Optimising Crop Production and Crop Water Management in a Developed Indigenous Drip Irrigation System

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Abstract

In order to carry out a more effective use and management of water for crop production, a strategy that involve the use of technical and agricultural options that can lead to increase production with less water are elaborated by using concept of water use efficiency and water productivity in this paper. In order to achieve this, improved irrigation technology is considered paramount as expressed in indigenous drip irrigation system developed in National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria, and other crop water management options such as irrigation scheduling techniques and more accurate estimates of crop water use using a model developed for an existing hydraulic weighing lysimeter in NCAM, Ilorin.

For water productivity to be optimized in crop production, crop water management is essential to estimate water use consumption of crops as well as the use of water management models to optimise water supply under an indigenous drip irrigation system. The integration of evapotranspiration model with irrigation model is a valuable tool because it enables trained and experienced irrigation specialists to provide irrigation scheduling services.

From the analysis of the result carried out from the research, it is evident that crop production is optimized when the crop water demand is attained with adequate water supply technique of a reliable irrigation system coupled with appropriate irrigation scheduling. This is achievable through the data established for water use consumption of crops and the appropriate supply of the irrigation water at different stages of growth. The water use efficiency and water productivity of the system is optimum when water supplied adequately meets the crop water demand. Further application of irrigation water have no any appreciable effect in yield. It is also affirmed that water productivity increased with yield.

Keywords Irrigation, Crop coefficient, Water productivity, Water use efficiency, Relative yield.

I. Introduction

The challenge the world likely to face in coming decades will be the task of increasing food production with less water due to serious shortages of fresh water with its growing competition when less water is available for agriculture. A more effective water use in the face of dwindling water resources and growing competition for water is a critical option in agricultural practices to face the challenge for the near future as population keeps increasing. Many important agricultural areas are suffering from inadequate supply of water [1], especially water used by farmers for irrigation ([2],[3]). As a result of growing competition for water for industrial and domestic purposes, the water available for irrigation especially during dry season farming to meet growing food demands needs to be used effectively for greater crop production. Since future development has a high dependency on water, its inability to meet up with the need is a critical constraint for development which could endanger food supplies. In order to meet future food demands, judicious use of water resources would help to sustain food production and help to address the growing competition for water.

A wide range of techniques and cultural practices to attain water requirements, increase the water availability and raise the yields can contribute to save water and improve the water use efficiency and productivity [4]. One achievable means of saving water in irrigation technique is through the use of a well developed drip irrigation system and if properly managed by avoiding clogging to preserve high emission uniformity would help to achieve a better water use efficiency in agricultural sector. This technique aims at achieving efficient water delivery and high productivity, while minimizing water usage, as affirmed by [5], “Reference [6] affirmed that drip irrigation system if well managed; some of its advantages include minimising soil water evaporation and nutrients leaching, maintaining a uniform water distribution resulting in greater control of the irrigation water and nutrients”. This is achievable as a result of water application under low pressure to the plant roots [1]. Even though, drip irrigation is becoming popular, the knowledge and adaptability of the technology is inadequate among the farmers.

Therefore related studies on drip irrigation specifically on water use efficiency and water productivity is important to convince the farmers to adopt this new technology in the field with confidence. In arid regions, water shortage due to limited ground water and surface water resources has become a major concern in the development of irrigated agriculture [7]. With the increase water scarcity, there is the need to optimize water use mainly for irrigation purposes [8]. This will ultimately encourage the famers to adopt improved irrigation management in order to optimize water use thus leading to higher water productivity. There is a need to systematically optimize the soil and water management practices and the irrigation equipment in order to achieve an efficient irrigation water use [9]. The allocation of water at the right time and in the right quantity of water is the key issue to increase water use efficiency and water productivity for optimal crop production.

