TECHNICAL ADVANCEMENTS & INNOVATIONS FOR EFFICIENT IRRIGATION MANAGEMENT

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ABSTRACT

Efficient Irrigation Management through lens of Water-Energy-Food (WEF) nexus is a complex multidimensional concept emerging in the international community, compounded with challenges of climate change and social changes including population growth, globalization, economic growth, urbanization, growing inequalities, and social discontent. These issues exert tremendous pressure on water, energy, and food resources, presenting communities with an increasing number of trade-offs and potential conflicts among these resources that have complex interactions. The demands for water, energy, and food are estimated to increase by 40%, 50% and 35%, respectively, by year 2030. Addressing the WEF nexus in a sustainable manner has therefore become one of the most critical global environmental challenges today, the need of an hour.

Water scarcity already impacts about one-third of the global population and the world is poised to experience even more fresh water constraints.

By improving water use and management in agriculture and the use of latest technical advanced tools and innovative approach, humanity will increase the water resources that are available to those that need it the most, help communities around the world in a sustainable manner, reduce soil erosion, reduce conflicts over natural resources, and help to ensure food security for everyone.

As water for irrigation and food production constitutes one of the greatest threats to the sustainability of the world’s freshwater resources, conservation & optimization techniques need to be constantly evolved and improved through interventions and innovations. The best systems require little maintenance while yielding maximum results. The focal areas identified to shape future through technical advancements & interventions in irrigation management predominantly include the following:

GROWING MORE WATER EFFICIENT CROPS

By growing a variety of less thirsty, more water efficient crops, including perennial crops with deep roots, crops that are well-suited to local climate conditions reduce the demand for water in agriculture, considerably.

Precision use of irrigation either by scheduling irrigation for times when the crops require it or using irrigation only in areas required. Methods can include direct measurement of soil water content to inform on timing and placement, sprinkler or drip irrigation. The issues of access to and management of water supplies can limit the feasibility of some of these techniques in some areas, which require efficient planning & management.

Use methods alternative to irrigation such as rainwater harvesting and treated wastewater.

Enhance water retention in the soil through farming methods and systems such as residue management, conservation tillage, zai, bunds, contouring and field levelling.

CROP MANAGEMENT STRATEGIES

Adoption of number of strategies for crop management that can improve water use efficiency including:
• Capturing more water for crop transpiration through water harvesting, reducing soil evaporation, improved weed control and by deeper root growth.
• Improving Biomass Water Ratio by exchanging transpired water for CO₂ more effectively and converting into biomass.
• Convert more biomass into harvestable yield.

SUPPORT HEALTHY SOIL
Ensuring healthy soil ecology capable of retaining water much more efficiently than depleted and heavily tilled soil. Methods that can help to maintain healthy soil include adding compost, residue management, conservation tillage, and no tilling farming techniques.

PERMACULTURE FARMING METHODS
Many permaculture farming methods, such as swales built on contour, inherently hold water on the landscape, reduce (or even eliminate) the need for supplemental watering of crops, and help to restore aquifers.

REDUCE FOOD WASTE
In today’s world, approximately 30-40% of food that is produced is wasted. By reducing the amount of food wasted, reduction in the amount of water, land, and energy that is used to produce the food can be minimized.

INNOVATIVE TECHNOLOGIES
Upcoming new innovative technologies such as micro-scale solar desalination units or nanotechnology hold future potential in shaping tomorrow. But whether at the frontiers of technology or tried and tested, many of the solutions to agriculture’s dependence on water require knowledge, research and access to forms of innovation.

Investing in participatory research that meets the water and production needs of local farmers is therefore critical to reducing water use in agriculture and building the sector’s sustainability.

Key words: irrigation management, interventions, innovations, crop management strategies, water efficient crops

INTRODUCTION
Nexus interactions are complex and dynamic, and sectoral issues cannot be looked at in isolation from one another. Importantly, they exist within a wider context of transformational processes – or drivers of change – that need to be taken into account.

