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Instructions to Authors

Introduction

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Examples of some common abbreviations: Time: min, hr, sec; Length: km, m, cm, mm; Mass: kg, g, mg, µg; Concentration: g/cm^3, g/L, mg/L, µg/L, ppm; Volume: cm^3, L, mL, µL

TABLE OF CONTENTS

Preface i

Instructions to Authors ii

Development and Validation of Predictive Model for Tractor Fuel Consumption in the Gezira Scheme, Sudan 1-13

Ahmed O. Elattaya, Lotfie A. Yousif, and Abdelkarim D. Elfadil

Application of Predictive Model for Tractor Fuel Consumption in the Gezira Scheme, Sudan 14-26

Ahmed O. Elattaya, Lotfie A. Yousif and Abdelkarim D. Elfadil

Discrepancies in Broad Bean Productivities between Traditional Farms and Research Experiments 27-40

Haidar Salaheldeen Abdalla, Adam Adoma Abdalla, Suliman Abdalla Ibrahim Ali, and Omer Hasab-elRasol Ibrahim

Influences of Light Intensity, and Soil Type on the Growth and Performance of the Indigenous Tree Seedling Species*(Leptadenia pyrotechnica)* 41- 47

Medani. I. Adlan, Dalia. A. Arabi, Khouther. M. ELkheder, and A. Mohamed

Shelf-Life Investigation for Two Newly Released Tomato Varieties Compared to Introduced one to Sudanese Environment 48-60

Amani Ahmed Abd-Elwahid Gabr, Ahmed Elgaili Ibrahim, Mohamed Suliman Mustafa and Abdelazim Mohamed Ali

Using a Low-cost Energy (carbon) Source to Produce Tissue Cultures Banana 61-71

Islam Fath Alrhman Ahmed Elmahi , Abdelazim Mohamed Ali, and Ibrahim Abdelmaksoud Ibrahim

Preface

This is the first issue of Volume 11 of the Nile Journal of Agricultural Sciences, published by the Deanship of Scientific Research and Publication at Nile Valley University in collaboration with the university's Faculty of Agriculture. The Deanship of Scientific Research currently publishes two issues per year using an open access publishing method. The opinions expressed in the published articles are those of their authors, and the journal bears no legal responsibility for these opinions. All articles are subject to peer review by at least two qualified scientists.

This issue, published amidst complex circumstances that paints a bleak picture of the food availability situation. The soaring prices of energy and fertilizers, coupled with the resulting closures in global trade routes through which more than 20% of fossil fuel resources and a significant portion of agricultural fertilizers pass, paint a grim picture. Food and agricultural producers are already facing an ever-expanding list of challenges. Climate change and extreme weather conditions, the ability of pests and parasites to resist pesticides that are constantly being renewed every generation or two, and the loss of soil fertility and productivity, along with salinization, all present challenges that demand continuous effort to address and overcome them in a world approaching eight billion inhabitants.

This issue features articles that attempt to find solutions to the problems of agricultural production. In the abovementioned context Dr. Elattaya and his co-authors tried, in two related articles, to predict fuel consumption for agricultural tractor in the Gezira Scheme, which is the largest irrigated unit scheme in Africa with about one million hectares of productive lands.

Reasons of yield variation between research experiments and traditional farming of broad bean production in Aliab scheme of River Nile State was fully discussed by a joint research team related to Sudan Agricultural Research Corporation (ARC) and Sinnar University. Shedding lights on the role of Agriculture Extension in improving the situation.

Another research team from Hudieba Research station of Agricultural Research Corporation made trials in reliable ways to raise seedings of promising indigenous tree species to sand movement and desertification control.

As described with its sister state in north of Sudan as promising horticultural region, The Faculty of Agriculture of Nile Valley University exert more effort to enrich research findings related to horticultural crops in River Nile State. Here you will find two articles related to two valuable fruits. Tomato and Banana are largely consumed by poor as well as well-off communities.

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Development and Validation of Predictive Model for Tractor Fuel Consumption in the Gezira Scheme, Sudan

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Abstract

Accurate estimation of tractor fuel consumption is essential for effective machinery management, cost control, energy efficiency assessment and environmental impact evaluation in irrigated agricultural systems. The Gezira irrigated scheme in Sudan operates a heterogeneous tractor fleet characterized by wide variations in engine power, age and operational efficiency, resulting in highly variable fuel consumption rates. This study aimed to develop, verify, validate and compare a predictive model for tractor diesel fuel consumption under the specific operational and environmental conditions of the Gezira scheme. Field experiments were conducted using eight tractors with engine powers ranging from 56.0 to 190.3 kW coupled with different implements. Actual fuel consumption (L/h) was measured using an auxiliary fuel tank method. Five regression models; linear, logarithmic, exponential, polynomial and power were developed using tractor engine power as the independent variable. Model performance was evaluated using the coefficient of determination (R^2), root mean square error (RMSE) and t-test analysis. Among the tested models, the power model (**$Y = 0.0679 X^{1.2203}$**) exhibited the best overall performance, combining high explanatory power (R^2), low RMSE, statistical robustness and physical interpretability. The model was successfully verified using experimental data and validated using independent datasets collected from Gezira, Al-Rahad, and El Suki irrigated schemes. Results showed no statistically significant differences were observed between predicted and measured fuel consumption values ($p > 0.05$). Comparative analysis demonstrated that the developed power model outperformed the commonly used linear PTO-based model reported in the literature, particularly at medium and high engine power levels. Sensitivity analysis further confirmed the robustness of the model and highlighted the exponent coefficient as the most influential parameter. The developed model provides a reliable and practical tool for estimating tractor fuel consumption, supporting farm planning, and mechanization management in Sudanese irrigated agriculture.

Keywords: *Tractor fuel consumption, Engine power, Predictive modeling, Agricultural mechanization, Gezira irrigated* scheme.

تطوير نموذج تنبؤي لاستهلاك وقود الجرارات في مشروع الجزيرة، السودان، والتحقق من صحته

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المستخلص:

يُعدّ التقدير الدقيق لاستهلاك وقود الجرارات أمرًا بالغ الأهمية للإدارة الفعّالة للآلات، والتحكم في التكاليف، وتقييم كفاءة الطاقة، وتقييم الأثر البيئي في النظم الزراعية المروية. يعتمد مشروع ري الجزيرة في السودان على أسطول جرارات متنوع يتميز باختلافات واسعة في قدرة المحرك وعمره وكفاءته التشغيلية، مما ينتج عنه معدلات استهلاك وقود متغيرة للغاية. هدفت هذه الدراسة إلى تطوير نموذج تنبؤي لاستهلاك وقود الديزل في الجرارات، والتحقق من صحته، ومقارنته، وذلك في ظل الظروف التشغيلية والبيئية الخاصة بمشروع الجزيرة. أُجريت تجارب ميدانية باستخدام ثمانية جرارات بقدرات محركات تتراوح بين 56.0 و190.3 كيلوواط، مزودة بمعدات زراعية مختلفة. تم قياس استهلاك الوقود الفعلي (لتر/ساعة) باستخدام طريقة خزان الوقود الإضافي. طُوّرت خمسة نماذج انحدار: خطي، لوغاريتمي، أسي، متعدد الحدود، ونموذج القوة، باستخدام قدرة محرك الجرار كمتغير مستقل. قُيّم أداء النموذج باستخدام معامل التحديد(R^2) ، وجذر متوسط مربع الخطأ(RMSE) ، واختبار t. من بين النماذج المختبرة، أظهر نموذج القدرة ($Y = 0.0679 X^{1.2203}$) أفضل أداء شامل، إذ جمع بين قدرة تفسيرية عالية(R^2) ، وانخفاض متوسط الجذر التربيعي للخطأ(RMSE) ، ومتانة إحصائية، وقابلية تفسير فيزيائية. وقد تم التحقق من صحة النموذج بنجاح باستخدام بيانات تجريبية، وتم التحقق من صحته باستخدام مجموعات بيانات مستقلة جُمعت من مشاريع الري في الجزيرة والرهد والسوكي. وأظهرت النتائج عدم وجود فروق ذات دلالة إحصائية بين قيم استهلاك الوقود المتوقعة والمقاسة .($p > 0.05$) وأظهر التحليل المقارن أن نموذج القدرة المُطور يتفوق على النموذج الخطي الشائع الاستخدام والقائم على مأخذ الطاقة (PTO) والمذكور في الأدبيات، لا سيما عند مستويات قدرة المحرك المتوسطة والعالية. كما أكد تحليل الحساسية متانة النموذج، وأبرز معامل الأس باعتباره المعلمة الأكثر تأثيرًا. يوفر النموذج المُطور أداة موثوقة وعملية لتقدير استهلاك وقود الجرارات، مما يدعم تخطيط المزارع وإدارة الميكنة في الزراعة المروية السودانية.

الكلمات المفتاحية: *استهلاك وقود الجرارات، قوة المحرك، النمذجة التنبؤية، الميكنة الزراعية، مشروع ري الجزي*

Introduction

The Gezira irrigated scheme is the largest and most important irrigated agricultural system in Sudan, covering vast areas cultivated mainly with cotton, sorghum, wheat, and other strategic crops. Due to its central role in national agricultural production and food security, improving the efficiency and sustainability of farming operations within the scheme has become a critical priority (FAO and UNIDO, 2008). Agricultural mechanization plays a key role in this process by enhancing productivity, reducing labor intensity and optimizing the use of production inputs.

Mechanization in the Gezira scheme represents a major transition from traditional labor-based farming toward machine-based agricultural operations. However, the level and effectiveness of mechanization vary considerably across crop types, field operations and management practices (Yousif *et al.*, 2025). The tractor fleet operating within the scheme is highly heterogeneous, with differences in engine power, age, maintenance status and operational efficiency. This variability often results in excessive and inconsistent fuel consumption, leading to increased production costs and reduced economic efficiency for farmers and mechanization service providers (Eltom *et al.*, 2014).

Accurate estimation of tractor fuel consumption is essential for effective farm planning, machinery management, fuel budgeting, and cost analysis (Grisso *et al.*, 2014). Moreover, reliable fuel consumption models form a fundamental basis for evaluating energy use efficiency and estimating greenhouse gas emissions associated with agricultural mechanization (Lal, 2004; FAO, 2016). Therefore, fuel consumption prediction has gained increasing importance in the context of sustainable agricultural production systems.

Tractor fuel consumption is influenced by a complex interaction of technical, operational and environmental factors. Tractor-related factors include engine power, engine efficiency, transmission type, drivetrain configuration, tractor mass and maintenance condition (Kutzbach, 2000; Grisso *et al.,* 2014). Operational factors involve forward speed, working depth, implement type and width, drawbar load, wheel slip, field efficiency and operator behavior (ASABE, 2015). Environmental and field-related factors include soil texture, soil moisture content, bulk density, surface roughness and field slope (Al-Suhaibani *et al.*, 2010; Keller *et al.,* 2019).

Despite the central role of tractors in the Gezira irrigated scheme, tractor fuel consumption remains inadequately quantified under local operating conditions. Fuel use varies widely among operations due to differences in tractor characteristics, implement combinations and field practices. Furthermore, locally calibrated fuel consumption prediction models are limited. Most existing models have been developed under temperate climatic conditions or controlled experimental environments and may not adequately capture the unique soil properties, irrigation practices and tractor fleet characteristics of the Gezira scheme (Babiker, 2011; Ahmed and Mustafa, 2018). This study addresses this critical knowledge gap by developing a locally calibrated and field-validated predictive model for tractor diesel fuel consumption under the specific biophysical and operational conditions of Sudanese irrigated agriculture.

The proposed model is based on extensive field measurements that reflect actual tractor–implement combinations, Vertisol soil conditions and real farm operating practices within the Gezira scheme. The novelty of this research lies in its use of tractor engine power as a practical and readily available predictor. The developed model provides a simple yet robust decision-support tool that can be readily adopted by farmers, mechanization service providers, engineers and policymakers for fuel budgeting, machinery selection and operational planning.

Therefore, this study aims to develop a locally applicable predictive model for tractor diesel fuel consumption based on engine power, to verify and validate the model using field data and to compare its performance with established fuel consumption models reported in the literature.

Materials and Methods

Study area

The study was conducted in the Gezira irrigated scheme, which is located between the Blue Nile and White Nile rivers south of Khartoum, Sudan. The scheme is one of the largest irrigated agricultural systems in the region, covering approximately 2.2 million feddans (1 feddan = 0.42 ha). The area lies within a semi-arid climatic zone, receiving annual rainfall ranging from 150 to 300 mm, which is concentrated mainly between July and September. The dominant soils in this area have a high holding capacity and exhibit pronounced shrink–swell behavior (Al-Naiem, 2009; Omer, 2011). These soil properties have significant impact on tractor traction performance and fuel consumption under field conditions.

Measurement of actual fuel consumption

Field tests were conducted using eight agricultural tractors of different makes, models and engine power ratings (56.0, 61.9, 74.9, 82.1, 113.4, 134.3, 166.4, and 190.3 kW), each coupled with representative agricultural implements. Experiments were carried out over a test area of 0.84 ha under typical field operating conditions.

Tractor diesel fuel consumption (L/h) and effective field capacity (ha/h) were measured using an auxiliary fuel tank system. For each tractor–implement combination, the time required to complete the operation and the volume of fuel consumed were recorded. Each test was replicated five times and average values were used for analysis. Fuel consumption and effective field capacity were calculated using the following equations:

$$K = F \times 60 / T \quad \text{……………………………………} \quad (1)$$

$$EFC = A \times 60 / T \quad \text{…………………………………} \quad (2)$$

Where:

K = Fuel consumption (L/h)

F = Fuel consumed during operation (L)

T = Time required (min)

EFC = Effective field capacity (ha/h)

A = Area covered (feddan)

60 = Conversion factor from minutes to hours

Model development

Five regression models were developed to predict tractor diesel fuel consumption (L/ are classified as Vertisols, which characterized by high clay content (50–60%), high water-h), with tractor engine power (kW) used as the independent variable. The tested functional forms included linear, logarithmic, exponential, polynomial and power models. Regression analyses were performed using Microsoft Excel and model parameters were estimated based on the experimental dataset obtained from the eight tested tractors.

The developed models were evaluated based on their ability to explain the relationship between tractor engine power and fuel consumption and to provide reliable predictions within the studied power range.

Additional data collection

To strengthen model verification and validation, secondary field data were collected from farmers, tractor operators, and agricultural engineers operating in the Gezira scheme. These data included tractor engine power ratings, implement types, effective field capacity, and corresponding fuel consumption rates. The independent dataset was used to evaluate the predictive reliability and generalizability of the developed model under real farm conditions.

Statistical analysis

Descriptive statistical methods, including mean values and correlation analysis, were used to explore relationships between engine power and fuel consumption. A paired t-test was applied to evaluate the statistical significance of differences between measured and predicted fuel consumption values at a 5% probability level.

Model predictive performance was further assessed using the root mean square error (RMSE), calculated as:

$$RMSE = \sqrt{1/n\sum_{i=1}^{n}(K-L){}^\wedge 2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where:

RMSE = Root mean square error (L/h)
K = Observed fuel consumption (L/h)
L = Model-predicted fuel consumption (L/h)
n = Number of observations (n = 8)

Lower RMSE values indicate stronger agreement between predicted and observed fuel consumption and higher model accuracy (Montgomery *et al.,* 2021; Kutner *et al.,* 2005).

Model selection criteria

The coefficient of determination (R^2) was used as the primary criterion for selecting the most appropriate predictive model. The model yielding the highest R^2 value and acceptable RMSE was selected as the best representation of the relationship between tractor engine power and fuel consumption.

Model verification and validation

Model verification was performed by comparing predicted fuel consumption values generated by the selected model with experimental measurements obtained from field tests. Statistical consistency between predicted and observed values was assessed using paired t-tests and descriptive statistical measures.

Model validation was conducted using independent datasets collected from Gezira, Al-Rahad, and El Suki irrigated agricultural schemes. Predicted and measured fuel consumption values were statistically compared to evaluate the robustness and external applicability of the developed model across different irrigated production environments.

Model comparison

The predictive performance of the selected model was compared with the linear fuel consumption model proposed by Bowers (2001), which is based on tractor power take-off (PTO) power. PTO power was estimated as 0.83 of engine power, following ASAE (2003) recommendations. Model comparison was conducted using R², RMSE, paired t-test results, and graphical trend analysis to evaluate differences in prediction behavior and model accuracy.

$$Y = 0.223\,x \text{ …………..….. (Bower, 2001) …………………… (4)}$$

Where: Y is tractor diesel fuel consumption (L/h) and X is tractor PTO power (kW).

Sensitivity Analysis

Sensitivity analysis was conducted to assess the robustness of the selected model and to determine the influence of model parameters on predicted fuel consumption. Tractor engine power was varied by ± 5%, ± 10%, and ± 15% while holding model coefficients constant, and corresponding changes in predicted fuel consumption were computed. Similarly, model coefficients (a and b) were varied within the same percentage ranges while keeping engine power constant. The resulting responses were analyzed to identify the most influential parameters and to evaluate the stability of the model across low- and high-power tractor categories (56.0 and 190.3 kW).

Results and Discussion

Model development and statistical analysis

Tractor diesel fuel consumption (L/h) was modeled as a function of tractor engine power (kW), treating fuel consumption as the dependent variable and engine power as the independent variable. Five regression models; linear, logarithmic, exponential, polynomial, and power, were developed to describe the relationship between engine power and fuel consumption. The regression equations and their corresponding coefficients of determination (R²) are presented in Table 1.

The results revealed a strong positive relationship between tractor engine power and fuel consumption across all tested models, as indicated by relatively high R² values. This finding is consistent with previous studies that reported engine power as a key determinant of fuel consumption under agricultural field conditions (Grisso *et al.,* 2004; Moitzi *et al.,* 2014). However, noticeable differences in predictive performance were observed among the models, emphasizing the importance of selecting an appropriate functional form to accurately represent fuel consumption behavior.

Table 1. Models developed for predicting tractor fuel consumption (L/h) by using tractor engine power (kW)

Model type	Equation	R^2
Exponential	$Y = 5.5406 e^{0.0111x}$	0.9637
Linear	$Y = 0.2443x - 5.2001$	0.9512
Logarithmic	$Y = 26.032 \ln(x) - 98.316$	0.9053
Polynomial	$Y = 0.0006 x^2 + 0.0945 x + 2.4278$	0.9588
Power	$Y = 0.0679 x^{1.2203}$	0.9740

The statistical adequacy of the developed models was further evaluated using paired t-test analysis (Table 2). For all models, the calculated t-values were lower than the critical tabulated value at the 5% significance level ($t_{0.05} = 2.3646$), indicating that differences between predicted and measured fuel consumption values were not statistically significant. These results confirm the statistical reliability of the developed models within the tested engine power range.

