Design and performance of a spring-damper device
for controlling plow lateral cutting angle

by

Hamid Fadhil Al-Jalil

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Major: Agricultural Engineering

Iowa State University
Ames, Iowa

1976

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Due to increased costs of labor, machinery, and energy, the cost of performing agricultural machinery operations is continuously increasing. This increase in the cost of farm operations is one of the causes of high food prices. One of the solutions to this problem is to increase productivity from labor and machinery investment. Since a large percentage of farm energy is consumed by tillage operations, an increase in productivity could be realized by increasing the capacity of tillage equipment.

The field capacity of plows can be increased by the following methods:

1. Increase the number of plow-bodies operating at conventional speeds.
2. Increase the plowing speed using the same number of plow-bodies which the tractor can handle in relation to its weight.
3. Increase both the number of plow-bodies and the plowing speed.

Increasing the number of plow-bodies must be accompanied by increasing traction ability, which has been accomplished by several methods such as increasing tire size, tractor weight, and torque capabilities of the drive train. The additional weight causes increased soil compaction, resulting in poor aeration, lower water infiltration and drainage rates, reduced water-holding capacity, and greater mechanical impedence to plant roots.

High speed tillage is a desirable way of increasing field plowing capacity, because it helps to reduce soil compaction associated with wide, high draft tillage equipment. The draft increase associated with the increase in forward speed has been one of the major hurdles to a high speed tillage system.

Tests by Eidet (1974) showed that the increase in draft at high speeds can be reduced without adversely affecting plowing performance by reducing the lateral cutting angle of the moldboard plow.

Plows designed to operate at high speed may not give acceptable results when speeds are reduced at the end of the fields and in cases where power is limited due to difficult plowing conditions. Thus it is desirable to design a plow that performs adequately at variable speeds. A high speed plow design, which works well in a certain soil type and condition may also give poor performance in another soil type and condition.

There is, then, a need for an automatic mechanism which rotates the plow bottom as a function of speed and soil type and condition to adjust the lateral cutting angle to provide minimum draft for the existing soil conditions.

Observations from previous tests by Eidet (1974) showed that the side force on the plow bottom was directly proportional to plow speed, and this proportionality changed from soil to soil. This means that in a certain soil type and condition where the side force increased sharply with speed, a high reduction in the lateral cutting angle is needed; while in another soil where the side force increased only slightly with speed, only a slight decrease in the lateral cutting angle is needed.

Considering the above observations, a spring damper mechanism has been designed making use of the side force to rotate the moldboard plow bottom about a hinge. The spring is precompressed to resist the initial side force at low speeds. As the speed increases the side force increases, compresses the spring farther, and hence reduces the lateral cutting angle. With a decrease in speed, the spring force will push the plow bottom back to the original position of the plow. The function of the damper in the mechanism is to provide smooth performance and stability.

Hydraulic control can also be used for controlling the lateral cutting angle of the plow bottom, but due to design simplicity, cheapness, compactness, and ease of maintenance the automatic mechanical control is considered more favorable.

OBJECTIVES

Most recent tillage studies have concentrated on two trends, high speed plowing, and reducing the amount of energy required to till the soil. One possible way of reducing the total energy is to reduce the draft. An indirect factor that must also be considered is reduced traction requirement, which reduces expensive traction equipment. Joining the above studies, the objectives of this research are:

1. To study the factors that affect tillage tool draft and the possible ways of reducing the draft without affecting plowing performance.
2. To design and evaluate the performance of a spring damper mechanism for controlling the lateral cutting angle of a moldboard plow bottom, suiting it for different soils and plowing speeds.

LITERATURE REVIEW

Evaluation of the Factors that Affect Tillage Tool Draft

The most important factors that have significant influence on draft of a tillage tool are:

1. Soil-metal friction and adhesion.
2. Soil-soil friction and cohesion.
3. Shape of the tool.
4. Share edge shape and sharpness.
5. Depth and width of plowing.
6. Speed of plowing.
7. Orientation of the tool.
8. Vibration.
9. Tool interaction.

Soil-metal friction and adhesion

An appreciable fraction of the total work done in plowing arises from frictional forces between the moldboard and the soil. Although no exact data are available, this amount has been estimated as one-third (Crowther and Haines, 1924). These frictional forces have a great influence upon the life and draft of tillage tools, because the intensity of this friction largely governs the wearing and scouring properties of the implement. The general laws of friction between soils and metals have been described by Nichols (1925, 1931).

One of the active soil factors affecting the soil adhesion to metal surface, and eventually the draft is soil moisture. The effect of moisture, however, is noticeable only when the percentage of clay in the soil is high. The moisture versus draft curves, Figure 1, rise sharply at the beginning and then flatten at high moisture contents (Telischi et al., 1956).

Nichols (1931) classified the general phases of soil friction (Figure 2). The phases were largely determined by the moisture content of the soil. The friction phase was found when the soil was dry. As moisture was added, adhesion began and the apparent coefficient of sliding friction increased. The adhesive phase was found when enough water was present to cause high adhesion but not enough to provide a free water surface. The final lubricating phase occurs when enough moisture was present to cause low moisture tension and a free water surface to lubricate the soil-metal surface, thus reducing total adhesion. Nichols also determined the effect of polish on friction. A polish higher than that commonly found on commercial plows was found to be of no practical value on sandy soil. The adhesion of soil to plow surfaces varied with the polish and composition of the metal. Steels containing chromium or nickel were the most satisfactory of other metals investigated, including several samples of chilled iron and a group of plow steels.

Adhesion occurred when the frictional resistance at the soil-tool interface was greater than the soil shearing resistance. Adhesion was reduced by employing materials that

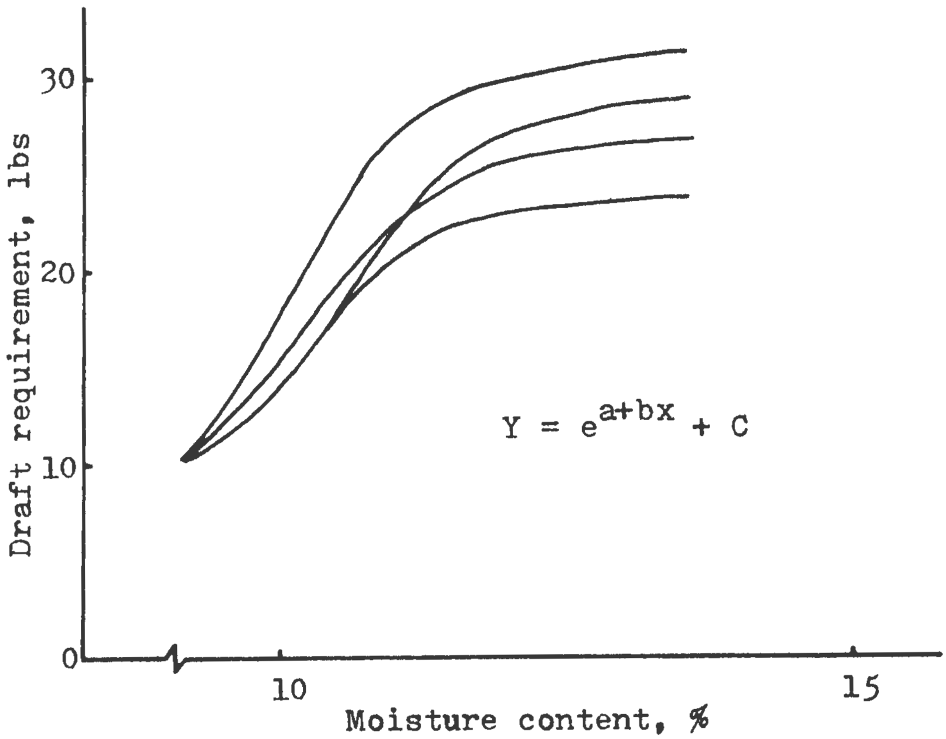


Figure 1. Percent moisture versus draft requirement of a 1-in. tooth pulled 4 in. deep. Packing force 54 lb and speeds 0.60, 0.94, 1.29 and 1.77 mph. Clay soil 16.7 percent (Telischi et al., 1956)

resist wetting. Kummer and Nichols (1938) studied the adhesive forces between soil solutions and metals. They tested a number of metal samples including a great variety of standard plow steels, special alloy steels, and iron. They found that cast irons, containing free graphite carbon, have a great attraction for the soil solution, and that the presence of alloying materials in steels and in cast irons materially reduced surface wetting. The test results also indicated that the grain size distribution and other structural differences due to heat-treatment affect adhesion or the wettability of

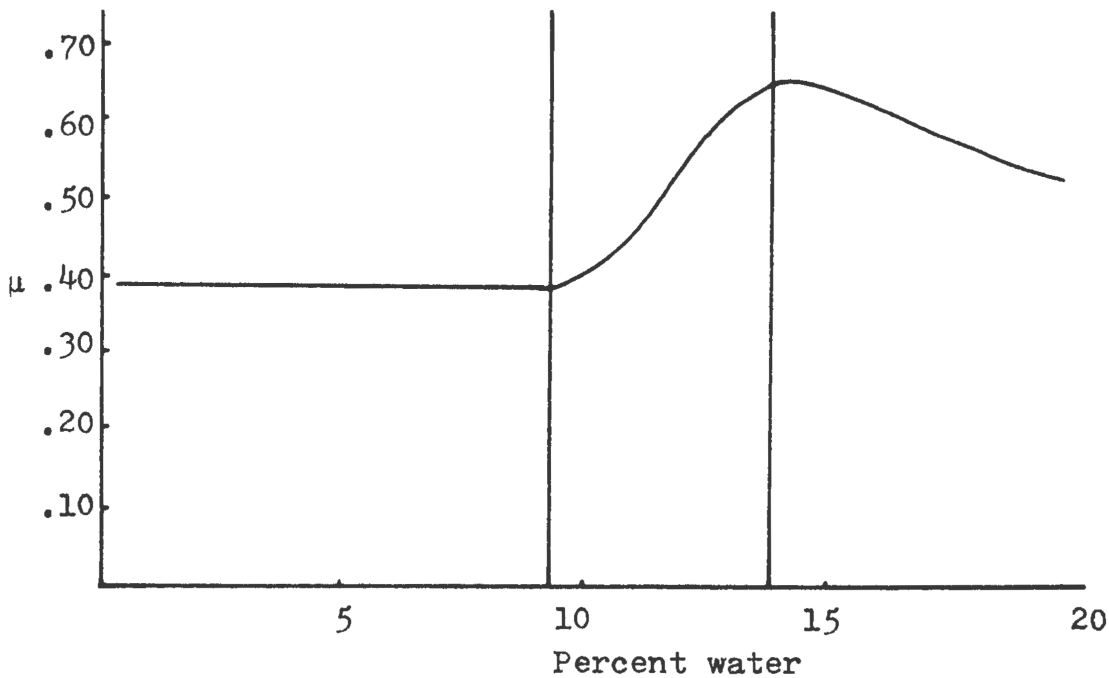


Figure 2. A typical curve showing the effect of soil moisture on friction values (Nichols, 1931)

the metal surface, which seems to decrease with increasing hardness of the metal. Bacon (1918) reported that moldboards made of plaster of Paris or hog hides scoured better in sticky Texas soils than any other type of moldboard investigated, including those made of steel, iron, glass, brass, and aluminum. Kummer (1939) constructed and tested different types of moldboards. The plowing tests showed that wood-slat moldboards impregnated with paraffins or linseed oil scoured better than steel-slat moldboards, especially in the higher moisture content soils.

Adhesion and friction can be reduced by taking advantage of the self-lubricating and anti-stick properties of teflon

(Pillsbury, 1960), but excessive wear is the principal factor restricting the use of plastics in plows. Fox and Bockhop (1962) using teflon or teflon with glass filler as a surface cover of a tillage tool, were able to reduce the draft by 6 to 38 percent depending on clay and moisture content of the soil. Their tests showed that teflon or teflon with glass filler would wear 8 to 10 times more rapidly than steel. Cooper and McCreery (1961) determined the friction, adhesion, and wear resistance properties of various plastic coatings and materials which might be suitable for reducing soil adhesion to tillage tools. Their tests on a teflon covered moldboard plow showed a reduction of draft up to 23 percent (Table 1).

Table 1. Effect of tetrafluoroethylene (teflon) plow coverings on the draft of plows operating at two speeds in clay soils (Cooper and McCreery, 1961)

	Draft force (pounds)			
	Decatur clay		Davidson clay	
Plow surface	1 mph	3.5 mph	1 mph	3.5 mph
Steel	450	490	480	575
Teflon covered moldboard and steel share	350	485	420	530
Teflon covered moldboard and share	365	430	310	440

The use of air as a lubricant for the share and moldboard was studied and found to have some rather exciting possibilities for reducing draft and assuring scouring under all conditions (Bertelsen, 1960a). Bertelsen (1960b) designed a plow using this principle.

The plow had a perforated moldboard through which jets of air were forced as the plow was pulled, creating an air cushion between the moldboard and the soil as the soil flowed across the moldboard. He stated that air lubrication would reduce draft and wear on the share and moldboard. Besides this he listed other advantages of air injection such as aeration of the soil, and the possibility of adding weed killers, insecticides or fertilizer directly to the soil while plowing, but he did not report any test results. Bigsby (1961) was unable to reduce the draft of model tools with air flows up to 69.8 cubic feet per minute per square foot of tool surface. He passed air through various configuration and sizes of holes. In more than one arrangement grains of soil were trapped and made a rougher surface so that draft was increased rather than decreased. However, he proposed that higher air flow rates may reduce draft of these tools, but the power required to supply the air becomes so great that the overall power required was greater than that required to operate the smooth tool. This could be an advantage under conditions where power is available, but it is not possible to develop tractive effort on the drive wheels of a tractor.

The adhesion between soil and the tool has been reduced by heat (Bacon, 1918). Nichols (1925) has reported some data concerning the influence of heat on adhesion. As shown in Table 2 the coefficient of friction of a hot steel slider was considerably less than that of a wetted slider. Unfortunately no details were available as to the temperature used or the quantity of heat lost from the slider during the operation. A new energy source would have to be considered in the study of heat requirement in order to determine whether the required heat could be economically produced.