Food and water are essential for human existence and energy is the key to human development, constituting a complex web of inter-linkages. Access to these resources and their sustainable management are the basis for sustainable development. Recognizing that efficient use of these limited or declining resources is essential to sustainability, the global community has turned its attention to the concept of the food, water, and energy nexus.

One of the major issues which the humanity is facing is food security and increasing productivity is one of the way to resolve major issue. Productivity and the availability of water, energy and land vary enormously between regions and production systems. There is a large potential to increase overall resource use efficiency and benefits in production and consumption, e.g. by addressing intensive agriculture (which often has higher water productivity but lower energy productivity than other forms of agriculture). The nexus approach can boost this potential by addressing externalities across sectors. For example, nexus thinking would address the energy intensity of desalination (also termed ‘bottled
electricity’), or water demands in renewable energy production (e.g. biofuels and some hydropower schemes) or water demands of afforestation for carbon storage. Also, action to avoid or land degradation saves water and energy, for example by increasing soil water storage and groundwater recharge, as well as reducing the use of energy intensive fertilizer.

Agricultural water management i.e. irrigation management plays a central role in food production and food security, and more importantly find its relevance in the changing climate scenario. On the one hand, poor water management practices contribute to depletion and degradation of land & water resources. On the other hand, improved water management plays a vital role in increasing food production and reducing food insecurity as well as supporting sustainable land and water resources development.

Water of appropriate quality and quantity is essential for the production of crops, livestock, and fisheries, as well as for the processing and preparation of these foods and products. Water is the lifeblood of ecosystems, including forests, lakes, and wetlands, on which the food and nutritional security of present and future generations depends. At the same time, agriculture is the largest water user globally, and a major source of water pollution. Unsustainable agricultural water use practices threatens the sustainability of livelihoods dependent on water and agriculture. So, interventions & innovations in irrigation is the need of an hour for sustainable development.

TECHNICAL ADVANCEMENTS & INNOVATIONS IN IRRIGATION MANAGEMENT

The best practices, interventions and innovation focus on all aspect of optimal water utilization include selection of crops, efficient irrigation practices, water saving & harvesting techniques, soil characterization and solution out of box.

A glimpse of similar such solutions towards resolution of water crises in food – water – energy nexus through the best of irrigation management practices is presented in the paper as follows.

1. GROWING MORE WATER EFFICIENT CROPS - DROUGHT TOLERANT CROPS AND SEEDS

Grow the right crop for the growing region. Regions which suffer water shortages are wise to plant crops which are more tolerant to drought. These include finger millet, pearl millet, Guinea millet, cowpea, teff, lentils, amaranth, fonio, emmer, various sorghums, African rice, Ethiopian oats, irregular barley, mung beans and many grasses. Ideally, researchers would be working with all of the crops on this list to improve the seeds for our crop requirements of tomorrow.

Figure - 1. Interwoven Relation amongst food Water & Energy development.

Figure - 2. Finger Millet
For example, researchers have improved cassava varieties over the past four decades which can increase yields two to four-fold over traditional varieties. Traditional millets require little water and can grow in poor soils without any synthetic fertilizers. Millet is a heat resistant crop which has high calcium and fiber content as well as essential amino acids.

In addition, drought tolerant crop seeds are available both through biotechnology and from native seed varieties. Examples of drought tolerant seeds available today include corn, rice, and cotton. Just as importantly, there are flood resistant rice seeds available. Having the right, reliable, and quality seeds in hand for a new planting season is of utmost importance.

2. PRECISION USE OF IRRIGATION

2.1 Drip or Micro - Irrigation

Drip irrigation delivers water (and fertilizer) either on the soil surface or directly to the roots of plants through systems of plastic tubing with small holes and other restrictive outlets. By distributing these inputs slowly and regularly, drip irrigation conserves 50% to 70% more water than traditional methods while increasing crop production by 20% to 90%. The water and fertilizer are also more easily absorbed by the soil and plants, reducing the risks of erosion and nutrient depletion.

Usually operated by gravity, drip irrigation saves both the time and labour that would otherwise be needed to water crops, leading to larger harvest yields. Small systems on timers can easily be set up by the home gardener, too.

