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POWER REQUIREMENT OF A BENTLEG PLOW AND ITS EFFECTS ON SOIL PHYSICAL CONDITIONS

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ABSTRACT

A 30° left hand facing bentleg plow (BL) was used to subsoil a moderately compacted clay-loam soil at three different depths (250, 350 and 450 mm) and three rake angles (7.5°, 15° and 22.5°). The tractor forward speed was maintained at kM hr^{-1} The power requirement and changes in soil physical conditions were measured and compared to those of a moldboard plow (MB) at 250 mm working depth. Draft was significantly affected by both BL characteristics and was minimum at rake angle of 7.5°. Draft $unit^{-1}$ of width of BL plow was 0.5, 1.0 and 1.4 times that of MB plow at working depths of 250, 350 and 450 mm, respectively. BL plowing decreased the soil bulk density from 1280-1500 to 1000-1350 kg m^{-3} for the depth range studied. Increase in cumulative water infiltration up to five times that of before tillage (BT) conditions and two times that of MB plowing was achieved by BL plow. The BL plow left 74% of surface residue undisturbed compared to 16% by MB plow. The cross-sectional area tilled by BL plow was larger compared to MB plowing and increased uniformly in all directions as depth was increased. The specific draft of the BL plow tilling at the depths of 250, 350 and 450 mm were 30, 46 and 40% that of MB plow, respectively. The power requirement for subsoiling with a BL plow was less than that for MB plowing and therefore it was within the

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capacity of most common tractors in local farms. The low power requirement and great improvement in soil physical conditions would suggest application of the new BL plow in many of the soils suffering from moderate to excessive compaction.

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ارزیابی توان کششی گاو آهن کج ساق و اثرات آن بر ویژگی های فیزیکی خاک

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به ترتیب دانشجوی سابق کارشناسی ارشد و استاد یار بخش ماشین های کشاورزی دانشکده کشاورزی دانشگاه شیراز، شیراز، ایران.

چکیده

عملکرد یک دستگاه گاو آهن عمیق کج ساق (BL) از نوع چپ گرد با زاویه ۳۰ درجه (زاویه تیغه نسبت به افق) به منظور رفع تراکم و بهبود سایر خصوصیات فیزیکی خاک مطالعه و با شرایط خاک قبل از خاک ورزی و خاک ورزی با گاو آهن برگردان دار (MB) مقایسه گردید. گاو آهن BL درسه عمق ۲۵۰، ۳۵۰ و ۴۵۰ میلی متر و سه زاویه نفوذ °۷/۵، ° ۱۵ و°۲۲/۵ با سرعت ۲ کیلومتر در ساعت در مزرعه ای با خاک رسی- لومی و تا حد متراکم به کار گرفته شد. عرض گاو آهن MB ، ۹۰۰ میلی متر و عمق آن در تمام آزمایش ها ۲۵ میلی متر در نظر گرفته شد. درصد پوشش گیاهی باقیمانده نسبت به حالت قبل از خاک ورزی برای گاو آهن های BL و MB

به ترتیب برابر ۷۴٪ و ۱۶٪ بود. جرم مخصوص ظاهری خاک در اثر خاک ورزی با BL از دامنه $Mg\ m^{-3}$ ۱/۵۰-۱/۲۸ به دامنه $Mg\ m^{-3}$ ۱/۳۵-۱/۰۰ کاهش یافت. نفوذ تجمعی آب در خاک تا حدود ۵ برابر نسبت به حالت قبل از خاک ورزی و ۲ برابر نسبت به خاک ورزی با MB افزایش یافت. بررسی سایر نتایج بیانگر آن است که مقاومت کششی به طور معنی داری با افزایش عمق و افزایش زاویه، افزایش یافته و بدین ترتیب برای این گاو آهن، تعبیه زاویه نفوذ $7/5^{\circ}$ برای تمام اعماق مورد مطالعه توصیه می گردد. مقاومت کششی به ازای واحد عرض کار برای اعماق ۲۵۰، ۳۵۰ و ۴۵۰ میلی متر به ترتیب ۰/۵، ۱/۰ و ۱/۴ برابر این شاخص برای گاو آهن MB بود. سطح مقطع حاصل از کار با گاو آهن BL بزرگتر از گاو آهن MB بوده و به موازات افزایش عمق، در تمام جهات به صورت یکنواخت افزایش یافت. نیروی مقاومت ویژه گاو آهن BL در اعماق ۲۵۰، ۳۵۰ و۴۵۰ میلی متر به ترتیب ۳۰، ۴۶و ۴۰ درصد نیروی مقاومت ویژه گاو آهن MB بود. قدرت مورد نیاز، کمتر از قدرت مورد نیاز گاو آهن شاهد ودر حد ظرفیت بیشتر تراکتور های مورد استفاده در منطقه بود. به لحاظ قدرت کم مورد نیاز و بهبود چشمگیر شاخص های یاد شده، استفاده از گاو آهن های BL برای بهبود اراضی تا حدی فشرده یا متراکم مناسب به نظر می رسد.