Table 2. Effect of heat on adhesion, as measured by the coefficient of friction μ of steel slider on dry sand (Nichols, 1925)

Slider weight (grams)	Slider condition		
	Dry	Wet	Hot
	----------	μ	----------
1,500	0.266	0.333	0.233-0.250
3,000	0.266	0.333	0.233-0.250
4,500	0.266	0.333	0.233-0.244

An electrical method and its possible application to plowing was proposed by Crowther and Haines (1924) for reducing the friction between a metal surface and soil. The method proposed depends upon the phenomenon of electroendosomose which is exhibited by moist soil. By virtue of the negative charge of the soil colloids, water will move through moist soil towards the negative electrode under the action of an electric current. It was suggested that, if a current is passed through soil having the moldboard of a plow as a negative electrode, then the film of water formed at the soil-metal surface should act as a lubricant and reduce the plowing draft. Large reductions in friction were obtained in laboratory tests with a metallic slider moving over moist soil. Figure 3 shows the percentage reduction in friction due to current for different voltages and water contents of a Rothamsted heavy loam soil. The percentage reduction in friction was found to be proportional directly to moisture content, current density, duration of the contact, and inversely to speed. In addition, preliminary tests in the field demonstrated that the draft of a plow was reduced by applying a current between the coulter and the moldboard. The magnitude of reduction obtained with this arrangement was too small to have immediate practical value, but the possibility of increasing the effect was discussed.

Even when draft can be reduced only with an increase in total power, traction requirements may make electro-osmosis practical or economical. Reduced traction requirements may reduce expensive traction equipment requirements, particularly since electro-osmosis seems to be most effective in moisture ranges where traction capacity is severely limited (Gill and VandenBerg, 1967, p. 268). Since the efficiency of power

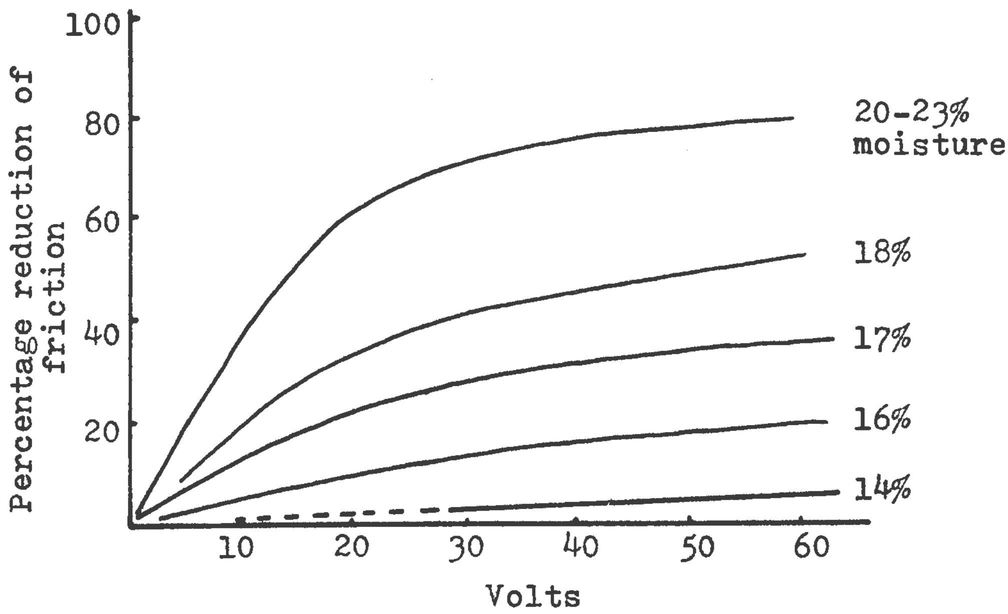


Figure 3. Effect of passing electrical current through a Rothamsted heavy loam soil on sliding friction at speed of 4 feet per minute (Crowther and Haines, 1924)

transmission through the traction system is often less than 50%, any possibility of reducing draft requirements is attractive.

A similar research study was conducted by Mackson (1962) to determine the effect of the electro-osmatic process on draft requirements of tillage tools with speed, soil moisture content and voltage as variables. The experimental results showed that up to an 80 percent reduction in sliding friction was possible at very low speeds and under wet soil conditions. At speeds approaching field speeds, however, and with soil which would not puddle in the field, the reduction in sliding friction was very small.

Soil-soil friction and cohesion

As a tillage tool advances through soil, the soil is subjected to compressive stresses which, in a friable soil, result in a shearing action. The shear stress is represented by the equation:

$$T = C + \sigma \tan \phi$$

where C = cohesion,

ϕ = angle of internal friction,

σ = normal (compressive) stress,

T = shearing stress.

This equation implies that soil strength is composed of two factors--cohesion and internal friction. Cohesion is defined as the force that holds two particles of the same type together while internal friction results from interlocking of particles within the soil mass. When soil fails in tension, only the cohesive part contributes to resistance since the normal stress is negative. Such reasoning immediately suggests that tensile failure may be exactly the measure of cohesion (Gill and VandenBerg, 1967).

The resistances of standard blocks of soil to transverse breaking, crushing, and parting under tensile load were measured by Hardy (1925) in order to compare cohesiveness in soils. The relative cohesiveness of the soils examined appears to follow the same order as their rates of settling from aqueous suspension. This observation strengthens the view that cohesiveness in colloidal soils is to a certain extent due to chemical forces that depend on the presence of active atoms or atomic groups possessing powerful fields of residual affinity, although probably film tension also plays a part.

In studying the relationship between the mechanical properties of soil and the performance of simple tillage tools, Payne (1956) found that cohesion was the property to which the draft was most sensitive, and almost a linear relationship existed between draft and cohesion as shown in Figure 4.

Shape of the tool

The shape of the tillage tool is one of the factors that has a definite influence on draft and can be controlled by the designer. Its relative effects are influenced by soil type and conditions, speed, and perhaps other factors. Soehne (1959, 1960) conducted a detailed study of the effects of shape, speed, and soil conditions on specific draft. He classified the plow body shape into digger, universal, spiral, and helocoidal. His study showed that plow bodies suitable for high speed can be developed from both universal and spiral shapes by changing the shape of the moldboard in such a way that the acceleration forces developed at higher speed will be lowered.

Five bottoms representing major classifications of plow

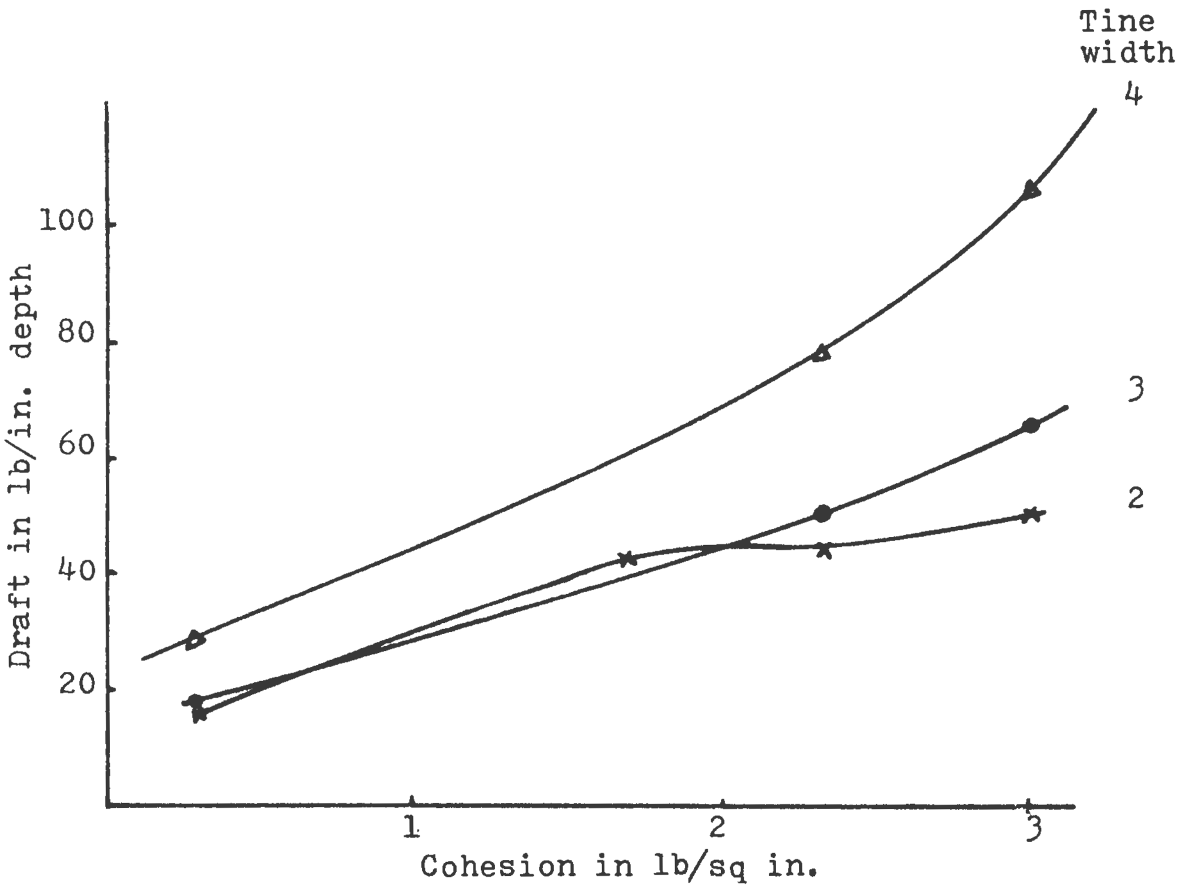


Figure 4. The relationship between draft/in. depth and cohesion for tine width of 2, 3, and 4 in. (Payne, 1956)

bottom shapes were tested by Reed (1941) in three different soils in order to determine the effect of these major shapes on the draft of 14-in. moldboard plow bottoms. The test data showed that the shape of plow bottom affects draft markedly and the effect varied with soil condition and speed.

Kaburaki and Kisu (1960) in their studies on cutting characteristics of plows proposed that modifications in the shape of tillage tools can give better scouring and therefore less draft.

Nichols and Reaves (1958) made a series of studies on a wide range of subsoilers designs. Draft was measured in several types of soil, and the results indicated that the subsoiler with the most curved configuration required the least draft as shown in Table 3.

Table 3. Comparative draft of two light subsoilers at 1.5 mph in different soils; the subsoilers were alike in all principal features, except for straight or curved standard (Nichols and Reaves, 1958)

	Soil					
	Hiwassee	Davidson	Decatur	Sharkey	Hurri-cane	Houston
Depth, inches	12.50	12.25	12.00	11.50	11.75	9.50
Curved standard	890	860	1415	1820	1820	1660
Straight standard	960	930	1829	2000	2120	2040

Share edge shape and sharpness

The plow share is responsible for approximately half the draft resistance of the plow (Gavrilov and Koruschkin, 1954) and, moreover, the quality of plowing depends on it to a great extent (Chase, 1942). Also, the penetrating ability of the plow depends on sharpness of point and share.

Share edge shape can significantly affect draft. Nichols et al. (1958) studied the basic effects of variations in plow share design on the total draft. Three different share edge shapes (Figure 5) were tested on a plow bottom at the National Tillage Machinery Laboratory, and drafts of 300, 288, and 270 lbs respectively were recorded when the shares were new.

Plow shares are the first element of the tool to encounter the soil and as a result they are subjected to greater forces and comparatively rapid wear. This wear modifies the share edge shape causing soil compaction in front of the edge, with the ultimate result that the plow draft resistance increases and quality of work deteriorates (Gill and VandenBerg, 1967).

One of the characteristics of wear is the formation of an underside chamfer on the lower side of the cutting edge of the share. With the appearance of this chamfer the rear angle γ, Figure 6, is decreased. When it passes the zero value, the chamfer is parallel to the furrow bottom, after which it acquires a negative value, at which the soil exerts a pressure on the surface of the chamfer AB. The highest resistance P created by the underside chamfer was found at an angle $\gamma = \tan^{-1}(\frac{1}{f})$ where f is the friction coefficient (Gavrilov and Koruschkin, 1954).

In one of the experiments on plow shares done by Gavrilov and Koruschkin (1954) the formation of an underside chamfer increased the specific soil resistance by more than 30% (Table 4).

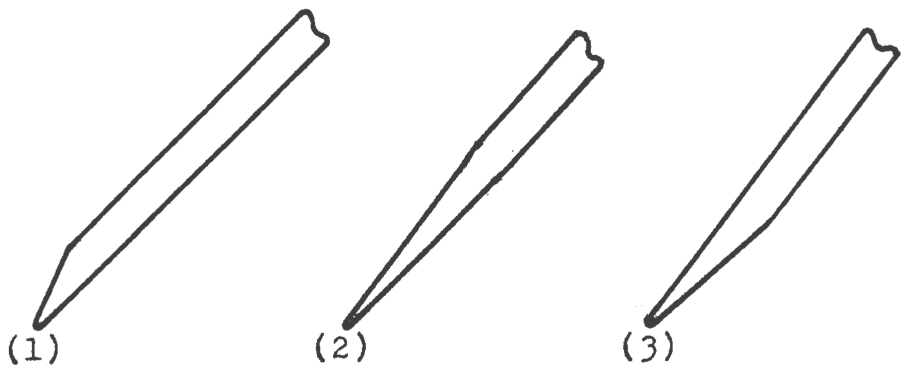


Figure 5. Three different share edge shapes

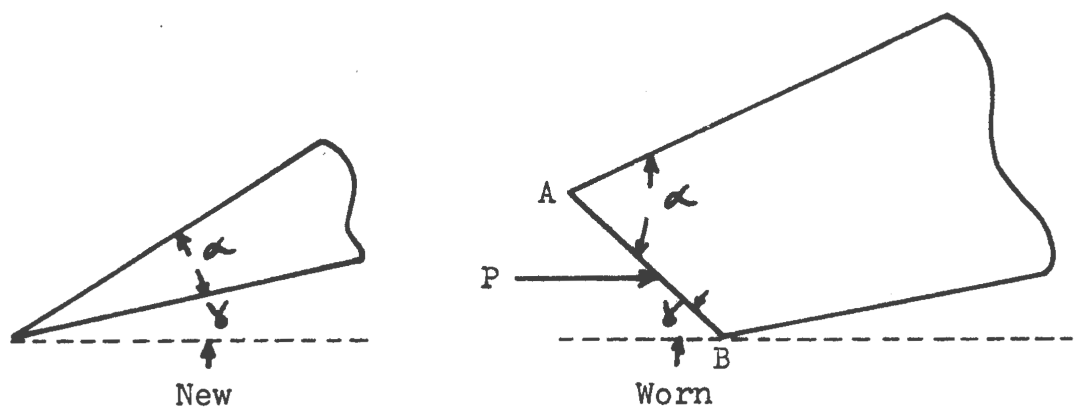


Figure 6. New and worn share edge with a positive rear angle γ when new and negative when worn (α is the angle of sharpening)

Table 4. Percentage increase in draft due to the formation of underside chamfer in plow shares

Angle of sharpening of the share α degree[a]	Specific soil resistance in kg/sq cm	Percentage increase in soil resistance
15	0.50	
30	0.59	18
36	0.63	26
42	0.66	32

[a]The increase in the sharpening angle α was due to wear as the share was used.