This technology must be innovated and tailored to the crop and conditions. For example, some systems are now solar powered and tubing materials have changed. There are many styles of drip inserts which can be incorporated into the hoses and soaker hose segments can also be used. Instead of using plastic tubing, ceramic can be used as it is more porous.

Small stream diversions, water collection tanks, or holding ponds can be used to provide a gravity water supply for drip irrigation systems. Hand or peddle powered pumps or elevated buckets can also be used, mainly fit for the remotest corner of the globe.

These micro-irrigation systems, while affordable, are less suitable for major rice growing areas or for staple grain growing. They are more suitable for high value vegetable gardens. Care should be taken to avoid the build-up of salts in drip-system soils.

Within the last two decades, the area irrigated using drip and other micro-irrigation methods has increased more than six-fold, to over 10 million hectares. The adoption of drip irrigation in more areas holds much hope for growing more food with less water. For example Zimbabwe is a country in African continent where approximately 80% of agricultural land lies in arid or semi-arid regions and the practice of drip irrigation helped to increase the productivity by 300%.
2.2 Bottle Irrigation and Pitcher (Olla) Irrigation
Buried clay pot (olla) irrigation is an ancient technology that uses a logical idea. By burying a porous clay pot up to its neck, and filling it with water, a gardener has a 70% efficient watering system. Water weeps slowly out of the pot and moistens an area about one-half the diameter of the olla. Since soil is not saturated, the environment created is very healthy for the plant roots, which form a mat around the olla. (Many modern gardeners kill plants by overwatering)

A perfect olla has a thick wall, is fired at a high temperature, has rough surfaces, and holds one quart to two gallons of water. After burying the pot and filling it with water, the top can be covered with a rock to keep it clean and prevent evaporation.

Depending upon the crop and the rainfall, filling the pots two to three times a week may be adequate. To use an olla, place it in the middle of several plants so that the plants draw moisture from the center and grow outward onto dry land. This uses the space and the water very efficiently. Smaller ollas may be used to water containers or patio pots. If the pots lose flow after many years of use, they can be soaked in vinegar to reopen pores. Always use clean or settled water and don’t add fertilizer so as not to clog the clay’s pores.

Feeding water in root zone can also be done using recycled bottles for bottle-micro irrigation. There are various designs to aid in using a recycled bottle as a slow release pot or plant waterer. Wine bottles, plastic bottles, and almost any bottle will work. Holes can be tapped into plastic sides or lids, or commercial plastic spikes can be purchased which the bottle can be inserted into. Or, a bottle can simply be filled with water and inverted next to a plant into moist soil.

3. ALTERNATIVE TO IRRIGATION

3.1 Rain Water Harvesting
Rainwater harvesting for agriculture generally involves the creation of structures such as
check dams, ponds, and percolation tanks to slow the flow of water, and to collect and hold limited quantities at a planned set of places along the flow path. The primary objective is to increase the percolation of the rainwater into the ground to recharge the groundwater table. This leads to a rise in the water table levels, increased supply of water in wells, and a longer period of availability of water. Decentralized small water harvesting structures present a major alternative to the conventional river basin water resource development models. An excellent example is the decentralized, large-scale, check dam rainwater harvesting movement in Saurashtra, Gujarat. This is also brought out by studies conducted by the Central Soil and Water Conservation Research and Training Institute, Dehradun (reported by Khurana 2003). The studies show a clear relationship between the size of catchment and amount of run-off that can be captured. Increasing the size of the catchment from 1 hectare (ha) to about 2 ha reduces the water yield per hectare by as much as 20 per cent. Thus, in a drought prone area where water is scarce, 10 tiny dams with a catchment of 1 ha each will collect more water than one larger dam with a catchment of 10 ha. Khurana (2003) indicates that the drought proofing benefits from small rainwater harvesting structures can very effectively distribute the available water when there is no drought or a limited drought. It has improved the stability of crop yields and can raise productivity from 1 tonne per hectare to 3-4 tonnes.