Model accuracy was also assessed using the root mean square error (RMSE). Lower RMSE values reflected stronger agreement between predicted and observed fuel consumption. Although all models demonstrated acceptable predictive accuracy, variations in RMSE highlighted differences in their practical suitability for field applications (Kutner *et al.*, 2005; Montgomery *et al.*, 2021).

Table 2. Statistical analysis for models developed to predict tractor fuel consumption

Model type	RMSE	T- calculated
Exponential	2.62	0.963575
Linear	2.59	0.997768
Logarithmic	3.60	0.999371
Polynomial	2.40	0.764329
Power	2.50	0.888702
T- tabulated	2.364624	

Model selection

Based on the combined evaluation of R^2, RMSE, statistical significance and practical applicability, the power model was selected as the most appropriate predictive model for tractor diesel fuel consumption. The selected model is expressed as:

$$\mathbf{Y = 0.0679\, X^{1.2203}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where: Y is tractor diesel fuel consumption (L/h) and X is tractor engine power (kW).

The power model achieved superior explanatory power and a relatively low RMSE value (2.5 L/h) compared with the other tested models. Although the polynomial model yielded a marginally lower RMSE, the power model was preferred due to its simpler structure, reduced risk of overfitting and stronger physical interpretability. Similar observations favoring power-type relationships between engine power and fuel consumption have been reported in earlier mechanization studies (Grisso *et al.*, 2010; Kim *et al.*, 2015; Bowers, 2012).

From a theoretical standpoint, the selected power model effectively captures the nonlinear nature of fuel consumption behavior. The exponent value (>1) indicates that fuel consumption increases at a rate greater than proportional with increasing engine power, reflecting higher engine loads, increased internal friction losses and variations in engine efficiency at higher operating capacities (Hunt, 2001; ASABE, 2011; Moitzi *et al.*, 2014). This behavior is consistent with established engine performance principles under field operating conditions.

Model verification

Model verification was conducted by comparing predicted fuel consumption values obtained from the selected power model with experimentally measured values from tractors of different engine power classes (Table 3). The comparison demonstrated strong agreement between predicted and observed fuel consumption across the evaluated power range. The percentage agreement ranged from 90% to 116%, indicating that the model provides reasonable estimates under diverse operating conditions.

Minor deviations were observed at higher engine power levels, particularly at 166.4 kW and 190.3 kW, where the model slightly overestimated and underestimated fuel consumption, respectively. These discrepancies can be attributed to variations in field load, engine operating efficiency, implement characteristics and soil conditions, which are not explicitly included in the single-variable model (Bowers, 2012; Kim *et al.*, 2015).

Table 3. Verification of the power model for fuel consumption prediction with actual data

Tractor engine power (kW)	Actual	Predicted	Comparative (%)
56.0	9.78	9.22	94
61.9	10.85	10.44	96
74.9	12.00	13.17	110
82.1	13.70	14.72	107
113.4	23.18	21.84	94
134.3	28.33	26.85	95
166.4	29.97	34.87	116
190.3	45.45	41.06	90
RMSE	2.50		

Statistical analysis further confirmed the verification results (Table 4). The paired t-test showed no statistically significant difference between measured and predicted fuel consumption values at the 5% probability level. The calculated t-value (0.8887) was substantially lower than the critical value (2.3646). Moreover, the mean values of actual and predicted fuel consumption were nearly identical (21.658 and 21.521 L/h, respectively). These results confirm the reliability and internal consistency of the developed power model.

Table 4. T-test for paired two sample for means of the predicted and actual data

Statistical Parameters	Values
Mean for actual fuel consumption	21.658
Mean for predicted fuel consumption	21.521
Variance for actual fuel consumption	156.641
Variance for predicted fuel consumption	139.800
Number of observations for each	8
Degree of freedom for each	7
T-calculated	0.8887
T-tabulated	2.3646

Model validation

The external validity of the developed power model was evaluated using independent datasets collected from three major irrigated agricultural schemes in Sudan: Gezira, Al-Rahad and El Suki. A paired two-sample t-test was applied to compare predicted and actual fuel consumption values for each scheme (Table 5).

For all three schemes, the calculated t-values were markedly lower than the corresponding critical values at the 5% significance level, indicating no statistically significant differences between predicted and measured fuel consumption. RMSE values ranged from 3.154 to 3.773 L/h, reflecting acceptable prediction accuracy under diverse field conditions. These results demonstrate that the developed power model is robust and applicable across different irrigated agricultural systems with varying operational characteristics.

The successful validation across multiple schemes highlights the potential of the model as a generalized predictive tool for tractor fuel consumption in Sudanese irrigated agriculture, beyond the specific conditions of the Gezira scheme.

Model comparison

Figure 1 presents a comparison between the developed power model and the linear PTO-based fuel consumption model proposed by Bowers (2001). The linear model assumes a constant proportional relationship between PTO power and fuel consumption, resulting in a uniform linear trend. While this approach provides reasonable estimates at lower power levels, increasing deviations were observed at medium and high engine power ranges.

Table 5. T-test for paired two sample for means of the predicted and actual fuel consumption in three irrigated schemes

Statistical Parameters	Gezira	Al-Rahad	El-Suki
Mean for actual fuel consumption	6.82	6.98	7.17
Mean for predicted fuel consumption	10.20	9.30	9.65
Variance for actual fuel consumption	2.594	5.657	5.15
Variance for predicted fuel consumption	1.810	0.055	0.183
Number of observations for each	13	12	13
Degree of freedom for each	12	11	12
T-calculated	0.00002	0.0041	0.0018
T-tabulated	2.1788	2.2010	2.1788
RMSE	3.773	3.154	3.293

In contrast, the engine power-based power model developed in this study exhibited greater flexibility in capturing the nonlinear behavior of fuel consumption under practical field conditions. Engine power inherently accounts for total energy demand, including drivetrain and auxiliary losses, which are not fully represented in PTO-based models. Consequently, the developed model provides a more realistic representation of actual tractor fuel consumption behavior.

Both statistical indicators and graphical analysis confirm the superior predictive performance of the developed power model, particularly across a wide range of tractor power and operational conditions (Bowers, 2001; Grisso *et al.*, 2010).

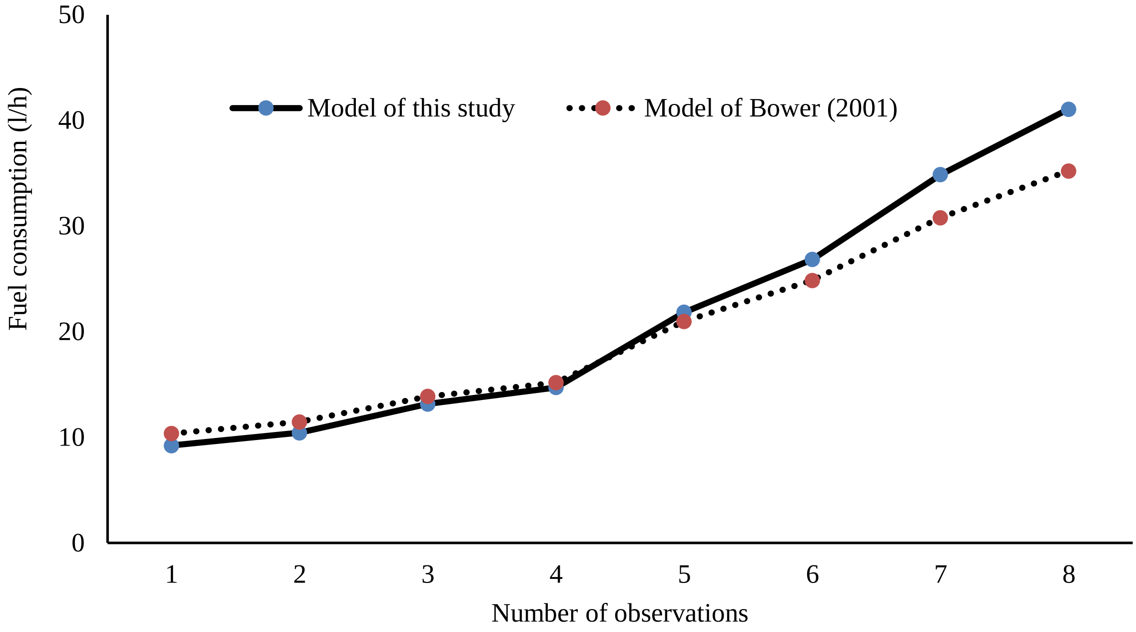

Fig. 1. Comparison between results from this model and Bower (2001) model for fuel consumption (l/h)

Sensitivity Analysis

Sensitivity analysis was conducted to evaluate the robustness of the selected power model and to identify the relative influence of its parameters. Variations in tractor engine power (±5%, ±10%, and ±15%), while keeping model coefficients constant, resulted in proportional changes in predicted fuel consumption at both low (56.0 kW) and high (190.3 kW) power levels (Table 6). This consistent response indicates stable and predictable model behavior across the evaluated power range. This confirms the internal consistency of the power model and its suitability for analyzing the impact of power variation on fuel consumption (ASABE, 2011).

Table 6. Effect of changing engine power in fuel consumption (l/h) at constant coefficients (a) and (b)

Change %	56.0 kW	190.3 kW
+5%	6.13	6.13
+10%	12.33	12.33
+15%	18.60	18.60
-5%	-6.07	-6.07
-10%	-12.06	-12.06
-15%	-17.99	-17.99

Changes in coefficient a, with engine power and exponent b held constant, produced equivalent proportional changes in predicted fuel consumption, confirming the role of coefficient a as a scaling factor. Percentage increases or decreases in a led to identical percentage changes in predicted fuel consumption at both engine power levels (Table 7).

Table 7. Effect of changing coefficient (a) in fuel consumption (l/h) at constant engine power and coefficient (b)

Change %	56.0 kW	190.3 kW
+5%	5	5
+10%	10	10
+15%	15	15
-5%	-5	-5
-10%	-10	-10
-15%	-15	-15

In contrast, variations in exponent b resulted in nonlinear and increasingly pronounced effects at higher engine power levels (Table 8). An increase in *b* led to a substantial rise in predicted fuel consumption, with the effect being more pronounced at 190.3 kW than at 56.0 kW. Conversely, reductions in *b* produced significant decreases, again with larger impacts observed at higher power levels. This behavior indicates that coefficient b is the most sensitive parameter in the model and plays a critical role in defining the curvature of the fuel consumption–power relationship (Bowers, 2012; Kim *et al.*, 2015).

Table 8. Effect of changing coefficient (b) in fuel consumption (l/h) at constant engine power and coefficient (a)

Engine power	56.0 kW	190.3 kW
+5%	27.84	37.75
+10%	63.42	89.74
+15%	32.56	44.42
-5%	-21.77	-27.40
-10%	-38.81	-47.30
-15%	-52.13	-61.74

The sensitivity analysis confirms the robustness of the developed power model and provides valuable insight into its structural behavior under varying conditions. These findings further support the suitability of the model for strategic fuel consumption assessment, machinery management and operational planning in agricultural mechanization systems (Hunt, 2001; Grisso *et al.,* 2004; ASABE, 2011).

Conclusion

1. A predictive power model was developed for tractor diesel fuel consumption based on engine power in the Gezira scheme, Sudan.
2. Model validation across multiple irrigated schemes confirmed its reliability and robustness under diverse field conditions.
3. The power model outperformed PTO-based linear models, accurately capturing the nonlinear relationship between engine power and fuel use.
4. Sensitivity analysis identified the exponent coefficient as the most influential factor, ensuring stable predictions across tractor power ranges.
5. The model provides a practical tool for fuel budgeting and machinery management in irrigated agriculture.
6. Future studies may further enhance model accuracy by incorporating additional operational and soil parameters and extending validation to rainfed agricultural systems.

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Application of Predictive Model for Tractor Fuel Consumption in the Gezira Scheme, Sudan

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Abstract

Fuel scarcity and rising energy costs are major challenges for mechanized agriculture in large-scale irrigated schemes such as the Gezira scheme, Efficient planning and allocation of diesel fuel are therefore critical for sustaining mechanized farming operations and maintaining productivity. This study aimed to apply a previously developed and validated predictive power model for tractor fuel consumption to support fuel requirement estimation, operational planning and economic analysis under real field conditions in the Gezira scheme. The model was used to estimate specific volumetric fuel consumption (SVFC), specific volumetric fuel efficiency (SVFE), fuel consumption per unit area (L/ha), unproductive fuel losses associated with off-road tractor movement, and total fuel requirements at farm and scheme levels. The application covered major crops grown in the Gezira scheme, namely cotton, wheat, groundnut and sorghum, under three farming systems: traditional, semi-mechanized, and fully mechanized. Fuel consumption for individual tractor–implement combinations was estimated using predicted hourly fuel consumption and effective field capacity, while unproductive fuel consumption was quantified based on tractor travel distance, speed and off-road fuel use. The model was further applied to estimate total seasonal and annual fuel demand and to assess fuel-related economic costs and potential savings. Results showed stable tractor fuel performance, with an average SVFC and SVFE values were 0.19 L/kW·h and 5.36 kW·h/L, respectively, indicating stable tractor fuel-use performance. Fuel consumption per hectare varied widely among implements, with unproductive fuel losses representing a significant share in high-capacity operations. Total fuel demand increased substantially with mechanization intensity, reaching a maximum under fully mechanized systems. Economic analysis revealed that fuel costs constitute a major component of production expenses, while a 10% reduction in fuel consumption could result in substantial financial savings at both farm and scheme levels. The findings demonstrate the practical applicability of the developed power model as a reliable decision-support tool for fuel budgeting and mechanization planning in large-scale irrigated agricultural systems.

Keywords: Tractor fuel consumption, predictive modeling, agricultural mechanization, unproductivefuel loss; Gezira scheme, Sudan.

Keywords*: Tractor fuel consumption, predictive modeling, agricultural mechanization, unproductive fuel loss; Gezira scheme, Sudan.*

تطبيق نموذج تنبؤي لاستهلاك وقود الجرارات في مشروع الجزيرة، السودان

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المستخلص

يُعدّ نقص الوقود وارتفاع تكاليف الطاقة من التحديات الرئيسية التي تواجه الزراعة الآلية في مشاريع الري واسعة النطاق، مثل مشروع الجزيرة. ولذلك، يُعدّ التخطيط الفعال وتوزيع وقود الديزل أمرًا بالغ الأهمية لاستدامة عمليات الزراعة الآلية والحفاظ على الإنتاجية. هدفت هذه الدراسة إلى تطبيق نموذج تنبؤي مُطوّر ومُدقّق سابقًا لاستهلاك وقود الجرارات، وذلك لدعم تقدير احتياجات الوقود، والتخطيط التشغيلي، والتحليل الاقتصادي في ظروف الحقل الفعلية في مشروع الجزيرة. استُخدم النموذج لتقدير استهلاك الوقود الحجمي النوعي(SVFC) ، وكفاءة استهلاك الوقود الحجمي النوعي(SVFE) ، واستهلاك الوقود لكل وحدة مساحة (لتر/هكتار)، وفقدان الوقود غير المُنتج المرتبط بحركة الجرارات على الطرق الوعرة، وإجمالي احتياجات الوقود على مستوى المزرعة والمشروع. شمل التطبيق المحاصيل الرئيسية المزروعة في مشروع الجزيرة، وهي القطن والقمح والفول السوداني والذرة الرفيعة، في ظل ثلاثة أنظمة زراعية: التقليدية، وشبه الآلية، والآلية بالكامل. تم تقدير استهلاك الوقود لمجموعات الجرارات والمعدات الزراعية الفردية باستخدام معدل استهلاك الوقود المتوقع بالساعة والقدرة الحقلية الفعالة، بينما تم تحديد كمية استهلاك الوقود غير المنتج بناءً على مسافة سير الجرار وسرعته واستخدامه للوقود على الطرق الوعرة. وطُبّق النموذج أيضًا لتقدير إجمالي الطلب الموسمي والسنوي على الوقود، ولتقييم التكاليف الاقتصادية المتعلقة بالوقود والوفورات المحتملة. أظهرت النتائج أداءً مستقرًا لاستهلاك وقود الجرارات، حيث بلغ متوسط قيمة استهلاك الوقود في الحقل (SVFC) وقيمة كفاءة استخدام الوقود في الحقل (SVFE) 0.19 لتر/كيلوواط ساعة و5.36 كيلوواط ساعة/لتر على التوالي، مما يشير إلى استقرار أداء استخدام وقود الجرارات. تفاوت استهلاك الوقود لكل هكتار بشكل كبير بين المعدات الزراعية، حيث مثّلت خسائر الوقود غير المنتجة نسبة كبيرة

في العمليات ذات القدرة العالية. ازداد إجمالي الطلب على الوقود بشكل ملحوظ مع زيادة كثافة الميكنة، ليصل إلى أقصى حد له في ظل الأنظمة المميكنة بالكامل. كشف التحليل الاقتصادي أن تكاليف الوقود تُشكّل عنصرًا رئيسيًا من نفقات الإنتاج، في حين أن خفض استهلاك الوقود بنسبة 10% يمكن أن يؤدي إلى وفورات مالية كبيرة على مستوى المزرعة والمشروع. تُظهر النتائج التطبيق العملي لنموذج الطاقة المُطوَّر كأداة موثوقة لدعم اتخاذ القرارات في مجال ترشيد استهلاك الوقود وتخطيط الميكنة في النظم الزراعية المروية واسعة النطاق.

الكلمات المفتاحية: *استهلاك وقود الجرارات، النمذجة التنبؤية، الميكنة الزراعية، هدر الوقود غير المُنتِج؛ مشروع الجزيرة، السودان.*

Introduction

Agricultural mechanization is a fundamental component of modern farming systems, providing enhanced productivity, improved timeliness of operations and better resource-use efficiency (Grisso *et al.*, 2004; Mamkagh, 2019). Mechanization reduces dependence on manual labor, enables large-scale operations within critical crop calendars and supports efficient input use, particularly in irrigated systems where large areas must be managed within narrow operational windows.

In Sudan, the Gezira scheme represents the largest and most important irrigated agricultural system, playing a crucial role in national food security and cash crop production (Yousif *et al.*, 2025). The scheme supports year-round cultivation of major crops such as cotton, wheat, groundnut, and sorghum, necessitating extensive use of diesel-powered tractors for soil preparation, planting, cultivation, and harvesting. As a result, diesel fuel becomes an indispensable input for sustaining agricultural productivity in the scheme.

