Comparative performance evaluation of power harrow with tandem disk harrow in northeastern region of Iran

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Abstract: The aim of the present research was to evaluate the performance of the power harrow (PH) and compare the quality of seedbed prepared by that of obtained from different numbers of disk harrowing (intensity of tillage), combination of power harrowing-number of disk harrowing and ground speed in dry soils of northeastern region of Iran. The results indicated that there was a significant difference between different treatments at 1% level of probability. It was also observed that the type of harrow used had a significant effect, at 5% level of probability, on Mean Weight Diameter (MWD) and aggregate mechanical stability (AMS). It was concluded that power harrowing instead of disk harrowing would reduce field traffic hence soil compaction and improve field efficiency as well as seedbed quality if used after moldboard ploughing.

Key Words: disk, kinematic index, soil properties, tillage

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1 Introduction

Tandem disk intense harrowing preceded by moldboard ploughing is the most often used operation in northeastern region of Iran for manipulation of dry soils. Apart from fatigue imposed on tractor drivers and soil compaction might occur due to intense traffic required, it is time consuming and requires considerable amount of energy and time hence reduction in farmers' income could also be anticipated. Almost 60% of energy consumed during seedbed preparation operations belongs to tillage operations; therefore, it is essential to recognize the parameters affecting the harrowing energy requirements, hence, ever-increasing use of combined machinery, lower traffic intensive as well as time-saving and cost-effective operations are all among available solutions that farmers may consider (Ahmadi and Mollazade, 2009). In general about 30 to 35 percent of the total energy required for crop production is utilized for tillage operations and because of it, the cost as well as time of operation plays a critical role in choosing tools for tillage (Dave and Aviral, 2016). The energy consumption of intensive tillage practices is higher, decreasing soil and environment sustainability. Conservation agriculture practices i.e. reduced or no-tillage could be suitable options to conserve energy

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and environment and increase profitability (Iqbal et al., 2024).

It is obvious that the most effective mean to produce appropriate MWD(Mean Weight Diameter) is tillage operation, secondary tillage operation in particular, if more disruption of the arrangement of the lumps of the soil is desirable (Srivastava et al., 1993). Recently, farmers show more tendencies towards use of powered seedbed preparation machines than pulled implements due to following reasons (Destain and Houmy, 1990):

(1) They are more efficient;

(2) Can better pulverize the soil;

(3) Can be combined with other machinery such planters;

(4) Intense field traffic reduction can be anticipated.

In this field the results of a research indicate that the active-passive combined offset disc harrow (CODH) outperformed the conventional passively-driven offset disc harrow (ODH) with respect to both energy consumption and quality of soil tilth (Upadhyay and Raheman, 2020).

In the field of comparative performance evaluation of power harrow vs tandem disk harrow results of a study showed significant differences among the operative performances of the two typologies of machines powered by the tractor's PTO(Power Take Off): the fuel consumption, the power and the energy requirements of the rotary tillers are strongly higher than power harrows. However, the results also showed a decrease of these parameters proceeding from conventional to more conservation tillage implements. The better quality of seedbed was provided by the rotary tillers (Fanigliulo et al., 2021).

A seedbed preparation machine composed of a rotary tillage device, ditch cleaning shovel, and soil leveling auger was designed to realize the function of rotary tillage, stubble ploughing, ditching, and soil leveling. The seedbed preparation machine was designed as the two parts of the middle section and the left–right symmetrical section to realize the need for middle ditching. Based on the principle of active scraping and anti-blocking, the curves of the soil contact section, soil throwing section, and transition section of the ditch cleaning shovel were analyzed. The structure of the seedbed preparation machine before transplanting is shown in Figure 1, mainly composed of rotary tillage device, ditch cleaning shovel, soil leveling auger, retaining grille, transmission system, frame, suspension bracket, and telescopic rod (Jiang et al., 2022).

Although the invention of rotational tillers can be considered a major advancement in the evolution of tillers in general, but still there is much left to be done upon vertical rotational tillers (Chan et al., 1993).

