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Evaluating the Performance of a Planting and Reservoir tillage Machine at Different Tractor Forward Speeds under Rainfed Conditions for Wheat Crop in Northwestern Coastal, Egypt

Eman.I.Emara[1], Adil.A.Meselhy[2], Taha.H.Ashour[1] and Zakaria.A.El-Haddad[1]
[1]Agricultural and Biosystems Engineering Dept., faculty of agriculture, Benha Univ., Qalyubiyya, Egypt
[2]Agricultural Mechanization Unit, Soil, and Water Conservation Dept., & Desert Research Center, Cairo, Egypt
E-mail: emanemara9214@gmail.com

Abstract

Northwestern Coastal of Egypt is located within arid and semi-arid zone. Whereas soil topography is characterized by large slopes which cause high surface rainwater runoff. This makes this region more vulnerable to soil erosion hazards that threaten the sustainable development of rainfed agriculture. Therefore, this research aims to evaluate the performance of a manufactured planting and reservoir tillage machine (PRT) used to harvest rainwater and planting of wheat crop at one pass on sloping area of a sandy loam soil in Wadi El Raml during winter cultivation season of 2021-2022. Field experiment was conducted to maximize efficiency of using limited rainwater unit and wheat yield productivity under rainfed conditions with lowest operating costs and lower negative impact of carbon dioxide (CO_2) emissions on environment. The statistical design was a split plot with three replicates for each treatment. Main plots included three of tractor forward speeds of 3,5 and 7km/h. Sub main plots included three types of pits' dimensions of 0.50×0.14×0.20 m(PD1), 0.60×0.17×0.14 m(PD2) and 0.70×0.20×0.10 m(PD3) for length × width × depth m, respectively with same volume of 10.35 liters, in addition to traditional cultivation. The results revealed that using PRT machine at forward speed of 3km/h and pit dimensions of PD1 achieved the most efficient performance. Whereas it recorded the greatest values of soil moisture storage, wheat grain and straw yields and net profit by about 105.77%, 60.25%, 53.62% and 61.55%, respectively compared to traditional cultivated. While the least CO2 emissions achieved at forward speed 3 km/h and at pit dimensions of PD3.

Keywords: Rainwater harvesting, Reservoir tillage, Farmyard manure, Fuel consumption, Wheat yield, Cost productivity, Net profit, Co_2 emissions.

1. Introduction

Water scarcity limits the sustainable development of rainfed agriculture in arid and semi-arid regions such as northwestern coast of Egypt [1]**.** In situ rainwater harvesting systems are the simplest and cheapest rainwater harvesting approaches and can be practiced in many farming systems. Also called soil and water conservation systems, they involve the use of methods to increase the amount of water stored in the soil profile by trapping or holding the rain where it falls [2]**.** Reservoir tillage is Defined as a system in which numerous small surface depressions are formed to hold and collect water during irrigation or rainfall to prevent surface runoff [3]. Currently, reservoir tillage is used predominantly for soil erosion control in environments with high annual, but low intensity rainfall, such as semi-arid environments. A similar work on reservoir tillage was conducted. The project was carried out through modeling and experiments under soil bin, rainfall simulator and glasshouse environmental conditions, and the author reported that the reservoir tillage reduced surface runoff by 54% and 91% when the depressions were positioned along and across the slopes, respectively[4]. The ridge-furrow rainwater harvesting system is an effective system of harvesting rainwater, improving rainwater use efficiency, reducing soil erosion, and increasing winter wheat productivity in arid and semi-arid regions of Wadi El Raml. The results showed that ridge-furrow system achieved the highest wheat grain yield and the highest profit about of 84% and 57% respectively, compared to the traditional flat soil system, which applied in the study area [1]. Various economic and environmental issues are resulted by soil degradation due to its negative impacts consequences for carbon reserves, drinking water supplies, crop production, and ecosystem services [5]. Therefore, it is important to adopt nonconventional systems in this context to increase water availability [6]. Generally, it is necessary to use water harvesting applications to optimize the water use management efficiency according to the priority of use [7]. In-situ rainwater harvesting is one of these applications that can ensure the availability of water for winter cropping. It involves different techniques such as Reservoir Tillage. It is defined as a system that includes small pits as catchment areas which can hold and force rainwater to percolate and store inside pits instead of losing it by surface runoff to satisfy crop requirements. The cost of a good and an appropriate rainwater management to improve rainfed agriculture is much less than the cost of establishing irrigation systems without considering the social and environmental problems [8]. On the other hand, climatic changes are considered one of the most critical problems resulting from the increase of greenhouse gas emissions. Scientists believe that human activities are responsible for the increase of the greenhouse gases level in the atmosphere. In recent years, about 95% of the nitrogen oxides generated by human activities were caused by burning of fossil fuels in power plants, engines, homes and industries. It is considered the primary source of anthropogenic CO_2 emissions that produces many pollutants [9]. An experimental work titled "Effect of reservoir tillage system and organic fertilization on soil water erosion resistance under rainfed conditions" was carried out. This experiment included an evaluation of a planting and reservoir tillage machine (PRT) on the productivity of wheat crop at tractor forward speed of 3km/h. The main results indicated that using the PRT machine at pit dimensions of 0.50×0.14×0.20 m (PD1) maximized the wheat crop productivity [10]. Therefore, the main objective of this study is to evaluate the performance of the PRT machine under three of tractor forward speeds and three pits' dimensions formed by this machine. This is to determine the most efficient treatment which can raise the efficiency of using the limited rainwater unit to maximize wheat crop productivity with lowest operating costs and with lower negative impacts of carbon dioxide (CO_2) emissions to the environment.

2. Materials and Methods

A. Materials

Tractor

Belarus tractor with diesel engine traction system 4×4, model 320SL and net rated power of 90 hp was used.

Chisel plow

A chisel plow with 7 blades and 1.75 m working width was used to carry out ploughing process to preparate a good seedbed.

Planting and reservoir tillage machine (PRT).

The PRT machine was locally manufactured as a mounted type, its weight is 540 kg without load (without seeds). Its length, width and height are 1850, 1500 and 1340 mm, respectively. It was attached to the tractor's hydraulic system via three-point hitches through a combination of three links, one was upper link and two were lower links. It consisted of main frame, mechanical planting unit, reservoir tillage unit and two ground wheels as shown in Fig(1and 2).

Fig.(1) Parts of planting and reservoir tillage machine.

1) three hitch points, 2) planting unit, 3) spring assistant, 4) Toothed ground wheels and 5) digging blades.

2)

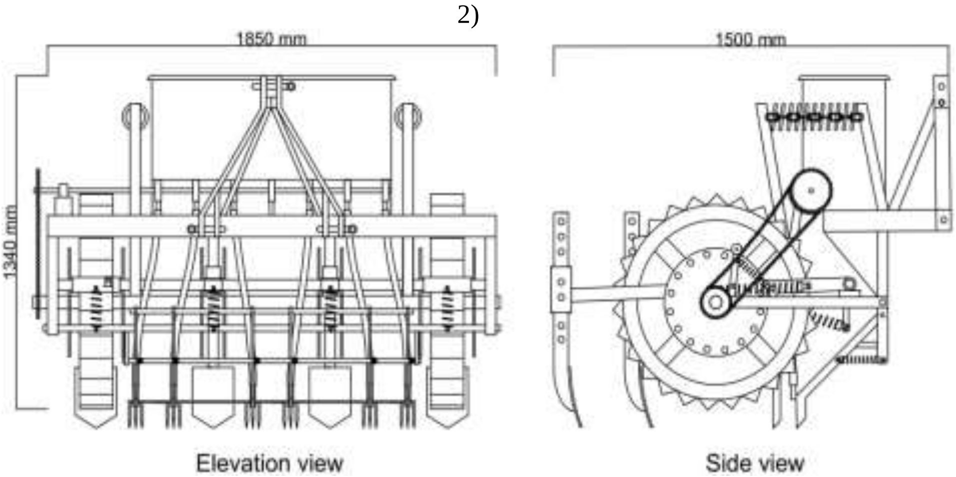

Fig. (2) Elevation and side view for study machine.

a. Main frame:

It was used to carry the other components of the PRT machine. It includes three hitch points to attach the PRT machine to the hydraulic system of the tractor.

b. Mechanical planting unit:

It was used to cultivate wheat seeds in a continuous flow along sowing line between the pits formed by reservoir tillage unit at uniform rate. It includes seed hopper, seed metering mechanism, openers and covering device.

c. Reservoir tillage unit:

It was used to form pits with different dimensions between sowing lines. It consists of two iron shafts, iron discs, four digging blades which can be changed for forming pits with different dimensions of and some accessories.

d. Ground wheels:

Two iron sprocket ground wheels were used to drive both feed shaft of the mechanical planting unit and rotary shaft driven the reservoir tillage unit by the friction force occurred between these wheels and soil surface.

