Review of Deficit Irrigation and Nutrient Use Strategies for Optimal Crop Yields

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Abstract

Optimal soil moisture ionizes the nutrient fertilizer into a form extractable by plant roots and minimizes drainage. Deficit irrigated crops abstract moisture at critical levels below field capacity sufficient for production. Current review of the existing literature has shown that optimal yields and profits are attained by balancing available water and nutrient application. It was further shown that reduction of water applied is justified when it results in yield reduction but significant saving is achieved in reduction of operation costs. A case study of Eldume irrigation scheme showed that irrigation water requirement is never attained and deficit irrigation was the only option.

Key Words: Deficit Irrigation, Evapotranspiration, Field Capacity, Matric Potential, Nutrient Use

INTRODUCTION

The challenge to be self sufficient in food production and to maintain a sustainable environment is to optimize the demand of both water and nutrient levels by the crops. The traditional practice of agricultural production applies the strategy of full irrigation maintained at field capacity level with intent to maximize yield and/or profit. The ultimate result of the irrigation leads to nutrient loss into sub-zones of the soil profile and may also cause surface runoff. Crops readily abstract water in the soil at moisture level of above 60% of the available regime. Limited reduction of irrigation water through deficit irrigation is a sustainable alternative as a demand management strategy (Kjne, 2003; Farahan, 2006).

Nutrients used in agricultural production are mainly Phosphorus and Nitrogen and are applied in Agricultural fertilizers. Field application of fertilizers are based on the gross levels recommended by the Agricultural extension workers and the advice obtained from the agricultural inputs (retailers/stockiest) in the market. Such rates are recommended with the assumption that water availability through rain-fed agriculture is above normal levels for the various crop water requirement. Under normal circumstances, the rates of fertilizer application are never consistent and do not necessarily apply what exactly the crop requires and at the same time the amount of soil moisture is not always maintained at the field capacity level due to inconsistent rainfall patterns. The objectives of this paper are (i) to review existing information on deficit irrigation strategy and its effect on nutrient use levels in crop production (ii) to present a socio-economic application of deficit irrigation management for optimal crop yields in arid environments.

Review of Deficit Irrigation

Deficit irrigation aims at saving on irrigation water without affecting both the quality and quantity of the crop yield. Water is applied below full irrigation and production costs decreases faster than revenue decline (Larry, 1988) and justified by the relatively minimal increase in yield for a unit increase in the soil water of a production function in the vicinity of full irrigation. In terms of irrigation scheduling deficit irrigation is considered as an incomplete supplemental irrigation or regulated deficit irrigation (Kipkorir, Raes, & Labardie, 2001). The strategy is further referred to as the application of less irrigation throughout the season than it is lost through Evapotranspiration (Costa *et al.*, 2007) and that implies the crop sustain deliberate drought stress that often lead to partial loss of yield. The on-farm strategy is to maximize crop water productivity in dry areas (Raes, 2009). Deficit irrigation is a crop sensitivity response to yield formation when crop water requirement is reduced below critical levels. Where water is limiting, it is more important and profitable to maximize crop water productivity than maximizing the harvest per unit land (Fereres, & Soriano, 2007). The maximum limit of soil water available to plants occur at field capacity, a level when the forces (matric potential) holding significant amounts of water which plants can remove and use is about 1/3 bar for most soils (Larry, 1988). A 50% level of the soil water content between field capacity and permanent wilting point defines a critical soil water content that marks the lower limit of readily available water or allowable depletion to plants. This implies that deficit irrigation must be maintained above this critical level in order to guarantee a healthy crop. Water holding capacities of different types of soils influence the amounts of irrigation demand daily. Course textured sandy soils stores less water and irrigation requirement is higher and more frequent than fine-grained clayey soils. The Agricultural Research Services of the USA reported that early application of deficit irrigation on peanut plants maintained sufficient yields and was attributed to the plant physiologically adapting to the stressful drought environment. However, maize crop is sensitive to drought stress during all its growth stages.

Crop Yield as a Function of Deficit Irrigation

Crops are sensitive to water stress and earlier studies by Jensen (1968), Doorenbos and Kassam (1986), and Allen (1994) led to the development of a parameter to represent crop sensitivity to water deficit. The extend of reduction in crop yield as a result of water stress is understood better by quantifying the expected benefits of irrigation in terms of the expected crop yield and graphically presented by a crop-water production function as shown in Fig.1.

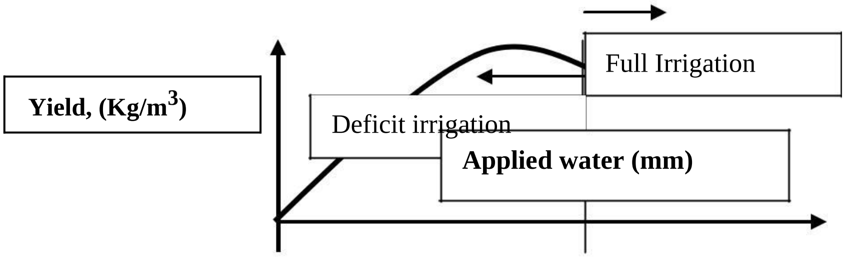

Figure 1. Generalized crop-production function

From the above function, at any given applied water level, a healthy crop is assumed to respond to irrigation at its maximum growth rate and nutrient levels are not limiting. The consumptive use of applied water is represented by Evapotranspiration and comprises of water lost into the atmosphere by evaporation from the plant and soil surface plus transpiration amount translocated through the stomata. A typical regression function developed by Cuenca, 1978 using experimental data expressed the crop-water production function by plotting the consumptive use, represented by Evapotranspiration against yield, gave a linear relationship described by the following equation:

$$Y = -0.499 + 3.12\,(ET) \qquad (1)$$

where Y=yield, kg/m^3 and ET=evapotranspiration (mm).