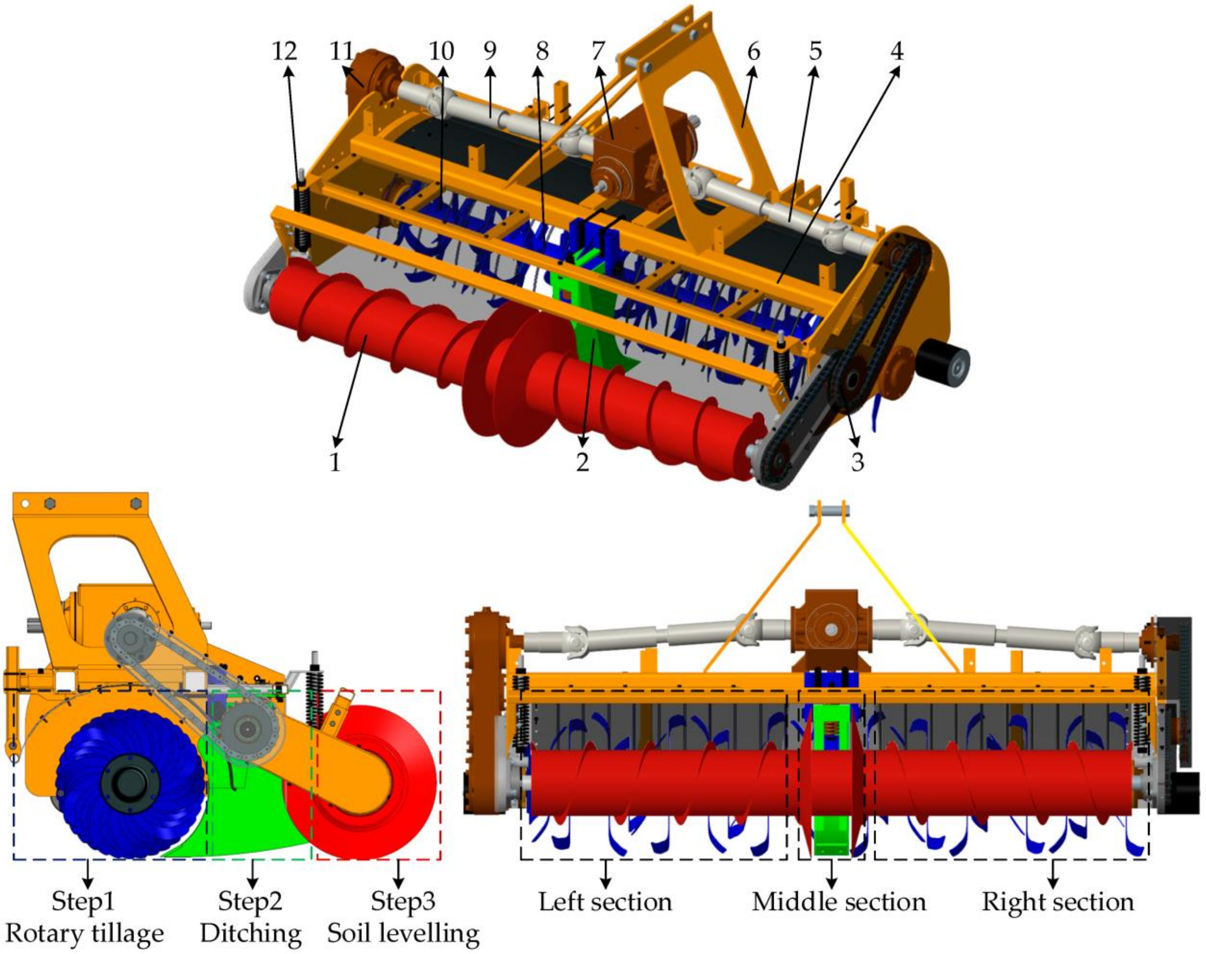
In the other study researchers consider the issue of dynamic and energy analysis of the rotary tiller with planetary transmission gear and vertical rotation axis designed for orchards and vineyards. In the result of investigations, analytical expressions have been derived, which enable to determine the resistance force factors of the cultivated medium affecting the rotary tiller and to set up their changing patterns during a single rotation of the rotor in conditions of forward movement of the aggregate/working unit(Tarverdyan et al., 2024).

