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FIELD EVALUATION OF A DUAL BENTLEG PLOW

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ABSTRACT

The objective of the present study was to test a dual bentleg (DBL) plow for deep tilling purposes. The experiments were conducted on a moderately compacted clay-loam soil. The performance of the plow was compared with a three bottom general purpose moldboard plow (MB) common in local farms. The tractor forward speed was maintained at 2.8 km h^{-1}. The power requirement of the DBL plow was 6.7-19 kW for the plowing depths of 250-450 mm compared to 13.4 kW for the MB plow at 250 mm depth. The draft per unit width of the DBL plow was less than 0.5, 1.0 and 1.3 times that of MB plow at working depths of 250, 350 and 450 mm, respectively. The cross-sectional area of the disturbed soil was almost doubled as the plowing depth was increased from 250 to 450 mm. The DBL plow disrupted the soil as wide as 1.8 to 2.5 times of its nominal width, but the tilled depth was not uniform. The soil underneath the plow shank was disturbed to a depth rarely exceeding one-half of the target depth. Specific resistance of the DBL plow was lower than the MB. A decrease in soil bulk density, an increase in cumulative water infiltration and undisturbed residue cover were among desirable characteristics. The optimum shank spacings between two subsequent rows were found to be 1400 and 2100 mm for the nominal plowing depths of 350 and 450 mm, respectively.

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ارزیابی مزرعه ای گاو آهن کج ساق دو طرفه

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

چکیده

هدف از انجام تحقیق حاضر، ارزیابی یک دستگاه گاو آهن کج ساق دو طرفه (DBL) به منظور انجام خاک ورزی عمیق بود. آزمایشات در مزرعه ای با خاک لومی - رسی و تا حدی متراکم انجام پذیرفت. اطلاعات و ارقام حاصله از ارزیابی مزرعه ای گاو آهن DBL با ارقام حاصله از آزمایشات مشابه بر یک گاو آهن سه خیش سوکی سوار چند منظوره مورد مقایسه قرار گرفت. سرعت پیشروی تراکتور به هنگام خاک ورزی در حد ۲/۸ کیلومتر بر ساعت تنظیم گردید. قدرت مورد احتیاج گاو آهن DBL برای انجام خاک ورزی برای اعماق ۴۵۰-۲۵۰ میلی متری برابر ۱۹-۶/۷ کیلووات و در مقایسه قدرت مورد نیاز برای تیمار شاهد (MB) برای خاک ورزی در عمق ۲۵۰ میلی متری برابر ۱۳/۴ کیلو وات بود. نیروی کشش به ازاء واحد عرض کار برای گاو آهن DBL در اعماق ۲۵۰، ۳۵۰و۴۵۰ میلی متری به ترتیب کمتر از ۰/۵، ۱ و۱/۳ برابر معیار مذکور برای تیمار شاهد بود. در اثر افزایش عمق خاک ورزی از ۲۵۰ به ۴۵۰میلی متر، سطح مقطع به هم خورده خاک تقریباً تا دو برابر افزایش یافت اما عمق خاک ورزی یکنواخت نبود. عرض کار واقعی گاو آهن DBL به هنگام کار درحدود ۲/۵-۱/۸ برابر عرض کار اسمی آن بود. عمق خاک ورزی در زیر ساق دستگاه به ندرت از نصف عمق خاک ورزی مورد نظر فراتر می رفت. مقاومت ویژه گاو آهن DBL به طور معنی داری از مقاومت ویژه تیمار شاهد کمتر بود. کاهش چگالی ظاهری، افزایش نفوذ تجمعی آب در خاک و حفظ قسمت عمده پوشش گیاهی نسبت به قبل از خاک ورزی و تیمار شاهد از دیگر مزایای به کار گیری گاو آهن DBL می باشد. فاصله بهینه دو ردیف مجاور گاو آهن DBL برای اعماق اسمی ۳۵۰ و ۴۵۰ میلی متری به ترتیب برابر ۱۴۰۰ و ۲۱۰۰ میلی متر تعیین گردید.

INTRODUCTION

Deep tillage operations are carried out to loosen, fissure and rearrange compact subsoils and subsurface pans. A wide range of implements are used for this purpose including subsoilers and chisel plows, slant and oscillating tines (12). An effective tillage and planting system creates soil conditions favourable for water infiltration, seed germination, plant emergence, early growth, and root development. It also manages soil residue for erosion control and results in economic crop yield (3, 10).