Depth and width of plowing

Depth of cut and width of cut are factors that may affect draft and the energy utilization efficiency for a specific soil condition. The effect of these factors varies with different types of implements and with different soil conditions (Kepner et al., 1972).

In assessing the effects upon draft, any accompanying effect upon the degree of soil pulverization must also be considered. Gill and McCreery (1960) showed that the efficiency of energy application decreases as the width of cut increases.

In a uniform soil condition, the draft of a tillage tool always increased with increasing depth or width of cut (Kynazev, 1957; Keen and Haines, 1925; Getzlaff, 1953; Davies, 1924).

The effect of depth and width of cut can be better expressed by measuring the specific draft, which is the draft per unit cross-sectional area of cut. Kynazev (1957) tested a chisel plow P5-35C and found that the specific draft is proportional to depth. He related the increase in specific resistance with increasing depth to the changes in the physical properties of the soil, especially compaction which increases approximately in proportion to depth.

Davies (1924) noted that the specific resistance slightly increased as depth of cut increased. His tests also showed that there were two conditions, on the one hand, where specific resistance slightly increased with width, and on the other hand, in which specific resistance slightly decreased as width increased. He concluded that width had little effect on specific draft. Randolph and Reed (1938) on the basis of their tests with a 14 in. general purpose moldboard plow, considered that at a depth of 6 inches specific resistance is minimum. Also, they reported that there was no change in specific resistance with 12 in. and 16 in. plows when width was altered between 8 in. and 20 in.

Experiments on plows by Kaburaki and Kisu (1959) show a gradual increase of draft with depth up to approximately 12 cm, but beyond 12 cm the increase rises sharply. They also showed that specific resistance decreased as width of cut increased, and in the case of model tests specific resistance was almost unaffected by width of cut.

Reaves and Schafer (1974) found that the performance of moldboard bottoms with width of cut from 40.6 cm to 50.8 cm was about the same, but the 40.6 cm width required 10% less specific draft than the larger bottoms in sandy loam soil. Also they found that within the normal operating depth, 20 to 25 cm, the specific draft requirement changes little with depth of operation, but in clay soils some increase in draft requirement can be expected with increasing depth.

Getzlaff (1953) in his field tests on four standard plow bodies noticed that the specific draft increased slightly at increasing depth in the case of all shapes of bodies and soils tested. The optimum working depth was nearly constant for all shapes. The optimum value of the width to depth ratio ranged from 2.7 for wide cutting to 1.5 for narrow cutting.

Kaburaki and Kisu (1959) conducted a series of tests on various kinds of plow. Using a 9.5 in. plow, and maintaining the width to depth ratio at 2, a linear relation was found between the cross-sectional area and the specific draft. Using the same plow, and keeping the cross-sectional area at 180 cm^2, the relation between the width to depth ratio and specific draft was found to be hyperbolic. From the above relations the general equation of specific draft was deduced in the form:

$$Rs = \frac{E}{-2.85 + 2.15\,E} + 0.00031\,F - 0.056$$

where Rs = specific draft (kg/cm^2)

E = width to depth ratio

F = cross-sectional area (cm^2).

Speed of plowing

High speed operation is desirable because it offers a means of increasing the output of machines without adding much to the size and weight of tractors or machines. The draft increase associated with speed is a major factor limiting the speed at which it is feasible to use tillage tools. The increase in draft is mainly caused by higher acceleration of any soil that is moved appreciably. Soil acceleration increases draft for at least two reasons--first, because acceleration forces increase the normal loads on soil engaging surfaces, thereby increasing the frictional resistance, and second, because of the kinetic energy imparted to the soil. The relation between draft and speed can be represented by the equation

$$Z = Z_0 + K\,V^2$$

where Z = draft at speed V

Z_0 = static component of draft, independent of speed

V = forward speed

K = a constant whose value is related to implement type and design and soil condition (Kepner et al., 1972; Soehne, 1960).

Telischi et al. (1956) conducted a series of experiments in an attempt to evaluate some of the factors that affect tillage tool draft. The relationship between the speed and draft requirement of tillage tools (Figure 7) was found to follow the equation

$$y = a\,x^{b} + c$$

where y = draft

x = speed

a, b, c = constants.

The factors b and a are related to the clay and moisture contents of the soil and also to the kind of implement and shape of the tool. In sandy soil and in any other type of soil where moisture content is low, the exponent b is nearly zero. The moisture content at which the speed does not have appreciable effect on draft is slightly above the wilting point. As the amount of moisture and clay increases, the slope of the lines increases. With high clay and moisture contents the exponent b will be greater than one and the relationship is not linear.

Rowe and Barnes (1961), on the other hand, used an analysis based on soil mechanics to calculate draft values for a tillage tool and compared them with actual measured values for the same tool over a range of operating speeds and soil conditions. They found that the major cause of the higher draft resulting from increasing the speed of a tillage tool is the increase in shearing strength of the soil due to the higher rate of shear, and the acceleration of the soil contributed only a small part of the total force increase with speed. The test also showed that the draft increase was not as large for

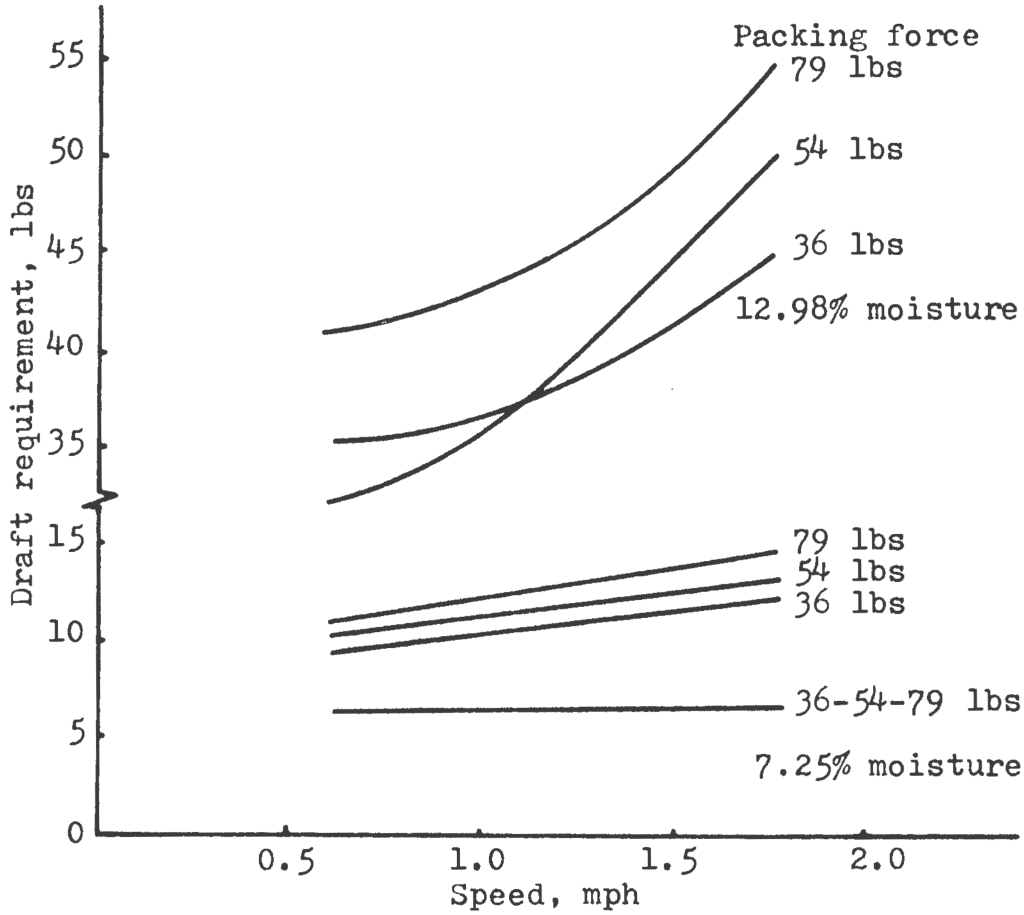


Figure 7. Speed versus draft requirement of a 1-in. tooth pulled 4-in. deep in soil containing 22.5 percent clay with three moisture contents and three packing forces (Telischi et al., 1956)

soils low in clay as it was for those having a considerable proportion of clay.

The increase in draft with higher speed can be reduced by slightly reducing the share cutting angle ϕ_1, the lift angle δ (Figure 8) and considerably reducing the lateral directional angle at the moldboard end. On the basis of this information

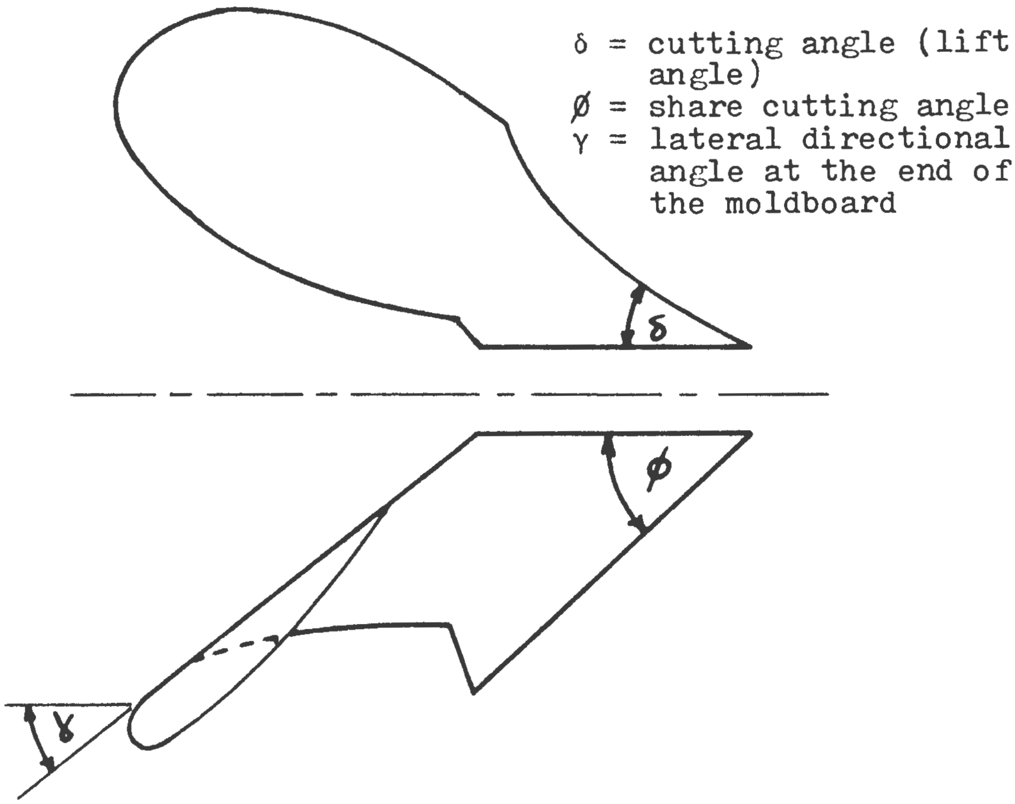


Figure 8. Front and top view of moldboard plow bottom

moldboards suitable for high speed plowing were developed from universal and spiral forms (Soehne, 1964).

Plowing at too low speeds is unfavorable because of sticking problems. Kaburaki and Kisu (1960) in their study on cutting characteristics of plows found that the volume of stuck soil decreases with increasing speed. The test plow showed a favorable result when the travel speed was more than 1 m/sec.

<u>Orientation of the tool</u>

The orientation of a tillage tool with respect to the direction of travel may significantly influence both the soil manipulation and the draft (Kepner et al., 1972; Payne and Tanner, 1959).

Kaburaki and Kisu (1959) measured the influence of the lift angle α of a simple inclined tool when it was swept back laterally with a side angle β. The projected area of the tool in the direction of travel was maintained constant for all variations studied. With a fixed cutting angle β, the cutting resistance increases with α. The cutting resistance increases when α is above 30^o, but the increase will be less sharp when α is below 30^o. Without changing α, the cutting angle β, when it is above 50^o, does not affect the cutting resistance, but when it is below 50^o, the smaller the angle, the greater is the resistance.

In similar tests done by Dransfield et al. (1964) the draft decreased as a plane-faced tine was given positive rake; the beneficial effect of rake falling off at about $\alpha = 45^o$ for loose soils, but at rather higher values for more compact soils. The effect of side rake on draft is relatively small and for looser soil conditions is zero. For firmer conditions a 20% reduction in draft can be expected in turning a vertical tine from a direction normal to the line of travel to one at 45^o, maintaining the projected area constant.

In an attempt to determine the design parameters necessary for high speed plowing, Eidet (1974) tested the effect of varied lateral cutting angle on moldboard plow performance. Two plow bottoms were tested at four different lateral cutting angles in three soil types ranging from a light sand to heavy clay. The design approach angle of each bottom was reduced a total of 15° in 5° increments. The forces in the three mutually perpendicular directions were measured versus speed for each plow bottom.

The results indicated that a draft reduction was possible by rotating the plow bottom. Within certain speed ranges the draft increase with increased speed could be completely eliminated. The draft force versus speed in sand is plotted in Figure 9.

