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EQUIPMENT COMPARISONS FOR DEEP PLOWING SOLONETZIC SOILS

by

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Abstract

Field measurements of tillage depth, tillage width and power requirements are presented for three deep tillage plows and a ripper when deep plowing solonetzic soils. An operating cost comparison is made. The effectiveness of the machines in improving solonetzic soils is also discussed.

POWER REQUIREMENTS FOR DEEP TILLAGE OF SOLONETZIC SOILS

SUMMARY AND CONCLUSIONS

No significant differences in required tractor size or in operating costs were apparent among the Kello-Bilt 1824 single bottom plow, the Three-layer plow or the Wheel plow. A sufficiently ballasted tractor with a power take-off rating of at least 150 kW (201 hp) is needed to operate any of these plows at a speed of 5 km/h (3 mph) and at a depth of 0.6 m (24 in) in the typical field conditions encountered. Fuel costs may be expected to vary from $20 to $26 per hectare ($8 to $11 per acre) for any of these plows.

As expected, the Kello-Bilt subsoiler had significantly lower specific power requirements and specific operating costs than the plows. Average power requirements, per unit width, for the subsoiler were only 59% of the average power requirements for the plows when operating at the same depth and speed. Average fuel costs for the subsoiler, per unit area were similarly only about 59% of average fuel costs for the plows. Results indicated a fuel cost of about $14 per hectare ($6 per acre) if the subsoiler could be operated at 5 km/h (3 mph) and at a depth of 0.6 m (24 in). This would require a sufficiently ballasted tractor with a power take-off rating of at least 280 kW (375 hp). However, the subsoiler was not capable of tilling to a depth of 0.6 m (24 in).

Final implement selection must be based on benefits as indicated by crop yield enhancement for the different methods of tillage. The above operating cost figures should be used in adjusting crop yield benefits once these data are available.

INTRODUCTION

Solonetzic soil is generally characterized by a soil profile that can be separated into three main soil layers, the A, B and C horizons (FIGURE 1). The distinctive hard columnar structure of the Bnt horizon is the main limitation to productivity in solonetzic soils. This horizon is nearly impermeable to both moisture and root penetration, resulting in poor moisture storage and root distribution characteristics. Deep plowing of solonetzic soils results in the physical breakdown of the Bnt horizon and soil horizon mixing, to provide improved water and root penetration and consequently increased crop yields.

In the winter of 1979 an ad hoc committee consisting of representatives from Alberta Agriculture, Canada Agriculture and the Prairie Agricultural Machinery Institute was formed. This committee decided to assess the relative performance of available equipment for deep plowing solenetzic soils.

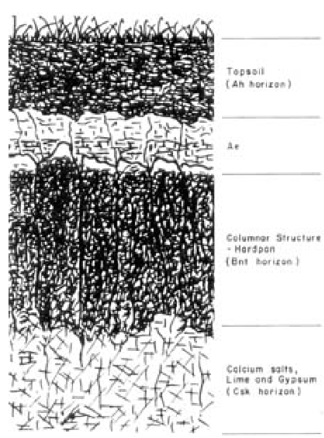

FIGURE 1. Characteristic Solonetzic Soil Profile.

SCOPE OF TEST

The study included three deep tillage plows and one deep tillage subsoiler as follows:
(1) Kello-Bilt Model 1824 single bottom plow.
(2) Three-layer topsoil saving plow designed by Alberta Agriculture.
(3) Wheel topsoil saving plow designed by Alberta Agriculture.
(4) Kello-Bilt Series 5000 deep tillage subsoiler.

Detailed soil surveys and soil analysis of each test site were conducted by Alberta and Canada Agriculture before and after deep plowing. The Prairie Agricultural Machinery Institute measured draft, forward speed, depth of tillage and width of cut for each plow. From these data, determinations of drawbar power, tractor requirements and operating costs were obtained.

NOTE: This report has been prepared in SI units of measurement. A conversion table is given in APPENDIX I.

DESCRIPTION OF TEST EQUIPMENT PLOWS

PLOWS

The Kello-Bilt Model 1824 (FIGURE 2) is a single bottom mold-board plow designed for deep plowing of solonetzic soils. Depth control is achieved with a hydraulic cylinder on the front wheels. The theoretical width of cut is 760 mm (30 in).

FIGURE 2. Kello-Bilt Model 1824 Single Bottom Plow.

