TECHNICAL AND ECONOMICAL PARAMETERS INFLUENCING THE PERFORMANCE AND FEASIBILITY OF ARMATRAC TRACTOR TO PERFORM PRIMARY TILLAGE AND PLANTING OPERATION IN SILTY CLAY LOAM SOIL.

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ABSTRACT

This study was aimed to determine the influence of performing primary tillage by moldboard plow and planting operation by four rows Gaspardo planter on some performance and economic indicators of Armatrac tractor 854e 84 hp (62kw). The system calculates and measures slippage percentage, draft force, energy requirements, and total costs for planting and tillage operation at three practical velocities and two depths. Planting operation performed at 5 and 7 cm depth under 2.90, 4.27, and 5.28 km.h^{-1}. while ploughing operation performed at 15 and 20 cm tillage depth under 3.89, 5.28, and 6.67 km.h^{-1}. Two factorial experiments were carried out using randomized complete block design with two factors and three replications. The results of analysis of variance showed that increases of practical velocity results in increase of slippage percentage and draft force but results in decrease of energy requirements and total costs. Furthermore, this study revealed that increases the depth of operation results in increase of slippage percentage, draft force, energy requirements, and total costs.

Keywords: machinery management, economic analysis, machinery costs, estimating farm power, total costs.

العوامل الفنية والاقتصادية المؤثرة في ألاداء والجدوى الاقتصادية للجرار Armatrac لعمليتي الحراثة الأولية والزراعة في الترب المزيجة الطينية الغرينية

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المستخلص

الهدف من هذه الدراسة هو تحديد تأثير أداء الحراثة الأولية بواسطة محراث مطرحي رباعي وعملية الزراعة بواسطة الزارعة Gaspardo أربعة صفوف وتأثير التشغيل في بعض المؤشرات الفنية والاقتصادية لجرار Armatrac 854e بقوة 84 حصان (62 كيلو وات) . تم حساب وقياس نسبة الانزلاق، وقوة الجر ومتطلبات الطاقة والتكاليف الإجمالية لعمليات الزراعة والحراثة عند ثلاث سرعات عملية وعمقين لكل عملية زراعية. تمت عملية الزراعة عند عمق 5 و 7 سم تحت 2.90 و 4.27 و 5.28 كم.ساعة$^{-1}$، بينما تمت عملية الحراثة عند عمق 15 و 20 سم تحت السرع العملية 3.89 و 5.28 و 6.67 كم.ساعة$^{-1}$. تم إجراء التجارب العاملية ثنائية العوامل بتصميم القطاعات العشوائية الكاملة بعاملين وثلاث مكررات. بشكل عام، أظهر تحليل التباين أن زيادة السرعة العملية تؤدي إلى زيادة نسبة الانزلاق وقوة الجر ولكن تؤدي إلى تقليل متطلبات الطاقة والتكاليف الإجمالية. علاوة على ذلك، كشفت هذه الدراسة أن زيادة عمق العملية تؤدي إلى زيادة نسبة الانزلاق وقوة الجر ومتطلبات الطاقة والتكاليف الإجمالية.

الكلمات المفتاحية: إدارة المكائن الزراعية ،التحليل الاقتصادي ، تكاليف المكائن ، تقدير قدرة المزرعة، التكاليف الكلية.

