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A REVIEW OF GROWTH STAGE DEFICIT IRRIGATION EFFECTING STICKY MAIZE PRODUCTION

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Abstract

The shortage of water resources influences the future sustainability of sticky Maize (Zea mays L.) production. Deficit irrigation (DI) – a water management strategy – has gained much attention from scientists because of enhanced water use efficiency (WUE). Nonetheless, in reality, when applying this technique, its impact on yield and economic returns should be considered. Through an analytical literature review, this study examined the effect of growth stage DI on Maize production factors, i.e. yield, WUE, and economic returns. The results revealed that Maize's WUE could be improved with the lowest reduction in yield as water stress was imposed during the vegetative or maturation growth stages. Therefore, the profitable returns could be reached even if the yield was reduced; however, the economic return was sensitive to commodity prices. The present review addressed that the Maize flexible capacities under growth stage water stress presented an opportunity for the optimization of irrigated water and profit preservation by accurately judging the managing time of irrigation implementation.

Key words: deficit irrigation; maize; water stress; water use efficiency

1 INTRODUCTION

The production of maize (Zea mays L.) plays a major role in the economic and socio-economic development of many countries. Being regarded as the world's third most important crop [1], its contribution to development and food security can be attributed to its diversified uses: as a grain commodity, feed commodity, and a significant bioethanol source. However, corn production is among the largest plant users of water with its production being heavily dependent on irrigated water [2]. This dependency is increasing, and would continue to increase, owing to declining water resources mainly ascribed to climate change. Consequently, to ensure the sustainability of water resources and to optimize water use in irrigated corn production to maintain its future production, new strategies must be developed and implemented. Deficit irrigation (DI) is one of the proposed strategies for optimizing the water used in irrigated corn production. DI means the intentional under-irrigation of crops below full crop water requirements (crop evapotranspiration), while maintaining a positive economic return [3, 4]. Normally, deliberately subjecting corn to water stress has an impact on the productivity factors such as yield, water use efficiency (WUE), irrigation WUE, and economic returns [5, 6]; the impact is very sensitive to localized environments and management practices. It is a strategy aimed at procuring a maximum yield with less irrigation water; or an optimum net economical return is achieved with limited resources. The influence of DI on these factors is a function of, individually or collectively, the phenological stage of implementation – growth stage DI, available soil water, the irrigation system and the genotype used [7, 8]. The adoption of DI as a water management strategy has received considerable commendations from the scientific community because of improved WUE [9, 10]. However, when assessing the practicality of employing this technique, its realistic impact on yield and economic returns should be considered. This report assessed the feasibility of employing DI as a water management strategy for corn production. The analyses were based on secondary data obtained from international journals, and the evaluation focused on the impact of growth stage DI on the aforementioned productivity factors.

2 MATERIALS AND METHODS

2.1 Impact of water stress on corn production

Irrigation is usually used as a supplemental source of water to rainfall to optimize crop production by supplying full crop water requirements (ETc). The amount of daily and or seasonal corn water use varies with climatic conditions, crop characteristics, and the specific developmental stage. The total amount of water used by corn will, therefore, vary depending on seasons and locations, and generally follow the pattern dictated by seasonal trends in weather variables and corn development. A general depiction of corn daily and seasonal water

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use is shown in Figure 1. The smooth curve (A) represents the average seasonal water use, while the jagged curve (B) illustrates the daily fluctuation for the season. Figure 1 also highlights the specific growth stages for corn. In this paper, the maize growing season was divided into three phases: vegetative – from emergence to tassel emergence; flowering – from tassel emergence to milk stage of grain, from milk stage to physiological maturity (maturation). When water supplies cannot fully compensate for ETc, deficit irrigation (DI), yields may be reduced compared to fully irrigated corn. The degree of the impact can be examined as a function of the growth stage of implementation [11]. According to Andrioli and Sentelhas [7] and Doerge [12] maize is extremely susceptible to water stress during the flowering stage and less sensitive during the vegetative periods. In fact, Doerge [12] noted, "the vegetative stage of corn is the least sensitive to water stress and judiciously delaying the first irrigation may offer an opportunity to conserve water and maintain profitability". Figure 2 illustrates the yield susceptibility of corn through the growing season. From the figure, it can be observed that early water stress has a less impact on grain yield as compared to the flowering, tassel to silk, stage.

