INVESTIGATION OF THE "SMEARING" EFFECT OF DULL MOLDBOARD PLOW SHARES

by

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ABSTRACT

Smearing may be generally defined as the reworking of the soil at the plowshare/soil interface. Experiments were performed in the field as well as in the laboratory.

In the fall of 1983, attempts were made to measure the smearing effect caused by a three bottomed moldboard plow with the outer two plowshares sharpened and the inner one left dull. The instruments used were found to be too insensitive to measure the small changes in the soil structure. Unfavorable weather conditions halted further studies.

In the winter of 1984, smearing was successfully simulated in a soil bin using a sharp and a dull blade each 7.6 cm. by 20.3 cm in dimensions. It was qualitatively established that the dull blade smeared the soil more. The results do not indicate that the influence of top and bottom beveled edgeshapes on the soil movement over the blades was significantly different. This was due in part to problems with the soil crumbling behind the blade and soil falling between the blade and the glass. The slow trolley speed may have minimized any effects due to the orientation of the bevel.

For further quantitative studies on smearing, more sensitive instruments will be needed to measure soil penetration resistance, water infiltration rate and bulk density. Soil type, rake angle and working depth are the parameters that can be varied with the existing apparatus.

ACKNOWLEDGEMENTS

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I would like also to acknowledge the help of two brothers, Mark McBratney and Terry O'Reilly for their very helpful suggestions in not only helping me prepare for the presentation but in proof reading the text of this paper. I feel that I owe Simeon Materechere a special thanks too, for helping me in the soil analysis and calculations. The fervent prayers and genuine concern of the Macdonald Christian Fellowship and the Robertson Terrace Bible Study Group should not go unthanked because I really appreciated and felt them.

Just to finish this comparatively short paper, it has been my pleasure to be involved with many people in major and in minor ways. For those whose help I have failed to acknowledge through oversight, I ask their pardon and thank them for it.

I almost forgot to thank my folks without whose help obviously, none of this would have been possible. "Thanks a million mum and dad."

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE **PAGE**

LIST OF TABLES

LIST OF PHOTOGRAPHS

I. INTRODUCTION

In its broadest sense, tillage includes all operations, from the desired soil manipulation by the implement to the traffic on the soil, required to grow the crop. Thus defined, most tillage operations are necessary evils (8).

The objectives of tillage can be summarized into one general objective which is, to produce a desired soil condition. For thousands of years, this has been achieved by the use of tillage implements. It is here that the moldboard plow enters the picture, because today it is by far the most used implement for primary tillage in seed bed preparation (11).

It is generally acknowledged that the excessive use of tillage implements can be detrimental to the soil structure. Smearing is one of the negative effects and has been attributed to plows in general that have been dulled or worn as a result of wear. Smearing has been generally defined as the soil reworking at the plowshare-soil interface (14).

To date, most of the studies that have been performed on the moldboard plow have been on the soil mechanics aspects. There are numerous theoretical models that have been made to try to understand the complex reactions between the tillage implements and the soil. However, in dealing with this subject matter, the author found few papers dealing with the actual "smearing" effects caused. The term smearing is practically non-existent in the literature read and hence this project was designed with the intent of investigating just what this smearing effect is whether or not it is significant and if so whether it is measurable?

II. LITERATURE REVIEW

2. 1 History of the Plow:

The plow is probably the oldest agricultural tool (16). The history of the moldboard and especially of the share is rather fascinating. This is because it shows how plow design to date has been developed more as an art than a science (13). This has resulted in many excellent plows which are well adapted to the soils for which they were designed and of which the manufacturers may be justly proud. On the other hand, there are many soils for which there are no plows satisfactory to the manufacturer or to the farmer (4).

The recorded history in the form of hieroglyphics and cuneiform characters shows that the ancients had a type of plow thousands of years B.C. It is recorded that about 900 B.C. Elisha was found "plowing with twelve yolk of oxen before him," 1 Kings 19:19.

Delving into the history books, one finds that metal shares have been in use for many centuries, usually attached to a wooden plow by animal skin thongs as there were no nails, bolts or haywire available. Even today, millions of wooden plows are still in use (11).

The Roman plow was imported into England about 1730. As it spread around, the shape of the plow and the materials it was made of changed as farmers implemented their ideas and improved on what they had. The Nolfork wheel plow of 1721 had a cast-iron share and an iron rounded moldboard. A curved moldboard plow made its appearance in 1760 on the Suffolk swing plow. The close of the eighteenth century saw the change in England from the wooden plow to the iron plow. (4)

In America, Jethro Wood developed a moldboard in 1814 of such curvature as to turn the soil in even furrows. When the first cast-iron plow was patented in 1797 by Charles Newbold, farmers rejected it because they thought it poisoned the soil. In 1831, John Deere at Grand Detour, Illinois, made a steel plow (share and moldboard in one piece) from an old sawmill saw.

The large ten to fifteen bottom plows were pulled by steam tractors in the 1890's and by the large, slow, cumbersome gasoline-engine tractors from about 1900 to 1910. The mounted type of moldboard plows were developed in the early forties by Ferguson and are still quite common on small and average sized farms (4). Today, the moldboard plow is by far the most used implement for primary tillage in seedbed preparation (11).

2. 2 Definition of terms used:

Tillage may be defined as the physical or mechanical manipulation of soil for any purpose. Tillage operations for seedbed preparation are often classified as primary or secondary, although the distinction is not always clear-cut. A **primary tillage operation** constitutes the initial, major soil-working operation; it is normally designed to reduce soil strength, cover residual plant materials and rearrange aggregates. **Secondary tillage operations** are intended to create refined soil conditions following primary tillage. Harrows and cultivators are examples of secondary tillage equipment and they are used to conserve moisture and destroy weeds among other things (11).

The moldboard plow is a primary tillage implement as are disk plows, subsoil plows or chisels, disc tiller plows and rotary tillers. One of the most important tillage objectives is to develop a desirable soil structure for a seedbed or a rootbed. This desirable soil structure consists of a granular soil structure that allows mainly two things. Firstly, rapid infiltration and good retention of rainfall to provide adequate air capacity and exchange within the soil, and secondly minimal resistance to root penetration.

This is precisely what **smearing** does not allow. Smearing may be generally defined as the reworking of the soil aggregate structure in the furrow bottom, which results in some compaction and a change in the arrangement of the soil particles. All dull or worn tillage implements may be "guilty" of this. This project paper is mainly concerned with the moldboard plowshare which, when worn, is suspected to cause the smearing effect.

2. 2 a) <u>Major parts of the Moldboard Plowbottom</u>:

To begin with, the moldboard plow bottom is a tillage tool which is distinct from a tillage implement in that the former is defined as an individual soil-working element. The latter, a tillage implement, consists of a single tool or a group of tools together with the associated frame, wheels etc. The plow bottom is the most important part of the plow. It is a precision tool and has been very carefully designed to perform efficiently. Shown below is the top view of an assembled plow and an exploded view showing the major parts.