Although 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. Paraplow and bentleg plow are two deep tilling tools recently introduced to replace conventional subsoilers, these new implements have lower energy requirement and less possibility of soil recompaction (2, 3, 5, 6, 7). The advantages claimed for the bentleg plow are that it is energy efficient, has fewer components, and is in lateral equilibrium when used in pairs on a tool bar (7). A study was conducted by Harrison *et al.* (7) to compare the performance of various deep tilling tools which indicated that an imitated single bentleg plow arrangement (a combination of a single left-hand facing BL plow and a matched dummy right-hand facing BL plow to remove lateral reaction) was more energy efficient than a ripper. However, the difference in power efficiency was very dependent on the soil conditions and varied from as little as 5% to more than 50%. Similarly they concluded that the single bentleg plow is more power efficient than a dual bentleg plow. The difference which was depending on soil conditions ranged from 10% to 20%. Although the single bentleg plow was more efficient, the vertical standard of the dual bentleg would not twist as much as that of the single leg.

In order to avoid twist in the plow shank, bentleg plow should either be used with an equal number of right and left-hand plows or with dual plow bottoms (5). The dual bentleg plow (DBL) is another type of bentleg plow consisting of a shank and two cutting legs (Fig. 1). This type of plow was first used and reported by Harrison, *et al.* (7), but design details has not been reported by them or available literature. Negligible twisting in the plow shank and lateral equilibrium are two important advantages claimed for this type of deep plow (7).

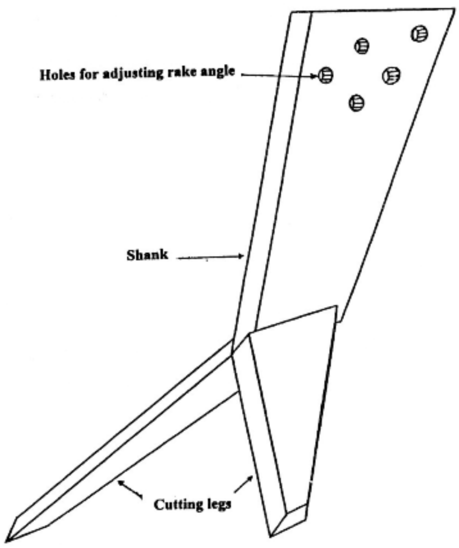


Fig. 1. The schematic diagram of the dual bentleg plow developed and used in the study.

The first stage of the present study was devoted to design and fabrication of a DBL plow. In the second stage the power requirement of the plow was measured, field tests were also conducted to study the effects of the new plow on the soil physical conditions as compared with pretilth (PT) and moldboard plowing (MB) conditions.

MATERIALS AND METHODS

The field studies were conducted at the Research Farm of the College of Agriculture, Shiraz University, I.R. Iran. The soil classified as Daneshkadeh soil series had a clay structure from the surface down to 540 mm depth. The soil texture was moderately compacted clay-loam and with an average moisture content of 15% (dry-basis) from the surface to 500 mm depth.

In the absence of any information regarding the DBL plow dimensions and other design features, it was decided to adopt a number of the design specifiactions of the single bentleg plow developed and evaluated earlier (9). Furthermore, the plow working width was selected based on the power capacity of medium-sized tractors available in the area. Finally a dual bentleg plow was fabricated from a steel plate (22, Rockwell C) 32 mm thick (Fig. 1). It consisted of a shank and two cutting legs (Figs. 1 and 2). Each leg of the plow was bent 60° to the side so that the leading edge of its tilling interface was at 30° with respect to the horizontal (Fig. 2, angle a).

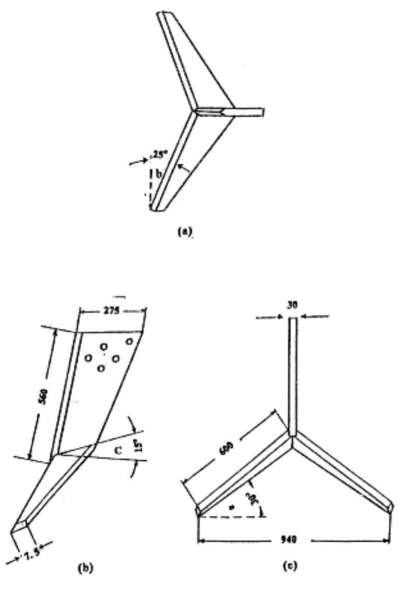


Fig. 2. The top (a), side (b) and front (c) views of the dual bentleg plow used in the study. Dimensions are in mm.