According to (Kataoka and Shibusawa, 2002) rotational tillers having horizontal axis deform soil through three phases of cutting, breaking, movement and throwing.

In rotational cultivators, dynamic powers play an essential role. The sudden impact upon the lump causes it to break. Beyond this, the shock of the impact, when transferred to the adjacent lumps, concentrates a sudden stress on the soil which, due to blade inertia, will cause a more efficient crack and break in the lumps (Destain and Houmy, 1990; Bernacki, et al., 1972).

Kinematic index of the blade (the ratio of peripheral speed of blade to forward speed), the counter effect of the blade form, tractor wheel traffic, blades overlap (i. e. the overlap between two blades rotating at opposite directions) are among the chief factors that affect soil final properties during power harrowing (Chan et al., 1993).

The cover cropping in orchards is an advantageous method of weeding which suppresses the weed growth as well as adds additional income. The side-shift offset rotavator was used to prepare a weed free seed bed in orchard field. Certain machine and soil parameter which governs the quality of a seedbed were selected as independent factors, it included: type of cutting blade; kinematic index (which affects the soil pulverization) and soil moisture content. While the soil particle size, weeding efficiency and fuel consumption was considered as the dependent parameters(Sahu et al., 2018). This research results revealed that there was a significant effect of soil moisture content, type of soil cutting blade and kinematic index on the performance of side-shift offset rotavator.



(1) Soil leveling auger; (2) Ditch cleaning shovel; (3) Chain box; (4) Frame; (5) Right cardan joint; (6) Suspension bracket; (7) Intermediate gearbox; (8) Retaining grille; (9) Left cardan joint; (10) Rotary tillage device; (11) Side gearbox; (12) Telescopic rod (Jiang et al., 2022).

Figure 1 Structure diagrams of seedbed preparation machine of rapeseed combined transplanter

According to Kinzel et al., (1981)) the final conditions of the soil after tillage is a function of the initial conditions of the soil, kinematics of the rotational blade and the soil dynamic flow. On the other hand, (Klenin, Popov and Sakun, 1985)) states that there is a strong correlation between the length of the cut soil with a blade and the blade feed rate.

The findings of (Osunbitan et al., 2005)) indicated a reduction in bulk density (BD) due to increase in the degree of disruption of the soil.

The disc arrangement on compact disc harrow (CDH) was studied by (Zeng et al., 2019). They found out that the soil cutting area ratio is dependent on disc spacing.

The amount of shearing and inertial forces on the tine were studied mathematically by (Kshetri et al., 2021)). According to their report the soil failure patterns affects these forces on the tine.

Farmlands in Khorasan Razavi province in Northeast of Iran are known with their heavy textured soil and suffer from a dry climate. For seedbed preparation, farmers usually have to carry out intense tillage operations and employ lengthy practices. Moldboard ploughing and leaving the soil untouched for one year before multiple harrowing by tandem disk is a common practice among farmers. Apart from fatigue imposed on tractor drivers and high energy consumption of energy caused by intense traffic involved during multiple harrowing, such practices adversely affect the soil structure which may lead to crust development, increase the costs and working time involved.

In an effort to find a way to partially alleviate the difficulties caused due to problems mentioned above, the performance of the power harrow was evaluated and the quality of seedbed prepared compared to that of obtained from different numbers of disk harrowing (intensity of tillage), combination of power harrowing-number of disk harrowing and ground speed. All the experiments were carried out on soil that had been undergone moldboard ploughing after previous crop harvest.

