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# NOTE

# A COMPARISON OF THE PERFORMANCE OF A HIGH SPEED DISK PLOUGH AND A GENERAL PURPOSE MOULDBOARD PLOUGH

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## ABSTRACT

A comparative study of two primary tillage tools was carried out at Nafferton Farm, University of Newcastle Upon Tyne, England. The experiments were conducted to investigate soil physical changes due to the effect of each implement in the soil. The primary tillage tools tested were, a general purpose mouldboard plough and a high speed disk plough developed at Newcastle University, which combines the use of tines and disks. The energy input was measured using a 3-point linkage dynamometer with an on board data acquisition system. Soil physical parameters including soil aggregate analysis, cone penetration resistance, bulk density, surface roughness, soil moisture content and soil mixing were compared. The aggregate analysis of the cultivated layer revealed that performance of the machines were broadly similar in terms of their physical effects on the soil, indicating no disadvantage from using the alternative to the mouldboard plough. The total power requirement for both ploughs were similar at forward speed of 3 km $h^{-1}$ but the high speed plough offers the potential of greater output through higher operating speeds.

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# مقایسه عملکرد گاوآهن برگرداندار و گاوآهن بشقابی سریع کار

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به ترتیب دانشجوی سابق دکترا (اکنون استادیار گروه ماشین های کشاورزی، دانشگاه شهرکرد، شهرکرد، ایران) و استاد دانشگاه نیوکاسل انگلستان، انگلستان.

## چکیده

مطالعه ای مقایسه ای بین دو گاوآهن شخم اولیه در مزرعه نافرتون دانشگاه نیوکاسل انگلستان انجام شد. برای بررسی تغییرات فیزیکی حاصل از هر کدام در خاک آزمایش ها یی به عمل آمد. ادوات خاک ورزی اولیه شامل یک دستگاه گاوآهن برگرداندار ویک دستگاه گاوآهن بشقابی سریع کار بود. گاو آهن بشقابی جدید از ترکیب تیغه های قلمی و بشقاب در دانشگاه نیوکاسل ساخته شده است. انرژی مورد نیاز هر یک توسط یک دینامومتر مخصوص اتصال سه نقطه مجهز به سیستم جمع آوری و انتقال داده ها اندازه گیری شد. تغییرات فیزیکی اندازه گیری شده عبارت بودند از: تجزیه اندازه خاک دانه ها، مقاومت به نفوذ، جرم مخصوص ظاهری، ناهمواری سطح زمین، رطوبت موجود در خاک و میزان مخلوط کردن مواد در خاک. تجزیه وتحلیل اندازه کلوخه های لایه شخم شده حاکی از آن بود که تأثیرات فیزیکی حاصل از اجرای دو دستگاه مذکورمشابه بوده و کاربرد دستگاه جدید معایبی در پی ندارد. قدرت مورد نیاز هر ماشین نیز در سرعتهای حدود ۳ کیلو متر در ساعت مشابه بود. لیکن، دستگاه جدید، عملکرد بهتری در سرعت های بالاتر پیشروی، داشت.

## INTRODUCTION

Water harvesting is one of the most important purposes of agricultural management specially in semi-arid areas of the world. It can be an important factor for increasing crop production. The shape of soil surface and soil roughness can play an important role in successful water harvesting. The tillage tools can be used to create reasonable surface roughness for water catchment. Other soil physical properties such as: soil bulk density, porosity, cone-index and soil aggregate size distribution are important for this study.

Tillage can amend water penetration in the soil by altering the soil porosity, creating a surface roughness or surface conditions which decrease water running. It can reduce evaporation and conserve moisture in the soil during the dry season. The root system can easily penetrate into the soil and enhance water uptake.

A number of studies have been conducted to investigate and compare the effect of various tillage tools on increasing soil water uptake. For instance, Makungu (5) conducted a comparative study on a number of primary and secondary tillage tools (mouldboard plough, disc plough, tandem disc, chisel plough, subsoiler, rotary tiller, rotary hoe and rod weeder) and found very good results on mouldboard plough with respect to water storage. But research has not been conducted on the high speed plough. Thus it would be necessary to compare this new machine with mouldboard plough. Our main aim was to compare mouldboard plough and high speed disk plough with respect to water catchment, with the effects of each one on the soil physical conditions and the energy requirement during the cultivation operation as the secondary objective.