Wheat crop

Winter wheat (Triticum aestivum L.), Giza 168 variety with sowing rate of 140 kg ha^{-1} was cultivated on 23 November in 2021 by using the PRT machine and traditional method.

Instruments:

Rain-gauge device.

It was locally manufactured and calibrated as shown in **Fig (3)** [1]. Each 1 mm on the calibrator of the device indicates to 1 mm of the amount of rainwater falling in the field.

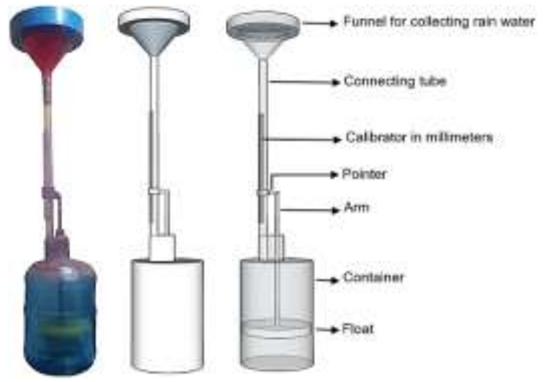

Fig. (3) Rain gauge device for measuring rainwater falling in the field [1].

Fuel meter

Fuel meter device [11] was used to measure the volume of consumed fuel quantity per unit time accurately as shown in **Fig(4)** The length of line which marked by the marker tool on the paper sheet indicates to the fuel consumption. This equipment was calibrated prior to its use.

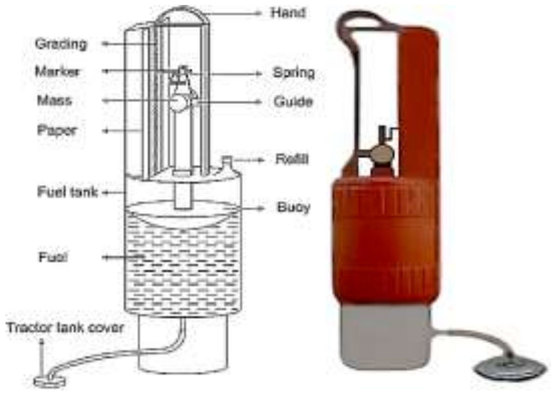

Fig. (4) Fuel meter for measuring fuel consumption [11].

Rainwater runoff and sediment Trough

It was fabricated from PVC material with rectangular shape. Its dimensions were 500 × 300 × 200 mm for length × width × height mm, respectively, as shown in **Fig (5**) Each trough was installed in auger holes at the down-slope edge of each plot to receive and collect rainwater runoff and sediment. It has a drainage hole connected to the drain tube (gutter) fixed beneath its edge to transmit water runoff to receiving containers after extracting sediment. These troughs were covered so that rainwater could not enter, and evaporation was assumed to be negligible. The runoff volume was determined from the measured depth of water in each trough.

Fig. (5) Trough used for collecting rainwater runoff.

1) trough. 2) container.

B. Methods:

Experimental procedure

The PRT machine's performance was evaluated by conducting a field experiment in winter cultivation season of 2021 - 2022 on area about 0.5 hectare of a sandy loam soil texture in Wadi El-Raml. This region is located in northwestern coastal zone (latitudes of 31° 09´ 00", 31° 21´ 00" N., longitudes of 27° 06´ 00", 27° 12´ 00" E.). This region characterized by average slope of 8% and some of soil physical and chemical properties were carried out according to [12] as showed in **Table (1**) The PRT machine's evaluation was carried out under the same procedure of performance according to [10] at three of tractor forward speeds and three pits' dimensions formed by this machine.

Table (1) Some physical and chemical characteristics of the soil of the study area.

Soil depth (cm)	Particle size distribution %				Texture Class	CaCO3 g kg^{-1}	O.M g kg^{-1}	pH	EC (ds/m)
	Coarse Sand	Fine Sand	Silt	Clay					
(0-20)	52.92	24.64	12.55	9.89	Sandy loam	67.8	3.1	7.72	1.21
(20-40)	48.15	24.52	17.22	10.11	Sandy loam	46	3.5	7.65	1.18
(40-60)	43.41	28.17	18.14	10.28	Sandy loam	50.2	3.6	7.46	0.99

The statistical design of the experiment

The field experiment design was a split plot with three replicates for each treatment at area of about 0.5 hectare. Main plots included three of tractor forward speed of 3, 5 and 7km/h. Sub main plots included three types of pits' dimensions which were 0.50×0.14×0.20 m (PD1), 0.60×0.17×0.14 m (PD2) and 0.70×0.20×0.10 m (PD3) for length× width× depth m, respectively. In addition to a control treatment with three replicates of traditional cultivation method of wheat as it prevails in the study region by manual sowing and without forming any pits. Therefore, the total number of experimental treatments were 30. All pits had the same volume of 10.35 liter as shown in **Fig(6**) The length of pits was perpendicular on slope direction as shown in **Fig(7)** All treatments were plowed in the same way using a chisel plow 7-blades at a tillage depth of 20 cm and twice perpendicular passes.

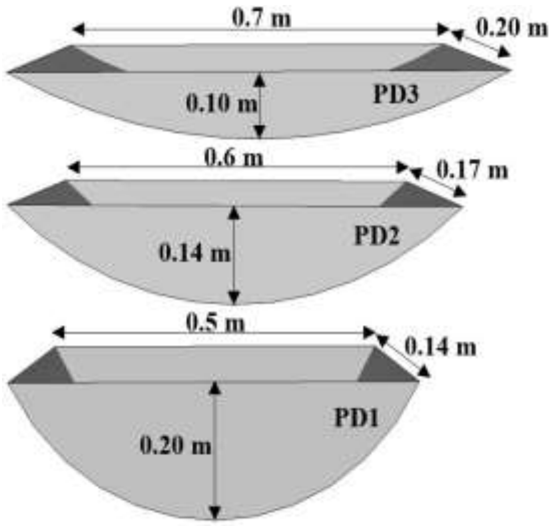

Fig. (6) Illustration of the dimensions of rainwater harvesting pits.

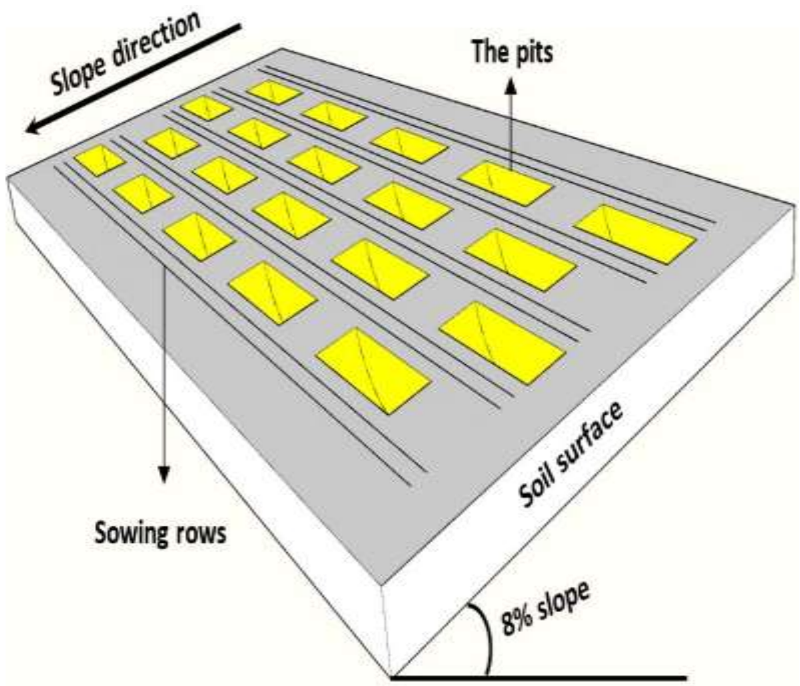

Fig. (7) Illustration of length of pits perpendicular on slope direction.