Treated Waste Water

Treated sewage water can be used for irrigation, industry, recharge of ground water and, in special cases, properly treated wastewater can be used for municipal supply. With careful planning various industrial and agricultural demands may be met by purified water. In arid and semi-arid areas water resources are so scarce that there is often a major conflict between urban (domestic and industrial) and agricultural demands for water. This conflict can usually only be resolved by the agricultural use of wastewater: the cities must use the fresh water first, urban wastewater after proper treatment-used for crop irrigation. As an example, a city with a population of 500,000 and water consumption of 200 l/d per person would produce approximately 85,000 m$^3$/d (30 Mm$^3$/year) of wastewater, assuming 85% inflow to the public sewerage system. If treated wastewater effluent is used in carefully controlled irrigation at an application rate of 6000 m$^3$/ha/year, an area of some 5000 ha could be irrigated. In addition to this economic benefit, the fertilizer value of the effluent is important. Typical concentrations of nutrients in treated waste water effluent from conventional sewage treatment processes are:

Nitrogen (N) - 50 mg/l
Phosphorus (P) - 10 mg/l
Potassium (K) - 30 mg/l

Assuming an application rate of 5000 m$^3$/ha/year, the fertilizer contribution of the effluent would be:
- N - 250 kg/ha/year
- P - 50 kg/ha/year
- K - 150 kg/ha/year

Thus, all of the nitrogen and much of the phosphorus and potassium normally required for agricultural crop production would be supplied by the effluent. Further, other valuable micronutrients and the organic matter contained in the effluent will provide additional benefits.

Waste waters contain valuable plant nutrients and thus its reuse in agriculture serves as an important source of nutrients and irrigation water for crops. Better crop growth particularly of leafy vegetable like cauliflower, cabbage, spinach etc. grown on fields receiving sewage waste water have been achieved. The results of many studies on the use of waste water for long period of time have recapitulated significant increased in crop yields than ground water irrigated fields. Significantly higher onion yield and maximum fertilizer use efficiency from plots fertilized with 40kg N, 20kg P$_2$O$_5$ and 20kg K$_2$O per ha dose conjointly with distillery effluents (25-times diluted) over ground water irrigated plots has been reported. The field experiments conducted on the use of waste water for irrigation to maize, sunflower, groundnut and soybean registered 19.3%, 29.9%, 5.9% and 4.8% higher grain yield, respectively over fields irrigated with ground water.

![Figure - 7. Waste water irrigation](image)

A favourable effect of treated paper and pulp industry effluents on maize, barley and wheat grown in coarse textured soil has also been reported in India. The yield increase from 6.9 to 13.9% in different sugarcane varieties grown with waste water over ground water irrigation has been recorded. An another long-term experiment have shown that sewage waste water irrigation had lead to highest grain yield of wheat, rice and cotton by 23, 46 and 50% than ground water irrigation. A gradual increase in peanut pod yield has also been reported with the application of waste waterupto 50% concentration in effluent from textile industry. So, recycling treated waste water is one of the best way to enhance crop productivity besides getting rid of the menace.

4. ENHANCE WATER RETENTION IN SOIL

4.1 Zai Pits

Zai planting pits are hand dug holes about ten inches wide, ten inches deep, and three feet apart (25cm x 25cm holes one meter apart). They are used to trap water and increase soil fertility, especially in arid regions with degraded, crusty soils. The pits are planted with a mixture of crop residues, manure, and seeds, and covered with a mulch of grass or leaves.
When digging the pits, the excavated soil is used to make a small ridge around the pit to help capture rainfall. The pits can be reused if silt and sand are removed annually. This simple technique can increase the amount of crops that smallholder farmers produce by 50% after just three years.

4.2 Ripper - Furrower Planting System

Ripper-furrower system is used to rip say 60 cm (2 feet) deep and form furrows which function to harvest rainfall. The crop seeds are planted into the rip lines with fertilizer and manure. When it rains, the water is funneled by the furrows to the crop roots. Tractors are used the first year to start the ripped furrow system. After the first year, farmers plant crops directly into the rip lines using an animal drawn direct seeder.

This practice is being used to plant drought tolerant millet, sorghum, and maize. Farmers using the system are encouraged to practice crop rotation with legumes. These practices together lengthen the growing season and improve the soil’s structure, fertility, and moisture retention. They improve crop growing in both droughts and floods. Average maize yields have increased from 300 kg/hectare to 1.5 tonnes/hectare, or five-fold in Namibia since using this system.