Numerous studies have shown that there is a great potential to achieve in a more efficient water use, mainly through enhanced distribution uniformity in a coverage area of a drip irrigation system ([10],[11]). Drip irrigation system were found to lead to higher water use performance in terms of beneficial water use and water productivity when compared with sprinkler irrigation system. One of the methods for increasing water use efficiency in irrigated agriculture is improved irrigation scheduling techniques using system optimisation methods. The specific objectives of this research work were to determine the followings:

1. The effects of different levels of irrigation water allocation to crops on different plots

2. The contribution and influence of water supply on relative yield of crops

(II) MATERIALS AND METHODS

The estimation of water use efficiency of maize and cowpea for this research involved the use of a water supply model developed for an indigenous drip irrigation system (IDIS) and the estimation of crop evapotranspiration (ET_{crop}) through the use of hydraulic weighing lysimeter. A buffer area of 100 m x 100 m was used on the lysimeter research field, which was planted with crop as on the lysimeter area of 3.24 m^2 [12]. The lysimeter was located at the centre of the field with a uniformly cropped surface to provide a reasonable fetch. ET_{crop} was calculated based on lysimetric facilities on the research field, while the reference crop evapotranspiration (ET_o) was determined using an empirical relationship of Pan evaporation method [13] with meteorological data obtained from NCAM meteorological station.

The indigenous drip irrigation system that was developed for the research work was installed on half an hectare of land on the lysimeter research field in NCAM. The soil of the site was sandy clay with a natural slope of 0.2%. The irrigation field was partitioned in zones with each zone comprising of eight plots of an area of 50 m^2 per plot. Using the water supply model developed for the IDIS [14], the amount of water supplied by the drip system in a given plot was determined. The irrigation water supply to a plot was in order of 7.7 x 10^{-4} l/s at a given point in time. Irrigation water was applied on different sensitivity stages (Establishment, Vegetative, Flowering, Yield formation and Ripening) with different irrigation levels for the different plots. The values of crop coefficient (k_c) for the crops were based on research findings obtainable from the relationship that exists between the crop evapotranspiration and reference crop evapotranspiration ([15],[16]).

The crop coefficient (k_c) is obtained by relating the actual crop evapotranspiration to reference crop evapotranspiration as given in equation 1

$$ET_{crop} = k_c \, ET_o \qquad 1$$

Where k_c is the crop coefficient, ET_{crop} is the crop evapotranspiration and ET_o is the reference crop evapotranspiration.

The method for calculating ETo from meteorological parameter is as follows

Pan evaporation method [13]

$$ET_o = k_p \, . \, E_{pan} \qquad 2$$

The estimation of water use efficiency for this research involved the use of a drip irrigation system developed for this work [17] and the estimation of crop evapotranspiration through the use of hydraulic weighing lysimeter. Water use efficiency is defined as the fraction of the total water made available by both rainfall and irrigation that is used by the crop for evapotranspiration [18].

$$\xi_w = \omega_c / \phi_s \qquad 3$$

Where ξ_w is the water use efficiency, ω_c is the crop water demand and ϕ_s is the water supply

The estimation of water productivity for this research work was carried out by a process of water supply conversion into yield. Water productivity is defined as the yield produced per unit of water for a given crop. This is expressed mathematically as follows:

$$W_P = Y / \phi_T \qquad 4$$

where W_P is the water productivity, Y is the crop yield and ϕ_T is the total water supplied

(III) RESULTS AND DISCUSSION

Table 1 and 2 shows the presentation of the effect of different irrigation water level allocated to different plot on the crop yield . The irrigation water supplied to a plot was in order of 7.7 x 10^{-4} l/s at a given point in time. This amount was varied within 60% to 100% for various sensitivity stages following a normal trend of crop coefficient curve. Plot 1 was selected as the reference plot over the other plots in which additional water supplied was varied downward between 50% to 1% of the initial water supplied. Irrigation water was applied to the crops to fulfil crop water demand. A corresponding decrease in the relative yield is assumed for an increase amount of irrigation water applied to the crop until it is minimized to a considerable level.

