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The effects of subsoiling, in addition to ordinary plowing and disking on crop yields and moisture and organic matter content of the soil

J. Newt Odom

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To the Graduate Council:

I am submitting herewith a thesis written by J. Newt Odom entitled "The effects of subsoiling, in addition to ordinary plowing and disking on crop yields and moisture and organic matter content of the soil." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

Eric Winters, Major Professor

We have read this thesis and recommend its acceptance:

Joe A. Martin, L. N. Skold

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

March 10, 1958

To the Graduate Council:

I am submitting herewith a thesis written by J. Newt Odom entitled "The Effects of Subsoiling, in Addition to Ordinary Plowing and Disking on Crop Yields and Moisture and Organic Matter Content of the Soil." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

Eric Winters
Major Professor

We have read this thesis
and recommend its acceptance:

Joe A. Martin

Laurence N Skold

Accepted for the Council:

Dale Hantling
Dean of the Graduate School

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THE EFFECTS OF SUBSOILING, IN ADDITION TO ORDINARY PLOWING AND DISKING ON CROP YIELDS AND MOISTURE AND ORGANIC MATTER CONTENT OF THE SOIL

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

by

J. Newt Odom

March 1958

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J. Newt Odom

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CHAPTER I

INTRODUCTION

This study was designed to determine the effects of shattering the subsoil below normal plowing depth on the yields of corn, wheat and red clover hay, the moisture content of the soil at critical periods during the growing season and the organic matter content of the subsoil as an evidence of increased root development in the subsoil. The longevity of these effects were also to be determined by repeating the crop rotation on the same plots without re-subsoiling. An evaluation of heavy-duty disking as a substitute for ordinary inplowing in the initial preparation of a seedbed for corn was included in this study as a secondary objective.

CHAPTER II

REVIEW OF LITERATURE

The literature relating deep tillage to crop yields and moisture retention in the soil is rather extensive, beginning with a few investigations early in the present century and increasing in number and complexity to the present date. However, definite conclusions as to the value of this practice are difficult to establish because the investigations have been made under widely varying soil conditions. The primary objective of many investigators has been to increase crop production or adaptability on a difficult soil situation rather than to prove the value of the practice on normally productive soils.

Smith (17) experimented with subsoiling, deep tilling and subsoil dynamiting on gray silt loam on tight clay soil at two locations in Illinois. On the basis of thirteen years results at one location and six to nine years at the other, he summarized:

> The yield differences were so small and variable that the only possible conclusion is, subsoiling has neither increased nor decreased the corn yields. None of the three practices had any beneficial effects on the yields of corn, wheat, soybeans or sweet clover. Shattering is essential to water and root penetration in these soils but they are rarely, if ever, dry enough and are very unlikely to remain shattered.

Call and Throckmorton (3) used dynamite to improve heavy clay soils at six locations in Kansas. In summarizing the results of this investigation they stated:

> In most cases the difference in yield was no greater than would occur on two areas of soil similarly treated. Moisture determinations showed no marked differences. The physical condition of the soil after dynamiting was poorer, being compacted and puddled rather than shattered and cracked.

Jones and Beasley (9) investigated substitutes for ordinary plowing for corn on a Putnam silt loam soil in Missouri. They found none of the substitutes, including subsoiling, equal to plowing as measured by corn yields. Putnam silt loam would be classified as a problem soil because of a dense "B" horizon with a high clay content.

Chilcott and Cole (4) conducted experiments with the subsoil plow, the Spaulding deep tillage machine and with dynamiting for ten different crops at eleven locations in eight Great Plains states from Montana to Texas. Based upon the results of these experiments they made statements as follows:

> There is perhaps no agricultural operation that is so often and enthusiastically advocated and at the same time so little practiced as that of loosening or tilling the soil below the depth reached by the ordinary plow.
>
> The supposed necessity or desirability of such an operation appears to be based on a widespread belief that only that part of the soil loosened and moved by man with his implements of tillage is utilized by nature in the production of crops; that this part of the soil is the only part that participates in the storage of water to be recovered by the crop; that the development and growth of the roots of crop plants is limited to this portion of the soil, and that this is the only portion of the soil from which plant food may be obtained by the crop.
>
> A less extreme belief recognizes that these things are not entirely limited to the portion of the soil that man loosens, stirs, pulverizes, or inverts, but holds that the soil so treated provides a more effective medium for their action than does the undisturbed soil.

Such beliefs apparently either overlook the luxuriant vegetation produced on land that has never known the tillage implements of man or assume that the roots of crop plants are essentially different in their relation to the soil than those of other plants or of the same plants growing wild

Extensive soil-moisture studies that have been made in connection with the investigations reported in this paper indicate that the ability of the soil to take in or to retain water, or to give up water to the crop, is not determined by the depth of tillage. Sands and light sandy soils offer little resistance to the entry and downward passage of water. They are little changed and certainly not improved in this respect by cultivation. With the heavier clay soils in which penetration is slower and more difficult it would seem that there was more opportunity for improvement by a mechanical loosening. The result is not, however, what it might at first thought appear to be. The mechanical loosening that may be affected when such soils are dry enough to be loosened by tilling is of no consequence so long as the soil remains dry. When rains come and water enters the soil, it carries soil material with it in the downward passage through the loosened soil. The clay expands on becoming wet and the loosened and wetted area becomes an amorphous mass. On drying, the soil contracts. A part of the shrinkage is downward, and a part of it is lateral. The lateral shrinkage results in cracks that may open the soil as effectively as any tillage operation.

Recognizing the fact that there may be times and places giving results favorable to subsoiling or other methods of deep tilling, the average yields obtained in the extensive experiments here reported seem to warrant the conclusion that as a general practice for the great plains as a whole no increase of yields or amelioration of conditions can be expected from the practice.

In their response to deep tillage there is no marked difference to be observed between crops.

Subsoiling and deep tilling have been of no value in overcoming drouth. The effect, on the contrary, apparently has been to reduce the yields in those seasons that are below the average in production.

Experiments have been conducted with the subsoil plow, the Spaulding deep tillage machine, and dynamite. The effect or lack of effect of deep tillage appears to be essentially the same, irrespective of the means by which it is accomplished.

The quite general popular belief in the efficiency of deep tillage as a means of overcoming drouth or of increasing yields has little foundation of fact, but is based on misconceptions and lack of knowledge of the form and extent of the root systems of plants and of the behavior and movement of water in the soil.

Hanks and Thorp (7) measured wheat yields, rate of rainfall infiltration and moisture storage on deep-tilled plots and on plots tilled at normal depth on six different soils in Kansas. Their results showed no difference in rate of infiltration or amount of moisture stored and no increase in wheat yields due to deep tillage.