Mechanism of forming pits and changing their dimensions by the PRT machine:

The reservoir unit includes a main shaft driven by the ground wheel, which carries pierced iron discs along its perimeter to install wrist pins for raising and lowering the digging blades, as shown in the **Fig (8)** The pit's length was changed by changing the places of the wrist pins installed in the iron disc's holes. While the pit's width was modified by changing the blades with the appropriate width with maximum value of 0.20 m. The pit's depth was changed by changing the length of the digging shank using the holes on it as shown in **Fig (9).**

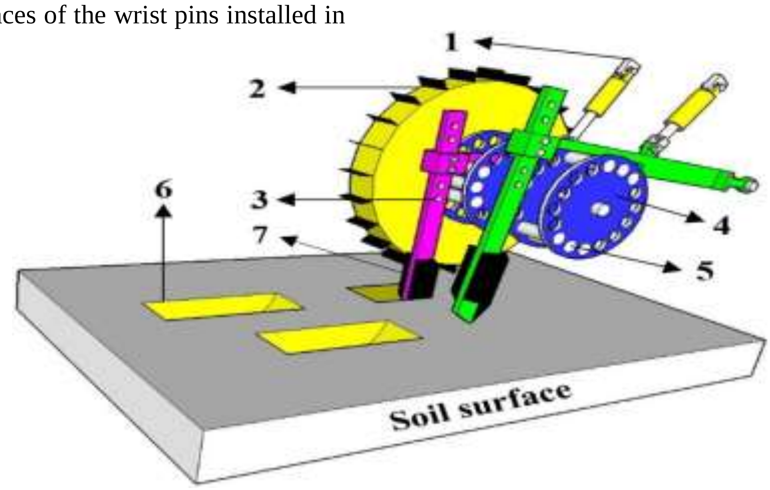

Fig. (8) The mechanism of making pits by the study machine.
1) spring assistant, 2) toothed ground wheels and 3) The shank, 4) iron disc, 5) wrist pin to raise and lower the digging blades and 6) the pits and 7) digging blades.

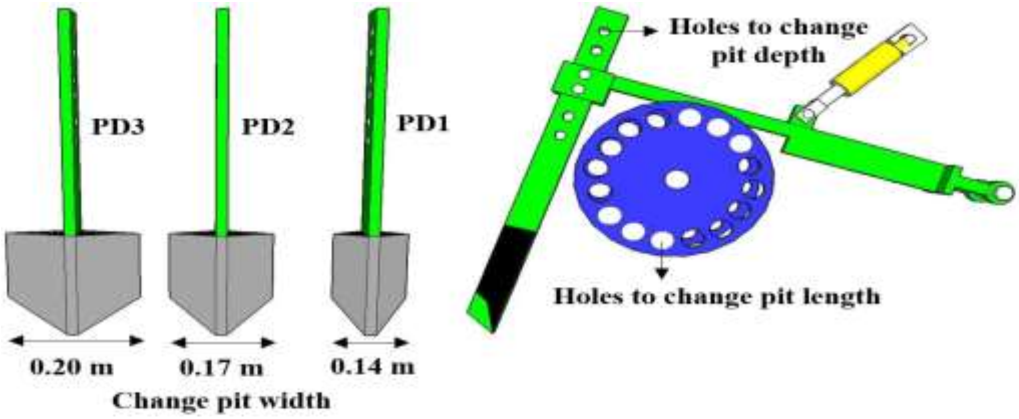

Fig. (9) Mechanism of changing the dimensions of pits.

Harvesting

Before harvesting wheat crop, three randomized samples were taken by hand from each plot using a wooden square frame (1 m^2) to determine the wheat yield per plot. Finally, the wheat crop was harvested using a mounted mower and threshed by thresher. Moisture content of wheat grain at harvesting was 12% db.

Statistical analysis

The statistical procedures were done by using SPSS version 19 (SPSS Inc., Chicago, Illinois, USA).

Measurements

Theoretical and actual field capacities and field efficiency

The theoretical and actual field capacities and field efficiency were calculated by the equations according to [13] as follows:

a. Theoretical field capacity:

$$\mathbf{TFC} = (\boldsymbol{S} \times \boldsymbol{W}) / \mathbf{10}$$

Where: $\mathbf{TFC} =$ Theoretical field capacity, ha/h, $\mathbf{S} =$ Operation speed of PRT machine, km/h and $\mathbf{W} =$ operational width of PRT machine, m. Whereas the operational width of machine changed as 1.59m, 1.62m and 1.65m with changing digging blades width as 0.14, 0.17 and 0.20 m, respectively.

b. Actual field capacity:

$$\mathbf{AFC} = (\mathbf{Apx3600}) / (\mathbf{Tpx10000})$$

Where: $\mathbf{AFC} =$ Actual field capacity, ha/h, $\mathbf{A_P} =$ Plot area (width × length), m^2 and $\mathbf{T_P} =$ Actual time required for conducting operation processes on plot area, s.

c. Field efficiency

Field efficiency is the ratio of actual field capacity to the theoretical field capacity, expressed as percentage. It was calculated as follows:

$$\varepsilon_f = (\mathbf{AFC} / \mathbf{TFC})\ \mathbf{x}\ \mathbf{100}$$

Where: ε_f = Field efficiency, %.

Filling efficiency of Pits

Actual volume of formed pit was estimated by covering the inside of the pit with thin plastic and then filling it completely with water, then measuring the volume of water by using graduated cylinder. The efficiency of pits filling was calculated as follows:

$$\varepsilon_i = (\mathbf{Va} / \mathbf{Vt})\ \mathbf{x}\ \mathbf{100}$$

Where: $\boldsymbol{\varepsilon_i}$ = Filling efficiency of Pits, %, $\mathbf{V_a}$ = Actual volume of pit formed by PRT machine, l and $\mathbf{V_t}$ = Theoretical volume of standard pit which equals 10.35 l.

Overall efficiency

As both field efficiency ($\boldsymbol{\varepsilon_f}$) and filling efficiency of pits ($\boldsymbol{\varepsilon_i}$) are influencing the final results and to express this influence, an overall efficiency is estimated as follows:

$$\boldsymbol{\varepsilon_o = \varepsilon_f \times \varepsilon_i \times 100}$$

Where: $\boldsymbol{\varepsilon_o}$ = Overall efficiency, %, $\boldsymbol{\varepsilon_f}$ = Field efficiency, % and $\boldsymbol{\varepsilon_i}$ = Filling efficiency of Pits, %.

Pulling force.

It was measured by coupling hydraulic dynamometer between two tractors with attaching the PRT machine to estimate its draught force. It was taken the average of 10 readings of the draught force at 10 second intervals [1].

Fuel consumption rate

It was measured by using the fuel meter as shown in **Fig. 4** according to [11].

Soil bulk density

Soil samples were taken with cylindrical core depths of 10, 20, and 30 cm from each plot. The core samples were immediately weighed and then dried at 105 °C for 24 h. Soil bulk density was measured according to the following formula [14]:

$$\boldsymbol{\rho b = m / v}$$

Where: $\boldsymbol{\rho b}$ = Soil bulk density, g/cm^3, **m** = Mass of oven dry soil sample, g and **v** = Total volume of soil and voids, cm^3.

