0.25 kg/m^2	Fresh appearance	Small size	Large size, 100% higher production
Onion	0.8 kg/m^2	sweet	9.8 kg	12.8 kg
Potato	0.5 kg/m^2	Green foliage	Small size	Bigger size
Peanut	0.4 kg/m^2	Bigger seeds	1.9 kg	5.7 kg
Sugarcane	0.4 kg/m^2	Improved tillering	35 kg	60 kg
Eucalyptus*	2 l/plant	Higher survival	7.2 cm girth	16.3 cm girth
Bamboo	1.5 l/plant	Higher growth rate	Yellow green	Dark green
Kinnow**	10 kg/plant	Higher survival	121 cm height	160 cm height
Mango***	10 kg/plant	More vegetative growth	121 cm height	149 cm height

*After 22 months; **After 18 months; ***Langra variety

Table 3. Productivity of crops as a function of SC and PGR spray

5.7 Public participation for awareness of problems

If local governments could frame the code of conduct by clearly defining water allocation policy, their efficient use for social, agricultural, industrial and environmental purposes, employing appropriate technologies, it is the necessity of time. In the long term, public awareness on the availability of limited water resources and its conservatively judicious use to meet long term needs has to be created so that public in large measure adopts to reduced demand practices.

An apparent view that rainfall was scanty and after long intervals may be true; however, whatever quantum is received in the limited period, if diverted for aquifer recharge will certainly be the best local strategy, totally independent of the government lethargy. Once the aquifers are recharged, their most efficient use will depend upon the local initiative in conveyance, distribution on the farm and its efficient scheduling so that it is more useful to crop and soil system and least available for evaporation.

At management level, scientists like to define water use efficiency (WUE) as a ratio between assimilation by rhizosphere to transpiration rate by the plants. However, the most creditable criteria of WUE the farmers understand is ratio between crop biomass (for cattle consumption) and grains production (for human consumption). Ultimately, the wholesome view has to take in to consideration necessary human needs and maintenance of cattle for daily livelihood to cater long range agricultural dependence. The net outcome would be water productivity (WP).

The take home lesson of the above facts is life without water is indeed unthinkable; in fact, many farmers who have migrated from water scarcity areas have developed a firm conviction that water is synonymous to life. Their upbringing in decade-long drought has left a deep and indelible scar on their mind, thought process and actions that they undertake water harvesting, conserve it by proper storage, use it judiciously and recycle each drop so that it will never invite another migration during their lifetime.

5.8 Problem alleviation strategies

Flood irrigation in rice, banana, sugarcane etc. has rendered soil saline and its remediation was desired through application of soil conditions and other means (Tyagi and Minhas, 1998; Patil *et al*., 2002a). Therefore, decisions on optimal strategies for irrigation under varying scarcity and climatic conditions are complex, especially when the farmers are totally dependent on rain-fed agriculture, where rainfall variability from year to year is extremely high.

In the last decade, a multi-date sowing strategy was suggested (a) to reduce the need of water during peak growth period by more than 20%, (b) minimize the chances of crop failure and (c) maximize the farm income. This rationale is based on a premise that at least one of the sowing dates will be able to meet local climatic optimal conditions to provide bumper crop to the farmers, which is denied to them by single cropping date, where chances of failure are more (Pareira *et al.,* 2002).

6. Partitioning of water

Traditionally, irrigation has been regarded as partitioning of water sources initially to soil and finally to plant system to alleviate heat stress for higher productivity. However, this concept has undergone radical change with understanding of the scientific processes at molecular level; it involves partitioning of moisture initially to soil to soften its texture for higher percentage of germination and ease of root ramification. From soil, roots peak up solubilized fertilizers and several microbial secretions by imparting momentum to colonization of useful microbial flora. Subsequent partitioning of plant growth promoters/protectors to ecto-/endo-mycorrhizae initiated for onward transmission to root and shoot system. Besides, moisture partitioned in the soil promotes composting of organic matter in the soil and thereby partitioning humic acids to tender surface of root hairs and rootlets for growth promotion and protection. Another forgotten aspect of irrigation has been transfer of moisture to earthworms and their eggs for promoting secretion of hundreds of unidentified growth promoters, which are eventually partitioned to the root system, without disturbing uninterrupted flow of oxygen for the respiration of root system, micro-flora, earthworms and other live forms. Thus, as per modern concept , irrigation has multifaceted functions to promote life in soil, solubilize soil secretions, partition them along with moisture to microbial flora associated with the root system for further transmission through surface and microbes to plant shoot system.