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INTRODUCTION

Food security and global poverty present formidable obstacles to sustainable development and human welfare on a global scale (7, 11). Despite the world's overall capacity to produce enough food for its entire population, millions continue to suffer from hunger and malnutrition, perpetuating the cycle of poverty (12). Throughout history, agriculture has served as the cornerstone of human civilization, providing sustenance and economic stability to societies worldwide. With the relentless growth of the global population and escalating demands for food, the imperative for efficient and sustainable farming practices has reached unprecedented levels (15, 20). The utilization of agricultural machinery and equipment, especially ploughing and planting machines, have heralded a new era in farming practices, fundamentally altering the dynamics of contemporary agriculture and catalyzing advancements throughout the agricultural value chain (26, 49). Preliminary tests indicated that planting machines offer a myriad of advantages to farmers, agricultural ecosystems, and society at large. An additional series of tests was mentioned that these benefits encompass heightened efficiency, amplified yield and quality, conservation of resources, reduction in labor demands, and the propagation of precision agriculture. Primary tillage, as ploughing, stands as a foundational practice in agriculture, initiating the process of soil preparation for crop cultivation (1, 42). It encompasses the mechanical manipulation of soil to achieve several objectives, including weed suppression, residue integration, and soil enhancement. Planting machines represent a pivotal advancement in modern agriculture, offering a transformative solution to the challenges of feeding a growing global population sustainably. With their diverse types and myriad benefits, these machines have revolutionized farming practices, driving efficiency, productivity, and environmental stewardship. Thus, the exploitation of these two operations and agricultural machinery and equipment, particularly ploughing and planting machines, epitomizes a paradigmatic shift in modern agriculture. Embracing the utilization of planting machinery presents a multitude of advantages to farmers and agricultural landscapes. These enhanced efficiency, elevated yield and quality, preservation of resources, and labor alleviation. Tillage and planting are the most expensive and energy consumed agricultural operations (17, 47). Economic analysis of farming systems is a vital as successful evaluation leads to cost reduction and horizontal and vertical expansion (38). It is used to understand the impact of changes in agricultural variables and their reflection on an economic aspect (35, 39). The benefits of conducting economic analysis for crop cultivation are to reduce the cost of production significantly by using mechanical seeding equipment with adopting the modern irrigation methods (27). Careful consideration is required to determine whether this cost is justified. Possible and tangible cost reduction may give an over-all saving sufficient to determine and cover operation costs. In determining the economic need for each treatment, a reasonably accurate evaluation must be studied (19). With regard to the above-mentioned points, the aim of this research were considered:

1- To evaluate the performance of Arma Trac tractor (84 hp) tractor.

2- To investigate the requirements of the most common agricultural operation (plowing and planting) applied to a silty clay loam soil.

MATERIALS AND METHODS

Field tests: Field experiments were carried out, on silty clay loam soils at Agricultural Research Center. A set of primary tillage (moldboard plow) and planting (four rows Gaspardo planter) were used in this research to investigate some performance indicators of these main agricultural operations. These performance indicators were tested for both operations over a wide range of practical speeds and depths. Three levels of practical speeds (2.90, 4.27, and 5.28 km. h^{-1}) by two levels of depths (5 and 7 cm) for planting operation were used. As for ploughing operation, the practical velocities were 3.89, 5.28, and 6.67 km.h^{-1} under 15 and 20 cm depth were tested. Three replications were made of each treatment combination. An experimental plot (20 m long and 5 m wide) was used for both implements for each treatment.

Studied traits:

Fuel consumption:

The following formula was used to measure the fuel consumption for each operation and treatment.

$$\mathbf{Fq} = \frac{\mathbf{Q*10000}}{\mathbf{TL*WP*1000}}$$

Whereas:

$\mathrm{Fq} = \mathrm{Fuel\ consumption\ (l/h)}$

$\mathrm{Q} = \mathrm{Fuel\ consumed\ during\ the\ treatment\ (ml)}$

$\mathrm{TL} = \mathrm{Length\ of\ the\ treatment\ (m)}$

$\mathrm{WP} = \mathrm{Width\ of\ the\ implement\ (m)}$

Energy requirements:

$$\boldsymbol{EFq} = (\boldsymbol{Fq} \times \boldsymbol{\rho} \times \boldsymbol{Hg}) / \mathbf{3600}$$

Whereas:

$EFq = Energy\ requirements\ (Kw)$

$Fq = Fuel\ consumption\ (l/h)$

$\rho = Density\ of\ diesel\ fuel$

$= (0.85\ Kg/L)$

$Hg = Gross\ heating\ value\ of\ diesel\ fuel$

$(assumed\ to\ be\ 45500\quad (Kj/kg)$

$3600 = Conversion\ factor$

Slippage percentage (S %):

Slippage percentage was calculated from the following formula

$$\boldsymbol{SP} = \frac{\boldsymbol{Vt - Vp}}{\boldsymbol{Vt}} \times \mathbf{100}$$

Whereas:

$Sp = Slippage\ percentage\ (\%)$

$Vt = Theoretical\ speed\ (km/h)$

$Vp = Practical\ speed\ (km/h)$

Theoretical speed (Vt):

