INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
12–011/AKA/2012/14–4–633–636
http://www.fspublishers.org

Full Length Article

Evaluation of Energy Efficient Zone Disk Drill for Sowing Wheat after Harvesting Paddy Crop

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ABSTRACT

Under paddy-wheat rotation, sowing of wheat crop is delayed due to late harvest of paddy and because of the extensive conventional tillage operations required for sowing of wheat. Tillage is time, energy and cost intensive production process. For successful adoption of till-plant technology, a technically suitable and economically feasible tractor power take off (PTO) driven 7-row zone wavy disc tiller drill, which pulverize a 50.8 mm wide and 101.6 mm deep soil zone in front of each furrow opener has been developed, fabricated and tested under farmer's fields in paddy. The rotor shaft rotates wavy disks at 172 rpm to prepare pulverized zone. This new system of planting saved on an average 3.2 times fuel energy and 1.1 times irrigation water, and increased wheat grain yield by 1.4 times as compared with the conventional method of wheat sowing in Pakistan.

Key Words: Conservation; Zone; Tillage; Wheat

INTRODUCTION

Population is increasing at a rapid rate in Pakistan and estimates indicate a near doubling to 243 million mouths to be fed by the year 2025 (Jehangir *et al.,* 2003). The country is facing both food and energy crisis, which warrants the use of resource conservation technologies in every sphere of life. Tillage is one of the major field operations, which contribute significantly to the total cost of production in agricultural systems. Presently, 500000 tractors, in Pakistan, with an annual use of each tractor for 400 h in tillage (assuming an hourly consumption of a gallon of diesel oil @ Rs. 72 L^{-1}) consume Rs. 7.3×10^{10} (US$$9.12\times10^{8}$) every year. Wheat crop is the staple food in Pakistan and it is grown on an area of 8 million haannually. About 2.3 million ha is under rice cultivation (GOP, 2010-2011). Mostly wheat sowing is delayed due to late vacation of rice fields, engagement of farmers in postharvest operations and time required for seed bed preparation by conventional methods. On average wheat sown after 15[th] November records a yield reduction of about 30 kg ha^{-1} day^{-1} (Ghafoor & Ahmed, 2001). Iqbal *et al.* (1995) reported that zero tillage system enhanced wheat grain yield by 14% and timely sowing boosted grain yield by 10%. Brula (2002) pointed out water saving amounted to 25-35%with the use of direct drilling technique. Gupta and Hobbs (2000) found that the rate of wheat seed emergence under zero tillage wheat was higher by 2.2-4.6% with dried soil and by 16.5-17.5% with wet soil tillage as compared with that sown by conventional method. Rautaray (2004) reported that there was an increase in yield by 5-10% in case of no-till drill and strip-till drill and savings in time was 65-70% with both the drills. Keeping in view the issue of energy crises and delayed wheat sowing by conventional methods, an energy efficient zone wavy disk tiller has been developed and fabricated, which can sow wheat crop in untilled hand harvested standing paddy residue field. This will not only decrease cost of production but also increase food for the growing population of the country. The study had been design to evaluate the performance of machine for its effect on soil physical properties and their impact on crop productivity.

MATERIALS AND METHODS

Development of zone disk tiller: A zone disk tiller was developed and fabricated, which has a rotary wavy disc coulter attachment for optimum soil manipulation running ahead of the normal seven furrow openers being operated with a tractor of 50 or higher horse power. The rotary attachment consists of a frame with a mild steel hollow rotor shaft (73 mm dia) having seven wavy coulters (457 mm dia). The spacing between two successive coulters is the same as the row spacing for the crop to be planted (230 mm). Power to the rotor shaft (172 rpm) is provided from the tractor PTO shaft (540 rpm) through speed reduction devices. The machine consists of two main units; (1) Zone tiller unit and; (2) Fertilizer and seed drilling unit. The zone disk tiller unit prepares seven rectangular zones (25.4-50 mm wide &150 mm deep each) with wavy disk coulters. The fertilizer and seed drilling unit places the calibrated

To cite this paper: Iqbal, M., A. Munir, M. Ahmad, K.A. Hussain and M. Umair, 2012. Evaluation of energy efficient zone disk drill for sowing wheat after harvesting paddy crop. *Int. J. Agric. Biol.*, 14: 633–636

amount of fertilizer at 75 mm depth and seed at 40 mm depth in the furrows made by furrow openers, respectively. The furrows are closed by covering devices with minimum quantity of soil.