Yield response to water is different for different crops and for a given crop, different stages can have different yield responses. A sensitivity stage or a crop with high yield response factor means that the stage or crop is more sensitive to water stress. Similarly, a lower k_c value means that a less sensitive stage or crop is considered. Having satisfied the crop water demand for each plot, the additional water supplied resulted in a lower yield until it is minimized to give a relatively high yield.

From Table 2, it was clearly indicated that the additional water supplied to the different plots were minimized to as low as 0.05% of the initial water supplied before any appreciable increase in yield was determined. This was due to the fact that the crop water demand for cowpea was comparatively lower than that of maize and consequent addition may not be necessary to give any appreciable increase in yield.

(IV) CONCLUSION

This report has shown a demonstration of a potential for using a water supply model in the analysis of the effect of different irrigation levels and the significance of yield response factors in irrigation water management. The result have also shown that for an optimal distribution of irrigation water over the growing season, irrigation amounts could be substantially increased without a large increased in expected yield. It can be concluded from the research carried out that water productivity increased with decrease additional water supplied and increased with relative yield.

It is therefore evident and clearly demonstrated from the research carried out that irrigation of water to crop must be tailored along the crop water demand of that crop at any given stage of growth. With adequate irrigation scheduling and application of right quantity and adequate irrigation water at appropriate time will give a desirable yield without wasting water unnecessarily.

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Table 1. Water allocation to the sensitivity stages under different levels of available irrigation water for maize.

					Plot 1		Plot 2 (+50%)		Plot 3 (+40%)	
Sensitivity stages	**ET_o**	**ET_{crop}**	**k_c**	**W_c**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**
Establishment	53.2	16	0.4	5.15	4.62	1.11	8.47	0.61	7.7	0.67
60% of Q_s	54.2	19	0.5	6.11	4.62	1.32	8.47	0.72	7.7	0.79
Vegetative	58.8	25	0.6	7.43	6.16	1.21	10.01	0.74	9.24	0.80
80% of Q_s	54.8	25	0.6	7.43	6.16	1.21	10.01	0.74	9.24	0.80
Flowering	51.0	14	0.4	4.50	7.7	0.58	11.55	0.39	10.78	0.42
100% of Q_s	48.1	23	0.6	7.39	7.7	0.96	11.55	0.64	10.78	0.69
Yield formation	31.9	21	0.9	6.75	6.16	1.09	10.01	0.67	9.24	0.73
80% of Q_s	43.2	30	0.9	7.43	6.16	1.21	10.01	0.74	9.24	0.80
Ripening	54.0	31	0.8	7.43	4.62	1.61	8.47	0.87	7.7	0.96
60% of Q_s	41.5	22	0.7	7.07	4.62	1.53	8.47	0.83	7.7	0.92
Total water supplied				66.69	**58.52**	114%	**97.02**	69%	**89.3**	75%
Relative yield					1.000		0.142		0.376	
Water productivity					0.017		0.001		0.004	

Table 1. contd...

	Plot 4 (+30%)		Plot 5 (+20%)		Plot 6 (+10%)		Plot 7 (+5%)		Plot 8 (+1%)	
Sensitivity stages	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**
Establishment	6.93	0.74	6.16	0.83	5.39	0.96	5.00	0.92	4.70	1.09
60% of Q_s	6.93	0.88	6.16	0.97	5.39	1.13	5.00	0.92	4.70	1.3
Vegetative	8.47	0.88	7.7	0.96	6.93	1.07	6.55	0.94	6.24	1.19
80% of Q_s	8.47	0.88	7,7	0.96	6.93	1.07	6.55	0.94	6.24	1.19
Flowering	10.01	0.45	9.24	0.49	8.47	0.53	8.09	0.95	7.78	0.99
100% of Q_s	10.01	0.74	9.24	0.80	8.47	0.87	8.09	0.95	7.78	0.99
Yield formation	8.47	0.80	7.7	0.88	6.93	0.97	6.55	0.94	6.24	0.99
80% of Q_s	8.47	0.88	7.7	0.96	6.93	1.07	6.55	0.94	6.24	0.99
Ripening	6.93	1.07	6.16	1.21	5.39	1.38	5.00	0.92	4.70	0.98
60% of Q_s	6.93	1.02	6.16	1.15	5.39	1.31	5.00	0.92	4.70	0.98
Total water supplied	**81.62**	82%	**73.92**	90%	**66.22**	100%	**62.38**	107%	**59.32**	113%
Relative yield	0.673		0.818		0.981		1.017		1.035	
Water productivity	0.008		0.011		0.015		0.016		0.017	

