OPTIMIZATION OF SOIL TEMPERATURE DYNAMICS UNDER DIFFERENT IRRIGATION SCHEDULES, TILLAGE METHODS, AND NPK FERTILIZER APPLICATION RATES.

Abstract

Soil temperature is a critical factor influencing crop growth and development. This study investigated the effects of tillage, irrigation, and Nitrogen, Phosphorous, Potassium (NPK) fertilizer on soil temperature, exploring optimal management strategies for improved crop productivity. A field experiment was conducted at Nnamdi Azikiwe University, Awka, using a central composite design in response surface methodology (RSM) to evaluate the interactions between conventional, conservative, and zero tillage, irrigation deficit levels, and NPK fertilizer rates.Using response surface methodology (RSM) to study the effect of tillage, irrigation and NPK application on soil temperature for the study area is grossly lacking in literature.

The results showed that tillage, irrigation management, and NPK fertilizer application significantly impacted soil temperature profiles. A quadratic model accurately predicted soil temperature, explaining 82.71% of the variability. Optimum conditions were identified as 11.59% irrigation deficit, 596.41 kg/ha NPK application rate, and conservative tillage, resulting in a soil temperature of 23.74°C.

This research contributes to the understanding of complex interactions between tillage, irrigation, and NPK fertilizer on soil temperature, informing evidence-based strategies for sustainable agriculture. The findings underscore the importance of holistic management practices that harmonize tillage, irrigation, and NPK fertilizer to optimize soil thermal dynamics for enhanced crop growth and development.

Keywords: soil temperature, tillage, irrigation, NPK fertilizer, crop productivity, sustainable agriculture.

1.0 INTRODUCTION

Climate change has become a pressing issue due to its significant impact on natural ecosystems and agriculture. Research shows that climate variability is a critical factor influencing crop yields (Adamgbe and Ujoh, 2013; Kang et al., 2009). Changes in temperature and precipitation patterns affect hydrologic cycles, water resources, and irrigation, ultimately disrupting agricultural production (Abeysingha et al., 2016).

In sub-Saharan Africa, where only 4% of arable land is irrigated, agriculture is highly vulnerable to climate variability (ACPC, 2011). Climate change threatens sustainable development, particularly in South Eastern Nigeria, where agriculture is the mainstay of the economy (Anyadike, 2009). The Intergovernmental Panel on Climate Change defines climate change as significant variations persisting over decades, including shifts in temperature, precipitation, and weather events (Eboh, 2009).

Climate change manifests through changes in average climate conditions, erratic rainfall, and increased temperature, leading to low agricultural productivity (Ozor, 2009). The major impacts on agriculture come from changes in temperature, rainfall, UV radiation, and carbon dioxide levels (Adamgbe and Ujoh, 2013). Regions like South Eastern Nigeria, with rural economies and limited agricultural diversification, are particularly vulnerable.

Studies show that climate change has reduced agricultural production in Nigeria, with crop yields potentially falling by 10-20% by 2050 (FAO, 2006). To address this, sustainable agricultural practices must be adopted, prioritizing environmental protection (Grace, 2016). Climate change affects farmers' decisions, enterprise choices, and management, necessitating adaptation strategies.

While developed countries have conducted extensive research on climate change, developing countries like Nigeria require more studies to address the significant impact on agricultural productivity. A 2°C temperature rise will lead to unusual changes in agricultural production and water availability, making increased production challenging.

Key statistics:

- 25% loss of cereals in developing world due to weather conditions (FAO, 2006)
- 10-20% potential crop yield fall in Africa by 2050 (FAO, 2006)
- Only 4% of arable land in sub-Saharan Africa is irrigated (ACPC, 2011)

Overall, climate change poses significant risks to agricultural productivity and food security in Nigeria, emphasizing the need for sustainable adaptation strategies.

2.0 METHODOLOGY

2.1 Study Area

A field experiment was conducted at the Department of Agricultural and Bioresources Engineering Experimental Site/Farm Workshop, Nnamdi Azikiwe University, Awka. The experimental site is located within latitudes 6°15'11.8"N - 6°15'5.3"E and longitudes 7°7'118"N - 7°7'183"N, at an altitude of 142m.