Productivity factors to evaluate corn responses to deficit irrigation. Corn is one of the globe's most widely used food staples and given its potential industrial application serves as a climate change mitigation option, while sustainable production is crucial in light of dwindling water resources.

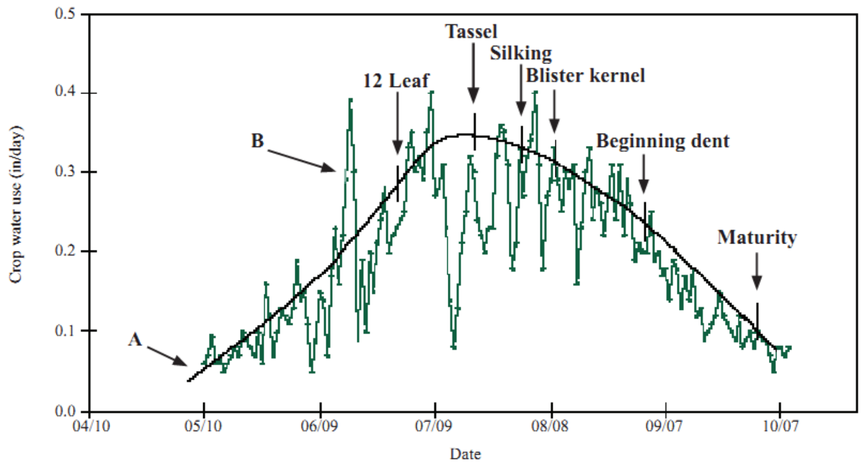

Fig. 1 The average ET for corn in a growing season (A) and the daily ET (B) [13]

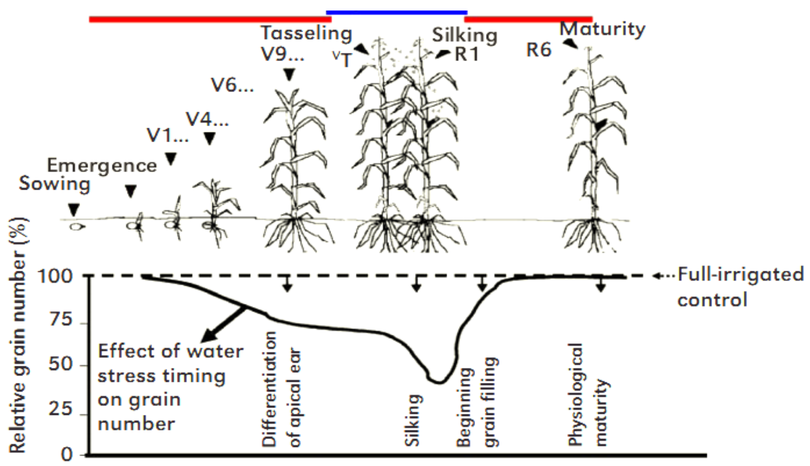

Fig. 2 Sensitivity of grain number to water stress at different growth stages [14]

Consequently, many studies had been directed towards understanding the dynamics of soil water relationships and the impact on corn production. This report analytically reviewed several works to investigate the feasibility of employing DI in corn production. The review utilized secondary data reported in international literature, conference proceedings, and technical reports and only considered the data collected from field experiments with similar methodologies – growth stage directed DI. Additionally, relevant criteria for selecting articles were concentrated on the impact of DI on the productivity factors such as maize yield, water use efficiency, and economic return, where applicable. Traditionally, for plants, water productivity was usually expressed as water use efficiency (WUE) (kg ha^{-1} mm^{-1}), defined as the ratio of biomass produced to the rate of transpiration:

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$$WUE = \frac{Y_a}{ET_c} \quad (1)$$

where:

Y_a – grain yield achieved $\left[kg \cdot ha^{-1}\right]$,

ET_c – total water used for the cropping season $\left[mm^{-1}\right]$,

However, using ET_c has its limitation in that not all the irrigation water is used in the evapotranspiration processes and a fraction of the ETc comes from sources other than irrigation [15]. Thus, the irrigation water use efficiency (IWUE) is another indicator used to investigate the water productivity as it was economically more important [5, 15].

$$IWUE = \frac{Y_a}{TI} \quad (2)$$

where:

TI – total irrigated water used $\left[mm^{-1}\right]$.