Vibration

The draft requirement of a tillage implement can be reduced substantially by oscillation of the soil working parts of the tool. Power not utilized by draft, because of traction limitations, is available through the tractor power-take-off to oscillate the soil working parts. Gunn and Tramontini (1955) performed a series of experiments on a simple inclined tillage blade like a subsoiler chisel. Their tests indicated that average net draft could be reduced greatly by oscillation of the experimental chisel. A rapid reduction in draft occurred as the forward speed of the tractor was reduced in comparison with oscillating velocity. Several dimensionless

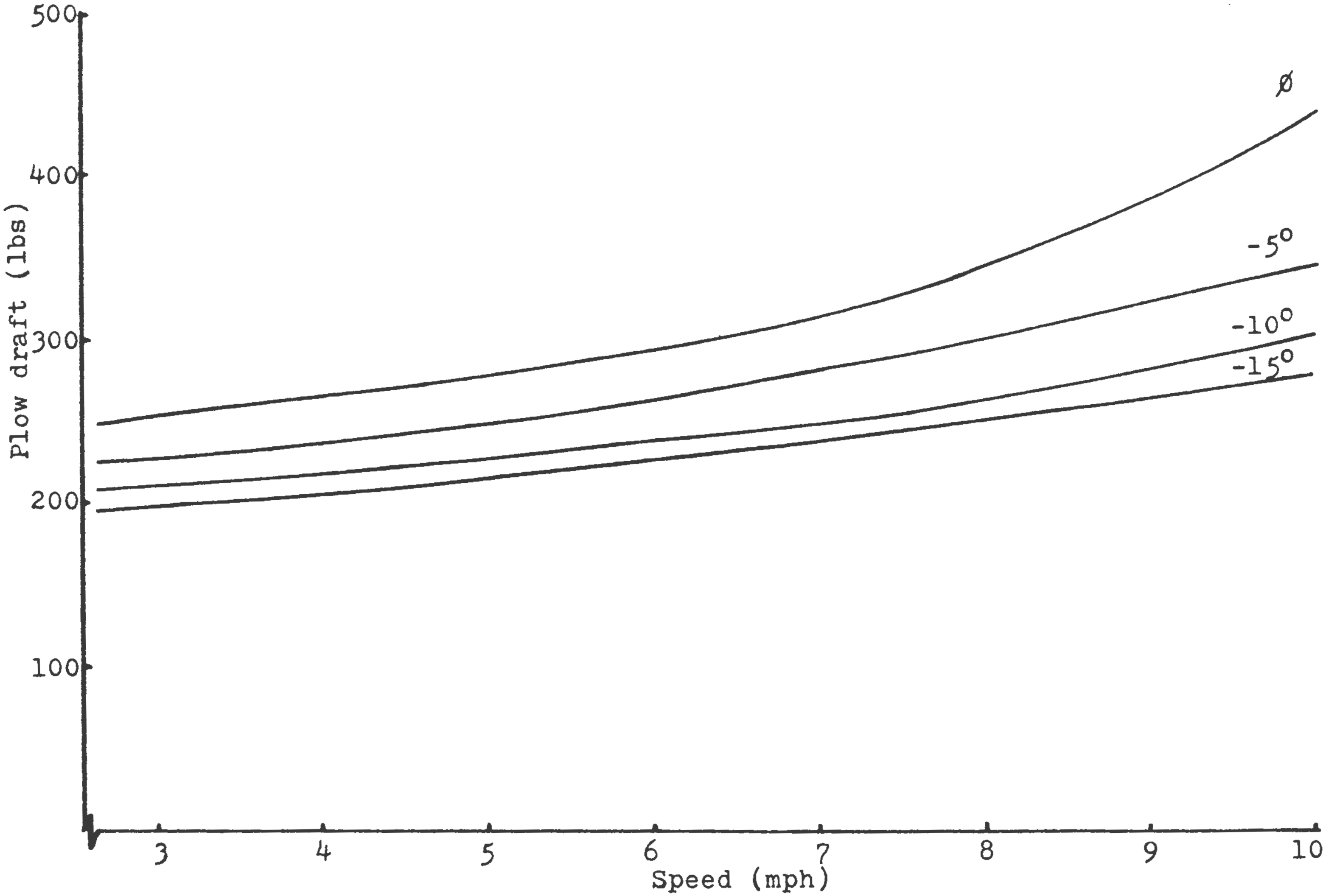


Figure 9. Plow draft versus speed for model 392 plow bottom tested in Lakeland loamy sand at four lateral cutting angles (Ø = 35) (Eidet, 1974)

parameters were used in the experiments, one of them was

$$k = \frac{Vt}{\omega r}$$

where ω = angular velocity of the pitman in radians per second

r = eccentricity of crank in feet

Vt = forward velocity of tractor in feet per second.

The greatest reduction of the draft was obtained by operating at values of k less than 1, i.e., at implement oscillating velocities that exceed the forward speed of the tractor.

An important result of these experiments was that this reduction in draft was not accompanied by a large or significant reduction in the total energy required to perform essentially the same tillage operation. Another result was that the oscillating tool appeared to give better soil fragmentation than a nonvibrating tool.

In an investigation by Dubrovskii (1956) a series of tests were conducted using models of a tool in the form of a single triangular wedge in sand. The results are shown by Figure 10, in which curve 1 is the nonoscillating relation between draft and speed. Curves 2, 3, and 4 are draft curves at various frequencies of oscillation. In all cases the vibrating tool resulted in a reduction of draft up to a certain forward speed, and then showed an increase in draft beyond that speed. The dashed curves in Figure 10 are lines of equal wave length of oscillation. Unfortunately Dubrovskii listed

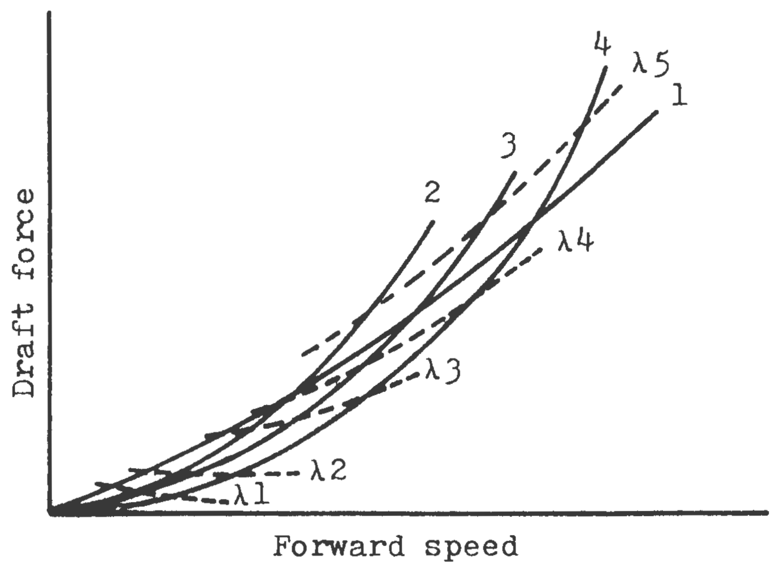


Figure 10. The relation between the draft of stationary tool (curve 1) and of a tool vibrating at three frequencies (curves 2, 3, and 4) with an increase in speed (λ = wave length) (Dubrovskii, 1956)

no specific values of draft and speed. His work does show that the speed of oscillation must exceed the forward speed of the tool if the oscillating tool is to have a lower draft than a nonoscillating tool.

Hendrick and Buchele (1963) reported that the reduction in draft of an inclined-plane tillage tool was rapid until the frequency of oscillation approached the frequency of the formation of shear surfaces. Their tests resulted in little or no total tillage energy reduction.

Shkurenko (1960) established an empirical equation of the relation between the reduction in draft force and the amplitude of oscillation for limited experimental conditions. The relation had the form

$$\delta = \gamma \ A^{0.83}$$

where $\delta = \dfrac{\text{draft (nonoscillated) - draft (oscillated)}}{\text{draft (nonoscillated)}}$

A = amplitude of oscillation

γ = constant of proportionality, depending on frequency and direction of oscillation, depth and angle of cutting, and soil properties.

All the tools in the investigations listed above were multipowered tillage tools to which oscillating energy was applied by mechanical means such as eccentrics, cams, or crankshaft and connecting rod arrangements. A practical oscillating tool that is not multipowered and that has uncontrolled oscillation is a spring tine (Telischi, 1962). The oscillations are induced by variations in soil resistance. When high resistance is encountered, the tine displaces; when resistance decreases, the restoring force of the spring returns the tine to its original position. Presumably, oscillation of a flexible tine permits the tool to take advantages of minor irregularities in soil strength.

Tool interaction

Interaction refers to the simultaneous operation of tools near each other. The two or more individual tools interact and behave as a new tool, in which frequently the total force required to move the combined system of tools through soil is reduced. The draft of a plow and coulter combination varies as the position of the coulter relative to that of the plow varies. Because of interaction, the draft of the plow and coulter combination may differ from the sum of the two components measured separately (Gill and VandenBerg, 1967).

Berry (1948) compared the total draft of a 14-inch general purpose plow bottom combined with a conventional coulter jointer with the same plow combined with a disk jointer. The test results showed a lower draft requirement with the disk jointer, presumably because of a better interaction with the plow bottom.

Thompson and Kemp (1958) developed a graphical method to illustrate the effects of disk diameter, spacing and angle of cut of a disk implement on the required depth of operation to improve the quality of work obtained from the disk equipment. Their study showed that the depth of cut has to be increased with an increase in spacing and with a decrease in disk diameter.

Rathje (1932) conducted studies concerning interactions of two standard blunt cutters, 15 mm thick, placed side by side at various distances apart and towed simultaneously through sand. The draft resistance was found to depend on the ratio of the distance between the cutters, d, and the depth of operation, t. When the cutters were close together a common compression wedge was formed similar to that in front of a single cutter of the same overall width. When the cutters were gradually moved apart, the resistance for a given depth increased and reached a maximum at d = 0.043 t. As the tools were moved farther apart, the compression wedge which had bridged over the gap was broken through, starting at the bottom, and the sand in the gap flowed backwards. The draft fell fairly rapidly with an increase in the spacing, reaching a minimum value when d = 0.34 t. At that point the draft force was only 10% higher than that of a single tool. Increasing the gap still further, the draft increased until the point d = 2.5 t was reached and the cutters were acting independently.

Draft force can be reduced by using a double-cut plow (two shares, one mounted above the other). Reed and Berry (1946) measured the draft of a double-cut plow and compared it with a conventional moldboard plow. The two shares of the double-cut plow were arranged so that the same volume of soil was tilled by the two types of plows. The test data (Table 5) indicate that under uniform soil conditions the draft of the double plow arrangement was 25 to 30% lighter than for the regular moldboard plow and that the various depth settings of the double-cut shares produced different total draft for the combination.

Davidson and Collins (1929) tested a modified plow and pulverizer combination. In this machine a share and shin section of a moldboard are used to turn a furrow slice partially over so that a revolving cylinder of pulverizer

Table 5. Comparison of conventional and double-cut plows with respect to the draft required to plow a furrow 14 inches wide to several depths

Type of soil	Depth of operation (in.)			Draft (lbs)	
	Conventional moldboard plow	Double-cut plow: Upper share	Double-cut plow: Lower share	Conventional moldboard plow	Double-cut plow
Norfolk sand	8	5	3	335	235
	8	6	2	335	270
	10	6	4	473	356
	10	7	3	473	350
Davidson loam	8	5	3	653	513
	8	6	2	653	520

blades may act upon the slice from the rear, insuring the same trash and plant growth coverage of a plow, and better efficiency of the rotary pulverizer driven directly by the engine through the power-take-off.

The removal of that portion of the moldboard which turns and pulverizes the soil provided a considerable saving in draw bar horsepower up to 14.8%. The performance of the combined plow and pulverizer with proper adjustment was claimed to be equal to plowing with several secondary tillage operations such as one preliminary disking, two subsequent diskings, and one harrowing.

EXPERIMENTAL WORK

Description and Test Result of Plow Model 1

A high-speed moldboard plow bottom (Allis-Chalmers production model 392) was chosen for the test of the spring damper device. The high-speed bottom was selected because it was originally designed for higher plowing speeds with a lateral cutting angle of 35^{o}. Another reason for selecting this plow bottom was to compare the test results with a previous test by Eidet (1974) in which the same plow bottom was used to find the effect of varying the lateral cutting angle on the performance of a high-speed moldboard plow.

The hinge (Figure 11) consisted of two individual parts welded together and inserted at the junction where the frog intersects the moldboard. The hinge was placed as close to the point of the share as space limitations would permit. After assembling the hinge, the frog was cut to provide free rotation of the moldboard about the hinge.

From previous tests by Eidet (1974), it was observed that when plowing at a lateral cutting angle of 20^{o}, the maximum side force was about 180 lb, and occurred at a speed of 9 mph in Norfolk sandy loam soil. The point of application of the resultant side force is not stationary, but is moving from the plow share towards the moldboard as the speed of plowing increases.

To allow for proper rotation of the moldboard, a spring was chosen which had the following specifications: mean diameter, D=4 inches; length, L=20 inches; wire diameter, d=0.25 inches; number of turns, n=14. The spring was fixed with an offset of 14 inches from the hinge. This location was chosen because there was already a plow bolt attached there by the manufacturer which can be used for fastening the spring to the moldboard. Also, it was found that this place is suitable for the size of the spring without interference with the furrow wall.

Assuming the furthest point of application of the side force is about 5 inches from the hinge, the force on the spring was calculated and found to be 64.29 lb. Then the deflection of the spring was checked using the formula $\delta = \frac{8PD^3n}{Gd^4}$ (Black and Adams, 1968); where δ = deflection of the spring (in.), P = force (lb), D = spring mean diameter (in.), n = number of turns, d = spring wire diameter (in.), G = modulas of rigidity; and was found to be about 9.83 inches, which can be handled by the spring.

The spring was precompressed to resist the initial side force at low speeds. Several holes were drilled in the column holding the spring to provide variable precompression.

To maintain smooth performance of the plow bottom and give more stability, a damper was fixed inside the spring. The damper has the following specifications: total length unstretched = 11 inches, stroke length = 6 inches.

The range of changing the lateral cutting angle was limited to 15° rotation from 35° to 20° lateral cutting angle. A groove and follower were used to limit the rotation. A complete picture of the plow bottom model 1 is shown in Figures 12 and 13.

