ET Fertilizer Use-Yield Predictions Using Crop Statistical Models

Ehumadu C. N.[1*], Ewemoje T. A.[2] and Dada O. A.[3]
[1]Department of Agricultural and Biosystems Engineering, University of Agriculture and Environmental Sciences, Umuagwo, Nigeria
[2]Department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria
[3]Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria
chikodinwokoma@yahoo.com

Received: 13-OCT-2024; Reviewed: 12-DEC-2024; Accepted: 28-DEC-2024
https://dx.doi.org/10.4314/fuoyejet.v9i4.1

ORIGINAL RESEARCH

Abstract— As population increases, and cost of providing water and fertilizer for crop production increases, profitability in agricultural practices becomes threatened. The urgent need to understand the response of plant to water supply and fertilizer applications in order to drastically minimize wastages, using crop models becomes inevitable. Fertilizer application for crop growth cannot be overemphasized, hence, the development of crop models for the evaluation of both water-yield relationships which can also be applied for fertilizer-yield relationships is important. The objective of this study was to develop an empirical equation used in predicting fertilizer use comparable to crop models used in evaluating crop yield under deficit and adequate water supply regimes. The field experiment was carried out using Split plot design replicated thrice on a Sandy loam soil at Crop Garden of the Department of Crop protection and Environmental Biology, University of Ibadan, during the dry season of 2018 and 2019. The result showed that Yield-ET response factor was significant (R^2 = 0.9863), Nutrient Uptake-ET (R^2 = 0.4025), and Nutrient Uptake-Yield (R^2 = 0.5793), respectively. The ET-Yield response factor equation in crop production can be successfully used in evaluating crop Nutrient Uptake-Yield relationships.

Keywords— Nutrient uptake, yield, Evapotranspiration, models, Fertilizer use

1 Introduction

As human population increases, in most cases farmers experience poor yield with the negative impact of intensive agriculture as major challenges witnessed during crop cultivation (Hall *et al*., 2017). Nitrogen is an important mineral taken in large quantity for plant growth and therefore, the most limiting (Leghari *et al.*, 2016). Over the years, the amount of inorganic N applied to soil for improving plant growth has risen drastically, resulting in increased yield with a considerable negative impacts on the environment (Akter *et al*., 2017; Tyagi *et al*., 2020). The mineral N fertilizer adds significantly to cost of crop production and in most cases pose serious environment challenges (Matheus *et al*., 2016; Prabhu *et al*., 2023). Nitrogen aids plant greenness, enhance yield quality, resistance to environmental stresses and CO_2 assimilation rate. Among essential nutrients needed for successful plant growth nitrogen is the most important, thereby making its excessive application a common practice during crop cultivation (Muhammad *et al*., 2020; Wenjie *et al*., 2023). Only half of the applied N are effectively utilized during crop cultivation, while the rest are lost to the environment as pollutants. Therefore, Nitrogen Use Efficiency (NUE) is critical for improving agronomic management practices. Improving NUE with the help of modern technological methods is expected to reduce the need for excessive N application. Hence minimizing its negative impact which is hazardous to the environment (Prabhu *et al*., 2023; Sharma *et al*., 2023). The potential yield of crops can only be attained if crop growth variables such as environmental factors, genetic potential of the crop, cultural management practices like soil fertility are set at optimal levels for the entire crop growing cycle. When soil water storage decreases significantly it impacts crop water availability which affects the actual crop evapotranspiration. This ultimately affects the crop actual yield (Moutonnet, 2000).

The dynamics of soil-crop water syntax gives an insight into how proper agricultural management practices at different phenological levels lead to yield improvement (Ghiberto *et al*., 2011). However, the level of damage or otherwise to which the crop experiences depend on whether the water supplied to the crop meets the crop physical and biological needs for its metabolism. Therefore, proper planning, design and well monitored operations involving both water supply and distribution are used for optimizing available water for cost effective crop production. The relationships existing among water, climate, soil and crops are complex with a lot of uncertainties involving numerous physical, physiological, chemical and biological processes (Kassam and Smith, 2001). Wilting due to moisture depletions cause significant decline in the vegetative growth of various plant species. Water stress occurring at critical growth stages causes significant reduction in crop yield. For instance, reproductive stage in crops is a critical phenological stage which has direct impact on yield. It is against this back drop that adequate knowledge of water conservation mechanism that will juxtapose irrigation with critical crop phenology needs to be developed for optimizing crop growth necessary for improving yield (Bauder *et al*., 2006).

