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ISSN 1028-8880

# Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 10 (22): 4050-4056, 2007
ISSN 1028-8880


# Evaluation of a New Tillage Tool; Considering Soil Physical Property, Energy Requirement and Potato Yield

M.A. Ghazavi
Department of Agricultural Machinery, Shahre-Kord University, Saman Road,
P.O. Box 115, Shahre-Kord, Iran

**Abstract:** Two series of field experiments were conducted for this comparison study, one in the UK and the second in Iran. First, the effects of each implement on the soil structure were investigated. Then these implements were used in the preparation of a potato seedbed for a final evaluation. Soil physical changes were measured including soil aggregate size analysis, cone penetrometer resistance, bulk density, surface relief and soil moisture content before and after cultivation. The field experiments concluded that an overall improvement of about 40% in output (ha $h^{-1}$) could be obtained when using the new plow (combination of disk and chisel) compared with a conventional plow. The aggregate analysis of the cultivated layer revealed that the performance of the two machines was largely similar and no significant differences were seen in potato production rates during two years of field experiments, indicating no disadvantage from using an alternative to the moldboard plow.

**Key words:** Soil preparation, potato, disk, chisel and moldboard plow, soil property, energy

## INTRODUCTION

In world food production, the potato is an important crop along with wheat and barley. In 2001, the world production of potato was estimated at about 307 million metric tons (Fennir, 2002). Increasing population and limited arable land have caused researchers to focus on the increased mechanization of potato production (Rembeza, 1993; Bentini, 1992), including soil preparation, planting, protection, harvesting and post harvest operations (Spiess, 1994; Gupta *et al*., 1994; Ridder *et al*., 1993). In fact any improvement in mechanization can affect the quality and quantity of potato production (Bentini, 1992).

One of the most important goals in tillage is maintaining a high degree of aggregation in a soil, because then roots can develop and penetrate the soil better and the maximum amount of water can be stored for plant needs. In addition, aggregated soil surface particles resist breakdown under rainfall better, preventing sealing over and allowing maximum water intake, reducing erosion due to runoff and reducing the breakdown of aggregates into fine particles which are transported by water. Also aggregated soil particles provide improved resistance to compaction by wheels or tracks of tractors and field machines and to the action of tillage machines (Ghazavi, 2004).

Tillage implements are significant part of the cost involved in an agricultural system. The researchers have concentrated on energy and draft requirement aspects because it is an important factor in decreasing cost and increasing work rate (Amran *et al*., 1999; Kasisira and du Plassis, 2005; Rohit and Raheman, 2005; Sayin *et al*., 2004).

There is no standard tillage system used in the preparation of potato fields, but it is obvious that as few operations as possible would be better to save time and energy and to reduce excessive soil compaction. The wide range of soil types on which potatoes are grown and the variety of tillage implements available for soil preparation are two important factors in tillage management. The correct amount of crop residue must be incorporated into the soil to allow the planter to work without trouble. The amount of tillage required to do this will depend upon the soil type and the ability of the planter to operate properly in crop residues. Tillage should produce enough loose soil to allow the planter shoe to penetrate to the desired depth and to provide the hilling tools with enough loose soil to construct a proper hill over the seed.

In certain soil types, the use of an inappropriate tillage tool, or cultivation at an unsuitable soil moisture content, will produce excessively strong soil aggregates that will remain intact throughout the growing season and into harvest. These soil clods affect tuber form and quality and also are difficult to separate from the potatoes on the mechanical harvester, thus reducing harvester efficiency and increasing harvesting cost. Hard dry clods that come into contact with the tubers on the harvester and other handling systems can cause black spot bruising. Further bruising can be created by the clod elimination mechanisms or methods used on the harvesters.

The most common tillage procedure is to plow down the previous year's crop residue with a moldboard plow in the fall or spring. Then a disk is used in the spring to break large soil clods. This is normally followed by a third operation with a spring tooth harrow that levels or smooths the soil and can incorporate fertilizer (Skorupinska and Wasilewska, 1993; Unger, 1994).