At the beginning of the functions all the applied water is used for Evapotranspiration at low levels of irrigation and the slope is relatively high showing that water is efficiently used but as irrigation level increases less water is imbibed but more percolates past the root zone or runoff the field. Adequate nutrient levels are applied to produce maximum growth at any level of irrigation and the crop is free of disease, weeds, and pests (Cuenca, 1978). Any increase of water applied for yields beyond the plateau level of the function decreases the yield achieved because the moisture level in the soil is beyond field capacity. Economical irrigation system reduces the amounts of applied water (deficit irrigation) to a level that does not drastically reduce the yields and eventually the cost of production saving is higher than the loss of the crop yields. Regulated deficit irrigation is used when water stress is applied to control vegetative–fruit competition (Ruiz-Sanchez & Domingo, 2010). Various techniques of deficit irrigation strategies are applied to balance the production of a crop while maximizing the use of the limited water resources. The strategy becomes a tool for reducing the amounts of crop water use in agricultural production (Fereres & Soriano, 2007).

Socio-Economic Application of Deficit Irrigation

Rainfall in marigat is not always reliable during the entire crop production season and this natural phenomenon is replicated in deficit irrigation as a means of saving the scarce water resources and achieving good levels of crop yields. Data on six crops grown in the ministry of water and irrigation funded Eldume irrigation scheme were compared by determining their respective irrigation water requirement and time taken to irrigate one hectare of each crop. The selected crops and their respective water requirements are tabulated in table1:

Table 1. A Case study of Eldume Irrigation Scheme (Marigat) crop water requirement

Crop water requirement for crops grown on clay loam soils and abstract water from Eldume riverdischarging1.0 m^3 per second.
Soil Water Properties: Field Capacity = 33 % Permanent Wilting Point = 17 %
Available Moisture = 16 % Maximum Allowable Depletion at 60%

S/No	Crop	Effective Rooting depth (cm)	Readily Availabl e Water (cm)	Amount of irrigation water per hectare (m^3/ha)	Time required to irrigate one hectare (hours)	Average Irrigation Interval (days)
1	Maize	60	5.76	5760	1.6	6
2	Soybeans	60	5.76	5760	1.6	6
3	Sorghum	60	5.76	5760	1.6	6
4	Cabbage	45	4.32	4320	1.2	5
5	Onion - dry	30	2.88	2880	0.8	3
6	Flowers	15	1.44	1440	0.4	2

Source: Ministry of Water and Irrigation (2005)

Eldume river is the only source of water for irrigation in the scheme and the water is also utilized by the community to meet the requirements of both domestic and livestock demands. Summary of the evaluation gave the amount of water required to irrigate one hectare of each crop, duration and interval of the irrigation based on potential evapotranspiration of 5mm/day. The data indicate that cereals and Soybeans in Eldume irrigation scheme (Marigat) would each require an average of 1.6 hours to irrigate one hectare by abstracting all the water in the river, a condition which is not legal because of the requirements of other water users downstream. To optimize on the water use, a well design water use and/or allocation plan is required to guide the users on the optimal area to irrigate and at the same time satisfy the domestic and livestock water demands. Irrigation farmers may maximize on the water allocation plan by applying deficit irrigation strategy and subdividing the allocated irrigation area into blocks and growing crops with different levels of water demands. The scenario shows how limited water resources can be a source of conflict if not managed well especially when the source of water is used for domestic, livestock and irrigation requirements.

CONCLUSIONS

When moisture in the soil is not sufficient to ionize the inorganic (chemical) fertilizer into a form extractable by plant roots, it leads to limited capacity of plants to imbibe maximum nutrient levels and yields are reduced. This implies that deficit irrigated crops abstract moisture from the soil at levels below field capacity and the maximum possible evapotranspiration by the crop is never achieved.

Deficit irrigation is a deliberate effort to save on irrigation water application and in the process cause drought stress to the crop but attain optimal yield. The results reported by other researchers show that crop yield vary with the amount of moisture available in the soil and maximum level achieved when moisture is at field capacity. Reduction of yield in deficit irrigation is justified by a significant saving achieved in the operation costs of supplying the amount of water. The water was efficiently used in deficit irrigation treatments and water use efficiency increased with lower amounts of water, a strategy that is beneficial in the management of crop production in arid areas. The review further showed that research on deficit irrigation and nutrients use is vast and demands a lot of effort to unlock important research findings.

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BIO-DATA

Mr John Kipketer Langat is a lecturer of Water Resources Engineering and a PhD student in University of Eldoret. He holds a Bachelor of Science in Agricultural Engineering from University of Nairobi, a Master of Science in Water Resources Engineering from University of Alberta, Canada and currently a Doctor of Philosophy student at University of Eldoret. He is currently the Head of Department of Agricultural and Biosystems Engineering at University of Eldoret. He has been teaching and supervising students since 2010. His research interests are in deficit irrigation, soil erosion and siltation, dilution of industrial effluents in crossflow and application of AquaCrop Model in Irrigation design and Management.