The site's geographical characteristics include:

- Soil type: Sandy loam (as identified in previous studies)
- Vegetation: Savanna grassland
- Geologic formation: Imo shale (Odoh et al., 2012)
- Drainage: Anambra River and its tributaries

The local climate is marked by two distinct seasons:

- Dry season (November to March): Temperatures range from 20°C to 38°C, promoting high evapotranspiration
- Rainy season (April to October): Temperatures range from 16°C to 28°C, with reduced evapotranspiration and an August break

Annual climatic averages are:

- Rainfall: 1,500-1,600mm
- Wind speed: 1.73kmph
- Relative humidity: 77%

The experimental site spans 5,227.08 square meters. The study was carried out from November 27, 2017, to February 22, 2018.

2.2 Field preparation

The experimental field, situated on level ground, was divided into three major sections: A, B, and C. Each section measured 27m x 27m and was leveled to ensure uniformity. The tillage treatments applied were conventional tillage (thorough ploughing and harrowing) in plot A, conservative tillage (single tractor pass ploughing) in plot B, and zero tillage in plot C.

A central composite design (CCD) was employed to accommodate both categorical and numeric factors. The design consisted of two numeric factors (irrigation deficit and NPK application) and one categorical factor (tillage). The experimental layout comprised three plots, each containing nine subplots.

The experimental design involved varying tillage methods (conventional, conservative, and zero), irrigation deficit levels (50% MAD, 30% MAD, and 10% MAD), and NPK fertilizer rates (450kg/ha, 550kg/ha, and 650kg/ha). The 27 subplots, each measuring 3m x 3m, were equipped with a drip irrigation system using 25mm, 19mm, and 12.5mm PVC pipes as main, submain, and lateral lines, respectively. Laterals were spaced 0.5m apart, with perforated holes at 0.45m intervals serving as emitters, resulting in a crop spacing of 0.5m x 0.45m.

Weather data, including mean temperature, monthly rainfall, relative humidity, and sunshine duration, were obtained from the Nigerian Meteorological Agency (NIMET). Average readings from each subplot were used for analysis.

This experimental setup allowed for a comprehensive evaluation of the effects of tillage, irrigation deficit, and NPK application on crop growth and development.

2.3 Soil temperature

Soil temperature readings were taken daily at various depths (0-25cm, 25-50cm, 50-75cm, and 75-100cm) across different blocks throughout the crop growth period, using a soil thermometer to measure the temperature profiles at these specified depths**.**

2.4 Experimental design

Table 2.1 Independent variables and levels used for response surface design

Independent variables	**Symbols**	**Ranges and levels**		
		-1	**0**	**+1**
Irrigation Deficit(%)	A	10	30	50
NPK Aplication rate (KG/HA)	B	400	500	600
Tillage	C	1	2	3

3.0 RESULTS AND DISCUSSION

3.1 Development of regression model

Central Composite Design (CCD) was used to optimize properties. The statistical combination of the independent variables along with the experimental response are presented in Table 3.1

Table 3.1 Experimental setup for 3Level factorial response surface design

		Factor 1	Factor 2	Factor 3	Response
Std	Run	A:Irrigation deficit%	B:NPK Application rate	C:Tillage	Soil temperature
		%	Kg/Ha		°C
22	1	50	600	3	28
17	2	30	600	2	25
10	3	10	400	2	25
18	4	30	500	2	23
23	5	10	500	3	26
24	6	50	500	3	27
7	7	30	400	1	28
21	8	10	600	3	26
14	9	10	500	2	23
25	10	30	400	3	26
8	11	30	600	1	28
2	12	50	400	1	28

12	13	10	600	2	23
20	14	50	400	3	29
4	15	50	600	1	28
11	16	50	400	2	25
19	17	10	400	3	26
3	18	10	600	1	27
27	19	30	500	3	27
13	20	50	600	2	24
16	21	30	400	2	25
5	22	10	500	1	25
1	23	10	400	1	25
15	24	50	500	2	23
26	25	30	600	3	27
6	26	50	500	1	27
9	27	30	500	1	26

1, 2 and 3 represents no tillage, conservative tillage and conventional tillage respectively.