7. Virtual water

By definition virtual water is the moisture embedded in a product, i.e. water consumed during its process of production and processing. This concept emerged in the 1990s and received increasing attention from scientists, technocrats and opinion makers concerned with water management related to food production/processing. Increasing inter-sectoral competition for water, the need to feed an ever growing population and increased water scarcity in many regions of the world, prompted to look at the way water is collected, stored, used and disposed on our planet. The water requirement for food is by far the highest, it takes 2-4 liters per head per day to satisfy the drinking water needs and about 1000 times as much to produce the food. This is why the concept of virtual water is so important when discussing food production and consumption.

The significance of virtual water at global level is likely to increase dramatically as projections show that food trade will increase rapidly (doubling for cereals and tripling of meat production between 1993 and 2020) (Rosegrant and Ringler, 1999). In simple words, a country that imports 1 million ton of wheat is importing 1 billion m^3 of water. For example, India imports oil/oilseeds and pulses to meet local demand. In this process, it is estimated that India imports gross virtual water to the extent of 3.9 billion m^3 per year (Chapagain and Hoekstra, 2003), while Zimmer and Renault, 2003 have computed import of 31 billion m^3 per year. Therefore, the transfer of virtual water embedded in the food that is traded is becoming an important component of water management on regional as well as global level, particularly in the regions where water is scarce.

By choosing a crop pattern for export purposes which has least ingredient of 'virtual water' for export at the cost of local population, economy and ecology, two aspects enjoy priority: local necessity (for service and ecology) and higher income to the farmers. While putting this philosophy in practice, (i) crop water requirement and (ii) irrigation scheduling (Pits *et al*., 1996) are to be considered as both have economic implications and welfare of local population.

In fact, if the cost of sugar production from sugarcane is meticulously followed in terms of water consumed and its subsequent processing in sugar industry, the scenario becomes clear that sugarcane crop should be restricted to meet national requirements only, beyond which one is exporting moisture in the form of sugar and rendering the soil unproductive due to salinity at a colossal loss to national GDP.

In totality, for virtual water, market orientation of the crop choice is a tricky issue in short and long range, while meeting local needs without loss of income is always a superior option (Burt *et al*., 1997). At such time, the use of micro-irrigation in preference to sprinkler system enhances distribution uniformity, a function of the choice of emitter for discharge for a crop and water pressure at emitters (Santhi and Pundarikanthan, 2000).

8. Conclusion

Water scarcity has huge implications for health, hygiene, sanitation, drinking water, agriculture and industry. Therefore, equitable distribution of this scarce resource has been accorded prime consideration in form of sustainable irrigation, which serves as a spring-board to provide food for public consumption as well as industrial raw materials. Drinking water enjoys second place in planning which in turn addresses legitimate needs of health, hygiene and sanitation. For this purpose, central, state, district and local (village level) governments have ensured voluntary public code of conduct to minimize the risk of over use of underground reservoirs and protect their water quality. Therefore, water extraction, conveyance, storage and delivery infrastructure is being augmented, pricing of water considered to reflect its net cost and delivery made at reduced pressure and reduced frequency. Towards this practice implemented in urban as well as rural areas, policy-makers and public have a tacit understanding that failure to judicious use of monsoon water costs health, industrial output and national economy as a whole.