*Corresponding Author

Section A- AGRICULTURAL ENGINEERING & RELATED SCIENCES
Can be cited as:
Ehumadu C. N., Ewemoje T. A. and Dada O. A (2024). ET Fertilizer Use-Yield Predictions Using Crop Statistical Models. FUOYE Journal of Engineering and Technology (FUOYEJET), **9(4), 558-564.**
https://dx.doi.org/10.4314/fuoyejet.v9i4.1

The relationship between the varying levels of water supplied and crops response with respect to yield can be described using crop water production functions at different water management regimes. Application of excess water or increase in frequency of irrigation will result to an increase in actual evapotranspiration (ETa) without necessarily resulting in an increase in yield, thus creating a nonlinear relationship (Liu, 2002). Maximizing scarce water resources requires sufficient ET_a data for sustainable agricultural production. After precipitation, ET_a is considered as surface water's second largest component (Djaman *et al.*, 2023; Ehumadu *et al.*, 2024). According to Zhang *et al.* (2023) and Ehumadu *et al*, (2024), during hydrological cycle, ET has a significant effect on plant growth and development, it is also a critical component for water balance in agricultural production.

Accurate estimations or availability of data on crop water use is critical for proper farm water management (Baldocchi *et al.*, 2019; Hatfield *et al.*, 2019; Ehumadu *et al.*, 2024). The relationship that exist between irrigation water and crop yield can be effectively determined when considering crop water deficits, crop water requirements, actual and maximum crop yield. Crop water deficits resulting to plants experiencing water stress effects evapotranspiration and yield. The relationship between actual and maximum evapotranspiration can be used to quantify water stress occurring in plants. When ETa = ETm, water requirements of the crop have been met; when crop water requirement are not met, ETa < ETm. Whenever, plant experiences water stress, crop water requirements have not been met, which affects crop growth and yield.

The effect of water deficit on plant growth and yield is felt differently by diverse species and growth period (Kassam and Smith, 2001). Water helps in the absorption of nutrient into plant through the roots. When these nutrients are insoluble, it does not play any role in the growth and development of the plants. Nutrient uptake through the roots of the plant is dependent directly on the available water with the soils root zone.

When the soil is well watered, the roots grow better, and the level of nutrient uptake increases. Fertilizer and irrigation cannot be considered separately or independently. Hence, the use of crop water production functions to describe the effects of water and fertilizer on crop yield. Fertilizer and water are critical inputs needed during crop production. The determination of the amount of water needed for plants to attain optimum fertilizer uptake is necessary. Adequate knowledge of water and fertilizer effect on crop growth and yield is needed under varying conditions (Erdal *et al.*, 2006; Nehe *et al.*, 2020). According to Peter *et al.* (2019) and Sharma *et al.*, (2023), long-term trials have shown that inorganic N fertilizer application above certain threshold can lead to accumulation of total soil nitrogen (TSN). Excess TSN in the soil poses serious environmental threat which will cause harm to human health. TSN is a nonpoint source of pollution for surface and groundwater. Leaching and soil surface runoff of excess TSN constitute a major factor that leads to environmental pollution. According to Ertek (2014), similar studies were conducted with interest in Yield-ET response factor, Nutrient Uptake-ET response factor and Nutrient Uptake-Yield response factor.

However, there are limited information on model applications used for determining irrigation and fertilizer use for crops so as to reduce unused inorganic fertilizer in the soil. The aim of this study was to develop an empirical equation that can be used in predicting fertilizer use comparable to crop models used in evaluating crop yield under deficit and adequate water supply regimes.

2.0 MATERIALS AND METHODS

2.1 STUDY SITE, EXPERIMENTAL DESIGN AND LAYOUT

The study was carried out at the Crop Garden of the Department of Crop Protection and Environmental Biology located at 3º89' E and 7º45' N with elevation of 223.5±12.0 m above sea level. The research was conducted during the dry seasons of 2018 and 2019. The 4 x 4 factorial experimental was laid out in a Split Plot and the treatments were arranged using a randomized complete block design in triplicates. The main plot effect was the irrigation depth 2, 4, 6 and 8 mm, while the sub-plot effect was the fertilizer rate comprising 0 (control), 100, 200, 300 and 400 Kg/ha NPK 15-15-15.

The field was cleared and beds of 1 m x 1 m each were with a spacing of 1 m between each bed. Seeds of *Corchorus olitorius* were sown at the rate of 3 g per m^2 using broadcasting method. After emergence, the seedlings were thinned to a spacing of 30 cm x 10 cm to give a plant population of 300,000 plants per hectare. Drip irrigation method was adopted on a 2-day basis for supplying water at the pre-determined depth based on volume/unit area.