This method of rainwater harvesting especially aids in regions where soil is dry, solid, and crusty. Whereas the rain previously ran off, now it soaks into the ground right where it is needed to grow the crop.

5. CROP MANAGEMENT STRATEGIES - BLACK PLASTIC MULCH, AND ORGANIC MULCHES

Organic vegetable producers in drier, cooler climates like to use black polyethylene plastic film as mulch on vegetable row crops for multiple reasons. When drip irrigation is laid underneath the plastic film, it delivers water and fertilizer to the plants and evaporation is reduced. But, because there is no surface evaporation of water, it
is easy to over-irrigate crops. For this reason, a moisture probe should be used to check root zone moisture levels. In addition to providing water conservation, this synthetic mulch controls weeds and warms the soil, making for an earlier crop. The black plastic mulch can be covered with hay or straw to protect crops from excessive heat later in the summer. Other than black plastic film, which can only be used one season, black woven landscape cloth is often used, which can be reused up to seven years. Organic mulches such as straw, hay, grass clippings, pine needles, and leaves also conserve moisture. These organic mulches add organic matter to the soil after they decompose. One needs to pay attention how different organic mulches can change the soil chemistry.

An experiment on mulching with plastic films was conducted for groundnut Aliyarnagar Research Station. The film was LLDPE black and the thickness were 15 micron (T10, 20 micron (T2), 25 micron (T3), coir pith at the rate of 20 T/ha (T4) and fifth plot was control (T5). Each plot was 2m x 1m and experiments were replicated four times. For sampling purpose, 5 plants in each of the experimental plots were considered for rot length on 60th day. The crop was harvested on 110th day since sowing. Parameters like soil moisture, soil temperature, germination; weed, root and yield were observed

Table 1. Comparison between Treatment method and yield

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Available moisture at harvest (%)</th>
<th>Wet weed wt. (g)/plot at 45th day</th>
<th>No. of pods/plant</th>
<th>Pod yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 – 15 micron LLDPE (black)</td>
<td>7.69</td>
<td>150</td>
<td>9.00</td>
<td>1337</td>
</tr>
<tr>
<td>T2 – 20 micron LLDPE (black)</td>
<td>7.62</td>
<td>156</td>
<td>7.75</td>
<td>1118</td>
</tr>
<tr>
<td>T3 – 25 micron</td>
<td>7.05</td>
<td>179</td>
<td>7.50</td>
<td>1275</td>
</tr>
<tr>
<td>T4 – Coir pith 20 t/ha</td>
<td>6.50</td>
<td>257</td>
<td>6.75</td>
<td>1012</td>
</tr>
<tr>
<td>T5 Control – no mulch</td>
<td>5.90</td>
<td>370</td>
<td>6.75</td>
<td>850</td>
</tr>
</tbody>
</table>

Mulching with 15 micron LLDPE film was found to give higher pod yield due to better moisture conservation, reduced weed growth, when compared to coir pith mulch and control. From the results it was also seen that the thickness of film did not matter much in conserving moisture.

6. SUPPORT HEALTHY SOIL- SYSTEM OF RICE INTENSIFICATION (SRI) OR SYSTEM OF CROP INTENSIFICATION (SCI) OR SYSTEM OF ROOT INTENSIFICATION (SRI)