Spiess (1994) and Edwards *et al.* (2000) reported that mulch treatments in soil preparation can reduce erosion and compaction, improve soil conditions for crop water and nutrient uptake and potentially increase yield. Agebede (2006) found effects of four tillage methods on soil properties and yam yield. An investigation is necessary to compare the performance of a moldboard plow with other tools that can leave some plant residue on the soil surface. Therefore, some experiments were performed in this study to compare the performance of a combination plow with that of a moldboard plow and to study their energy requirements, soil behavior and potato yield (Lutter *et al.*, 1991; Doerkes, 1992; Ghazavi, 1997).

## MATERIALS AND METHODS

Two series of experiments were carried out during 8 years. The first was conducted on the Nafferton Farm at the University of Newcastle Upon Tyne, UK. The soil was a sandy clay loam and its physical properties were measured before and after the tillage treatments, which were conducted immediately after the harvest of a barley crop in August 1995. The average soil moisture content at the time of treatments and measurements was 19.4%. The soil physical property and energy measurement tests and instruments are shown in Table 1. All tillage draft measurements were carried out using a Zetor model 7211, 56 kW tractor equipped with a three point linkage dynamometer developed at the Koln Fachhochschule, Germany. Data acquisition was achieved through a notebook computer with an Amplicon 226 16 channel data acquisition card (Ghazavi, 1997). The Microsoft Windows based software system used was from Signal Centre Inc. Eight channels were used to collect the required data from six force transducers, one speed meter and a position sensor attached to the tractor linkage. The complete real-time PC laboratory was mounted within the tractor cabin with three transducers placed exterior to the cab between the implement and the tractor. The transducers measured the vertical and horizontal forces used to calculate tillage energy data during field operations. To measure 3-point linkage angles, a linkage position sensor was mounted at the end of the lift-arm shaft. A small generator was used as a signal for ground speed measurement, mounting on the axle of a fifth tire connected to the frame by a universal joint at the front of the tractor. A three-point hitch dynamometer that was designed by Lutter *et al.* (1991) was used to measure implement energy following the method of Doerkes (1992). This dynamometer comprised two bottom-link transducers and one on the top link and left the geometry of the tractor linkage unchanged.

Table 1: Soil physical property and energy measurement tests and instruments

| Tests | Instruments |
|---|---|
| Soil moisture content | Core sampler |
| Dry bulk density | Core sampler |
| Cone-index | Bush penetrometer |
| Soil aggregate | Special core sampler and BS siews |
| Soil roughness | Microrelief-meter |
| Energy measurement | 3 point linkage dynamometer |
| Speed | Speed meter |
| Angle of the 3 point linkages | Linkage position sensors |
| Data collecting | Dasylab data acquisition system |

The Signal Centre software is specifically designed for data acquisition applications. It allows mathematical functions and file handling operations to be carried out on the data as it is being collected through the Amplicon 226 data acquisition card. Further facilities included on-screen information regarding the data during collection. Its flexible design allowed it to be used for a large number of diverse applications.

In the first series of experiments, tillage tests were conducted using a fully randomized strip design with four replications of the tillage treatments. The plots in each experiment were 100 m in length and 4 m wide. The tillage instruments were tested, an improved disk plow (combination of disk and chisel tine), a conventional three furrow moldboard plow. The combinatory plow was designed by Yule and Roddy (1994) and it was completed by Ghazavi (1997) with some modifications.