However, fuel scarcity and rising fuel prices have emerged as significant constraints to agricultural production in Sudan, particularly during peak cultivation seasons when demand for fuel surges. Limited fuel availability at critical times, inefficient fuel allocation and high variability in field-level tractor fuel consumption have increased production costs and disrupted farm operations. Highlighting the urgent need for reliable tools that support fuel estimation and energy management.

Tractor fuel consumption is influenced by multiple interacting technical and operational variables, including engine load, transmission type, implement characteristics, field conditions and operator behavior (Wei, 2024; Xiao *et al.*, 2018). Research has shown that optimizing engine load and operating conditions can significantly improve fuel economy, while advanced designs such as hydro-mechanical transmissions and adaptive systems further enhance efficiency (Xiao *et al.*, 2018). In addition, fuel consumption models increasingly incorporate multiple parameters to improve prediction accuracy and operational relevance (Al-Sager *et al.*, 2024).

While numerous predictive models have been developed internationally, many are calibrated under temperate climates or controlled experimental conditions and may not fully reflect the unique operational environments of large-scale irrigated schemes in tropical contexts. Dimensional analysis and machine learning approaches have recently been applied to tractor fuel consumption prediction, demonstrating improved modeling flexibility and predictive performance (Labad *et al.*, 2024; Al-Sager *et al.*, 2024).

However, there remains a gap in applying such models to actual field operating conditions in regions like Sudan.

In a preceding study, a predictive power-based model for tractor fuel consumption was developed and validated specifically under the field conditions of the Gezira scheme, showing strong statistical performance and practical relevance. Nonetheless, the utility of such models depends on translating their outputs into actionable decision-support tools for fuel planning and mechanization management.

Therefore, this study builds on the previously developed predictive model by applying it to estimate key fuel consumption indicators across different operations, quantify fuel requirements per unit area and assess fuel demand under traditional, semi-mechanized and fully mechanized farming systems. The research also evaluates the economic implications of fuel consumption and explores strategies to reduce unproductive fuel losses. The findings aim to support effective fuel budgeting, mechanization optimization and energy-efficient practices in large-scale irrigated agricultural systems.

Materials and Methods

Study area

The study was conducted in Gezira irrigated scheme, which is located between the Blue Nile and White Nile Rivers to the south of Khartoum. One of the largest irrigated scheme in the region, covering about 0.924 million hectares. The scheme is located in semi-arid region. The soil is Vertisols, with high clay content (50-60%) (Al-Naiem, 2009; Omer, 2011).

Crops and rotation

Crop diversity is a common characteristic in the Gezira scheme. Four main field crops are grown. These crops include cotton, groundnut and sorghum, as summer crop, besides wheat as winter crop. Since its establishment, a lot of crop rotations were applied (Mahgoub, 2014). Currently, a five-course rotation is applied. The summer and winter cultivated crops make the use of tractors and implements almost during the year.

Model application

The developed and validated power model (equation 1) predicts fuel consumption (L/h) based on tractor engine power. It was applied to estimate fuel consumption for different tractor-implement combination. The following procedures illustrates the application of the developed model and calculation methods.

$$\mathbf{Y = 0.0679\ X\text{^}\ ^{1.2203}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

Where:

Y = Diesel fuel consumption (L/h)
X = Tractor engine power (kW)

Specific volumetric fuel consumption (SVFC)

The SVFC in L/kW.h based on the tractor engine power, and was calculated as follows:

SVFC = Predicted fuel consumption (L/h)/ Tractor engine power (Kw)…………… (2)

Specific volumetric fuel efficiency (SVFE)

The SVFE in kW.h/L was calculated as follows:

SVFE = Tractor engine power (kW)/ Predicted fuel consumption (L/h)…………… (3)

Fuel consumption for tractor-implement combinations

For each specific farm operation, fuel consumption was computed by using engine power of the used tractor and effective field capacity of the attached implement as follows:

FC = PFC/EFC ……………………………… (4)

Where:

FC = Fuel consumption (L/ha)
PFC = Predicted fuel consumption (L/h)
EFC = Effective field capacity (ha/h)

This equation was used to compute fuel consumption for 17 implements usually used in the Gezira scheme.

Unproductive fuel consumption

The unproductive fuel consumption is that consumed for off road movement of the tractor and implement to and from farms. Fuel consumption measured in experiments and tests underestimates actual consumption because it does not include unproductive movements. The unproductive fuel consumption (L/ha) was calculated by the following equation:

UPFC = (D * ORFCR)/ (S * A) ……………………………… (5)

Where:

UPFC = Unproductive fuel (L/ha)
D = Distance to and from the farms (km)
ORFCR = Off-road fuel consumption rate (L/h)
S = Tractor speed for off-road movement (km/h)
A = Area covered per one trip of tractor (ha)

This unproductive fuel consumption was added to fuel consumption calculated by equation 4 to give the total fuel consumption for each specific farm operation.

Fuel requirement in Gezira scheme

Fuel consumption from land preparation to harvest for the main crops was computed by using three options of mechanization levels; fully mechanized, semi-mechanized and tradition farming system. The total fuel consumption (L/ha) for each crop is the summation of fuel consumption for the mechanized operations. The total fuel requirement (L) was computed by multiplying total area for each specific mechanized operation by its fuel consumption rate (L/ha) estimated including unproductive fuel consumption. The area for each crop was taken as 184.8 thousand hectares.

Cost and economic saving in fuel consumption

Fuel cost was calculated based on the predicted fuel consumption obtained from the developed power model. Official fuel price at petrol filling stations was used at 4331 Sudanese Pounds per liter (SDG/L). Fuel cost was calculated for annual consumption (L/yr) the following equation:

$$TFC_{fs} = TFC * P_{f} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where:

TFC_{fs} = Total fuel cost for a farming system (SDG/yr)
TFC = Total fuel consumption per farming system (L/yr)
P_{f} = Diesel fuel price (SDG/L) = 4331

On the other hand, a ten percent (10%) reduction in total annual fuel consumption was used as saving factor. This reduction percentage may be achieved through better tractor-implement matching, reduction of unproductive fuel consumption, proper maintenance and operator training. The following equation was used to calculate monetary values of economic saving.

$$ES = (1- 0.9) * TFC * P_{f} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where:

ES = Economic saving (SDG/yr)
TFC = Total fuel consumption per farming system (L/yr)
P_{f} = Diesel fuel price (SDG/L) = 4331

Results and Discussion

Application of the developed fuel consumption power model

The developed power model was further applied to evaluate tractor fuel use performance through the estimation of specific volumetric fuel consumption (SVFC) and specific volumetric fuel efficiency (SVFE). These indicators provide a normalized measure of fuel use relative to engine power and offer practical insight into tractor energy performance and operational efficiency (Grisso *et al.*, 2004; Kim *et al.*, 2015).

Specific volumetric fuel consumption (SVFC) represents the volume of fuel consumed per unit of engine power output (L/kW·h), whereas specific volumetric fuel efficiency (SVFE) expresses the amount of engine power delivered per unit volume of fuel consumed (kW. L/h). The descriptive statistical characteristics of both indicators are presented in Table 1.

The results showed that the average SVFC value was 0.19 L/kW·h, with a maximum of 0.22 L/kW·h and a minimum of 0.16 L/kW·h. The relatively low standard deviation (0.02 L/kW·h) indicates limited variability in fuel consumption per unit of power, suggesting stable fuel use performance across the evaluated operating conditions.

In contrast, SVFE exhibited a mean value of 5.36 kW. L/h, with minimum and maximum values of 4.63 and 6.07 kW. L/h, respectively, and a standard deviation of

0.54 kW. L/h. Higher SVFE values indicate more efficient fuel utilization, reflecting improved conversion of fuel volume into useful engine power (Grisso *et al.,* 2010; Bowers, 2012).

The inverse relationship observed between SVFC and SVFE confirms the internal consistency of these performance indicators. Lower SVFC values corresponded to higher SVFE values, indicating improved operational efficiency. These results demonstrate that SVFC and SVFE can be effectively used for comparative evaluation of tractor performance, benchmarking energy efficiency and supporting fuel management and machinery selection decisions (Moitzi *et al.*, 2014; Kim *et al.*, 2015).

The application of the developed power model extends beyond fuel consumption prediction and provides a practical analytical framework for evaluating tractor energy efficiency and optimizing fuel use in agricultural mechanization systems.

Table 1. Specific volumetric fuel consumption and Specific volumetric fuel efficiency

Measure	Average	Max	Min	STD
Specific volumetric fuel consumption (L/kW. h)	0.19	0.22	0.16	0.02
Specific volumetric fuel efficiency (kW. L/h)	5.36	6.07	4.63	0.54

Predicted fuel consumption by implement type

Predicted fuel consumption rates (L/h) associated with different agricultural implements, corresponding tractor engine power and effective field capacity are summarized in Table 2. The results clearly demonstrated that fuel consumption is strongly influenced by the combined effect of tractor power demand and the operational characteristics of the attached implement (Grisso *et al.*, 2004; Bowers, 2012).

Heavy-duty, high-power implements such as the Abu Ishreen ditcher recorded the highest predicted fuel consumption, reaching 38.12 L/h. This high fuel demand reflects the substantial engine power requirement (179.04 kW) associated with deep soil excavation and sustained high draft resistance. Medium-power tillage implements, including the chisel plow, heavy-duty disk harrow and moldboard plow, exhibited moderate fuel consumption values ranging from 17.2 to 18.38 L/h, consistent with their intermediate power demands and intensive soil–tool interaction (Hunt, 2001; Moitzi *et al.,* 2014).

For lighter implements operating at lower power levels (approximately 55–60 kW), fuel consumption values clustered around 9 to 10 L/h. Despite similar hourly fuel use, these implements showed substantial variation in effective field capacity. High-capacity operations such as fertilizer spreading and spraying achieved effective field capacities of 11.6 and 8.0 ha/h, respectively, indicating superior fuel utilization per unit area. Conversely, operations such as stationary threshing, digger shaking and moldboard plowing recorded very low field capacities (<1 ha/h), resulting in relatively high fuel consumption per unit of productive output (ASABE, 2011; Kim *et al.*, 2015).

These findings highlight that operations characterized by low field productivity tend to consume fuel without proportional gains in output, thereby reducing overall energy efficiency. The results emphasize the importance of appropriate tractor–implement matching and effective operational planning to minimize fuel losses and improve mechanization efficiency (Grisso *et al.*, 2010; Bowers, 2012).

Table 2. Predicted fuel consumption (L/h) and effective field capacity (ha/h) for different tractor and attached implements

Implement	Matched tractor power (kW)	Fuel consumption (L/h)	Effective field capacity (ha/h)
Abu Ishreen ditcher	179.04	38.12	59.2
Chisel plow	93.25	17.2	1.5
Heavy duty disk harrow	98.5	18.38	1.4
Moldboard plow	98.5	18.38	0.7
Disk plow	55.5	9.13	0.7
Disk harrow	55.5	9.13	1.3
Ridger	55.5	9.13	2.0
Abu Sita ditcher	59.68	9.98	2.5
Planter	55.5	9.13	2.0
Fertilizer spreader	55.5	9.13	11.6
Sprayer	55.5	9.13	8.0
Leveler	59.68	9.98	2.5
Seed drill	59.68	9.98	1.3
Wide level disk	59.68	9.98	2.9
Digger shaker	55.5	9.13	0.6
Stationary thresher	55.5	9.13	0.5
Combine harvester	56.7	9.37	2.1

Fuel consumption per unit area and unproductive fuel losses

Fuel consumption expressed on an area basis (L/ha), including productive, unproductive and total fuel consumption for different tractor–implement combinations, is presented in Table 3. Expressing fuel use per hectare provides a more realistic indicator of operational efficiency, as it integrates both fuel consumption rate and effective field capacity (Grisso *et al.*, 2004; Bowers, 2012).

Substantial variation in fuel consumption per hectare was observed among implements. Operations such as moldboard plowing, stationary threshing and digger shaking recorded the highest total fuel consumption values, reaching 25.43, 17.43, and 15.80 L/ha, respectively. These elevated values are attributable to high draft requirements combined with low effective field capacities, which amplify fuel consumption per unit area (Hunt, 2001; Moitzi *et al.*, 2014).

In contrast, high-capacity operations including the Abu Ishreen ditcher, fertilizer spreader and sprayer exhibited very low total fuel consumption per hectare, ranging from 1.36 to 1.86 L/ha. Although some of these operations involved moderate to high hourly fuel consumption, their large field capacities substantially reduced fuel use per unit area, demonstrating superior energy efficiency (Kim *et al.*, 2015; ASABE, 2011).

A constant unproductive fuel consumption value of 0.71 L/ha was observed across all operations, representing fuel used during non-productive activities such as tractor movement to and from fields. This unproductive component constituted a significant proportion of total fuel consumption in high-capacity operations. For example, unproductive fuel accounted for more than 50% of total fuel use in fertilizer spreading and spraying activities.

These results underscore that total fuel consumption per hectare is governed not only by implement draft and tractor power but also by operational efficiency and field capacity. Reducing unproductive fuel losses through improved field layout, appropriate implement selection and optimized tractor–implement matching is therefore critical for enhancing energy efficiency. The findings further confirm the practical applicability of the developed power model under real field conditions (Moitzi *et al.,* 2014; Kim *et al.*, 2015).

Table 3. Predicted fuel consumption, unproductive fuel consumption and total fuel consumption for different tractor-implement combinations

Implement	Fuel consumption (L/ha)	Unproductive fuel consumption (L/ha)	Total fuel consumption (L/ha)
Abu Ishreen ditcher	0.64	0.71	1.36
Chisel plow	11.53	0.71	12.24
Heavy duty disk harrow	13.43	0.71	14.14
Moldboard plow	24.73	0.71	25.43
Disk plow	13.59	0.71	14.29
Disk harrow	7.25	0.71	7.96
Ridger	4.60	0.71	5.31
Abu Sita ditcher	3.96	0.71	4.67
Planter	4.65	0.71	5.37
Fertilizer spreader	0.79	0.71	1.50
Sprayer	1.14	0.71	1.86
Leveler	3.96	0.71	4.67
Seed drill	7.42	0.71	8.13
Wide level disk	3.44	0.71	4.15
Digger shaker	15.09	0.71	15.80
Stationary thresher	16.72	0.71	17.43
Combine harvester	4.46	0.71	5.17

Fuel consumption requirements for different crops and farming systems

Estimated fuel consumption requirements per unit area (L/ha) for selected crops under different farming systems are presented in Table 4. The results demonstrated that fuel consumption varies considerably with crop type and mechanization level (Hunt, 2001; Grisso *et al.*, 2004), reflecting differences in operation intensity, machinery use and production practices.

Under the traditional farming system, fuel consumption was relatively low for cotton and groundnut, at 22.0 and 11.4 L/ha, respectively. Whereas, sorghum recorded a higher value of 28.8 L/ha, likely due to land preparation and additional field operations. Wheat was not included under this system, as it is predominantly cultivated using mechanized practices.

Fuel consumption increased markedly under the semi-mechanized farming system for all crops. Cotton, groundnut, sorghum and wheat recorded fuel requirements of 25.4, 30.9, 36.1, and 31.9 L/ha, respectively. However, the increase use of mechanical operations such improve productivity but require higher energy inputs (Moitzi *et al.*, 2014; Kim *et al.*, 2015).

As expected, the fully mechanized farming system exhibited the highest fuel consumption levels, with values ranging from 44.4 to 47.4 L/ha across all crops. This suggests that under full mechanization, fuel consumption is driven more by the number and intensity of field operations than by crop-specific characteristics (Grisso *et al.*, 2010; Bowers, 2012).

The results reveal a clear relationship between mechanization level and fuel consumption. While higher mechanization substantially increases fuel consumption per hectare, it is typically associated with improved timeliness and reduced labor dependency. These findings highlight the need to optimize mechanization strategies to balance fuel requirements and productivity gains in irrigated agricultural systems (Hunt, 2001; Kim *et al.*, 2015).

Table 4. Fuel consumption (L/ha) requirement for different crops and farming system

Farming system	Cotton	Groundnut	Sorghum	Wheat
Tradition	22.0	11.4	28.8	-
Semi-mechanized	25.4	30.9	36.1	31.9
Fully-mechanized	44.4	46.7	45.3	47.4

Total fuel consumption requirements

Total fuel consumption requirements (L) for selected crops under different farming systems are summarized in Table 5. Unlike area-based fuel consumption, total fuel use reflects the combined effect of fuel intensity per hectare and total cultivated area, providing a comprehensive assessment of energy demand at the system level (Hunt, 2001; Grisso *et al.*, 2004).

Under the option of traditional farming system, total fuel consumption was lowest for groundnut (approximately 2.11 million L), followed by cotton (4.07 million L), while sorghum recorded the highest value (5.32 million L). These differences reflect both crop-specific fuel requirements and cultivated area. Wheat was not included due to its limited presence under traditional practices.

A substantial increase in total fuel consumption was observed under the option of semi-mechanized system, with fuel requirements of 4.70, 5.71, 6.67, and 5.90 million L for cotton, groundnut, sorghum and wheat, respectively.

The option of fully mechanized farming system recorded the highest total fuel consumption, exceeding 8 million L for all crops. Cotton, groundnut, sorghum and wheat recorded total fuel requirements of 8.21, 8.63, 8.37, and 8.76 million L, respectively. The relatively narrow variation among crops indicates that under full mechanization, total fuel demand is largely governed by the scale of mechanized operations rather than crop-specific differences (Grisso *et al.*, 2010; Bowers, 2012).

These results demonstrate that increasing mechanization intensity leads to a pronounced rise in total fuel consumption at the system level. While mechanization enhances productivity and operational efficiency, it also imposes higher energy demands, underscoring the importance of optimizing fuel use and machinery efficiency.

Table 5. Fuel consumption (L) requirement for different crops and farming system

Farming system	Cotton	Groundnut	Sorghum	Wheat
Tradition	4067227	2107563	5324370	-
Semi-mechanized	4695798	5712605	6673950	5897479
Fully-mechanized	8208403	8633613	8374790	8763025

Seasonal fuel requirements in the Gezira scheme

Total diesel fuel requirements for summer and winter crops under different options of farming systems, expressed in metric tons, are presented in Table 6. Fuel quantities were converted from volume to mass using a diesel fuel density of 0.84 kg/L to allow standardized comparison across seasons and systems.