Three Layer Plow: The Three-layer plow (FIGURE 3) was designed by Mr. John Kienholz, Alberta Agriculture, and was fabricated by Kello Brothers at Stettler, Alberta.

This plow is designed to retain the Ap soil horizon on top of the plowed soil. The front grader blade removes the Ap horizon from the untilled soil and deposits it on top of the C horizon which is removed on the right side of the furrow by the second bottom. The moldboard on the second bottom mixes the Ap and C horizons, leaving the mixture on top of the tilled soil. The third bottom mixes the B horizon and some of the C horizon from the area previously scraped by the grader blade and places it in the furrow formed by the second bottom. In this manner, the impermeable B horizon is mixed under the C horizon while retaining most of the Ap horizon on the soil surface. The theoretical width of cut is 610 mm (24 in).

Depth and side-to-side plow levelling is controlled by hydraulic cylinders on each front wheel. The rear furrow wheel is adjustable to level the frame and each share can be manually adjusted for depth.

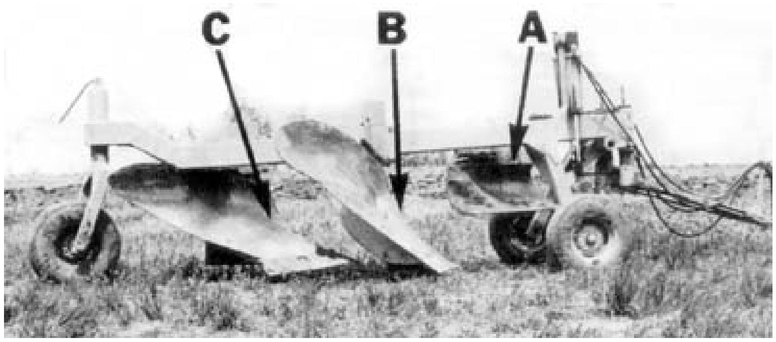

FIGURE 3. Three Layer Plow. (A) Grader Blade (First Bottom), (B) Second Bottom, (C) Third Bottom.

Wheel Plow: The Wheel plow (FIGURE 4), also designed by Mr. John Kienholz of Alberta Agriculture, is a further development of the Three-layer plow.

This plow mechanically conveys the Ap horizon onto the plowed soil surface. The grader blade, located on the left side of the plow, removes the Ap horizon and deposits it on the side of a large rotating inclined disc in the bottom of the furrow. The Ap horizon is lifted by the disc and deposited on the tilled soil surface. The disc is driven by contact with the furrow wall. A small paddle wheel, which removes the Ap horizon at the top of the disc, is chain driven from the disc shaft. The moldboard located on the right side of the plow inverts and mixes the B and C horizons. The theoretical cutting width is 810 mm (32 in).

Depth and side-to-side levelling are controlled by hydraulic cylinders on each front wheel. The grader blade and moldboard can be manually adjusted for depth.