The leading edge of the cutting interface was rotated towards the direction of travel by 25° as shown in Fig. 2 (angle b). The plow rake angle was 15° with respect to the horizontal, thus creating a rake angle of 15° in the tilling interface (Fig. 2, angle c). A total of four different rake angles could be obtained by rotating the plow about a horizontal axis (Fig. 1). In order to achieve a deeper penetration and to reduce the soil resistance, the cutting edges of the plow were sharpened to 35°.

Preliminary tests revealed that the plow could not operate satisfactorily at 0° rake angle, because of insufficient penetration. Three rake angles (7.5°, 15° and 22.5°) and three plowing depths (250, 350 and 450 mm) were considered for evaluating the plow. The performance of the DBL plow was compared with that of a three bottom general purpose moldboard plow (MB) which is common and acceptable to local farmers. Furthermore, the draft requirement of such MB plows is within the capacity of most medium powered tractors available on local farms. The MB plow (control) was operated at tilling depth of 250 mm. With three replication, a total of 30 experimental plots (4×40 m), including control were arranged in a randomized complete block design. In each test, draft force and soil physical conditions including cumulative water infiltration over 45 min, bulk density, and cross-sectional area of the soil disturbed were measured and compared with pretilth conditions (PT) and the control.

The nominal width of cut of the DBL plow and MB plows were 940 and 900 mm, respectively. The experiments were conducted on a field covered with stubble left from previous wheat crop. The draft required to pull each plow was measured using the procedure recommended by RNAM (11). The measurements were taken in two stages, first when the implement was engaged in soil and second, when the implement was raised by the hydraulic lift of the tractor. In both cases the forward speed was maintained at 2.8 km h^{-1}. The net difference between the two measurements was the draft needed to pull the plow in soil.

Prior to the tests, the soil bulk density of each plot was measured by core sampler at five depth ranges of 0-150, 150-250, 250-350, 350-450 and 450-550 mm. The cumulative infiltration over 45 min was measured before and after plowing at three different locations in each plot using a double ring infiltrometer as recommended by Bertrand (1). Both measurements were repeated after the tillage operation in each plot. For each plot, the loosened cross-sectional areas were measured in three locations. The data on the measured draft, the cross-sectional area disturbed, and the corresponding implement width (940 and 900 mm for DBL and MB plows, respectively) were used to calculate the draft/unit width and the specific resistance (4, 12). The Power requirement of the plow was calculated using the following relationship:

$$D.B.P = (F.S)/C \qquad [1]$$

where,

D.B.P. : Drawbar power, kW,

F : Draft force, kN,

S : Tractor forward speed, km h^{-1},

C : Conversion factor = 3.6.

For measuring plant residue cover, the method suggested by RNAM (12) was adopted. In each plot, the soil residue cover in a square measuring 1 m^2 was collected before and after plowing operation. The collected residue cover was oven dried (24 h, 105° C) and weighed. The percent of soil residue cover was calculated using the following relationship:

$$RC = 100- [(Wp-We)/Wp]\ 100 \qquad [2]$$

where,

RC : Residue cover retained on soil, %,

Wp :Mass of the soil residue cover before tillage, g,

We : Mass of the soil residue cover after tillage, g,

Each measurement was replicated five times.

RESULTS AND DISCUSSION

1. Draft

The draft of the dual bentleg plow was significantly affected by the depth, rake angle and their interaction at 1% level. The mean values of the draft force, as affected by plowing depth and rake angle, were compared by Duncan's multiple range test (DMRT) (Table 1). Any increase in plowing depth and rake angle was associated with a corresponding increase in the draft force. Therefore, to minimize energy, the plow should be used at a minimum rake angle (7.5°) for all tilling depths. The larger soil volume and the higher compaction at lower soil depths are the main reasons for the increase in the draft at higher soil depths.

Table 1. Comparison of means of draft force as affected by depth and rake angle for the DBL plow.