The economics of production used in this report is adopted from [3, 16]. The economic water productivity ratio (EWPR), shown in Equation 3, relates to the yield value with the full farming cost of total water used (TWU):

$$EWPR = \frac{Value\left(Y_a\right)}{Cost\left(TWU\right)} \quad (3)$$

3 RESULTS AND DISCUSSION

Exposed to limited water supplies, agronomic management strategized that meticulously control, when irrigating, by limiting water during the growth stages that were least sensitive to water stress while saving water for the critical stages, could be a valuable strategy to maximize yield return from limited water (Figure 3). According to Doerge [12], growers can conserve water by delaying the first irrigation later into the season, as late as tasseling (see Figure 2) in years of lower evaporative demand, without any significant reduction in yield. Similar results were reported by Huang et al. [17]. Table 1 highlighted some key works illustrating that selective growth stage DI could be employed as a water management strategy with a limited impact on yield procured. For instance, the WUE factor of 30.9 and 21.4 kg ha-1·mm-1 for DI imposed at vegetative stage only, compared to 29.1 and 19.2 kg ha-1mm-1, respectively, under full irrigation treatment, indicated with a minor yield depression of 2.99 % and 5.79 % that it was possible to improve water used in corn production.

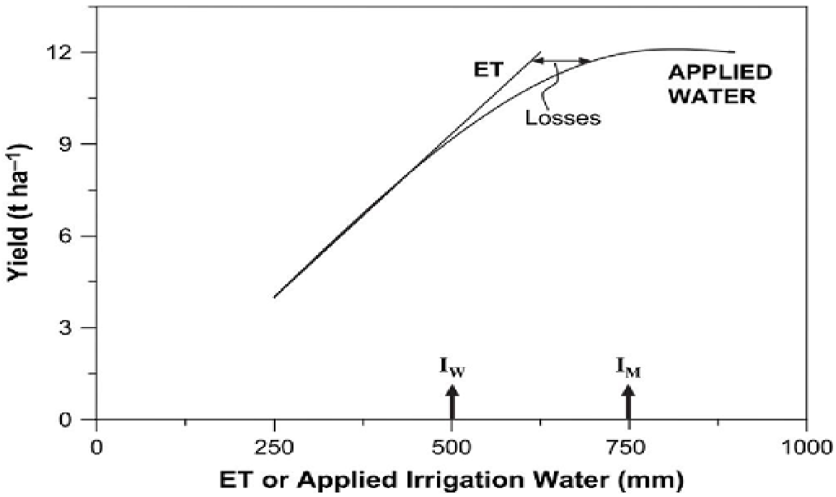

Fig. 3 Generalized relationship between yield, irrigation water, and ET. IW - the point at which the productivity of irrigation water starts to decrease and IM - the point beyond which yield does not increase any further with additional water application [4]

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Indeed, when water supplies were inadequate, the farmer's goal should be to maximize net income per unit of water used rather than per land unit. Notably from Table 1, any potential water saving by supplying DI at the flowering stage does not compensate for the severe yield loss as indicated by the low WUE of 14.4. Generally, as observed in Table 1, the WUE increases under DI, relative to its value under full irrigation. Small irrigation amounts increase the crop ETc linearly up to a point where the relationship becomes curvilinear because some of the applied water is not used in ETc [4], as illustrated in Figure 3. The 'law of diminishing returns' becomes applicable, as additional amounts of irrigated water does not result in an increase in yield at some point (indicated by the IM point; Figure 3). Besides, the IWUE was higher with DI than under full irrigation, as shown in Table 1. These results indicated that under water deficit conditions, except during the flowering stage, deficit irrigated maize was able to produce more grain yield per unit of irrigation water applied than maize subject to full irrigation. This had important economic implications because it meant that economic returns could be high for users who paid high cost for irrigated water. Other works also report similar findings. Based on a 9-year field studies conducted in Kansas, Doerge [12] reported that delaying the first irrigation significantly depressed yield in only 3 of the years, and yields were not significantly impacted in any year unless the first irrigation was delayed by at least 4 weeks. In the 3 years, when the delayed irrigation curtailed yields, the average yield losses for delaying for four and five weeks before making the first water applications were 11 and 42 %, respectively. Nebraska, Hergert et al. [18] reported corn yields of 10.1 and 11.8 Mg ha^{-1} for limited irrigation and full irrigation respectively, with noteworthy DI water returns of 31 kg ha^{-}1·mm^{-1} with 11 kg ha-1mm-1 for full irrigation.