3.2 Statistical analysis for soil temperature

Table 3.2 Sequential model sum of Squares for soil temperature

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	18148.15	1	18148.15			
Linear vs Mean	59.52	4	14.88	16.10	< 0.0001	
2FI vs Linear	5.22	5	1.04	1.18	0.3617	
Quadratic vs 2FI	**7.15**	**2**	**3.57**	**6.73**	**0.0082**	**Suggested**
Cubic vs Quadratic	4.80	8	0.5995	1.33	0.3617	Aliased
Residual	3.17	7	0.4524			
Total	18228.00	27	675.11			

The sequential model (linear, two factor interactions 2FI, Quadratic and cubic polynomial) above gave the quadratic model vs 2FI as selected Model by design expert 11.0.2.1 version due to its highest order polynomial

Table 3.3 Analysis of variance (ANOVA) for the fitted quadratic model for soil temperature

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	71.89	11	6.54	12.31	< 0.0001	Significant
A-Irrigation deficit%	9.39	1	9.39	17.69	0.0008	
B-NPK Application rate	0.0556	1	0.0556	0.1047	0.7508	
C-Tillage	50.07	2	25.04	47.16	< 0.0001	
AB	0.3333	1	0.3333	0.6279	0.4405	
AC	2.78	2	1.39	2.62	0.1060	

BC		2.11		2	1.06	1.99	0.1714
A^2		0.4630		1	0.4630	0.8721	0.3652
B^2		6.69		1	6.69	12.59	0.0029
Residual		7.96		15	0.5309		
Cor Total		79.85		26			

Std. Dev.	0.7286	**R^2**	0.9003
Mean	25.93	**Adjusted R^2**	0.8271
C.V. %	2.81	**Predicted R^2**	0.6797
		Adeq Precision	10.8655

The statistical analysis utilized Analysis of Variance (ANOVA) to evaluate the quadratic model's fitness and significance. Table 3.3 reveals an F-value of 12.31 and a P-value of <0.0001, indicating the model's significance at a 95% confidence level.

The P-value assessment confirmed the significance of individual regression coefficients and interaction effects. Model terms A, C, and B2 exhibited significant effects, with P-values of 0.0008, 0.0001, and 0.0029, respectively.

Model performance metrics include:

- R-squared (R^2): 0.9003
- Standard deviation: 0.7286
- Predicted R-squared: 0.6797
- Adjusted R-squared: 0.8271

The strong agreement between predicted and actual soil temperature values (R2 = 0.8271) indicates that the model explains 82.71% of the variability (Fig 3.1).

Overall, the results demonstrate the model's excellent fit and predictive capability, supporting its application for soil temperature predictions.

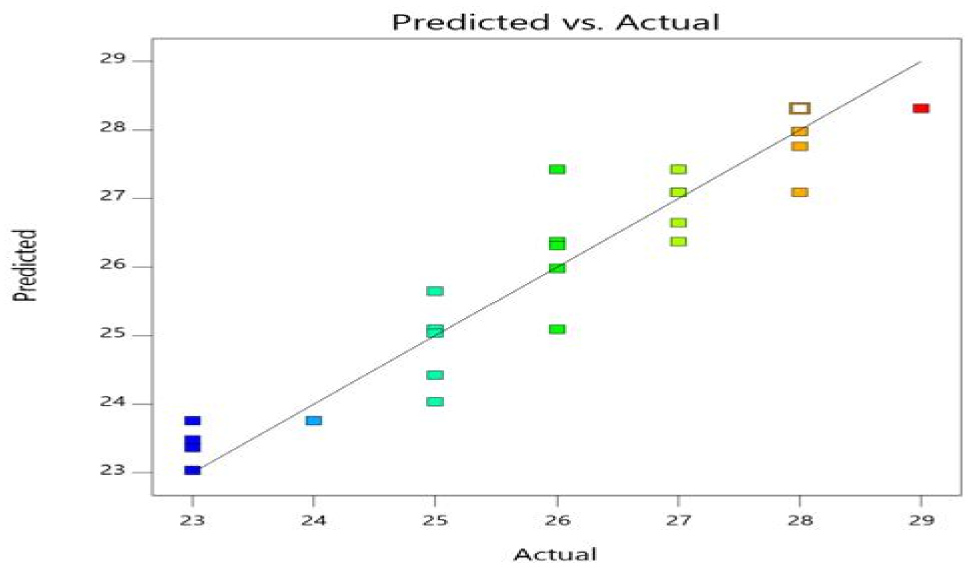

Fig 3.1 Diagnostics plots of the fitted quadratic model for soil temperature

To validate the model's adequacy, a residual analysis was conducted, focusing on the differences between observed and predicted responses. The actual versus predicted plot (Fig 3.1) was examined to assess the model's performance.