Soil moisture storage

It was calculated by summing the water content at each depth multiplied by the depth of soil layer that represented by that water content. It was determined according to [15] as follows:

$$\mathbf{TWS} = ((\boldsymbol{\theta fc} - \boldsymbol{\theta wp}) / \mathbf{100})\ \mathbf{x}\ (\mathbf{Dr}\ \mathbf{x}\ \boldsymbol{\rho b})$$

Where: $\mathbf{TWS}$ = Water stored in the root zone, mm/day, $\boldsymbol{\theta_{fc}}$ = Soil moisture content at field capacity (Gravimetric moisture content after rain), %, $\boldsymbol{\theta_{wp}}$ = Soil moisture content at permanent wilting point (Gravimetric moisture content after rainless period), %, $\mathbf{D_r}$ = Effective root depth, mm and $\boldsymbol{\rho_b}$ = Soil bulk density, g/cm^3.

Surface runoff.

Runoff volume and sediment were determined by using the Troughs as shown in **Fig. 5.**

Crop yield

It included both wheat grain and straw yields, Mg ha^{-1}.

Operation Costs

The hourly costs of tractor, chisel plow and PRT machine were calculated according to the well-known conventional method of estimating both fixed and variable costs for each implement according to [16] under some assumptions as shown in **Table 2** as follows:

Table (2) Values of the calculation parameters of tractor, chisel and PRT machine.

Assumption	Tractor	Chisel plow	PRT machine
	Fixed costs		
purchase price, EGP	750000	15000	75000
Salvage value*		10% the purchase price	
Average annual use*, h	1000	300	500
Average lifespan*, h.	15000	2400	2500
Interest rate*, %		12	
Insurance, housing and taxes*		3% of purchase price per year.	
	Variable costs (EGP/h)		
Fuel price in 2021, EGP	6.75		
Lubrication cost*, EGP	30% of the fuel cost	80% of fixed costs*	
Repair and maintenance *	4.5% of total cost price		
Labor charge EGP/day	200		

The values marked by * in **Table 2** refer to standard data according to [17].

Total costs

$$\mathbf{TC} = (\mathbf{Fixd\ costs} + \mathbf{variable\ costs}) \times \mathbf{1.10}$$

Where: $\mathbf{TC}$ = Hourly total cost for tractor or chisel plow or PRT machine, EGP/h.

- **For ploughing process**

It included the operational cost of tractor and chisel plow.

- **For planting and reservoir tillage processes**

It included the operational cost of tractor and PRT machine.

Total cost per unit area:

Total cost per unit area was determined according to [18] as follows:

$$TCA = TC/AFC$$

Where: **TCA** = Total operational cost per unit area, EGP/ha, **AFC** = Actual field capacity, ha/h and **TC** = Hourly total cost, EGP/h.

Net profit:

It was estimated as follows:

$$NP = TR - TCA$$

Where: **NP** = Net profit, EGP/ha and **TR** = Total revenue, EGP/ha.

Calculating CO_2 emissions from stationary combustion

It was estimated according to [19] as follows:

$$FE = FC \times EF$$

Where: **FE** = Fuel CO_2 emissions (kg/h), **FC** = Fuel consumption L/h and **EF** = Emission Factor for diesel fuel = 2.7 kg/L according to [20].

3. RESULTS AND DISCUSSION

Actual field capacity

The results as shown in Fig. 11 illustrated that actual field capacity increased about of 52.14% and 95.73 % at tractor forward speeds of 5 and 7 km/h, respectively, compared to the speed of 3 km/h. This may be due to the fact that increasing the forward speed causes a decreasing the operational time, so the actual field capacity increases, and this is in agreement with [21], [22] and [23].

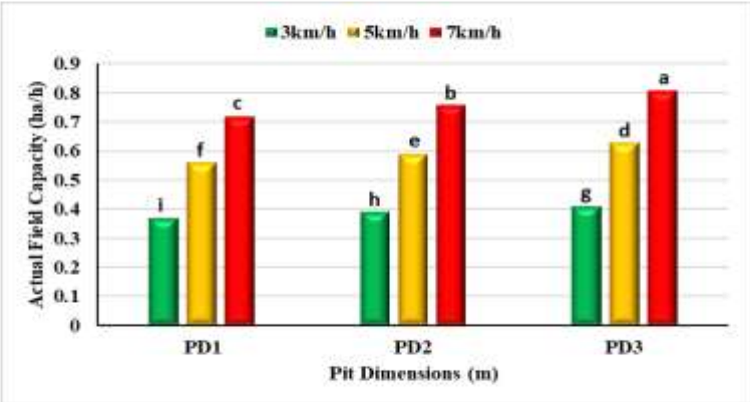

Fig. (11) Effect of treatments on actual field capacity (ha/h). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 0.01875.

On the other hand, the results showed that actual field capacity decreased as the pit depth increased. Whereas the actual field capacity decreased by about 5.95% and 10.81% at the pits' dimensions of PD2 and PD1, respectively compared to the pit dimension PD3. This may be due to the fact that the pit with smaller surface area and greater depth increases the soil resistance facing the machine diggers, so the operational time increases which reduces the actual field capacity, and this result is in agreement with [24]. The results generally indicated that there were significant effects of the treatments on actual field capacity at a significance level of 0.05. Therebefore, it is clear that the greatest actual field capacity value was achieved at a forward speed of 7 km/h and pit dimensions of PD3. While the lowest actual field capacity was obtained at tractor forward speed of 3 km/h and pit dimensions of PD1.

Field efficiency

The results as shown in **Fig (12)** indicated that field efficiency decreased about of 8.73% and 16.13 % at tractor forward speeds of 5 and 7 km/h, respectively, compared to the speed of 3 km/h. The main reason for this result may be that by increasing the tractor forward speed, both actual field capacity and theoretical field capacity increased. But the increasing rate of the theoretical field capacity was more than the increasing rate of the actual field capacity, so, the field efficiency decreased, this is in agreement with [22], [23] and [25].

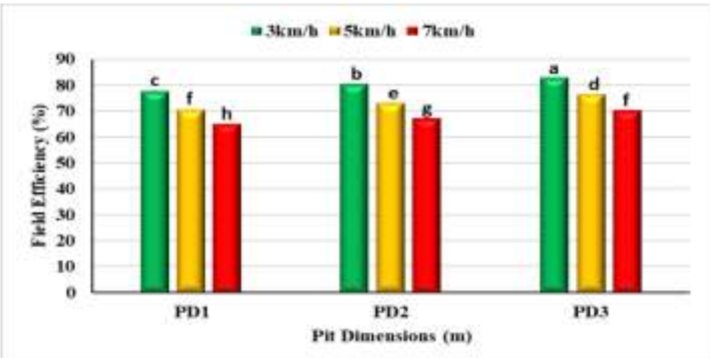

Fig. (12) Field efficiency values (%) followed by different letters are significant at $p < 0.05$ and L.S.D = 1.9487

On the other hand, the results showed that field efficiency increased as the surface area of the pit increased, and its depth decreased. Whereas the field efficiency decreased by about 5.56% and 10.32% at the dimensions of the pit PD2 and PD1, respectively compared to the dimension PD3 m. This may be because the fact that the pits with smaller surface area and greater depth increases the soil resistance facing the machine digger, which causes an increase of the actual operational time and the lost time. Therefore, actual field capacity reduces, in addition to the fact that the theoretical field capacity of the PRT machine has a constant value in all treatments under the same speed, so the field efficiency reduces, and this result is in agreement with [11] and [26]. The results generally indicated that there were significant effects of the treatments on field efficiency at a significance level of 0.05. Thereby, it is appeared that the most efficient treatment that achieved the greatest value of field efficiency was at a forward speed of 3 km/h and pit dimensions of PD3. While the lowest field efficiency was obtained at tractor forward speed of 7 km/h and pit dimensions of PD1.