Millions of smallholder farmers have found that by using system of rice intensification (SRI) and system of crop intensification(SCI) methods of farming, they can get higher yields with fewer inputs through setting up an environment with optimal conditions for the plant. The effect is to get crop plants to grow larger, healthier, longer-lived root systems, accompanied by increases in the abundance, diversity and activity of soil organisms. These organisms constitute a beneficial microbiome for plants that enhances their growth and health. These principles, applied to growing rice in systems for 30-some years, are being successfully applied to growing vegetables, legumes, wheat, corn, finger millet, and sugarcane. The methods use 25 to 40 % less water, and make crops more resilient to temperature and precipitation stresses. Crops can be productive with less irrigation water or rainfall because
SRI or SCI conditions enhance the capacity of soil systems to absorb and provide water.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger millet</td>
<td>200% - 300%</td>
</tr>
<tr>
<td>Legumes</td>
<td>50% - 200%</td>
</tr>
<tr>
<td>Maize</td>
<td>75%</td>
</tr>
<tr>
<td>Mustard</td>
<td>200% - 300%</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>20% - 100%</td>
</tr>
<tr>
<td>Turmeric</td>
<td>25%</td>
</tr>
<tr>
<td>Vegetables</td>
<td>100% - 270%</td>
</tr>
<tr>
<td>Wheat</td>
<td>10% - 140%</td>
</tr>
</tbody>
</table>

SRI methodology is based on four main principles that interact in synergistic ways:

- Establish healthy plants early and carefully, nurturing their root potential.
- Reduce plant populations, giving each plant more room to grow above and below ground and room to capture sunlight and obtain nutrients.
- Enrich the soil with organic matter, keeping it well aerated to support better growth of roots and more aerobic soil biota.
- Apply water purposefully in ways that favor plant – root and soil – microbial growth, avoiding flooded (anaerobic) soil conditions.

7. **Permaculture Farming Methods - Swales Built on Contour**

Contour swales can be used effectively by small farms to slow and capture surface runoff, and infiltrate rainfall into the soil. These swales are built on the contour, perpendicular to the direction of the runoff, and are designed for waterspread, not watershed. Water that might otherwise leave the property in large rainstorms is slowed and allowed to seep into the soil, storing it there for use by trees in drier seasons.

![Figure - 11. Contour Swales](image)

The primary goal of a swale is to increase the soil’s storage capacity. The soil moisture in and around a swale remains long after the spring rains have gone. Because of this, garden beds below a swale will be gravity-fed and remain lush for many weeks longer than the surrounding area. The moist microclimate will require much less irrigation. Humus will build and absorb even more moisture, storing water in the ground deeper and longer than water spreading across the soil surface.
8. INNOVATIVE TECHNOLOGIES - MICRO - SCALE SOLAR DESALINATION UNITS

Water challenge in arid countries is considered one of most critical challenges facing agriculture and food systems, and is expected to grow with time. This is due mainly to the scarcity and rapid depletion of freshwater resources, and the increasing groundwater salinity. Nevertheless, these countries have generally a great solar energy potential. This potential can be best developed by solar desalination concepts and methods specifically suited for rural water supply, including small-scale irrigation, and also the protection of available water resources against overuse and pollution.

Renewable-energy-based desalination methods offer a promising solution irrigation in arid region. The solar still is one such sustainable method that has been in operation for hundreds of years. In their simplest design, solar stills consists of transparently-roofed basins that are normally black-painted to maximize solar heat absorption. Brakish or sea water is placed in the basin and slowly evaporates due to heating by the sun rays. This vapour condenses as it hits the cooler cover of the still and trickles down where it is collected by separated channel as distillate.

The stills can have various forms, shapes and cover materials and their operation requires little maintenance besides regularly flushing the basin to remove accumulated salts. The major limitations on the use of solar stills include their low productivity per unit installation area compared to fuel-based desalination methods, their high initial costs for production unit, the need of large installation areas, variability of the energy source and limited experience with large-scale applications. Therefore research and development work is being conducted in this direction.

CONCLUSION

Food security is one of the major challenge faced by the human race. Water energy food nexus approach is one way to deal with this issue. It can be achieved by exploring various dimension of the nexus. One such dimension is reducing the water used in the agricultural activity. Reducing the water used indeed highlights the point that the mitigating provision of additional water to the crops which ultimately remain untapped and occur as loss. The best results can be obtained by the blend of traditional irrigation practices with the modern advanced technologies and innovations, as highlighted in the paper.

REFERENCES

1. Agriculture: Increase water harvesting in India by Jhonrockstrom&MalinFalkenmark.
2. http://pubs.sciepub.com/ajer/1/2/1
3. Irrigation with treated municipal waste water – ateefhamdy.
9. www.hobbyfarms.com