2.2 DATA COLLECTION

2.2.1 ET–YIELD RESPONSE FACTOR (K_{YET})

The effect of water stress on yield was evaluated through proper quantification of its relative evapotranspiration (ET_a/ET_m), the determination of relative yield losses was actualized when adequate information on actual yield (Y_a) and maximum yield (Y_m) were made available under different irrigation regimes. The yield of the crop was obtained by weighing the fresh weight of the harvested crop (Ertek, 2014). Water stress effect was quantified and the relationship between deficit in relative evapotranspiration and yield was derived empirically. The relationship was referred to as yield response factor (K_y) (Kassam and Smith, 2001). The equation is shown as:

$$K_{yET} = [1 - Y_a/Y_m)]/ [1 - (ET_a/ET_m)] \quad (1)$$

where Ya = actual yield,

Ym = maximum yield,

K_{yET} = evapotranspiration (ET) – yield response factor,

ET_a = actual evapotranspiration, ETm = maximum evapotranspiration,

$(1 - Y_a/Y_m)$ = relative yield decrease, and $(1 - ET_a/ET_m)$ = relative evapotranspiration deficit.

$$WUE = Y_a/ ET_a \quad (2)$$

Where WUE = water use efficiency

2.2.2 FERTILIZER–YIELD RESPONSE FACTOR (K_{YF})

Crop yield increases as the amount of nutrients taken from the root zone of the soil increases. Crop nutritional requirement must be met using the application of fertilizer and an efficient supply of water. The idea of the yield response factor can be replicated in determining the amount of fertilizer consumed by the plant. This makes it possible to determine the yield loss due to decrease in fertilizer uptake. It is clear that the yield loss per unit of fertilizer decrease can be determined using developed model from the fertilizer-yield response factor. Studies by Erdal *et al.* (2006) has shown that fertilizer deficiencies which leads to yield reductions are usually greater than those occurring due to water deficit. Therefore, ET–yield response factor equation used for water deficit and yield deficit estimations could also be used for fertilizer uptake which will be referred to as fertilizer–yield response factor equation. The determination relative yield losses using relative yield reduction (Y_a/Y_m) at different fertilizer uptakes can be actualized. The empirical derivation of fertilizer–yield response factor (K_{yF}) can be expressed as:

$$K_{yF} = [1 - (F_{upa}/F_{upm})]/ [1 - (Y_a/Y_m)] \quad (3)$$

where F_{upa} = the actual fertilizer amount used by plants (kgha^{-1}),

F_{upm} = the maximum fertilizer amount used by plants (kg ha^{-1}),

K_{yF} = the fertilizer–yield response factor

$[1- (F_{upa} / F_{upm})]$ = the relative fertilizer deficit.

The fertilizer–yield response factor (K_{yF}) helps to indicate if the crop can withstand stresses due to deficiencies in fertilizer uptake. When the fertilizer-yield response factor is greater than 1 it shows that the expected relative yield decrease for a given fertilizer uptake deficit is proportionately greater than the relative decrease in fertilizer uptake by the crop. Erdal *et al*. (2006), described nitrogen uptake method of determination. Nitrogen uptake of the crops biomass were oven dried at constant weight at 65 °C. Hence, Nitrogen uptake was determined by multiplying concentration (g/kg) of N by weight of the oven-dried matter (Scholberg *et al*., 2000)

$$N_{up} = DM \times N_C \quad (4)$$

Where N_{up} = Plant N uptake (kg ha–1), DM = the oven-dried matter (kg ha^{-1}), and N_C = Nitrogen concentration (g/kg).

The determination of nitrogen is done using the micro Kjeldahl N digestion method (Kacar and İnal, 2008).

The determination of the effect of varying fertilizer application on yield at different crop growth stages was achieved by using the equation. The equation can only be used for the fertilizer for which it was developed. The developed fertilizer use efficiency which is similar to water use efficiency equations shown:

$$FUE = (Ya/Fupa) \times 100 \quad (5)$$

Where FUE = fertilizer use efficiency (t kg^{-1})

Ya = actual yield

An increase in fertilizer–yield response factor (K_{yF}) can lead to a decrease in crop FUE, which means that benefiting from fertilizer uptake deficit is not likely. Crops having fertilizer–yield response factor less than 1 ($K_{yF} < 1.0$) are tolerant and can significantly save fertilizer during deficit fertilization.

2.2.3 ET–FERTILIZER RESPONSE FACTOR ($K_{F–ET}$)

The effect of irrigation and fertilization on crop production are more compared to their individual impacts. Water availability brings about/or better crop fertilizer uptake. However, excessive watering can lead to leaching of fertilizers below the soil root zone. It is very important to control the amount of fertilization and irrigation taking place to increase yield. Water shortage can lead to decrease in yield but the impact can be reduced with the help of fertilization (Li *et al*., 2004). When water supply is not enough for plant fertilizer uptake, fertilizers remaining in the soil will lead to soil pollution. Therefore, adequate knowledge of the right amount of water needed for the plants to absorb fertilizer is necessary. The ET–fertilizer response factor developed from the yield–response was used to determine the right amount of water and fertilizer to apply. This was derived using the equation below:

$$K_{F-ET} = [1 - (F_{upa}/F_{upm})]/ [1 - (ET_a/ET_m)] \quad (6)$$

Where K_{F-ET} = the ET– fertilizer response factor.