Table 1 Project plan (Index *i* stands for number of harrowing, and *j* for speed of power harrowing)

CPH_{21}		CPH_{22}		CPH_{23}
CPH_{13}		CPH_{12}		CPH_{11}
CDH_2	CDH_4		CDH_1	CDH_3
BPH_{11}		BPH_{12}		BPH_{13}
BPH_{23}		BPH_{22}		BPH_{21}
BDH_3	BDH_1		BDH_2	BDH_4
APH_{21}		APH_{22}		APH_{23}
APH_{13}		APH_{12}		APH_{11}
ADH_1	ADH_3		ADH_4	ADH_2

Table 2 Implement specifications

Implement	Working depth (mm)	Width (mm)	specification					
Power harrow	125	3000	Attachment	Number of rotors	Rotor diameter (mm)	Rotor speed at 540 PTO rpm	Rotor spacing (mm)	
			Integrated	12	250	274	250	
Tandem disk harrow	125	3700	Attachment	Number- size of disk(mm)	Disk spacing (mm)	Disk type back-front	Disk angle (Deg) back-front	Concavity (mm)
			pull	36-500	190	Plain-serrate	15-11.5	45

2 Material and methods

The present research was conducted in a 1 ha farmland of the Center of Research and Natural Resources of Khorasan in holy city of Mashad - located at 36.20° latitude and 59.35° east longitude (northeastern city of Iran) in year 2007 (Statistics, 2009). The farmland under our study had gone under cultivation of barley in the previous year. The land, however, had been tilled by moldboard after crop harvest operation. The tilled land included big and solid lumps as well as gravels.

In this project, The effect of the type of machinery at two levels (power harrow and tandem disk harrow), and number of harrowing at 6 levels (1,2,3,4 tandem disk harrowing , and 1 and 2 power harrowing), as well as the average forward speed at 3 levels, namely, 2.7, 3.96 and 5.69 km h^{-1} for power harrowing, and 7.38 km h^{-1} for tandem disk harrowing were studied using CRD(Completely Randomized Design) with10 treatments, 3 replications each, and the final physical properties of the soil were examined. Out of these 10 treatments, 6 combinative treatments, consisting of 3 speeds and 2 levels of harrowing were predicted on factorial scale with CRD as the basis. Index *i* stands for number of harrowing, and *j* for speed of power harrowing at the scale of km h^{-1} (2.7=1, 3.96= 2 and 5.69=3). All the machinery were adjusted according to instructions given in operation manual (Baghban et al., 2008).

Table 1 presents the project plan, while Table 2 indicates their features.

ITM 399 tractor (with 110 nominal horsepower, in three definite gears and in rabbit status) was used in PH, and JD3140 (with 105 nominal horsepower, in low gear 4) was employed in TDH. Direction of travel for each run was taken in right angle to the direction of previous one. Prior to harrowing, however, the physical properties of the soil were measured. Soil particle size analysis was made using hydrometer and three mineral fractions, namely, sand, silt and clay was determined as 28%, 51% and 21% respectively, hence soil textural class of silt loam was stablished. The variation of soil texture as well as soil moisture within 150 mm of depth throughout the farmland was negligible.

Due to rocky nature of the farmland and high fraction of gravels was recommended not to soil cone index. However, other physical properties of the soil such as MWD, BD, and AMS were determined.

2.1 Soil moisture content (SMC)

Special auger was used for soil sampling. Samples taken from depths of 0 to 150 mm. The weight of the wet soil samples was measured and then the soil sample was put in an oven at 105°C for 24 hr and then the weight of dry sample was measured. The following formula was used for calculating the soil moisture content (Javadi and Hajiahmad, 2006).

$$SMC = \frac{W_w - W_d}{W_d} \times 100 \tag{1}$$

Where: *SMC* is dry base soil moisture content (%), W_w is the weight of wet soil sample (g) and W_d is the weight of dry soil sample (g).

2.2 Soil bulk density

Core sampling method was used to estimate soil bulk density. To ensure filling the coring cylinder completely, sampling sites were wetted prior to taking of the samples. Three different sites were chosen and three replicate determinations were made for any pre and post tillage work per site. Each sample was taken to laboratory in a sealed container. After weighing, the samples were oven dried at 105ºC for 8 hours and then cooled in a desiccator before re-weighing (Smith et al., 1994). Bulk density was calculated as follows:

$$BD_d = \frac{M_{ds}}{V_c} \tag{2}$$

Where: BD_d is the dry bulk density (g cm^{-3}), M_{ds} is the mass of dried soil (g), and V_c is the volume of the cylinder (cm^3).