Calculated by the following formula:

$$\boldsymbol{Vt} = \left(\frac{\boldsymbol{M}}{\boldsymbol{t}}\right) \times \mathbf{3.6}$$

Whereas:

$Vt = Theoretical\ speed\ (km/h)$

$M = Theoritical\ distance\ (m)$

$t = Theoritical\ time\ (s)$

Total cost of combined unit (tractor + implement):

$$U\ TC = TrTC + ImTC$$

Whereas:

$U\ TC = Unit\ Total\ Cost$

$TrTC = Tractor\ Total\ Cost$

$ImTC = Implement\ Total\ Cost$

Tractor Total Cost:

$$Tr\ TC = TrVC + TrFC + TrMaC$$

Whereas:

$Tr\ TC = Tractor\ total\ cost$

$TrVC = Tractor\ variable\ cost$

$TrFC = Tractor\ fixed\ cost$

$TrMaC = Tractor\ management\ cost$

Implement Total Cost:

$$Im\ TC = ImVC + ImFC + ImMaC$$

Whereas:

$Im\ TC = Implement\ total\ cost$

$ImVC = Implement\ variable\ cost$

$ImFC = Implement\ fixed\ cost$

$ImMaC = Implement\ management\ cost$

Fixed Cost:

$$FC = Dep + In + SIT$$

Whereas:

$FC = Fixed\ cost$

$Dep = Annual\ average\ depreciation$

$In = Interest\ on\ investment$

$SIT = Shelter, insurance, and\ taxes$

Variable Cost:

$$VC = Fco + Oco + M\&R\ co + Lco$$

Whereas:

$VC = Variable\ cost$

$Fco = Fuel\ cost$
$Oco = Oil\ cost$
$M\&R\ co = Repair\ and\ Maintenance\ cost$
$Lco = Labor\ cost$

RESULTS AND DISCUSSION

Identifying possible ways to increase yield and decrease cost is essential to meet the sustainable development goals (16, 24, 29, 44). For each agricultural operation test, ploughing and planting, a typical set of tests was performed in order to investigate the effect of practical velocity and depth of operations on a silty clay loam soil.

Slippage percentage:

Slippage percentage under field conditions varied with the changing the implements, practical speeds, and depths. Table (1) shows the effect of all selected practical speed and planting depth on slippage percentage. As shown in Table (1), it is obvious that increasing the planting speeds from 2.90 to 4.27 to5.28 km.hr^{-1} resulted in suppressing slippage percentage significantly (at P ≤ 0.05) from 6.94% to 7.94% to 9.48%, respectively. These results were may be because of slippage percentage is typically influenced by planting speeds due to the occurrence of decreasing the contacted area of the tractor tires with the soil. The same results were reported by (43, 46). Furthermore, the statistical analysis reveals that a significant difference at P ≤ 0.05 level was found between planting depths operation. It can be noticed that increasing planting depths from 5 to 7 cm led to a significant increase in the slippage percentage from 6.69 to 9.56 % (Table1.). This attributes that planting depth have a linear relationship with slippage percentage may be due to the increment of draft force by increasing the depth. These results were in line with (10, 40, 48). Table. 1. Also shows a significant interaction between planting speeds and depths on slippage percentage. Data showed that the lowest planting speed of 2.90 km.hr^{-1} at 5 cm planting depth produced a lower slippage percentage (5.896%). Within the selected 5 cm planting depth, it was noted that increasing the practical speeds from 2.90 to 4.27 to 5.28 km.h^{-1} increased slippage percentage from 5.896 to 6.729 to 7.441%.

Table 1. Effect of the practical speed and depth of the operation for both operations on slippage percentage (%).