Some of the more recent investigations of the effects of deep tillage have included deep placement of fertilizer materials. Woodruff and Smith (20) compared normal plowing with turning a second furrow in the bottom of normal furrows and as a third treatment added lime and complete fertilizer on the second furrow. The work was done in Missouri on a soil with a claypan and poor internal drainage. Corn, oats, barley and sweetclover were used as test crops. A small increase in corn yield was obtained by deep tillage alone. An additional small increase resulted from the use of lime and fertilizer in the second furrow of the deep-tilled plots. Wheat and barley yields were depressed slightly by deep tillage alone, but were restored or very slightly increased by addition of lime and fertilizer in the subsoil. Sweetclover had large lateral roots, but no tap roots on the check and deep-tilled plots and was damaged by winter-killing. Normal rooting with deep tap roots and no winter-killing damage was reported for the sweetclover on plots which had lime and fertilizer in the subsoil. The increased corn yields on the deep-tilled plots were attributed to improved aeration. The moisture content of the subsoil was determined at seven dates between May 30 and July 26. The deep-tilled plots averaged 2.3 percent more moisture at the eighteen-inch depth than the check plots. This was described as the equivalent of .62 inches of rainfall, which is not enough to offset the damages of a drought.

Robertson and Fiskel (13) studied the effects of subsoiling and deep placement of fertilizer on the growth of corn on Flatwood soils in northern Florida. Their investigations were based on the suppositions that a high level of fertility develops in the surface soil from repeated fertilization and that low fertility exists in the subsoil, favoring shallow root systems and that deeper root systems, encouraged by deep fertilization, would result in a larger reservoir of water which would carry the corn through short drought periods without greatly decreasing the yield. Subsoiling through the hardpan about fourteen inches below the surface of Leon fine sand resulted in a ten-bushel increase over the fifty-bushel average corn yield from the check plots. Lime and fertilizer banded at depths of thirteen to fifteen inches in addition to subsoiling resulted in a twenty-two-bushel increase over the check plots which had equal amounts of fertilizer in the surface. All plots had four hundred pounds of 4-12-4 fertilizer at planting and forty pounds of nitrogen as a side-dressing. Lime in addition to subsoiling on Ona fine sand produced eighteen bushels increase in corn yield over the sixty-bushel yield of the check plots. All of these yield differences were described as significant.

Kohnke and Bertrand (10), pursuing the hypothesis that fertilizing the subsoil provides for better water utilization by crops, experimented with subsoiling twenty inches deep and placing one hundred pounds each of N, P and K in the subsoil. The abstract written on the results of this investigation with corn, wheat, soybeans and hay over a three-year period was:

> Subsoil fertilization experiments were conducted on several Indiana soils. The fertilizer was applied in vertical bands from 7 to 20 inches deep. The distance between the bands varied between 28 and 48 inches.
>
> The growth of corn roots greatly increased as a result of subsoil fertilization; subsoiling without fertilizing the subsoil increases root growth only slightly. Subsoil that was chiseled and fertilized maintained a higher porosity for over 2 years. The reason for the difference is probably the presence of additional organic matter (roots and microbes) in the fertilized subsoil.
>
> The subsoiled areas generally contained more moisture than the untreated plots, pointing to less runoff and erosion and to a greater water supply for the crops.
>
> Yield increases from subsoil fertilization have been substantial in many cases, but not consistent. It is assumed that benefits from this practice will increase as it is repeated on the same area.

There have been a few investigations of the effects on crop yields when tillage below the normal depth of plowing was done on soils which have no physical pecularities such as hardpans or other restrictive layers near the surface. Noll (11) compared the effects of seven to eight-inch plowing to twelve-inch plowing in both spring and fall on the yields of corn, oats, wheat, barley and alfalfa. Summarized briefly, the results were: "The two kinds of plowing gave practically the same results for all the crops grown." Other statements indicated that there were greater differences between spring and fall plowing than between deep and normal plowing. Dynamometer draft tests conducted in connection with this experiment indicated approximately three times more power requirement for twelve-inch plowing than for seven to eight-inch plowing.

The Ohio Agricultural Experiment Station (2) compared plowing fifteen inches deep and normal plowing plus subsoiling fifteen inches deep with normal plowing for corn and wheat followed by oats and clover, respectively. The conclusions based on twelve years of crop yield data were: "It would be difficult to arrange a uniform treatment which would result in yields more nearly identical. In view of the expense involved, it is evident that the seven and one-half inch plowing is by far the most profitable."

In West Virginia, Sudds (18) subsoiled and dynamited the soil before and after setting and at bearing age in both peach and apple orchards on DeKalb, Lickdale, Lehew and Berks soils. He found no significant, nor consistent, difference in moisture content of the soil at critical periods, the rate of growth of young trees nor the yield of fruit on trees of bearing age. A greater rate of rainfall infiltration was reported but the difference in moisture retention was not measurable. Established trees were damaged by the root-pruning action of subsoiling. Subsurface investigations seven years after subsoiling and blasting revealed that the soil was more loose and friable and that the tree roots had penetrated the loose holes and furrows. In the conclusions drawn from this investigation, the use of these practices was not recommended under similar circumstances.

Hume (8) compared several depths and methods of plowing for corn, wheat and sweetclover in a three-year rotation on Williams silt loam soil at Highmore, South Dakota. The methods and depths used were moldboard plowing seven inches deep as a check, subsoiling eight inches deep without plowing, moldboard plowing four inches deep, moldboard plowing six inches deep plus subsoiling six and ten inches deep and turning with a deep disk tiller eight, ten and twelve inches deep. The twenty-year average crop yields from this experiment showed no significant increases in corn yields for any depth or method over seven or eight-inch plowing. There were some significant decreases in wheat yields for methods deeper or shallower than seven to eight inches.

Schwantes, et al. (16) compared subsoiling twelve to fifteen inches deep with ordinary plowing for nine different crops on three loam and fine sandy loam soils at three locations in Minnesota. They found no significant increases in crop yields from subsoiling. Their check plots produced greater yields than the subsoiled plots in over fifty percent of the trials.

Garner and Sanders (6) studied the effects of normal plowing seven inches deep, subsoiling eight to nine inches deep in addition to plowing and gyrotilling twelve to fourteen inches deep on yields of several crops. Gyrotilling is similar to subsoiling but results in greater disturbance of the subsoil. Wheat and oats produced insignificantly more grain on gyrotilled plots than on normally plowed plots on Gault clay. Better surface drainage was observed on the gyrotilled plots in rainy winter weather. On a light gravelly soil which has a tendency to form a pan below the normal plow depth, oats produced a significantly higher yield on gyrotilled plots than on normally plowed plots. Under the same conditions, sugar beets showed no significant difference in yield. On another light gravelly soil, sugar beet yields were high, medium and low on subsoiled and plowed, plowed normally, and gyrotilled plots, respectively. Under the same treatments there were no significant differences in yields of barley. The conclusions drawn by the authors were:

> There were insignificant differences in yields in eleven of twelve trials. Gyrotilling gave insignificantly higher yields in five of seven trials on clay soil. The effects of the gyrotiller were harmful on gravelly soils. The use of the gyrotiller or subsoiler does not reduce the necessity of subsequent cultivation, therefore, the cost of the extra operation is lost.