Under the option of traditional farming system, fuel consumption was limited to summer crops, with a total requirement of 9659 tons. The absence of winter fuel demand reflects limited mechanization and lower cropping intensity under traditional practices (ASABE, 2011; Grisso *et al.,* 2004).

Fuel demand increased substantially under the option of semi-mechanized system, with 14349 tons required for summer crops and an additional 4954 tons for winter crops, resulting in a combined total of 19303 tons. This increase reflects expanded mechanization and multi-season cropping (Moitzi *et al.,* 2014; Kim *et al.,* 2015).

The fully mechanized system option recorded the highest fuel demand, with summer crops consuming 21182 tons and winter crops 7361 tons, bringing total annual fuel requirements to 28543 tons. Compared to the traditional system option, full mechanization resulted in nearly a threefold increase in fuel demand. This highlights the substantial energy implications of intensive mechanized agriculture (Grisso *et al.,* 2010; Bowers, 2012).

These findings demonstrate that mechanization level and cropping intensity are major determinants of fuel demand in large-scale irrigated schemes, emphasizing the need for energy-efficient machinery and strategic planning.

Table 6. Total fuel requirement (ton) for summer and winter crops in the Gezira scheme

Farming system	Summer crops	Winter crop	Total
Tradition	9659	-	9659
Semi-mechanized	14349	4954	19303
Fully-mechanized	21182	7361	28543

* Diesel fuel density = 0.84 kg/L

Economic implications of fuel consumption

Fuel consumption expenses and potential economic savings across different farming systems are presented in Table 7. Fuel cost represents a major component of mechanized agricultural production expenses, and its impact increases sharply with higher mechanization levels (Hunt, 2001; Grisso *et al.,* 2010).

The results show that annual fuel expenditure under the fully mechanized system was approximately three times higher than under the traditional system, exceeding 147 billion SDG at the scheme level. To assess potential economic benefits, a fuel-saving scenario assuming a 10% reduction in fuel consumption through improved machinery management was evaluated.

The analysis indicates that a 10% reduction in fuel use could generate annual savings of approximately 5, 10, and 14.7 billion SDG for traditional, semi-mechanized, and fully mechanized systems, respectively. These results highlight that even modest improvements in fuel efficiency can yield substantial economic benefits, particularly at large system scales.

Improved fuel efficiency through optimized tractor–implement matching, reduced unproductive fuel consumption, and better operational management could allow savings to be redirected toward machinery maintenance, farmer support services, or investment in energy-efficient technologies (Moitzi *et al.,* 2014; Grisso *et al.,* 2004). The findings confirm that fuel efficiency is a critical driver of economic sustainability in irrigated agricultural systems and that the developed power model provides a valuable tool for fuel budgeting and cost control.

Table 7. Economic saving of 10% reduction in fuel consumption (L/yr) across farming systems

Farming system	Fuel consumption (L/yr)	Fuel expense (SDG/yr)	10% reduction in fuel consumption (L/yr)	Economic saving (Billion SDG/yr)
Tradition	11499160	49802861960	10349244	5.0
Semi-mechanized	22979832	99525652392	20681848.8	10.0
Fully-mechanized	33979831	147166648061	30581847.9	14.7

Conclusion

This study demonstrated the practical applicability of a predictive power-based model for estimating tractor fuel consumption under real operating conditions in the Gezira scheme, Sudan. The model was successfully applied to quantify specific fuel consumption indicators, fuel use per unit area, unproductive fuel losses and total fuel requirements across different crops and mechanization levels. The results confirmed that fuel consumption is strongly influenced by mechanization level, implement type and operational efficiency, with unproductive fuel losses constituting a significant share of total fuel use in several operations. Higher mechanization increases total fuel demand and economic costs, but even modest improvements in efficiency can generate substantial savings. Proper tractor–implement matching, operational planning and reduction of unproductive fuel use are critical for sustainable mechanized agriculture.

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Discrepancies in Broad Bean Productivities between Traditional Farms and Research Experiments

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Abstract

The main objective of this survey was to estimate the yield variation between research experiments and traditional farm of broad bean production in the River Nile State (RNS). The specific objectives were: to investigate the production capability of the traditional farmers in this area; to make comparison of productivities between research and traditional farmer; to investigate the potentiality of crop production in the River Nile State; and to evaluate the financial challenges facing the traditional farmers. Data was collected from the traditional farmers using structured survey questionnaires with specific sample size put into considered all variations among the traditional farmers. The analysis was based on a descriptive analysis, farm partial budget and benefit-cost ratio analysis. The analysis has concluded into significant yield gap between research experiments and the traditional farmers reached up to about 50% extra for the research sites. However; the traditional farmers were still economically efficient to some extent in producing broad been in the area. The study has recommended that: the government of the RNS has been advised to establish savings programs by encouraging farmers to participate with part of the expenses; also an advisement to encourage research and extension services in supporting farmers; the cropping patterns has to be diversified with focusing on broad bean cultivation; and the yield variation could be bridged by applying appropriate Recommended Technical Package (RTP)).

Keywords: *Discrepancies, Traditional, Productivities, RTP, farm-level, Broad Bean, BCR.*

تباينات إنتاجية الفول بين المزارع التقليدية والتجارب البحثية

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المستخلص

الهدف الرئيسي من هذه الدراسة هو تقدير التباين في إنتاج الفول بين التجارب البحثية والمزارع التقليدية في ولاية نهر النيل. وتضمنت الأهداف الفرعية ما يلي: دراسة القدرة الإنتاجية للمزارعين التقليديين في هذه المنطقة؛ ومقارنة الإنتاجية بين التجارب البحثية والمزارعين التقليديين؛ ودراسة إمكانات إنتاج المحاصيل في ولاية نهر النيل؛ وتقييم التحديات المالية التي يواجهها المزارعون التقليديون. جُمعت البيانات من المزارعين التقليديين باستخدام استبيانات منظمة، مع تحديد حجم عينة مناسب لمراعاة جميع الاختلافات بينهم. واستند التحليل إلى تحليل وصفي، وميزانية جزئية للمزارع، وتحليل نسبة الفائدة إلى التكلفة. وخلص التحليل إلى وجود فجوة كبيرة في الإنتاجية بين التجارب البحثية والمزارعين التقليديين، حيث بلغت الزيادة حوالي 50% في مواقع التجارب البحثية. ومع ذلك، لا يزال المزارعون التقليديون يتمتعون بكفاءة اقتصادية إلى حد ما في إنتاج الفول في المنطقة. وأوصت الدراسة حكومة ولاية نهر النيل بإنشاء برامج ادخار من خلال تشجيع المزارعين على المشاركة بجزء من النفقات. كما يُنصح بتشجيع البحوث وخدمات الإرشاد الزراعي لدعم المزارعين؛ وضرورة تنويع أنماط الزراعة مع التركيز على زراعة الفول؛ ويمكن معالجة تباين المحاصيل بتطبيق حزمة التقانات الموصى بها.

الكلمات المفتاحية: *التباينات، الزراعة التقليدية، الإنتاجية، حزمة التقانات الموصى بها، مستوى المزرعة، الفول، نسبة العائد إلى الإنتاج.*

Introduction

After loss of oil export resources, considerable attention has been put into agriculture in Sudan. Special attention was paid to legume crops as important sources of protein to numerous people of the country. Broad bean is considered as one of the most important cool-season food legumes produced in the River Nile State (RNS). The major production of it is consumed domestically and also small quantities were imported from Ethiopia in the recent years according to the reports of the Ministry of Agriculture, Irrigation and Forestry in River Nile State (MAIFRNS).

The research on food legumes has been ongoing at Hudeiba Research Station since the early sixties. The main objective of that research is for improving both the productivity and quality of the legume crops through crop husbandry programs. On-farm research on legumes and grain in Sudan was initiated since 1979 as the Nile Valley Project (NVP) as formulated by the Agricultural Research Corporation (ARC) in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) through financial support from the International Fund for

Agricultural Development (IFAD) (Salih, *et al.*, 1995).

Improving broad bean-climate models, planning of adaptation measures (such as agronomic changes), and breeding of new genotypes capable of tolerating or avoiding projected stresses, it is vital to carefully quantify the response of the crop to heat stress (Siebert, and Ewert, 2014). In many environment studies the impact of heat stress during floral development and anthesis on crop yield has now been quantified for many species {e.g. (Hedhly, 2011), (Luo, 2011)}, permitting extreme weather events to be incorporated into crop-climate models (Luo, 2011). Nevertheless, the response of broad bean (*Vicia faba* L.) to heat stress during floral development and anthesis has not been previously investigated (Anonymous, 2025). In particular, broad bean has appreciated role in increasing food production and sustainable escalation (Pretty and Bharucha, 2014).

Discrepancies in Broad Bean yield between traditional Farms and research experiments due to both abiotic and biotic stress are related to many factors. Faba beans are poor competitors with weeds, particularly in the seedling stage (Ali *et al.*, 2000). This makes integrated weed control important for successful crop production. Fields with light weed pressure preferable. Tillage several weeks before planting and killing emerged weeds with shallow tillage just ahead of planting is advisable as well as rotary hoeing of fields 7 to 10 days after planting and use a row cultivator if rows are 50 cm or more apart. One of the abiotic stresses is heat stress during floral development causes reductions in key yield parameters of Faba bean. There are many demonstration studies in negative drought stress but only one previous work in heat stress that focused in initial broad bean vegetative growth {Hamada, 2001; Oney and Tabur, 2013)}. Also heat stress during the floral stage caused severe reduction in yield. (Barber *et al.*, 2015) cited that it can be hard to dependably identify key stages of reproductive development. The crop yield was reduced by heat stress within the temperature range known to provoke yield reductions in other crop species. Sometimes yield reductions were due to gametophyte damage and consequent failure of fertilization. However, it is difficult to forecast how the frequency and magnitude of high temperature differences will change and consequently impact on broad bean harvest (Porter, *et al.*, 2014).

The major insect pest which reduce the quantity and quality of broad bean production in Sudan, as reportedly, (Siddig, 1980), they include: Aphis craccivora Koch; *Acyrthosiphonses baniae* Kan. Dav; Aphis gossypii Geov.; Bemisia tabaci Genn; *Empoasca lubica* Deberg; *Erythron euralubiae* China; *Creontiade spallidus* Ramb; *Spodoptera exigua* HB; *Maruca testalis* Gey; *Caliothrips impurus* Pr; *Caliothrips sudanensis* Bagn Cam; *Bruchus elanairensis* Pic; and *Callosobruchus maculatus* F. Nonetheless, *Callosobruchus maculatus* F is considered as the most harmful pulse beetle attacking stored grains.

Always researchers and pioneer farmers refer to seed dressing and prevention spray to reduce pest infestation. Whereas, the traditional farmers don't apply the full technical package in growing broad bean i.e. they don't use important techniques such as improved seeds, seed dressing, prevention spray, regular irrigation and good land preparations. This generally resulted in decreasing the yield of broad bean among the traditional farmer.

The main objective of this study was to quantify the yield variation between research and traditional farming for broad bean in the River Nile State; so, the field surveys were conducted in two locations (Al-Aliab and Gabaty). These field surveys were conducted with specific objectives including the followings: To investigate the production capability of the traditional farmers in this area; to make comparison of productivities between research and traditional farmer; to investigate the potentiality of crop production in the River Nile State; and to evaluate the financial challenges facing the traditional farmers.

Methodology

Research methodology included the methods of data collection, data sources (primary and secondary), sample size and the analytical techniques used. A structured questionnaire was prepared to obtain the detailed information from the broad bean traditional farmers in River Nile State, in addition to the field observations. Secondary data was obtained from the official records. Descriptive analyses, partial budget and benefit-cost ratio analysis were used to analyze the collected data for achieving the objectives of the study.

Site Selection

The River Nile State had been selected for the purpose of this study for many reasons. Firstly: it represents the second potential area for farming broad bean in Sudan after the Northern State. Secondly: it uses and adopts relatively best farming systems and the availability of information and good infrastructures. The State is composed of seven localities namely: Shendi, El-Matama, Ed-Damer, Atbara, Berber, Abu-Hamad, and El-Buhayra. However, the survey was conducted in Ed-Damer locality and it covered two villages namely: Alaliab and Gabaty.

Sample Size

The sample size was determined by the desired level of precision increase. Scientifically, it is known that the degree of precision increases as sample size increases. Also the level of precision can be increased by strata issuing more homogeneous sub-samples (Abdalla, 2008). Therefore due to homogeneity of the socio-economic characteristic of the agricultural community in River Nile State and considering limitation of funds and transportation cost about 100 respondents had been selected to represent the total sample size. This sample has been divided equally between the two villages.

Analysis Techniques

To achieve the targeted objectives of the study various techniques were used. A wide range of tools (frequencies, percentages, and averages) of descriptive analysis were used. The comparison between the production of broad bean at the farm and on-station levels also tested. Furthermore, a partial budget was done as analysis to estimate feasibility of broad bean cultivation in the study area. Finally, a benefit-cost ratio analysis was done to determine how well, or how poorly, a planned action will turnout.

Results and Discussion

These results were based on number of techniques that used for analyzing the data in case to realize the objectives of this study. Nonetheless, the parameters included yield variation formula (research site yield – traditional yield/ research site yield) measurements, partial budget analysis, and benefit-cost ratio analysis (CBA).

Yield Variations Between Research and Traditional Farming

Table 1 shows both averages broad bean productivity for research sites and traditional farming in the River Nile state. Maximum outputs of the crop were 2.20 and 1.30 metric ton (MT) per hectare for the research sites and traditional farming respectively. The minimum yield of broad bean in research sites was amounted to about 0.84 MT per hectare; whereas the minimum yield of the crop of on traditional farms was equivalent to 0.47 MT/ hectare. Yield variation was calculated by subtracting the averages yield of broad bean of the traditional farms from the yield of research site, then divided by average research yield. The formula was:

$$\text{Yield variation} = \frac{\text{Research yield–Traditional farms yield}}{\text{Research yield}} \times 100$$

From Table 1 below, the maximum yield of the research sites was 5.2 MT/ha while the maximum yield of traditional farms was 2.9 MT/ ha, so the result will be:

$$\text{Yield variation} = \frac{1.08 - 0.55}{1.08} \times 100 = 49.07\%$$

<u>The drawn conclusion, however, demonstrated that the production of broad bean on research sites was approximately doubled the production of traditional farms.</u>

Table 1.The maximum, minimum and average yields of the research and traditional farms (monitored farmers' plots in Aliab Scheme during 2012/2013 crop season).

Farming sites	**Yield MT/ ha.**		
	Maximum	**Minimum**	**Mean**
Research yield	2.2	0.84	1.08
Traditional yield	1.3	0.47	0.55
Total	3.5	1.31	1.53

Source: Field survey 2013/2014.

Partial Budget

It has been informed that the partial budgeting is an excellent managerial tool to help evaluate the financial considerations caused by changes in a business (http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/beef11843). However, in some cases, partial budget is usually done to examine farmers' financial abilities to grow a certain crop. Regarding the <u>**inflation rates in Sudan**</u>, nowadays, all prices and costs had been adjusted to exchange rates of dollar ($)/ Sudanese pound ($).

Selected Cases of the Study

The following farmers' cases were selected among other cases of this survey to show the finance situations and budgets of broad bean growers in River Nile State season 2013/2014. Two farmers are randomly selected from each village which ended to four farmers.

Farmer No. (F3)/ with 10 Feddans at Al-Aiab Village, in the River Nile State Season 2013/14.

The farmer was 46 years old with total area of about 4.2 hectares and all of the area was utilized. Two of his sons assisted in cultivating broad bean in winter as well as grain sorghum in summer seasons. The farmer hadn't any other income than farming. His total return from both faba bean and sorghum during faming season 2103/2014 was estimated at $2477.14 and the net income was $1134.29 (Table 2).

Table 2 Partial Budgets for Farmer No. (F5)/ 4.62 hectares at Al-Aliab village, in the River Nile State Season 2013/2014 (source: Field survey, 2013).

(1) Beginning cash balance	0
(A) Cash inflow	
(2) Farm product sales	2724.86
(3) Capital sales	0
(4) Other cash income	0
(5) Total cash inflow	2724.86
(B) Cash outflow	0
(6) Farm operation expenses	1194.29
(7) Capital purchases	0
(8) Other expenses	282.86
(9) Total cash outflow	1477.14
(10) Cash balance (5-9)	1247.71
(13) Ending cash balance	1247.71

Source: Field survey 2013/2014.

Farmer No. (F12)/ with 10 feddans at Al-Aliab Village, in the River Nile State season 2013/14.

The farmer was 30 years old. He is very young. The total area of his farm was 4.2 hectares and all of it was utilized. It was cultivated by the assistance of his family members. The farm was cultivated with broad bean, wheat and sorghum in winter and with Forage sorghum (Abu-sabeen) as forage in summer season. The farmer hadn't any income other than crops production. His total return from both winter and summer crops was estimated by $1700. However, his ending cash balance was $661.43 (Table 3).

Table 3 Partial Budgets for Farmer No. (F9)/ 4.62 hectares at Al-Aliab village, in the River Nile State Season 2013/2014 (source: Field survey, 2013).

(1) Beginning cash balance	0
(A) Cash inflow	
(2) Farm product sales	1870
(3) Capital sales	0
(4) Other cash income	0
(5) Total cash inflow	1870
(B) Cash outflow	0
(6) Farm operation expenses	906.71
(7) Capital purchases	0
(8) Other expenses	235.71
(9) Total cash outflow	1142.43
(10) Cash balance (5-9)	727.57
(13) Ending cash balance	727.57

Source: Field survey 2013/2014.

Farmer No. (F28)/ with 1.7 Hectares at Gabaty Village, in the River Nile State Season 2013/14

The farmer was 40 years old. The total area of his farm was 1.7 hectares. It was cultivated by the assistance of one of his family members. The farm was cultivated with only broad bean in winter season and with Forage sorghum (Abu-sabeen) as a forage crop in summer. The farmer hadn't any income other than crops production. His return from his farm product sales was estimated by $828.57. His ending budget was $160.57 (Table 4).

Table 4. Partial Budget for Farmer No. (F22)/ 1.87 hectare at Gabaty village, in the River Nile State Season 2013/2014 (source: Field survey, 2013).

(1) Beginning cash balance	0000
(A) Cash inflow	
(2) Farm product sales	911.43
(3) Capital sales	0
(4) Other cash income	0
(5) Total cash inflow	911.43
(B) Cash outflow	0
(6) Farm operation expenses	624.8
(7) Capital purchases	0
(8) Other expenses	110
(9) Total cash outflow	734.8
(10) Cash balance (5-9)	176.63
(13) Ending cash balance	176.63

Source: Field survey 2013/2014.