Field performance evaluation of zone disc tiller: After harvesting paddy crop, the newly developed machine was used for planting wheat crop in sandy clay loam and loam soils under paddy-wheat rotation at two different sites in the University of Agriculture, Faisalabad. The zone tiller sowing treatments included two wave sizes (25.4 & 50 mm wide waves) of wavy disk coulters and three cutting indices (ratio of coulter linear speed to tractor forward speed). Keeping the tractor power take off (PTO) speed constant and varying tractor forward speeds at 5.1, 6.8, and 10.4 km h^{-1} resulted in the cutting indices of 3.14, 2.36 and 1.54, respectively. The objective was to determine the effects of two levels of wavy coulters and three levels of soil cutting indices on soil physical properties and their related effects on wheat emergence, seedling growth, and crop yield. The experiments were conducted using randomized complete block design (RCBD) with eight treatments (including conventional method & zero tillage method) and three replications. The conventional method consisted of standard field preparation adopted by farming community i.e., two operations of rotavator, four operations of field cultivator, two operations of a planker and sowing seed with seed drill (Anonymous, 2000-2001). Before planting, soil samples were collected from 0-50 and 50-100 mm depth from soil surface for determination of moisture and bulk density. The samples were collected from 21 randomly selected sites from the experimental area. At seed emergence, soil sampling was done for moisture content and bulk density from three randomly selected furrows under each treatment from three different locations. However, plant emergence and seedling growth were recorded along three meter long sections of three randomly selected rows under each treatment. A standard cone penetrometer was used to measure soil strength, both before seeding and at seed emergence from 0-50 and 50-100 mm depth from the soil surface (ASAE, 1997). Before planting, soil strength was measured at 21 randomly selected spots in the experimental field. However, strength measurements at seedling emergence were made from three randomly selected spots along the length of three furrows under each treatment. Seed emergence indices for all the treatments were determined using the method described by Erbach (1982). The fuel consumption for each treatment was measured by fitting one liter measuring cylinder in the fuel line of the tractor. Crop yield was measured by manually harvesting one m^2 area from three randomly selected sites under each treatment. The collected data were statistically analyzed using PROC GLM (General Leaner Model) procedures of the SAS Institute (SAS, 2009). The least significant differences (LSD) at 5% probability level among the means were determined to find their significant differences.

RESULTS AND DISCUSSION

Statistically analyzed data (Table I) revealed that before planting, the experimental sites (Ste) had non-significant differences in bulk density (BDB) but had significant differences in both the soil moisture content (MCB) and soil penetration resistance (PRB). The effects of depth on BDB and MCB did not vary significantly with depth but penetration resistance did vary significantly with depth. After planting, the sites, treatments and depth significantly affected the bulk density (BDA), moisture content (MCA) and soil penetration resistance after planting (PRA). This indicated that the soil manipulation treatments changed soil bulk density at both the depths which directly affected MCA and PRA. Data (Table II) revealed that sites (Ste) and treatments (Trt) significantly affected seed emergence rate index (ERI), grain yield (Yld), and fuel consumption (FC). Mean values of ERI observed at Ste-1 (ARA) and Ste-2 (PARS) were 12.14% and 11.82% respectively (Table II). Relatively higher BDA at Ste-1 (1.34 Mg m^{-3}), presumably helped in maintaining favorable seed to soil contact, hence resulting in rapid water imbibition by planted seeds and faster seedling emergence.

Relatively higher BDA at Ste-1 (1.34 Mg m^{-3}) might have helped in maintaining favorable seed to soil contact and hence resulting in rapid water imbibition by planted seeds and faster seedling emergence. The treatment, γ1C2 (seeding by zone disk tiller drill (Fig. 1) excelled significantly in performance of ERI values than those of all the other treatments at both the sites (14.48 at Ste-1 & 14.05 at Ste-2). Higher the ERI value, higher was the crop grain yield that has been proved by the treatment γ1C2 at both the experimental sites (Ste-1=5.49 t ha^{-1}, and Ste-2=4.79 t ha^{-1}). Conventional method and zero tillage resulted in significantly lowest values of ERI at both the sites as compared with ERI values for all other treatments, and hence in lowest grain yield at both the sites. These findings were in accordance with Gupta and Hobbs (2000). Both the higher and lower bulk density values (Fig. 2) were in effective in increasing the ERI. The optimum ERI value recorded was12.25% at abulk density of 1.32 Mg cm^{-3}.