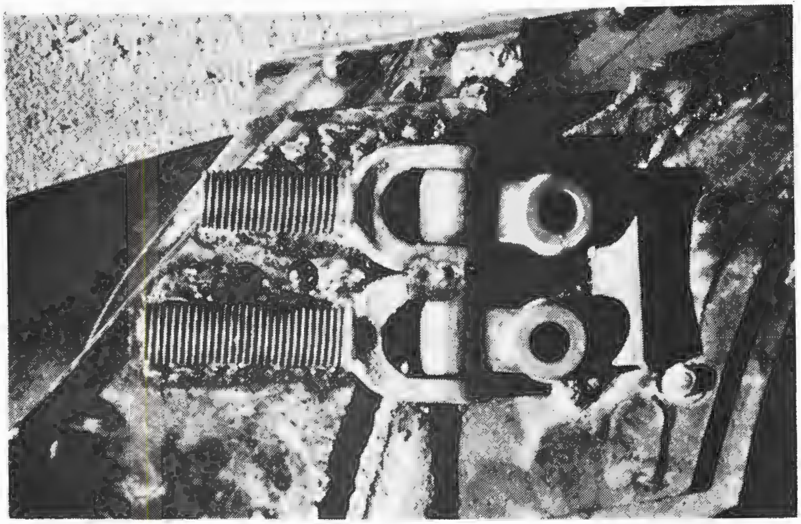
The plow bottom was tested in the National Tillage Machinery Laboratory (NTML), Auburn, Alabama, without preliminary test in the field due to weather difficulties in winter.

During factory production, the plow bottoms are polished to remove surface scale and any large defects. After the final polishing, they are painted to protect the steel surfaces from corrosion. Before running the test, the plow was run several times in sandy soil to remove the protective paint and give it soil polish to ensure proper operation of the plow bottom during any experimental testing.

The plow bottom was run in sand soil bins; but, unfortunately, the tests gave disappointing results; the plow was unstable. Instead of vibrating within a small range under the influence of variations in draft force with speed, the moldboard moved to one or the other extreme limits. This action is related to the largest concentration of the force being on the point of the share. At low speeds, the force distribution on the plow resulted in a counterclockwise moment on the plow bottom when viewed from the top. Thus, the plow stayed at its maximum angle. If, for any reason, the moment was decreased so that the plow started to rotate, the moment

Figure 11. The hinge as it was used for plow model 1. It was inserted at the junction where the frog intersects the moldboard

Figure 12. Allis-Chalmers high speed moldboard plow bottom model 392 with the spring damper mechanism assembled



due to the force on the point of the share would be further decreased or even reversed, in sense, accelerating the rotation.

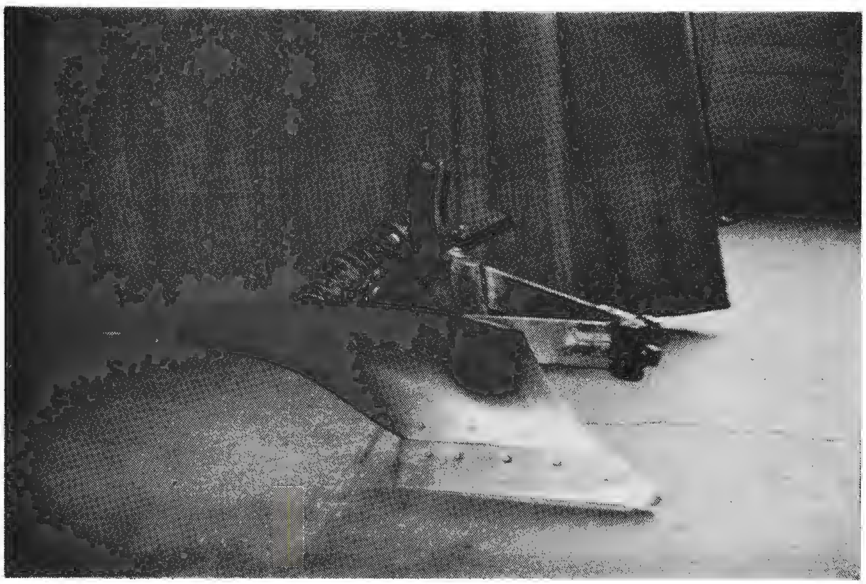
The above action was observed in a number of tests. With the spring and damper attached, the plow never rotated; that is, it always stayed at the maximum angle. With the spring and damper completely removed, the plow bottom rotated to the 20^{o} angle on some passes and did not rotate at all on others. This was also true when the spring was attached, but the damper was removed.

Description of Plow Model 2

Since the largest concentration of force is on the point of the share, it was suggested that the hinge in model 1 be placed where this force would have only a small effect on rotation of the bottom.

The hinge was removed, modified a little, and place above the share point (10 inches ahead of the moldboard shin) in such a way that the axis of rotation of the hinge almost passed through the share point (Figures 14 and 15). Care was taken to insure that the design lift angle for the plow bottom was maintained as the hinge was removed and placed in its new position. Two extended arms were used to connect the hinge to the frog, making a rotation radius of 28 inches between the spring and the hinge. The spring was held in its original position. This new arrangement was expected to eliminate or

Figure 14. The hinge as it was used for plow model 2. It was placed above the share point (10 inches ahead of the moldboard shin)



reduce the effect that the large force on the share point exerted on the rotation of the bottom, thus providing more stability.

Due to the increase in the length of the rotation radius, the original groove and the follower permitted a smaller range of rotation and smaller lateral cutting angles. To bring back the original range of rotation from 35^{o} to 20^{o} lateral cutting angle, the groove was extended 2 inches. The damper, as mentioned previously, has a 6-inch stroke. In the new model, the 6-inch stroke gave a reduction in the lateral cutting angle from 35^{o} to 25^{o} only. However, this new range is expected to give satisfactory results in plowing performance.

Test Procedure

Plow model 2 was tested in the field at the Agricultural Engineering-Agronomy Research Center, Iowa State University.

To evaluate the performance of the spring damper mechanism in changing the lateral cutting angle with speed and its effect on plowing performance, qualitative tests were conducted in which the furrow profile was inspected at different speeds. The speeds 4, 6, and 8 mph were of interest because they represent both common and high speed plowing. The average speed of plowing for each test was accurately determined by measuring the time to complete 100 feet of a test run.

A 2-bottom mounted plow pulled by a rear wheel drive tractor was used in the field test. The plow had a rear gage wheel to regulate the depth of plowing, which was set at approximately 6 inches. The flexible plow bottom was mounted behind a general purpose plow bottom (Allis-Chalmers production model 387) to control the width of cut. The width of cut in all the tests was adjusted at about 10 inches.

The field tests were conducted on ground which had been cropped with corn the previous year. The ground was disked before the test to insure a relatively level surface with a light covering of weeds and corn stalks.

In the first few runs the spring was observed to compress completely at low plowing speeds. Additional tension springs were used as shown in Figure 17 to increase the rotation resistance. These springs also increased the torsional moment exerted on the support holding the hinge, and caused failure of the support. After stiffening the hinge support, the position of the tension spring was moved back as shown in Figure 16, and a balancing weight was used to reduce the effect of the torsional moment. One tension spring working together with the original compression spring was enough to give the proper rotation of the plow bottom. The tension spring has the following specifications:

Mean diameter, $D = 3$ in.

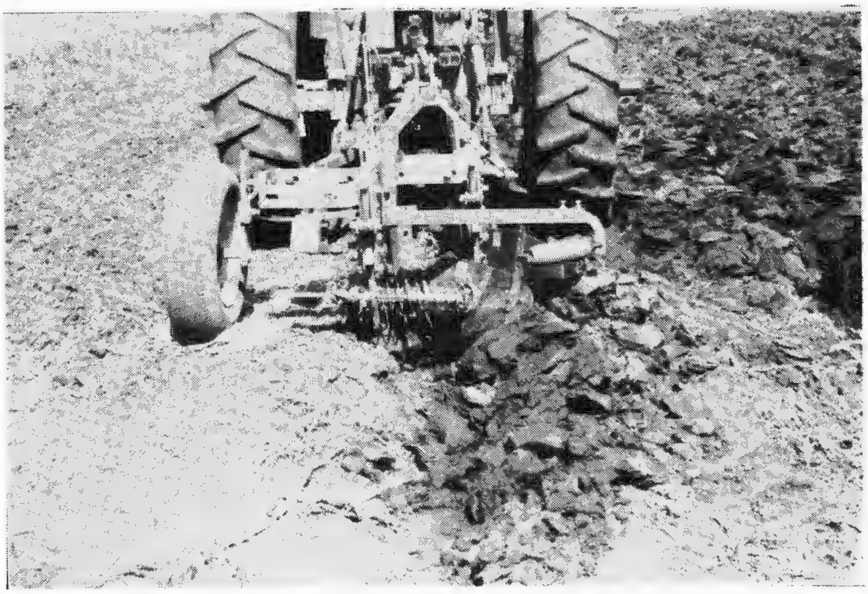
Length, $L = 8.5$ in.

Wire diameter, $d = 5/16$ in.

Number of turns, $n = 28$.

The shape of the furrow profile was established with the

Figure 16. Plow model 2 with one tension spring fastened to the wing and a balancing weight located at the original position of the tension spring

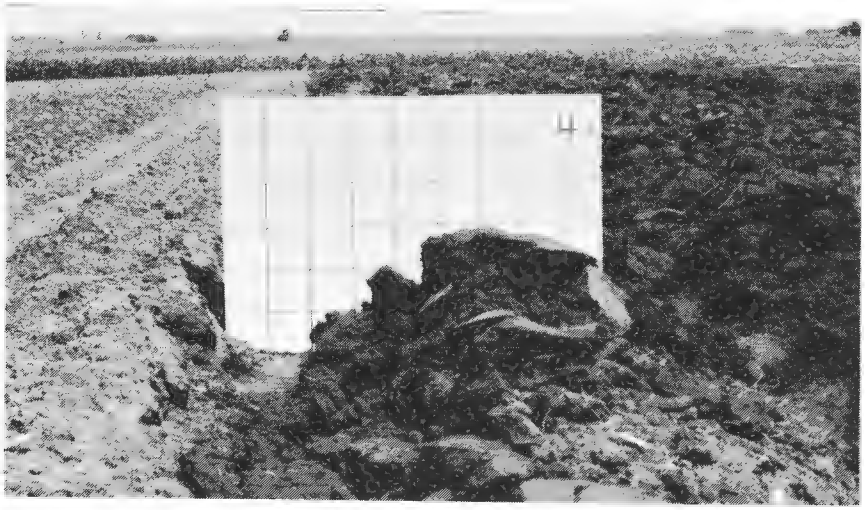


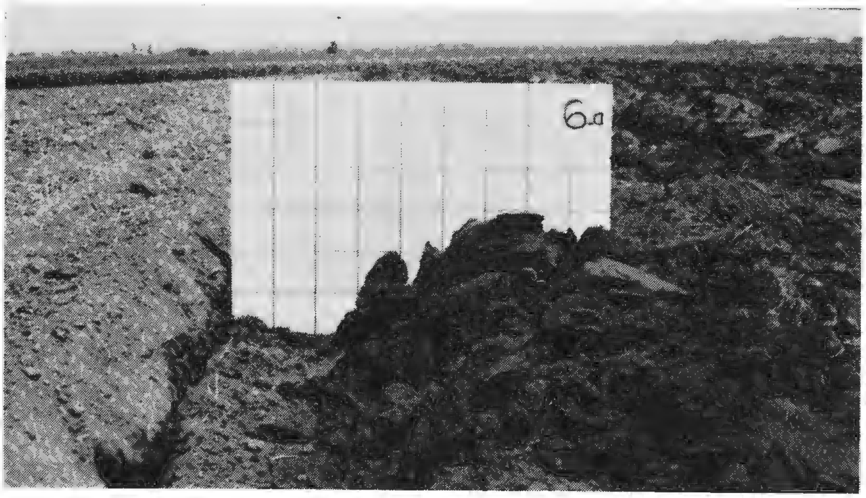
aid of a grid board inserted in the plow furrow. The 24-inch by 36-inch board was constructed of quarter-inch thick plywood. The plywood was first painted with white enamel. The lines to establish the grid system were 4 inches apart on center and painted with waterproof black ink over the white background. The grid board as it was used in testing the plow at three different speeds is shown in Figures 18 and 19.

After the 100-foot test run was completed for each speed a trench was dug in the plowed ground at right angles to the furrow wall, into which the grid board was inserted. The left edge of the grid board was positioned against the furrow wall while the bottom edge of the board was placed even with the bottom of the plow furrow. A level was used on top of the grid board to insure that the grid board was always parallel with the furrow bottom. Photographs were taken of the grid board positioned in the furrow to record the profile. The test consisted of 6 runs, two for each speed. Three furrow profiles for each run were recorded at three randomly chosen positions. The furrow profiles examined are shown in Figures 20, 21, 22, 23, 24, and 25.