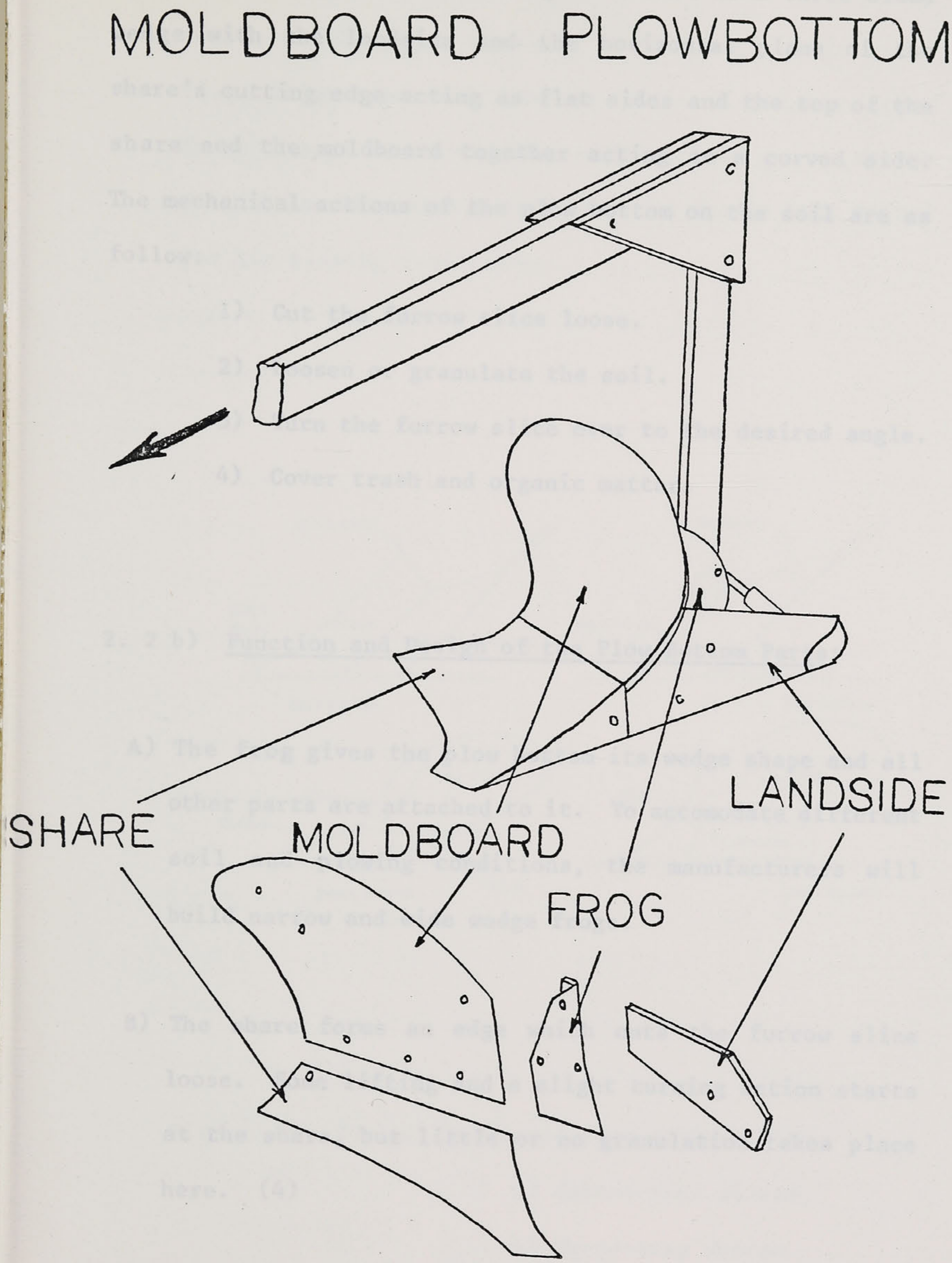


Figure 1. Exploded view of the moldboard plowbottom.

Essentially, a moldboard plow bottom is a three sided wedge with the landside and the horizontal plane of the share's cutting edge acting as flat sides and the top of the share and the moldboard together acting as a curved side. The mechanical actions of the plow bottom on the soil are as follow:

1) Cut the furrow slice loose.
2) Loosen or granulate the soil.
3) Turn the furrow slice over to the desired angle.
4) Cover trash and organic matter.

2. 2 b) Function and Design of the Plow Bottom Parts:

A) The **frog** gives the plow bottom its wedge shape and all other parts are attached to it. To accomodate different soil and plowing conditions, the manufacturers will build narrow and wide wedge frogs.

B) The **share** forms an edge which cuts the furrow slice loose. Some lifting and a slight turning action starts at the share, but little or no granulation takes place here. (4)

For many years, most plows had shares of the type shown in the figure below. This type of share has a vertical portion, known as the gunnel, that acts as a forward extension of the landside. However, nowadays, practically all plows manufactured have throw-away shares of the types shown in the figure: single piece disposable type and the two piece disposable type. These shares are available with various point shapes which allow the plowman to choose the design best suited for his plowing conditions.

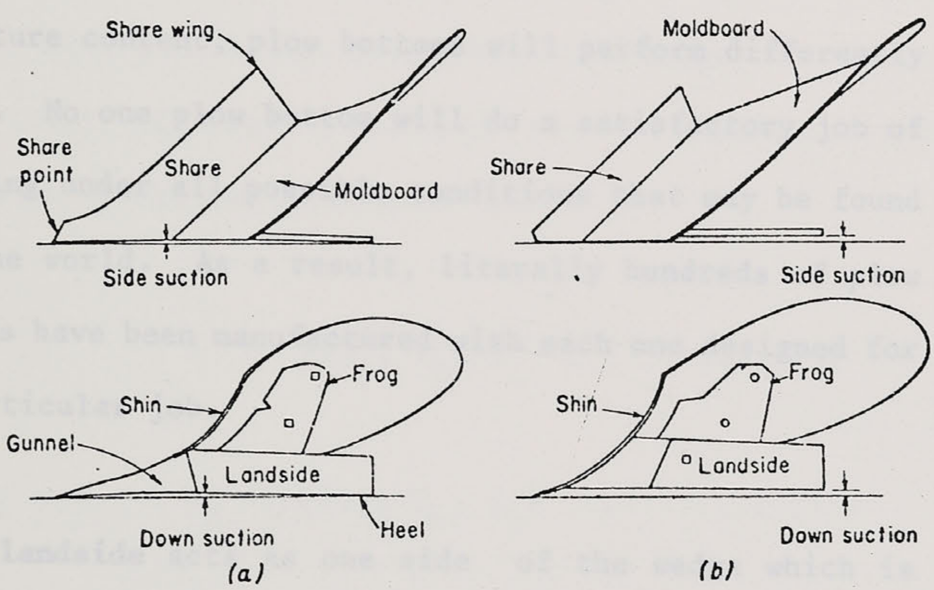


Figure 2. Typical Moldboard Plow Bottoms With:

a) Gunnel-type shares,

b) Throw-away shares.

C) The **moldboard** granulates the soils as it turns the furrow slice on edge. The lower part of the moldboard is where most granulation takes place. Most of the turning is done by the upper part of the moldboard. Here the final action is to push or throw the soil into the open furrow. The amount of throw depends largely upon the speed of operation and curvature of the moldboard.

Depending on the soil type, physical condition and moisture content, plow bottoms will perform differently (10). No one plow bottom will do a satisfactory job of plowing under all possible conditions that may be found in the world. As a result, literally hundreds of plow shapes have been manufactured with each one designed for a particular job.