Depth (mm)	Rake angle			
	A1 (7.5°)	A2(15°)	A3(22.5°)	Mean
D1 (250)	6.01C†c§	7.96 Bc	11.67 Ac	8.46 c
D2 (350)	8.86 Cb	14.17 Bb	25.49 Ab	16.18 b
D3 (450)	16.63 Ca	24.60 Ba	31.41 Aa	24.22 a
Mean	10.50 C	15.58 B	22.86 A	

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

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

Table 1 shows that the average draft of the DBL plowing at 250 mm soil depth (for all rake angles) is almost half of the draft requirement of the MB plow at similar depth. Similarly it can be seen that the average draft of the DBL plowing at 350 mm and 450 mm depths is 1 and 1.4 times that of the energy needed by the MB plow tilling at 250 mm depth (control). The main reasons for such energy savings are the structural differences between the two plows. Furthermore, the soil fractures in tension when plowing with the bentleg plow which reduces the draft needed to till the soil (6). For the depth range in the present study, the draft requirement of the DBL plow was not more than 1.5 times that of a three bottom general purpose MB plow (tilling at 250 mm) and therefore, the draft was within the capacity of medium sized tractors available to most farmers. The mean values of the power consumption for different treatments were compared by DMRT (Tables 2 and 3).

Table 4 shows the average cross-sectional area of the disturbed soil measured for all treatments. The analysis of variance indicated that the disturbed cross-sectional area was affected by both tilling depth and plow rake angle.

Table 2. Comparison of mean values of draft/unit width, power and cumulative infiltration with respect to depth.

	Plowing depth, mm	Draft/unit width kN m^{-1}	Power kW	Infiltration over 45 min, cm
DBL	250	9.09d†	6.67d	5.69c
DBL	350	17.21c	12.62c	7.37b
DBL	450	25.76a	18.88a	13.13a
MB	250	19.14b	13.39b	5.90c
PT	-	-	-	2.37d

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

Table 3. Comparison of mean values of draft/unit of width, power and cumulative infiltration with respect to rake angle.

Plow type	Rake angle	Draft/ unit width kN m^{-1}	Power kW	Infiltration over 45 min, cm
DBL	7.5°	11.17d†	8.16d	6.79c
DBL	15.0°	16.57c	12.11c	9.03b
DBL	22.5°	24.31a	17.77a	10.37a
MB		19.14b	13.39b	5.90c
PT	-	-	-	2.37d

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

Figure 3a shows that the DBL plow did not till the soil uniformly throughout its tilling width. The soil underneath the plow shank was less disturbed than the soil located either sides of the shank. In general, the soil depth tilled underneath the shank was less than half of the target tilling depth. Furthermore, for treatments with shallow depth (250 mm), the soil underneath the shank was not pulverized satisfactorily and was left as large clods in need of subsequent secondary tillage operations.

The effective working width or the shank spacing between two adjacent rows can be estimated once the minimum acceptable tilled depth across the entire working width is decided. For instance, if an average tilled depth of 200 mm satisfies our plowing requirements, the shank spacing for the DBL plow at nominal depths of 350 mm and 450 mm are found to be 1400 mm and 2100 mm, respectively (Fig. 3 b and c).

Table 4. Draft force and Disturbance as influenced by various treatments.

Treatment	Draft force, kN	Disturbed area m^2	Specific resistance $kN\ m^{-2}$	Tilled width mm
A1D1	6.01	0.3033	19.825 h†	1760
A2D1	7.97	0.3446	23.125 g	1860
A3D1	11.67	0.2875	40.591 d	1700
A1D2	8.86	0.4755	18.637 h	2190
A2D2	14.17	0.5359	26.442 f	2120
A3D2	25.49	0.5070	50.276 b	2070
A1D3	16.63	0.6887	24.147 g	2330
A2D3	24.60	0.7252	33.922 e	2390
A3D3	31.41	0.6913	45.436 c	2440
MB	17.22	0.1950	88.300 a	1000

† Means followed by the same letter are not significantly different at $P<0.01$ (DMRT).

The actual tilling width of the DBL plow for each treatment have been measured and reported in Table 4. In general, it can be seen that the plowing width increased for any increase in the plowing depth. The average widths tilled by DBL plow were 1.8, 2.25, and 2.5 times the plow nominal width (940 mm) for tilling depths of 250, 350 and 450 mm, respectively. The actual tilling width for the MB plow was 1000 mm compared to the implement width of 900 mm. Therefore, it can be concluded that the DBL plow has a higher field capacity compared to the control (MB plow). The fact that the DBL plow tills the soil wider than its nominal width, can be regarded as a unique advantage of the new plow over the MB plow. However it should be noted that for the DBL plow, the tilled cross-sectional area is not necessarily uniform in depth across the working width.