The field tests were repeated using a single stroke air cylinder connected to a small air reservoir instead of the spring damper mechanism. The new device (Figure 30, page 62) was expected to give better results because the proper rotation resistance and precompression force can be provided by varying the reservoir volume and pressure. The single stroke

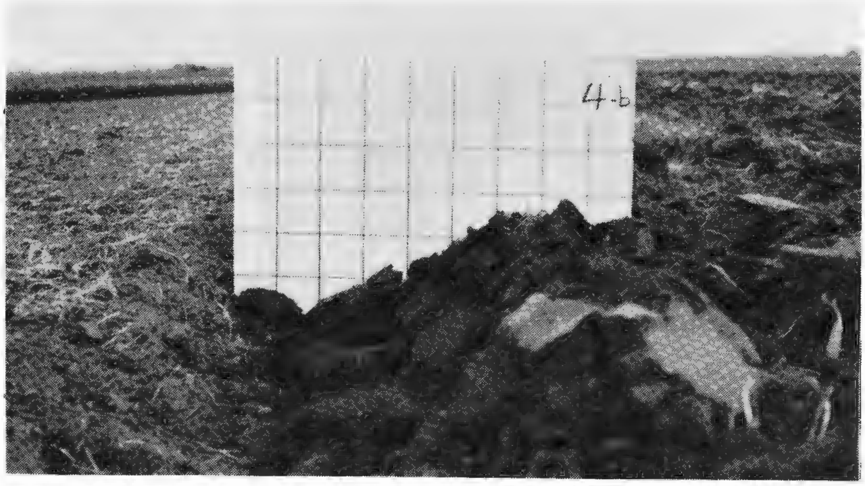
Figure 18. Grid board as positioned in furrow profile for tests (furrow profiles are for the first run of the compression and tension spring combination shown in Figure 16, at speeds of 4, 6, and 8 mph)


4


6a


8

Figure 19. Furrow profiles for the second run of the compression-tension spring combination at speeds of 4, 6, and 8 mph


4-b


6-b


8-b

Figure 20. Furrow profiles at speed of 4 mph, recorded at three randomly chosen positions (first run of the compression-tension spring mechanism shown in Figure 16)

Figure 21. Furrow profiles at speed of 6 mph

Figure 22. Furrow profiles at speed of 8 mph

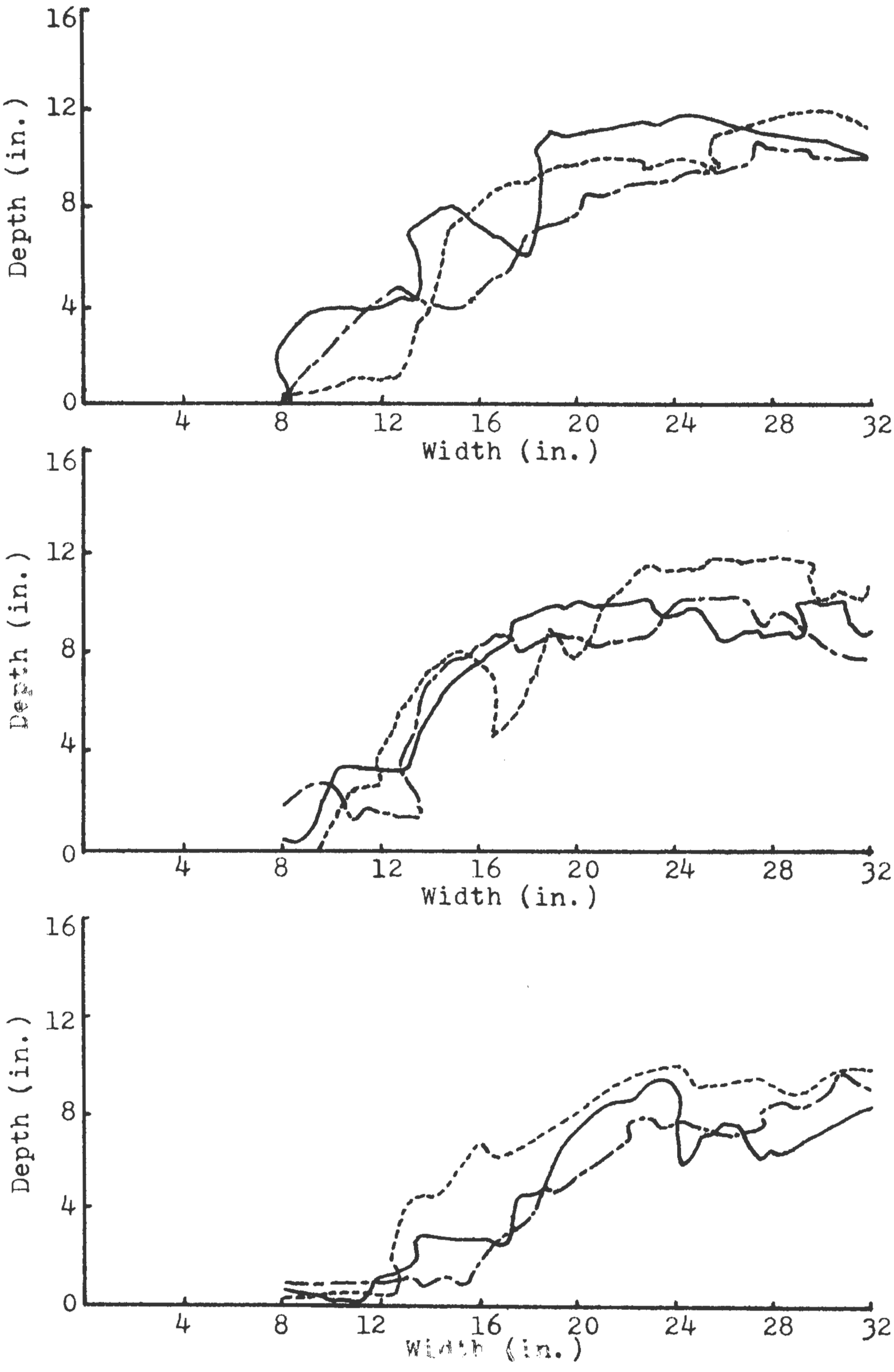
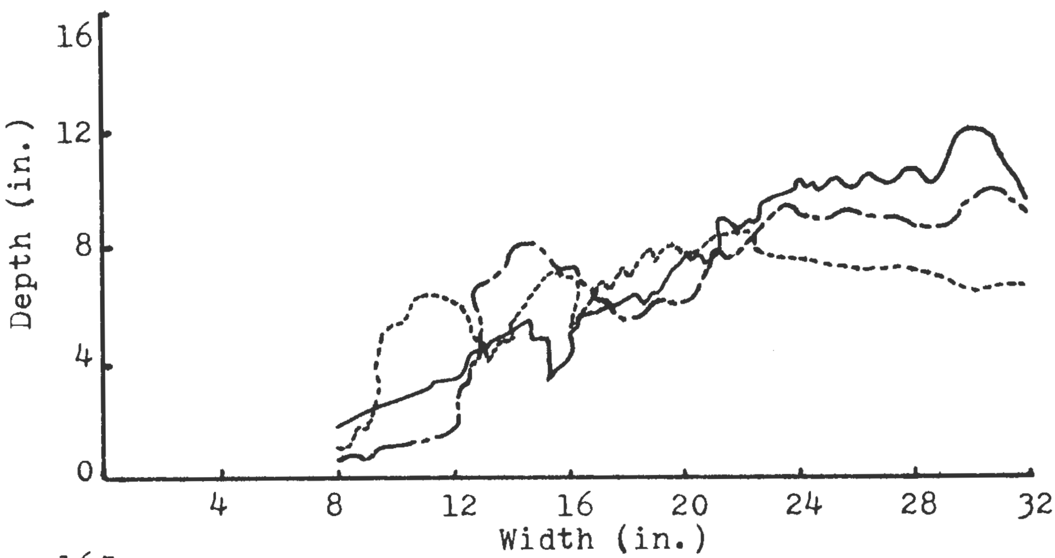
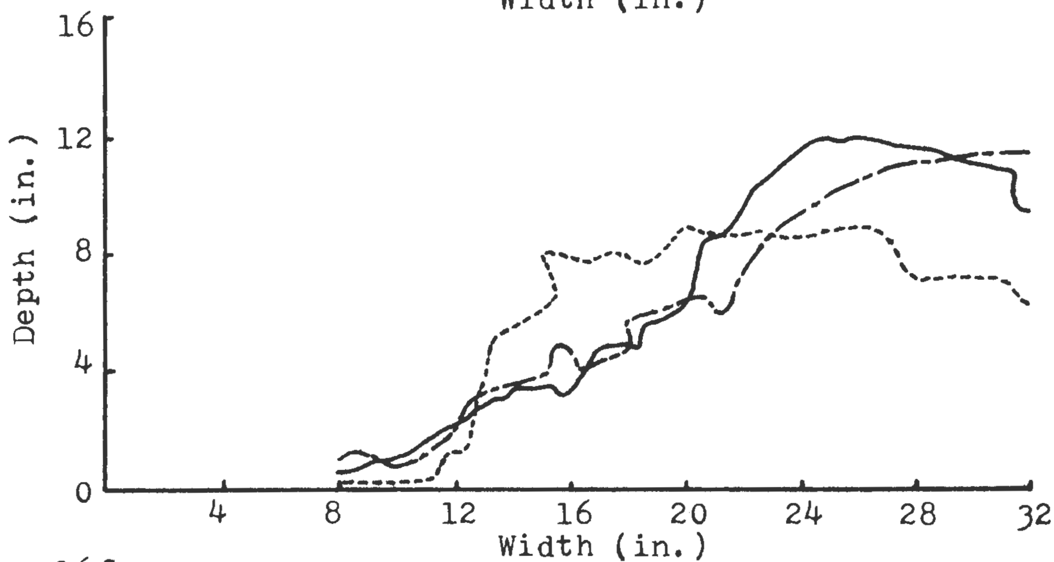

16
12
8
4
0
Depth (in.)
4
8
12
16
20
24
28
32
Width (in.)
16
12
8
4
0
Depth (in.)
4
8
12
16
20
24
28
32
Width (in.)
16
12
8
4
0
Depth (in.)
4
8
12
16
20
24
28
32
Width (in.)

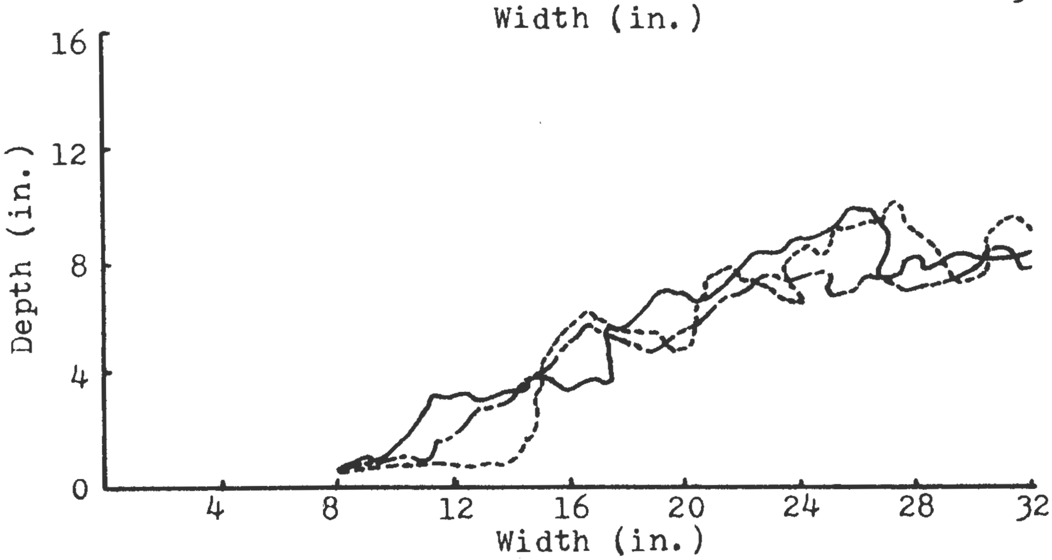
Figure 23. Furrow profiles at speed of 4 mph, recorded at three randomly chosen positions (second run of the compression-tension spring mechanism shown in Figure 16)

Figure 24. Furrow profiles at speed of 6 mph

Figure 25. Furrow profiles at speed of 8 mph


16
12
8
4
0
Depth (in.)
4
8
12
16
20
24
28
32
Width (in.)


16
12
8
4
0
Depth (in.)
4
8
12
16
20
24
28
32
Width (in.)


16
12
8
4
0
Depth (in.)
4
8
12
16
20
24
28
32
Width (in.)

cylinder used in the test had the following specifications:

Stroke length, $L = 9.25$ in.

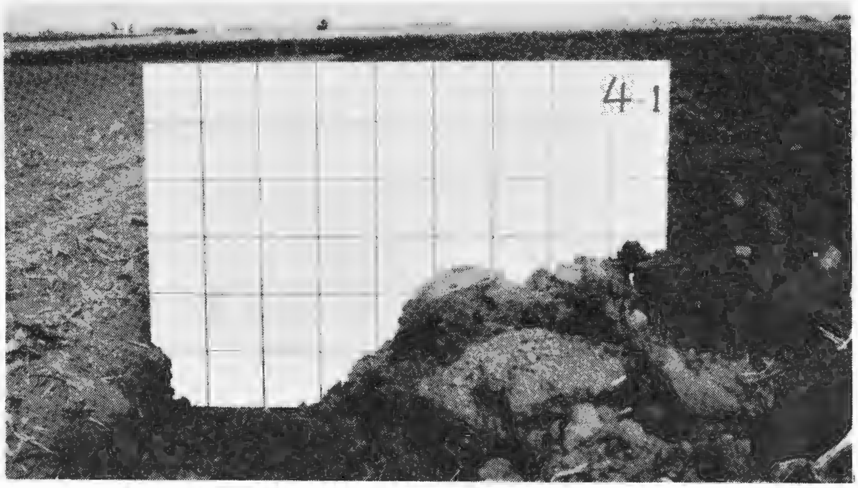
Diameter, $D = 1.5$ in.

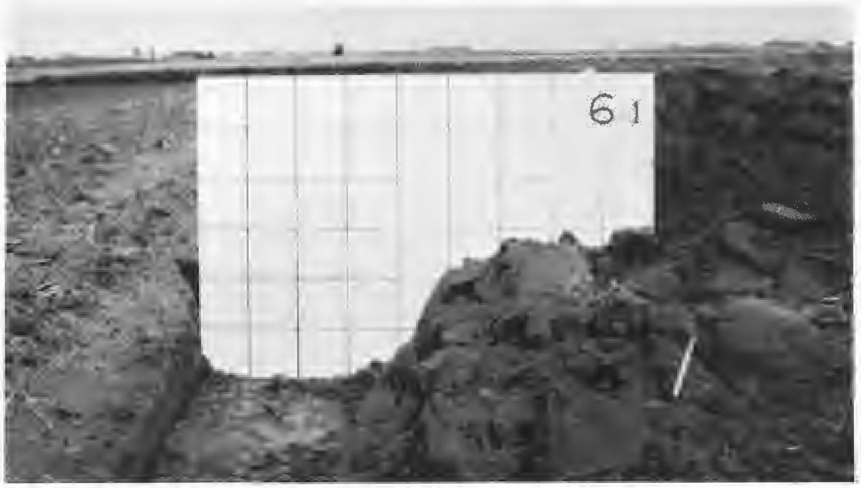
The reservoir was constructed from a 4-inch diameter and 4-inch long pipe. Two caps were screwed on the threaded pipe ends to provide ease of assembling and disassembling the reservoir. Solid blocks were placed inside the reservoir to decrease the volume. The proper air cushioning effect was obtained at about 42 in.^{3} for all the field tests.