Fig. 1: Zone disk tiller in operation

Table I: Analysis of variance (ANOVA) of soil and crop characteristics before sowing, at crop emergence, and harvesting

a. Soil characteristics before planting				
		BDB	**MCB**	**PRB**
Source	**df**	**Mean Square**	**Mean Square**	**Mean Square**
Ste	1	0.00	26.45**	32.81**
Blk (ste)	4			
D	1	0.106 NS	8.15NS	266435*
Ste x D	1	0.008*	1.57NS	728.02 NS
Ste x Blk x D(Ste)	4			
b. Soil characteristics at crop emergence				
		BDA	**MCA**	**PRA**
Source	df	**Mean Square**	**Mean Square**	**Mean Square**
Ste	1	0.123**	61.81**	321560.4**
Blk (ste)	4			
Trt	7	0.059**	53.33**	345098**
Ste x Trt	7	0.03	0.97**	9768.1**
Blk x (Ste)	28			
D	1	0.37**	225.64*	2322355*
Ste x D	1	0.00 NS	0.35*	3588.04 NS
Ste x Blk x D (Ste)	7			
c. Crop characteristics and fuel consumption				
		ERI	**Yld**	**FC**
Source	Df	**Mean Square**	**Mean Square**	**Mean Square**
Ste	1	1.25**	4.136**	12.83**
Blk (Ste)	4			
Trt	7	11.71**	1.616*	1593.44**
Ste x Trt	7			

*Significant at $\alpha = 0.05$ **Significant at $\alpha = 0.01$; Ste = Site-1 ARA, UAF and Site-2 PARS, BDB & BDA = soil bulk density before and after planting; MCB & MCA = soil moisture content before and after planting; PRB & PRA = soil penetration resistance before and after planting; ERI = emergence rate index (% seeds emerged per day); Yld = grain yield, (t ha^{-1}); FC = fuel consumption (L ha^{-1})

Table II: The effect of different treatments on emergence rate index, fuel consumption, grain yield and irrigation water requirement

Soil cutting index	**Trt**	**Ste 1**				**Ste 2**			
		ERI (%)	**FC (L ha^{-1})**	**Yld (t ha^{-1})**	**Ign (m^3 ha^{-1})**	**ERI (%)**	**FC (L ha^{-1})**	**Yld (t ha^{-1})**	**Ign (m^3 ha^{-1})**
γ 1	γ 1C1	11.32 d	18.57 b	4.43 c	2864.69 c	11.33 cd	17.92 c	3.56 cd	2812.63 c
γ 2	γ 2C1	11.47 d	17.40 d	4.46 bc	2859.81 c	11.63 c	15.63 e	3.77 c	2814.79 c
γ 3	γ 3C1	12.34 c	16.04 e	4.51 bc	2884.81 c	12.11 c	15.46 e	3.81 c	2892.19 c
γ 1	γ 1C2	14.48 a	19.56 b	5.49 a	2842.51 c	14.05 a	17.53 c	4.79 a	2816.12 c
γ 2	γ 2C2	13.27 b	17.59 d	4.85 b	2870.81 c	12.91 b	18.73 b	4.64 a	2843.16 c
γ 3	γ 3C2	12.74 bc	16.86 d	4.77 b	3004.08 b	12.83 b	16.76 d	4.11 b	2965.36 b
	Con	10.37 d	63.75 a	3.93 d	3141.08 a	9.35 e	61.96 a	3.30 e	3134.39 a
	Z	10.75 d	15.71 e	3.90 d	2727.68 d	10.31 de	13.21 f	3.48 de	2727.10 d
Mean		12.14	23.18	4.53	2897.18	11.82	22.15	3.94	2875.72
LSD (α=0.05)		0.8451	0.7286	0.3903	52.016	1.1352	0.5643	0.1975	84.451

Means with the same letter in each column are not significantly different at $\alpha = 0.05$; Ste 1 = ARA, UAF; Ste 2 = PARS; C1 = Coulter with 25.4 mm wide wave; C2 = Coulter with 50 mm wide wave; γ 1, γ 2 and γ 3 = Soil cutting indexes 3.14, 2.36 and 1.54 respectively; C = Conventional; Z = Zero tillage

It could be concluded that an optimum value of bulk density might accelerate the ERI values. PR value of about 733.3 was optimum and favorable for accelerating ERI values (Fig. 3). The loose soil with low penetrating resistance and more compact soil with high penetrating resistance were ineffective in increasing ERI. The loose soil did not expose seed to proper soil contact, which definitely had reduced the water movement from soil towards seed for fair germination and the lower ERI values at higher soil bulk densities might had decreased soil aeration and impeded seedling emergence.