On the basis of observations and review of research reports from many locations regarding the effects of subsoiling, Winters and Simonson (19) stated:

> In a few instances crop yields seem to be better but generally results are negative. Field observations do indicate beneficial effects from moderately deep tillage, however, on certain soils underlaid at shallow depths by "D" horizons of soft shale. Subsoiling breaks up the shale easily and thus seems to increase the effective rooting zone of crops.
>
> When soils with fragipan layers occur on moderate slopes and are cultivated frequently, they commonly suffer erosion which brings the fragipan layer close to the surface. Under such conditions, moderately deep tillage to break up part of the fragipan layer seems to result in better growth of many crops, though not of alfalfa. The beneficial effect of the deep tillage

> seems to be expansion of the rooting zone, analogous to that in certain shallow soils overlying shale. Deep tillage of soils with fragipans has been most beneficial when the entire pan layer could be broken up by the operation. Unfortunately, fragipan layers are often several feet thick and pose serious difficulties to effective subsoiling. Furthermore, the power requirements and costs increase sharply as depth of tillage increases.
>
> Because the costs are high and multiply rapidly as greater depths are reached, the expense and probable returns must be weighed carefully against those for alternative approaches.
>
> Possible alternative management practices for cultivated lands include: (a) Attempts to promote deeper rooting by the selection of crops and liberal fertilization to encourage vigorous rootgrowth, (b) the adoption of a rotation which would involve less frequent growth of row crops, and (c) the selection of crops better adapted to the unfavorable subsoil conditions.

In a study of the effects of cropping systems on soil properties, Page and Willard, et al. (12) found that: (1) Higher corn yields were produced following alfalfa and grass than following alfalfa alone in a four-year rotation. (2) A three-year rotation of corn, oats and alfalfa or sweetclover had little effect on the productive capacity of soils. (3) Soils remain harsh and cloddy throughout the season and drain very slowly under a rotation of corn, soybeans and oats or continuous corn. Additional tile spaced closer did not solve the drainage difficulty. (4) A soil which had been cropped forty years weighed approximately 25 percent more per cubic foot in the first and second foot of depth and 19 percent more in the third foot than a nearby area of virgin soil of the same series. The soil on which these investigations was made was Nappanee silty clay loam in Paulding County, Ohio.

On the subject of soil structure, Russell (14) wrote:

> The effects of cultivation implements on the soil can be considered from two aspects, namely, their effect on the distribution of aggregates and the distribution of pores.
>
> The pore space distribution in the surface soil must be as stable as possible against the disturbing effects of the climate and cultivation. The subsoil is not subjected to these mechanical shattering forces in the same way.

In a very indirect manner, this noted author suggests that disturbance or shattering of the subsoil should be avoided. In the introduction to a study of tillage practices, Russell and Keen (15) expressed the belief that many of the present tillage practices are customs carried over from earlier times when there were frequently surpluses of labor and horse power which were employed by cultivation because of the belief that extra cultivation was always beneficial.

An editorial in a monthly publication presented regional answers to the question, "Does Subsoiling Pay?" by quoting Alderfer _et al_. (1) as follows:

NORTHEAST

by Russell B. Alderfer

> THE CHIEF purpose of deep tillage is to increase the rooting depth of a soil by improving its physical condition. It doesn't pay on most soils because poor physical condition isn't a problem in the subsoil; or where it is, any improvement from deep tillage doesn't last long enough to make it worthwhile. Done under the wrong conditions, it can actually make the situation worse and reduce yields. We know a great deal more about where it won't pay than where it will.

Our biggest problem is measuring the physical condition of the soil so that we can set up standards to tell how good or poor it is.

One standard which has promise on medium-textured soils is based on air space. Whenever the air space in any recognizable part of the first 18 inches of the soil is less than 15 percent at field moisture capacity, the yield of some crops is reduced. This decrease may be as great as 50 percent for sweetcorn, potatoes, and field corn in soils with only 6 to 8 percent air space. The extent to which deep tillage may increase the air space in a soil layer up to 15 percent for any length of time could determine its real value.

Lacking experimental proof, but basing our conclusion on many field observations, the following soil conditions in New Jersey might be improved by deep tillage.

(1) Plow soles or plow pans, especially prevalent in intensively tilled vegetable soils.
(2) Badly compacted traffic areas in orchards, and in potato and vegetable fields.
(3) Hardpans caused by a high water table which can be reached by the subsoiler blade and shattered enough when dry to help move water to tile drains.
(4) Certain types of cemented hardpans.

The improvement might be expected to last long enough to be of some practical value, either by increasing crop yield or by making it easier to plow, irrigate, or drain a soil.

In New Jersey, many people are firmly convinced that deep tillage is the means for making deep applications of lime and fertilizer. The practice is usually recommended for establishing a new asparagus planting. The presence of a noticeable concentration of roots in the limed and fertilized part of the subsoil would indicate that something had been done which will show up sooner or later in higher productivity of that soil. A few experiments and some farmer experience seems to bear this out. The reverse is also true, however.

As with deep tillage alone, there are soils which can be benefited by deep fertilization and liming. To determine where and what they are and how much they can be improved will require a lot of good, thorough research.

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New Brunswick, N. J.

MIDWEST

by Dwight D. Smith

COMPARED with 9- to 10-inch deep plowing with full fertility treatment, deep tillage (or subsoiling) to depths of 14 to 18 inches, has not given lasting benefits on Midwest claypan soils.

Experiments in central Missouri show that yields of grain crops are usually decreased by the practice, unless lime and phosphate are placed in the soil below the depth of 9 to 10 inches. Small increases in corn and soybean yields can then be expected, but hardly enough to return a profit.

Early results indicate that the deep fertility treatments may be profitable with alfalfa. Corn yields were increased substantially in 1955, the first crop season after a 30-inch deep subsoiling and liming.

Some additional water absorption has been measured from rains occurring within a few months after subsoiling, but when the rains continued the increased storage space was soon filled and runoff occurred as before. Apparently, deep tillage on these soils has not improved the downward movement to a ground water table.

Midwest claypan soils are quite different from soils with compacted traffic "pans," on which deep tillage has usually been helpful. They usually have about 10 inches of surface soil and are medium to low in natural fertility. The clay content of the subsoil reaches a maximum at 20 to 24 inches and continues high to a much greater depth. When dry, the subsoil cracks and is easily shattered. When wet, the cracks swell shut, excluding much of the air and decreasing the rate of downward movement of water to almost zero. Calcium and phosphate are low to a depth of 20 to 24 inches, although the capacity of this subsoil zone to absorb nutrients is high. The results are consistent with these conditions.

With the present knowledge, deep tillage of the Midwest claypan soils as described here should not be practiced more widely unless accompanied by deep liming and fertilizing. Farmers will be ahead if they invest their money in full fertility applications to the upper 9 or 10 inches of their soil.

Dwight D. Smith is agricultural engineer, Soil and Water Conservation Research Branch, USDA Agricultural Research Service and research associate, Missouri Agricultural Experiment Station, Columbia, Missouri.

WEST

by Chester E. Evans

THE QUESTION of whether subsoiling, chiseling, or deep plowing are valuable has been a controversial one for many years. But in Western states, a favorable response can usually be expected on soils with compact layers or horizons that restrict the downward movement of roots and water. However, some soils with tight layers will not respond to subsoiling.

Experiments started in Kansas in 1952 on soils varying from a fine sandy loam with a distinct hardpan to loam with a tight subsoil showed that subsoiling did not affect the infiltration of water, moisture storage, or wheat yields.

On the other hand, deep tillage, either by a subsoiling implement or plow-type implement, showed favorable results in 1952, on a fine-textured soil at the Wheatland Conservation Experiment Station near Cherokee, Oklahoma. In each of the two seasons that followed, runoff from the deep-plowed plot was only about half that of the untreated area. But in the third season after treatment, there was no visible effect of the deep tillage operation.