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Table 2. Water allocation to the sensitivity stages under different levels of available irrigation water for cowpea

					Plot 1		Plot 2 (+20%)		Plot 3 (+10%)	
Sensitivity stages	**ET_o**	**ET_{crop}**	**k_c**	**W_c**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**
Establishment	29.34	7.8	0.3	2.51	4.62	0.54	6.16	0.41	5.39	0.46
60% of Q_s	34.4	8.34	0.2	2.68	4.62	0.58	6.16	0.44	5.39	0.50
Vegetative	28.1	11.34	0.4	3.64	6.16	0.59	7.7	0.47	6.93	0.53
80% of Q_s	24.5	15.22	0.6	4.89	6.16	0.79	7.7	0.64	6.93	0.71
Flowering	23.1	18	0.7	5.79	7.7	0.75	9.24	0.63	8.47	0.68
100% of Q_s	29.54	22.53	0.8	7.24	7.7	0.94	9.24	0.78	8.47	0.85
Yield formation	32.2	20.76	0.7	6.67	6.16	1.08	7.7	0.87	6.93	0.96
80% of Q_s	30.8	16.8	0.9	5.40	6.16	0.88	7.7	0.70	6.93	0.78
Ripening	30.8	14.81	0.4	4.58	4.62	0.99	6.16	0.74	5.39	0.85
60% of Q_s	48.6	13.91	0.3	4.47	4.62	0.97	6.16	0.73	5.39	0.83
Total water supplied				47.87	**58.52**	82%	**73.92**	65%	**66.22**	72%
Relative yield					1.000		0.388		0.402	
Water productivity					0.017		0.003		0.004	

Table 2. contd...

	Plot 4 (+5%)		Plot 5 (+1%)		Plot 6 (+0.5%)		Plot 7 (+0.1%)		Plot 8 (0.05%)	
Sensitivity stages	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**	**Q_s**	**ξ_w**
Establishment	5.00	0.50	4.70	0.53	4.66	0.54	4.62	0.54	4.62	0.54
60% of Q_s	5.00	0.54	4.70	0.57	4.66	0.58	4.62	0.58	4.62	0.58
Vegetative	6.55	0.56	6.24	0.58	6.20	0.59	6.17	0.59	6.16	0.59
80% of Q_s	6.55	0.75	6.24	0.78	6.20	0.79	6.17	0.79	6.16	0.79
Flowering	8.09	0.72	7.78	0.74	7.74	0.75	7.71	0.75	7.7	0.75
100% of Q_s	8.09	0.89	7.78	0.93	7.74	0.94	7.71	0.94	7.7	0.94
Yield formation	6.55	1.02	6.24	1.07	6.20	1.08	6.17	1.08	6.16	1.08
80% of Q_s	6.55	0.82	6.24	0.87	6.20	0.87	6.17	0.88	6.16	0.88
Ripening	5.00	0.92	4.70	0.97	4.66	0.98	4.62	0.99	4.62	0.99
60% of Q_s	5.00	0.89	4.70	0.95	4.66	0.96	4.62	0.96	4.62	0.96
Total water supplied	**62.38**	77%	**59.32**	80%	**58.92**	81%	**58.58**	82%	**58.52**	82%
Relative yield	0.429		0.737		0.835		0.861		0.931	
Water productivity	0.005		0.009		0.013		0.015		0.016	