PRECISION IRRIGATION- A TOOL FOR SUSTAINABLE MANAGEMENT OF IRRIGATION WATER

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ABSTRACT

Water resources management approaches around the world are changing dramatically. This "changing water management paradigm" has a plethora of components. These components are- a shift from sole reliance on finding new sources of supply to address perceived new demands, a growing emphasis on incorporating ecological values into water policy, a re-emphasis on meeting basic human needs for water services and a conscious breaking of the ties between economic growth and water use. A reliance on physical solutions continues to dominate traditional planning approaches, but these solutions are facing increasing opposition. At the same time, new methods are being developed to meet the demands of growing populations without requiring major new construction or new large-scale water transfers from one region to another. Irrigation water suppliers and planning agencies are exploring efficiency improvements, implement measures for managing water demand and allocating water among stakeholders/users to reduce projected gaps and meet future needs in a sustainable manner. The connections between water and food are receiving increasing attention in the context of an ever-growing population as freshwater availability is reducing. This is rightly so because of the fact that agriculture is by far the largest consumer of fresh water. These shifts have not come easily; they have met strong internal opposition. These changes represent a real shift in the way we human beings, especially the farmers, water management experts, water resources planners think about water use. This paper summarizes the components of this ongoing shift and looks at the new paths in the form of Precision Irrigation being explored in different parts of the world. Precision irrigation, an existing aspect of precision agriculture is just beginning to be explored. This means applying water in the right place with the right amount at the right time. The approach is still in the development stage and requires a lot of investigation and experimental work to determine its feasibility and applicability across a range of crops and agro-climatic regions. The availability of some low-cost data gathering methods, positioning systems and the development in computer programming will help in regulating the depth of water within a field. So the next generation in irrigation scheduling would be not just when and how much to irrigate but when, how much and where to irrigate. That is to say that the paradigm shift would be from 'uniform irrigation treatment' that underlies traditional irrigation approach to 'differential irrigation treatment'.

Keywords: Precision, irrigation, demand, supply, scheduling, efficiency

INTRODUCTION

Of all natural resources, water is the most essential and fundamental to all vital processes. It seems abundant at first sight-almost 70% of the earth's surface is covered with water. First of all, the seemingly abundant availability of water is misleading. Freshwater- the only usable kind, as far as human needs are concerned--is only a small fraction (2.5%) of the water present on our planet. Further, most of freshwater is in the form of permanent ice and snow or of groundwater which, given its life cycle of several thousand years, must be regarded as unrenewable on a human time scale. In the end only 0.30% of freshwater is renewable. Thus, in order to understand the nature of water use issues it is necessary to understand some characteristics of water supply. It is estimated that about 3 billion people live in areas with chronic water shortages. Fresh water for the rest too is not entirely adequate. Quantitative supply and water quality problems are mounting and could constrain economic development and human well-being. Adequate food and water and concurrent maintenance of the resource base and the environment for the present and future generations are two challenging tasks that confront mankind today. Estimates point out that agricultural production system consumes about 70% of the fresh water i.e. 1,500 billion m^3 out of the 2,500 billion m^3 of water annually (Goodwin and O'Connell 2008).

It is also estimated that about 40% of the fresh-water used for agriculture in developing countries is lost either by evaporation, spills or absorption by deeper layers of soil, beyond the reach of plants' roots (Panchard et. al., 2007).

Growing pressure from competing sectors (domestic, industrial, municipal, service etc.) for water, along with environmental imperatives, mean that agriculture must obtain "more crops from fewer drops" and that too with less negative impact on the environment. This is a significant challenge and implies that water management for sustainable crop production will need to be smarter in the context of an ever growing world population, especially in countries like India and China with population of India projected to be 1600 million and that of China stabilizing at 1340 million by 2050.

THE INDIAN SCENARIO

The challenges of irrigation in India can be summarized as Per Drop More Crop. Increasing incomes, growing urbanization and rising prosperity are rapidly changing the composition of food basket from cereals to fruit, vegetables, milk, poultry, fish and meat. Although per capita consumption of food grains has declined over the years, its total demand has been projected to increase due to increase in population and indirect demand from feed. Most of the fruit, vegetables and livestock products are more water intensive as compared to cereals other than rice. Further preference to have fresh fruit and vegetables round the year is resulting in increase in their cultivation in off season requiring much higher use of water. The amount of water required to produce a unit of animal origin products is much higher than plant origin products. These developments point to rising pressure on India's limited water resources. Moreover, about 55% of current area under cultivation is not covered by irrigation resulting in low productivity and high risk to production due to erratic rainfall.

India accounts for about 18% the world's population but only 4% of fresh water resources, distribution of which is also uneven. Therefore, as incomes rise and the need for water rises for reasons explained above, the pressure for efficient use of water resources will increase manifold. A country is classified as Water Stressed and Water Scarce if per capita water availability goes below 1700 m^3 and 1000 m^3, respectively. With about 1544 m^3 per capita water availability, India is already a water-stressed country and moving towards becoming a water scarce country.