Filling efficiency of pits

The results indicated that the filling efficiency of pits decreased by about of 5.24% and 10.48% at forward speeds 5 and 7 km/h, respectively, compared to the speed of 3 km/h as shown in **Fig. 13**. This can be explained by the fact that the increase of tractor forward speed, increases the shear strength of soil's particles which led to an increase of soil penetration resistance, consequently, the machine's diggers did not have enough time to penetrate into the soil to form the pits efficiently and accurately, thus the filling efficiency of pits decreased, this is in agreement with the results of [1] and [25]**.**

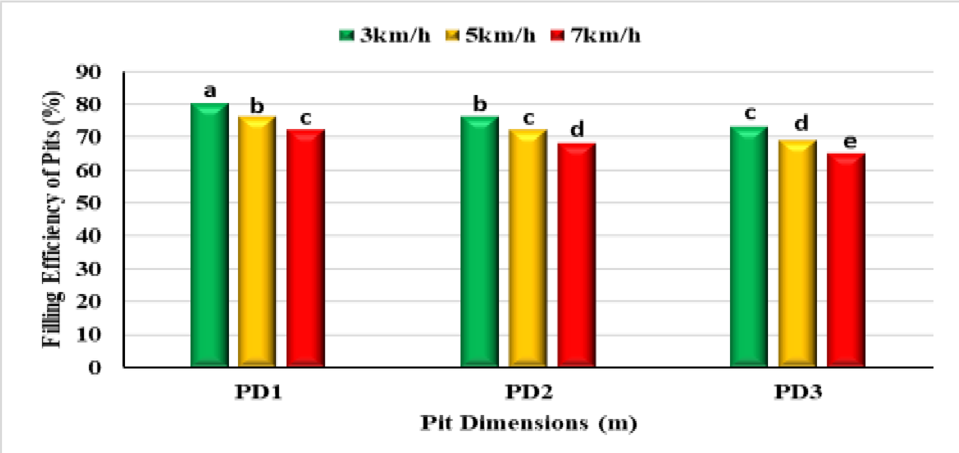

Fig. (13) Efficiency of pits implementation values (%) followed by different letters are significant at $p< 0.05$ and L.S.D = 2.0542.

On the other hand, the results revealed that the filling efficiency of pits increased as the surface area of the pit decreased, and its depth increased. Whereas the filling efficiency of pits increased by about 4.35% and 10.14% at the dimensions of the pit PD2 and PD1, respectively compared to the pit dimension of PD3. The main reason for this is by increasing the digging depth, the soil bulk density increases, so higher proportion of small diameter pores increases in the soil and consequently, greater cohesion forces and compaction between the soil grains increased. Thus, the pits that have smaller surface areas and greater depths are more resistant to collapse over time and have the ability to conserve their shapes better than the pits that have greater surface areas and smaller depths, and this corroborates with [25]. The obtained results illustrated that there were significant effects of the study treatments on the filling efficiency of pits at a significance level of 0.05. Finally, it is concluded that the greatest value of filling efficiency of pits was achieved at tractor forward speed of 3km/h and pit dimensions of PD1 m. While the lowest value was obtained at tractor forward speed of 7 km/h and pit dimensions of PD3 m.

Overall efficiency

The results indicated that overall efficiency decreased by about of 13.53% and 24.94% at forward speeds 5 and 7 km/h, respectively, compared to the speed of 3 km/h as shown in **Fig. 14**. This may be because the increase of tractor forward speed decreases both field efficiency and filling efficiency of pits, so the overall efficiency decreased, and this is in agreement with [1] and [25]**.**

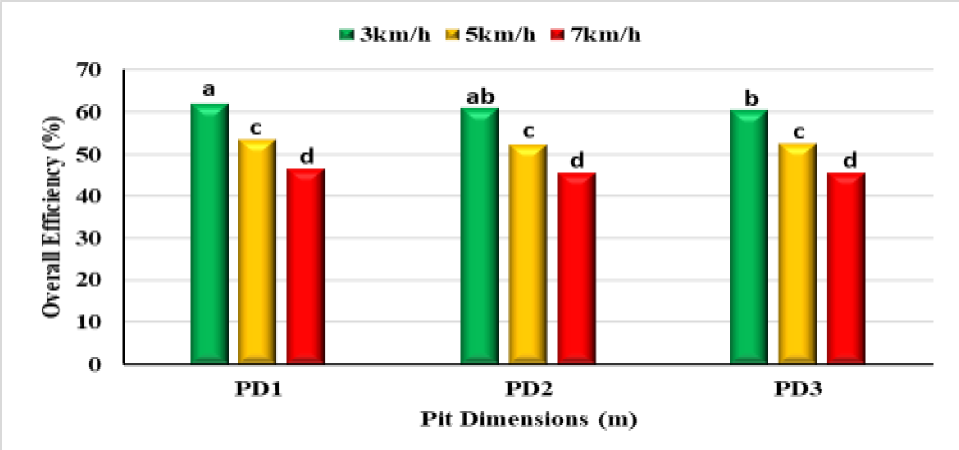

Fig. (14) Overall efficiency (%). Values followed by different letters are significantly at p< 0.05 and L.S.D = 1.2579.

On the other hand, the results illustrated that the overall efficiency increased as the surface area of the pit decreased, and its depth increased. Whereas the overall efficiency of pits increased by about 0.17% and 2.16% at the dimensions of the pit PD2 and PD1, respectively compared to the pit dimension of PD3. The main reason for this is despite the decrease of the field efficiency by decreasing the surface area of pit and increasing its digging depth, the filling efficiency of pits increases. Whereas the increase rate of the filling efficiency is greater than the decrease rate of the field efficiency, so the overall efficiency increases, and this corroborates with [25]. The results generally indicated that there were significant effects of the study treatments on the overall efficiency at a significance level of 0.05**.** Finally, it is concluded that the maximum value of overall efficiency was at tractor forward speed of 3km/h and pit dimensions of PD1 m. While the minimum value was obtained at tractor forward speed of 7 km/h and pit dimensions of PD3 m.

Pulling force and Fuel consumption by PRT machine

The results as shown in **Figures 15** and **16** revealed that pulling force and fuel consumption of PRT machine increased by about of 17.48% and 32.89% at forward speed of 5km/h and 33.70% and 57.23% at tractor forward speeds of 5 and 7 km/h, respectively, compared to the speed of 3 km/h. This may be because the fact that the increase of tractor forward speed increases the soil resistance, so the required pulling force by PRT machine increases which requires more power by the tractor's engine, and consequently fuel consumption increases, and this is in agreement with [1]**,** [21] and [25]**.**

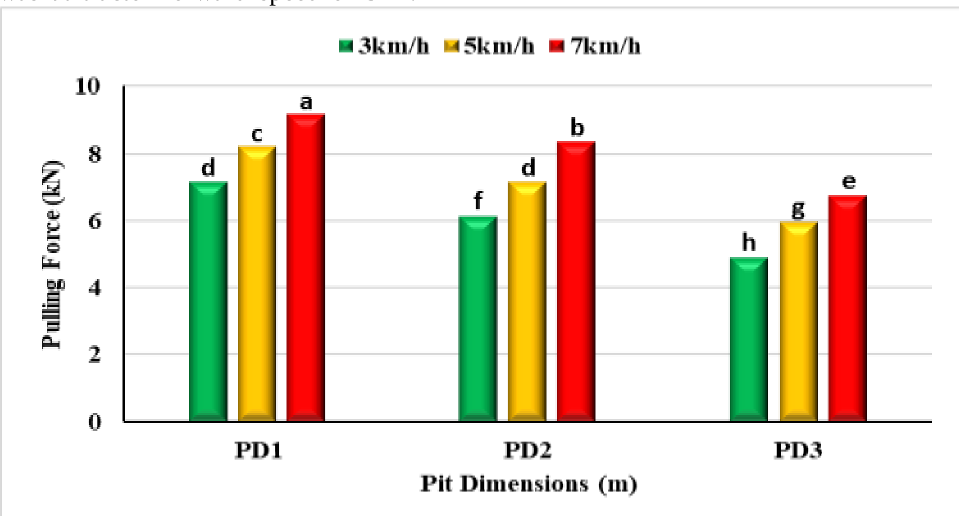

Fig. (15) Influence of treatments on pulling force (kN). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 0.1193.