INTRODUCTION

Soils are subsoiled to fracture the compacted layers in order to increase water infiltration and root growth for various crops. A survey by Goddard *et al.* (4) disclosed that soil amelioration by deep tilling improves water infiltration and often increases yield. Some of the interest is due to the reduction in ponding and run-off during the spring snowmelt (9, 11). It is also important that adequate plant residue be retained on the soil surface during subsoiling, to control soil erosion (10). Even small amounts of plant residue helps to increase infiltration and reduce runoff. Plant residue on the soil surface, however, reduces soil temperature and may depress crop yield (8).

The working depths of 250-300 mm are common for alleviating machinery-induced compaction, but for pedogenetically compacted soils, much greater working depth is required (9). Although a number of implements, including chisel plows and conventional subsoilers, can be used for loosening and disrupting plow pans and subsurface pans, respectively, the limited working depth of the former and the high energy demand of the latter severely limits their use.

The conventional subsoilers associated with high energy requirement and possibility of natural soil recompaction have been recently replaced by deep plows such as the Paraplow (a trade mark, Howard Rotovar Co., Inc., U.S.A.) and bentleg plows (2, 3, 5, 7, 12). Erbach *et al.* (3) conducted experiments to evaluate the use of Paraplow, a tillage tool that loosens the subsoil without inversion, for continuous corn production. Their study indicated that soils tilled with the Paraplow remained less dense after planting compared to other tillage systems. However, the presence of the chisel point and adjustable flap on the back of the Paraplow result in increasing cost and energy demand. More recently the bentleg plow has been successfully used to improve soil physical properties at lower energy demand (6). Other advantages claimed for bentleg plow are fewer components and lateral equilibrium for an implement having an equal number of left and right-hand plows (5, 6).

A preliminary survey indicated that moderate soil compaction exists in some of the soils of the Shiraz University Research Farm. The present study was conducted to obtain information about the power requirement and effects of bentleg plowing on soil physical conditions in one of such soils.

MATERIALS AND METHODS

The study was conducted at the Badjgah Experimental Station, College of Agriculture, Shiraz University, located 16 km north of Shiraz, Iran. The soil was classified as Daneshkadeh soil series (fine, mixed, mesic, Calcixerollic Xerochrepts) with a cloddy structure from the surface down to 540 mm depth. The soil texture for the entire depth (0-540 mm) was clay loam and moderately compacted. The soil bulk density varied from 1.31 to 1.52 Mg m^{-3} as the soil depth was increased from 250 to 500 mm. The average moisture content of the soil was 16% (dry-weight basis) from the surface to 500 mm depth. A single 30° left-hand facing bentleg plow similar to the half-scaled model bentleg plow used by Harrison and Licsko (7) was designed and fabricated (Figs. 1 and 2). The leg of the plow was bent 60° to the side so that the leading edge of its tilling interface was 30° with respect to horizontal plane (Fig 1, angle a). This type of bentleg plow proved to be energy-efficient compared to other models studied by Harrison and Licsko (7). The leading edge of the cutting interface was rotated towards the direction of travel by 25° (Fig. 1, angle b). The bending axis for the plow was 15° with respect to the horizontal plane, thus creating a rake angle of 15° in the tilling interface (Fig. 1, angle c). Other rake angles were obtained by rotating the plow about a horizontal axis that was at right angle to the direction of travel. The desired rake angle could be selected and fixed using the holes drilled in the plow shank (Fig. 2).