The variable results obtained with deep tillage make it hard to recommend the practice widely. Early results show unquestionably that the moisture content of the soil at the time of the deep tillage operation has a great effect on the final results.

In general, compact soil layers must be shattered when the soil is quite dry, if the tillage is to have a maximum effect. In fact, chiseling of wet soils has been known to compact the soil to the depth of the operation.

Increased moisture storage has been attributed to the use of subsoiling implements in parts of the winter rainfall belt of the Pacific Northwest. Part of the increase has been due to snow accumulations on the rough fall-tilled areas. The furrows or channels left by the chisel tools serve as temporary water reservoirs for melting snow and speed the water intake.

Because of the higher power requirements, the cost of subsoiling or deep plowing is always greater than normal tillage. It follows, then, that an appreciable increase in moisture storage and later crop yields must be realized to offset the cost of the operation. Another factor unfavorable to deep tillage in semiarid areas is that any operation which stirs the soil, particularly one that exposes subsurface layers, speeds up evaporation losses of water already stored.

Because the problem is complex and we lack adequate information, there is no question but that we need an accelerated research program on deep tillage.

Instead of approaching this problem by merely comparing crop yields in relation to the various tillage implements used to stir the soil to varying depths, we need to take a more fundamental approach--one directed toward finding out exactly what happens when compacted zones or subsoil horizons are subjected to mechanical treatment.

Chester E. Evans is assistant head, Western Soil and Water Conservation Research Branch, USDA Agricultural Research Service, Beltsville, Maryland.

SOUTH

by Perrin H. Grissom

IN MISSISSIPPI, deep tillage does pay on soils where hardpans have been formed by traffic, cultural practices, and erosion. On soils having a natural pan, the response to deep tillage is questionable. And on soils without a compacted zone or those which show surface cracks when dry, crops do not respond to deep tillage.

The benefits of deep tillage are improved stands, increased yields, and, frequently, reduced grass and weed population. These are made possible by the increased intake and storage of water and the greater root development resulting from the shattering of an impeding layer.

Two requirements must be met before deep tillage can pay: (1) the soil must be dry enough and the tillage deep enough to shatter the pan, and (2) for a given crop, the treatment must be early enough to take advantage of natural rainfall.

Deep tillage increases the production potential and creates conditions where higher rates of fertilization can be used. Thus, the two practices help each other. However, on heavily fertilized hardpan soils where the fertilizer tends to accumulate, deep tillage permits utilization of the previously applied fertilizer, thus reducing the requirements for a year or two.

The cost of deep tillage in the Mississippi Delta area varies from $3 to $8 an acre. The yield of cotton has been increased an average of 1/2 bale per acre on hardpan soils, with greater responses in dry years and less in wet seasons. The value of the increase has exceeded $75 an acre. Thus, the practice has been quite profitable.

Deep tillage need not be encouraged or discouraged in the area. But farmers should be encouraged to follow the practice where hardpans exist. A "sharpshooter" or shovel is all you need to find a hardpan. At present, from 300,000 to 400,000 acres in the Delta are being deep-tilled each year, and at least half of the land doesn't need it.

Perrin W. Grissom is agronomist at the Delta Branch of the Mississippi Agricultural Experiment Station, Stoneville, Mississippi.

FAR WEST

by H. W. Henderson

THE ONLY form of deep tillage practiced to any extent in California is subsoiling or ripping. The results obtained are favorable in some cases, without effect in others, and under certain conditions decidedly harmful. Evidence is too limited for a complete understanding of the factors necessary for a favorable response to subsoiling, but results can be predicted in the more clearcut situations.

Subsoiling should be considered a corrective measure, and therefore should only be done to shatter and loosen soils in which penetration of water and roots is limited. Effective action of the implement depends upon shattering and heaving, which occur only when the soil is dry--preferably near the wilting percentage--throughout the tillage depth. Best results occur when there is a compact layer underlain by soil of better structure, and the layer is completely penetrated and shattered by the subsoiler.

If the impervious soil can be properly shattered, there are still two conditions which must be met if the soil is to remain open long enough for the operation to pay dividends in better crop growth. First, the soil must have enough water stability so it will not "run together" again during subsequent wettings by rain or irrigation. Secondly, traffic over the soil must be minimized to insure that the soil is not compacted again within a short time.

Subsoiling when the soil is moist can be harmful, especially if done repeatedly. If the soil "flows" around the subsoiler point rather than shattering, the kneading action results in further compaction.

D. W. Henderson is assistant professor irrigation, Department of Irrigation, University of California, Davis, California

SUMMARY

by Lewis B. Nelson

DEEP tillage will pay under certain soil conditions, but not under others. The big problem is to recognize these conditions and then deep-till only those areas, or soils, where benefits are likely.

Deep tillage often will give good, and sometimes phenomenal returns in areas where "traffic pans" develop. These pans are easily-recognized, compacted layers which usually result from machinery traffic and occur in the 7- to 15-inch soil zone. In the East and South, the pans occur mostly in areas where intensive row-crop farming is practiced and where moist soil is subjected to machinery traffic.

Deep tillage of soils with impermeable, clayey subsoils of considerable depth (clay pans) hasn't appeared too promising. Neither has the introduction of lime, fertilizer, or crop residues into impermeable subsoils proven particularly beneficial. While it does appear that such deepening of the root zone should be beneficial, most research findings to date would not permit its recommendation as a general practice. Possibly future refinements may insure greater benefits.

Breaking up tight, naturally-occurring layers within reach of a chisel sometimes gives good returns. Also, shattering impervious underlying shales has shown benefits. On the other hand, deep tillage is of little or no benefit on well-drained soils with permeable subsoils.

Even where conditions favor deep tillage, it may not pay unless done correctly. For example, dragging a chisel through wet or moist soil will do little good, and may make the situation even worse. Tilling should be done only when the soil is dry enough to shatter.

Lewis B. Nelson is head, Eastern Soil and Water Management Section, Soil and Water Conservation Research Branch, USDA Agricultural Research Service, Beltsville, Maryland.

CHAPTER III

METHODS AND PROCEDURES

This project was started in 1948 on an area which was abandoned after one year in favor of a larger project. Corn yield, soil moisture content and organic matter content data were recorded on this area in 1948. Only the soil moisture data from this area were used in the final analysis of this study. The project was resumed in 1950 on an adjacent area of the same soil type.

Corn, wheat and red clover were grown in three-year rotations on The University of Tennessee Experimental Farm in Blount County, Tennessee on a well-drained upland soil on a slope of 5 percent gradient. The rotations were initiated in each of three consecutive years on three adjacent ranges with corn followed by wheat and red clover. The three initial seedbed preparations for corn consisted of (1) ordinary turning, (2) subsoiling followed by ordinary turning and (3) subsoiling followed by heavy duty disking. The rotations were continued for two cycles on the same areas without re-subsoiling. The general nutrient level and the organic matter content of the soil were determined initially and the moisture content was determined periodically. Grain and hay yields were obtained.

The soil on which the experiment was conducted was classified as Dewey silt loam. The soils of the Dewey series are developed over high grade limestone with some insoluble silica impurities. The surface soil is a brown to grayish-brown friable silt loam. The subsoil is a yellowish-red moderately friable heavy silty clay loam grading into a firm moderately plastic silty clay at a depth of about sixteen inches.