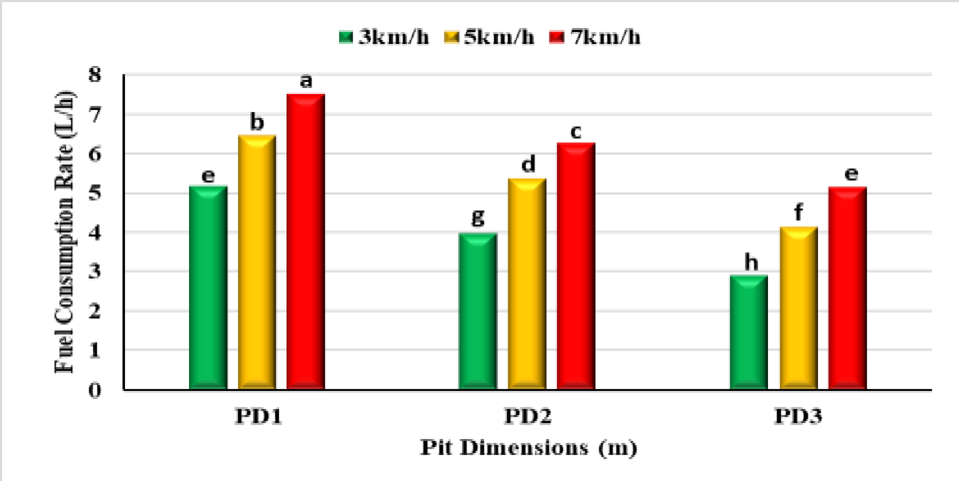

Fig. (16) Influence of treatments on fuel consumption (L/h). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 0.1099.

On the other hand, the results showed that the pulling force and fuel consumption increased as the pit depth increased. whereas pulling force and fuel consumption increased by about 22.85% and 28.33% at pit dimension of the PD2 and by about 39.29% and 57.31% at pit dimension of PD1, respectively compared to the dimension PD3. This may be because the fact that the pit with smaller surface area and greater depth increases the soil resistance as a result of the increase of soil bulk density and compaction between soil particles as the pit depth increases. Thus, it requires greater pulling force which requires greater tractor's engine power, and consequently the fuel consumption increases, and this is in agreement with [26] and [27]. The results generally indicated that there were significant effects of the study treatments on the pulling force and fuel consumption rate at a significance level of 0.05. Finally, it is appeared that the greatest values of pulling force and fuel consumption were achieved at tractor forward speed of 7 km/h and pit dimensions of PD1. While the lowest values were obtained at tractor forward speed of 3 km/h and pit dimensions of PD3.

Surface rainwater runoff

The average depth of rainfall per each effective rainstorm event during 2021-2022 is shown in **Fig (17)** The total annual rainfall reached 185 mm.

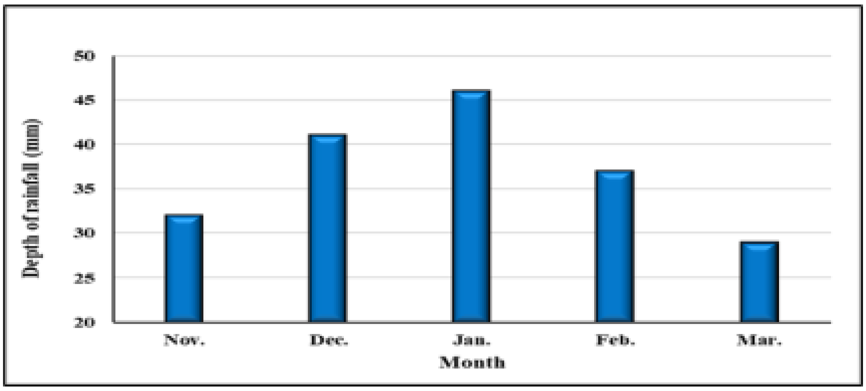

Fig. (17) The average depth of rainfall per each effective rainstorm event during 2021-2022.

The results as shown in **Fig.(18)** revealed that the surface rainwater runoff increased with increasing forward speed. where, surface rainwater runoff increased by about 31.69% and 70.06% at speeds 5 and 7 km/h, respectively compared to 3 km/h. On the other hand the surface runoff decreased as the surface area of the pit decreased and its depth increased, where the surface runoff decreased by about 11.05% and 17.56% at the dimensions of the pit PD2 and PD1, respectively compared to the pit dimension PD3.These results may be because the fact that when increasing of the machine forward speed, increasing of the pit surface area and decreasing of the pit depth, the filling efficiency of the pits decreases, which causes an increasing in the surface rainwater runoff, these results corroborated by many other studies such as [26] and [28]. Generally, it is appeared that the most efficient treatment that achieved the lowest value of surface runoff was at tractor forward speed of 3 km/h and pit dimensions of PD1. In contrary the highest value was obtained at tractor forward speed of 7 km/h and pit dimensions of PD3. Comparing all previous treatments of the machine with the traditional cultivation, it was found that all the PRT machine's treatments were the most efficient. Whereas they proved their effectiveness of reducing surface runoff particularly under using the PRT machine at forward speed of 3 km/h and at pit dimensions of PD1 which achieved a reduction by about 78.37%. This is because the traditional cultivation treatment was carried out on flat soil, without soil formation. Therefore, there were no pits to impede the movement of rainwater falling on the sloping soil, thus the speed of rainwater runoff was increased, so it was lost, this is in agreement with [1].

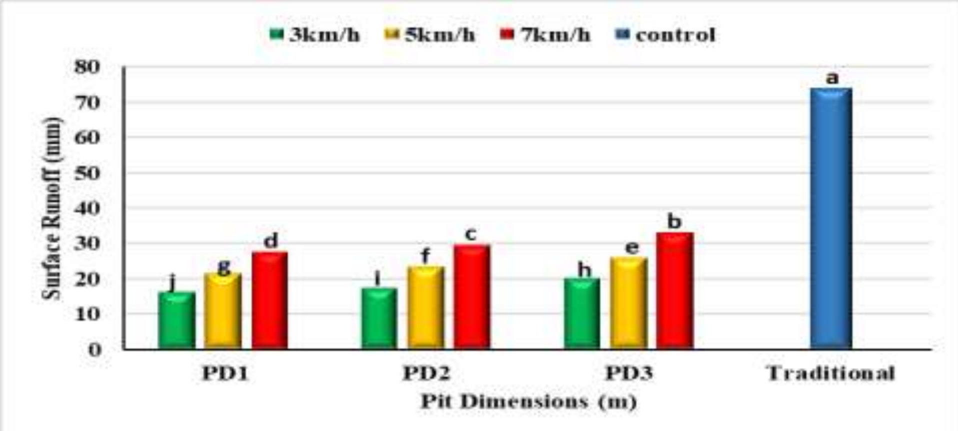

Fig. (18) Influence of treatments on rainwater runoff (mm). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 0.7839.

Comparing the results of the previous treatments of the machine with the traditional cultivation, it was found that all the PRT machine's treatments were the most efficient. Whereas they proved their effectiveness of reducing surface runoff particularly under using the PRT machine at forward speed of 3km/h and at pit dimensions of PD1 which achieved a reduction by about 78.37 %. This is because the traditional cultivation treatment was carried out on flat soil, without any soil formation. Therefore, there were no pits to impede the movement of rainwater falling on the sloping soil, thus the speed of rainwater runoff was increased, so it was lost this is in agreement with [1] and [29].