Farmer no. (f37)/ with 4.2 Hectares at Gabaty Village, in the River Nile State Season 2013/14

The farmer was 55 years old. He was mid age farmer. He was primary level educated. The total area of his farm was 4.2 hectares. It was cultivated by the assistance of three of his family members. The farm was cultivated with broad bean, wheat and alfalfa hay in winter season and with sorghum in summer. The farmer hasn't any income other than crops production. His total on-farm return was estimated by about $742.86. Nonetheless, he realized some losses that estimated by $-393.86 (Table 5).

Table 5 Partial Budget for Farmer No. (F37)/ 4.2 hectares at Gabaty village, in the River Nile State Season 2013/2014 (source: Field survey, 2013).

(1) Beginning cash balance	0000
(A) Cash inflow	
(2) Farm product sales	817.14
(3) Capital sales	0
(4) Other cash income	0
(5) Total cash inflow	817.14
(B) Cash outflow	0
(6) Farm operation expenses	986.43
(7) Capital purchases	0
(8) Other expenses	264
(9) Total cash outflow	1250.43
(10) Cash balance (5-9)	-433.29
(13) Ending cash balance	-433.29

Source: Field survey 2013/2014.

1.1. Benefit-Cost Ratio (BCR) Analysis

The Benefit-Cost Ratio Analysis (BCR) is an indicator showing the relationship between the relative costs and benefits of a proposed project, expressed in monetary or qualitative terms. If a project has a BCR greater than 1.0, the project is expected to deliver a positive net present value to a firm and its investors

However, the technique estimates and sums up the equal money value of the benefits and costs to community of projects to establish whether they are valuable (Shively,1995).). A Benefit Cost analysis is done to determine how well, or how poorly, a planned action will turn out. Although the analysis can be used for almost anything, it is most commonly done on financial questions. Since the BCR analysis relies on the addition of positive factors and the subtraction of negative ones to determine a net result, it is also known as running the numbers. From this study we itemized the benefits by adding all positive factors then we identified and quantified all negative items, cost. The difference between the two indicates whether the planned action was advisable (Table 5).

Table 6. Broad bean Cost items (Source: Field Survey 2013/2014).

Item	**Cost $/ ha**
Land preparation	103.71
Seed cost	201.43
Seed broadcasting (sowing)	4
Fertilizers (chemical + organic)	0
Pest control	31.43
Supportive hand weeding	39.29
Fuel	7.86
No. of applied irrigations	59
Hand-harvest	113.57
Mechanical harvest	0
Empty sacks/ bags	14.86
Transportation	9.57
Taxation	2.43
Total	587

Source: Field survey 2013/2014.

Table 7. Effects of planting date and seed rate on grain yields of broad bean in Aliab Scheme, during 2013/2014 crop season.

	Mean grain yield (MT/ha)
Planting Date:	
1st -15th November	1.66
16th November – 1st December	1.25
Seed Rate (kg/ha)*a:	
150 – 170	1.45
180 – 200	1.41
>200	1.45

Source: Field survey 2013/2014.

*a = Means over plots irrigated at 6 and 7 days intervals at the farm level.

Table 8. Effects of irrigation regime on mean grain yields of broad bean in Aliab Scheme, 2013/2014 crop season.

No. of applied irrigations	**Mean grain yield (MT/ha)**
(a) At the Farm-Level:	
5 (Five irrigations)	0.72
6 (six irrigations)	1.54
7(seven irrigations)	1.25
8 (eight irrigations)	2.46
(b) At the Station-Level:	
9 (nine irrigations)	2.86

Source: Field survey 2013/2014.

Table 9 Effects of weed control on mean grain yields of broad bean in Aliab Scheme, 2013/2014 crop season.

Weed control	Mean yield (MT/ha)
(a) At the Farm-Level:	
No weed control (same number of irrigations as the treated plot, within the same section)	1.89
No weed control (same number of irrigations as the treated plot, within all sections)	1.48
One spray with herbicide (Stomp)	2.23
(b) At the Station-Level:	
One spray with herbicide (Stomp + Pursuit)+ 1 supportive hand weeding	2.86

Field survey 2013/2**Planting Date**

At the farm level early (1-15 November) planting gave 1660 kg/ha whereas the late (16 November- 1 December) planting gave about 1.25 MT/ha (Table 7). This result emphasized the importance of early planting for obtaining high yields of broad bean at the farm level. However, the early sowing costs two additional irrigation i.e. additional \$15.71/ha (Table 6). So the 1-15 November planting date costs in total about \$587/ha (Table 6). The harvesting price was estimated to be about \$39.29/50 kg of broad bean (MAIFRNS[1]). Consequently, the return was estimated by about \$1185.71/ha and the benefit-cost was:

NB= 1185.71 – 602.71 = \$583/ha.

BCR= 583/602.71= 0.96

The late sowing date (16th November to 1 December) costs about \$583; so the net benefit was \$304 and the BCR was (0.96):

NB= 891 – 587 = \$304 /ha.

BCR= 587/304 = 1.93

The aforementioned calculations have indicated that the early sowing date (1st -15th November) has given relatively advanced economic efficiency (1.93) compared to late planting date (16th -1st December).

Seed Rate (Kg/ha)

Table 6 shows the total cost of cultivating one hectare of broad bean was estimated by \$587. Whereas, Table 7 had shown the three seed rates exactly: 150 - 170 kg/ha, 180 - 200 kg/ha, and over 200 kg/ ha.

The first seed rate costs in average about \$301.71/ha (50 kg broad bean price was \$94.29) (MAIFRNS). If we considered other factors constant this seed rate would bring about 1.45 MT/ha which its value was estimated by about \$1032.43 (50 kg broad bean price was \$39.29 at harvesting time). Therefore the BCR analysis could be calculated as follows:

NB= 1032.43 - (587 – 201.43 + 301.71) = $948.57 / ha.

BCR= 948.57/83.86 = <u>11.3</u>

The second seed rate expenses about $358.29/ha. Which produces about 1.28 MT/ha of broad bean this could be sold out in approximately $1004.14. Using the previous formula the benefit-cost ratio could be as follows:

NB= 1004.14 - (587 – 201.43 + 358.28) = $920.29/ha.

BCR= 920.29/83.85 = <u>10.98</u>

The third seed rate cost was about $377.14 /ha.; that produced about 1.45 MT/ha broad bean this could be generate a cash estimated by about $1038.71. So, by doing the same approach above the benefit-cost ratio would be as follows:

1038.71 - (587 – 201.43 + 377.14) = $1030.29 /ha.

BCR= 1030.29/83.85 = <u>12.29</u>

From the preceding results we did terminate that the seed rate 150- 170 kg/ha was the most efficient one.

Irrigation Regime

Table 8 shows the effects of irrigation regime on mean grain yield of broad bean in Aliab Scheme that could be counted from 5, 6, 7, and 8 irrigations at farm-level. On the other hand the number of applied irrigation at the station-level was equal to 9 irrigation times per season. However, an irrigation at farm level each costs additional $7.14 /ha (the cost of additional fuel), while there was no additional irrigation cost at station-level (Hudeiba Research Station- ARC). To compare the economic efficiency of irrigation between the farm and on-station production; we had to calculate the fuel cost for the 8 irrigations at farm level which realizes the best output (2.5 MT/ha). This cost equals to about $62.9/ha per season. So the benefit-cost ratio for the 8 irrigations (farm-level) was:

NB= 1931.71 – (587 – 7.14 + 62.9) = 1931.71- 642.76 = $1288.95/ha.

BCR= 1288.95/642.76 = <u>2.01</u>

The benefit-cost ratio for the 9 irrigations at station-level was:

2244.98 –587 = $1657.98/ha.

BCR= 1657.98/587 = <u>2.82</u>

Based on the aforementioned calculations we could conclude into results that the irrigation was more economical (35.40%) at station level compared to traditions levels. The eight irrigations were the most efficient one at the on-farm level.

Weed Control

Table 9 shows the effects of weed control on average productivities of broad bean in Aliab Scheme. Nevertheless, at the farm level the highest yield was achieved by applying one spra

with herbicide (Stomp) (yield= 2024kg/ha). One spray with herbicide (Stomp + Pursuit) + one supportive hand weeding gained about 2855 kg/ha at station-level.

The additional cost of Pursuit and hand weeding was estimated at about $110/ha ($31.4+ 78.6) (MAIFRNS).

The BCR for the weed control at station-level was estimated as follows:

NB= 1931.71 – (587 -110) = $1454.71/ha.

BCR= 1454.71/477 = <u>3.05</u>

While the benefit-cost ratio at the farm-level was:

NB= 1590.29 – 587 = $1003.29.

BCR= 1003.28/587 = <u>1.71</u>

Despite its additional cost, but the application of pursuit and supportive hand weeding has realized more benefit at the station-level compared to traditional level. Whereas, the one spray with herbicide at on-farm level realizes most benefit (same number of irrigations as the treated plot, within the same section) comparing to those without applying any means of spray (no weed control).

Findings and Discussions

The study has concluded that the yield gap between research and the on-farm productions was reached to about 50% in favor of research experiments. The partial budgeting analysis, to the selected cases, showed that most of farmers had a positive ending cash balances. However, benefit-cost ratio (BCR) analysis showed that at the farm level at the early sowing date (1st -15th November) was economically efficient than the late planting date (16th Nov. – 1st December) and the seed rate 150- 170 kg/ha was the most efficient element. The analysis summarized that the irrigation system on station was more economically efficient than that of on-farm level. However, the eight irrigations application was the most efficient at on-farm level. The one spray with herbicide at on-farm level recognized most benefit (same number of irrigations as the treated plot, within the same section) comparing to those without applying any means of spray

Conclusion

The study analysis had indicated that the productivity at research experiments was almost double the traditional levels. The traditional farmers had demonstrated weak performance. This was attributed to many factors; probably the limitation in financial resources could be the paramount reason behind the low productivities, this is in addition to technical knowhow. The benefit-cost ratio analysis had shown that broad bean cultivation in the River Nile State was economically efficient.

Recommendations

The study has recommended the followings:

1. Provision of technical packages for bridging the yield gap between research and traditional farming.
2. Encouragement of the producers for the establishment of cooperatives capable for facilitate the financial issues and participate in capital formation. Research on irrigation regime should be revisited in this area.
3. Government of RNS should subsidize Farmers with some production inputs (fertilizers, improved seeds, etc.).

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Influences of Light Intensity, and Soil Type on the Growth and Performance of the Indigenous Tree Seedling Species *(Leptadenia pyrotechnica)*

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Abstracts

Forest rehabilitation has a great role to play in the desert region of Sudan in terms of production and protection, one of the main causes of the degradation in the area is deforestation which leads to soil degradation and soil erosion especially by wind speed so this area needs stabilization by planting tree seedling. The experiment was carried out at the nursery of Hudieba Research Station in River Nile State in September 21Th 2022. The objective of this study was to examine the effect of light intensity and soil type on growth and development of *(Leptadenia pyrotechnica)*. Murkh seedling. The treatments tested were arranged in spilt plots design with three replications. The studied factors were light intensity (50% under plastic net, 100% under direct sun light) and soil type's (sand, sand & clay, and clay). The measurements were taken within the first to the second weeks and after three months for germination and different parameters of seedlings, respectively. Results showed that, germination percentage of *Leptadenia pyrotechnica* seeds was high in 50% sand soil type and similarly in 50% and 100% in sand & clay 1:1, however it was better in 100% than 50% light intensity in clay soil type compared to the other treatments. Also Highly significant effect were observed between treatments on plant height at different stage of growth seedling growth in (first, second and third months), and in fresh and dry weight of roots, shoot (stem and levees) and length of root in different light intensity and soil type, respectively. Fresh and dry weight of root and shoot and roots length were better in100% light intensity in clay and sand & clay 1:1 soil type. The interaction between different treatments showed significant differences in plant hight at various stages, as well as in the fresh and dry weight of roots and shoots. Moreover, seedlings grown under 100% light intensity in clay and sand & clay 1:1 soil type recorded high fresh and dry weight of root and shoot than those in other treatments three months after sowing. The results proved that the best combination of these factors recommended for production of healthy seedling was: 100% light intensity, clay and sand & clay 1:1 soil type.

***Keywords**: Murkh Seedling, light intensity, soil type.*

تأثير شدة الإضاءة ونوع التربة على نمو وتطورشتلات شجرة المرخ

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المستخلص

أجريت هذه التجربة في مشتل محطة أبحاث الحديبة – ولاية نهر النيل شمال السودان خلال شهر سبتمبر 2022 بهدف دراسة تأثير شدة الضوء ونوع التربة على نمو وتطورشتول شجرة المرخ المحلية، البيئة الأصلية لها شمال السودان الإسم العلمى *(Leptadenia pyrotechnica)*. تم استخدام تصميم القطع المنشقة لترتيب المعاملات تحت الاختبار مع ثلاثة مكررات لكل معاملة . المعاملات التى تمت دراستها هي كثافة الضوء 50٪ (تحت الشبكة البلاستيكية) داخل المشتل و 100٪ (تحت أشعة الشمس المباشرة) و تمت زراعة البذور قى الأكياس البلاستكية المعبئة بترب مختلفة النوع (الرمل - الرمل والطين - الطين) داخل وخارج المشتل. تم أخذ وقراءة نسبة الإنبات من اليوم الأول حتى الإسبوع الثانى وقياس الطول فى الشهرالأول والثانى والثالث بالإضافة إلى الوزن الرطب والجاف للجزور، المجموع الخضرى (الساق والأوراق) وطول الجزور بعد الشهر الثالث من تأريخ زراعة البذور للشتول النامية. أظهرت النتائج أن إنبات أفضل للبذور تحت كثافة ضوء 50% فى التربة الرملية ومتماثل الإنبات داخل وخارج المشتل حيث كثافة الضوء 50% و 100% فى التربة المخلوطة بالطين والرمل بنسبة 1: 1 ، بينما أفضل إنبات عند كثافة الضوء 100٪ فى التربة الطينبة مقانة بالمعاملات الاخرى. كذلك وجود أثر معنوى عالى للمعاملات على طول الشتول فى الشهر الأول والثاتى والثالث، وطول الجزور والوزن الرطب والجاف للجزور والجموع الخضرى بعد الشهر الثالث من تأريخ الزراعة. طول الجزور والوزن الرطب والجاف للجزور والجموع الخضرى تحت كثافة الضوء 100% أعلى مقارنة تحت كثافة الضوء 50%. التداخل بين المعاملات المختلفة يوجد أثر معنوى على طول الشتول فى مراحل النمو المختلنة (الشهر الأول والثاتى والثالث) سيما الوزن الرطب والجاف للجزور والجموع الخضرى، فوق ذلك نمو الشتول (من حيث الوزن الرطب والجاف للجزور والجموع الخضرى) تحت كثافة الضوء 100% فى التربة الطينة ، والتربة المخلوطة بالطين والرمل بنسبة (1:1) افضل مقارنة بين المعاملات الاخرى بعد الشهر الثالث من تأريخ الزراعة. أثبتت النتائج أن حجم الشتلة لشجرة المرخ (Murkh) الموصى بها أن تزرع تحت كثافة الضوء 100% فى التربة الطينة ، والتربة المخلوطة بالطين والرمل بنسبة (1:1).

***كلمات مفتاحية**: شتلات المرخ، قوة الاضاءة، نوع التربة*

Introduction

The northern region of Sudan consists of desert and semi-desert climate which is prone to low rainfall, poor agricultural productivity and desertification resulting in continual decline in cultivated land. Desertification is the greatest environmental hazard that hinders the development of agriculture in the area, planting woody trees has protective and productive role in the region (Bouda *et al.*, 2013). Because one of the main causes of desertification in the area is deforestation, which leads to soil degradation and soil erosions especially by wind and water, the most degraded zones were the arid and semi- arid zones where about 76% of the human population of the Sudan live. Wind erosion is the most widespread soil degradation type in the arid zone, while water erosions was dominant in the semi-arid zone, so Sudan forest considered the most important natural resources (FAO, 2021). This area requires the propagation of tree seedling. Indigenous trees are suitable for reducing sand movement and improvement diversities of vegetation cover. There for the objective of this study was to examine the effect of light intensity and soil type on the growth of *Leptadenia pyrotechnica***,** (local name murkh) seedlings.

Materials and Methods

The experiment was conducted at Hudieba Research Station northern Sudan (17.57 N and 33.8 E). The investigated indigenous tree species was *Leptadenia pyrotechnica* (local name murkh), the experiment was carried out in September 21^{Th} 2022. The experimental design was split plot with three replications. The main plots were assigned to light intensity factor as 50% (under plastic net) and 100% (under direct sunlight), and the sub-plots were assigned to soil types (sand, sand and clay 1:1, and clay). The seeds used were collected from Abu dom near New hamdab Research Station-northern Sudan. They were sown at the rate of two seeds per polythene bag (15x20 cm size) with watering interval of every 3 to 4 days. Five seedlings were chosen randomly from each treatment in each replication, the seedlings sample were freed carefully from the polythene size bags using water for further measuring of shoot and root length and then dried in an oven set at 65 C° for 24 hours to determine the dry weight of each component.