A second series of experiments was conducted on a clay soil in the Khatoon Abad Farm at the Islamic Azad University of Khorasgan in Isfahan, Iran. The implements tested were the high speed disk plow and a conventional three furrow moldboard plow. The plots were the same size as that in the first series of experiments mentioned above. A randomized complete block design was used to compare the primary tillage machines' behavior on potato growing. A manually fed planter was used to plant the tubers at 6 cm below the surface of the soil in the last week of March 2000 and 2001. Four workers fed the seeds manually onto a rotating disk before the seeds were dropped in the soil. After planting and as the plants began to grow, the same cultivation was performed each year using the same implements. This was a mechanical press that piled soil on top of the seeds to produce a hill structure. Nearly flat coverage was provided by the hill to protect the growing tubers from becoming sunburned. The irrigation system and other conditions were similar for all plots.

At harvest, a tractor semi-mounted direct potato harvester produced by the Sabzdasht Company in Isfahan, Iran was used. The harvester dug the potatoes from the rows and immediately passed them to the separator within the machine. A day before mechanical harvesting, some potato samples were taken by hand and carried to the laboratory for different tests and measurements on tuber yields.

## RESULTS AND DISCUSSION

In Fig. 1-5, samples of the results of penetrometer cone index, dry bulk density and soil moisture content are illustrated in the plow layer, which was considered to be of 25 cm depth. In terms of the soil cone index, the moldboard plow left the soil in the weakest condition, while the improved disk plow achieved better consolidation at Nafferton Farm. The same results were seen in some experiments at Khatoonabad Farm. Cone index measurements were consistent with soil dry bulk density results, while the measurement of soil moisture content showed that the conventional moldboard plow caused losses in moisture content, probably due to soil inversion. Cone-index and dry density increased with depth of plowing. Comparison of dry density and cone index versus depth before and after cultivation resulted higher soil resistance in uncultivated plots, then in cultivated field by improved disk plow and moldboard plow, respectively. Resultly, the improved disc plow output is closer to uncultivated field condition than the moldboard plow output. Possibly due to amount of operation occurred by each implement in the field or clod breakdown (Owende and Ward, 1990; Gemtos *et al*., 1999; Raper *et al*., 2000).

In the series of experiments reported in this section, conditions were dry by United Kingdom standards with an average moisture content in the cultivation layer of 19 g/100 g of dry mass. The energy measurement

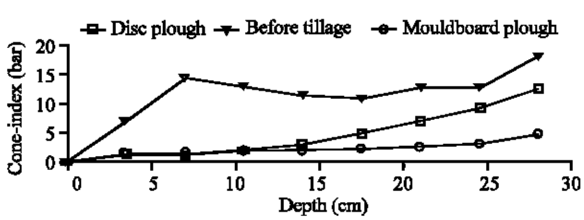


Fig. 1: Soil cone index in the plow layer before and after tillage (Nafferton Farm)

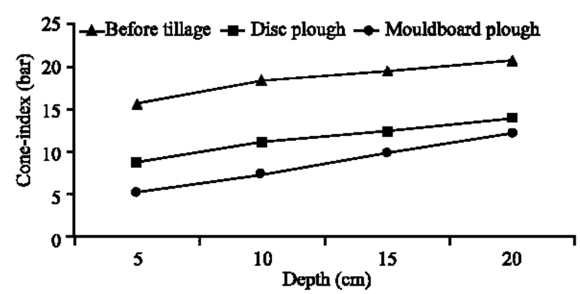


Fig. 2: Soil cone index in the plow layer before and after tillage (Khatoonabad Farm)

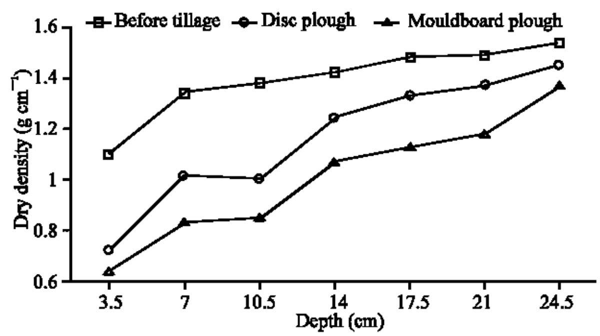


Fig. 3: Soil dry density in the ploe layer before and after tillage (Nafferton farm)