2.2.4 Relationship between response factors

Determination of the relationships of the above mentioned factors was actualized by considering the crop yield to water and fertilizer consumption as stipulated by Ertek (2014):

$$K_{yET} = K_{yF} \times K_{F-ET} \quad (7)$$

2.3 STATISTICAL ANALYSIS

A two factorial-based, Randomized Complete Design was used to sort out the experimental data. Each treatment was analyzed statistically with the aid of MS Excel 2019 and STATISTICS 8.1. The values were reported as means of the three replication using the analysis of variance (ANOVA) technique.

3.0 RESULTS AND DISCUSSIONS

Table 1 showed the response factor values and indicated that plant water consumptive use (ET) have a greater effect on yield of *Corchorus olitorus* than the application of

http://dx.doi.org/10.46792/fuoyejet.v9i4.1 engineering.fuoye.edu.ng/journal

fertilizer. Considering the response factor of ET-fertilizer on the nutrient uptake due to application of irrigation water, a significant effect was noticed. Increase in irrigation water applied to *C. olitorus* directly leads to a yield increase. This is perhaps due to ease at which moisture was made available to dissolve the applied fertilizer thereby making nutrient available absorption by the crop. It was observed that an increase in irrigation water and increase in fertilizer applied caused an increased yield of *C. olitorus* till a threshold was attained. Beyond this threshold, an increase in irrigation water and quantity of fertilizer applied led to a reduction in yield of the crop. This adverse effect of increase in fertilizer and irrigation water was not well noticed during the planting period in field trials.

Table 1: Actual evapo-transpiration, Yield, Nitrogen uptake, Water use efficiency, Fertilizer use efficiency of *Corchorus olitorus*

Irrigation (mm)	NPK (kg)	ETc (mm)	Y(t/ha)	N	Nup	1-Nup/Nma	1-(ETa/ETm)	1-Ya/Ym	WUE	FUE	WUE/FUE
2.0	0.0	7.97	0.73	0.00	14.71	0.00	0.80	0.95	0.09	0.05	1.85
2.0	100.0	8.47	0.73	33.30	10.72	0.68	0.79	0.95	0.09	0.07	1.27
2.0	200.0	8.97	0.80	66.70	10.11	0.85	0.77	0.95	0.09	0.08	1.13
2.0	300.0	9.47	0.87	100.00	10.24	0.90	0.76	0.94	0.09	0.09	1.08
2.0	400.0	9.97	0.80	133.30	10.45	0.92	0.75	0.95	0.08	0.08	1.05
4.0	0.0	14.78	1.27	0.00	12.77	0.00	0.62	0.92	0.09	0.10	0.86
4.0	100.0	15.28	1.30	33.30	6.32	0.81	0.61	0.92	0.09	0.21	0.41
4.0	200.0	16.78	1.33	66.70	18.65	0.72	0.57	0.92	0.08	0.07	1.11
4.0	300.0	17.28	1.43	100.00	15.21	0.85	0.56	0.91	0.08	0.09	0.88
4.0	400.0	18.78	1.47	133.30	15.22	0.89	0.52	0.91	0.08	0.10	0.81
6.0	0.0	21.82	2.63	0.00	27.03	0.00	0.45	0.83	0.12	0.10	1.24
6.0	100.0	22.32	2.87	33.30	25.76	0.23	0.43	0.82	0.13	0.11	1.15
6.0	200.0	22.82	2.80	66.70	30.28	0.55	0.42	0.82	0.12	0.09	1.33
6.0	300.0	23.32	2.80	100.00	31.63	0.68	0.41	0.82	0.12	0.09	1.36
6.0	400.0	24.82	2.97	133.30	29.93	0.78	0.37	0.81	0.12	0.10	1.21
8.0	0.0	26.14	3.53	0.00	28.15	0.00	0.34	0.77	0.14	0.13	1.08
8.0	100.0	26.64	3.87	33.30	23.33	0.30	0.32	0.75	0.15	0.17	0.88
8.0	200.0	27.14	3.77	66.70	46.80	0.20	0.31	0.76	0.14	0.08	1.72
8.0	300.0	27.64	4.23	100.00	28.43	0.72	0.30	0.73	0.15	0.15	1.03
8.0	400.0	28.14	4.03	133.30	31.10	0.77	0.29	0.74	0.14	0.13	1.11

Data from figure 1, shows a model generated with the aim of predicting yield reduction with respect to evapotranspiration reduction. The model, $y = 28.263x^5 - 69.51x^4 + 65.037x^3 - 29.477x^2 + 7.1939x - 0.0219$, $R^2 = 0.9863$, shows the relationship between yield and evaporation. The model indicates that the crop yield reduces due to evapotranspiration loss. The obtained R^2 value is seen to be greater than 0.9 indicating that the model is highly reliable, implying a strong relationship exist between evapotranspiration reduction and nitrogen uptake reduction. The model aids in postulating the impact of a unit decrease of water depth applied to the nitrogen uptake of plants. Models were developed with the aim of predicting evapotranspiration reduction with respect to yield reduction as shown in Figure 2. The developed model from Figure 2 indicates that the equation can be relied upon. Equation, $y = -15948x^6 + 48465x^5 - 59430x^4 + 37511x^3 - 12809x^2 + 2236.9x - 155.19$, $R^2 = 0.3726$, simulates

http://dx.doi.org/10.46792/fuoyejet.v9i4.1 engineering.fuoye.edu.ng/journal

relationship between nitrogen uptake reduction and evapotranspiration reduction, which is similar to what was generated by Ertek (2014).