The draft force, and soil physical conditions including cumulative water infiltration over 45 min., bulk density, percentage of residue cover and cross-section of soil disturbed for three working depths (D1: 250, D2: 350 and D3: 450 mm) and four rake angles (0°, 7.5°, 15° and 22.5°) were measured and compared with before tillage (BT) conditions and the control. The preliminary experiments indicated that BL plow does not penetrate well at 0° rake angle. Therefore, the study was limited to three rake angles (A1: 7.5°, A2: 15° and A3: 22.5°). A three bottom mounted general purpose moldboard plow tilling at 250 mm depth was used as control (MB). The width of cut of the moldboard plow was 900 mm.

The land had been used for wheat production for the last few years and was in a fallow phase and covered with wheat stubble prior to the tests. Experiments were conducted on 4×40 m plots arranged in a randomized complete block design with three replications. Tests were carried out in a total of 30 plots inclusive of controls. A 90 kW John Deere (John Deere

Tractor Plant, Arak, Iran) (JD-4230) tractor was used to pull a 53 kW Massey Ferguson (Iran Tractor Manufacturing Co., Tabriz, Iran) (MF-285) tractor carrying the bentleg and moldboard plows. The draft was measured and recorded by a recording spring drawbar dynamometer (Karl Kolb, Germany.) placed between the two tractors and the procedure recommended by RNAM (13) for draft measurement was adopted. The tractor forward speed was maintained at about 2 km h^{-1} throughout all experiments.

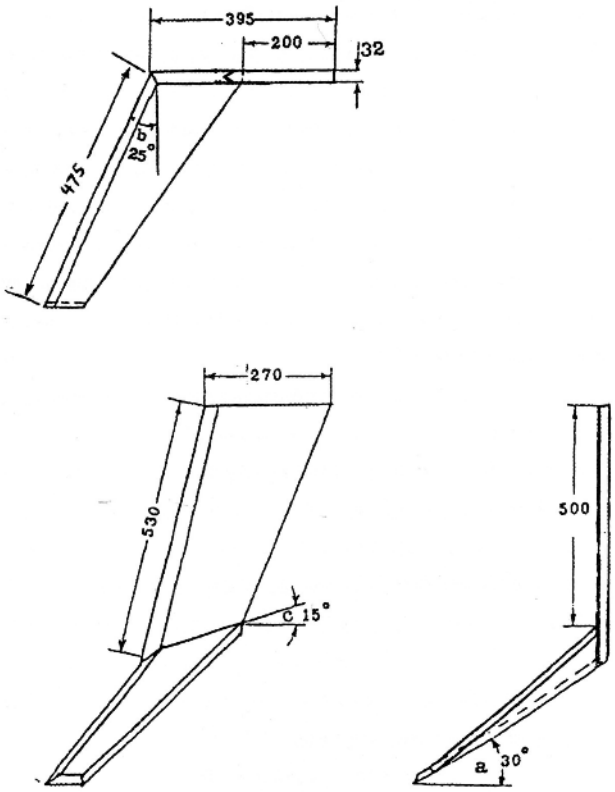

Fig. 1. Diagram of the left-hand facing bentleg plow used in this study.

Before conducting the experiments (BT) the soil bulk density of each plot was measured by a core sampler (internal diameter and height 54 and

97.5 mm, respectively) at five different depth ranges; 0-150, 150-250, 250-350, 350-450 and 450-550 mm. The measurements were replicated in three random locations in each plot. Fig. 3 shows the average soil bulk density prior to tillage at various soil depths. For measuring surface plant residue cover the method suggested by RNAM (13) was adopted. In each plot, surface plant residue cover in three randomly selected non-trafficked areas measuring 1 m^2 was collected and weighed both before and after plowing operations. The percent of surface plant residue cover was then calculated by the method suggested by RNAM (13). The cumulative infiltration over 45 min. was measured before plowing at three different locations in each plot using double ring infiltrometer as recommended by Bertrand (1). Similar measurements were performed after pulling the plow in each plot. The cross-sectional areas of the soil disturbed at three locations in each plot were estimated by measuring the cross-sectional area of the soil loosened due to the tine movement. Then, the draft and the average soil disturbance for each plot was used to calculate draft/disturbance ratio as a measure of tool performance (14,15). Measured draft forces and their corresponding implement widths were used to calculate the draft per unit of width for each treatment.