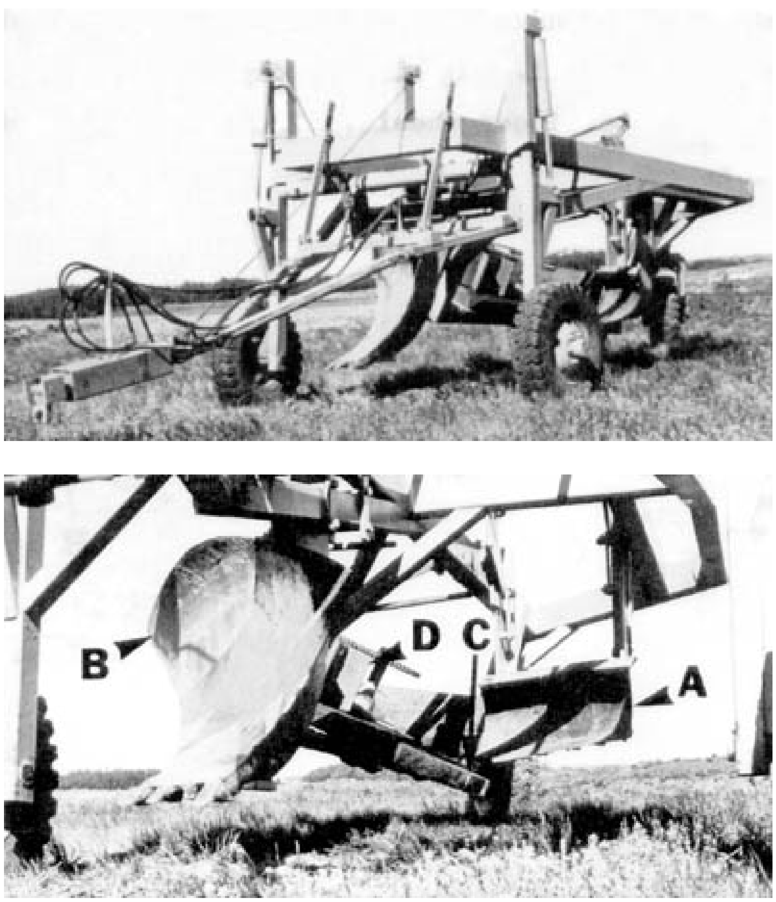

FIGURE 4. Wheel Plow: (A) Grader Blade, (B) Moldboard, (C) Rotating Disc.

SUBSOILER

Kello-Bilt Series 5000 Subsoiler: The Kello-Bilt Series 5000 deep tillage subsoiler (FIGURE 5) is a five shank subsoiler designed to loosen the soil. Operating depth is controlled by manual adjustment of the two outrigger wheels. The theoretical width of cut is 2980 mm (117 in).

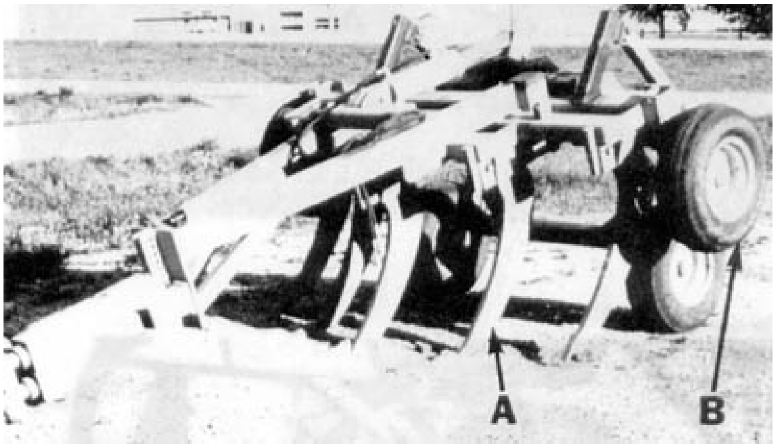

FIGURE 5. Kello-Bilt Series 5000 Subsoiler: (A) Shank, (B) Outrigger Wheels.

TRACTOR

A 1976 Steiger Cougar II four-wheel drive tractor was used during draft measurements. This tractor is powered by a turbo charged Caterpillar 3306 six cylinder diesel engine. The maximum available drawbar power (Nebraska Test No. 1170) is 166 kW (222 hp). The tractor was equipped with eight 20.8 x 38 tires and had a ballasted mass of about 12,700 kg (28,000 lb).

TEST PROCEDURES

FIELD TESTING

Test Sites: Each test plot was 30 x 426 m (100 x 1400 ft) resulting in a 1.3 ha (3.2 ac) area. Test site layout is shown in FIGURE 6. Draft, speed, depth, and width of cut were monitored while each implement made one complete pass down and back on the test strip.

Data Logging: Each implement was instrumented so that draft, speed and depth of cut were monitored and recorded continuously. Draft and speed variation were measured using the power cart shown in FIGURE 7. Draft was measured with a 220 kN (50,000 lb) capacity load cell and speed was measured with a magnetic pickup which monitored cart wheel speed. Depth was measured continuously with SAK depth indicators (FIGURE 8) which measured the distance from the plow frame to the soil surface. Signals from the draft, speed and depth transducers were recorded on FM magnetic tape.

The SAK depth indicator did not maintain accurate calibration since the plow frames did not remain level while operating. Depth of tillage was therefore manually measured (FIGURE 9) at 30.5 m (100 ft) intervals. Operating depth of the moldboard plows was measured vertically from the furrow bottom to the undisturbed soil surface beside the furrow. Operating depth of the subsoiler was determined by inserting a 25 mm (1 in) diameter rod into the furrow left by the shanks until it reached bottom and measuring to the undisturbed soil surface.

The width of cut for plows was determined by measuring the distance from the plot boundary to the edge of the furrow before and after tillage. Subtracting these measurements resulted in the effective width of cut. The 2980 mm (117 in) theoretical width of cut of the subsoiler was assumed to be its operating width.