D) The **landside** acts as one side of the wedge which is formed with the share. It is a flat metal piece bolted to the side of the frog. It helps absorb side forces caused when the furrow slice is turned. It also helps in steadying the plow. As one would expect, varying plowing conditions and plow designs require landsides of different design.

2. 3 <u>Functional Relations Between Soil and Tool Parameters:</u>

Any type of simulation of a real occurence is usually quite an undertaking and this one is particularly difficult. This is because so little has been analytically understood in this area. The reasons are numerous. For one thing, in the actual case, the whole process is hidden from direct view which is why the glass sided soil box was seen to be particularly helpful. But even then what is seen through the glass is not necessarily what actually occurs in the soil outside. Gill and Vanden Berg (6), have suggested that the generalized tillage relation can be mathematically represented by the two equations

$$F = f(T_s, T_m, S_i) \text{ .... (i)}$$

and $$S_f = g(T_s, T_m, S_i) \text{ .... (ii)}$$

where: F = forces on the tool to cause movement,

T_s = tool shape,

T_m = manner of tool movement,

S_i = initial soil condition,

f = functional relation between F, T_s, T_m, S_i,

S_f = final soil condition,

g = functional relation between S_f, T_s, T_m, S_i.

The two equations-- the tillage force equation and the soil condition equation-- represent the most general situation because, as written, the functional relations f and g are completely arbitrary. Furthermore, the two functions may or may not be different. Available knowledge does not conclusively indicate whether F and S_f should be related (6).

The above functional relationships serve to show how even today, so little is actually known about the interaction between the different variables that are known to be involved. In achieving a desired soil condition S_f, which is the main objective of all tillage operations, forces are applied on the tools. These forces produce some deleterious side-effects on the soil such as smearing.

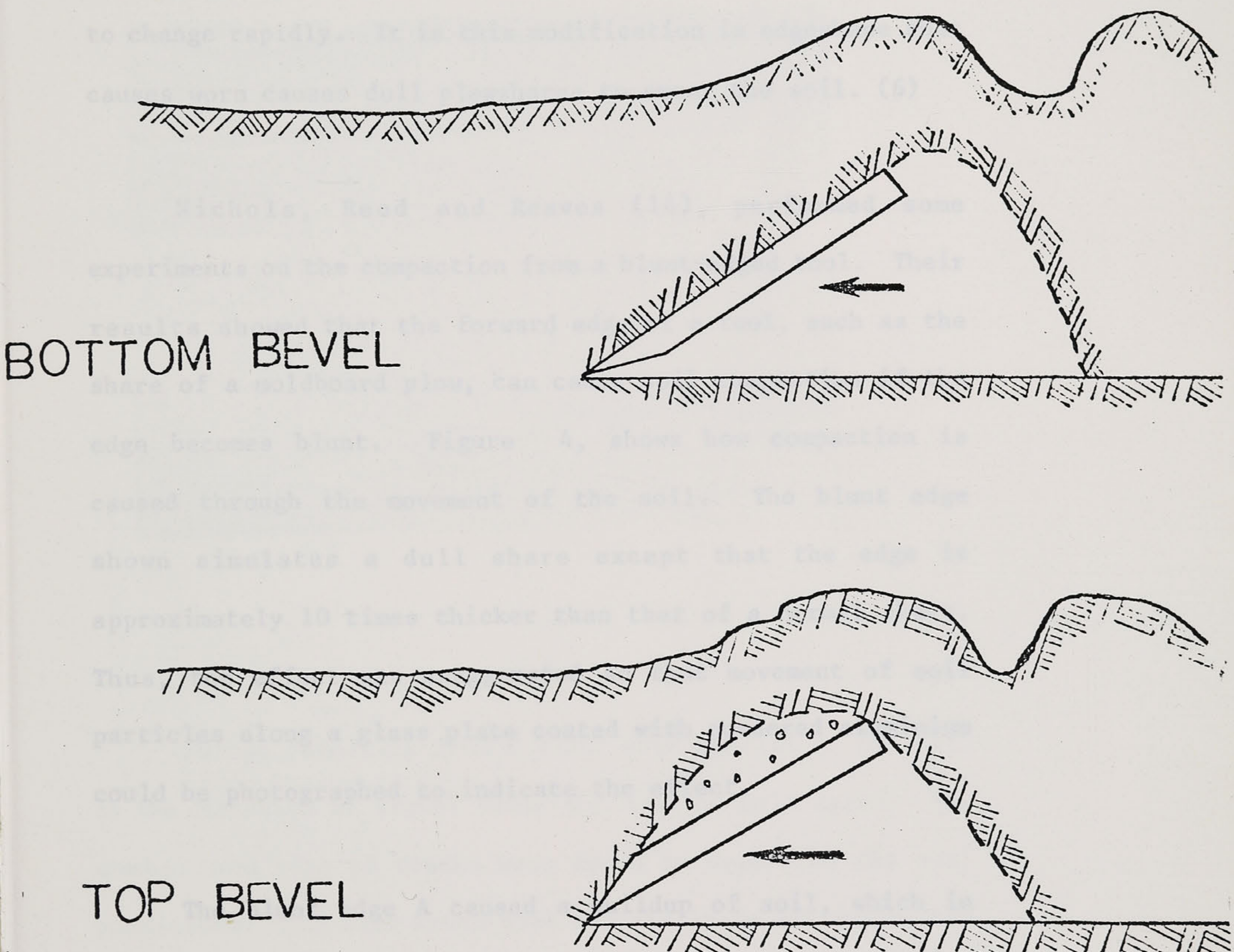
2. 4 The Nature of the Problem:

Edgeshape refers to the shape of edges of the finite tool surface that comes in contact with the soil. Usually, the overall tool shape has no relation to its edgeshape. In spite of the small area of the edge as compared to the total area of the tool, the shape of the edge can affect the total draft of the plow. (6)

2. 4 a) Effect of Edgeshape on Wear:

Chase (1) reported that the angle of the approach edge is important. Figure 3 shows how an upper and a lower bevel on the edge of a plane tool affected soil movement. When the bevel was on the lower surface, a "low pressure area" caused the soil to adhere to the surface as shown at the right in Figure 3. Soil adherence increased the draft of the tool. When the bevel was on the upper side of the surface, sticking was not observed. Chase also reported that tools needed sharpening more frequently when the bevel was on the top.

Figure 3. Influence of bevel orientation on soil movement over blades.