Bulk and core soil samples from the area were analyzed. The results are presented in Table I.

The experiment, consisting of three treatments, was laid out in a randomized block design with four replications. The size of each plot was fifteen by sixty feet or 1/48.4 acre, each plot consisting of seventeen rows forty-two inches apart and fifteen feet long.

Two plots in each of the four blocks were subsoiled eighteen inches deep during the normally dry fall period in October or November with the furrows eighteen inches apart. The remaining plot in each block was turned seven inches deep in December. One subsoiled plot in each block was turned 7 inches deep on the same date. The other subsoiled plot in each block was disked with a heavy-duty plowing harrow to a depth of about 5 inches.

During the following April, all plots were prepared for corn in a uniform manner by disking and harrowing. All plots were fertilized uniformly with eight hundred pounds of 6-12-12 fertilizer per acre with five hundred pounds broadcast and three hundred pounds banded under the row.

Corn was planted on April 22 at the rate of one kernel every seven to eight inches. Dixie 17 was the variety used. Approximately three weeks after planting, all plots were thinned to one plant every fifteen inches or twelve plants per fifteen feet of row, making a stand equivalent to 10,000 plants per acre. The corn was cultivated three times during the growing season. The crop was harvested on October 24. Field weights of ear corn were recorded and later converted to bushels of shelled corn per acre on a 15.5 percent moisture basis.

The corn stalks were cut and a seedbed was prepared by disking all plots. Thorne wheat was seeded on all plots on October 26 at the rate of one and one-fourth bushels per acre. Four hundred pounds of 4-12-4 fertilizer per acre was applied.

Kenland red clover was seeded on the wheat in the following March by the means of a cultipacker-seeder.

The wheat was harvested on June 22 and grain yields recorded. Red clover hay was harvested on the following July 30 and during the next year on May 27 and July 7.

During the succeeding three years, the rotations were repeated on the same plots, using as nearly the same cultural practices as possible except that subsoiling was not repeated.

The procedure outlined above was repeated on three adjacent ranges. The rotations were started on three consecutive years.

TABLE I

PHYSICAL CHARACTERISTICS OF THE DEWEY SILT LOAM SOIL ON WHICH THE SUBSOILING EXPERIMENT WAS CONDUCTED

	Surface Soil 0-8 inches	Subsoil 8-18 inches
Textural Separations (percent by weight)		
sand	11.7	5.4
silt	76.1	65.7
clay	12.2	28.9
Organic Matter (percent by weight)	1.8	0.4
Pore Space (percent by volume)		
large	18.2	16.3
small	33.2	35.1
total	51.4	51.4
Specific Gravity	2.9	3.0
Bulk Density	1.4	1.5

CHAPTER IV

RESULTS

Yields

Yield data are summarized in Tables II, III, and IV. These data were subjected to analysis by methods outlined by Cochran and Cox (5).

Corn

The subsoiled and turned plots gave the highest average yield of corn in two of three years immediately following subsoiling. There was, however, no significant yield increase at the .05 level for subsoiling in addition to turning over turning only in any of the three years. The subsoiled and turned plots showed a significant yield increase over the subsoiled and disked plots in one of the three years. There was no significant yield difference between the plots turned only and those subsoiled and disked in any of the three years immediately following subsoiling.

Corn yields in the fourth year after subsoiling showed less difference between treatments than in the year immediately following subsoiling. The subsoiled and disked plots yielded significantly less at the .05 level than the turned only and the subsoiled and turned plots in one of the three years. The subsoiled and disked plots gave slightly higher average yields than the two other treatments in two of the three years in the second cycle of the rotation.

Wheat

There were no significant differences in wheat yields at the .05 level in the first cycle of the rotation, when wheat was seeded one year after subsoiling. The differences in yields were so small that it would be difficult to arrange a replicated set of plots with uniform treatment for all plots and get more uniform results.

In the second cycle of the rotation, when wheat was seeded four years after subsoiling, the subsoiled and disked plots gave a significantly lower yield at the .05 level than the plots which were turned only in one of the three years. With this one exception, the yields in the second cycle were equally as uniform as in the first cycle of the rotation.

Red Clover

There were no significant differences in red clover hay yields at the .05 level between any of the three initial tillage treatments.

The great difference in yields between years is due to the amount and distribution of rainfall and the fact that a second cutting of hay was produced in the seasons having adequate rainfall in midsummer.

Moisture Content of the Soil

Soil moisture data are summarized in Tables V and VI. These data were also subjected to analysis by methods outlined by Cochran and Cox (5).

The moisture content of the soil at the date corn was planted, as presented in Table V, did not vary significantly among the three methods of initial seedbed preparation in any of the three years in either the surface or the subsoil. Even though the differences in moisture content are statistically insignificant, it should be pointed out that the plots which were subsoiled and turned had the highest average moisture content in the surface soil in each of the three years. This same trend did not exist in the moisture content of the subsoil.

There were no significant differences in the moisture content of the soil at the earing stage of corn among the three methods of tillage in either the surface soil or the subsoil.

Organic Matter Content of the Soil

Soil organic matter data are summarized in Table VII. These data were subjected to analysis by methods outlined by Cochran and Cox (5).

Analysis of the organic matter content of soil samples taken at the date of the initial subsoiling shows that significant differences did not exist among plots used for this experiment. There was no significant difference in the organic matter content of either the surface six inches or the subsoil among any of the treatments after two cycles of the three-year crop rotation, or six years after the initial subsoiling was done. The difference between the organic matter content of both the surface and subsoil at the initial compared to the final sampling is very small. Also, the difference among ranges is no greater than among replicated sets of plots within the ranges. The only consistent difference in these data is the slightly less organic matter in the subsoil at the final as compared with the original sampling.

TABLE II

YIELD OF CORN[a] IN BUSHELS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Treatment	First Cycle of Rotation				Second Cycle of Rotation			
	1950	1951	1952	Av.	1953	1954	1955	Av.
Turned only	93.1[b]	72.8	22.7	62.9	83.2	59.0	85.3	75.8
Subsoiled and turned	100.0	75.4	24.8	66.7	79.9	60.7	84.2	74.9
Subsoiled and disked	87.0	69.4	26.7	61.0	85.5	52.9	86.6	75.0
L.S.D. .05	11.5	N.S.	N.S.		N.S.	5.1	N.S.	

[a] Grain yields are based on 15.5 percent moisture.

[b] Figures represent an average of four replications.

TABLE III

YIELD OF WHEAT IN BUSHELS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Treatment	First Cycle of Rotation				Second Cycle of Rotation			
	1951	1952	1953	Av.	1954	1955	1956	Av.
Turned only	22.6[a]	24.0	46.4	31.0	39.8	36.6	47.9	41.6
Subsoiled and turned	24.0	27.6	43.8	31.8	38.6	37.3	44.0	40.1
Subsoiled and disked	24.0	25.8	44.8	31.5	37.7	38.4	42.2	39.5
L.S.D. .05	N.S.	N.S.	N.S.		N.S.	N.S.	5.7	

[a] Figures represent an average of four replications.