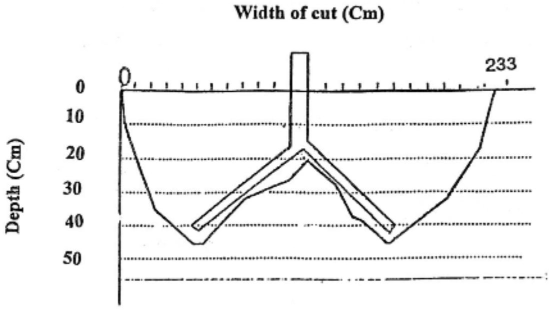
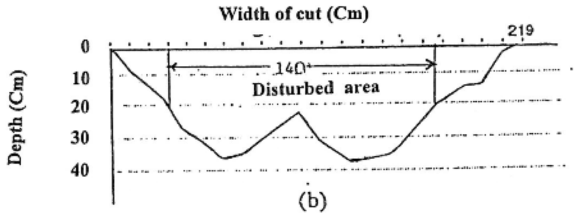


Fig. 3a. Typical cross-sectional area of the soil disturbed by the DBL.



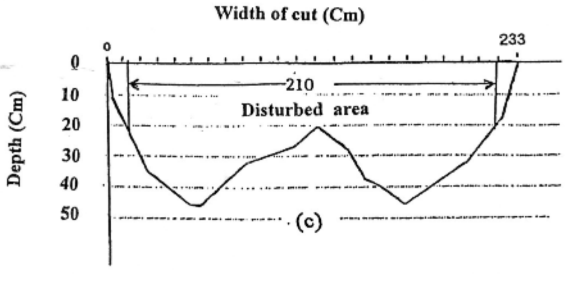


Fig. 3b,c. The cross-sectional area of the soil disturbed by DBL, tilling at 350 mm (b) and 450 mm (c) nominal soil depths.

Another important measure of the tool performance is the specific resistance (draft/soil disturbance, kN m^{-2}) of the plow (4, 12). The analysis of variance of the data indicated that rake angle, depth and their interaction significantly affected the specific resistance of the DBL plow. Means of the specific resistance for various treatments have been compared by DMRT (Table 4). The specific resistance of the DBL plow at the depths of 250, 350 and 450 mm were 31% , 36% and 39% of the specific resistance of the MB plow tilling at the 250 mm depth, respectively (Table 4).

Comparison of the mean values of draft per unit width (kN m^{-1}) for various combinations of depths and rake angles of the dual bentleg plow (Tables 2 and 3) indicated that the draft per unit width of the DBL plow is less than 0.5, 1.0 and 1.3 times that of MB plow at working depths of 250, 350 and 450 mm, respectively.

2. Bulk Density

As indicated earlier, the soil bulk density was measured at five different depth ranges in each plot. The measurements were taken before and after plowing.

Analysis of variance of the average reduction in soil bulk density for the 150-250 mm depth ranges of all treatments, revealed that this factor has been affected by depth of plowing and the interaction of depth and rake angle but not by the plow rake angle. The average reduction in bulk density for the depth ranges 150-250 mm for ali plots were compared by DMRT (Table 5). Although the effect of rake angle on the reduction in soil bulk density was insignificant, comparison of mean values of reduction in bulk density before and after plowing for all treatments indicated that higher rake angles have been associated with higher reduction in the bulk density. The highest reduction in bulk density was observed in those treatments tilling at 250 mm and a rake angle of 22.5°.

Fig. 4 shows the soil bulk density prior to plowing, after DBL plowing and after MB plowing. Although similar improvement in the soil bulk density to a depth of 250 mm could be achieved with either MB or DBL plows, the reduction in the bulk density below the plowed layer can only be achieved by DBL plowing. The bulk density of the soil underneath the tilling edge of the DBL plow was measured and compared with that of the untilled soil (PT). The two sets of data were almost similar, and therefore, it can be concluded that operation of the DBL plow has not led to formation of a new compacted layer in the soil underneath the cutting edges of the plow.

Table 5. The reduction in bulk density (Mg m^{-3}) as affected by depth and rake angles for the DBL.