Treatments resulting in fast emergence should be given due consideration (Fig. 4). In present investigation, coulter wave 50 mm wide at a soil cutting index of 1.54 was the most favorable treatment for increasing the ERI and ultimately boosting up the crop yield. Conventional treatment resulted in significantly greatest values of fuel consumption (Ste-1=63.75 L ha^{-1} & Ste-2=61.96 L ha^{-1}) and irrigation water requirement (Ign) for crop production (Ste-1=3141.08 m^3 ha^{-1} & Ste-2=3134.39 m^3 ha^{-1}) than the values at all the other treatments (Table II). This new system of planting saved on an average 3.2 times fuel energy and 1.1 times irrigation water and increased crop grain yield by 1.4 times as compared with conventional method of wheat sowing. The results are in line with the findings of Rautaray (2004), Brula (2002) and Iqbal *et al*. (1995). Zero tillage treatment stood second in order for fuel consumption and irrigation water requirement for crop

Fig. 2: Effect of soil bulk density (Mg m^{-3}) on seed emergence rate index (ERI)

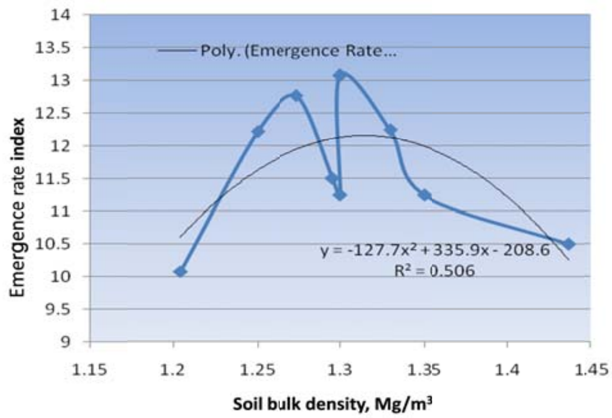


Fig. 3: Effect of sil penetration index (kPa) on seed emergence rate index (ERI)

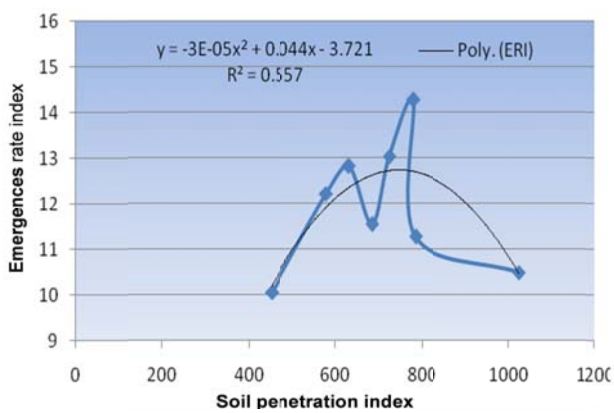
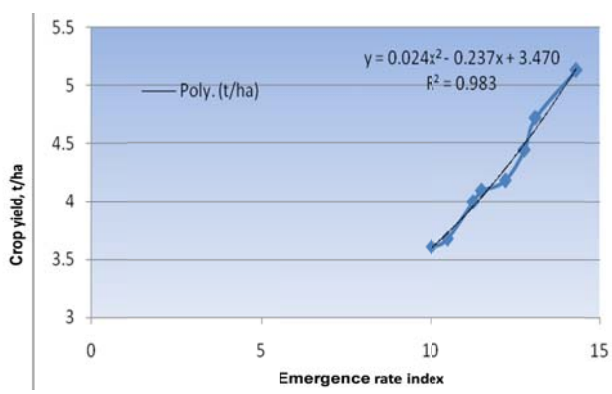


Fig. 4: Effect of seed emergence rate index (ERI)on crop grain yield (tha^{-1})



production at both the sites. All the treatments related to zone disk tiller produced more ERI and grain yield with less fuel consumption and less water consumption than the conventional and zero tillage treatments. The study concluded that both the conventional tillage treatments were uneconomical to be employed by the farming community in rice-wheat rotation system. Since the use of energy efficient zone disk drill saved an average 3.2 times fuel energy and 1.1 times irrigation water and increased wheat grain yield by 1.4 times as compared with the conventional method of wheat sowing therefore, it is proposed that the new machine should be adopted by the farmers and operated at cutting index of 3.14 attached with a 46 cm diameter coulter having a wave of 5 cm.

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(Received 06 January 2012; Accepted 13 June 2012)