TABLE IV

YIELD OF RED CLOVER HAY[a] IN TONS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Treatment	First Cycle of Rotation				Second Cycle of Rotation			
	1952	1953	1954[b]	Av.	1955	1956[b]	1957	Av.
Turned only	0.90[c]	0.12	1.30	0.77	0.80	1.57	d	1.19
Subsoiled and turned	0.88	0.13	1.22	0.74	0.74	1.50		1.12
Subsoiled and disked	0.93	0.15	1.21	0.76	0.75	1.44		1.10
L.S.D. .05	N.S.	N.S.	N.S.		N.S.	N.S.		

[a] Hay yields are based on air-dry forage.

[b] Yields represent combined total of two cuttings.

[c] Figures represent an average of four replications.

[d] 1957 crop not harvested because of poor stands due to adverse conditions at time of seeding.

TABLE V

MOISTURE CONTENT[a] OF THE SOIL AT PLANTING DATE OF CORN AFTER THREE METHODS OF INITIAL SEEDBED PREPARATION

Treatment	1948		1950		1951		Average	
	Surface 0-6 Inches	Subsoil 11-15 Inches	Surface 0-6 Inches	Subsoil 11-15 Inches	Surface 0-6 Inches	Subsoil 11-15 Inches	Surface 0-6 Inches	Subsoil 11-15 Inches
Turned only	16.1[b]	19.4[b]	14.7[c]	18.7[c]	18.8[c]	19.0[c]	16.5	19.0
Subsoiled and turned	17.6	20.7	15.2	17.1	19.6	19.7	17.5	19.2
Subsoiled and disked	16.3	20.5	13.9	17.1	18.7	20.5	16.3	19.4
L.S.D. .05	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.		

[a] Figures represent parts per one hundred by weight.

[b] Figures represent an average of three replications.

[c] Figures represent an average of four replications.

TABLE VI

MOISTURE CONTENT[a] OF THE SOIL AT THE EARING STAGE OF CORN AFTER THREE METHODS OF INITIAL SEEDBED PREPARATION

Treatment	1948		1954		Average	
	Surface 0-6 Inches	Subsoil 11-15 Inches	Surface 0-6 Inches	Subsoil 11-15 Inches	Surface 0-6 Inches	Subsoil 11-15 Inches
Turned only	8.6[b]	11.9[b]	6.5[c]	10.9[c]	7.6	11.4
Subsoiled and turned	9.4	12.1	6.3	12.3	7.8	12.2
Subsoiled and disked	9.4	12.8	5.8	12.5	7.6	12.6
L.S.D. .05	N.S.	N.S.	N.S.	N.S.		

[a] Figures represent parts per one hundred by weight.

[b] Figures represent an average of three replications.

[c] Figures represent an average of four replications.

TABLE VII

ORGANIC MATTER CONTENT[a] OF THE SURFACE AND SUBSOIL AT THE DATE OF SUBSOILING AND AFTER TWO CROP ROTATIONS

	Range II				Range III			
	Surface 0 to 6 Inches		Subsoil 11 to 15 Inches		Surface 0 to 6 Inches		Subsoil 11 to 15 Inches	
	At Date of Subsoiling	After Two Rotations	At Date of Subsoiling	After Two Rotations	At Date of Subsoiling	After Two Rotations	At Date of Subsoiling	After Two Rotations
Turned only	1.81[b]	2.37	0.79	0.58	2.13	2.02	0.62	0.48
Subsoiled and turned	2.06	2.36	0.75	0.64	1.98	2.01	0.51	0.48
Subsoiled and disked	2.20	2.35	0.95	0.58	2.14	2.00	0.63	0.49
L.S.D. .05	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

[a] Figures represent parts per one hundred by weight.

[b] Figures represent an average of four replications.

CHAPTER V

DISCUSSION OF RESULTS

Crop Yields

Only three significant differences in corn yield were recorded during the entire experiment. Two of these were between the subsoiled and turned and the subsoiled and disked plots with the former treatment giving the significantly higher yield in each year. One of these was in the first year after subsoiling; the other in the fourth year or second cycle of the rotation. Since the plots producing these significantly varying yields were both subsoiled, these differences are of little importance in the major objective of the experiment; the only difference in the two treatments being the method of surface tillage. Subsoiling in addition to turning never gave a significantly higher corn yield than turning only. The subsoiled and turned plots gave slightly higher average corn yields than those which were turned only in each of the three years in which corn was grown immediately following subsoiling. Since this trend is not evident in the second cycle of the rotation it should be assumed that if these small differences were a result of subsoiling, the effects were very temporary. These small yield differences of less than four bushels of corn per acre would scarcely pay for the extra tillage operation under the existing price of corn and costs of machine operation.

The plots which were subsoiled and disked gave a significantly lower corn yield than those which were turned only in one of the six years; that being in the second cycle of the rotation. The former treatment gave slightly, but insignificantly higher yields of corn in two of the three years in which corn was grown immediately following subsoiling. These yields indicate subsoiling and disking is not a satisfactory substitute for ordinary turning. Neither subsoiling nor heavy duty disking (bush and bogging) is a less expensive operation than ordinary turning.

None of the three treatments produced wheat yields which were significantly different from those of either of the other two treatments in the same year in the first cycle of the rotation. The plots which were turned only for the preceding crop of corn averaged slightly lower yields of wheat in two of the first three years, but gave a slightly higher yield in the third year than the other treatments. In the second cycle of the rotation the plots which were turned only produced higher average wheat yields than the other two treatments in two of the three years, but in only one year was the difference significant. The subsoiled and disked plots produced a slightly higher average yield of wheat in the second year of the last cycle of the rotation. These small differences are so erratic that they in no way support the single significant difference in wheat yields recorded.

There were no significant differences in yields of red clover hay in any of the five years for which data were recorded. The plots which were turned only for the initial crop of corn produced a slightly higher yield of red clover hay in three of the five years, with the subsoiled and disked plots producing slightly higher yields in the other two years.

Moisture Content of the Soil

There was no significant difference in the moisture content of either the surface soil or subsoil between any two of the three treatments in the spring following the initial seedbed preparations in any of the three years. If the plots which were subsoiled had more rapid infiltration of rainfall or greater moisture holding capacity, the resulting differences in moisture content had dissipated before the soil became sufficiently dry to permit surface tillage operations. If these findings are correct, soil moisture differences should not be expected to exist during moisture stress periods in the corn growing season. Soil samples taken at the earing stage of corn showed no significant differences in the moisture content of either the surface soil or the subsoil between any two of the three treatments.

Organic Matter Content of the Soil

If loosening the soil to a depth greater than the usual depth of plowing encourages greater root penetration, evidence of such should be seen in the organic matter content of the subsoil. The average organic matter content of soil samples taken from two of the three ranges after two cycles of the rotation had been completed did not differ significantly between any two of the three treatments in either the surface soil or the subsoil. The average organic matter content of the subsoil of the plots in each treatment was less at the end of the two rotations than at the date of the initial subsoiling. The reverse was true of the surface soil in four of six analyses.

CHAPTER VI

SUMMARY

Subsoiling in addition to ordinary turning, and subsoiling and disking were compared with ordinary turning as a means of initial seedbed preparation for corn. The effects on yields of corn, wheat and red clover and on the moisture and organic matter content of the soil were determined. The crops were grown in a three-year rotation on each of three ranges. The rotation was repeated on each range to determine the longevity of effects of the initial subsoiling.