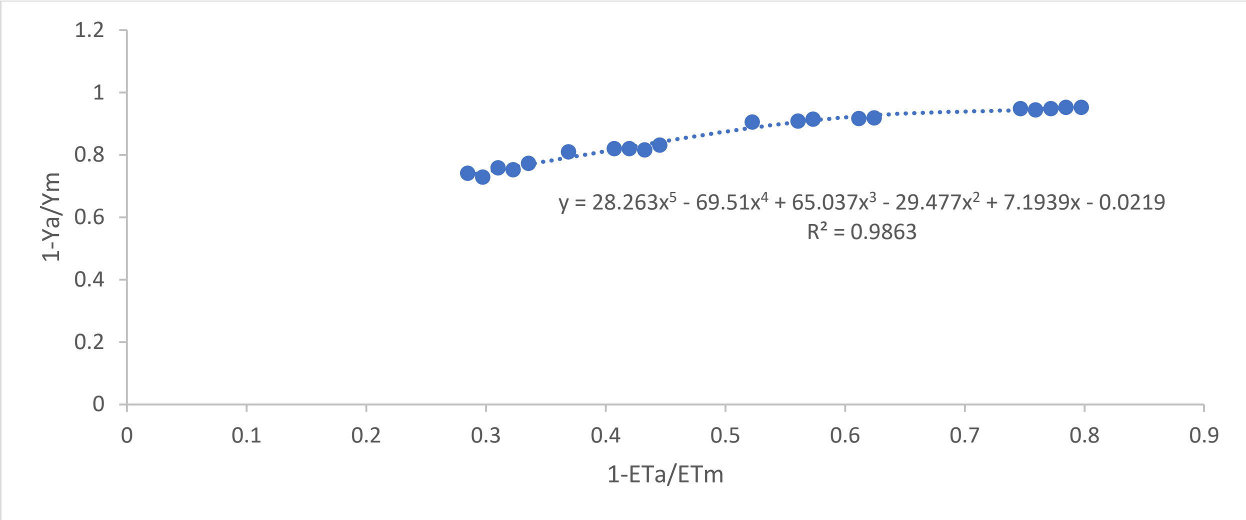

Figure 1: Relationship between yield reduction and evapotranspiration reduction

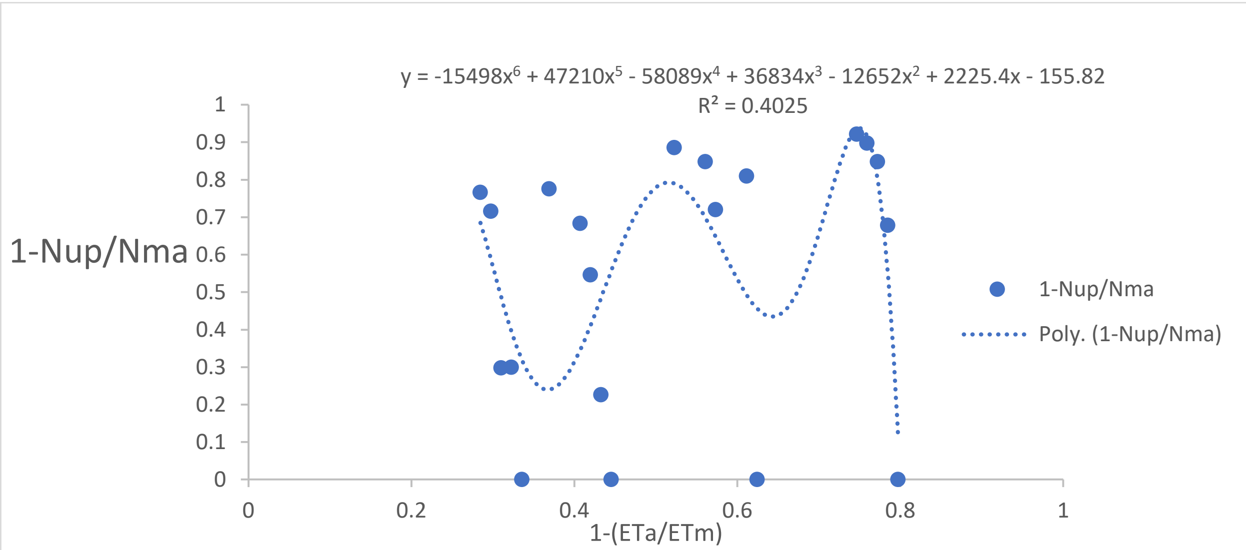

Figure 2: Relationship between nitrogen uptake reduction and evapotranspiration reduction