While the stress on limited water resources in the country is rising the scarcity is not reflected in use of water. India uses 2-4 times water to produce one unit of major food crops as compared to China, Brazil, USA (Hoekstra and Chapagain 2008). This implies that if India attains water use efficiency of those countries it can save at least half of water presently used for irrigation purposes. At present, irrigation consumes about 84% of total available water followed by industrial (12%) and domestic (4%). With irrigation predicted to remain the dominant user of water, "per drop more crop" is an imperative. The efficiency of water use must improve to expand area under irrigation while also conserving water.

Irrigation infrastructure in India has undergone substantial expansion. The total irrigation potential created from major, medium and minor irrigation schemes has increased from 22.6 million hectares during pre-plan period to 113 million hectares at the end of 11th Plan. This irrigation potential represents 81% of India's ultimate irrigation potential estimated at 140 million hectares. Hence, the scope for further expansion in this regard is limited implying that efforts must be to improve utilization of irrigation potential of the existing irrigation potential. This is where Precision Irrigation steps in as the savior.

PRECISION IRRIGATION (PI)

Precision irrigation is worldwide a new concept in irrigation. Drip irrigation is often regarded as epitomizing precise irrigation because of its ability to control application rate and timing. A review of literature on precision irrigation brings up a range of definitions, including:

- Precise application of water to meet specific requirements of individual plants or management units and minimize adverse environmental impact (Raine et al., 2007).
- Application of water to a given site in a volume and at a time needed for optimum crop production or other management objective (Camp et al., 2006)
- Applying water in the right place with the right amount (Al-Karadsheh et al., 2002).
- Irrigation management based on crop need to defined sub-areas of a field referred to as management zones (King et al., 2006).

The common element to all of these definitions is the 'differential irrigation treatment' of field variation as opposed to the 'uniform irrigation treatment' that underlies traditional irrigation. Essentially, this is a high-tech sensor-based irrigation water application method/approach with necessary flexibility.

CHARACTERISTICS OF THE SYSTEM

- Optimal management of the spatial and temporal components of irrigation;
- Optimal performance of application system with crop, water and solute management;
- It is not a specific technology. It is a way of thinking, a systems approach.
- It is adaptive, it's a learning system; and
- It is applicable to all irrigation methods and for all crops at appropriate spatial and temporal scales.
- The system (s) therefore, would have the ability to apply water where it is needed, saving water and preventing excessive water runoff and leaching

WHY PRECISION IRRIGATION?

Internal reasons

- Very few fields are uniform and irrigation needs differ between different zones of a particular field
- Most irrigation systems apply water at constant rates; therefore some areas of a field receive too much water while other areas may remain deficit.

Driving forces

- Excessive water application contributes to surface water runoff or leaching of nutrients and chemicals to groundwater

Benefits of Precision Irrigation

Precision irrigation can increase water use and economic efficiencies. Economic benefit lies in reducing the cost of inputs or increasing yield for the same inputs. Precision irrigation improves application efficiency of water up to 80-90% as against about 40-45% in surface irrigation method (Dukes, 2004).

ESSENTIAL STEPS OF A PI SYSTEM

Precision irrigation is best viewed as a management approach defined by the precision farming cycle. There are four essential steps in the process viz. data acquisition, interpretation, control and evaluation.

Data acquisition-

Precision irrigation systems need clear evidence of spatial and temporal variability in soil and crop conditions within a field and between fields and the ability to identify and quantify such variability. Existing technology can measure the various components of the soil-crop-atmosphere continuum (soil based monitoring, weather based monitoring, plant sensing) in real-time and can provide precise control of irrigation applications.

Interpretation-

Data acquired is interpreted and analyzed at an appropriate scale and frequency. The stumbling block currently is inadequate decision support systems for taking precise decision. Multi-dimensional simulation tools (involving crop response, system constraints etc.) would be of much help for optimizing irrigation.

Control-

The ability to adjust irrigation at appropriate scales in space and time is an essential component of a precision irrigation system. Applying different depths of water over a field can be achieved in two ways: by varying the application rate or by varying the application duration. Automatic controllers with real time data from sensors would provide the most reliable and potentially accurate means of controlling irrigation applications.

Evaluation-

It is an important step in the precision irrigation process. Measuring the engineering, agronomic and economic performance of the irrigation system is essential for feedback and improving the system.