Soil moisture storage

The results as shown in **Fig. 19** explained that the soil moisture storage decreased with increasing forward speed, where the soil moisture storage decreased by about 6.05 % and 11.24 % at the speeds 5 and 7 km/h, respectively compared to the speed of 3km/h. the results also indicated that the soil moisture storage increased as the surface area of the pit decreased and its depth increased, where the soil moisture storage increased by about 11.18 % and 24.94 % at the dimensions of the pit PD2 and PD1, respectively compared to the dimension PD3. This was due to the fact that when increasing of the machine forward speed, increasing of the pit surface area and decreasing of the pit depth, the filling efficiency of the pits decreases, which causes decreasing in the soil moisture storage. In addition, when the surface area decreases and the depth of the pit increases, the water evaporation rate from it decreases and the rate of lateral infiltration increases, which causes an increase in soil moisture storage, this is in agreement with [30], [31], [32] and [33].

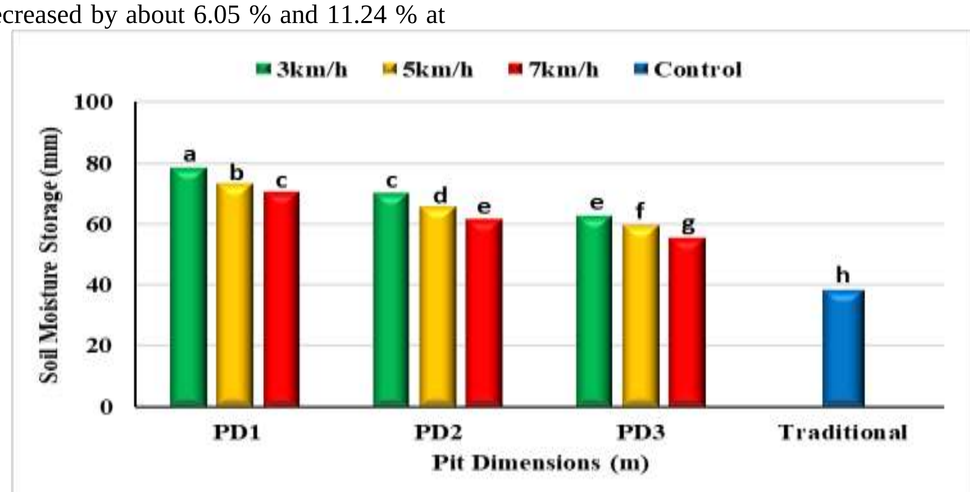

Fig. (19) Effect of study treatments on soil moisture storage (mm). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 1.2531.

Therefore, it is clear that the most efficient treatment that achieved the greatest value of soil moisture storage was at tractor forward speed of 3 km/h and pit dimensions of PD1. while the least value was obtained at tractor forward speed of 7 km/h and pit dimensions of PD3. The results generally indicated that there were significant effects of the treatments on the soil moisture storage at a significance level of 0.05. Moreover, it was observed that all previous treatments of the machine achieved greater values of soil moisture storage compared to the traditional cultivation, particularly under using the PRT machine at forward speed of 3km/h and at pit dimensions of PD1 which achieved an increase by about 105.77 %. This is because the traditional cultivation treatment was accomplished on flat soil without any pits' formation. This leads to increases the opportunity of losing the fallen rainwater by surface runoff. In contrary, all treatments of the PRT machine, distinguished from the traditional cultivation treatment by the abundance of rainwater catchment areas that acted as rainwater reservoirs in such a way that provided the opportunity to absorb more rainwater and increase the soil moisture storage, which was in accordance with [32], [33]and [34].

Wheat grain and straw yields

The results revealed that wheat yield decreased by about of 4.40% and 9.34% for grain yield and by about 4.37% and 8.96% for straw yield at forward speeds 5 and 7 km/h, respectively, compared to the forward speed of 3 km/h as shown in **Figures 20** and **21**. This may be due to the lack of soil moisture storage that results from the decrease of the efficiency of pits implementation with the increase of tractor forward speed. This leads to increase the surface runoff of rainwater which accumulates away from pits at the edge end of the sloping plot instead of capturing it by catchment pits. Thus, both of grain yield and straw yield decrease, and this is in agreement with [1].

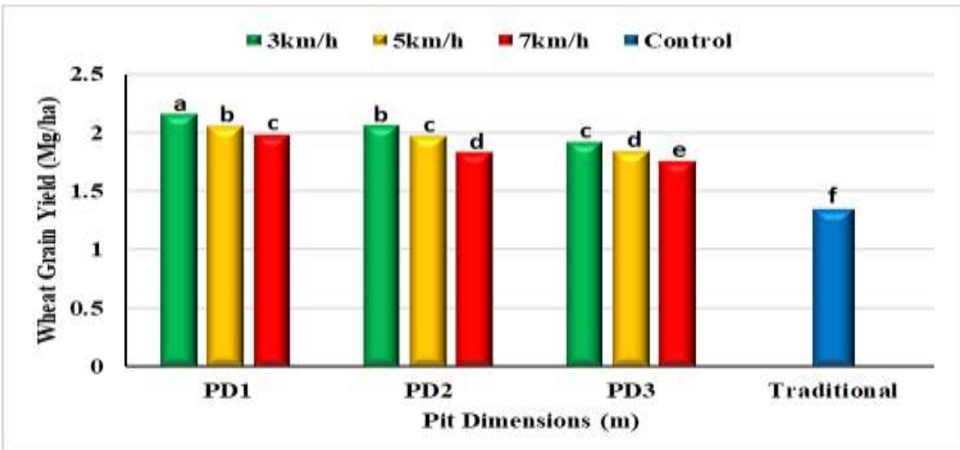

Fig. (20) Impact of treatments on wheat grain yield (Mg/ha). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 0.0616.

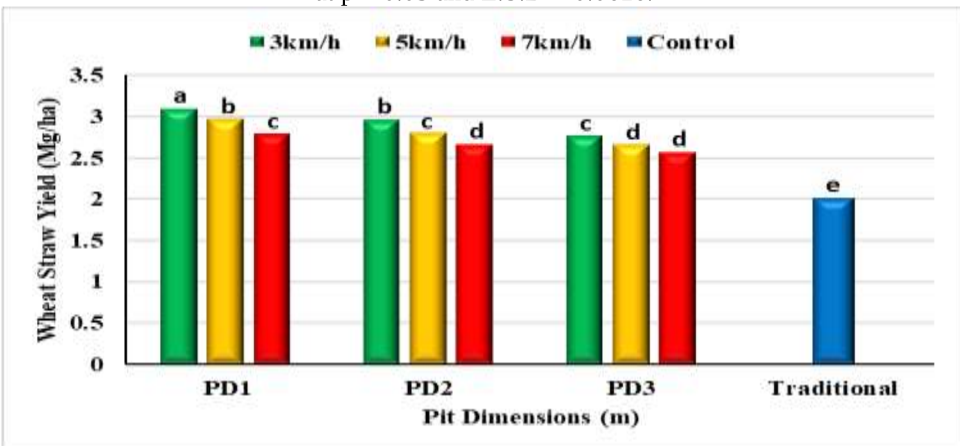

Fig. (21) Impact of treatments on wheat straw yield (Mg/ha). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 0.0795.

On the other hand, the wheat yield increased as the surface area of the pit decreased, and its depth increased. Whereas wheat yield increased by about 6.28% and 12.28% for grain yield and 5.31% and 10.80% for straw yield at the pit dimensions of PD2 and PD1, respectively compared to the pit dimensions of PD3. This is due to the increase of the soil moisture storage in the pits that have smaller surface areas which leads to decrease rainwater lost by evaporation to the air. Moreover, by increasing the pit depth the overall efficiency of the pit's implementation increases. This is due to the increase of soil bulk density and soil compaction between soil particles with the increase of the digging depth. This can consolidate the internal surface of the pit; thus, rainwater can be held to percolate into the soil with conserving the pits' shapes for a long time which consequently promotes wheat crop growth, and this is in agreement with [32], [35] and [36]. The results generally indicated that there were significant effects of the treatments on the wheat yield including grain and straw yields at a significance level of 0.05. Therefore, it is clear that the most efficient treatment that maximized both of grain yield and straw yield were at tractor forward speed of 3 km/h and at pit dimensions PD1. By contrast, the least values were obtained at tractor forward speed of 7 km/h and at pit dimensions PD3. Comparing the results of the previous treatments of the machine with the traditional cultivation, it was found that all the PRT machine's treatments were more efficient. Whereas they proved their effectiveness of increasing wheat productivity particularly under using the PRT machine at forward speed of 3km/h and at pit dimensions of PD1 which achieved an increase by about 60.25 % and 53.62% for grain and straw yields, respectively compared with traditional cultivation [37] and [38]. This is because the traditional cultivation treatment was carried out on flat soil, without any soil formation. Therefore, there were no pits to impede the movement of rainwater falling on the sloping soil, thus the speed of rainwater runoff was increased, so it was lost and decreased in soil moisture storage, this is in agreement with [1].