Results and discussion

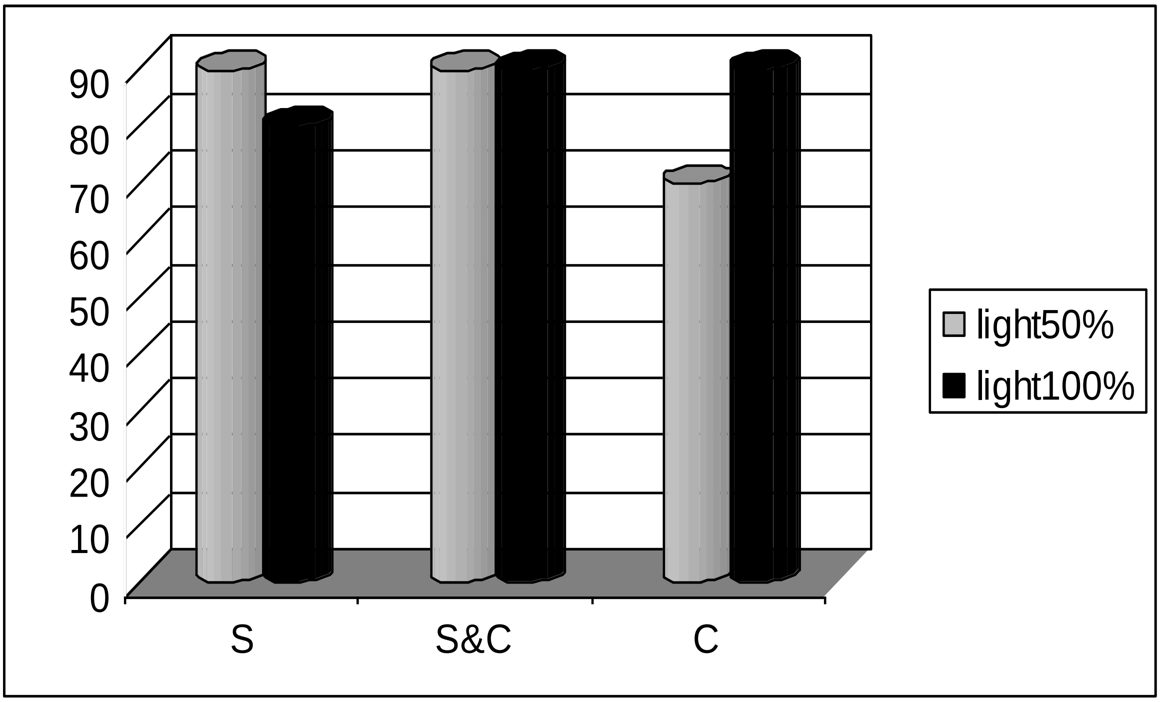
As shown in Fig 1, the germination of *Leptadenia pyrotechnica* after two weeks was better and similar under 50% light intensity on sand, and sand & clay (1:1), while under 100% light intensity was better on sand & clay, and clay soil types respectively. Seedling survival percentage for the tree species under 50% and 100% light intensity in different soil type ranged between (75-97 and 86-97%), respectively. A highly significant effect was observed between light intensity and soil types on plant height, fresh and dry weight of root and shoot and on root length. Plant height under 50% was better than under 100%, and better in clay soil than others soil type as recorded by the first, second- and third-month readings. On the other hand, significantly higher fresh and dry weight of root, shoot and root length, under 100% were observed than those under 50% light intensity and in clay and sand and clay 1:1 than in sand soil type (Table 1). The mean values of fresh and dry weight of root and shoot, as well as root length, under 100% were significantly higher than those under 50%, and the values in the clay and sand and clay (1:1) were better than in sand soil type (Table 1).

Germination of many species require specific light conditions, with species responding to slight variations in the light spectra associated with the season or shaded habitat, triggering or inhibiting germination (Fenner and Tompson 2005). The successful afforestation requires planting quality seedling with optimal potential for high rate of survival and growth height and basal diameter over time (Grossnickle and MacDonald 2017). Light availability is a major ecological factor influencing seed germination, seedling survival and establishment (Guenni *et al.*, 2018).

Generally, the interaction between different treatments showed that significant differences in height in the third month, and in fresh and dry root, shoot weight were observed. Significantly better fresh root, shoot and dry shoot weight under 100% in clay and sand & clay (1:1) soil type obtained compared to that under 50% light intensity in other soil type (Table 2). NeSmith, *et. AL.*, (2001) reported that plantable height, which is generally about 20 cm tall, and preferably 30 cm usually resulted in better survival. Therefore, clay soil under 100% light intensity was much better than the other soil type under 50% and 100% light intensity.

Recommendations

More research is needed on the physiology and growth of indigenous trees to afforestation and establishment. The natural forest vegetation performance in the semi-desert region particularly in Sudan, is especially prone to desertification. The study recommends the following combination of treatments for raising well established nursery seedlings of *Leptadenia pyrotechnica* local name (murkh) to be sown under full sun shine (100% light intensity) in clay and sand and clay soil types.



S = sand, S&C = sand and clay 1:1, C = clay

Fig1.Germination, 50%&100% light intensity of *Leptadenia pyrotechnica* in different soil type.

Table (1) Effect of light intensity and different soil type on plant height, fresh and dry weight of root and shoot and root length of *Leptadenia pyrotechnica*

Parameters	**Height (cm)**			**Fresh weight (g)**		**Dry weight (g)**		**Length root (cm)**
Treatments	**First month**	**Second month**	**Third month**	**Root**	**Shoot**	**Root**	**shoot**	
50%	14.4	41.4	63.2	0.33	3.21	0.10	0.74	13.8
100%	8.4	29	50.8	0.62	5.21	0.24	1.6	21.4
Sig.L	**	**	**	**	**	**	**	**
S.E±	0.14	1.02	1.61	0.03	0.14	0.02	0.02	0.96
l.sd	0.82	6.22	9.8	0.20	0.88	0.11	0.13	5.8
Sand	9.5	28	54.3	0.16	2	0.06	0.5	16.5
Clay&Sand	12	38.17	55.5	0.38	3.7	0.16	1	19
Clay	12.8	39.50	61.2	0.88	7	0.29	1.9	17.5
Sig.L	**	**	**	**	**	**	**	*
S.E±	0.18	0.65	1.5	0.05	0.26	0.02	0.08	1.03
LSD	0.59	2.13	5	0.17	0.88	0.06	0.27	3.4
C.V%	**2.1**	**5**	**4.9**	**12.2**	**5.9**	**4.9**	**3.1**	**9.4**

Table (2) The interaction effect of light intensity and different soil type on, plant height, fresh and dry weight of roots and shoot and root length of *Leptadenia pyrotechnica*

Parameters	**Height (cm)**			**Fresh weight (g)**		**Dry weight (g)**		**Length root (cm)**
Treatments	**First month**	**Second month**	**Third month**	**Root**	**Shoot**	**Root**	**Shoot**	
50%x S	13.7	38.3	62.3	0.13	1.7	0.013	0.40	13
50x S&C	14.3	42.3	62	0.19	3.6	0.07	0.87	15
50x C	15.3	43.8	65.3	0.6	4	0.22	0.97	13
100%x S	5.3	17.7	46	0.19	2.3	0.10	0.6	20
100x S&C	9.7	34	49	0.6	4	0.24	1.2	22.6
100x C	10.3	35.3	57	1.1	9.7	0.35	2.9	21.6
Sig.L	**	**	*	**	**	*	**	NS
S.E±	0.25	1.27	2.4	0.07	0.3	0.03	0.1	1.5
LSD	0.79	4.8	7.98	0.21	1.1	0.09	0.32	4.96
C.V%	**3.9**	**4.5**	**6.6**	**18.7**	**15.3**	**19.5**	**17.8**	**14.3**

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Shelf-Life Investigation for Two Newly Released Tomato Varieties Compared to Introduced one to Sudanese Environment

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Abstract

This study aimed to evaluate shelf life for two newly released (Darmali and ZahratElneel) and one introduced (Castle Rock) tomato varieties grown at Hudaiba Research Station Farm, River Nile State, season 2014-2015. They were kept at room temperature (27^{0}C) and under cold storage conditions (10-12^{0}C) to assess their consumable shelf life. The fruit firmness, weight loss, curliness and overall decay components of the fruits were the daily tested parameters. Tomato fruits stored under cold storage showed longer shelf-life than those stored at room temperature. Generally, Castle Rock had longer shelf-life, followed by Dar-mali and ZhratElneel, respectively. The storage life of tomatoes was determined as 1-14 days.

Keywords: *Tomato, Released varieties, Shelf life, Firmness, Deterioration*

دراسة عمرالعرض لصنفين جديدي الاجازة من الطماطم مقارنةً بصنف اخرمُدخَل إلى البيئة السودانية

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المستخلص

هدفت هذه الدراسة إلى تقييم مدة صلاحية العرض لصنفين جديدين من الطماطم (دارمالي وزهرة النيل) وصنف مُدخَل (كاسل روك) زُرعت في مزرعة محطة أبحاث الحديبة، بولاية نهر النيل، خلال موسم 2014-2015. حُفظت الأصناف في درجة حرارة الغرفة (27 درجة مئوية) وفي ظروف التخزين البارد (10-12 درجة مئوية) لتقييم مدة صلاحيتها للاستهلاك. شملت المعايير التي تم اختبارها يوميًا صلابة الثمار، وفقدان الوزن، والتجعد، ومكونات التلف العامة للثمار. أظهرت ثمار الطماطم المحفوظة في ظروف التخزين البارد مدة صلاحية أطول من تلك المحفوظة في درجة حرارة الغرفة. بشكل عام، تميز صنف كاسل روك بفترة صلاحية أطول، يليه صنف دار مالي ثم صنف زهرة النيل. وقد حُددت فترة صلاحية الطماطم من يوم إلى 14 يومًا.

الكلمات المفتاحية: *الطماطم، أصناف مُجازة، فترة الصلاحية، الصلابة، التلف*

Introduction

Tomato (*Solanum Lycopersicon L.*) is one of the most cultivated and popular vegetables belonging to the family Solanaceae worldwide. Latin America is believed to be the origin of the crop where it was cultivated as a vegetable centuries ago. In Sudan tomato is a cool season vegetable (MAAW, 2017). However, warm climate cropping needs special precautions by skilled farmers or otherwise to be produced under cooled green houses. The fruit is considered as a valuable nourishment vegetable, rich source of minerals, vitamins, dietary fibers and lycopene. It is consumed in fresh forms as well as processed products and valued for its health benefits. World tomato production was estimated to reach 186 million metric tons in 2022 (FAOSTAT, 2023). China, India, turkey, United States and Egypt are the global leading producing counties (FAOSTAT, 2025). In Sudan, tomato comes second after onion with an estimated production of 633000 metric tons in 2022.

Tomatoes can be divided into two groups; processing tomatoes and fresh consumption tomatoes (Hogberg, 2010). There are also many varieties within these two groups, especially among the fresh tomatoes, apart from classical round tomato, can be with many different sizes, shapes and colours ranging from beef tomatoes to cherry tomatoes. Tomato varieties differ in their characteristics in relation to production environments, consumer preference, whether for fresh consumption or processing, etc. This necessitates their evaluation to meet such requirements (Ketema and Beyene, 2021).

Tomato fruit ripens through climacteric mechanism which is accompanied by a peak in respiration and is regulated by ethylene. Exposure to exogenous ethylene accelerates ripening of green tomatoes (Carrari and Fernie, 2006; Alexander and Grierson, 2002). The ripening process affects physical, chemical, and physiological properties of the fruit. The fruit soften, chlorophylls degraded and carotenoids increased. There is also an increase in the respiration rate, ethylene, organic acids, sugars and lycopene production (Cano *et al.,* 2003). Respiration is a metabolic process that provides energy for plant biochemical processes. It involves oxidative breakdown of organic reserves to simpler molecules (O_2 and H_2O), with the release of energy (Ravindra and Goswami, 2008). These changes start while the fruit is still on the plant and accelerate after harvest and fruit reaches an over-ripe state in a short period of time (Guillen *et al*., 2006). Qualitative attributes, such as texture, generally change with time, as part of the normal metabolism of the product (Tijskens and Evolo, 1994). Most of the physiological, biochemical and microbiological activities contributing to the deterioration of produce quality are largely dependent on temperature (Tano *et al*., 2007). Low temperature is the most important factor in maintaining quality and extending the shelf-life of fruits and vegetables after harvest. However, gas composition of the ambient air also plays an important role. Shelf-life of fresh fruits and fresh-cut fruits may be extended by atmospheres reduced in O_2 and elevated in CO_2, by means of modified atmosphere packaging that slows deterioration and reduces ethylene production and respiration rates. Controlled atmosphere storage or modified atmosphere packaging, combined with low temperature storage, can reduce respiration and ethylene production rates, then retard or slow down changes related to ripening and senescence (Fonseca *et al.*, 2002).

Fruit firmness, is an important parameter to know the minimum pressure required for skin puncture and hence design of suspension system of transport vehicle. In addition, data of post-harvest mechanical properties in fruits and vegetables are important for the adoption and design of several handling, packaging, storage and transportation systems (Singh and Reddy, 2006).

Shelf-life is the most important criteria in fresh marketing of fruits and vegetables. Shelf-life is defined as the period in which a product should maintain a predetermined level of quality under specified storage conditions (Shewfelt, 1986). A number of chemical and physical processes take place in fruits and vegetables during storage.

Since tomato is highly perishable, it suffers several postharvest losses during storage, transportation, and marketing (Ben *et al*., 1986). Tomato fruits shelf-life is calculated by counting the days required to attain the last stage of ripening, but up to the stage when fruit remained still acceptable for marketing.

Hardenburg *et al*. (1986) and Ball (1997) stated that low temperature storage is the most efficient method to maintain quality of most fruits and vegetables due to its effects on reducing respiration rate, transpiration, ethylene production, ripening, senescence and rot development. Ball (1997) and Schuelter *et al*. (2002) stated that temperature plays an important role in maintaining post-harvest quality and shelf-life of tomato fruits. However, optimal storage temperatures depend on the maturity stage of the tomatoes.

Maul *et al*., (2000) reported that red tomatoes can be stored at 7°C for a number of days, although tomatoes stored at 10°C were rated lower in flavor and aroma than those held at 13°C. They also concluded that ideal conditions for ripening are 19 to 21°C with 90 to 95% relative humidity. Castro *et al*. (2005) mentioned that ripe tomato can be stored at a temperature of 10-15°C and 85-95 relative humidity for longer periods. Similarly, Dragan and Tomaz (2006) stated that, though tomato fruits can be stored at ambient temperature for a period of up to 7 days, they, at lower temperature showed more stability, greater storage life and acceptable weight loss.

Fruit firmness is considered to be a good indicator of fruit maturity for determining the shelf-life of products (Beaulieu and Gorny, 2001). Fruit firmness is also affected during storage. However, mature fruits with greater firmness have longer shelf-life (Zdravkovic *et al*., 2010). Storage at low temperature is a common practice to retard softening of fruits and vegetables. However, accelerated softening of tomato can occur at low temperature due to chilling injury (Jackman *et al.*, 1992). Cold temperature will cause tomatoes firm texture to turn pulpy (Adegoroye *et al*., 1989; McDonald *et al*., 1999). Decay organisms can enter through such breaks in the skin. However, Ressureccion and Shewfelt (1985) established that tomato should not be stored in the refrigerator; as refrigeration will reduce its flavour by approximately 30%. The flavour of tomatoes is largely determined by the sugar and acid composition of the fruit (Moretti *et al*., 1998).

The colour of a ripe tomato is determined by the ratio of two pigments, lycopene and β-carotene (Hobson and Grierson, 1993). The colour changed in fruit corresponds to a fall in chlorophyll and an increase in carotenoids synthesis (Pretel *et al*., 1995). Storage at over 27 °C reduces intensity of red color.

Quality of most fruits and vegetables is affected by water loss during storage, which depends on the temperature, relative humidity and storage time (Perez *et al*., 2003). Varieties respond differently in terms of weight loss, and the best vapor heat treatment condition should be determined for each variety to reduce weight loss and prolong shelf life (Castaneda *et al*., 2010). Mallik *et al*. (1996) reported that tomato fruits showed the lowest physiological weight loss (7.7-9.7%) after 6 days of storage under ambient condition. However, Akand *et al*. (2015) found that different varieties exhibited a significant influence on shelf-life of tomato at different storage conditions. The loss of water can lead to wilting and shriveling, which both reduce market value and consumer acceptability (Ball, 1997). According to Znidarcici and Pozrl (2006) weight loss of tomato fruit is closely related with the temperature. Tomato fruit stored at lower temperatures have an acceptable weight loss and more stability and greater storage life than fruit stored at higher temperatures. Weight losses of 8-6% affects the visual appearance and texture of the fruits and causes a reduction of marketability of the fruits (Haffner *et al.*, 2002). Kader (2002) stated that products must lose about 5 % of their fresh weight before visual appearance is affected. This is likely due to the high temperature, which melted the wax to such an extent that it ran off and was lost and caused major injuries to fruit tissues.

Acid concentration in the fruit is also temperature dependent. Concentration of acid linearly reduced when temperature increased and then went up again when fruit stored at 15°C (Islam *et al*., 1996). However, tomato cultivars with high pH are not suitable for processing.

Goojing *et al*. (1999) reported that 78.2 and 47.5% of rotting can be found in red ripen and mature harvested fruits, after three weeks of storage at 15-20°C, respectively.

Apart from physical quality, serious losses also occur in the essential nutrients, vitamins and minerals.

This study aimed to evaluate the shelf life for two newly released (Dar-mali and ZahratElneel) and one introduced (Castle Rock) tomato varieties grown at Hudaiba Research Station Farm, River Nile State

Material and Methods

Fresh, fully ripped tomato fruits from three varieties; Castle Rock, Dar-mali and ZahratElneel, were collected from Hudaiba Research Station Farm, River Nile State, season 2014-2015. Hundred fruits selected randomly from each cultivar.

Tomato fruits were submitted to different storage temperatures and evaluated for their quality. The tomatoes stored at room temperature (27^0C) and those stored at lower temperatures ($10\text{-}12^0$C) showed gradual change in their intensity of measured parameters with storage time. The fruit firmness, weight loss, curliness and overall decay components of the fruits were recorded daily. The storage life of tomatoes was determined as 1-14 days.

Fruit shelf-life was determined in terms of fruit firmness, curliness, weight loss% and decay according to the methods applied by Jan *et al*. (2012) and Parker and Maalekuu (2013) with some modifications. Tomato fruits varieties under investigation were stored at room temperature (about 27^0C) and in refrigerator ($10\text{-}12^0$C) for 1-15 days. Quality parameters; fruit weight loss, fruit firmness, curliness and decay were evaluated.

Fruit firmness was determined by feeling how hard or soft the fruit was. The fruits were rated on a scale of 1-5 with;

5-4= very firm
4-3= firm
3-2= soft
2-0 = very soft

Five fruits in each variety were separated for weight loss test. The initial weight of each fruit was noted daily with the help of electronic balance. The average loss of weight was calculated at day's intervals. The weight loss (%) was calculated as:

$$\text{Weight loss \%} = \frac{\text{Weight of fresh fruits – Weight after interval}}{\text{Weight of fresh fruit}} \times 100$$

Fruit curliness was determined visually. The fruits were rated on a scale of 1-4;

1-2= non
2-3= very little
3-4= little
4 to above= much

Fruit decay was determined by the visual observation. Development of spots on the fruit's skin and softening and rotting of fruits were rated on a scale of 1-4;

1-2= non
2-3= very little
3-4= little
4 to above = much

Results and Discussion

Fruit weight loss

Weight loss% depends on water loss mainly and it is important because it affects the visual appearance and texture of the fruits and causes a reduction in saleable weight (Jones, 1999).