Imp.	Speed	Depth (cm)		Av
		5	7	
Planter	2.90	5.896	7.981	6.94 C
	4.27	6.729	9.151	7.94 B
	5.28	7.441	11.518	9.48 A
	Av	6.69 B	9.56 A	
L S D	S= 1.633	D= 1.333		S*D= 2.309
Plow	Speed	Depth (cm)		Av
		15	20	
	3.89	8.409	14.023	11.216 C
	5.28	10.727	15.818	13.272 B
	6.67	15.104	19.683	17.394 A
	Av	11.413 B	16.508 A	
L S D	S= 1.721	D= 1.405		S*D= 2.434

Whilst, at 7 cm planting depth, the lowest slippage percentage was found 7.981% when the practical speed was 2.90 km.h^{-1}. At the same conditions, increasing practical speeds from 2.90 to 4.27 to 5.28 km.h^{-1} resulting in increasing slippage percentage from 7.981 to 9.151 to 11.518%, respectively. This suggests that slippage percentage increases linearly with increasing of both practical speeds and operation depths for tillage and planting operations. This trend was also shown by (10, 30, 33).

Furthermore, in regards to the effect of selected practical speeds and tillage depths on slippage percentage, there was a significant difference ($P \leq 0.05$) between practical speeds and ploughing depths in slippage percentage at all treatments (Table.1). It is clear from the obtained data presented in Table1 that increasing the practical speeds from 3.89 to 5.28 to 6.67 $km.h^{-1}$ tends to increase the slippage percentage from 11.216 to 13.272 to 17.394 %, respectively. This phenomenon may be explained by the fact that values of rolling resistance were increased and tire-soil contact area was decreased. Consequently, resulting in coherence reduction of the tire with the soil and increasing slippage percentage. This result is full agreements with (4, 30, 31). They reported that, slippage percentage values tended to increase with increasing practical speeds. In regards to the effect of ploughing depths on slippage percentage, a similar trend was observed. The outcomes revealed a minimum slippage percentage (11.413%) at the 15 cm ploughing depth. Likewise, the highest slippage percentage (16.51%) achieved at 20 cm ploughing depth. These results are agreed with the results which obtained by (28). The interaction effect of two factors was also statistically significant ($P \leq 0.05$). At 15 cm fixed tillage depth, slippage percentage increased from 8.409 to 10.727 to 15.104 % when practical speeds increased from 3.89 to 5.28 to 6.67 $km.hr^{-1}$, respectively. Then, at 20 cm tillage depth, increasing the speeds from 3.89 to 5.28 to 6.67 $km.hr^{-1}$ increased the slippage percentages from 14.023 to 15.818 to 19.683%, respectively. These results indicated that slippage percentage increased for both planting and ploughing equipment with increase practical speeds and depths of operation which is confirmed with the findings of (22, 25, 37).

Draft force:

Table 2. illustrates the effect of practical speed on draft force at two different levels of operation depth for ploughing and planting implement on silty clay loam soil. From Table (2), it could be noticed that draft force significantly increased with increase in practical speeds and the depths. For planting operation, draft force increased from 6.778 to 8.545 to 9.728 kn when practical speeds increased from 2.90 to 4.27 to 5.28 $km.h^{-1}$, respectively. The results of Table 2 also showed that change of planting depth from 5 to 7 cm are effective on draft force ($P \leq 0.05$). Minimum draft force occurred at planting depth of 5 cm (7.864 kn) and maximum occurred by planting depth of 7 cm (8.838 kn). As would be expected, the highest value of draft force (15.4567 kn) was obtained at the highest practical velocity and highest depth. However, the lowest practical velocity (3.89 $km.h^{-1}$) and the lowest depth (15cm) showed less draft force (Table.2). These results are similar to those obtained by (2, 6), who studied the effect of velocity and depth on draft force.

Table 2. Effect of the practical speed and depth of the operation for both operations on draft force (kn).

Imp.	Speed	Depth (cm)		Av
		5	7	
Planter	2.90	6.273	7.283	6.778 C
	4.27	8.120	8.973	8,545 B
	5.28	9.200	10.257	9.728 A
	Av	7.864 B	8.838 A	
L S D	S= 0.6213		D= 0.5073	S*D= 0.879
Plow	Speed	Depth (cm)		Av
		15	20	
	3.89	11.4733	12.4833	11.978 C
	5.28	13.3200	14.1733	13.747 B
	6.67	14.4000	15.4567	14.928 A
	Av	13.064 B	14.038 A	
L S D	S= 0. 621	D= 0.5073		S*D= 0.8787

For ploughing operation, the values of draft force differed statistically ($P \leq 0.05$) for both practical velocity and depth treatments (Table.2). As to the working depths, significant difference ($P \leq 0.05$) showed between the ploughing depths, with lower requirement of draft force (13.064) at the lowest depth (15 cm). Comparing to lowest value, the highest value of draft force (14.038) observed at the highest depth (20 cm). Meanwhile, there was also significant difference ($P \leq 0.05$) between the values of draft force with different practical speed (Table2). The lowest practical velocity of 3.89 km.h-1 required lower draft force (11.978 kn). With the increment of practical velocity to 5.28 and then to 6.67 km.h^{-1}, promoted significant increase in the values of draft force (13.747 and 14.928), respectively.