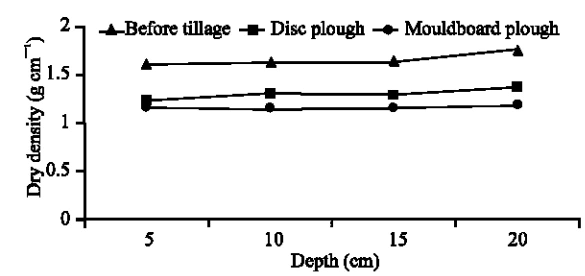


Fig. 4: Soil dry density in the plow layer before and after tillage (Khatoonabad Farm)

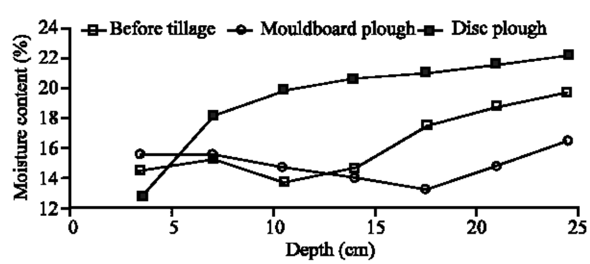


Fig. 5: Soil moisture content in the plow layer before and after tillage (Nafferton Farm)

Table 2: Plot means, average and mean square of draft (KN), tractive power (KW), peak draft, peak TP and speed for two kinds of Plows

| | Tractive power | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Draft KN | | KW | | Peak draft | | Peak TP | | Speed | |
| Plot | ID[a] | MP | ID | MP | ID | MP | ID | MP | ID | MP |
| 1 | 13.76 | 20.10 | 11.490 | 13.14 | 16.20 | 28.51 | 16.20 | 25.50 | 3.00 | 2.39 |
| 2 | 13.63 | 16.22 | 11.190 | 12.14 | 18.74 | 30.50 | 16.89 | 22.66 | 2.96 | 2.34 |
| 3 | 14.82 | 16.47 | 12.490 | 12.49 | 18.28 | 24.69 | 21.22 | 18.82 | 3.04 | 2.44 |
| 4 | 13.17 | 15.73 | 9.680 | 13.14 | 16.24 | 21.60 | 13.86 | 19.92 | 2.89 | 3.08 |
| Average | 13.84 | 17.13 | 11.210 | 12.72 | 17.36 | 26.32 | 17.04 | 21.72 | 2.97 | 2.56 |

| SV | df | MS | | | | |
|---|---|---|---|---|---|---|
| Plow type | 1 | 21.58* | 4.59* | 160.56** | 43.85* | 0.34* |
| Error | 6 | 2.25 | 0.80 | 8.76 | 9.09 | 0.06 |
| CV | | 9.69 | 7.47 | 13.55 | 15.64 | 9.03 |

a: ID = Improved Disk Plow and MP = Moldboard Plow; *, ** = Significant at $p<0.05$ and 0.01, respectively

results of the different tillage implements are shown in Table 2. In the tractive effort measurements, the minimum coefficient of variation was seen with the moldboard plow. When examining draft, the moldboard plow results had a greater coefficient of variation than those of the high speed disk plow. Yet when examining values for tractive power, the moldboard plow had a reduced level of variation in relation to the improved disk plow. The data can be explained by the response of the tractor to sudden increases in draft. With the moldboard plow, because of the higher loading, increases in draft were met with a drop in tractor speed, whereas with the improved disk plow the tractor had enough reserve power and speed to be less responsive to sudden change in draft, where the coefficient of variation was higher for the moldboard plow results than for the improved disk plow. Also, the mean, minimum and maximum values of draft were lower for the improved disk plow than for the moldboard plow in all experiments.