## MATERIALS AND METHODS

As part of the project, a data acquisition system was commissioned which allowed all of the energy input data to be recorded. The system was designed as a comprehensive data acquisition and processing tool. Components measured included vertical and horizontal forces in the three point linkage, a position sensor to determine the angle of the linkage in relation to the tractor and a speed meter. These signals were processed through an Amplicon 226, 16 channel data acquisition card which was connected to a ruggedised notebook computer mounted in the tractor cab. The software used was Signal Center®[1] which allowed data processing to be carried out in real time while conducting the field experiments as well as recording data to various file formats. A Zetor model 7211, two-wheel drive tractor with 70 hp was used in all the tests.

Under the field experiments, a general purpose three-bottom mouldboard plough was used. The high speed disk plough was that designed by Yule and Roddy (10) with minor modifications. Scott and Yule (7), developed and tested an improved disk plough at the University of Newcastle Upon Tyne. Yule and Roddy (10) redesigned it and carried out some experiments. This machine is a 4 disk plough with an individual rigid tine in front of each disk. The disks are mounted on a beam behind the tine, in which a shear bolt protects each furrow unit from any obstruction, Each furrow unit comprises of a rigid tine and a 710 mm disk, mounted on a common beam. The reasons for the modifications were to improve rigidity of each disc and hub assembly in individual clamps during hard operation and to reduce the draught requirement (4). The combination of the disks and tines are able to displace the soil and completely mix it with straw provided the working depth was adjusted to within the optimum operation range of 200 to 250 mm and at a tractor speed of 7 km $h^{-1}$. Falling short of these values results in an inadequate performance of the plough due to insufficient soil displacement and soil/straw mixing. Fig. 1 shows the high speed plough used in the present study.

Field experiments were conducted at Nafferton Farm, located about 20 km west of Newcastle Upon Tyne, where the agricultural engineering projects could be developed at the Nafferton Farm workshop, tested and

1. Signal Center® is a registered trade mark of Signal Center, Broughton Grange, Headlands, Kettering Northants, NN15 6XA, UK.

carried out in different fields. Redesign of the improved disk plough, development of the energy measurement system and soil physical property measurement instruments and also their testing and calibrations were carried out at the workshop. The experiments were done at Welton Field. Soil texture was sandy clay loam (Table 1).

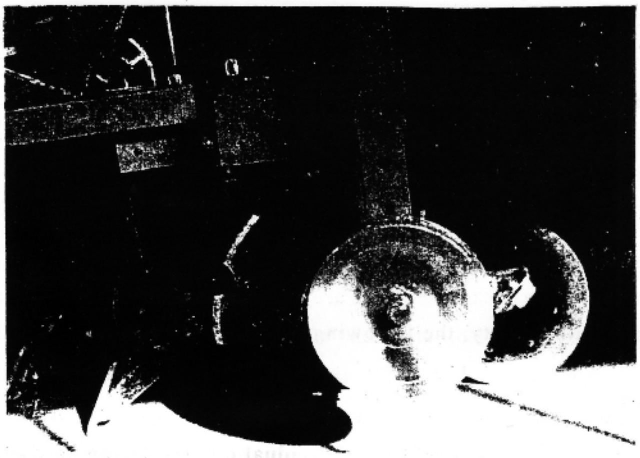

Fig. 1. The high speed plough picuture.

Table 1. Soil texture analysis results.

| Particle | (%) |
|---|---|
| Sand | 52.46 |
| Silt | 25.20 |
| Clay | 22.34 |
| Carbon | 2.20 |
| Organic matter | 3.74 |

A fully randomized strip design on two experiments with four replications of the three tillage treatments was used. The 12 plots in each experiment were 100 m in length and 4 m wide. Prior to starting tillage operation, base-line data for bulk density, moisture content, penetration resistance and surface roughness were collected. The tillage treatments were then applied to each plot. Disturbed soil cores to a depth of 20 cm were taken. A core sampler was driven into the soil with a hammer provided with the sampler. It was then pulled up and the soil sample for each 3.5 cm depth was transferred to a plastic bag. Each bag was numbered for plot and treatment. The mass was determined before and after drying to constant weight at 105° C for 24 hr, and the volume of the samples as taken in the field was recorded. Samples were used to determine soil bulk density and moisture content. Equation (1) can be used for calculating the moisture content.

$$W = [(m2-m3)/(m3-m1)]\ 100\% \qquad [1]$$

where:

m1= the mass of container (g).

m2= the mass of container and wet soil (g).

m3= the mass of container and dry soil (g).

To determine bulk density, the following formula was used:

$$BD = W_{od} / V_t \qquad [2]$$

where:

BD = dry bulk density of soil, g $cm^{-3}$,

$W_{od}$ = mass of oven dried soil, g.