The weight loss of tomatoes was almost linear at both storage temperatures. The weight loss appeared after 4 days in all varieties. After 7 days Dar-mali and ZhratElneel lost about 18.5% (in average) while Castle Rock lost 14.7% (Fig.1a). At cold storage, weight loss goes slowly compared with storage at room temperature (Fig.1b.), after 7 days Dar-mali and ZhratElneel loss was about 4.5% fruit weight but Castle Rock loss was 3.3%. Results showed higher weight loss in ZhratElneel than in Dar-mali and Castle Rock, respectively. The high level of moisture in ZhratElneel render it to be more perishable and hence requires to be handled with much care to minimize losses. Storage at lower temperature tended to increase tomato longevity.

Fruit firmness

Fruit firmness of the three tomato varieties showed a progressive decline during storage at room temperature and at cold storage (Fig 2 a-b). The decline occurred earlier at room temperature mostly after 7 days storage. The decrease in firmness observed earlier in ZhratElneel, followed by Dar-mali and Castle Rock, respectively. Zdravkovic *et al.* (2003) established that Castle rock variety had greater firmness that causes long shelf-life of its mature fruit.

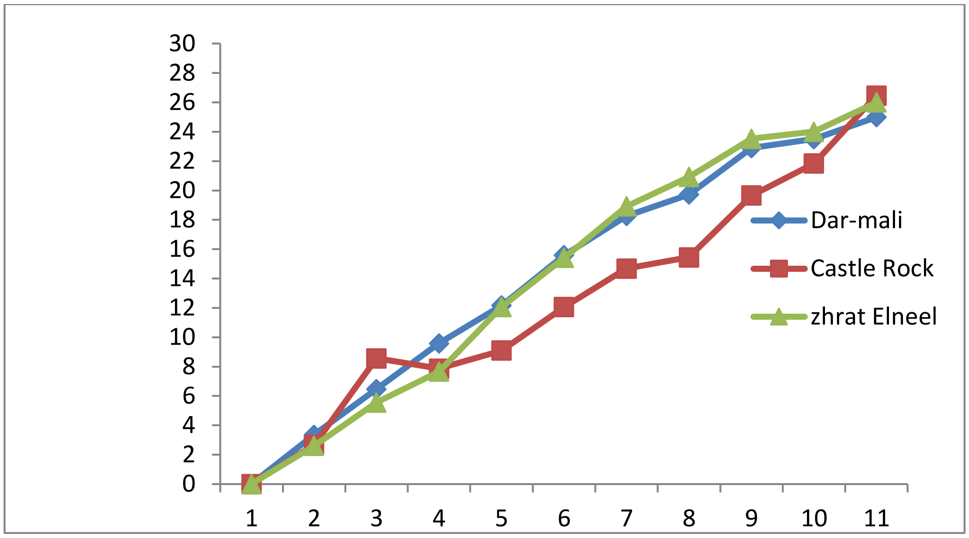

Fig.1a. Tomato fruits weight loss (%) at room temperature

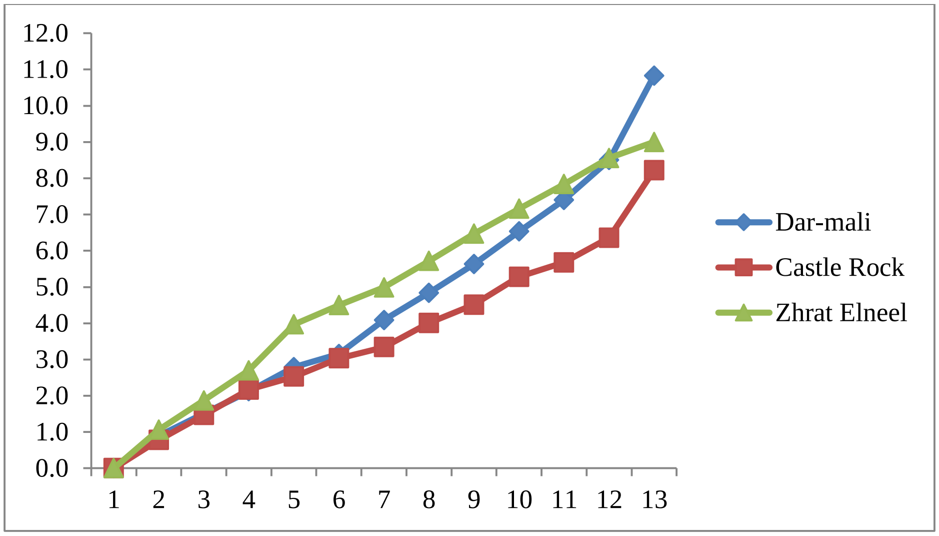

Fig.1b. Tomato fruits weight loss (%) at cold storage

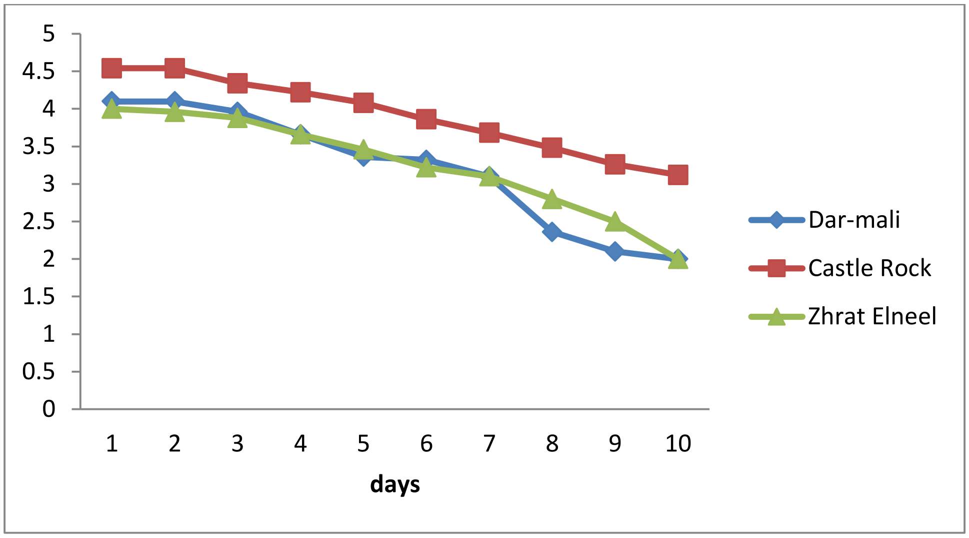

Fig.2a Tomato fruits firmness during storage at room temperature

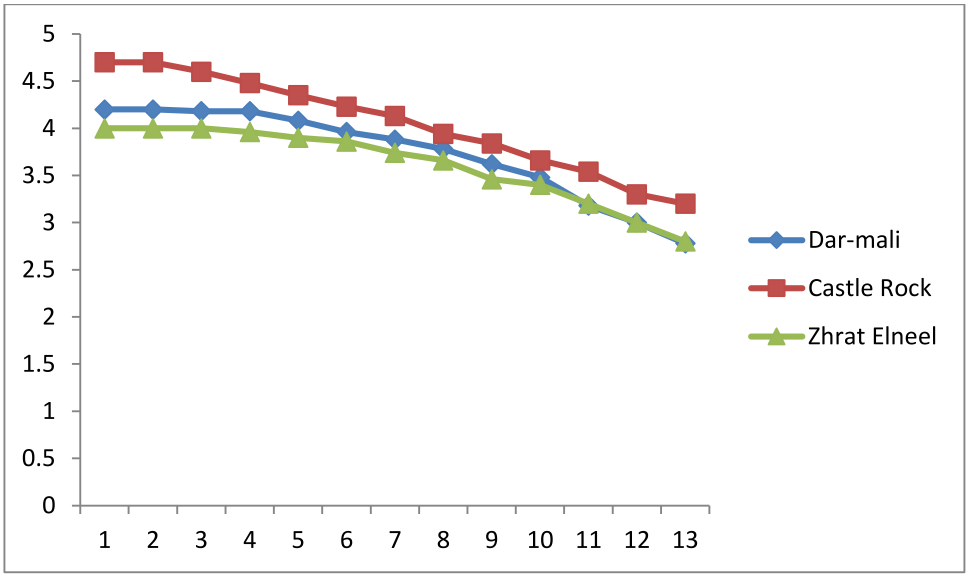

Fig2b: Tomato fruits firmness during cold storage

Fruit curliness (shriveling)

Fruits curliness was observed earlier during the storage of tomato at room temperature than at cold storage conditions. However, under both storage conditions, Castle Rock showed no tendency to shrivel and sustain its natural good appearance for the first 7 days. Dar-mali and ZhratElneel shriveled earlier with sharper decline after 2 days at room temperature and after the 4th day at cold storage conditions (Fig3a and b).

4.2.4 Fruit overall decay

After seven days of storage at room temperature rotting was very little in Dar-mali and ZhratElneel tomato varieties, while Castle Rock showed no rotting until the ninth day (Fig. 4 a.). Under cold storage conditions, the decay or rotting is not found in the three tomato varieties until the 9th day (Fig.4 b.).

Generally, the shelflife results showed that Castle Rock had a better keeping quality, followed by Dar-mali and ZhratElneel, respectively. The higher rate of decay in ZhratElneel variety could be attributed to its higher moisture content (95%).

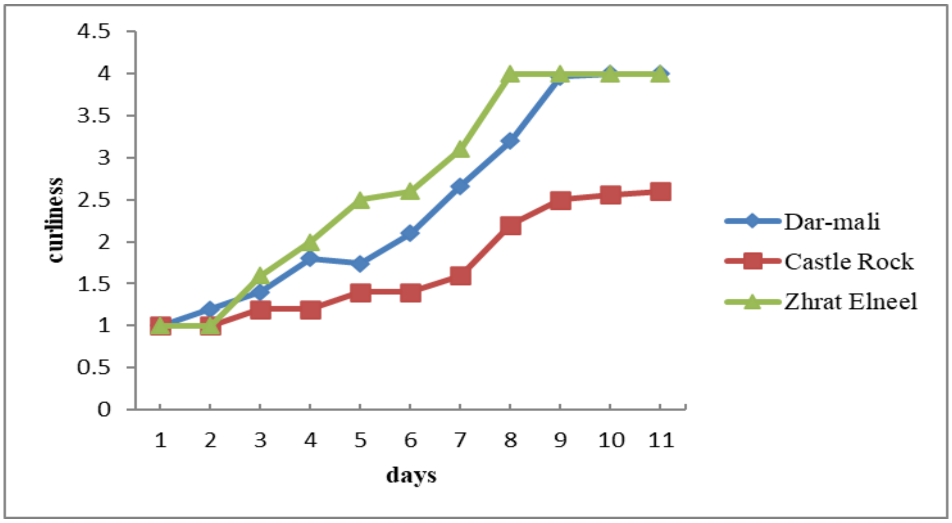

Fig.4a. Tomato fruits curliness at room temperature

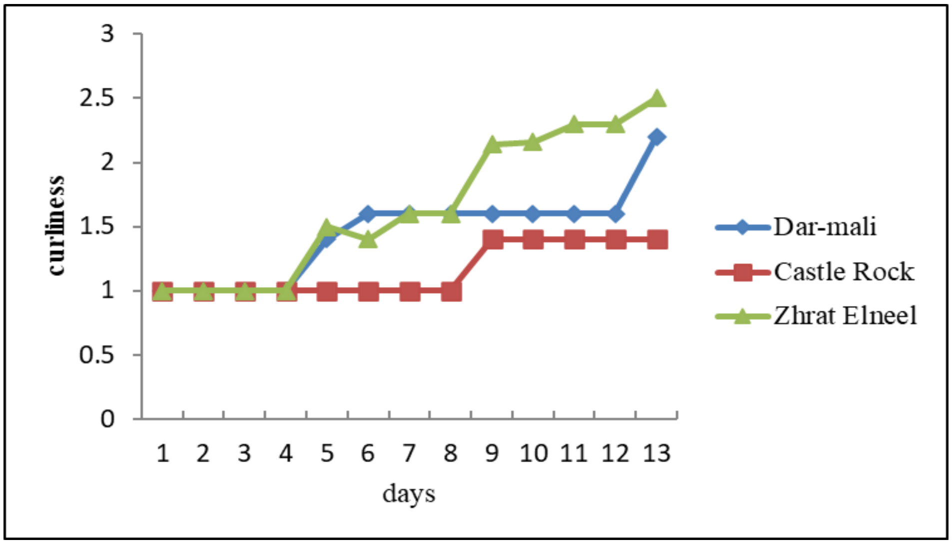

Fig.4b. Tomato fruits curliness at cold storage

Conclusion

Three tomato fruit varieties; Castle Rock, Dar-mali and ZahratElneel were evaluated for the shelf-life at room temperature and under cold storage conditions.

In term of fruits shelf-life, fruits stored under cold storage showed longer shelf-life than those stored at room temperature. The percentage of decay, weight loss, fruit softening, fruit curling gradually increased with storage time. Generally, the shelf life results showed that Castle Rock had longer shelf-life, followed by Dar-mali and ZhratElneel, respectively.

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Using a Low-cost Energy (carbon) Source to Produce Tissue Cultures Banana

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Abstract

This study aimed to test commercial sugar, available in Sudan, as a carbon source instead of pure sucrose as a low-cost energy source for tissue culture-derived banana seedling production. Grand Nain banana offshoots were used as initial source of explants in a series of subculturing to produce healthy plantlets and their subsequent regeneration using two sugar types with low and high concentrations (15 and 30 g per liter). Results obtained indicated that sugar concentration rather than sugar type affected significantly and positively bud formation in the first two week after subculturing. However, in the last weeks low concentration of commercial sugar behave in a similar way to high concentration of both sugar types on its effect on bud regeneration. Regarding leaf appearance, high concentration of both sugars significantly produced more leaves in the first week only, and then after, leaf appearance was same in both type and concentration of sugars. Higher rooting was significantly recorded by low concentrations of both types of sugars in 2 later weeks of plantlets.

Keywords: *Banana, Tissue culture, Sugar concentration, Commercial sugar*

استخدام مصدرطاقة (كربون) منخفض التكلفة لإنتاج شتلات الموزبزراعة الانسجة

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المستخلص:

هدفت هذه الدراسة إلى اختبار السكر التجاري المتوفر في السودان كمصدر للكربون بدلاً من السكروز النقي، وذلك كمصدر طاقة منخفض التكلفة لإنتاج شتلات الموز بتقنية زراعة الأنسجة. استُخدمت شتلات موز جراند نائين كمصدر أولي للأجزاء النباتية في سلسلة من عمليات الاستزراع المتكررة لإنتاج شتلات صحية، ثم تجديدها باستخدام نوعين من السكر بتركيز منخفض وعالٍ (15 و30 غرامًا لكل لتر). أشارت النتائج إلى أن تركيز السكر، وليس نوعه، هو ما يؤثر بشكل ملحوظ وإيجابي على تكوين البراعم خلال الأسبوعين الأولين بعد إعادة زراعة الأنسجة. مع ذلك، في الأسابيع الأخيرة، أظهر التركيز المنخفض للسكر التجاري تأثيرًا مشابهًا للتركيز العالي لكلا نوعي السكر على تجديد البراعم. أما بالنسبة لظهور الأوراق، فقد أدى التركيز العالي لكلا نوعي السكر إلى زيادة ملحوظة في عدد الأوراق خلال الأسبوع الأول فقط، ثم أصبح مظهر الأوراق متماثلًا بعد ذلك بغض النظر عن نوع السكر أو تركيزه. وتم تسجيل تجذير أعلى بشكل ملحوظ عند استخدام التركيز المنخفض لكلا نوعي السكر خلال الأسبوعين الأخيرين من عمر المستنبتات.

الكلمات المفتاحية: الموز، زراعة الأنسجة، تركيز السكر، السكر التجاري

Introduction

Bananas are grown in many regions of the world, including tropical, subtropical, and even sometimes, cooler zones. The area planted with bananas in Sudan has increased to over 23,000 hectares, planted with various banana varieties, most of which are the Dwarf Cavendish variety, producing over 1,150,000 tons. The Ministry of Agriculture, along with some producers and research centers, have imported, tested, and cultivated some other so-called excellent varieties. These varieties have proven their ability to grow and produce well, which foretells well the potential to increase the export capacity of this crop (Osman et al., 2015).

Banana seedlings can be produced using micro propagation. This technique produces a large number of high-quality, disease-free plants in a short period of time, regardless of the season and weather (Anonymous, 2004). Micro propagated banana plantlets are progressively becoming the suitable planting material due to its disease and nematode control, crop growth uniformity and also due to its rapid multiplication nature. However, growers have to face higher costs of seedlings compared to conventional suckers. Bananas, however, require a suitable culture medium that is inexpensive. Conventionally it requires quantities of sucrose, growth regulators, gelrite or agar, and components of the Murashige and Skoog culture medium salts (Nasr et al., 2014). The main

obstacle to plant tissue culture propagated seedlings is its relatively high costs of materials and high level working skill demand compared to conventional cultivation methods. Therefore, low-cost alternatives are preferred to reduce production costs (Ssamula et al., 2015). The use of chemicals, a carbon source, a gelling agent, organic and inorganic nutritional supplements, and growth regulators in the culture medium makes this technique relatively expensive. Sucrose is usually used as a carbon source and agar as a gelling agent, and together they constitute the most expensive components of the culture medium (Rakshi et al., 2017).

Commercial sugar as carbon source and locally available salts, such as nutrients, can be used as an alternative source to reduce the cost of the medium (Gitonga et al., 2010). The carbon source, sucrose, which is very important for micro propagation of plants, contributes approximately to 34% of the production cost (Demo et al., 2008). Kaur et al., 2005, found that replacing sucrose with commercial sugar in the banana culture medium reduced the cost of tissue culture by 90%. Therefore, the use of low-cost materials for banana growth and development contributes to increasing banana production worldwide. This system can be adopted to reduce costs for farmers and establish low-cost tissue culture laboratories in their regions to increase banana production (Dhanalakshmi and Stephan, 2014). To reduce the cost of banana tissue culture, Stephan and Dhanalakshmi (2014) replaced the conventional medium with micronutrients and macronutrients, adding 30 g/L of commercial sugar and 8 g/L agar.

Laboratory grade sucrose, common grade sugar, cube sugar, rock sugar, candy sugar, glucose, jaggery and sugarcane juice were evaluated for in vitro propagation of banana cv. GrandNaine. Best response in terms of shoot multiplication and rooting were achieved with rock sugar and common grade sugar, respectively which could be compared well with that of analytical grade sucrose. The results showed the possibility of successful use of cheaper carbon sources for micro propagation of banana cv. GrandNaine (Prabhuling and Sathyanarayana, 2017).