The results in Figure 3, showed the equation $y = -1169.2x^6 + 4097.7x^5 - 5741.5x^4 + 4087.1x^3 - 1545.6x^2 + 291.97x - 20.688$. The $R^2 = 0.5793$ units which indicates how the fertilizer uptake decreases when crop water needed decreased by 1 unit. This implies that deficit in water supplied will lead to a corresponding yield reduction in the crop. The usefulness of the fertilizer applied to the plant through the soil can be assessed with the aid of the applied water. This indicates that water and fertilizer are two inseparable factors in nutrient use uptake that cannot be discussed isolating one from the other. When considering water as a limiting factor, application of fertilizer alone cannot guarantee the desired level of plant development and yield. The data obtained shows that increased yield is usually obtained through the right quantity of fertilizer and water. However, fertilizer application exceeding the plants need will result in yield reduction which will lead to farmer incurring losses. Table 1 revealed that fertilizer application led to increase in crop development. The yield increased by 20% and 18.7% as a result of NPK 15-15-15 application at different trials. However, optimum yield for profitability was achieved by applying approximate quantity of water i.e taking into consideration crop water requirement and quantity of fertilizer. The table also indicated that when the amount of fertilizer is more than the required proper crop development becomes impeded, which will result to loss of yield. The nutrient available in the soil for cultivation of the crop is proportional to the nutrient utilized by the crop. The nitrogen uptake increases as water applied increases. Thus, fertilizer uptake was lowest in plants where deficit water application occurred.

Fertilizer use efficiency (FUE) increased as plant nitrogen uptake and crop water requirement increased.

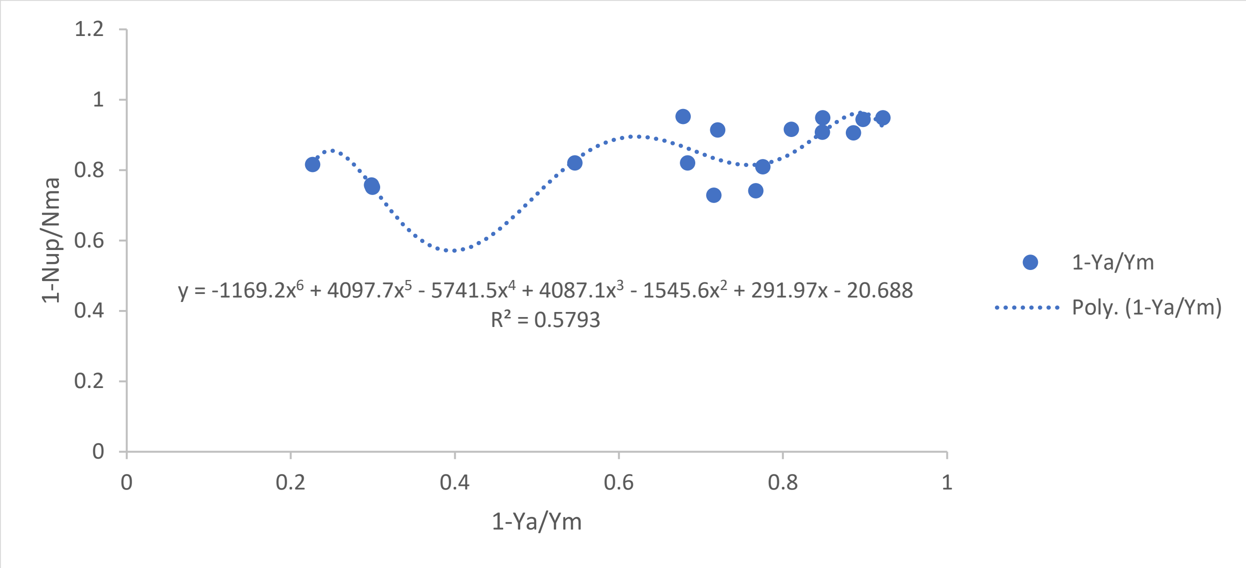

Figure 3: Relationship between nitrogen uptake reduction and yield reduction

Plants where the same quantity of water was applied, but fertilizer applied at different rates experienced growth and development up to an optimum point where increase in fertilizer became harmful to the plant. Fertilizer use efficiency (FUE) and water use efficiency (WUE) values are critical determinants in ascertaining fertilizer quantity and water levels needed for optimum *C. olitorus* yield for profitability and environmental pollution control. High values obtained from the ratio of WUE and FUE signifies higher crop yield. Hence, the dynamics of water and fertilizer uptake on crop yield requires that WUE and FUE should not be evaluated distinctly.