Agriculture being the major user of water, besides reliance on rain-fed irrigation, gradually surface or flood irrigation is being replaced by sub-surface (drip/sprinkler/mist) micro-irrigation, which has inherent capacity to double the acreage under irrigation, without loss to agri-output. By experience, the farmers have also got educated that flood irrigation largely employed in sugarcane, rice and banana cultivation has rendered soil saline and less productive over the years. To reduce water use and transform saline soil into a productive matrix, sustainable water management is made through the enhanced use of farmyard manure, soil conditioner, press mud, fly ash/bio-fertilizers/plant growth regulators/bio-pesticide/ siderophores, which permit reduced use of water and at the same time soil fertility, is enhanced over 3-4 year duration. Similarly, crop planning is considered to restrict the cultivation of crops consuming “virtual water”. For arid, semi-arid and desert landscapes, contingency irrigation/ deficit irrigation/ supplementary irrigation is considered to save the standing crops through recycling municipal effluents. Everything said and done, the ultimate success of irrigation practices depends on certain regulatory measures by the government and public participation through keen awareness.

9. References

[1] Allen RG, Pareira LS, Raes D, Smith M, 1998. Crop evapo-transpiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAo, Rome, 300 pp.

[2] Ayars JE, Phene CJ, Hutmacher RB, Davis KR, Schoneman RA, Vail SS, Mead RM, 1999. Subsurface drip irrigation of row crops: a review of 15 years research at the Water Management Research Laboratory, Agric. Water Manage. 42, 1-27.

[3] Bralts VF, Edwards DM, Wu I-Pai, 1987. Drip irrigation design and evaluation based on the statistical uniformity concept. In: Hillel, D. (Ed.), Advances in Irrigation, Vol. 4. Academic Press, Orlando, pp. 67-117.

[4] Burt CM, Clemmens AJ, Strelkoff TS, Solomon KH, Bliesner RD, Hardy LA, Howell TA, Eisenhauer, DE, 1997. Irrigation performance measures: efficiency and uniformity. J. Irrig. Drain. Eng. 123, 423-442.

[5] Capra A, Scicolone B, 1998. Water quality and distribution uniformity in drip/trickle irrigation systems. J. Agric. Eng. Res. 70, 355-365.

[6] Chapagain, AK and Hoekstra AY (2003). ‘Virtual water trade: A quantification of virtual water flows between nations in relation to international trade of livestock and livestock products’. In: ‘Virtual water trade’ Proceedings of the International Expert Meeting on Virtual Water Trade. Value of Water Research Report Series No. 12.

[7] Chaudhari AB and Kothari RM, (2009). Soil conditioners as a pivotal biotech input for integrated farming and contingency income Textbook on molecular biotechnology, (Eds. A. Varma and N. Verma), I. K. International Publ. Pvt. Ltd., New Delhi.

[8] Chaudhari AB, Phirke NV, Patil MG, Talegaonkar SK and Kothari RM, (2008). Bio-fertilizers and soil conditioner for organic farming. in: Bio-fertilizers (Ed. P.C. Trivedi), Pointer publisher, Jaipur, pp. 39-79.

[9] Chincholkar SB, Chaudhari BL, Talegaonkar SK and Kothari RM, (2000). Microbial iron chelators: A sustainable tool for the biocontrol of plant diseases. In: Biocontrol

potential and its exploitation in sustainable agriculture. (Eds. R. K. Upadhyay, K. G. Mukerji and B. P. Chamola), Kluwer Acad / Plenum Publ., New York, Vol 1, 49-70.

[10] Endale DM, Fipps G, 2001. Simulation-based irrigation scheduling as a water management tool in developing countries. Irrig. Drain. 50, 249-257.

[11] English M, Raja SN, 1996. Perspectives on deficit irrigation. Agric. Water Manage. 32, 1-14.

[12] Fukuoka, M 1978. The One Straw revolution: *An Introduction to Natural Farmin,* Rodale Press, New York, USA.

[13] Gadgil A, Drinking Water In Developing Countries (1998), Annual Review of Energy and the Environment, 23, 253-286.

[14] Goyal D, Sharma RK, Ramamurthy V and Kothari RM, (2001). An integrated biotech approach for the sustainable improvement in agro-forestry systems. Innovative Approaches in Microbiology (Eds. D. K. Maheshwari and R. C. Dubey), B. Singh Publ., Dehradun, pp. 367-377.

[15] Jain B H (2003). A Telling tale, Jain Irrigation Systems Ltd., Jalgaon, pp 1-112.

[16] Jolly S, Yadav KR, Sharma RK, Kothari RM and Ramamurthy V, (2005). Response of *D. strictus* (Roxb) *Nees* seedlings to soil conditioner and PGR. J. Non-timber Forest Prod., 12, 187-190.