	Rake angle			
depth (mm)	A1 (7.5°)	A2 (15°)	A3(22.5°)	Mean
D1 (250)	0.195 B[†]a[§]	0.240Cb	0.256Aa	0.230a
D2 (350)	0.155Ab	0.154Aa	0.158Ab	0.156b
D3 (450)	0.146Ab	0.136Aa	0.117Ac	0.133c
Mean	0.165A	0.176A	0.177A	

† Means within each row followed by the same letter are not significantly different at P<0.01 (DMRT

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

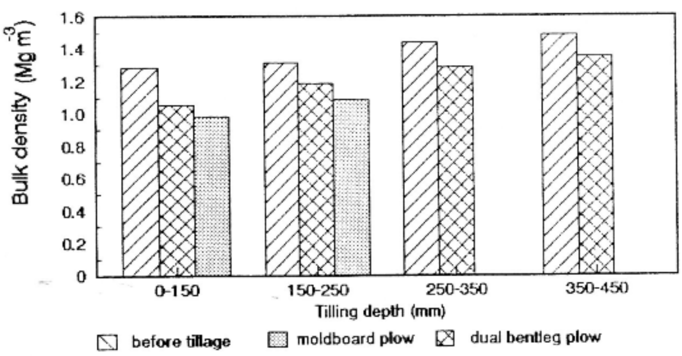


Fig. 4. Effect of tillage system on bulk density at various soil depths.

3. Soil Water Infiltration

The cumulative infiltration over 45 min was affected by plow working depth, rake angle and their interaction at the 1% level. The means of cumulative infiltration as affected by depth and rake angle and their interactions are compared in Tables 2, 3 and 6. The means of cumulative infiltration for all treatments of DBL plow, MB plow and PT conditions have been plotted and compared in Fig. 5. The data revealed that whereas tilling with MB plow increased infiltration about 2.5 times compared with pretilth conditions (PT), the increase was up to 5.5 times with DBL plowing.

Table 6. Comparison of average cumulative infiltration as affected by various plowing depths, plow rake angle and their interactions.

	Rake angle			
Depth (mm)	A1 (7.5°)	A2 (15°)	A3 (22.5°)	Mean
D1 (250)	3.8 B†c§	6.33 Ab	6.93 Ac	5.69 c
D2 (350)	5.39 Cb	7.47 Bb	8.24 Ab	7.37 b
D3 (450)	11.18 Ca	13.29 Ba	14.92 Aa	13.13 a
Mean	6.79 C	9. 03 B	10.37 A	

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

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

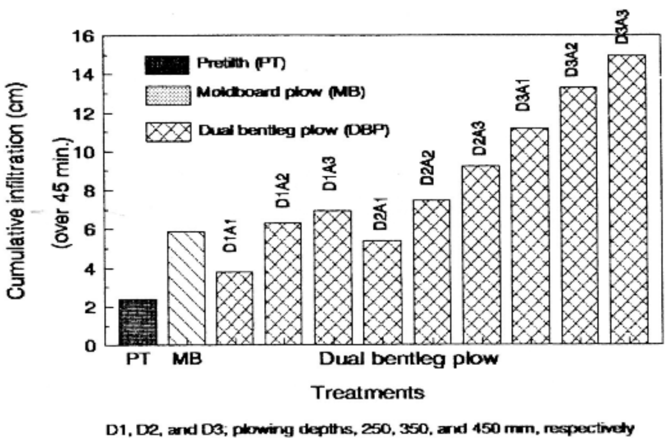


Fig. 5. Cumulative infiltration as affected by moldboard and DBL.

4. Soil Residue Cover

The MB plow left only 20% of soil residual cover compared with 75% residue after plowing with DBL plow. Similar findings have been reported by

Laflen and Colvin (8), who believed that the residue cover after plowing with the DBL plow is capable of minimizing soil erosion.

CONCLUSIONS AND RECOMMENDATIONS

1. The DBL plow designed and developed in the present study performed satisfactorily during prolonged field operations, but no satisfactory penetration was obtained when the plow rake angle was set at 0°
2. The power requirement of the DBL plow increased directly with the rake angle and working depth. For the depth range of 250-450 mm, the power requirement of the DBL plow was not more than 1.4 times that of the MB plow. This level of power can be met by most tractors available in local farms.
3. The lower specific resistance of the DBL plow is advantageous and in addition, results in markedly better soil physical conditions in subsoil layers.
4. The new plow does not till the soil uniformly across its working width, because the soil underneath the plow shank was disturbed to a depth not exceeding one-half of the target depth. This fact has to be taken into consideration especially when the target depth is 250 mm or less.
5. The optimum shank spacings between two subsequent rows for the DBL plow tilling at nominal depths of 350 and 450 mm were found to be 1400 and 2100 mm, respectively.
6. The fact that the width tilled by the DBL plow is almost twice the plow nominal width suggest that the new plow has a high field capacity.

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