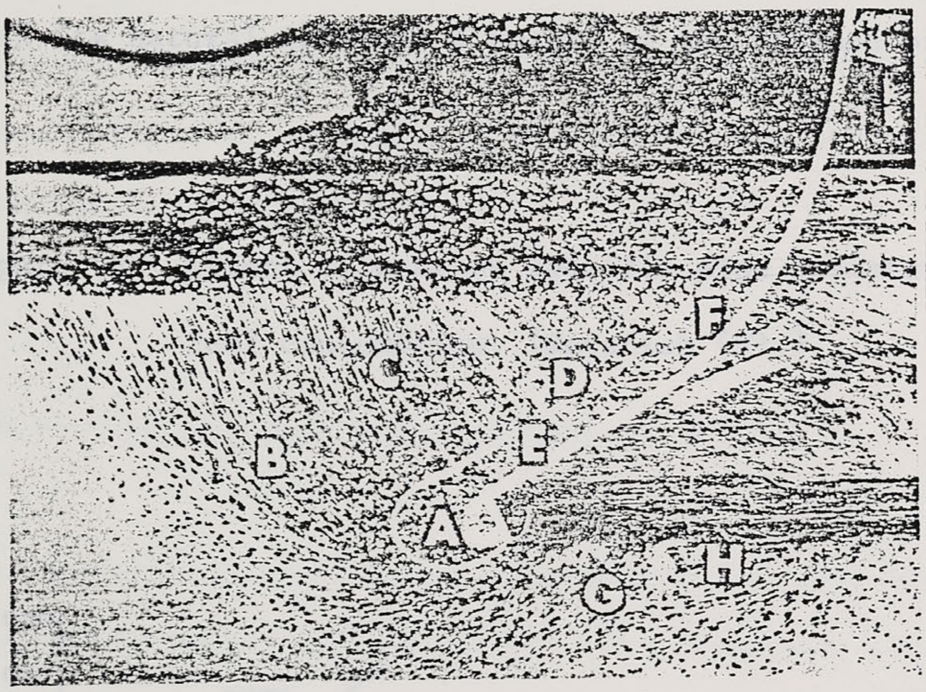


The edges of a tool surface are usually the first element of the tool to encounter the soil and as a result they are subjected to greater forces and wear (3). The macroshape of the entire tool generaly remains relatively unchanged as wear progresses. On the other hand, because of the small area and the concentration of wear, edgeshape tends to change rapidly. It is this modification in edgeshape that causes worn causes dull plowshares to smear the soil. (6)

Nichols, Reed and Reaves (14), performed some experiments on the compaction from a blunt-edged tool. Their results showed that the forward edge of a tool, such as the share of a moldboard plow, can cause soil compaction if the edge becomes blunt. Figure 4, shows how compaction is caused through the movement of the soil. The blunt edge shown simulates a dull share except that the edge is approximately 10 times thicker than that of a normal share. Thus, the effect was exaggerated so that movement of soil particles along a glass plate coated with powdered aluminium could be photographed to indicate the effect.

The blunt edge A caused a buildup of soil, which in turn forced some soil to move downward and cause compaction at G. Soil in areas B and C moved upward into a zone of less confinement. Vertical cracks in the bottom of a furrow of a moldboard plow, similar to those seen at area H, have also been observed with earth-moving equipment (15).

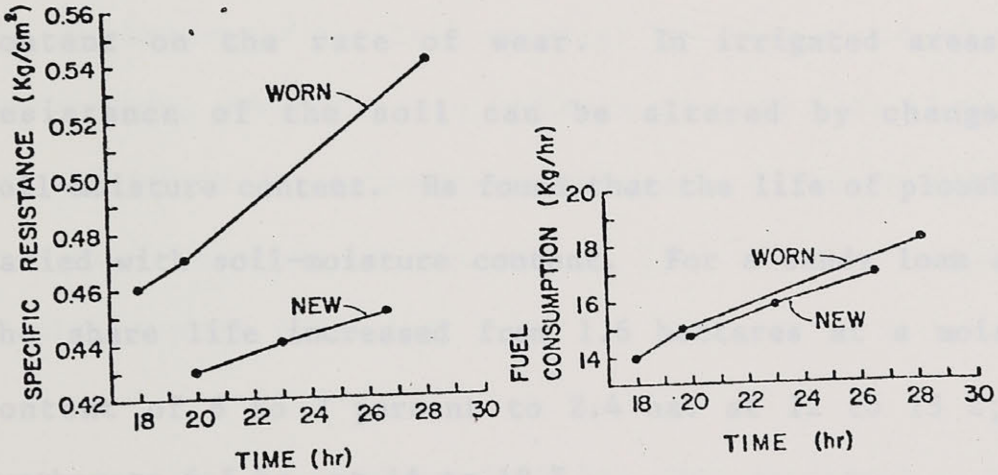
Figure 4. The compaction of soil by a blunt-edged tool.



Forces resulting from a blunt edge applied to the soil in the direction of travel cause the soil to pull apart. The number and size of cracks were found to depend on the soil conditions. They also found that especially in wet soils, the "smearing action" could conceivably close the soil pores completely so that no air or water could be transferred across the layer (14).

The radical change in edgeshape that can occur in plowshares and the change in forces required to operate the plow bottom are shown in Table 1. A negative vertical force, as shown in Table 1, indicates that the bottom had to be pushed downward into the soil to operate at the designated depth. A positive vertical force indicates that the plow had to be pulled upward to prevent it from going deeper. In normal operations the moldboard plow is free to float and seek its natural depth as a result of the balance of forces.

Figure 5. Effect of wear on specific plow resistance and fuel consumption. (Karatish (9).)



Several researchers have demonstrated that wear occurs rapidly. Gavrilov and Koruschkin (5) showed that wear increased draft resistance as much as 30 percent (Figure 1), and that nearly half of the increase had occurred after only a few hectares of land had been plowed. Figure 5 shows how the specific resistance of new and worn shares increased with hours of operation. The rapid increase in total draft detected after a few hours of operating time indicates the significance of wear.

2. 4 b) Effect of Moisture Content on Wear:

Karatish (9) studied the effect of soil moisture content on the rate of wear. In irrigated areas the resistance of the soil can be altered by changes in soil-moisture content. He found that the life of plowshares varied with soil-moisture content. For a sandy loam soil, the share life increased from 1.6 hectares at a moisture content of 6 to 7 percent to 2.4 ha. at 12 to 13 %; and further to 6.5 ha. at 16 to 18 %.

2. 5 Materials for Moldboards and Shares:

Moldboards are usually made from soft-centre steel. This is a 3-ply steel, the outer layers being high-carbon steel (usually C-1095, which has 0.90 to 1.05% carbon) and the centre layer being low-carbon steel (such as C-1010, which has 0.08 to 0.13% carbon). After heat treatment, the outer layers are somewhat brittle but extremely hard, giving a smooth surface that wears well and scours well in most soils. The centre layer, because of its low carbon content, does not respond to the heat treatment. It remains soft and tough, thus providing shock resistance. Similar characteristics can be obtained by carburizing a low-carbon steel on both sides (11).

2. 6 Summary of literature reviewed:

Wear is a complicated process that involves not only the properties of the tool material but also those of soil. Furthermore, available data indicate that the rate of wear is just as important as the amount of wear. It is evident that much more research is required to find out more about the wearing process (6).

In light of what research has been performed to date, this project set out to investigate the smearing effect of dull moldboard plowshares. This began with quantitative studies out in the field and later evolved to qualitative studies in the laboratory which became the main thrust of the project. For this reason, the objectives that follow, relate to the second phase of the project studies.

III. OBJECTIVES

1) To simulate the action of the moldboard plowshare/soil interface in a soil bin.

2) To contrast the soil condition after passing a dull and a sharp blade through the soil bin.

3) To investigate the influence of edgeshape on soil movement over a plowshare.