Three test runs were conducted, one for each speed. An initial pressure of 90 psi was used in all tests. Figure 26 shows the grid board as used to record the furrow profile and Figures 27, 28, and 29 show the furrow profiles examined at three different positions for each run.

The air cylinder was replaced by an air adjustable shock absorber (MONROE MAX), Figure 31, to give more stable and smooth performance of the moldboard plow. The air cushion of the shock absorber was connected to the small reservoir to provide a pneumatic spring. The new device performed more smoothly and helped to eliminate the pulsing caused when the plow encountered a very hard portion of the soil.

Figure 26. Grid board as positioned in furrow profile for tests (furrow profiles are for the pneumatic spring shown in Figure 30) at speeds of 4, 6, and 8 mph


4-1


6-1

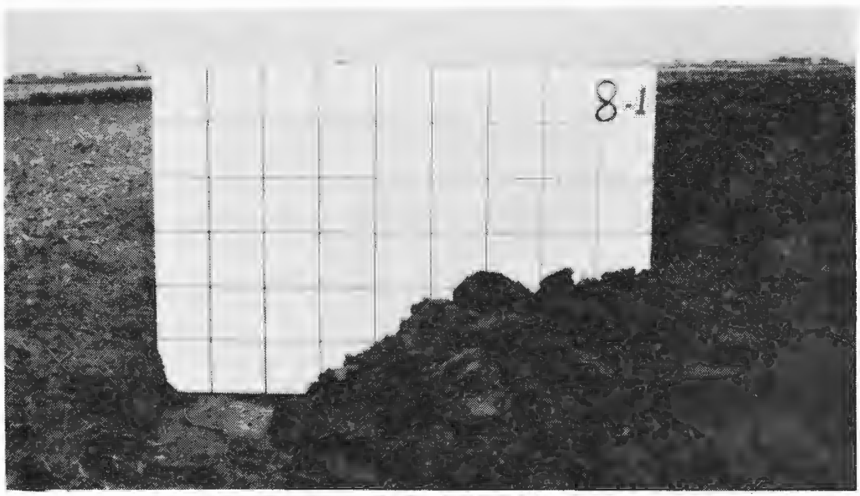
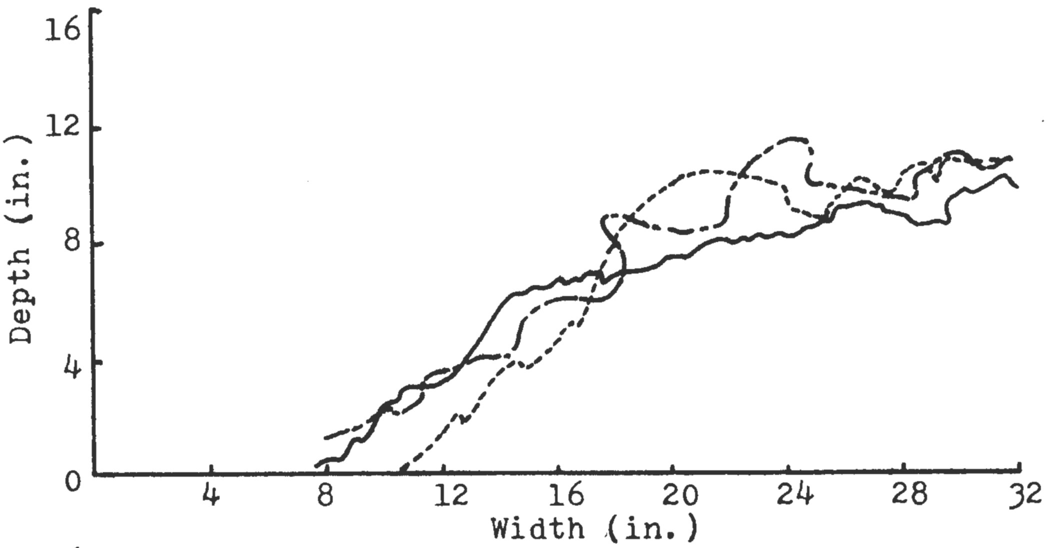

8-1

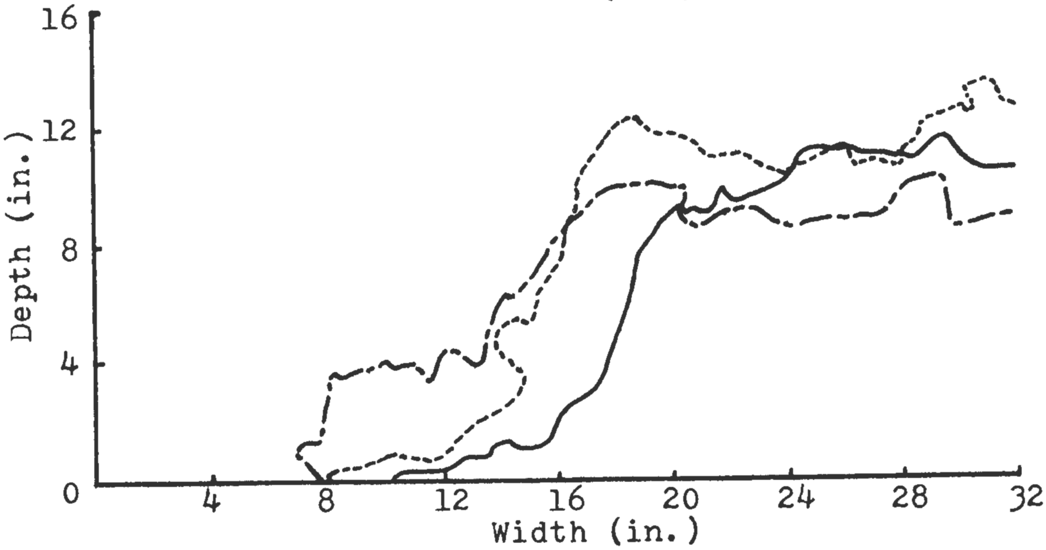
Figure 27. Furrow profiles at speed of 4 mph recorded at three randomly chosen positions (pneumatic spring shown in Figure 30)

Figure 28. Furrow profiles at speed of 6 mph

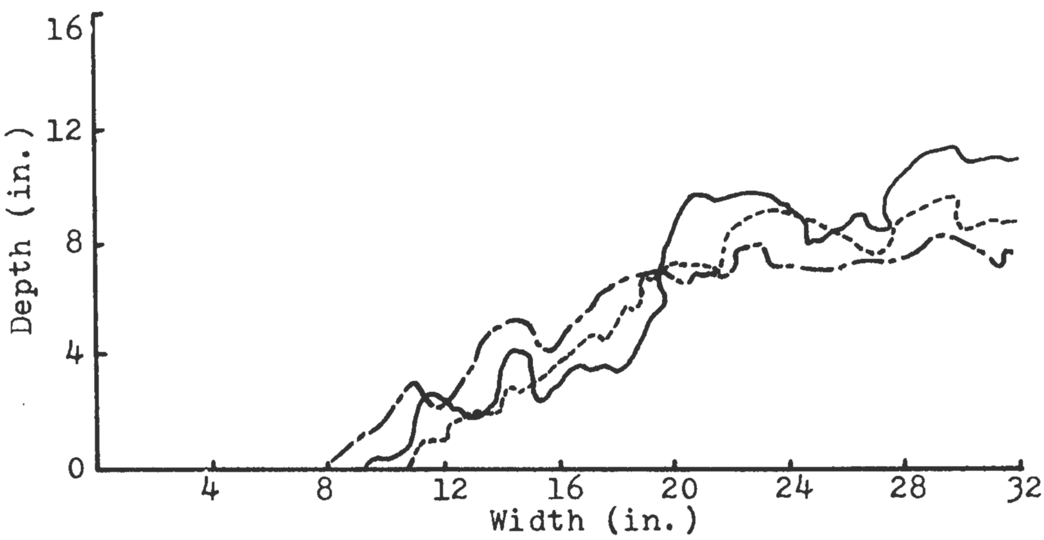
Figure 29. Furrow profiles at speed of 8 mph



Depth (in.)
0
4
8
12
16
4
8
12
16
20
24
28
32
Width (in.)



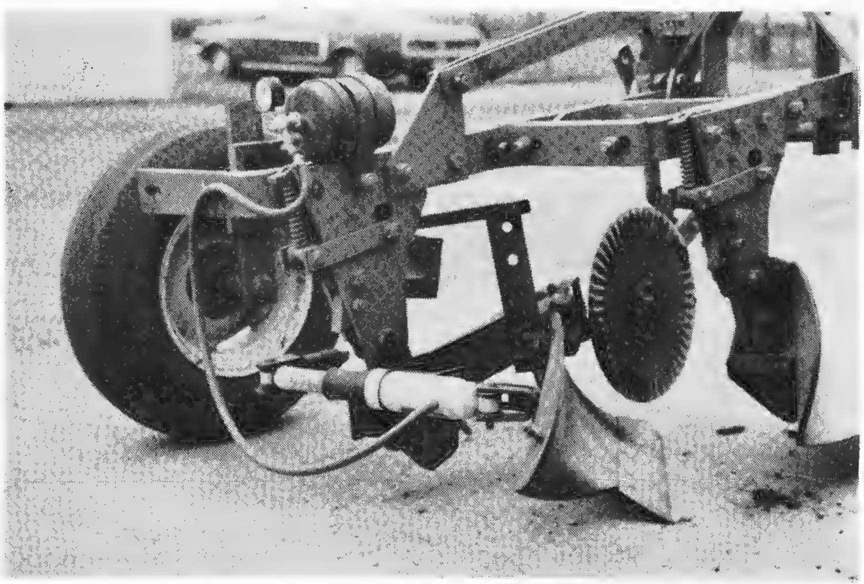
Depth (in.)
0
4
8
12
16
4
8
12
16
20
24
28
32
Width (in.)



Depth (in.)
0
4
8
12
16
4
8
12
16
20
24
28
32
Width (in.)

Figure 30. Pneumatic spring constructed of a single stroke air cylinder connected to a small air reservoir

Figure 31. Pneumatic spring constructed of an air cushion shock absorber connected to a small air reservoir



RESULTS AND DISCUSSION

The field tests were qualitative measurements of plowing performance which can be related to the forces acting on the plow bottom. The plowing performance was evaluated by observing the plow bottom in operation and taking pictures of the furrow profile. The field tests indicated that the lateral cutting angle was changing according to speed and soil condition, and the lateral and vertical movement of the soil at high speed was less than it would have been with a rigid bottom. The main goal of this research was to reduce the increase in the lateral and vertical movement of soil with speed and to obtain the same plowing performance at all speeds. This will reduce the increase draft with speed and hence reduce the extra energy spent on plowing at high speed. A reduction in the plow vertical force is not advantageous if the force is carried on the rear tractor wheels for increased traction. A portion of the plow side force is carried by the landside of the plow bottom and the rest is carried by the tractor. The frictional force of the landside against the furrow wall adds to the draft and is reduced if the plow side force is reduced.

One of the problems associated with a variable angle plow is that it is necessary to remove the landside so that the lateral cutting angle can become smaller as speed increases. With the landside removed there is little lateral support available from the furrow wall, and this support decreases as the lateral cutting angle is reduced, because less of the plow bottom is in contact with the furrow wall as shown in Figure 32. A suggested solution to this problem is to design a steeper moldboard plow bottom with a design share angle equal to the final reduced lateral cutting angle at high speed. In this design the area of contact between the landside of the plow and furrow wall is small at low speed and will increase gradually with speed giving more support of the larger side force at high speed. This idea is illustrated in Figure 33.

The field test consisted of 9 runs. Two runs for each speed for the compression-tension spring mechanism and one run for each speed for the pneumatic spring. The width of cut was about 10 inches at a depth of 6 inches for all the runs. The results of the first run for the compression-tension spring mechanism are shown in Figures 20, 21, and 22. The figures showed the furrow profiles at three randomly chosen positions for each of the speeds 4, 6, and 8 mph. A close look at Figures 20 and 21 showed that the furrow profiles at 4 and 6 mph are almost the same, which leads to a conclusion that the reduction in the lateral cutting angle was effective at 6 mph, and gave the same plowing performance as that of the 4 mph speed, i.e., no increase in the lateral and vertical movement of the soil.

A comparison between the furrow profiles at 4 and 6 mph

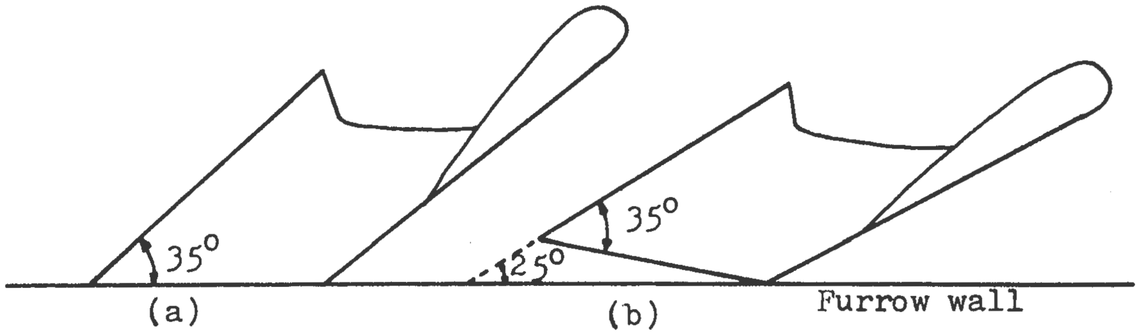


Figure 32. Top view of the moldboard plow at (a) design lateral cutting angle of 35°; (b) lateral cutting angle reduction of 10° at higher speed

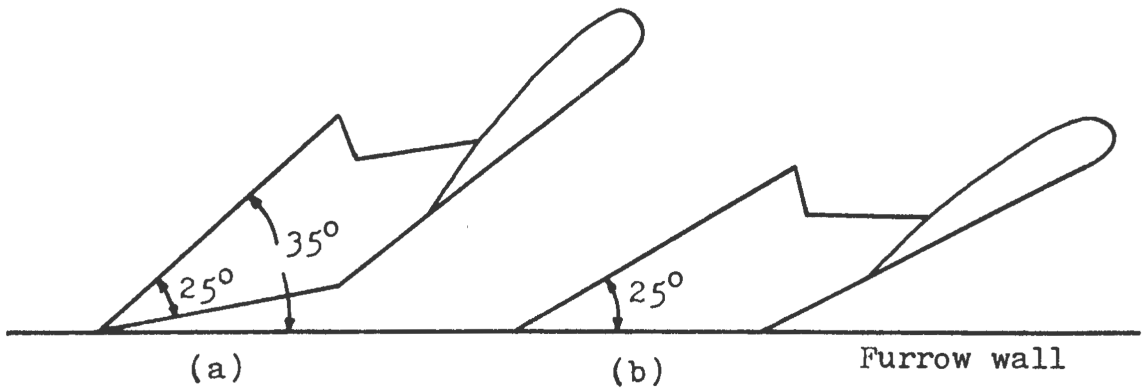


Figure 33. Top view of the modified moldboard plow at (a) design lateral cutting angle of 35° and share angle of 25°; (b) lateral cutting angle reduction of 10° at higher speed

with that at 8 mph, Figure 22, shows that the furrow profile at 8 mph is different. It has been shifted about 4 inches to the right and has been lowered about 2 inches. This explains that at 8 mph the acceleration forces of the soil are still high which tends to throw the soil far away from the furrow wall. So a greater reduction in the lateral cutting angle is needed. The second run also showed a soil profile at 8 mph about 2 inches lower than that at 4 and 6 mph, which emphasizes that the soil has been spread more at 8 mph, Figures 23, 24, and 25.