Net profit of Wheat crop productivity

The results as shown in **Fig.(22)** indicated that the net profit decreased by about of 2.85% and 7.84% at tractor forward speeds of 5 km/h and 7 km/h, respectively, compared to the tractor forward speed of 3 km/h. This may be due to the fact that by increasing the tractor forward speed, the total energy requirements of operation increase, and by consequence, the fuel consumption increases. This leads to increase the operation cost of the machine. Moreover, wheat yield decreases as the tractor forward speed increase, thus the net profit decreases, and this is in agreement with [39] and [40].

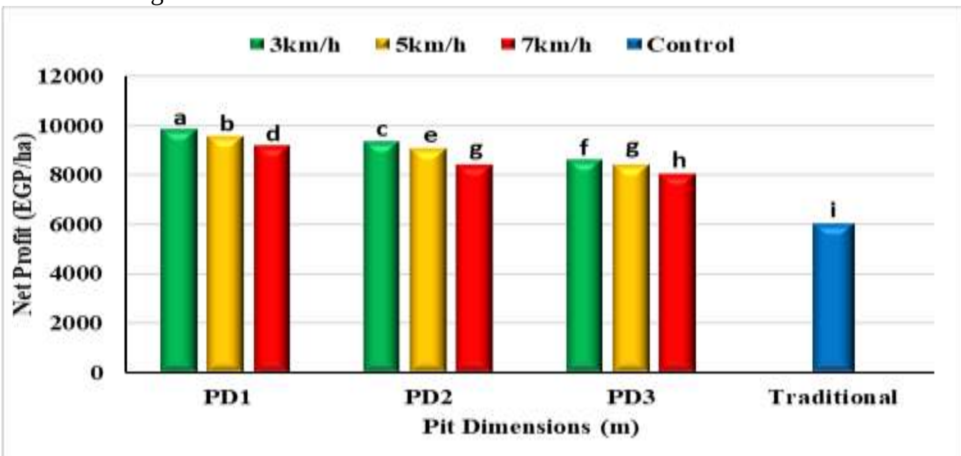

Fig. (22) Influence of treatments on net profit (EGP/ha). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 75.3247.

On the other hand, the results revealed that the net profit increased as the surface area of the pit decreased, and its depth increased. Where the net profit increased by about of 7.07% and 13.89% at the pit dimensions of PD2 and PD1, respectively compared to the dimension PD3. This is due to the increase of the wheat yield that resulted from the increase of the soil moisture storage around the wheat roots at smaller surface area of the pits so, rainwater lost by evaporation to the air decreases. Moreover, the increase of the efficiency of the pits implement as the digging depth increases. This can consolidate the internal surface of the pits so that more rainwater quantity could be held to percolate into the soil with conserving their shapes for a long time, thus wheat yield increases. Therefore, the net profit increases, and this is in agreement with [1] and [39]. The results generally indicated that there were significant effects of the study treatments on the net profit at a significance level of 0.05. Finally, the results confirmed that the most efficient treatment that maximized net profit of wheat productivity was at tractor forward speed of 3 km/h and at pit dimensions PD1. While the least value was obtained at tractor forward speed of 7 km/h and at pit dimensions PD3. Comparing the results of the previous treatments of the machine with the traditional cultivation, it was found that all the PRT machine's treatments were the more efficient. Because they proved their effectiveness of increasing the net profit particularly under using the PRT machine at forward speed of 3km/h and at pit dimensions of PD1 which achieved an increase by about 61.55% compared with traditional cultivation. This is because the traditional cultivation treatment was achieved the lowest yield of wheat crop compared to the treatments using the study machine, this is in agreement with [1] and [41].

Carbon dioxide (CO_2) emissions of wheat productivity

The results indicated that the Carbon dioxide (CO_2) emissions increased by about of 32.89% and 57.23% at tractor forward speeds of 5 km/h and 7 km/h, respectively, compared to the tractor forward speed of 3 km/h as shown in **Fig. 23**. This may be due to the fact that by increasing the tractor forward speed, the total energy required for operation processes increases which increases fuel consumption rate, consequently the CO_2 emissions increases, and this is in agreement with [9].

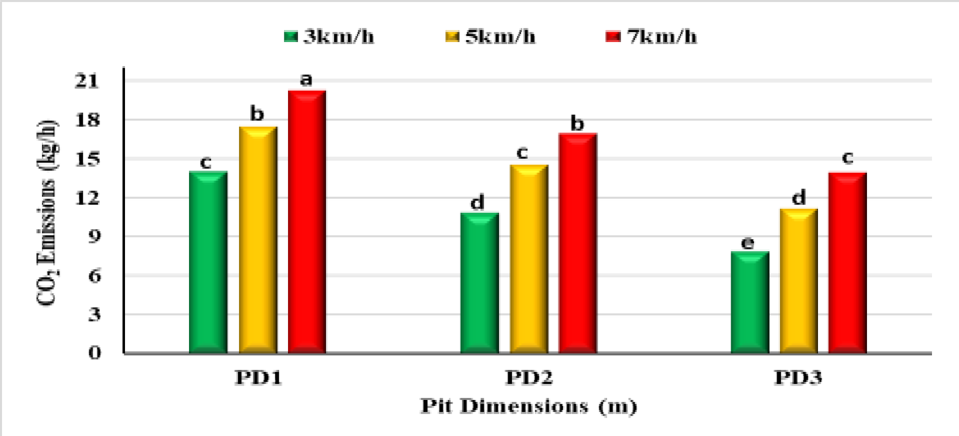

Fig. (23) Environmental impacts of study treatments on Co_2 emissions (t). Values followed by different letters are significant at $p < 0.05$ and L.S.D = 1.7789.

On the other hand, the results illustrated that the CO_2 emissions increased as the surface area of the pit decreased, and its depth increased. Where the CO_2 emissions increased by about of 28.33% and 57.31% at the dimensions of the pit PD2 m and PD1 m, respectively compared to the pit dimension PD3 m. This is due to the fact that by increasing the pit depth, the total energy required for digging process increases due to the increase of soil bulk density and compaction between particles. Thus, the fuel consumption increases which leads to increase the CO_2 emissions, and this is in agreement with [9] and [42]. The results generally indicated that there were not significant effects of the study treatments on CO_2 emissions at a significance level of 0.05. Thereby, the results indicated that the most efficient treatment that minimized the CO_2 emissions was at tractor forward speed of 3 km/h and pit dimensions PD3. While the maximum value was obtained at forward speed of 7 km/h and pit dimensions of PD1.

4. Conclusion

In general, the most important result obtained from the previous study was an increase in the quantities of rainwater harvesting by using the PRT machine for applying the reservoir tillage system. This caused an increase in the productivity of the wheat crop under rainfed conditions in Wadi El-Raml in the northwestern coastal of Egypt. The most important recommendation was applying the reservoir tillage system by the PRT machine at tractor forward speed of 3 km/h and at pits' dimensions of PD1 due to achieving the greatest values of rainwater harvesting, machine performance, wheat crop productivity with achieving the lowest possible operational costs. Whereas it maximized the values of soil moisture storage, wheat crop productivity for grain and straw and net profit by about 105.77%, 60.25 %, 53.62 % and 61.55%, respectively compared to the traditional cultivated system. The results showed that the lowest emission of carbon dioxide from the combustion of diesel fuel was achieved when using the study machine at a forward speed 3 km/h and pit dimensions PD3.

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