2.3 Soil Aggregate Size

Three pre and three post harrowing samples were taken randomly from soil surface to 125mm below the soil surface for each tilled plot, using a special auger. Samples were air dried and sieved using a set of sieves (aperture size of 70, 63, 32, and 16 mm) with a shaking duration of 30s (Eghball et al., 1993). The clod mean weight diameter was calculated from the following formula (Boydas and Turgut, 2007).

$$MWD = \sum_{i=1}^{n} \frac{w_i}{w} D_i \tag{3}$$

Where: *MWD* is clod mean weight diameter, w_i is the weight of soil particles retained on each sieve (g), *w* is The total weight of soil sample (g), and D_i is the size of each sieve (cm).

2.4 Porosity

Volume of pores and spaces was calculated from the formula given by (Smith et al., 1994) as follows:

$$P = (1 - \frac{BD}{AD}) \times 100 \tag{4}$$

Where: *P* is the porosity (%), *AD* is the actual density (g cm^{-3}), and *BD* is the dry soil bulk density (g cm^{-3}).

2.5 Aggregate Mechanical Stability

Lumps aggregate resistance against pulverization was calculated for treatments PH and TDH from the formula given by (Adam and Erbach, 1992) as follows:

$$AMS = \frac{MWD_B - MWD_A}{MWD_B} \tag{5}$$

Where: AMS stands for aggregate mechanical stability, MWD_A is soil aggregate size after tillage (cm), and MWD_B is soil aggregate size before tillage (cm).

Kinematic index of PH blade was also measured according (Klenin et al., 1985)). It is defined as ratio of blade peripheral speed to ground speed. Soil moisture content was 3.5% throughout the experiments and test plots were all lumpy.

Having ascertained normality in data distribution, variance analysis, based on SRD, was made. Using Duncan Test with least significant difference at 1% probability, a comparison was made between the averages. In order to compare the treated groups and to get answer for some of the questions, orthogonal comparisons at 5% probability level were also applied. The related graphs are included.

3 Results and discussion

3.1 The average diagonal of the bulks

Variance analysis on MWD indicated that at 1% probability there was a significant difference between various tillage treatments (Table 3). The average MWD of 10 different treatments were compared to each another based on Duncan test at 1% of significance (Table 4). PH$_{22}$ and PH$_{23}$ had the least MWD while TDH$_1$ had the highest. Statistically also, the two treatments with the least MWD were sensible only with TDH$_1$ and TDH$_2$ but indicated no significant difference from the other treatments. As Table 4 illustrates, PH treatments were more effective on MWD. An analysis of the major factors in PH revealed the fact that the effect of number of harrowing on MWD was only significant at 5% probability. And the major factor of harrowing speed and the mutual effect between these two indicated no significant difference (Table 5).

Table 3 Analysis of variance for different parameters

SV	df	MS			
		MWD (cm)	Porosity (%)	BD (gr cm^{-3})	AMS
Between Groups	9	13.633**	2.203^{ns}	0.002^{ns}	0.088**
Within Groups	20	2.870	3.022	0.005	0.019
Total	29				
Coefficient of Variation		41.410%	3.410%	5.420%	20.450%

Note: ns and **, stand for not significant and significant at 1% level of probability respectively

Table 4 Parameters mean comparison applying Duncan test(TDH=Tandom Disk Harrow,PH=Power Harrow)