Subsoiling in addition to ordinary turning produced small, but not significant increases in corn yield over ordinary turning.

The differences in corn yield were not sufficient to justify the expense of the extra tillage operation

Subsoiling and disking is not a satisfactory substitute for ordinary turning in preparation of a seedbed for corn.

Subsoiling in preparation of a seedbed for corn did not significantly affect the yield of succeeding crops of wheat and red clover.

Subsoiling in preparation of a seedbed for corn did not significantly affect the moisture content of the surface soil nor the subsoil at the planting time or at the earing stage of corn.

Subsoiling in preparation of a seedbed for corn did not significantly affect the organic matter content of the surface soil nor the subsoil after two cycles of a rotation of corn, wheat and red clover.

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LITERATURE CITED

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APPENDIX

APPENDIX A

YIELD OF CORN[a] IN BUSHELS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range I

First cycle of rotation 1950

Treatments	Replications				Average
	1	2	3	4	
Turned only	82.2	96.4	103.2	90.4	93.1
Subsoiled and turned	94.8	97.4	107.5	100.1	100.0
Subsoiled and disked	96.2	96.4	69.8	85.7	87.0

C.V. 11.9% L.S.D. (.05) 11.5 bu.

Second cycle of rotation 1953

Treatments	Replications				Average
	1	2	3	4	
Turned only	97.6	83.8	74.0	77.3	83.2
Subsoiled and turned	88.4	78.6	70.7	81.9	79.9
Subsoiled and disked	92.4	84.5	74.0	91.0	85.5

C.V. 5.0%

[a] Yield based on 15.5 percent moisture.

APPENDIX B

YIELD OF CORN[a] IN BUSHELS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range II

First cycle of rotation 1951

Treatments	Replications				Average
	1	2	3	4	
Turned only	65.3	78.7	70.7	76.6	72.8
Subsoiled and turned	75.6	85.3	74.8	65.7	75.4
Subsoiled and disked	83.2	71.5	67.2	55.8	69.4

C.V. 11.6% N.S.

Second cycle of rotation 1954

Treatments	Replications				Average
	1	2	3	4	
Turned only	63.1	58.7	55.4	58.6	59.0
Subsoiled and turned	64.1	61.3	61.5	55.8	60.7
Subsoiled and disked	53.2	53.0	57.3	48.2	52.9

C.V. 5.0% L.S.D. (.05) 5.1 bu.

[a] Yield based on 15.5 percent moisture.

APPENDIX C

YIELD OF CORN[a] IN BUSHELS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range III

First cycle of rotation 1952

Treatments	Replications				Average
	1	2	3	4	
Turned only	13.6	27.4	24.0	25.6	22.7
Subsoiled and turned	14.5	23.9	30.6	30.2	24.8
Subsoiled and disked	19.3	24.0	30.0	33.4	26.7

C.V. 11.7% N.S.

Second cycle of rotation 1955

Treatments	Replications				Average
	1	2	3	4	
Turned only	67.2	92.7	88.9	92.5	85.3
Subsoiled and turned	64.6	88.4	93.9	89.8	84.2
Subsoiled and disked	79.3	81.8	92.6	92.6	86.6

C.V. 6.6% N.S.

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[a] Yield based on 15.5 percent moisture.

APPENDIX D

YIELD OF WHEAT IN BUSHELS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range I

First cycle of rotation 1951

Treatments	Replications				Average
	1	2	3	4	
Turned only	27.2	16.5	22.6	24.0	22.6
Subsoiled and turned	25.4	24.2	22.4	23.8	24.0
Subsoiled and disked	23.2	27.0	21.8	24.0	24.0

C.V. 13.7% N.S.

Second cycle of rotation 1954

Treatments	Replications				Average
	1	2	3	4	
Turned only	43.3	40.4	34.9	40.4	39.8
Subsoiled and turned	37.6	37.8	40.6	38.4	38.6
Subsoiled and disked	41.2	36.2	39.4	34.0	37.7

C.V. 7.8% N.S.

APPENDIX E

YIELD OF WHEAT IN BUSHELS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range II

First cycle of rotation 1952

Treatments	Replications				Average
	1	2	3	4	
Turned only	24.0	23.7	26.7	21.5	24.0
Subsoiled and turned	28.0	26.8	30.4	25.1	27.6
Subsoiled and disked	30.5	27.8	25.4	19.5	25.8

C.V. 9.3% N.S.

Second cycle of rotation 1955

Treatments	Replications				Average
	1	2	3	4	
Turned only	38.1	38.9	34.5	35.0	36.6
Subsoiled and turned	41.4	34.5	41.1	32.5	37.3
Subsoiled and disked	38.6	39.8	39.8	35.2	38.4

C.V. 7.2% N.S.

APPENDIX F

YIELD OF WHEAT IN BUSHELS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range III

First cycle of rotation 1953

Treatments	Replications				Average
	1	2	3	4	
Turned only	48.5	45.6	46.2	45.3	46.4
Subsoiled and turned	42.0	49.8	41.9	41.6	43.8
Subsoiled and disked	48.6	44.5	41.9	44.3	44.8

C.V. 6.4% N.S.

Second cycle of rotation 1956

Treatments	Replications				Average
	1	2	3	4	
Turned only	51.5	45.6	47.3	47.3	47.9
Subsoiled and turned	46.3	42.6	42.9	44.0	44.0
Subsoiled and disked	40.9	44.1	47.2	36.5	42.2

C.V. 7.2% L.S.D. (.05) 5.7 bu.

APPENDIX G

YIELD OF RED CLOVER HAY IN TONS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range I

First cycle of rotation 1952

Treatments	Replications				Average[a]
	1	2	3	4	
Turned only	1.32	0.82	0.75	0.70	0.90
Subsoiled and turned	1.15	0.82	0.84	0.69	0.88
Subsoiled and disked	1.19	1.00	0.74	0.77	0.93

C.V. 8.9% N.S.

[a] Yield based on two cuttings

Second cycle of rotation 1955

Treatments	Replications				Average
	1	2	3	4	
Turned only	1.33	0.65	0.64	0.58	0.80
Subsoiled and turned	0.95	0.72	0.75	0.54	0.74
Subsoiled and disked	0.83	0.71	0.63	0.83	0.75

C.V. 22.4% N.S.

APPENDIX H

YIELD OF RED CLOVER HAY IN TONS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range II

First cycle of rotation 1953

Treatments	Replications 1	2	3	4	Average
Turned only	0.17	0.14	0.08	0.10	0.12
Subsoiled and turned	0.14	0.17	0.08	0.11	0.13
Subsoiled and disked	0.17	0.22	0.11	0.08	0.15

C.V. 15.4% N.S.

Second cycle of rotation 1956

Treatments	Replications 1	2	3	4	Average[a]
Turned only	3.62	3.47	2.74	2.76	3.15
Subsoiled and turned	3.55	3.22	2.84	2.38	3.00
Subsoiled and disked	3.03	3.29	3.06	2.10	2.87

C.V. 8.0% N.S.