[17] Mendki PS, Kotkar HM, Upasani SM, Maheshwari VL and Kothari RM, (2003). Use of various botanicals for combating the attack of pulse bettle, *Callosobruchus chinensis* (Linnaeus). In : Biopesticides and pest management, Vol. 2, (Eds. O. Kaul, G. S. Dhaliwal, S. S. Marwaha and J. K. Arora), Campus Book International, New Delhi, pp. 70-79.

[18] Mendki PS, Maheshwari VL and Kothari RM, (2000). Papaya leaf dust as a post-harvest preservative for five commonly utilized pulses. J. Plant Biol., 27, 197-199.

[19] Patil AB, Vasane SR, Moharir KK and Kothari RM (2010). Contamination control and disease management of banana var. *Grand nain* plantlets. Acta Horti. 865, 247-253.

[20] Patil DP, Kulkarni MV and Kothari RM, (2001). Biotech inputs inherently bear the capacity to remediate saline soils. Perspectives in Biotechnol. (Eds. S. M. Reddy, D. Rao and Vidyavati), Sci. Publ., Jodhpur, 35-40.

[21] Patil DP, Kulkarni MV, Maheshwari VL and Kothari RM, (2002). A sustainable agro-biotechnology for bioremediation of saline soil. J. Sci. Ind. Res., 61, 517-528.

[22] Patil DP, Kulkarni MV, Maheshwari VL and Kothari RM, (2002). Recycled agro-waste and modified industrial byproduct with halophiles for improved yield of wheat (*T. aestivum* L) in saline soil. Physiol. Mol. Biol. Plants, 8, 117-124.

[23] Patil MG, Chaudhari AB, Phirke NV, Talegaonkar SK and Kothari RM, (2005). Why performance of PSMs was not guaranteed? In : Frontiers of plant science. (Eds. K. G. Mukerji, K.V.B.R. Tilak, S. M. Reddy, N. V. Gangawane, R. Prakash and I. K. Kunwer), IK International Pvt. Ltd., New Delhi, pp. 465-480.

[24] Patil RP, Chaudhari AB, Mendki PS, Maheshwari VL and Kothari RM (2006). Soybean as a Cindrella crop for enhanced soil fertility and human health. Focus on plant agriculture – 1: Nitrogen nutrition in plant productivity. (Eds., R. P. Singh, N. Shankar and P. K. Jaiswal), Studium Press LLC, Houston, USA.