Moreover, the interaction effect of practical velocity and ploughing depths are effective on draft force (Table.2). At a ploughing depth of 15 cm, draft force increased from 11.473 to 13.320 to 14.4000 kn at ploughing velocity 3.89, 5.28, and 6.67 km.h^{-1}, respectively.

Then, at depth 20cm, draft force increased from 12.483 to 14.173 to 15.456 kn with the increment of practical velocity from 3.89 to 5.28 to 6.67 km.h^{-1}, respectively. These results corroborate those of (3, 5), who observed higher requirement values of draft force in the deepest ploughing depth.

Total cost:

The effect of the practical speed and the depth and their interaction on the total cost for each operation is given in Table (3).

It could be seen from the obtained results that there are significant differences ($P \leq 0.05$) of practical speed on the mean values of total costs for both ploughing and planting operation.

Table 3. Effect of the practical speed and depth of the operation for both operations on total cost (ID/ha).

Imp.	Speed	Depth (cm)		Av
		5	7	
Planter	2.90	21147.7	23858.3	22503.0 A
	4.27	17081.0	20746.7	18913.8 B
	5.28	15156.3	18144.0	16635.2 C
	Av	17795.0 B	20906.3 A	
L S D	S= 335.42	D= 273.87	S*D= 474.35	
Plow	Speed	Depth (cm)		Av
		15	20	
	3.89	48261.7	53137.7	50699.7 A
	5.28	44075.7	50689.0	47382.3 B
	6.67	38201,0	46170.3	42185.7 C
	Av	43512.8 B	49999.0 A	
L S D	S= 568.95	D= 464.54	S*D= 804.61	

For planting operation, a remarkable drop could be noticed in total cost with increment of practical speed. By increasing the practical speed from 2.90 to 4.27 to 5.28 $km.h^{-1}$, decrease the mean values of total cost from 22503 to 18913 to 16635 ID, respectively (Table 3). Increasing the practical speed led to increase the practical productivity. Thus, the total costs decreased as a result of reverse relationship between productivity and cost. These results are consistent with the ones obtained by (8, 9, 21), who referred that there was a reverse relationship between total costs and practical productivity. Also, the results in the same Table (3) show that increasing the planting depth from 5 to 7 cm caused a noticeable increase ($P \leq 0.05$) in the mean value of the total costs from 17795 to 20906 ID. The reason for the clear increase in total costs is attributed to the fact that the increase of planting depth has led to reduce the practical productivity and increased fuel consumption and draft force, thus, increased the mean values of total costs. The results of this study were consistent with what was studied by (32, 45), as this study showed that increasing the depth of operation caused a significant increase ($P \leq 0.05$) in the values of economic total costs. At the same time, regarding the interaction effects, the lowest mean value of planting total costs (15156.3 ID) was found at 5 cm for 5.28 $km.hr^{-1}$. and the highest mean value (23858.3 ID) was found at 7cm planting depth for 2.90 $km.hr^{-1}$(Table3). Referring to the effect of ploughing speeds and depths and their interactions on total costs, it is noticed that, increasing the practical speeds of tillage from 3.89 to 5.28 to 6.67 $km.hr^{-1}$ significantly impacted ($P \leq 0.05$) the values of total costs and decreased from 50699 to 47382 to 42185 ID/ha, respectively. The decrease of total cost values by increasing the ploughing speeds could be due to the increase in the practical productivity that caused covering more areas during the same time period. These results are consistent with the ones obtained by (18, 34, 36). As to the effect of ploughing depths, data show that the lowest mean values of total costs was 43512 and 49999 ID. for 15 and 20 ploughing depth, respectively. Similar results were reported by (13, 23, 41), who confirmed that total cost increased by increasing the ploughing depth because of increase in power requirement consumed to overcome the resistance. In terms of the interaction effects of ploughing speeds and depths on total cost, the highest mean values of total cost (53137 ID) was obtained at highest ploughing depth (20 cm) under the lowest practical velocity (3.89 $km.hr^{-1}$) while the lowest value of total cost (38201 ID) was at the ploughing depth of 15 cm and practical speed of 6.67 $km.hr^{-1}$ (Table 3).