$V_t$ = total volume of undisturbed samples, $cm^3$.

A hand-held cone penetrometer equipped with a scale dial, was used to measure penetration resistance. Readings were recorded at every 3.5 cm to a depth of 50 cm, depths before and after the treatment.

To collect surface roughness data of the plots, the Micro Relief Meter designed by Wigglesworth (9), was used before and after the tillage in the field. A total of 20 photographs for each plot was taken. It consisted of contact pins, back board, contact pin channel "rack" guiding channel, the thread system attached to the rack, top slide rod brackets, camera and rubber. The contact pin in dark grey color was located against a white back board. There were many holes on the contact pin channel so that each contact pin has got a pair of individual hole on a vertical line. Two guiding channels were at the two ends of the back board, sliding on a section of the frame. Also, two slide rod brackets were in two end sides on the top of the white back board. A camera was placed on the end of a triangular frame, opposite to the back board at the same distance in each test. The rubber serves as a brake for the guiding channel on the frame. The tread system attached to the rack was used to raise the pins after testing. After selection of an arbitrary position in the field, the apparatus was adjusted by the legs until the frame was horizontal. The pins were lowered into contact with the soil surface. Then a photograph was taken using the standard 35 mm single lens reflex camera. The mentioned test was repeated along a length of a meter. So, the pins were arisen by the thread system; the bridge was slid a distance forward, equal to the pin spacing, that was 50 mm, to a new measuring position and the pins ware lowered again. A photograph was taken for each plot and the procedure was repeated for each transact across until the obtained area (1 $m^2$ i.e. 20 transacts at 50 mm spacing).

The depth of tillage, as the vertical distance from initial soil surface to a specified point of tool was measured after each cultivation.

A special sampler for obtaining the clod size distribution was used. The sampler was pushed by hand into the tilled layer of the soil to tillage depth. All of the samples were transported from the field to the sieve stand for separation of the clods. A set of sieves with class no. of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and clod size of >75 to <6.33 mm diameter, based on the British Standard Test Code was selected (2). The soil sample was passed through a set of sieves, and the soil retained on the sieve was weighed, as well as the soil that passed through the smallest aperture sieve. The MWD (mean weight diameter) of the individual sample was calculated and reported in Table 2. The MWD is defined as:

$$MWD = \sum X_i W_i$$

where:

$X_i$ is mid size of each sieve.

$W_i$ is the weight of aggregates of that size as a proportion of the total sample weight.

A greater MWD value indicates a greater proportion of large -sized aggregates (1).

## RESULTS

Soil conditions were dry by UK standards with an average moisture content in the cultivated layer of 18.9% in experiment 1 and 22% in experiment 2. The soil physical data is indicated in Table 2.

Energy requirements were calculated from the data collected in the field (Table 3). Energy requirements were broadly consistent in the two moisture conditions. At the similar speed of approximately 3 km $h^{-1}$, the mean of draught (Ftrc), draught power (Ptrc) and total power (Ptot) were measured. The high speed disk plough had a slightly reduced draught power requirement specially in dry conditions. Draught power is the limiting factor for primary tillage.

Table 2. Average of the mean value experimental data.

| Experiment† | Moist. Cont. (%) | Cone Index (bar) | Dry Density (g $cm^{-3}$) |
|---|---|---|---|
| 1MB | 14.85 | 2.07 | 1.01 |
| 2MB | 18.57 | 1.34 | 0.93 |
| 1TD | 16.26 | 4.10 | 1.16 |
| 2TD | 18.32 | 2.52 | 1.02 |
| 1BT | 19.37 | 11.65 | 1.39 |
| 2BT | 21.84 | 7.07 | 1.32 |

†1MB = Mouldboard plough data in experiment 1.

2MB = Mouldboard plough data in experiment 2.

1TD = Tined disk plough data in experiment 1.

2TD = Tined disk plough data in experiment 2.

1BT = Before tillage data in experiment 1.

2BT = Before tillage data in experiment 2.

Table 3. Average of the mean value energy input results from field experiments.

| Speed =3 km $h^{-1}$ | Tools | $F_{trc}$,kN | $P_{trc}$,kW | $P_{tot}$, kW |
|---|---|---|---|---|
| Experiment 1 | TD† | 12.247 | 10.206 | 10.206 |
| | MB§ | 21.999 | 18.332 | 18.332 |
| Experiment 2 | TD | 13.498 | 11.248 | 11.248 |
| | MB | 16.981 | 14.151 | 14.151 |

† Tined disk (high speed ) plough.