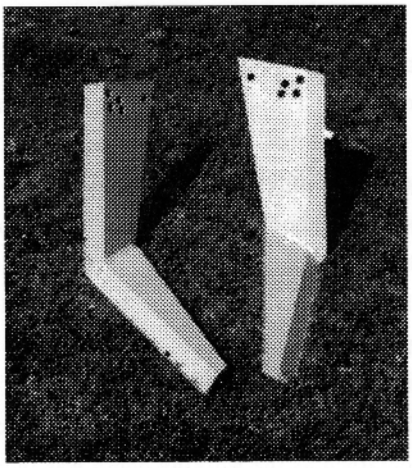

Fig. 2. A left- hand (a) and a right hand (b) facing bentleg plow.

The design of experiment was a completely randomized design with 3 replications and means were compared using Duncan's new multiple range test (DNMRT).

RESULTS AND DISCUSSION

Preliminary tests indicated that the plow penetration was impossible for the zero rake angle and therefore, the study was limited to other three rake angles indicated earlier. In similar studies (5, 7) the lack of adequate clearance beneath the bentleg plow blade caused increase in the draft and some difficulties in achieving satisfactory penetration. Implement performance is discussed in the following sections.

1. Subsoiling Operation Parameter Effects on Residue Cover

The percent of residual cover for the two conditions of MB and BL plowing were 16 and 74% as compared to BT conditions. In general, it can be concluded that the BL plow leaves almost five times more residue compared to MB plowing. Similar results have been reported by others (8). and show that this level of residue cover (74%) is sufficient for minimizing soil erosion.

2. Subsoiling Operation Parameter Effects on Bulk Density

A review of the measured data on the bulk density for the three field conditions of BL plowing, MB plowing and before tillage (BT) conditions revealed that in general tillage reduced soil bulk density, with BL plowing causing the greatest loosening (Fig. 3). Similar improvement in the soil bulk density to a depth of 250 mm could be achieved with either MB or BL plows, whereas, changing the bulk density below the plowed layer can only be achieved by BL plowing.

The analysis of variance of data on changes in bulk density for the depth range of 150 to 250 mm indicanted that a significant decrease in soil bulk density was obtained as the working depth was increased but the effect of rake angle on the bulk density was not significant. Fig. 3 shows the average bulk density for the three conditions of BL plowing, MB plowing and soil prior to tillage at various depths.

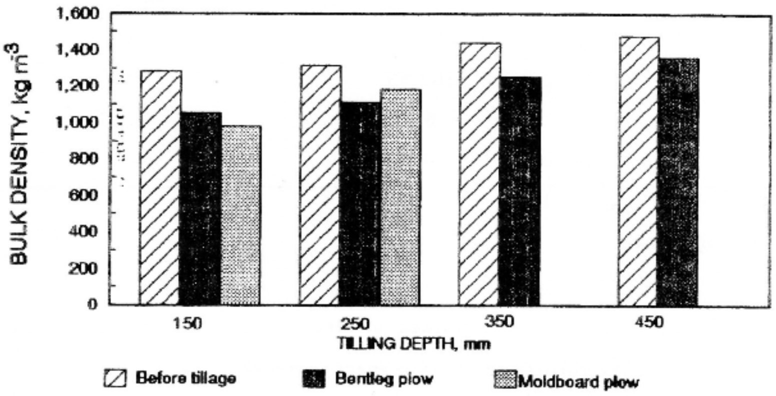

Fig.3. Effect of tillage systems on bulk density at various depths.

The bulk density of the soil underneath the tilling edge of the BL plow was measured and compared to that of untilled soil (BT condition). Close examination of the data revealed there was not any compact zone in the vicinity of the cutting edge of the tool.