Tillage Treatment	PH$_{22}$	PH$_{23}$	PH$_{21}$	PH$_{11}$	PH$_{12}$	TDH$_4$	PH$_{13}$	TDH$_3$	TDH$_2$	TDH$_1$
MWD(cm)	2.04^{a}	2.12^{a}	2.58^{ab}	3.25^{ab}	3.49^{ab}	3.63^{ab}	3.96^{ab}	4.42^{ab}	6.58^{bc}	8.88^{c}
Tillage Treatment	TDH$_4$	TDH$_3$	TDH$_1$	PH$_{23}$	PH$_{11}$	PH$_{13}$	PH$_{22}$	TDH$_2$	PH$_{12}$	PH$_{21}$
Porosity (%)	49.24^{a}	50.28^{a}	50.63^{a}	50.72^{a}	51.06^{a}	51.11^{a}	51.41^{a}	51.41^{a}	51.58^{a}	52.45^{a}
Tillage Treatment	PH$_{12}$	PH$_{11}$	TDH$_2$	PH$_{21}$	TDH$_1$	PH$_{13}$	PH$_{23}$	PH$_{22}$	TDH$_3$	TDH$_4$
BD (gr cm^{-3})	1.26^{b}	1.27^{b}	1.29^{b}	1.30^{b}	1.30^{b}	1.31^{b}	1.32^{b}	1.32^{b}	1.33^{b}	1.35^{b}
Tillage Treatment	TDH$_1$	TDH$_2$	TDH$_3$	PH$_{13}$	TDH$_4$	PH$_{12}$	PH$_{11}$	PH$_{21}$	PH$_{23}$	PH$_{22}$
AMS	0.29^{a}	0.47^{ab}	0.65^{bc}	0.68^{bc}	0.71^{bc}	0.74^{bc}	0.74^{bc}	0.79^{bc}	0.83^{bc}	0.84^{c}

Note: Means with different letters have significant difference (p<1%)

Table 5 Analysis of TN and TS effect on soil properties in PH

SV	df	MS			
		MWD(cm)	Porosity (%)	AMS	BD(gr cm^{-3})
Tillage Number (TN)	1	7.831*	0.336^{ns}	0.045*	0.005^{ns}
Tillage Speed(TS)	2	0.114^{ns}	1.109^{ns}	0.002^{ns}	0.001^{ns}
Number× Speed	2	0.537^{ns}	1.422^{ns}	0.004^{ns}	0.001^{ns}
Error	12	1.048	4.498	0.007	0.004
CV (%)		35.19	4.130	0.910	4.890

Note: ns and **, stand for not significant and significant at 1% level of probability respectively

3.2 Porosity

In terms of porosity, no significant difference was observed among the various tillage treatments (Table 3). The comparisons made among the various average tillage treatments revealed that in two levels of probability, despite having no significance difference, the highest value for porosity goes to PH_{21}, while the lowest value for porosity belonged to TDH_4. It is noteworthy to mention that an increase in the number of harrowing in TDH reduced porosity. This can be related to soil compaction under tractor wheel traffic as well as to the nature of TDH performance (Table 3). Analyzing the factors involved in PH indicated no significant effect on porosity (Table 5).

3.3 Soil bulk density

Variance analysis for BD indicated that there was no significance among results obtained from different tillage treatments (Table 3). With regard to the lumpy structure of the soil, variation of bulk density followed no definite pattern. According to Table 5, the lowest value for BD resulted from PH_{12}, and the highest value belonged to TDH_4. However, analysis of the major factors confirmed no significant effect (Table 5).

3.4 Aggregate mechanical stability

AMS at 1% level of probability indicated a significant difference among the various tillage treatments (Table 3). Comparisons were made among the various tillage treatment averages by Duncan (Table 4) which confirmed that TDH_1 had the highest AMS (resistance in the lump against breaking) whereas in PH_{22} and PH_{23} the lumps are the lowest resistant against breaking.

Statistically, the effect of PH_{22} with TDH_2 and TDH_1, as well as PH_{23} with TDH_1, at 1% level of probability indicated a significant difference (Table 4). Analysis of the major factors confirmed that tillage number, at 5% level of probability, had been significantly effective. However, neither tillage speed nor the mutual effect between tillage speed and tillage number proved to be significantly effective (Table 5).