The plot reveals a strong correlation between observed and predicted values, indicating that the model accurately captures the underlying relationships. This suggests that the model is adequate and effectively predicts soil temperature.

3.3 Model Equation for Soil Temperature

Soil Temperature (No tillage) = 47.71759 + 0.133333A - 0.099722B - 0.000083A * B - 0.000694A^2 + 0.000106B^2 3.1

Soil Temperature (Conservative tillage) $= 50.24537 + 0.091667A - 0.108056B - 0.000083A * B - 0.000694 A^2 + 0.000106B^2$ 3.2

Soil Temperature (Conventional tillage) $= 49.38426 + 0.133333A - 0.103056B - 0.000083A * B - 0.000694A^2 + 0.000106B^2$ 3.3

Eliminating the non significant terms:

Soil Temperature (No tillage) $= 47.71759 + 0.133333A - 0.099722B - 0.000083A* 0.000106B^2$ 3.4

Soil Temperature (Conservative tillage) $= 50.24537 + 0.091667A - 0.108056B - 0.000083A * 0.000106B^2$ 3.5

Soil Temperature (Conventional tillage) $= 49.38426 + 0.133333A - 0.103056B - 0.000083A * 0.000106B^2$ 3.6

3.4 Optimisation solutions

Table 3.4 Optimisation solutions

Number	Irrigation deficit (%)	NPK application rate (Kg/Ha)	Tillage	Soil temperature (°C)	Desirability	
1	**11.594**	**596.406**	**2**	**23.740**	**1.000**	**Selected**
2	10.154	599.069	2	23.747	1.000	
3	12.194	599.053	2	23.800	1.000	
4	11.048	597.860	2	23.750	1.000	
5	10.428	595.845	2	23.699	1.000	

The responses of the variables in Table3.4 were generated by Design Expert 11.0 software for the optimization based on the model obtained and the experimental data input. From Table 3.4, the run 1 order gave the optimum condition and was selected. The selected marked in run 1 order shows that it contains the best optimization results. The optimum values based on the run order 1 gave irrigation deficit as 11.594%, NPK application rate as 596.406 KG/HA, best tillage method as conservative tillage, Soil temperature of 23.740°C.The soil temperature is also in agreement with observation by Onwuka (2016) in South Eastern Nigeria, soil temperature ranging from 10°C - 28°C is good for maize growth, Broadbent (2015) also observed that soil temperature between 21°C - 38°C increases organic matter decomposition.Conservative tillage was also selected as the best tillage method, Alteri (2011) observed conservative tillage to be the best tillage method because it creates suitable soil environment for crop growth, and conserves soil and water energy through the reduction in tillage intensity, he also stated that conservative tillage leaves at least 30% of the soil residue on the soil surface, which slows water movement which reduces erosion.

4.0 Conclusion

In summary, this investigation has unearthed the profound influence of tillage, irrigation, and NPK fertilizer on soil thermal dynamics, a pivotal determinant of crop performance and resilience. The quadratic model employed accurately captured soil temperature fluctuations, accounting for 82.71% of the observed variability.

The analysis revealed that diverse tillage practices, irrigation regimes, and NPK fertilizer applications exerted a significant impact on soil temperature profiles, underscoring the necessity for synergistic management strategies. Notably, conservative tillage and precision irrigation management emerged as effective mitigators of soil temperature extremes, while NPK fertilizer application enhanced soil fertility and thermal stability.

This research contributes meaningfully to the elucidation of complex interactions between tillage, irrigation, and NPK fertilizer on soil temperature, offering actionable insights for agricultural stakeholders and policymakers. The findings of this study inform data-driven approaches to sustainable agriculture, ultimately fostering improved crop productivity, water stewardship, and soil sustainability.

Ultimately, this study underscores the vital significance of soil temperature optimization in agricultural productivity and highlights the imperative for holistic management practices that harmonize tillage, irrigation, and NPK fertilizer to cultivate an optimal soil thermal environment conducive to robust crop growth and development.

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