Measurements were conducted only in one tractor gear at what was assumed to be a suitable working depth. No attempt was made to determine draft-speed-depth relationships.

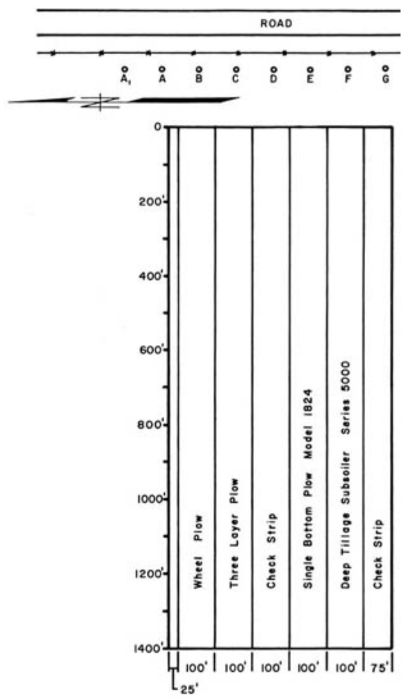

FIGURE 6. Deep Plowing Test Site Layout on SE 5-38-16-W4, June, 1979.

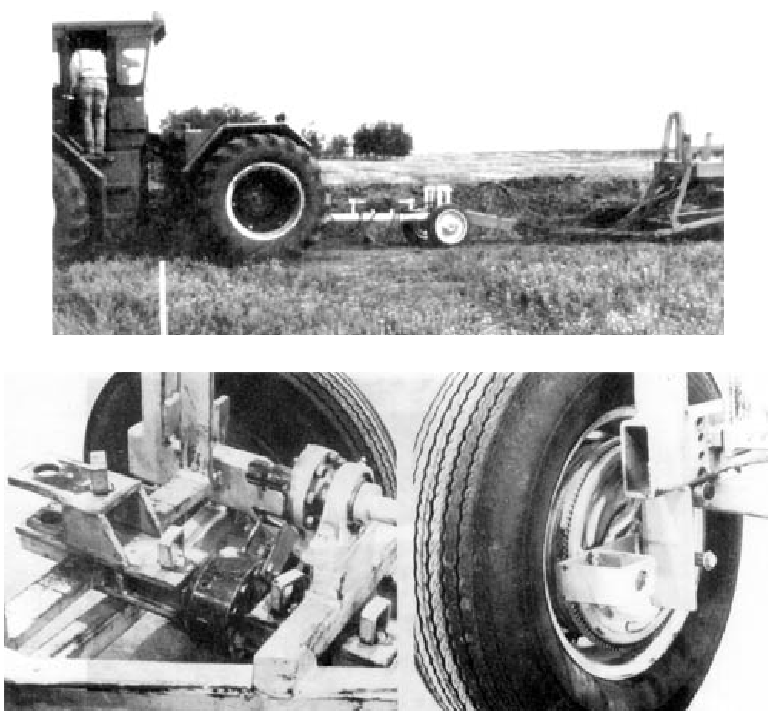

FIGURE 7. Power Cart: (A) Draft Transducer, (B) Speed Transducer.

FIGURE 8. SAK Depth Indicator.

FIGURE 9. Manual Measurement of Tillage Depth.

Soil: Soil was sampled by Alberta and Canada Agriculture before and after plowing. Samples were taken before plowing and soil was classified after plowing by detailed analysis of the furrow wall at 7.6 m (25 ft) intervals. Soils were classified as solonetz, solodized solonetz, solod or chernozem. In general, soils containing a higher percentage of solonetz are more difficult to till.

DATA ANALYSIS

Draft, speed, and depth measurements recorded on FM tape were digitized by computer and average values of draft, speed, power and depth calculated. Depth measured electronically was correlated to manual depth measurements.

As well, the draft, speed and depth measurements were transferred to strip chart recordings (FIGURE 10) and the charts were analyzed for correlation to soils data obtained by Alberta and Canada Agriculture.

RESULTS AND DISCUSSION

KELLO-BILT MODEL 1824 SINGLE BOTTOM PLOW

Soil Characteristics: The Kello-Bilt Model 1824 single bottom plow was operated in soil classified as 70% solonetz, 20% solodized solonetz, 7% solod and 2% chernozem.