IV. MATERIALS AND METHODS

This project set out to make a careful study of smearing in order to discover the facts about it. Experiments were performed in the field as well as in the laboratory and hence the natural division of this section into, Field Experiments (Fall 1983) and Laboratory Experiments (Winter 1984).

4. 1 Field Experiments Fall 1983:

It was initially thought that the best way to investigate smearing was to go out in the field and actually work with a moldboard plow which had both new and worn plowshares. By pulling the plow through various soil types, and comparing the soil condition in the furrow bottom after the passage of the sharp and the dull plowshares, it was belived that a beginning could be made into seeing exactly what effect a dull plowshare has on the soil.

4. 1 a) Equipment:

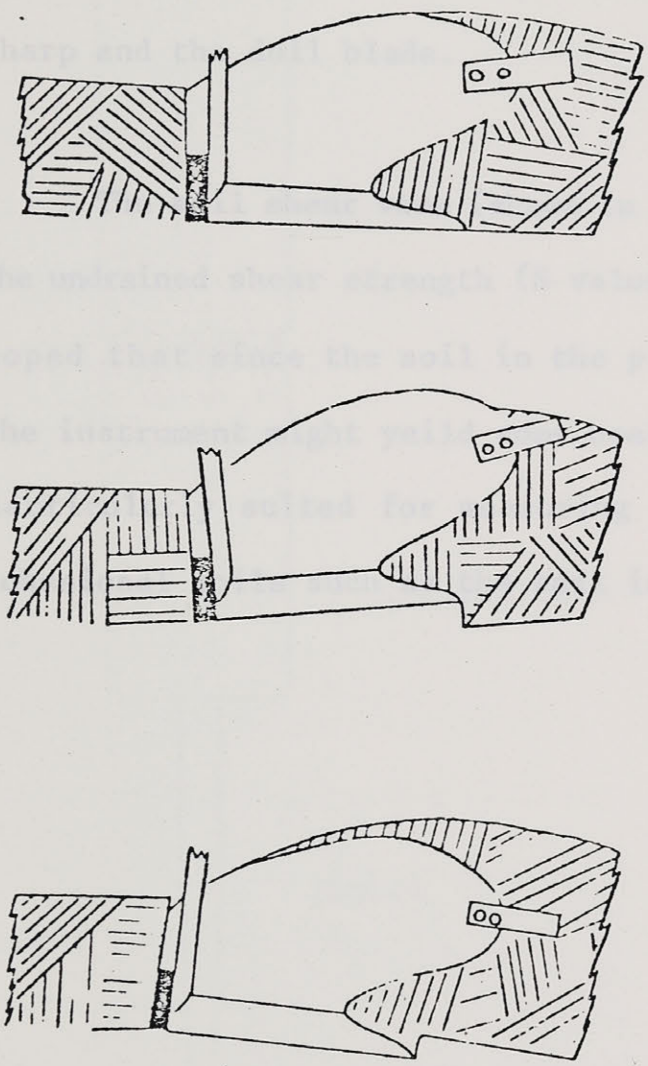
After a tractor became available (a Massey Ferguson 165), a suitable three-bottomed moldboard plow was found and the two outer plowshares were sharpened and the middle one was left dull.

Photo 1. Clearing of the plot of land.

A plot with clay soil (see Photo 1) on the north part of the College near the Seed Farm, was cleared of its vegetation using a bush hog.

The plow then had to be set so that the plowbottom would run level and exert even pressures across the furrow slice. Otherwise, poor granulation results from exerting either too much or too little pressure in the furrow slice when the plowbottom is "out of level". Furthermore, the curvature of the moldboard cannot function as designed for turning the furrow slice (see Figure 6) (4).

Figure 6. Effect of levelness of the plowbottom.



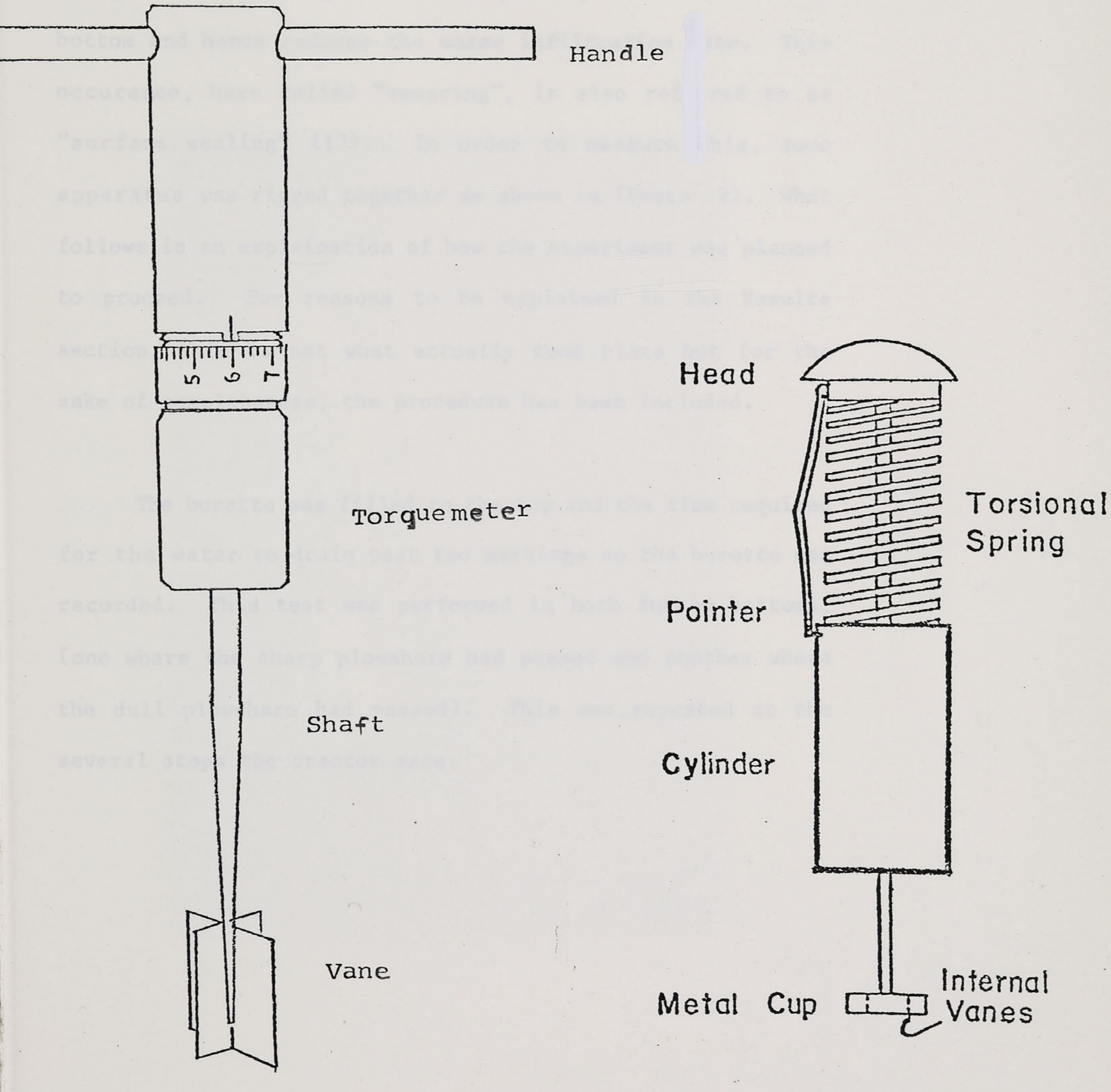
When this was finally ready, it snowed. In spite of this, attempts were made to quantitatively measure the smearing effect.