3. Subsoiling Operation Parameter Effects on Water Infiltration

The analysis of variance of the cumulative infiltration over 45 min as affected by depth, rake angle and their interactions is shown in Table 1. The subsoiling depth significantly increased cumulative infiltration whereas the rake angle had no effect. The means of cumulative infiltration as affected by depth and rake angle are compared in Tables 2 and 3. The means of infiltration for all treatments of BL plow, MB plow and BT condition are compared in Table 4. The comparisons reveal that where tilling with MB plow increased infiltration about three times compared to conditions prior to tillage, BL plowing increased the cumulative infiltration up to 5 times that of BT conditions.

Table 1. Anlysis of variance for the draft force and cumulative infiltration.

Source	df	Mean squares	
		Draft force	Cumulative infitration
Replications	2	0.35^{NS}	0.30^{NS}
Treatment	8	65.13**	18.65**
Rake angle (A)	2	83.57**	0.40^{NS}
Depth (D)	2	162.99**	72.35**
A×D	4	6.97**	1.10^{NS}
Error	16	0.12	1.33

** Significant at P<0.01.

NS Nonsignificant.

Table 2. Comparison of mean values of draft unit^{-1} of width, power and cumulative infiltration with respect to depth.

Plowing depth (mm)	Draft unit width^{-1} (kNm^{-1})	Power (kW)	Infiltration over 45 min (cm)
BL (250)	9.59 a†	2.32 a	6.21 a
BL (350)	17.90 b	4.68 b	9.21 b
BL (450)	26.99 c	7.05 c	11.79 c
MB (250)	19.14 b	9.57 d	5.90 c
BT			2.37 e

† Means in each column followed by the same letter are not significantly different at P<0.01 (DNMRT).

4. Effects of Subsoiling Operation Parameters on Draft, Draft per Unit Width and Specific Draft

The analysis of variance of the draft force of the single left-hand facing bentleg plow used in the study revealed that draft was significantly affected by both depth and rake angle (Table 1). Table 4 shows the draft force for various treatments studied. The data on mean values of the draft force as affected by plowing depths and rake angle are shown in Table 5. Any increase in plowing depth and rake angle was associated with

Table 3. Comparison of mean values of draft unit^{-1} of width, and cumulative infiltration with respect to rake angle.

Rake angle (deg.)	Draft unit width^{-1} (kNm^{-1})	Power (kW)	Infiltration over 45 min (cm)
BL (7.5)	12.18 a†	3.13 a	9.31 a
BL (15)	17.12 b	4.40 b	9.36 a
BL (22.5)	25.18 c	6.49 c	9.23 a
MB	19.14 b	9.57 d	5.90 b
BT	-	-	2.37c

† Means in each column followed by the same letter are not significantly different at P<0.01 (DNMRT).

Table 4. Draft unit^{-1} of width and cumulative infiltration as influenced by various treatments.

Treatment	Draft (kN)	Draft unit width^{-1} (kNm^{-1})	Cumulative infiltration over 45 min (cm)
A1D1	2.98a	6.86a†	6.22b
A2D1	3.85ab	8.86ab	6.10b
A1D2	4.82b	10.25 b	15.45cd
A3D1	5.68c	13.07c	6.33b
A2D2	7.40d	15.74d	10.15cd
A1D3	9.30e	19.43e	11.27cd
A2D3	12.59f	26.78f	11.85d
A3D2	13.03f	27.72f	9.13c
A3D3	16.34g	34.76g	12.25d
MB	17.22e	19.14e	5.90a
BT	-	-	2.37a

†. Means in each column followed by the same letter are not significantly different at P<0.01 (DNMRT).

Plow rake angle; A1, A2 and A3 are 7.5°, 15° and 22.5°, respectively.

Plowing depths; D1, D2 and D3 are 250, 350 and 450 mm, respectively.

MB Moldbard plowing.

BT Before tillage.

corresponding increase in the draft force. Therefore, to save the energy the plow should be used at minimum rake angle (7.5^o) for all tilling depths. The main causes of the increase in draft at higher depths are the larger soil volume which in turn increases soil tool friction (5) and the higher compaction at lower soil depths.

Table 5. Comparison of means of draft force (kN) as affected by depth and rake angle for the BL plow.

Depth (mm)	Rake angle		
	7.5^o	15^o	22.5^o
250	2.98 C†c§	3.85 Cb	5.68 Ca
350	4.82 Bc	7.40 Bb	13.03 Ba
450	9.30 Ac	12.59 Ab	16.34 Aa

† Means within each column followed by the same letter are not significantly different at $P<0.01$ (DNMRT).