3.5 Optimum operation speed and working conditions

With 3 meter working width PH, the efficient field capacities at 3 different speed levels were 0.69, 1.01 and 1.45 ha hr^{-1} respectively, while with 3.7 meter working width TDH it was 2.07 ha hr^{-1}(ASAE, 1998). The mentioned numbers concern one tillage treatment; however, taking into account the various tillage treatments, the effective capacity for TDH was 2.07, 1.04, 0.69 and 0.52 ha hr^{-1}, while it was 0.69, 1.01 and 1.45 ha hr^{-1} for one test run with PH, and 0.34, 0.51 and 0.73 ha hr^{-1} for PH in two test runs. Since in machinery operations besides the high field capacity, work quality is essential as well, therefore, MWD, porosity percentage, bulk density and AMS were also considered. The findings revealed that 5.69 ha hr^{-1} was the best speed. However, 3.96 ha hr^{-1} was also acceptable because of the integrated nature of PH in contrast to the pulled nature of TDH and the higher maneuverability of the machine.

3.6 Kinematic index

With regard to Table 2, peripheral speed for rotor was taken 12.91 km hr^{-1}. Therefore, the kinematic index at 2.7, 3.96 and 5.69 km hr^{-1} forward speed of PH was 6.37, 3.27 and 2.27 respectively. To achieve the highest working rate in rotary tillers with lowest energy consumption, the best arrangement is known to be at speed of 4.68 km hr^{-1}, plow depth of 12 centimeters and the peripheral rotor speed of 5.91 m s^{-1} (Kosutić et al., 1997). Studies demonstrate that, at optimum soil moisture content, with only one power harrowing one can achieve the most appropriate seedbed conditions (Mandang et al., 1993). For instance, the quality of seedbed achieved by one time power harrowing in silt loam soils, competes to the quality of seedbed if prepared with several times of traditional harrowing (Solhjou et al., 2003). Also For increases in kinematic index, the power requirements for tool draft force decreases, whereas the power requirements for rotating the tool increases for each travel speed (Kshetri et al., 2021).

The effect of kinematic index on overall performance of tractor drawn rotavator at different levels of peripheral to forward speed (u/v) ratio (4.05, 5.87 and 8.34) varying the forward speed with a constant peripheral speed of 5.48 m s^{-1} and at two tilling depths of 80 and 120 mm was studied by Behera and Raheman (2021). The result showed that development of negative draft power at all operating conditions, which decreased by increasing the u/v ratio. Because of the negative draught power, rotary power and total equivalent power at power take-off were lowered as the u/v ratio increased, and total equivalent PTO power was lower than rotary power in all operating conditions.

Relying on pure theory, one may claim that the lowest tillage speed accompanied with highest index value would lead to optimum tillage operation. But considering some other parameters involved, might put forward a different strategy; i.e. harrowing a soil containing a moisture content at field capacity level, might lead to high quality seedbed if the soil otherwise was heavy textured, lumpy and free of moisture and had been undergone ploughing.

4 Conclusion

A variance analysis showed that at 1% level of probability significantly different values resulted for MWD and AMS in different tillage treatments. It was concluded that, two times power harrowing at 3.96 km hr^{-1} forward speed was the most efficient operation in terms of breaking soil. Results obtained from harrowing with TDH vs PH were significantly different at 1% probability level. Despite the significant difference between porosity percentage values from different treatments, two times power harrowing left the soil with the highest values for porosity. In analyzing the chief performance factors of power harrowing, the number of harrowing, at 5% level of probability, had a significant effect on MWD and AMS. Yet, the other factors revealed no effect. In this study, the lumps affected by two times of harrowing at 3.96 as well as 5.69 km hr^{-1} was resulted in lowest resistance value against breaking. With regard to working rate and performance quality, two times power harrowing at 3.96 as well as 5.69 km hr^{-1} were recognized to be the best working conditions compared to TDH. Finally, economical aspects as well as machine performance in high moisture content condition of the soil still remain to be investigated. Research needs to be mentioned are:

(1) Research on efficiency of PH in different regions under different soil conditions;

(2) Comparing power harrowing performance with secondary tillage methods;

(3) Using of PH in primary tillage operations;

(4) Incorporating other operations such as planting, etc. to PH;

(5) Studding fuel consumption of the machine;

(6) Redesigning its mechanisms, and customizing the machine with regard to the needs of the farmers in different regions.

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