Plow Operating Characteristics: The Model 1824 single bottom plow did an effective job of turning the soil but topsoil was turned into the bottom of the furrow leaving a lumpy field surface (FIGURE 11). In hard spots, the plow was unstable, skewing sideways. It also did not maintain depth in hard soils. Average operating depth was 620 mm (24 in) but depth varied from 500 to 740 mm (20 to 29 in)*.

Uniform width of cut was difficult to maintain. Width of cut varied from 550 to 1090 mm (22 to 43 in)* with an average width of 820 mm (32 in). This was 60 mm (2 in) greater than the theoretical width of cut.

*95% confidence interval

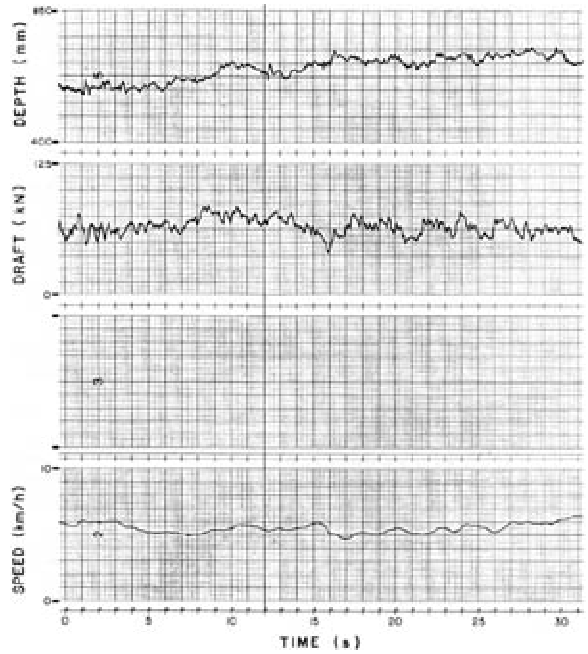

FIGURE 10. Sample Strip Chart Recording.

FIGURE 11. Lumpy Field Surface Left after Plowing with the Model 1824 Single Bottom Plow.

Drawbar Power Requirements: The Steiger Cougar II tractor had sufficient power to pull this plow in fourth gear at an average speed of 5.8 km/h (3.6 mph). Average draft at this speed was 63 kN (14,200 lb). Average drawbar power required was I00 kW (134 hp) with instantaneous peak power requirements of 181 kW (243 hp).

THREE-LAYER PLOW

Soil Characteristics: The Three-layer plow was operated on a test strip where the soil was classified as 42% solonetz, 37% solodized solo-netz, 7% solod, and 14% chernozem. Due to the lower percentage of solonetz, this soil may have been easier to till than the test strip tilled with the single bottom plow.

Plow Operating Characteristics: The Three-layer plow did an effective job of turning the soil and left some of the topsoil on the tilled surface. The tilled field surface remained lumpy (FIGURE 12).

The Three-layer plow did not penetrate as well as the Model 1824 single bottom plow, but was more stable. An experienced operator could maintain a level plow frame by adjusting the remote hydraulic cylinders on each front wheel. Tillage depth varied from 460 to 640 mm (18 to 25 in)*, resulting in an average depth of 550 mm (22 in). The width of cut varied from 730 to 1080 mm (29 to 43 in)*, with an average width of cut of 905 mm (36 in). This was 295 mm (12 in) more than the theoretical width of cut.

* 95% confidence interval

FIGURE 12. Field Surface after Plowing with Three-Layer Plow.

Drawbar Power Requirements: The Steiger Cougar II tractor was operated in third gear at an average speed of 4.2 km/h (2.6 mph) for this test. Average draft at this speed was 50 kN (11,200 lb). Average draw-bar power was 58 kW (78 hp) with instantaneous peak power requirements of 100 kW (134 hp).

WHEEL PLOW

Soil Characteristics: The Wheel plow was operated on soil classified as 33% solonetz, 42% solodized solonetz, 16% solod and 8% chernozem. This soil, for comparative purposes, was also considered easier to till than the test strip tilled with the single bottom plow.

Plow Operating Characteristics: The Wheel plow was effective in mixing the lower soil horizons and left topsoil on the surface, resulting in a smoother field surface as shown in FIGURE 13.