§ Means within each row followed by the same letter are not significantly different at $P<0.01$ (DNMRT).

The analysis of the data on the draft requirement indicated that the draft of BL plow tilling at 450 mm (7.5^o rake angle) is approximately equal to the draft requirement for MB plow working at 250 mm depth (Table 4).

This finding emphasizes the high tilling efficiency, in terms of energy requirement, of the bentleg plows. The main reasons for such energy savings are the absence of a chisel point, moldboard, non-uniform plowing depth of BL plows, and the fact that soil fractures in tension when plowing with this type of plow (5).

Considering an average tractor forward speed of 2 km h^{-1}, the mean values of power requirement of the BL as affected by depth and rake angle were calculated and compared (Tables 2 and 3, respectively).

The implement widths of the bent!eg plow at 250, 350 and 450 mm tilling depths were 435, 435, and 470 mm, respectively. The working width for the MB plow tilling at the depth of 250 mm was 900 mm. Measured draft forces and their corresponding implement widths were used to calculate the draft per unit width (kN m^{-1}) for each treatment. Comparison of mean values of draft per unit width for various combinations of depths and rake angles of BL plow and of MB plow system (Table 4) reveals that the draft per unit width of BL plow is 0.5, 1.0 and 1.4 times that of MB plow at working depths of 250, 350 and 450 mm, respectively.

The average cross-sectional area of the disturbed soil (soil disturbance) were 1577, 2086.5 and 3681.5 cm^2 for working depths of 250, 350 and 450 mm, respectively. In general the cross-sectional area was V-shaped and increased uniformly in all directions by increasing depth. It was found that the width of the soil disturbed was generally proportional to the plowing depth. The disturbed width was independent of the rake angle and was equal to 835, 1000 and 1190 mm for the nominal depths of 250, 350 and 450 mm, respectively.

The actual tilling widths of the BL and MB plows were 835 and 1000 mm compared with the implement widths of 435, and 900 mm, respectively (both plowing at 250 mm depths). Therefore it can be concluded that the BL plow can till the soil with much higher efficiency when tilling at equal depths.

The data on draft and cross-sectional area tilled have been used to calculate the specific draft (11, 12). The specific draft (draft soil $disturbance^{-1}$, kN m^{-2}) for BL tilling at the depth of 250 mm is approximately less than 30% that of the MB tilling at the same depth (Fig. 4). Furthermore, the specific draft for MB plowing at 250 mm depth is still 2.5 times that required when plowing with a BL at 450 mm depth. This comparison emphasizes the great savings in energy input when using the new bentleg plow for alleviation of subsoil compaction.

CONCLUSION

For the conditions of the soil and timing of operations that pertained to these experiments, use of the bentleg plow produced sufficiently improved soil conditions which are expected to result in greater yield (1). The percentages of residual cover for the two conditions of MB and BL plowing were 16 and 74% as compared to BT conditions. The BL plow caused greater loosening and resulted in lower bulk density to a depth of 450 mm. The subsoiling depth significantly increased cumulative infiltration whereas the rake angle had no effect. An increase of about three times in cumulative infiltration was obtained by MB plowing. The BL plow can increase this factor up to five times compared to conditions prior to tillage.

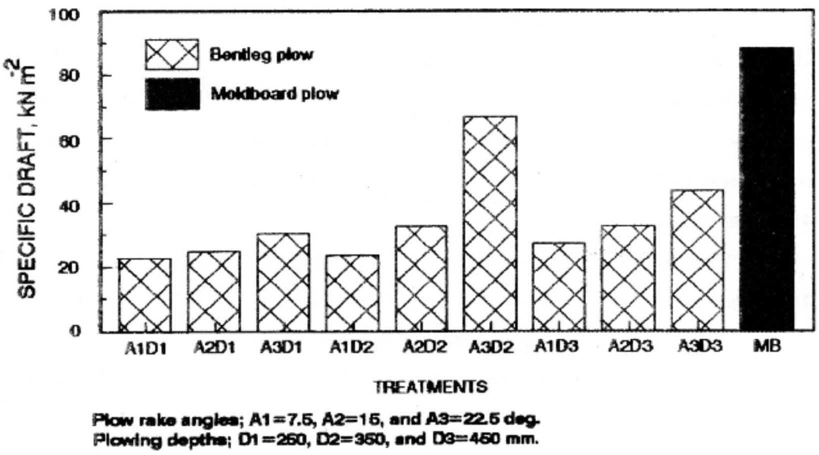

Fig. 4. Specific draft for various treatments of bentleg plow relative to moldboard plow.