4. 1 b) Instruments:

The **Torsional sheargraph** (shown in Figure 7) measures the soil cohesion (c), soil-soil friction angle (ϕ) and soil-metal friction angle (δ) (2). It was used to see if any differences would be observed in the furrow bottoms of the sharp and the dull blade.

The **soil shear vane** (shown in Figure 7) which measures the undrained shear strength (S value) was also used. It was hoped that since the soil in the plot was of the clay type, the instrument might yeild some useful results because it is particularly suited for measuring the S values of purely cohesional soils such as the soil in the plot.

Figure 7. Torsional sheargraph and soil shear vane.



SOIL SHEAR VANE

TORSIONAL SHEARGRAPH

Infiltration is the passage of water into the soil surface and is distinguished from percolation which is the movement of water through the soil profile (17). It is thought that smearing blocks the pore spaces on the furrow bottom and hence reduces the **water infiltration rate.** This occurance, here called "smearing", is also referred to as "surface sealing" (17). In order to measure this, some apparatus was rigged together as shown in (Photo 2). What follows is an explaination of how the experiment was planned to proceed. For reasons to be explained in the Results section, this is not what actually took place but for the sake of completeness, the procedure has been included.

The burette was filled to the top and the time required for the water to drain past two markings on the burette was recorded. This test was performed in both furrow bottoms, (one where the sharp plowshare had passed and another where the dull plowshare had passed). This was repeated at the several stops the tractor made.

Photo 2. Water infiltration set-up.

4. 2 Laboratory Experiments, Winter 1984:

The project was continued in the laboratory, and the objectives changed to those listed on page 20.

4. 2 a) Equipment:

With these objectives in mind, a glass-sided soil bin was obtained. Its dimensions were 14.0 cm. (width), 19.1 cm. (height) and 86.4 cm. (length). This allowed observation of the interaction between the soil and the blade. A trolley was designed and built to ride on the rim of the soil bin as shown in Photo 3. Three blades of differing edgeshapes, shown in Photo 4, were then designed and brackets were welded on to facilitate convenient changing between the different blades.

In order to begin to approximate the real soil conditions, it was necessary to increase the soil moisture content. This was done by flooding the soil and allowing the water to drain overnight or longer if necessary. The factor S_i, was then assumed to have been taken care off, that is, the soil was ready to be 'plowed'.

The blade was designed and made (see Photo 3) to the dimensions 7.6 cm. (width) x 20.3 cm (length). 20.3 cm. was chosen in order to keep soil from falling over the rear end of the blade and burying the working area, where the smearing occurs. This length dimension was constrained by the fact that a very long blade would restrict the variation in the rake angle.

The 7.6 cm. width, was arbitrarily chosen since it is the dullness of blade and not the width of the blade that affects smearing. However, if the forces were being measured, the width would become a factor because it has been found that these same dull plowshares that cause smearing, also increase the draft (the horizontal component of the pull force). Since a qualitative rather than a quantitative analysis was sought, the width was designed to minimize edge effects and to not exceed the soil bin width.

The manner of tool movement involves the orientation of the tool (angle of approach or rake angle), its path through the soil (depth of cut), and its speed along the path. Under actual conditions, this factor T_m is controlled by the user. In this experiment, the trolley was designed so that both the angle of approach and the working depth could be easily varied. The former was varied by tightening the bolt that holds the blade and trolley together, and the latter by using the hole and slot adjustment at the rear end of the trolley. The speed along the path was kept constant by just pushing the trolley at a speed that 'felt' about constant. For a qualitative analysis, the magnitude of the speed was not as important as the fact that it was kept constant.

4. 2 b) Instruments:

A camera was used to photograph what changes were seen when the dull and the sharp blades were passed through the soil. The best of these pictures have been included in this project paper. A soil pocket penetrometer was used to measure the penetration resistance of sections of soil removed from the the path of each blade.

4. 3 Experimental Procedure:

When the test was run, four soil samples were taken. These were weighed and baked overnight in aluminium cans to establish the soil moisture content.

Two 40 gram soil samples were taken to determine the textural class of the soil being used. The particle size analysis was performed by the hydrometer method. In this method, 50 millilitres of sodium hexametaphosphate are added to each sample and then mixed in a mixer for five minutes. Each of these mixtures is then poured into a 1000 ml. cylinder and hydrometer readings are taken after given time intervals as shown in Table 1 in section 5. 2.

A sharp blade was attached to the trolley which was then pushed at a constant speed to about the half way mark (indicated in the photographs by the scraper). The blade was carefully lifted out to keep the 'plowed' soil from falling and covering the bottom of the 'furrow slice'. The sharp blade was changed for a dull one and the trolley was again pushed at approximately constant speed to the end of the bin.