The Wheel plow penetrated deeper than the other moldboard plows and was more stable. An experienced operator could maintain a level plow frame by adjusting the remote hydraulic cylinder on each front wheel. The large rotating disc turning against the bottom and side of the furrow wall helped to maintain depth and width stability, since the disc absorbed the side thrust acting on the moldboard. Tillage depth varied from 560 to 750 mm (22 to 30 in)*, resulting in an average depth of 655 m (26 in). The width of cut varied from 580 to 930 mm (23 to 37 in)* with an average of 755 mm (30 in). This was 55 mm (2 in) less than the theoretical width of cut.

*95% confidence interval

FIGURE 13. Field Surface after Plowing with Wheel Plow.

Drawbar Power Requirements: The Steiger Cougar II tractor had sufficient power to pull the Wheel plow in fourth gear, at an average speed of 5.8 km/h (3.6 mph). Average draft at this speed was 55 kN (12,400 lb). Average power required at the drawbar was 88 kW (118 hp), with instantaneous peak power requirements of 144 kW (193 hp).

KELLO-BILT SERIES 5000 DEEP TILLAGE SUBSOILER

Soil Characteristics: The Kello-Bilt Series 5000 deep tillage subsoiler was operated on soil classified as 60% solonetz, 20% solodized solonetz, and 20% solod. Due to the high percentage of solonetz, this soil was of similar difficulty to till as that in the test strip for the single bottom plow.

Plow Operating Characteristics: The Series 5000 subsoiler operation differed from the moldboard plows since it did not turn the soil. The soil was loosened as the shanks passed through it. FIGURE 14 shows the soil surface after subsoiling.

The Series 5000 deep tillage subsoiler would not penetrate as deep as the moldboard plows. Tillage depth varied from 290 to 480 mm (11 to 19 in)*, with an average depth of 385 mm (15 in). The theoretical width of cut of the Series 5000 deep tillage subsoiler was 2980 mm (117 in) which was also the effective width of cut.

* 95% confidence interval

FIGURE 14. Field Surface Left by the Kello-Bilt Series 5000 Deep Tillage Subsoiler.

Drawbar Power Reqirements: The Steiger Cougar II tractor had insufficient power and traction to pull the Series 5000 subsoiler in fourth gear. Third gear operation resulted in an average speed of 4.2 km/h (2.6 mph). Average draft at this speed was 78 kN (17,500 lb). Average power measured at the drawbar was 90 kW (121 hp) with instantaneous peak power requirements of 152 kW (204 hp).

During the test run, sufficient traction was difficult to obtain. An estimated 27 kN (6000 lb) vertical force, exerted at the subsoiler hitch and normally transferred to the tractor drawbar, was absorbed by PAMI's power cart located between the tractor and subsoiler. This reduced the weight on the tractor wheels causing slippage, making it necessary to reduce tillage depth to pull the subsoiler through hard spot.

COMPARISON OF PLOW PERFORMANCE

Performance data are summarized in TABLE 1. In an attempt to permit a logical comparison of tillage performance, all draft, power and cost data presented in this table have been adjusted to a common tillage speed of 5 km/h (3 mph) and a common tillage depth of 0.6 m (24 in). Since tractor size and soil variability did not permit determination of draft-depth-speed relationships for the four implements during the test, draft and speed adjustments were based on tillage draft-speed-depth relationships derived by PAMI for heavy duty cultivators in heavy primary tillage[1]. Draft per metre of width was adjusted by 0.1 kN (22.5 lb) for a 1 km/h (0.6 mph) speed change and by 63 N (14 lb) for a 1 mm (0.04 in) depth change.

Field capacity was determined using a field efficiency of 80%[2]. Estimated suitable tractor sizes were based on average draft, assuming a tractive efficiency of 0.74[2] and a load factor of 1.25. Fuel consumption in L/h (gal/h) was based on a factor of 0.49 (0.08) times the estimated tractor size in kilowatts (hp)[2], while fuel cost was based on a net cost of $0.15 per litre ($0.68/gal).

TABLE 1. An Approximate Comparison of Performance at a Speed of 5 km/h and a Depth of 0.6 m.