The highest draft and tractive power was required by the moldboard plow. A significant difference was seen between the draft and draft power measurements of the improved disk plow and the moldboard plow. These results are largely consistent with those of studies carried out by Yule and Roddy (1994) and Gol *et al*. (2007).

The peak measurements can be a good indication of the maximum energy requirement for the purposes of tractor selection or implement design. Farm managers need to know tractive power and total power required in order to select suitable and economical tractors for their implements. Design engineers can use the draft force to calculate the resistance of the machine parts and also they can select different materials with which to manufacture the machinery. A comparison of peak tractive power measurements resulted a result similar to those mentioned above. A highly significant difference was seen between the implements with respect to the peak draft.

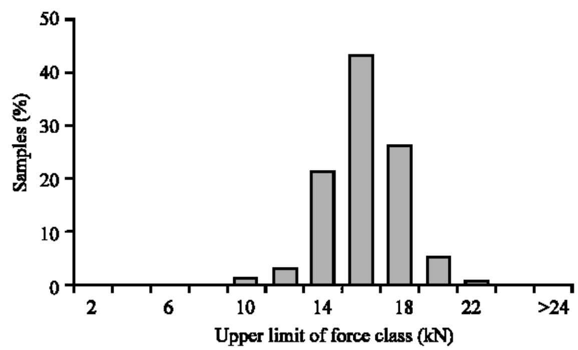


Fig. 6: Frequency distribution of the improved disk plow draft forces (Nafferton Farm)

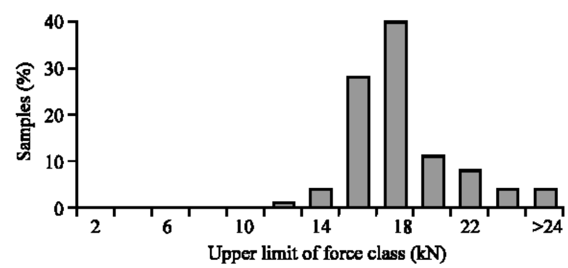


Fig. 7: Frequency distribution of the moldboard plow draft forces (Nafferton Farm)

Frequency distributions show the profiles of the forces encountered by each machine (Fig. 6, 7). The range of 0 to 26 kN was divided into 13 force classes of 2 kN range each and the percentage of samples in each range is shown. The upper limit of each of these force classes is indicated as the x-axis. The graphs give an insight into the composition of each mean value for draft. The skewness values were 1.4 and 1.6 and the kurtosis quantities were 0.9 and 1.5 for the modified disk plow and moldboard plow, respectively.

Table 3: Profile Length Ratio (RZ), surface relief area and MWD of experiment

| | Experiment-1 | | Experiment-2 | |
|---|---|---|---|---|
| Measurement | Improved disk plow | Moldboard plow | Improved disk plow | Moldboard plow |
| Height (H) (mm) | 11.550 | 8.66 | 9.91 | 10.15 |
| Profile length ratio (RZ) | 1.030 | 1.06 | 1.04 | 1.05 |
| Surface relief area ($m^2$) | 1.116 | 1.08 | 1.06 | 1.05 |
| Mean Weight Diameter, (MWD) (mm) | 2304.000 | 2053.00 | 1223.00 | 1330.00 |

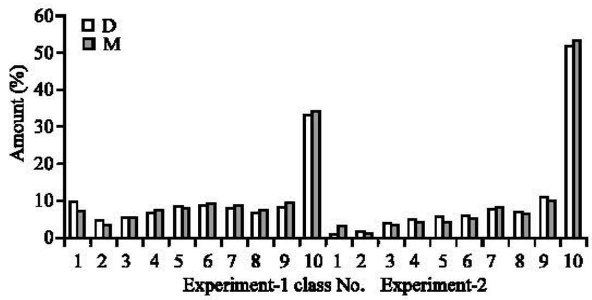


Fig. 8: Soil plow layer sieve size classification after cultivation (Nafferton Farm)

Aggregate size distribution revealed broadly consistent results between machines. Experiment 2 provided better conditions for clod breakdown, with a higher percentage of aggregates below 6.3 mm (class 10) for the 2 implements. The correspondence between sieve class number was categorized as numbers (1-10) and size in mm (>75-<6.3) orderly.