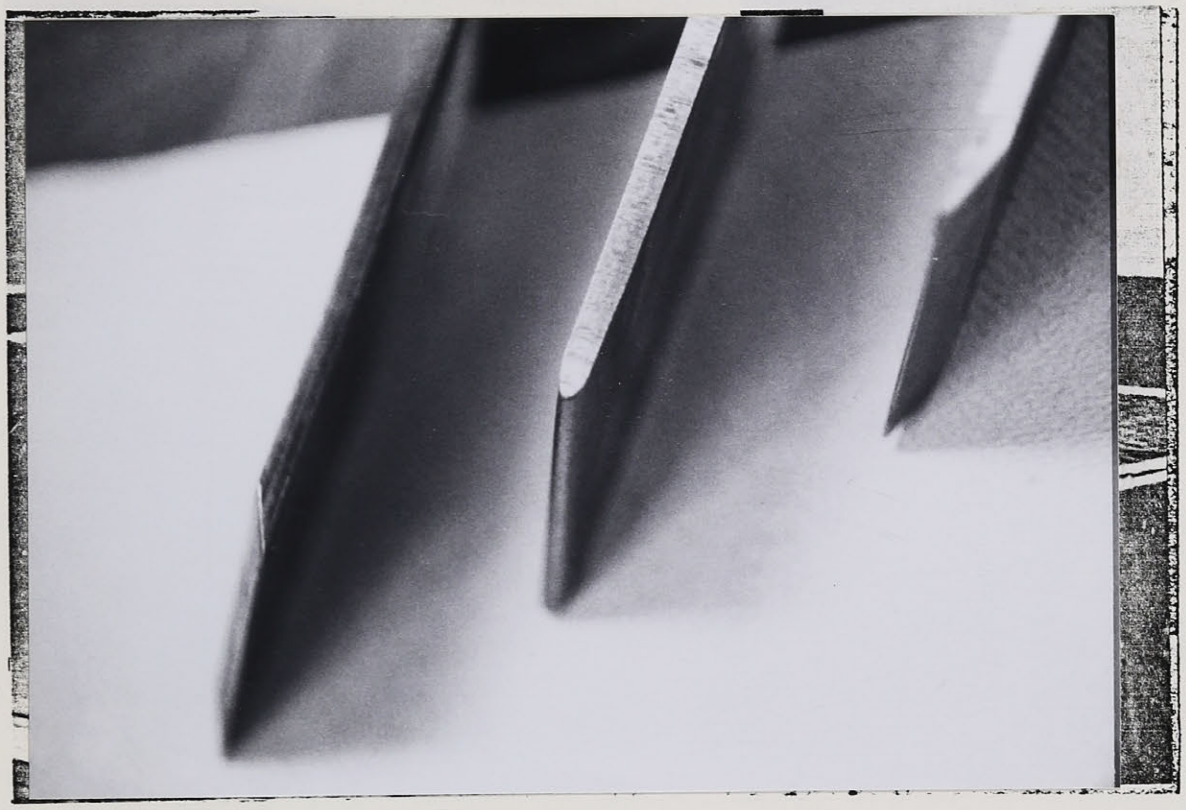
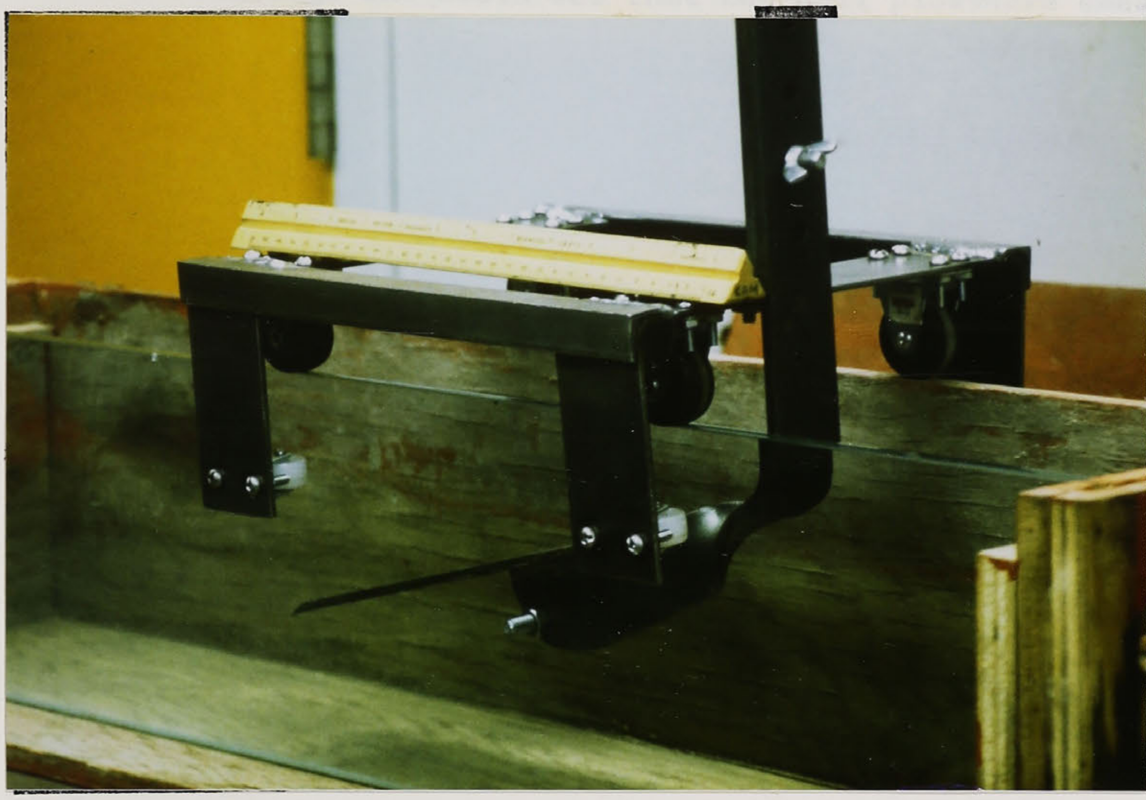


Photo 3. Different bevel orientations. From L to R, bottom bevel, round (dull) and top bevel.

Photo 4. Trolley and blade set-up in the soil bin.



V. RESULTS AND DISCUSSION

5. 1 Field Experiments, Fall 1983:

Although one could see that the dull plowshare smeared the soil more than the sharp one, the readings taken from the the torsional sheargraph and the soil shear vane showed no observable difference. One had to conclude that either there was no smearing (evidently wrong) or the instruments used were too crude to measure the small changes that took place in the soil structure.

The ground was wet with snow and the tractor wheels were slipping as the plowing went on. Attempts were made to measure the water infiltration rate as shown in photo 2, but it was found that before the burette could fill with water the core at the bottom flipped and the water began pouring out of the sides. This was due to the excessive water pressure from the column of water, about 1.5 metres high.

An attempt was made to collect soil samples using cores about 0.5 centimetres in thickness and 2 centimetres in diameter. The core remover was hammered over the core but when the core was removed it was found that the soil structure had obviously been damaged by the core remover. Hence, a better system will have to be devised for taking samples of soil at 0.5 cm. intervals so that analyses can be performed on them. Ambient temperatures well below zero handicapped further work. In January, the investigation was continued in the laboratory.

5. 2 Laboratory Experiments, Winter 1984:

The soil was first wet by flooding the bin and allowing it to drain overnight. Four randomly selected soil samples were taken to determine the moisture content at the time of the test run. For the main test run, the moisture content was found to be 26%.

After the soil moisture content soil samples had been taken, the test was carried out as outlined in the Experimental Procedure (section 4. 3). The smearing effect was quite obvious to the naked eye. The best photographs obtained of the smearing effect are shown below. Note that the sharp blade was passed through first and then the dull one. The second part of the soil surface was quite noticably different (smeared) from the first.

The results from the particle size analysis are displayed in Table 1 overleaf.

Determination of the Soil Type Used by Hydrometer Method:

TABLE 1

	SAMPLE 1		SAMPLE 2	
Time	Temp.(C)	(g/1)	Temp.(C)	(g/1)
40 sec	25	13.0	25	13.5
1 min.	"	12.0	"	12.0
5 min.	"	10.0	"	11.0
30 min.	"	7.0	"	7.0
1 hr.	"	6.0	"	6.0
4 hr.	"	3.0	"	3.0

Checking in the U.S.D.A. Soil Textural Triangle with the above results showed that with 25% silt, 8% clay and 67% sand the soil used was a **sandy loam.** The organic matter content and the organic carbon content were found to be 7.0% and 3.4% respectively for the soil used in the laboratory experiment.

Viewed from one side, the smeared layer had the appearance of being smooth and from the other side the appearance of being rippled. The photographer attempted to capture this by using lighting so that shadows were cast on one side. The dual effect produced is much like what is felt by one, when the fingers are run over fish scales: in one direction the scales feel sharp but in the opposite direction they feel smooth. This ripple-like surface (see Figure 8) was caused by the buildup of soil in front of the dull blade, which piled up and periodically broke off to form the ripples.