Machine	Soil Description	Average Tillage Width (m)	Draft (kN) Average	Draft (kN) Peak	Power Consumption (kW) Average	Power Consumption (kW) Peak	Field Capacity (ha/h)	Approximate Fuel Cost ($/ha)	Estimated Suitable Tractor Size (kW, pto)
Kello-Bilt #1824 single bottom plow	70% solonetz 20% solodized solonetz, 7% solod 2% chernozem	0.82	62	113	86	157	0.33	$26.00	145
Three-layer Plow	42% solonetz 37% solodized solonetz, 7% solod 14% chernozem	0.90	53	89	74	124	0.36	$20.00	125
Wheel plow	33% solonetz 42% solodized solonetz, 16% solod 8% chernozem	0.76	52	87	72	121	0.30	$24.00	122
Kello-Bilt subsoiler	6% solonetz 20% solodized solonetz, 20% solod	2.98	119	172	165	239	1.19	$14.00	279

From TABLE 1 it may be seen that there is no significant difference in required tractor size or in estimated fuel cost per hectare, among the three plows. Although the table indicates that the single bottom plow requires a slightly larger tractor and will be slightly more expensive to operate than the other two plows, this conclusion is not valid, since the higher percentage of solonetz in this test strip indicated a soil with higher power requirements. It may be concluded that a sufficiently ballasted tractor with a power take-off rating of at least 150 kW (201 hp) will be required to operate any of these three plows at a speed of 5 km/h (3 mph) and a depth of 0.6 m (24 in). Fuel costs may be expected to vary from $20 to $26 per hectare ($8 to $11 per acre) for any of the plows.

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1 PAMI Detailed Test Procedures for Heavy Duty Cultivators.
2 American Society of Agricultural Engineers Yearbook, "ASAE Data D230.3, pp. 248 to 255, 1979.

Specific power requirements and fuel consumption for the subsoiler are significantly lower than for any of the plows. Average power requirements for the three plows were 165 kW/m (67 hp/ft) width as opposed to 97 kW/m (40 hp/ft) width for the subsoiler. This is to be expected, since the subsoiler only breaks the soil while a plow inverts it as well as breaking it. From the results, it may be concluded that the fuel costs for subsoiling to a 0.6 m (24 in) depth would on an average be less than $15/ha ($6/ac). A tractor with power take-off rating of at least 280 kW (375 hp) would be required to operate the 2.9 m (117 in) wide subsoiler at a depth of 0.6 m (24 in) and a speed of 5 km/h (3 mph). However, the subsoiler was not capable of tilling to a depth of 0.6 m (24 in).

In summary, it may be concluded that any of the plows are about 35% more expensive to operate than the subsoiler. Machine selection must, however, be based on benefits as indicated by crop yield. The above operating cost figures should be used in adjusting crop yield benefits, once these data are available.

The data were analyzed for correlation of power requirements with soil classification. The results were inconclusive for the following reasons:

1. Width of cut varied considerably for each test run. Width was not monitored continuously so the actual width of cut at a given location was impossible to determine. Width of cut affects draft and power requirements so valid correlation to soil was impossible.

2. The depth of tillage also varied considerably. Depths were monitored continuously using the SAK depth indicators, but these proved to be only an indication of plowing depth. Calibration of these indicators was difficult because the pitching and rolling of the plow frame during field runs changed the depth indicator calibration reference. For example, if the plow frame tipped towards the land side, the depth indicator would indicate the plow was operating deeper when actually it was not. Therefore all depth data presented is based on manual depths measured every 30.5 m (100 ft). Since continuous accurate depth measurements were not available, no correlation to soil classification could be made.

REQUIREMENTS FOR FURTHER TESTING

Valid correlation of plow performance to soil classification can be made only if more data are obtained. Ideally, the test plots should be uniform. However, solonetzic soil is seldom uniform so continuous monitoring of width and depth would be required. Techniques to monitor width and depth accurately would have to be developed. Alternatively, a detailed soil survey of the furrow wall could be done before measuring draft, and manual depth and width measurements taken at key locations where soil conditions change. In this manner, depth, width, speed, draft and soil data could be correlated for each plow.

Draft measurements on each plow through a range of forward speeds would also be desirable so that optimum field speed for each plow could be determined.

Appendix I

Conversion table

1 metre (m)	= 3.3 feet (ft)
1 millimetre (mm)	= 0.04 inches (in)
1 kilowatt (kW)	= 1.3 horsepower (hp)
1 kilogram (kg)	= 2.2 pounds (lb)
1 kilometre/hour (km/h)	= 0.6 mile/hour (mph)
1 hectare (ha)	= 2.5 acres (ac)
1 newton (N)	= 0.2 pounds force (lb)
1 litre (L)	= 0.2 Imperial gallons (gal)