Tab. 1 Growth stage DI impact on water productivity variables

Yield, Y_a, (kg ha^{-1})	% Reduction in Y_a	WUE (kg ha^{-1}mm^{-1})	IWUE (kg ha^{-1}mm^{-1})	Source
16554		29.1	42.5	[3]
16074	2.99	30.9	44.7	
14784	10.7	26.0	44.0	
14279	13.7	29.0	47.6	
11650		19.2	21.7	[15]
10975	5.79	21.4	22.3	
7005	39.9	14.4	16.9	
10740	7.81	21.3	27.7	
10954		18.4	26.9	[5]
8981	18	25.4	41.7	
11073		20.3	11.3	[17]
9951	10.1	25.5	16.2	
8527	23	26	16.2	

*Referred to average yield over the study period; V – vegetative; F – flowering; M – maturation. Note: Some of the presented values were not directly listed in the cited works, but were calculated by equations 1 and 2.

The literature was sparse in presenting a monetary value of the economic impact of practicing DI, owing to the dynamic and sensitive nature of production costs. However, it could be assumed that with a yield reduction the profit return would be negatively affected. The degree of this depended on the factors such as commodity price, farming size – as economies of scale could be applicable, and technology use, including an irrigation system. Rodrigues et al. [3] showed that under a low commodity price scenario (154 € ton-1), EWPR for full and DI irrigation treatments (Table 1) ranged between 0.64 and 0.97, indicating that the economic return, becoming unprofitable even when using a high efficient irrigation system, decreased as shown in Figure 4. In contrast, when considering high commodity prices (264 € ton-1), EWPR greater than that shown in Figure 4, farming maize under DI, could still lead to profit, even if the yield was reduced.

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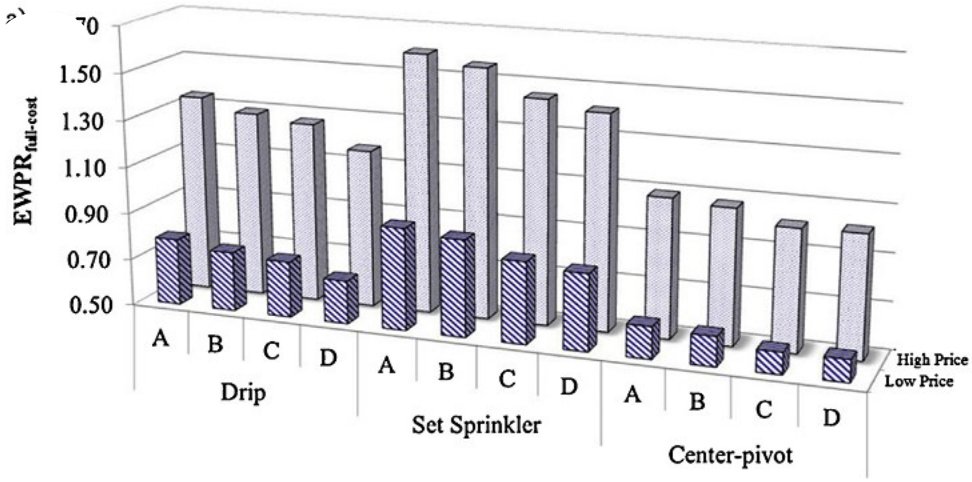

Fig. 4 Economic water productivity ratio (EWPR) for all deficit irrigation treatments and irrigation systems applied to 5-hectare farm sizes when adopting low and high commodity prices. A - full irrigation; B - stress imposed at V; C - stress imposed at M and; D - stress imposed at V & M. [3]

4 CONCLUSIONS

This review was conducted to assess the effect of DI on water use and corn yield and to determine the feasibility of employing growth stage DI as an effective water management strategy. The review indicated that it was possible to achieve relatively high yields in maize if DI was applied in stages other than flowering. With improved WUE and IWUE recorded for DI, minor yield reductions imply that there was a potential for water conservation. However, its practicality was limited, as commodity price would dictate. There was a trade-off between water conservation and profit return. In some cases, DI could be practiced with expectations of achievable profit, despite a yield reduction. Most research works, however, were advocated in this area as many of them focused on environmental benefits. Exposed to limited water supplies, agronomic management strategized that meticulously control, when irrigating, by ensuring limited water provided at critical growth stages could be a valuable strategy to maximize yield return from limited water.

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