[25] Patil SG, Patil MG, Mendki PS, Maheshwari VL and Kothari RM, (2000). Antimicrobial and pesticidal activity of *Nerium indicum.* Pestology, 24, 37-40.
[26] Pereira LS, 1989. Mitigation of droughts. 2. Irrigation. ICID Bull. 38, 16-34.
[27] Pereira LS, 1999. Higher performances through combined improvements in irrigation methods and scheduling: a discussion. Agric. Water Manage. 40, 153-169.
[28] Pereira LS, Oweis T and Zairi A, (2002). Irrigation management under water scarcity. Agricultural Water Management 57, 175-206.
[29] Phirke NV, Chincholkar SB and Kothari RM, (2002). Optimal exploitation of native arbuscular and vesicular arbuscular mycorrhizae for improving the yield of banana through IPNM. Indian J. Biotechnol., 1, 280-285.
[30] Phirke NV, Chincholkar SB and Kothari RM, (2004). Applicability of fly ash is sound for rhizosphere, biomass yield, enhanced banana productivity and sustainable ecosystem. In: New horizons in biotechnology (Ed., S. Roussos), Kluwer Academic Publ., San Diego, USA, pp. 423-436.
[31] Phirke NV, Patil RP, Chincholkar SB and Kothari RM (2001). Recycling of banana pseudostem waste for economical production of quality banana. Resources Conservation Recycling, 31, 347-353.
[32] Phirke NV, Patil RP, Sharma RK, Kothari RM and Patil SF, (2001). Eco-friendly technologies for agriculture, horticulture, floriculture and forestry for 21st Century. In: The Environment – Global changes and challenges. (Ed. R. Prakash), ABD Publ., Jaipur, 77-127.
[33] Pitts D, Peterson K, Gilbert G, Fastenau R, 1996. Field assessment of irrigation system performance. Appl. Eng. Agric. 12, 307-313.
[34] Prinz D, 1996. Water harvesting – pst and future. In: Pereira LS, Feddes RA, Giley JR, Lessafre B (Eds), Sustainability of Irrigated Agriculture. Kluwer Academic Publishers, Dordrecht, pp. 137-168.
[35] Ramamurthy V, Sharma RK and Kothari RM, (1998). Microbial conversion of lignocellulosic wastes into soil conditioners. Advances in Biotechnol., (Ed. A. Pandey), Educational Publ., New Delhi, 433-438.
[36] Ramamurthy V, Sharma RK, Yadav KR, Kaur J, Vrat Dev and Kothari RM (1996). *Volvariella*-treated eucalyptus sawdust stimulates wheat and onion growth. Biodegradation, 7, 121-127.
[37] Rosegrant M and Ringler C 1999. Impact on food security and rural development of reallocating water from agriculture. IFPRI. Washington DC.
[38] Santhi C, Pundarikanthan NV, 2000. A new planning model for canal scheduling of rotational irrigation. Agric. Water Manage. 43, 327-343.
[39] Sarwar A, Bastiaanssen WGM, 2001. Long-term effects of irrigation water conservation on crop production and environment in semi-arid areas. J. Irrig. Drain. Eng. 127, 331-338.
[40] Seginer I, 1987. Spatial water distribution in sprinkler irrigation. In: Hillel, D. (Ed.), Advances in Irrigation, Vol. 4. Academic Press, Orlando, pp. 119-168.
[41] Shangguan Z, Shao M, Horton R, Lei T, Qui L, Ma J, 2001. A model for regional optimal allocation of irrigation water under deficit irrigation and its applications. Agric. Water Manage. 52, 139-154.

[42] Sharma KD, 2001. Rainwater harvesting and recycling. In: Goosen, MFA, Shayya WH (Eds.), Water Management, Purification and Conservation in Arid Climates. Technomic Publishing Company, Lancaster, PA, pp. 59-86.
[43] Sharma RK and Kothari RM (1993). An innovative approach to improve productivity of rice, Internat. Rice Res. Newslett. (IRRN), 18, 19-20.
[44] Sharma RK and Kothari RM (1993). Recycled cereal proteins as foliar spray enhances quality and production of food crops. Resources, Conservation and Recycling, 9, 213-221.
[45] Sharma RK and Kothari RM 1992 Innovative application of corn steep liquor for the increased production of food grains. Technovation, 12, 213-221.
[46] Sharma RK, Yadav KR and Kothari RM (1994). Innovative recycling of vegetable proteins waste for the increased crop productivity. , Technovation, 14, 31-36.
[47] Sharma RK, Yadav KR, Vrat Dev and Kothari RM (1995). Cereal protein hydrolysate: Environmental friendly plant growth promoter. Fresenius Environ. Bulletin, 4, 86-90.
[48] Sharma RS, Kothari RM and Ramamurthy V, (2004). The role of potting media in raising *Acacia auriculiformis* plantlets in nursery. Indian J. Forestry, 27, 51-55.
[49] Singh G, Sharma RK, Ramamurthy V and Kothari RM (1995). Enhancement of *Sprirulina* biomass productivity by a protein hydrolysate., Appl. Biochem. Biotechnol., 50, 285-290.
[50] Singh HP, Mann JS, Pandey UB, Singh L and Bhonde SR (2002). Planting material of horticultural crops: Issues and strategies. Publi. of Dept. of Agri. and Co-op and Natl. Horti. R & D Foundation, Nashik, pp 1-220.
[51] Suryawanshi PC, Kirtane RD, Chaudhari AB and Kothari RM, (2009). Conservation and recycling of pomegranate seeds and shells for value addition. *J. Renew. Sustain. Energy.*
[52] Talegaonkar SK (2000). Use of press mud for sustainable preservation of biofertilizers under ambient conditions. Ph.D. Thesis, North Maharashtra University, Jalgaon, India.
[53] Talegaonkar SK, Chincholkar SB and Kothari RM, (1999). Application of press mud as plant growth regulator and pollution arrester. Biofertilizers and Biopesticides, (Ed. A. M. Deshmukh), Technosci. Publ., Jaipur, 66-71.
[54] Talegaonkar SK, Chincholkar SB and Kothari RM, (2001). Press mud for sustainable agro-productivity. Indian J. Environ. Protection, 21, 41-50.
[55] Teixeira JL, Fernando RM, Pereira LS, 1995. Irrigation scheduling alternatives for limited water supply and drought. ICID J. 44, 73-88.
[56] Tyagi NK, Minhas PS (Eds.), 1998. Agricultural Salinity Management in India. Central Soil Salinity Research Institute, Karnal, India, 526 pp.
[57] Unger PW, Howell TA, 1999. Agricultural water conservation – a global perspective. In: Kirkham MB (Ed.), Water use in crop production. Food Products Press, New York, pp. 1-36.
[58] Vasane SR and Kothari RM, (2009). An integrated biotech approach to sustainable cultivation of banana var. *Grand naine*. Textbook on molecular biotechnology, (Eds. A. Varma and N. Verma), I. K. International Publ. Pvt. Ltd., New Delhi.