The pneumatic spring gave better results at 8 mph. Figures 27, 28, and 29 show the furrow profiles at 4, 6, and 8 mph. A comparison of these three figures shows a similarity between the furrow profiles at 4 and 8 mph, from which we can conclude that the acceleration forces of the soil at 8 mph have been reduced significantly.

The results indicated that the variable lateral cutting angle plow could eliminate the need for production of several different bottoms, each designed to operate at a specific speed. In other words, the problem of the increase in the acceleration forces of the soil with speed can be solved by using a variable lateral cutting angle plow which will give the same plowing performance at all speeds by reducing the lateral cutting angle and hence reducing the increase in the acceleration forces as speed increases.

The increase in the acceleration forces with speed is one of the major factors that contribute to the increase in draft at higher speeds, and any decrease in these forces leads to a reduction of the draft force.

CONCLUSIONS

1. A devioe for controlling the lateral cutting angle as a function of speed and soil condition can be constructed from a coil spring or pneumatic spring and a damper.

2. The pneumatic spring is recommended since it can provide the desired stiffness of the spring which is suitable for any width and depth of plowing.

3. The decrease in the lateral support available from the furrow wall is one of the hurdles which tends to offset the idea of variable angle plow especially when larger number of plow bottoms is used.

4. The bottom with the compression-tension spring mechanism gave the same plowing performance at 4 and 6 mph, but threw the soil farther at 8 mph. The pneumatic spring mechanism gave better results at 8 mph.

5. The variable angle plow managed to reduce the increase in the lateral and vertical movement of the soil furrow slice as a function of speed. Hence, it reduced the high acceleration forces which contribute to the increase in draft at higher speeds.

SUMMARY

The increase in draft usually associated with increased speeds tends to discourage this method of increasing tillage capacity. The first objective of this research was to review and study the factors that affect tillage tool draft and the possible ways of reducing the draft without affecting plowing performance. One of the factors that affects tillage tool draft is the lateral cutting angle of the moldboard plow. The increase in draft with speed was reduced by reducing the lateral cutting angle. Applying this principle, the second objective of the research was to design and evaluate the performance of a spring damper mechanism for controlling the lateral cutting angle for a moldboard plow bottom, suiting it for different soils and plowing speeds.

A spring damper mechanism was designed making use of the resultant side force applied by the soil to compress a spring, rotating the plow about a hinge and hence reducing the lateral cutting angle at higher speeds. A tension spring was used to assist the compression spring to resist the side force and give the proper rotation of the plow as a function of speed.

The performance of the controlling device was tested in the field at the Agricultural Engineering-Agronomy Research Center, Iowa State University. The field tests qualitatively evaluated plowing performance as a function of speed. A high speed moldboard plow (Allis-Chalmers production model 392) was

used to test the spring damper mechanism. The furrow profiles at speeds of approximately 4, 6, and 8 mph were observed. A comparison of these furrow profiles showed that the plow gave the same performance at speeds of 4 and 6 mph, but it threw the soil about 4 inches farther at 8 mph. A pneumatic spring was used instead of the coil spring to provide the proper stiffness of the spring. The pneumatic spring gave better results at 8 mph.

The results indicated that the lateral cutting angle can be controlled by a coil or pneumatic spring and a damper. The variable angle plow managed to reduce the increase in acceleration forces which tend to throw the soil farther at higher speed, and hence reduced the increase in draft associated with the increase in the acceleration forces.

RECOMMENDATIONS FOR FURTHER RESEARCH

The adhesion between soil and a tillage tool has been reduced by heat (Bacon, 1918, and Nichols, 1925). The heat rejected from the tractor is suggested to be used to heat the moldboard plow bottom, which will help reduce the adhesion forces and hence reduce the draft requirement. The hot water coming from the tractor engine can be passed through a chamber mounted behind the moldboard plow bottom, before entering the radiator. In addition to that the exhaust of the tractor can also be used as a source of heat.

The decrease in the lateral support at higher speeds could be eliminated by designing a steeper plow bottom with a share cutting angle equal to the reduced lateral cutting angle at the highest operating speed. Another suggested solution is to fix the share and rotate the moldboard. In other words to maintain a stationary share at all speeds and a flexible moldboard rotating about a hinge as a function of speed and soil condition.

Finally the effect of varying the vertical cutting angle of the moldboard plow on draft and plowing performance as a function of speed and soil condition should be evaluated.

REFERENCES

Bacon, C. A. 1918. Plow bottom design. Amer. Soc. Agr. Eng. Trans. 12: 26-42.

Berry, M. O. 1948. Coulter tests. U.S. Tillage Mach. Lab. (Auburn, Ala.) Ann. Rept.

Bertelsen, W. R. 1960a. The aeromobile: A peripheral jet vehicle. Agr. Eng. 41: 290-292.

Bertelsen, W. R. 1960b. Something brand new in plows--the aeroplow. Des Moines Register, Aug. 21, Sect. H, p. 17-H.

Bigsby, F. W. 1961. Effect of an air film on soil to tillage surface friction. Ph.D. thesis. Library, Iowa State University, Ames, Iowa.

Black, P. H. and Adams, O. E., Jr. 1968. Machine design. Third edition. McGraw-Hill Book Company, New York.

Chase, L. W. 1942. A study of subsurface tiller blades. Agr. Eng. 23: 43-45, 50.

Cooper, A. W. and McCreery, W. F. 1961. Plastic surfaces for tillage tools. Amer. Soc. Agr. Eng. Paper 61-649.

Crowther, E. M. and Haines, W. B. 1924. An electrical method for the reduction of draft in plowing. J. Agr. Sci. 14: 221-231.

Davidson, J. B. and Collins, E. V. 1929. The direct application of mechanical power to soil tillage. Agr. Eng. 10: 165-168.

Davies, W. M. 1924. A preliminary investigation into the draft of the plough. J. Agr. Sci. 14: 370-406.

Dransfield, P., Willott, S. T., and Willis, A. H. 1964. Soil-to-implement reaction experienced with simple tines at various angles of attack. J. Agr. Eng. Res. 9: 220-224.

Dubrovskii, A. A. 1956. (Influence of vibrating the tools of cultivation implements upon draft resistance.) Vsesoiuzz. Akad. Sel'skokhozhaistvenny k h Nauk. Zeml. Mekh. Sborn. Trudov. (Leningrad) 3: 182-185. (Natl. Inst. Agr. Eng. English Translation 51.)

Eidet, J. H. 1974. Effect of varied approach angle on high speed plow performance. M.S. thesis. Library, Iowa State University, Ames, Iowa.

Fox, W. R. and Bockhop, C. W. 1962. Characteristics of a teflon-covered simple tillage tool. Amer. Soc. Agr. Eng. Paper 62-649.

Gavrilov, F. I. and Koruschkin, E. N. 1954. (The underside chamfer of plough shares.) Seikhozmashina 3: 18-21. (Natl. Inst. Agr. Eng. English Translation 21.)

Getzlaff, G. 1953. (Comparative studies on the forces acting on standard plough bodies.) Grundlagen der Landtechnik 5: 16-35. (Natl. Inst. Agr. Eng. English Translation 6.)

Gill, W. R. and McCreery, W. F. 1960. Relation of size of cut to tillage tool efficiency. Agr. Eng. 41: 372-374. 381.

Gill, W. R. and VandenBerg, G. E. 1967. Soil dynamics in tillage and traction. Agricultural Handbook No. 316. U.S. Government Printing Office, Washington, D.C.

Gunn, F. T. and Tramontini, V. N. 1955. Oscillation of tillage implements. Agr. Eng. 36: 725-729.

Hardy, F. 1925. Cohesion in colloidal soils. J. Agr. Sci. 15: 420-433.

Hendrick, J. C. and Buchele, W. F. 1963. The tillage energy of a vibrating tillage tool. Amer. Soc. Agr. Eng. Trans. 6: 213-216.

Kaburaki, H. and Kisu, M. 1959. (Studies on cutting characteristics of plows.) Kanto-Tosan Agr. Exp. Sta. Jour. (Konosu, Japan) 12: 90-114. (Natl. Inst. Agr. Eng. English Translation 79.)

Kaburaki, H. and Kisu, M. 1960. (Studies on cutting characteristics of ploughs. Part II. Soil sticking to the plough.) Kanto-Tosan Agr. Exp. Sta. Jour. (Konosu, Japan) 16: 309-322. (Natl. Inst. Agr. Eng. English Translation 108.)

Keen, B. A. and Haines, W. B. 1925. Studies in soil cultivation. J. Agr. Sci. 15: 375-406.

Kepner, R. A., Bainer, R., and Barger, E. L. 1972. Principles of farm machinery. Second edition. The AVI Publishing Company, Inc., Westport, Connecticut.

Kummer, F. A. 1939. The hynamic properties of soil. VIII. The effect of certain experimental plow shapes and materials on scouring in heavy clay soils. Agr. Eng. 20: 111-114.

Kummer, F. A. and Nichols, M. L. 1938. The dynamic properties of soil. VII. A study of the nature of physical forces governing the adhesion between soil and metal surfaces. Agr. Eng. 19: 73-78.

Kynazev, A. A. 1957. (Draught resistance of chisel ploughs.) Sel'khozmashina 2: 7-9. (Natl. Inst. Agr. Eng. English Translation 89.)

Mackson, C. J. 1962. The effect of electro-osmosis on soil to steel sliding friction as influenced by speed, voltage and soil moisture. Amer. Soc. Agr. Eng. Paper 62-650.

Nichols, M. L. 1925. The sliding of metal over soil. Agr. Eng. 6: 80-84.

Nichols, M. L. 1931. The dynamic properties of soil. II. Soil and metal friction. Agr. Eng. 12: 321-324.

Nichols, M. L. and Reaves, C. A. 1958. Soil reaction: To subsoiling equipment. Agr. Eng. 39: 340-343.

Nichols, M. L., Reed, I. F., and Reaves, C. A. 1958. Soil reaction: To plow share design. Agr. Eng. 39: 336-339.

Payne, P.C.J. 1956. The relationship between the mechanical properties of soil and the performance of simple cultivation implements. J. Agr. Eng. Res. 1: 23-50.

Payne, P.C.J. and Tanner, D. W. 1959. The relationship between rake angle and the performance of simple cultivation implements. J. Agr. Eng. Res. 4: 312-325.

Pillsbury, R. D., Jr. 1960. Applications of fluorocarbon resins in farm equipment. Agr. Eng. 41: 802-803, 825.

Randolph, J. W. and Reed, I. F. 1938. Tests of tillage tools. II. Effects of several factors on the reactions of fourteen-inch moldboard plows. Agr. Eng. 19: 29-33.

Rathje, J. 1932. The cutting of sand. Engineering 134: 116-118.

Reaves, C. A. and Schafer, R. L. 1974. Force versus width of cut for moldboard bottoms. Amer. Soc. Agr. Eng. Paper 74-1588.

Reed, I. F. 1941. Tests of tillage tools. III. Effect of shape on the draft of 14-inch moldboard plow bottoms. Agr. Eng. 22: 101-104.

Reed, I. F. and Berry, M. O. 1946. Tests comparing plow bottoms. Natl. Tillage Mach. Lab. Ann. Rept., Auburn, Ala.

Rowe, R. J. and Barnes, K. K. 1961. Influence of speed on elements of draft on a tillage tool. Amer. Soc. Agr. Eng. Trans. 4: 55-57.

Shkurenko, N. S. 1960. (Experimental data on the effect of oscillation on the cutting resistance of soil. (Jour. Agr. Eng. Res. 5: 226-232. English translation.)

Soehne, W. 1959. (Investigations on the shape of plough bodies for high speeds.) Grundlagen der Landtechnik 11: 22-39. (Natl. Inst. Agr. Eng. English Translation 87.)

Soehne, W. 1960. Suiting the plow body shape to higher speeds. Grundlagen der Landtechnik 12: 51-62. (Natl. Inst. Agr. Eng. English Translation 101.)

Soehne, W. 1964. The influence of working speed on the design of plow bodies. Unpublished mimeo. Agr. Eng. Department, Iowa State University, Ames, Iowa.

Telischi, B. 1962. Spring tooth profile development. Amer. Soc. Agr. Eng. Trans. 5: 204-206, 209.

Telischi, B., McColly, H. F., and Erickson, E. 1956. Draft measurement for tillage tools. Agr. Eng. 37: 605-608, 617.

Thompson, J. L. and Kemp, J. G. 1958. Analyzing disk cuts graphically. Agr. Eng. 39: 285-287.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. S. J. Marley, major professor, Dr. W. F. Buchele, and Dr. F. M. Graham for their guidance and assistance as graduate committee members.

Sincere thanks to Dr. S. J. Marley for his valuable suggestions and his help in conducting the field tests.

My gratitude to the Iraqi Government for providing me with a scholarship.

Thanks to Allis-Chalmers for equipment and financial support to this research.

Thanks to my wife, Rafia, for her patience and encouragement throughout the program.