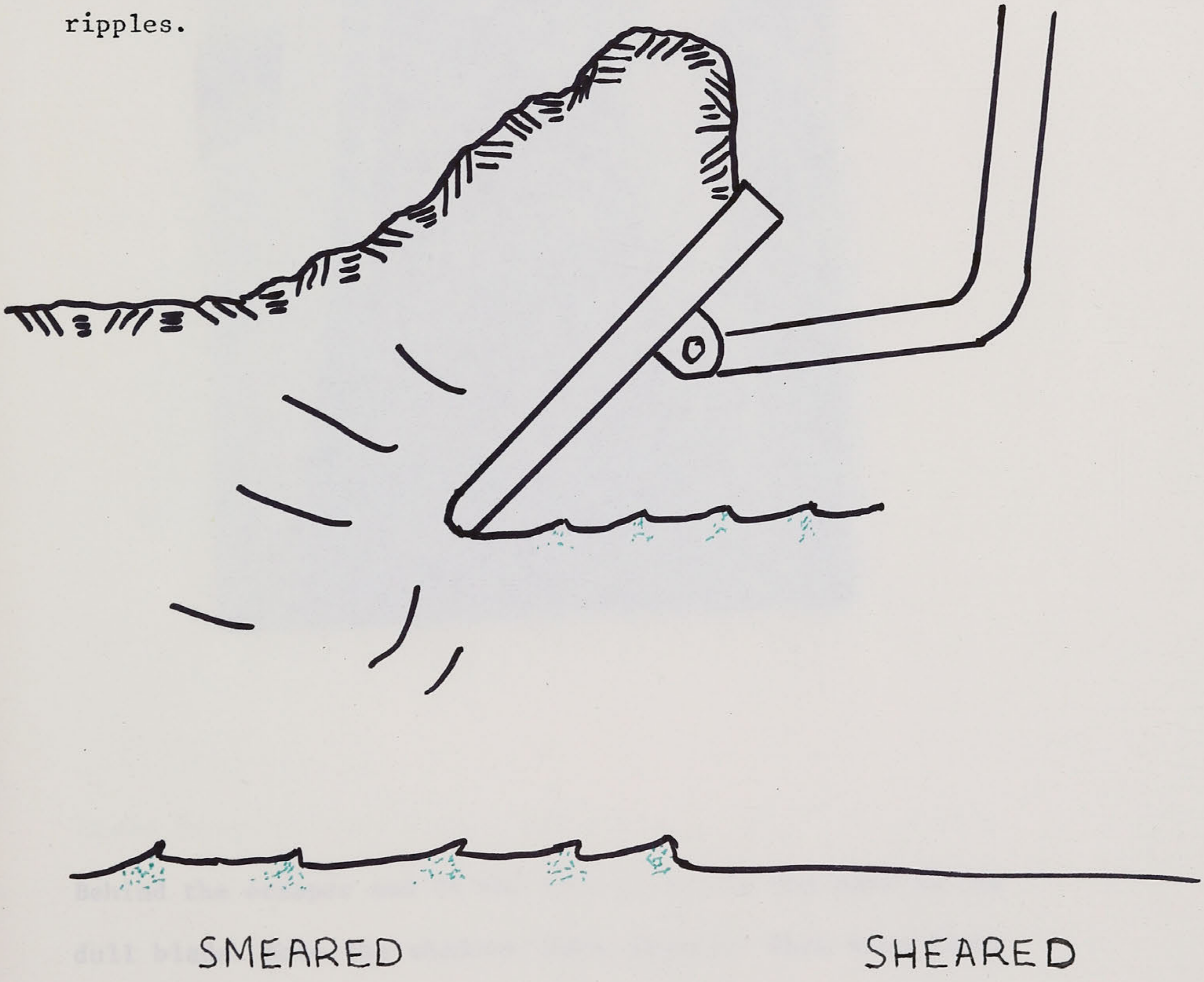


Figure 8. Profile of the smeared and sheared layers.

Photo 5. "Ripple effect" caused by dull blade.

Behind the scraper and to the left of it, is the path of the dull blade. Note the shadows (dark lines). This view shows the "sharp" or "rippled" smearing effect that is caused by the dull blade.

Photo 6. Comparison between sheared and smeared layers.

In the foreground and to the left of the scraper, is the path of the sharp blade. Although difficult to see in the photo, this part of the path was smoother, compared to the "ripples" that appeared behind and to the left of the scraper were the dull blade passed.

Photo 7. "Smooth effect" caused by dull blade.

This photo was taken from the opposite end to that shown in the last two. In the foreground and to the right of the scraper, is the path of the dull blade which was pushed toward the observer. From this angle, it is evident that the smeared layer is smoother than it appeared to be in Figure 9, when looking from the other end.

VI. SUMMARY AND CONCLUSIONS

Considering the available information, the investigation of the smearing effect of dull moldboard plowshares seems to have asked more questions than it answered. However, in any research where new ground is broken, the initial work always seems to have this characteristic.

Smearing is not synonymous with compaction. This is important difference is seen in that, while compaction is a direct function of the load placed above it, this is not so with smearing. Smearing is more directly related to the wear of the plowshare. Also, while the plowpan caused by compaction occurs at depths of up to 61 cm. (7), the smearing effect is found mainly in the top 2.5 cm. of soil, below the furrow bottom. Furthermore whereas compaction is cumulative (12), the smeared layer was observed to be destroyed with each pass at different plowing depths, because the layer is so thin.

Though obviously visible to the naked eye, the photographer experienced difficulty in trying to capture the differences between the smeared layer and the sheared one. Results observed from the movement of soil over the different edgeshapes revealed no significant differences. Afew modifications would need to be made to the apparatus in order for the results to concur with those found by Chase (1).

Needless to say, given more time, more and better results would have been obtained. The designing and building of the trolley and blades took the better part of the time available leaving time for only two test runs.

In conclusion, the investigation has cleared up some of the grey areas that formerly surrounded smearing and also established some of the important variables that affect it. The apparatus built and the knowledge accumulated, provide a framework within which further research can be done to further the investigation of the smearing effect.

VII. RECOMMENDATIONS FOR FURTHER RESEARCH

On the basis of the research which has been performed, it is clear that much more remains to be performed in the area of investigating the smearing effect. The relationship between the rate of wear of the plowshare and the degree of smearing has been established. It therefore follows that further research in unravelling the wearing process could reveal some significant information.

Empirically, wear can perhaps be quantitatively described in terms of altered shape. Since wear appears to change edgeshape so rapidly, perhaps variables such as T_s (section 4. 2 a) should be based on "worn" tool shape rather than on macroshape. Efforts have not been made to include edgeshape or wear into the design equations; however, for design to be complete, these special shape factors must be included (6). Edgeshape must first be described qualitatively and then quantitatively, and the description must be related to its functionally dependent factors.

Another area for further research is in the development of more sensitive instruments which would enable better quantitative measurements. These instruments should be able to accurately measure small changes in:

-- water infiltration rate,

-- soil strength,

-- soil structure (aggregate arrangement),

-- soil bulk density.

Tests should be performed in different soil types, especially clays and loams, and at varying moisture content levels. For further studies, new apparatus may need to be developed. What is presently available can be used to investigate the effect of rake angle and working depth on the rate of plowshare wear and hence the effect on smearing.

When the information has been compiled, much progress will have been made into understanding among other things just exactly what the smearing effect is, its implications for plant growth, its national significance and its importance to the average farmer. When this is done, the investigation of the "smearing" effect of dull moldboard plowshares will be closer to deciding the role of the moldboard plow in causing the smearing effect.

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