[59] Vasane SR and Kothari RM, (2006). Optimization of secondary hardening process of banana plantlets. *Musa paradisiaca* L. Var. Grand Naine. Indian J. Biotechnol., 5, 394-399.

[60] Vasane SR and Kothari RM, (2008). An integrated approach to primary and secondary hardening of banana var. Grand Naine. Ind. J. Biotechnol., 7, 240-245.

[61] Vasane SR, Patil AB and Kothari RM, (2010). Bio-acclimatization of *in vitro* propagated banana plantlets var. *Grand nain.* Acta Horti. 865, 217-224.

[62] Verma RK, Sharma RK, Maheshwari VL and Kothari RM, (2000). Calcium conjugates of amino acids and ecologically safe plant growth regulators. J. Plant Biol., 27, 85-88.

[63] Yadav KR, Sharma RK and Kothari RM (2002). Eco-friendly bioconversion of *eucalyptus* bark waste into soil conditioner. Biores. Technol., 81, 163-165.

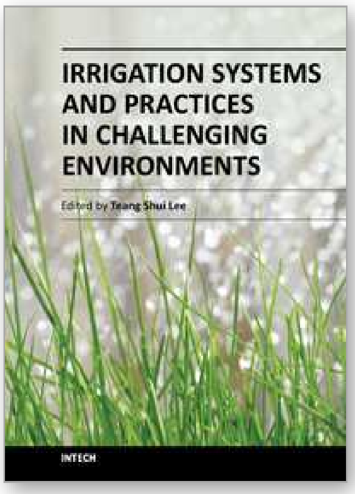
[64] Yadav KR, Sharma RK, Yadav MPS and Kothari RM (1995). Human hair waste: An environmental problem converted into an eco-friendly plant tonic. Fresenius Environ. Bulletin, 4, 491-496.

[65] Zhang H, Oweis T, 1999. Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agric. Water Manage. 38, 195-211.

[66] Zhang H, Oweis TY, Garabet S, Pala M, 1998. Water-use efficiency and transpiration efficiency of wheat under rain-fed conditions and supplemental irrigation in a Mediterranean type environment. Plant Soil 201, 295-305.

[67] Zimmer D & Renault D 2003. Virtual Water in Food production and Trade at global scale: review of methodological issues and preliminary results. Proceedings Expert meeting on Virtual Water, Delft, December 2002.

[68] Zope HN, Kulkarni VA, Mendki PS, Nagasampagi BA, Naik K and Kothari RM (2000). An effort towards development of eco-friendly rural technology for *Parthenium*-based biopesticide. Ind. J. Environ. Protection, 20, 332-336.



Irrigation Systems and Practices in Challenging Environments
Edited by Dr. Teang Shui Lee

ISBN 978-953-51-0420-9
Hard cover, 370 pages
Publisher InTech
Published online 28, March, 2012
Published in print edition March, 2012