Energy requirements:

Table (4) reflects the significant effect ($P \leq 0.05$) of practical speeds and depths on energy requirements for both planting and tillage operations. The results of Table 4 indicated that change of practical velocity and the depth of operation and interaction effect of them are effective on the energy requirements ($P \leq 0.05$).

Table 4. Effect of the practical speeds and depths for both operations on energy (Kw).

Imp.	Speed	Depth (cm)		Av
		5	7	
Planter	**2.90**	**14.312**	**20.991**	**17.651 A**
	4.27	**8.326**	**12.810**	**10.568 B**
	5.28	**5.602**	**9.166**	**7.384 C**
	Av	**9.413 B**	**14.322 A**	
L S D	**S= 2.993**		**D= 2.444**	**S*D= 4.233**
Plow	**Speed**	**Depth (cm)**		**Av**
		15	**20**	
	3.89	**135.75**	**188.66**	**162.203 A**
	5.28	**85.67**	**116.06**	**100.867 B**
	6.67	**56.15**	**76.90**	**66.526 A**
	Av	**92.524 B**	**127.207 A**	
L S D	**S= 18.922**		**D= 15.449**	**S*D= 26.759**

By considering the obtained energy requirements from planting experimental tests, (Table 4) shows that when practical velocity increased from 2.90 to 4.27 to 5.28 $km.h^{-1}$, energy requirements significantly decreased from 17.651 to 10.568 to 7.384 Kw, respectively. This reduction in energy requirements is attributed to reduce the required time to accomplish the agricultural operation. Consequently, reducing the total amount of fuel consumption. These results are in agreement with (6, 14, 37), who found that increasing forward speeds resulted in decreasing the energy requirements for the operation. Additionally, Table (4) clearly showed that minimum energy requirements for planting (9.413 Kw) occurred by shallower 5 cm planting depth and maximum (14.322Kw) occurred by 7 cm depth. This increment in energy requirements may be occurred due to the fact that increasing the depth tends to increase the total resistance. Slippage percentage and draft force. Also, many researchers confirmed this relationship between and depths of operation end energy requirements (28, 56,) the most rapid energy requirements (20.99 Kw) resulted from performing planting operation at the practical speed of 2.90 $km.h^{-1}$and 7 cm planting operation. The minimum energy requirements (5.602 Kw) occurred at the highest practical speed 5.28 $km.h^{-1}$ for 5 cm planting depth. As the effect of practical velocity on the energy requirements of ploughing operation, results in Table. (4) shows that increasing the mean value of practical velocity from 3.89 to 5.28 to 6.67 $km.h^{-1}$ has led to a significant decrease in energy requirements ($P \leq 0.05$) form 162.203 to 100.876 to 66.526 Kw.

As would be expected, at 15 cm depth, mean value of energy requirements was near the minimum (92.524 Kw) required for performing tillage. While, at 20 cm depth, the mean value of energy requirements was near maximum value (127.207 Kw). The interaction between practical speeds and ploughing depths also showed significant differences in energy requirements (Table.4). The lowest energy requirement was found at 56.15 Kw. under 15 cm tillage depth when the practical speed was 6.67 km.h^{-1}, whilst the highest energy requirements was 188.66 Kw at 20 cm tillage depth and a practical velocity of 3.89 km.h^{-1}. Increasing practical velocity from 3.89 to 5.26 to 6.67 km.h^{-1} under constant 15 cm ploughing depth, decreased the energy requirements from 135.75 to 85.67 to 56.15 Kw, respectively. Likewise, under constant 20 cm depth, the same increment in practical velocity has led to decrease the energy requirements from 188.66 to 116.06 to 76.90 Kw.

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