Figure 8 shows the results from experiments 1 and 2 were primarily influenced by differences in moisture content between the two experiments. Clod breakdown appeared to be broadly comparable between implement treatments in both case, however the very dry conditions in experiment 1 led to increased clod strength and poorer breakdown. The mean weight diameter is slightly higher in experiment 1, but again increased soil moisture and easier soil breakdown conditions meant that this difference was reduced in experiment 2 significantly due to T test result.. Profile Length Ratio RZ (total surface area per 1 square meter area) comparison was not significant, where as T test showed difference between them significantly (Table 3) (Ghazavi, 1997).

The costs of operating each machine were calculated based on the following data (Ghazavi, 1997):

- Fifty ha per annum work, interest on capital 10%, straight line depreciation, 10 year life.
- Machine costs: 3 furrow plow 5000US$, 3 furrow disk plow 4400$.
- Work Rates: Moldboard plow 0.56 ha $h^{-1}$, improved disk plow 0.66 ha $h^{-1}$.
- The hire cost of the 56 kW tractor was $23 $Ah^{-1}$.

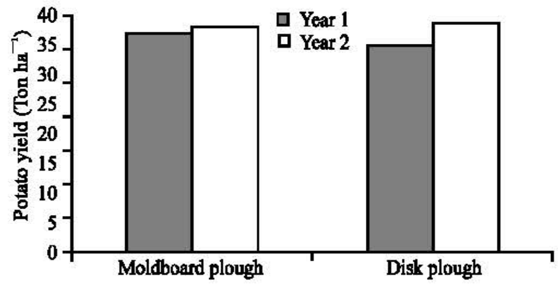


Fig. 9: Potato production rate for the moldboard plow and the improved disk plow in two different years (Khatoonabad Farm)

Fig. 10: An improved disk plough picture (combinatory)

It was observed that the main advantage of using the moldboard plow was its more complete soil inversion which allowed good burying of trash. The improved disk plow achieved good mixing with a relatively clear soil surface and it had the advantage of being cheaper to operate with a faster work rate than the standard moldboard plow. Although the degree of soil inversion was less than the moldboard plow and more plant residue was-left on the soil surface, the improved disk plow was able to reduce moisture loss in late summer and autumn conditions (Fig. 9, 10).

## CONCLUSIONS

Soil physical changes before and after cultivation and also, energy requirement are the most important factors to evaluate a tillage tool. There is a relationship between soil physical parameters such as soil type, moisture content, dry density, cone-index, mean weight diameter, RZ etc., energy requirement and yields of products. (Desbioles *et al.*, 1997, 1999; Ghuman and Sur, 2001; Rohit and Raheman, 2005; Natsis *et al.*, 1999).

The use of Improved Disk Plow was an effective method to reduce the force; incorporate soil, moisture and residue better for improving the soil fertility; achieve suitable pulverization and soil mixing and leaving some residue on the surface to reduce soil erosion and water running; better dynamics of soil engaging due to speed operation comparison result. However, it is exempt of creating hard pan layer and has the advantage of being cheaper to operate with a faster work rate than the standard moldboard plow especially in arid and semi arid area like Iran (Yule and Roddy, 1994; Gol *et al*., 2007). Over all, the new plow as an alternative implement gave good performance and would appear to offer a financial advantage to farmers, making it worthy of further development and testing. Also, it can play a main role in potato mechanization.

Further studies should be done to investigate the effect of new tillage management on potato quality and quantity.

## ACKNOWLEDGMENTS

The author acknowledges the financial support from the Shahre-Kord University and Islamic Azad University (Khorasgan branch) of Iran that made this research work and study possible.

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