Two banana cultivars (Monthan and Poovan) were grown and the cost of nutrients used in the medium was determined. Results indicated that by 61.4% cost reduction, a reasonable number of buds were produced on the low-cost medium compared to the conventional medium. The average production of the Mothan cultivar was 4.6 buds per plant, while the average production of the Poovan cultivar was 4.5 buds per plant on the low-cost medium. The production of the Poovan cultivar was 5.1 buds per plant compared to the Mothan cultivar, which had an average of 4.9 buds per plant on the conventional medium. We find that both cultivars produced the highest number of buds in Traditional medium compared to low-cost medium. In root production, the traditional medium produced a greater number of roots compared to the low-cost medium.

Dhanalakshmi and Stephan (2016) Stated that the overall comparative cost reduction analysis percentage was 73.20 % for medium used with conventional nutrient salts and table sugar. Ahamad (2024) Suggest replacement of highly expensive media components such as agar,
Sucrose, and water that cost more than 70-85 % of total production cost by cheaper alternatives. He suggest refined household sugar and other types instead of pure sucrose.

This study aimed to test commercial sugar, available in Sudan, as a carbon source instead of pure sucrose as a low-cost energy source for tissue-derived banana production.

Materials and Methods

Experimentation Site

This experiment was conducted in the tissue culture laboratory of Al Rajhi Company in Berber, 5 km from the city. Berber is located in the center of River Nile State, on the eastern bank of the Nile River, parallel to the course of the Nile. latitudes 17.40 and longitudes 32.20 north of Atbara.

Plant Source**:**

Grand Nain banana offshoots were brought from the University of Gezira farm, east of Wad Medani, to the tissue culture laboratories of the Kafaa Project in Berber.

Experimentation:

Sterilization and cultures initiation:

The plants were washed for cleaning under running water, and the corms were brought to the company's tissue culture laboratory. Prepared explants were cleaned and surface sterilized with sodium hypochlorite, followed by pre cultivation treatments and incubation as stated in the steps bellow. Some of regenerating buds were subsequently taken for further studies according to the suggested investigation treatments

In the first stage, Murashige and Skoog's (1962) medium salts were prepared as nutrient solutions in liquid medium with activated charcoal. The pH of the medium was adjusted to 5.8 using both potassium hydroxide and hydrochloric acid. Sucrose was used as a carbon source, and a growth regulator was added. In every 250 ml containers 30 ml of the medium was dispensed and covered with Teflon caps. All containers were autoclaved at 121°C and 15 psi for 30 minutes to sterilize the medium. In a dark room at 27°C the containers were then incubated for 4 days and examined for contamination before planting. Explants were then planted in the culture medium under a sterilization cabinet (hood). The cultures were then incubated at 27°C in complete darkness and transferred to a fresh medium every month three times. They were then transferred to the multiplication medium specified for each experimental treatment as stated bellow. The plantlets that had 4-5 shoots were selected and spliced into cuttings for further culturing. The sucker cuttings were put in low cost fresh prepared medium of the composition as in Table (1). Morphological changes were observed and recorded weekly. After the 4th week of culturing, final plantlets produced per each treatment was compared to others for detecting suitability of culture medium for further recommendation.

Four treatments were used in which two types of sugar (sucrose and commercial sugar) each in two concentrations (15 and 30 grams per liter), while MS salt strength was kept at 3.3 grams per liter and with 2 grams of gelrite and 5 mg benzyel adenine as indicated in Table (1).

Ten cultures were grown to be tested for growth parameters with four replicates, and the experiment was statistically analyzed according to a randomized complete block design (RCBD). Readings were taken at different periods of the experiment, as shown in the results tables (bud emergence, leaf emergence, and root emergence). At the end of the experiment (after 4 weeks), the number of shoots, leaves, and roots in the culture were calculated.

Table (1) Media component used for banana bud regeneration in comparison between two types of sugar

Treatment	Ms salt strength gram/liter	Sucrose concentration gram/liter	Commercial sugar concentration gram/liter	Benzyel adenine concentration mg/ liter	Added Gelrite gram/liter
1	3.3	15	0	5	2
2	3.3	30	0	5	2
3	3.3	0	15	5	2
4	3.3	0	30	5	2

Results and discussion

Effect of commercial sugar:

The effect of sugar type and concentration on the formation and growth of banana buds in plant tissue culture were shown in Figure (1) in the initial reading seven days after the cultures were grown, the high sugar concentration (30 g/L) resulted in a significant increase in the number of bud-forming culture containers. The percentage of bud-forming culture containers was 20%, compared to the low sugar concentration (15 g/L) containers, which represented 10% of the incubated cultures containers ($p<0.0060$). No significant difference was found between the two sugar types.

In the second reading, 14 days after culture, the high sugar concentration of both types resulted in a significant increase in the number of containers forming new buds (30%) compared to the low sugar concentration of both types (15 g/L) which was 20% with commercial sugar, and 10% of bud forming containers of 15 g/L sucrose ($p<0.0005$).

In the third reading, 21 days after culture, the highest percentage of regenerating containers forming buds was produced with both 30 g/L sucrose and 30 and 15 g/L commercial sugars, representing 40% of total number of tested containers. No increase was observed with sucrose 15 g/L compared to the previous week which was only 10% of total number of containers, and the differences were highly significant ($p<0.0001$).

In the fourth reading after 28 days of planting the cultures, commercial sugar at a concentration of 15 g/L showed the highest percentage of containers forming new buds (80% of total number of containers), followed by sucrose at a concentration of 30 g/L (50% of total number of containers), while there was no increase in the percentage of cultures forming buds at a concentration of commercial sugar of 30 g (40% of total number of containers) and sucrose of 15 g/L (10% of total number of containers), and the differences were highly significant ($p < 0.0001$).

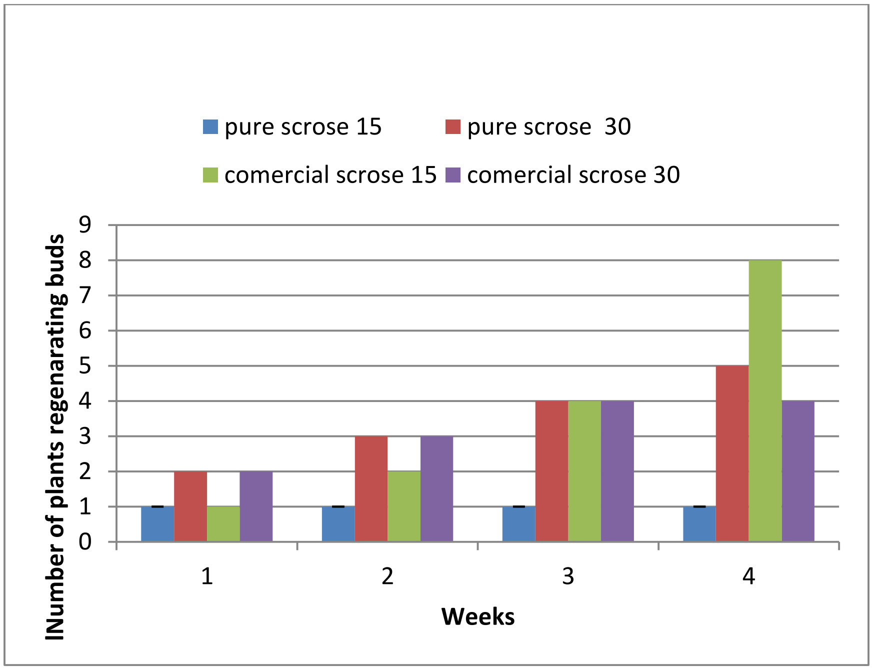

Figure (1) Effect of sugar type and concentration on the regenerated cultures

Figure (2) shows a significant difference in leaf growth regarding sugar type and concentrations. In the first reading, seven days after the culturing, as a result of the different treatments. The highest percentage of leaf formation resulted from the high sugar concentration of 30 g/L (100% leaf-forming cultures), compared to the low concentration of both sugar types (15 g/L), where the percentage of leaf-forming culture containers was 70% ($p<0.0006$).

In the second reading, 14 days after the culturing, the highest leaf growth resulted from high sucrose concentration (30 g/L) and commercial sugar of 30 and 15 g/L concentrations, where the percentage of leaf-forming culture containers was 100%, compared to the low sucrose concentration (15 g/L), the percentage of leaf-forming culture containers was 80% of the total containers number. The differences were highly significant ($p<0.0001$).

In the third reading, 21 days after culturing, the highest percentage of leaf-forming containers resulted from the high sugar concentration of the two types and from low concentration of commercial sugar (15 g/L). The percentage of leaf-forming containers was 100%, and the lowest percentage was from the low sucrose concentration (15 g/L), despite the increase in the percentage of leaf-forming containers to 90% ($p<0.0877$).

In the fourth reading, 28 days after culturing, all sugar concentrations of both types resulted in complete leaf development, and there was no difference between treatments (p<0.436).

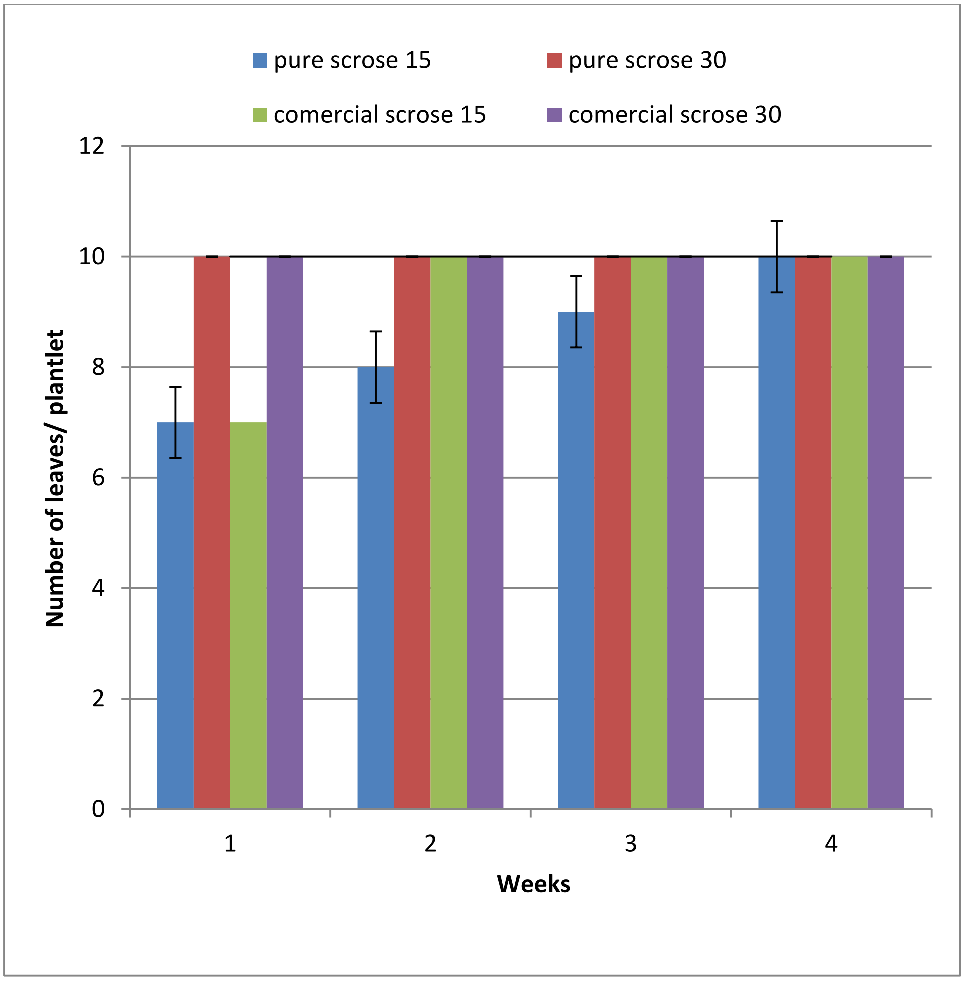

Figure (2) Effect of sugar type and concentration on leaf emergence on banana shoots in tissue culture

The effect of sugar type and concentration on plantlets rooting in banana tissue culture treatments was shown in figure (3). Results showed a significant effect of sugar type and concentration on the percentage of rooting containers. In the initial reading, seven days after the cultures were made, the effect of sugar concentration and type showed significant differences in the number of rooting containers. The highest percentage of rooting containers (20%) was registered by the highest sugar concentration of 30 (g/L) of both sugar types and the commercial sugar concentration of 15 g/L, the percentage of culture containers with roots was 10% (p<0.015).

In the second reading, 14 days after culture, the type and concentration of sugar produced significant differences in the percentage of rooting culture containers. The highest percentage of rooting culture containers (50%) was recorded by concentration of 15 g/L of both sugar types, followed by sucrose at 30 g/L, with a 40% rooting culture container percentage. The least rooting occurred at a commercial sugar concentration of 30 g/L, with a 30% rooting of the total number of culture container (p<0.0291).

In the third reading, 21 days after culture, an increase was observed in the percentage of containers of rooting culture, reaching 50% for the low sugar concentration compared to 40% for the high sugar concentration. The differences were significant (p<0.0460).

In the fourth reading, 28 days after culturing, the results appeared as in the third week, without an increase in the percentage of rooting containers.

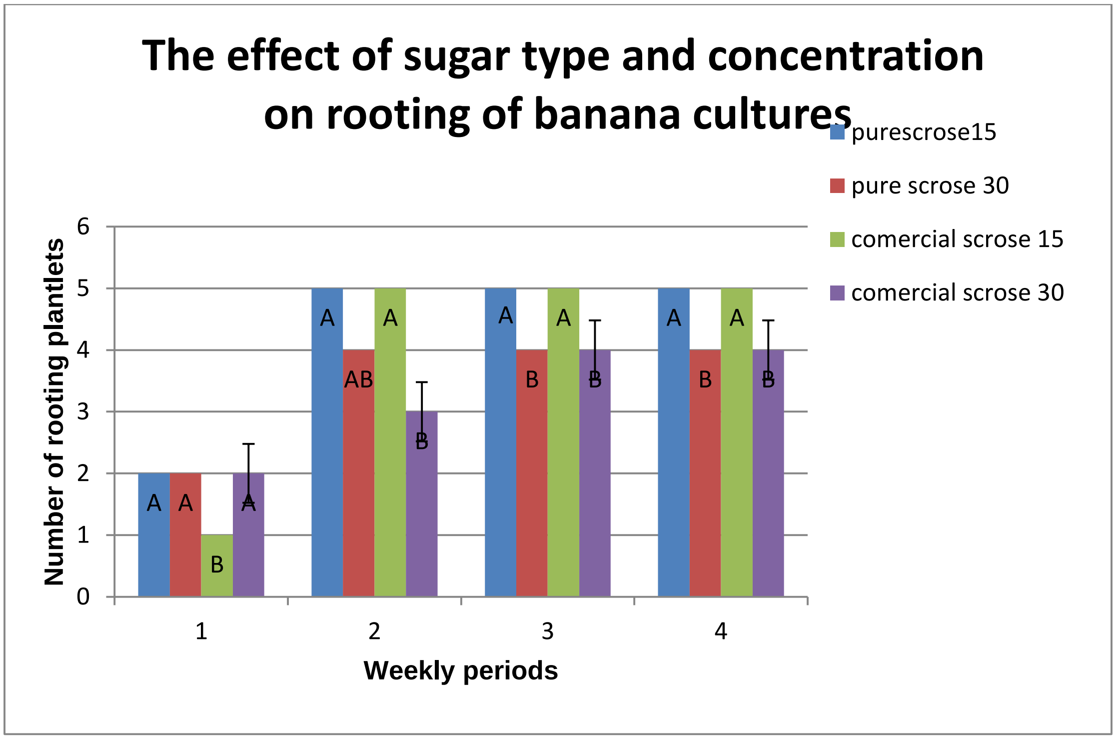

Figure (3) Effect of sugar type and concentration on banana rooting in tissue culture

Table (2) shows the performance of banana plantlets as affected by different type of sugars and their concentration at the end of the fourth week. Regarding bud formation, which demonstrates the doubling of banana plantlets during the multiplication phase, results indicate no significant differences in banana bud formation, whether pure sucrose or commercial sugar was used. The 15 g/L concentration achieved the best results in both sugar types. The average number of buds ranging between 3-4, with no significant differences between the two sugar types and concentrations. These results are similar to those obtained by Stephan and Dhanalakshmi (2014) for the number of regenerating buds when he used commercial sugar.

Regarding the number of leaves, there were no significant differences between treatments. Regarding the number of roots, the results indicate significant differences between the 30 g /l commercial sugar concentration and the remaining treatments.

The average plant height did not differ significantly between sugar treatments, whether commercial sugar or sucrose used. It is well known that the carbon source is important for the growth of plant parts in tissue cultures, whether buds or other parts, due to the inability of cultures to provide the plant with energy through photosynthesis in its early stages. The above results demonstrate that the banana tissue culture medium is not affected by the type of sugar added to banana plant propagation. Therefore, the cost of seedlings and foreign currency can be reduced by using commercial sugar instead of pure sucrose, either at a concentration of 15 or 30 grams of sugar per liter of the nutrient medium containing essential macro and microelements, vitamins, amino acids, and plant growth regulators. Energy sources in tissue culture media are important for plants whose photosynthetic efficiency is not sufficient under laboratory conditions. The energy source in tissue cultures is high, making plant tissue culture expensive (Ssamula et al., 2015). In this experiment, sugar was used as a less expensive carbon source in tissue culture, which is expensive to produce plantlets at a lower cost due to the high cost of pure sucrose, its scarcity under Sudanese conditions, and the time it takes to import. Locally produced commercial sugar is about 5% of the price of pure sucrose at the time of experimentation.

Table (2) Effect of sugar type and concentration on growth parameters 4 weeks after banana explant culturing

Type and concentration of sugar in grams	**Culture reading at the end of the 4th week**			
	Number of shoots	**Number of leaves**	**Number of roots**	**Average plant height in cm**
Pure sucrose 15	3.55 a	5.11 a	1.11 b	2.03 a
Pure sucrose 30	3.22 a	5.11 a	1.33 ab	1.92 a
Commercial sugar 15	3.44 a	5.11 a	0.22 b	1.87 a
Commercial sugar 30	3.11 a	5.11 a	2.0 a	1.76 a
CV%	17.47	0.00	72.72	19.87
LSD	1.16	0.00	1.6902	0.76

Conclusion

This study indicated that commercial sugar can be used as low cost and safe media component for banana micro propagation. This can help in decreasing seedling cost of disease free material in banana production

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