[a] Yield based on two cuttings

APPENDIX I

YIELD OF RED CLOVER HAY IN TONS PER ACRE FOLLOWING THREE METHODS OF INITIAL SEEDBED PREPARATION

Range III

First cycle of rotation 1954

Treatments	Replications 1	2	3	4	Average[a]
Turned only	1.11	1.42	1.31	1.37	1.30
Subsoiled and turned	0.97	1.33	1.43	1.16	1.22
Subsoiled and disked	1.12	1.22	1.50	0.99	1.21

C.V. 10.5%   N.S.

[a] Yield based on two cuttings

1957 crop not harvested because of poor stand due to adverse conditions at time of seeding.

APPENDIX J

MOISTURE CONTENT OF THE SOIL AT THE PLANTING DATE OF CORN

Range X 1948

Surface soil

Treatments	Replications			Average[a]
	1	2	3	
Turned only	14.9	16.3	17.0	16.1
Subsoiled and turned	17.6	17.0	18.3	17.6
Subsoiled and disked	15.9	17.6	15.3	16.3

C.V. 6.0%   N.S.

Subsoil

Treatments	Replications			Average[a]
	1	2	3	
Turned only	20.8	19.0	18.3	19.4
Subsoiled and turned	21.2	19.8	21.2	20.7
Subsoiled and disked	19.8	22.0	19.8	20.5

C.V. 6.4%   N.S.

[a] Average yields based on three replications.

APPENDIX K

MOISTURE CONTENT OF THE SOIL AT THE PLANTING DATE OF CORN

Range I 1950

Surface soil

Treatments	Replications				Average
	1	2	3	4	
Turned only	17.5	16.1	14.4	10.7	14.7
Subsoiled and turned	14.7	15.3	17.0	13.6	15.2
Subsoiled and disked	15.5	9.9	14.6	15.4	13.9

C.V. 17.1% N.S.

Subsoil

Treatments	Replications				Average
	1	2	3	4	
Turned only	18.6	18.5	20.9	16.8	18.7
Subsoiled and turned	17.3	18.8	14.7	17.7	17.1
Subsoiled and disked	16.6	17.7	16.9	17.3	17.1

C.V. 9.0% N.S.

APPENDIX L

MOISTURE CONTENT OF THE SOIL AT THE PLANTING DATE OF CORN

Range II 1951

Surface soil

Treatments	Replications 1	2	3	4	Average
Turned only	17.0	20.0	20.3	17.9	18.8
Subsoiled and turned	17.0	20.2	20.3	20.8	19.6
Subsoiled and disked	17.6	20.9	20.9	18.7	18.7

C.V. 5.8% N.S.

Subsoil

Treatments	Replications 1	2	3	4	Average
Turned only	19.9	18.7	20.1	17.2	19.0
Subsoiled and turned	20.2	19.8	18.0	20.7	19.7
Subsoiled and disked	20.1	20.6	19.1	22.2	20.5

C.V. 7.1% N.S.

APPENDIX M

MOISTURE CONTENT OF THE SOIL AT THE EARING STAGE OF CORN

Range X 1948

Surface soil

Treatments	Replications 1	2	3	Average[a]
Turned only	10.1	10.5	5.1	8.6
Subsoiled and turned	10.2	8.3	9.7	9.4
Subsoiled and disked	11.6	9.6	7.0	9.4

C.V. 19.8% N.S.

Subsoil

Treatments	Replications 1	2	3	Average[a]
Turned only	13.5	10.8	11.5	11.9
Subsoiled and turned	13.8	11.2	11.2	12.1
Subsoiled and disked	13.8	14.1	10.4	12.8

C.V. 9.8% N.S.

[a] Average yields based on three replications.

APPENDIX N

MOISTURE CONTENT OF THE SOIL AT THE EARING STAGE OF CORN

Range II 1954

Surface soil

Treatments	Replications 1	2	3	4	Average
Turned only	6.1	5.9	7.6	6.3	6.5
Subsoiled and turned	6.2	5.5	6.6	6.7	6.3
Subsoiled and disked	4.2	5.6	6.6	6.7	5.8

C.V. 10.1% N.S.

Subsoil

Treatments	Replications 1	2	3	4	Average
Turned only	7.3	12.6	11.5	12.1	10.9
Subsoiled and turned	11.4	11.9	12.0	13.9	12.3
Subsoiled and disked	9.0	12.9	12.6	15.5	12.5

C.V. 10.2% N.S.

APPENDIX O

ORGANIC MATTER CONTENT OF THE SURFACE SOIL OF RANGE II

At the date of subsoiling 1950

Treatments	Replications				Average
	1	2	3	4	
Turned only	2.00	1.75	1.44	2.04	1.81
Subsoiled and turned	1.97	2.07	2.21	1.97	2.06
Subsoiled and disked	1.93	2.04	2.81	2.00	2.20

C.V. 16.8% N.S.

After two cycles of the rotation 1957

Treatments	Replications				Average
	1	2	3	4	
Turned only	2.28	2.42	2.35	2.42	2.37
Subsoiled and turned	2.21	2.45	2.55	2.24	2.36
Subsoiled and disked	2.28	2.48	2.38	2.24	2.35

C.V. 3.8% N.S.

APPENDIX P

ORGANIC MATTER CONTENT OF THE SUBSOIL OF RANGE II

At the date of subsoiling 1950

Treatments	Replications 1	2	3	4	Average
Turned only	0.66	0.59	0.77	1.12	0.79
Subsoiled and turned	0.94	0.52	0.80	0.73	0.75
Subsoiled and disked	1.05	0.87	0.80	1.80	0.95

C.V. 18.1%   N.S.

After two cycles of the rotation 1957

Treatments	Replications 1	2	3	4	Average
Turned only	0.55	0.58	0.55	0.65	0.58
Subsoiled and turned	0.55	0.88	0.61	0.51	0.64
Subsoiled and disked	0.55	0.58	0.58	0.61	0.58

C.V. 17.2%   N.S.

APPENDIX Q

ORGANIC MATTER CONTENT OF THE SURFACE SOIL OF RANGE III

At the date of subsoiling 1952

Treatments	Replications 1	2	3	4	Average
Turned only	1.79	2.06	1.66	2.99	2.13
Subsoiled and turned	1.97	1.97	1.99	1.97	1.98
Subsoiled and disked	2.27	1.86	2.23	2.18	2.14

C.V. 17.3% N.S.

After two cycles of the rotation 1957

Treatments	Replications 1	2	3	4	Average
Turned only	1.86	2.20	1.96	2.06	2.02
Subsoiled and turned	1.96	2.10	2.06	1.93	2.01
Subsoiled and disked	2.03	2.03	1.96	1.99	2.00

C.V. 4.0% N.S.

APPENDIX R

ORGANIC MATTER CONTENT OF THE SUBSOIL OF RANGE III

At the date of subsoiling 1952

	Replications				
Treatments	1	2	3	4	Average
Turned only	0.28	0.76	0.97	0.46	0.62
Subsoiled and turned	0.50	0.51	0.37	0.64	0.51
Subsoiled and disked	0.53	0.71	0.48	0.81	0.63

C.V. 37.3% N.S.

After two cycles of the rotation 1957

	Replications				
Treatments	1	2	3	4	Average
Turned only	0.37	0.57	0.51	0.48	0.48
Subsoiled and turned	0.44	0.48	0.54	0.48	0.49
Subsoiled and disked	0.51	0.37	0.54	0.54	0.49

C.V. 15.1% N.S.