Precision irrigation scheduling

- Scheduling is the heart of PI and involves **where, when** and **how much** to irrigate
- This schedule helps to maximize profit while minimizing water and energy use
- The w**here and when** to irrigate aspect may be accomplished in three ways viz. measuring soil-water, checkbook method and remote sensing
- How much to irrigate means **e**nough irrigation water should be applied to replenish the depleted Plant Available Water (PAW) within the root zone and to take care of irrigation inefficiencies

SYSTEMS HAVING POTENTIAL FOR PRECISION IRRIGATION

(a) Center pivot and similar linear-move systems have the maximum potential due to the fact that-

- They provide an outstanding platform on which to mount sensors for real time monitoring of plant and soil conditions
- Interact with a control system for optimal environmental benefits

(b) Drip irrigation system also offers precision irrigation technology. However,

- Drip irrigation represents only a small share of total irrigation
- In addition, high costs limit this to mainly higher-value crops like fruit and vegetables

Precision Irrigation for Rice Cultivation

A lot of water is used in the production of rice as the staple food of more than half the world population. However, despite the constraints of water scarcity, rice production must be raised to feed the growing population. Producing more rice with less water through appropriate precision irrigation technology is a formidable challenge for food and water security. The most populous and rice producing and consuming countries like India and China are approaching the limit of water scarcity. In these countries about 84% of water withdrawal is for agriculture, with major emphasis on flooded irrigation for rice. It is high time that the two countries start adopting precision irrigation methods for growing paddy.

THE STUMBLING BLOCK

A potential stumbling block to the introduction of an effective precision irrigation system is the lack of necessary understanding of the crop production systems. Additionally, difficulty arises in identifying the interactions between the various crop inputs, the productivity gains, operating constraints and costs.

The crop simulation models provide the first step towards identification of optimal strategies. These models are an essential part of the real-time decision systems required for precision irrigation. Lack of low-cost, non-invasive sensors able to provide measures of crop and soil responses at relevant spatial scales means that precision irrigation systems will have to rely on simulation for the foreseeable future.

RESEARCH OPPORTUNITIES

While many of the tools and technologies that will comprise precision irrigation systems are currently available, substantial research and development is required before a truly precision system is available for testing and adoption by the irrigation community. The R & D opportunities that emerge from the review fall into four categories.

- *Integration of technologies*
- *Technical feasibility*
- *Economic benefits*
- *Component technologies*

These areas/aspects of research and development are discussed here.

Economic benefits

Current and past work has established that there are benefits to be obtained from adoption of precision irrigation (including spatially varied irrigation applications). However it is far from clear if the benefits outweigh the costs by a sufficient margin to warrant the adoption. Work needs to be undertaken across a sufficient range of crops, soils and irrigation application systems to determine where the maximum benefit can be obtained and to direct the priorities for research investment. This will also establish the advantages of full versus staged or partial adoption.

In specific, quantifying the costs/ benefits of full automation of surface irrigation and the agronomic benefits of spatially varied applications for a range of crops appear to be of high priority. It also remains to be seen, via the mechanism of field trials rather than simulation, that adaptive systems can provide substantially greater benefits than simple automation and/or traditional irrigation scheduling.

Integration of technologies

Integration of the various component technologies for precision irrigation stands out. Combining the crop and soil sensing with appropriate crop growth simulation models to provide the seasonal decision making model is a necessary first step for all of the major crops. Combining that with the system for the control and optimization of the particular irrigation application system completes the precision irrigation system.

Given the dominant position in the irrigation sector occupied by the various forms of surface irrigation and the substantial gains possible in application efficiency and yield (and hence water use efficiency) this would seem the likely priority area.

Technical feasibility

The technical feasibility of precision irrigation is needed to be established at two levels, conceptual and practical. To conceptualize, simulation can establish the optimum spatial scales for the range of crops and application systems. This will account for the spatial limitations of the application system, the constraints imposed by the sensing needs and capability/ability of the simulation tools to accurately predict the effects on crop growth and yield. This stage must also determine if the diagnostic tools needed to determine the causes of particular crop responses are available and sufficiently accurate.

At the practical level, precision irrigation systems will have to be proven and demonstrated in field trials across a range of crops as well as agro-climatic zones.

Component technologies

Development of improved tools and technologies will have to be an on-going process. However, there are immediate needs for sensing and simulation tools for PI systems. These are:

-low-cost, spatially-distributed, non-invasive sensing of soil moisture and crop response;

-development of a sprinkler pattern model for center pivot and lateral move machines to account for varying sprinkler pressure, height, sprinkler pattern overlap, wind and machine movement accurately;

-Development of a hydraulic diagnostic model for drip systems capable of interaction with the system control to deliver spatially varied applications;

-Improved crop models sensitive to small variations in irrigation and with a self-learning capability; and

- Use of short range radar for the measurement of the spatial distribution of rainfall at the sub-field scale.

CONCLUSIONS

Precision irrigation gives farmers the ability use irrigation water more effectively. This means better crop yield and/or quality, without polluting the environment. However, it may be difficult to determine the cost benefits of precision irrigation management at this stage. At present, many of the technologies used are in their infancy, and pricing of equipment and services is hard to pin down. This can make our current economic statements about a particular technology biased. The concept of “doing the right thing in the right place at the right time” has an intuitive appeal. The success of precision irrigation would depend on how well the knowledge needed to guide the new technologies can be found.

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