§ Mouldboard plough.

The aggregate analysis of the cultivated layer revealed that the performances of the machines were broadly similar, indicating no disadvantage from using this alternative to the conventional mouldboard plough.

Unimap software was used to draw the three dimensional soil surface after each tillage operation and using Arc/Info v.7 software the surface area of the soil disturbed and soil surface volume were calculated. Analysis of the data indicated no significant differences between these parameters. These results are summarised in Table 4.

Table 4. Soil physical parameters from field experiments.

| Speed | 3 km h$^{-1}$ | MWD†, mm$^{1}$ | RZ§ | S, mm$^{2}$ | V, m$^{-3}$ |
|---|---|---|---|---|---|
| Exper. 1 | TD | 2307.46 | 1.031 | 1.116 | .129 |
| | MB | 2053.19 | 1.219 | 1.075 | .093 |
| Exper. 2 | TD | 1222.72 | 1.040 | 1.057 | .104 |
| | MB | 1330.30 | 1.049 | 1.050 | .107 |

† MWD = mean weight diameter.

§ RZ = Profile length ratio.

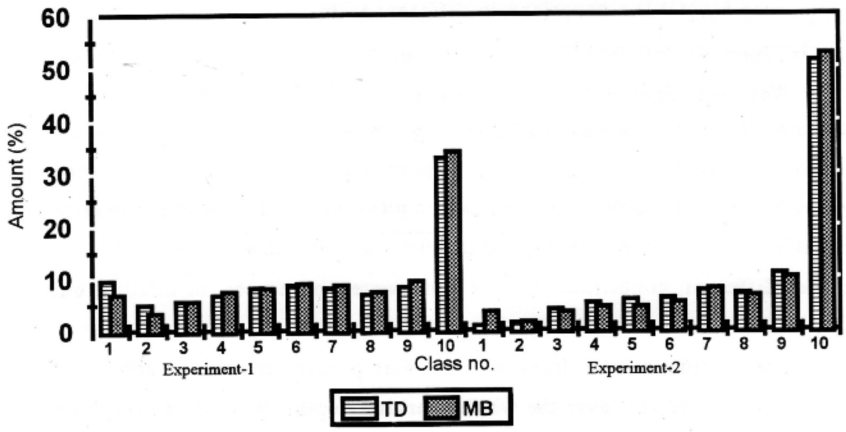


Fig. 2. The aggregation size distribution two experiments.

An aggregate size analysis of the cultivated soil was performed and very similar results were again obtained as illustrated in Fig. 3. The correspondence between sieve class number and size in mm is given in Table 5.

Table 5. Sieve class number and sieve size in mm.

| Class No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sieve | >.75 | 75- | 63- | 50- | 37- | 28- | 20- | 14- | 10- | <6.3 |
| Sizes (mm) | | 63 | 50 | 37 | 28 | 20 | 14 | 10 | 6.3 | |

## CONCLUSIONS AND RECOMMENDATIONS

A summary of the most important points drawn from the observations made during the field trials, statistical analysis and configurations are discussed in this section, as following: The field experiments concluded that an overall improvement of about 40% in output (ha $hr^{-1}$) could be obtained when comparing the improved disk plough's performance with that of a conventional plough. This can be an important factor in machinery selection when buying a tillage tool.

Dry density test and Micro Relief Meter tests showed broadly similar results between the cultivation treatments. Thus in the Relief Meter test, plough layer thickness can be used as a soil porosity indicator that it could be compared by MWD comparison in different tests.

To analyze the results of soil surface roughness test, it is not enough to use only the profile length ratio (RZ), but a height parameter would be necessary. Evaporation was greater from plots using the mouldboard plough than the improved disc plough. These appeared to be a relationship between the degree of soil movement and mixing test results and water loss after each tillage. Treatment can depend on soil and climatic conditions. Tillage induced different conditions on the soil water processes of infiltration, redistribution and evaporation.

Using a tine at the front of the disc plough, caused the mixing of surface residue and soil over the whole working depth. It would be possible to work at higher speed by using a more powerful tractor. The output was limited by the available tractor power for these experiments. In addition, soil and straw mixing and incorporation, water infiltration, stopping surface water run off, preventing soil surface crusting and soil erosion, and reducing evaporation can be of advantages for the improved disc plough. Mouldboard plough inverts the soil more completely. It is recommended that the two machines be used in some experiments in different areas with different conditions. Although, the mouldboard plough is a standard tillage tool, the improved disk plough with the mentioned benefits can be as an alternative machine for tillage and rainwater catchment systems.

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