When depth of water applied was constant and the fertilizer quantity increased, an increase in yield was experienced. However, fertilizer and water rates increase produced a linear relationship which varied with changes in fertilizer or water levels. This produces an unfavorable effect on the yield at certain levels of water and fertilizer application. The dynamics showed the synergetic relationship between fertilizer application and irrigation during crop growth and development. The synergetic relationship of ET–yield response factor (K_{yET}), fertilizer–yield response factor (K_{yF}), and ET–fertilizer response factor (K_{FET}) can be decided by proper application. The relationship between response factors can be determined by considering one with the other. The relationship can be applied in analyzing the economic benefits or demerits derived from an increase or decrease in 1 unit of water or fertilizer. Figure 2 showed the ET–fertilizer response factor (K_{FET}) where water and fertilizer requirements for maximum yield and profitability to prevent wastages during crop growth was generated.

Wastages in plant growth and development could be monetary losses or an adverse environmental impact or both. The monetary consideration involves situations where huge amount of money is expended on water and fertilizer, this affects the sustenance of the process. Agriculture and its sustainability is a business, therefore profitability becomes paramount. Adverse environmental impact considers the effect of excessive application of inorganic fertilizer and water in the top-soil. Leaching can occur due to excessive water application resulting to the washing down of soil nutrients. Erosion of the soil can also occur but it will affect the structure of the soil. Application of fertilizer beyond the recommended or optimum amount which could be deduced fom the generated response factors will lead to the washing down of nutrients and also result in the contamination of the groundwater leading to bacteria enrichment.

4.0 CONCLUSION

The study generated statistical models ET-Yield response factor, ET-Fertilizer use, and Nutrient Uptake-Yield. The relationship between response factors using models explains the dynamics of how plant water consumption (ET) had greater effect on yield of *Corchorus olitorus* than fertilizer application. Fertilizer application exceeding the optimum amount results in yield reduction. The study was designed to show how soil amendment can sustainably support cropping systems. However, the impact of inorganic N on crop yield vis-à-vis its possible environmental concerns can be checked with the help of statistical models thereby reducing TSN accumulation over time and its cost implications. Agriculture is a business, so profitability for sustainability of the venture is paramount.

AUTHOR CONTRIBUTIONS

C. N. Ehumadu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Writing – original draft, review & editing. **T. A. Ewemoje:** Project administration, Supervision, Validation, Writing (review & editing). **O. A. Dada:** Methodology, Supervision, Validation, Validation, Writing (review & editing).

ACKNOWLEDGEMENTS

The authors wish to appreciate the following Departments; Crop Protection and Environmental Biology, Agricultural and Environmental Engineering, and Agronomy, situated in the prestigious University of Ibadan, Nigeria, for providing land, equipment and constructive comments for the actualization of this study.

REFERENCES

Akter Z., Lupwayi, N. Z. and Balasubramanian, P. M. (2017). Nitrogen use efficiency of irrigated dry bean (Phaseolus vulgaris L.) genotypes in southern Alberta. Canadian Journal of Plant Science. 97: 610–619. doi.org/10.1139/cjps-2016-0254

Baldocchi, D., Dralle, D., Jiang, C. and Ryu, Y. (2019). How Much Water Is Evaporated Across California? A Multiyear Assessment Using a Biophysical Model Forced with Satellite Remote Sensing Data. Water Resources. 55:2722–2741.

Bauder, J. W., Bauder, T., Cardon, G. and Schneekloth, J. (2006). Guide to Choosing Crops Well-Suited to Limited Irrigation. Bozeman, MT, USA: Montana State University Extension Water Quality Program.

Djaman, K, Mohammed, A. T., Koudahe, K. (2023). Accuracy of Estimated Crop Evapotranspiration Using Locally Developed Crop Coefficients against Satellite-Derived Crop Evapotranspiration in a Semi-arid Climate. Agronomy (MPDI) https://doi.org/10.3390/agronomy13071937

Erdal, İ., Ertek, A., Şenyiğit, U. and Yılmaz, H. İ. (2006). Effects of different irrigation programs and nitrogen levels on nitrogen concentration, uptake and utilisation in processing tomatoes. Aust J Exp Agr 46: 1653–1660.

Ertek, A., Erdal, İ., Yılmaz, H. I. and Şenyiğit, U. (2012). The appropriate water and nitrogen application levels for the optimum of processing tomato yield and efficient water usage. J Agric Sci Technol 14: 889–902.

Ertek, A., Şensoy, S., Kucukyumuk, C. and Gedik, İ. (2006). Determination of plant-pan coefficients for field-grown eggplant using class A pan evaporation values. Agr. Water Manage 85: 58–66.

Ghiberto, P. J., Libardi, P. L., Brito, A. S. and Trivelin, P. C. (2011). Components of the water balance in soil with sugarcane crops. Agricultural Water Management.102:1-7.

Hatfield, J. L. and Dold, C. (2019). Water-use efficiency: Advances and challenges in a changing climate. Frontiers Plant Science. 10:1-13.

Kacar, B. and İnal, A. (2008). Bitki Analizleri. Ankara, Turkey: Nobel Akademik Yayıncılık (in Turkish).