The study indicated that the draft of BL plow increases as plowing depth and rake angle increase and therefore it is minimum at rake angle of 7.5°. Draft of the BL plow tilling at 450 mm (7.5° rake angle) was approximately equal to the draft of the MB plow working at 250 mm depth.

The draft per unit of width of BL plow was 0.5, 1.0, and 1.4 times that of MB plow, at working depths of 250, 350 and 450 mm, respectively. In general the cross-sectional area tilled by BL plow was larger compared to MB plowing and increased uniformly in all directions by increasing depth. The specific draft for BL plow tilling at the depths of 250, 350 and 450 mm were 30, 46 and 40% of the specific draft of the MB plow, respectively. The study also showed that power requirement of subsoiling with a BL plow was less than that for MB plowing and therefore it is within the capacity of most common tractors operating in local farms.

LITERATURE CITED

1. Bertrand, A.R. 1965. Rate of water intake in the field. Part I. Agronomy Monograph No. 9. ASA Madison. WI, U.S.A. 197-209.
2. Erbach, D.C., J.G. Benjamin, M. Cruse, M.A. Elamin, S. Mukhtar, and C.H. Choi. 1992. Soil and corn response to tillage with Paraplow. Transactions of the ASAE 35:1347-1354.
3. Erbach, D.C., R.M. Cruse, M.A. Elamin, S. Mukhtar, J.G. Benjamin, and C.H. Choi. 1984. Soil condition and corn growth response to Paraplowing. ASAE Paper No. 84, 1013. ASAE, St. Joseph, MI, U.S.A.
4. Goddard, T.W., D.S. Chanasyk and H.P. Harrison. 1991.A review of agricultural ripping activities in Alberta. Special Report, Farming for the Future, Project No. 88-0404.
5. Harrison, H.P. 1990. Soil reacting forces for two bentleg plows. transactions of the ASAE 33: 1473-1476.
6. Harrison, H.P, D.S. Chanasyk and J.C. Kienholz. 1992. Deep tilling with a bentleg plow. Proc. Int.Conf. Agric. Eng. June 1-4, Uppsala, Sweden. Paper No. 92-01-106. 12 p.
7. Harrison, H.P. and Z.J. Licsko. 1989. Soil reacting wrenches and dynamics for three models of bentleg plows. Transactions of the ASAE. 32:50-53.
8. Laflen, J.M. and T.S. Colvin. 1981. Effect of crop residue on soil loss from continuous row cropping. Transactions of the ASAE 24:605-609.
9. McConky, B.G. 1987. Making water stay longer. Western Producer (August 27).
10. Mukhtar, S., J.G. Baker, R.H. Horton and D.C. Erbach. 1985. Soil water infiltration as affected by the use of the Paraplow. Transactions of the ASAE 28:1811-1816.

11. Nicholaichuk, W. and D.M. Grey. 1986. Snow trapping and moisture infiltration enhancement. Unpublished Report of the National Hydrology Research Institute, Saskatoon, SK, Canada.

12. Owen, G.T., H. Drummond, L. Cobb and R.J. Godwin. 1987. An instrumentation system for deep tillage research. Transactions of the ASAE 30:1578-1582.

13. Regional Network for Agricultural Machinery. 1983. RNAM Test Codes and Procedure for Farm Machinery. Technical Series No. 12. Philippines.

14. Soomro, M.S., G. Spoor and R.J. Godwin. 1982. Appropriate tine arrangement for better tillage and efficient tool performance. Agricutltural Mechanization in Asia, Africa and Latin America. Autumn. 21-26.

15. Spoor, G. and R.J. Godwin. 1978. An experimental investigation into the deep loosening of soil by rigid tines. J. Agric. Eng. Res. 23: 243-258.