Kassam, A. and Smith, M. (2001). FAO Methodologies on Crop Water Use and Crop Water Use and Crop Water Productivity. In: Expert Meeting on Crop Water Productivity, 3–5 December 2001. Rome, Italy: Food and Agriculture Organization of the United Nations, Paper No. CWP-M07.

Kirda, C. (2002). Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. In: Deficit Irrigation Practices, FAO Water Reports 22. Rome, Italy: Food and Agriculture Organization of the United Nations.

Li, F., Song, L., Guan, C., Ge, D. and Liu, Z. (2000). Coupling effect of water and fertilizers on spring wheat yield in semi-arid area of western Liaoning Province. Ying Yong Sheng Tai Xue Bao 11: 535–539.

Li, W., Li, W. and Li, Z. (2004). Irrigation and fertilizer effects on water use and yield of spring wheat in semi-arid regions. Agr Water Manage 67: 35–46.

Liu, W. Z., Hunsaker, D. J., Li, Y. S., Xie, X. Q. and Wall, G. W. (2002). Interrelations of yield evapotranspiration and water use efficiency from marginal analysis of water production functions. Agr Water Manage 56: 143–151.

Matheus H., Todeschini, A., Simionato M., Diego M. T., Elesandro B., Taciane F., Lindolfo S., Giovani B. (2016). Nitrogen use efficiency in modern wheat cultivars. Soil and Plant Nutrition Bragantia, Campinas. 75(3):351-361, 2016

Moutonnet, P. (2000). Yield response factors of field crops to deficit irrigation. In: Deficit Irrigation Practices FAO Water Report 22. Rome, Italy: Food and Agriculture Organization of the United Nations.

Muhammad A., Fen L., Krishan K. V., Muhammad A. S., Aamir M., Zhong-Liang C., Qiang L., Xu-Peng Z., Yang L. and Yang-Rui L. (2020). Fate of nitrogen in agriculture and environment: agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. Biological Research. Pg 1-20. https://doi.org/10.1186/s40659-020-00312-4

Nehe A. S., Misra S., Murchie E. H., Chinnathambi K, Tyagi B. S, Foulkes M. J. (2020). Nitrogen partitioning and remobilization in relation to leaf senescence, grain yield and protein concentration in Indian wheat cultivars. Field Crops Resource. https://doi. org/10.1016/j.fcr.2020.107778.

Peter O., Lawrence A., and William R. R. (2019). Nitrogen Uptake Efficiency and Total Soil Nitrogen Accumulation in Long-Term Beef Manure and Inorganic Fertilizer Application. Hindawi, International Journal of Agronomy. Pg1-6 https://doi.org/10.1155/2019/9594369.

Prabhu G., Senthilkumar K. M., Muthukumar B., Jake M., Prasanth K. J., Aniruddha M., Hanamant M. H., Sujayananad G. K., Rajagopal V., Das T. K., Rishi R., Vijay P., Subhash B., Sanjay S. R., Muralikrishnan L. and Gopal T. (2023). Nitrogen use efficiency—a key to enhance crop productivity under a changing climate. Frontiers in Plant Science. Pg 1-19. DOI 10.3389/fpls.2023.1121073

Scholberg, J., McNeal, B. L., Boote, K., Jones, J. W., Locascio, S. J. and Olson, S. M. (2000). Nitrogen stress effects on growth and nitrogen accumulation by field-grown tomato. Agron J 92: 159–167.

Sharma S., Kumar T., Foulkes M. J., Orford S., Sing A. M., Wingen L. U., Karnam V., Nair L. S., Mandal P. K., Griffiths S., Hawkesford M. J., (2023). Nitrogen uptake and remobilization from pre- and post-anthesis stages contribute towards grain yield and grain protein concentration in wheat grown in limited nitrogen conditions. *CABI Agriculture and Bioscience 4(12):1-20*. https://doi.org/10.1186/s43170-023-00153-7

Tyagi B. S., Foulkes J, Singh G, Sareen S., Kumar P., Broadley M. R, Singh G. P. (2020). Identification of wheat cultivars for low nitrogen tolerance using multivariable screening approaches. Agronomy. https://doi.org/10.3390/agronom10030417.

Wenjie Z., Ting Z., Jia Z., Weiwei L., Lin Z., Shuai W., Mengyun S. and Meng W. (2023). Low Nitrogen Stress Promotes Root Nitrogen Uptake and Assimilation in Strawberry: Contribution of Hormone Networks. *Horticulturae (MDPI).* Pg 1-19. https://doi.org/10.3390/horticulturae9020249

Zhang H., Wang Z., Yu S., Teng A., Zhang C., Lei L., Ba Y. and Chen X. (2023). Crop coefficient determination and evapotranspiration estimation of watermelon under water deficit in a cold and arid environment. Frontiers Plant Science. 14:1-16.doi: 10.3389/fpls.2023.1153835

