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Contents

Minimum Tillage for Growing Corn

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Minimum tillage refers to any method that reduces the number of conventional operations involved in growing corn. Most of these "short cuts" center around seedbed preparations, but some also influence the number of required cultivations later in the growing season.

Minimum tillage methods can be grouped into four systems:

1. Wheel track planting
2. Hard ground listing
3. Plow plant
4. Strip processing

Other methods presently used are combinations or variations of the four listed above. An example of a minor variation is mulch planting. This is a form of strip processing where a mulch is retained on the soil surface. Examples of more extensive variations are the "Buffalo Till Planter" and "Bush Hog Varetiller Planter" which are built commercially and have a basic structure similar to the lister.

Rotary tilling does not fit into the above grouping. This is a "once over" but not necessarily a minimum tillage method, because soil is quite thoroughly tilled.

Some minimum tillage methods are old and some are new. Older methods discredited or discarded years ago now hold promise when combined with new selective weed killers and commercial fertilizers.

Each minimum tillage method has its own merits, its own problems, and its own limitations. Fortunately, most of these problems and limitations can be overcome.

WHY USE MINIMUM TILLAGE?

Reduces Operating Costs

Minimum tillage is a practical way to reduce corn planting costs. The dollar and cents reduction in operating costs (figure 1) is one of the most important reasons for using this practice.

Costs per acre were determined for 1963 on a custom rate basis which included labor costs. Custom rates were compiled from a South Dakota survey* and local commer-

*Helfenstine, R. and Eno, W. Custom Rates Paid by South Dakota Farmers in 1962. South Dakota State College Extension Fact Sheet 188, 1962.

cial operators. The following values per acre were used in calculating costs: plowing, $3.50; disking (tandem), $1.50; dragging, $.60; planting, $1; hard ground listing, $3; strip processing, $3; and plow plant, $4.50.

Operating costs will not be the same for every farm or every locality. They depend on which minimum tillage method is used, the number of times a farmer normally goes over his field with conventional methods, and the number of acres planted. For example, the operator of a large farm will usually have lower per acre costs for each tillage operation because his depreciation costs are spread over a greater number of acres. Savings up to $10 per acre* have been reported. Savings of $6 to $8 per acre in favor of minimum tillage methods are more common. These figures include savings in land fitting, planting, and cultivation costs.

Figure 1 shows a $4.20 saving per acre in land fitting and planting costs for certain minimum tillage methods. These figures are conservative but realistic for local

*Musgrave, R. B. *et al.*, Plow Planting of Corn. Ag. Eng. 36:593-594. September, 1955.

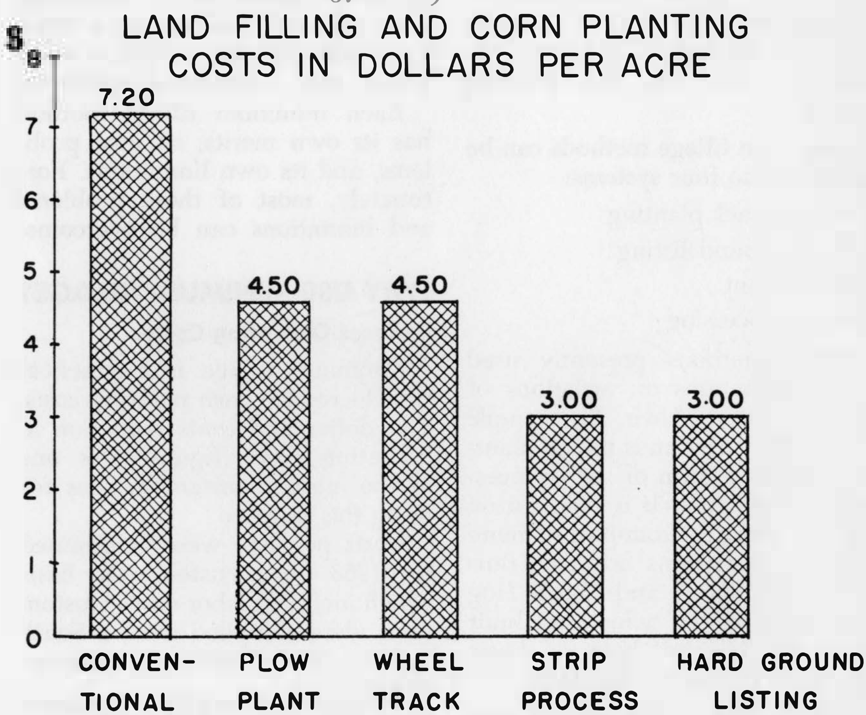


Figure 1. Effect of minimum tillage systems on cost per acre for planting corn.

conditions. No estimate of savings was made for weed control costs in the period after planting because weed control problems varied so much between locations. Greatest opportunities for reducing expenses are in land fitting operations.

Conventional seedbed preparation and planting costs for 40-bushel-per-acre corn and 100 bushel-per-acre corn are about the same. At 40 bushels per acre, fixed costs are a much higher percentage of gross return than at 100 bushels per acre. A savings of $4 per acre with 40-bushel corn is 10%; with 100-bushel corn it would be only 4%.

In the western fringe of the corn belt, the expected yield is 35 to 40 bushels per acre. In this area the average farm size is expanding rapidly and emphasis is often placed on bushels of corn per farmer rather than bushels of corn per acre. Under these conditions a saving of $3 to $4 per acre represents a special opportunity for more efficient corn production, if comparable yields can be maintained. (See tables 5, 6, 7, 8).

Saves Time

Plowing is the most time-consuming operation in seedbed preparation. Approximately 2 million pounds of soil are moved in every acre plowed. Minimum tillage methods such as strip processing and hard ground listing that can be used without plowing are much faster because only a fraction of the 2 million pounds of soil is moved or thoroughly tilled.

Every minimum tillage method saves at least one trip over the field; some methods save several trips. This saving in time can be very important for some farmers. Since the optimum corn planting season is about 2 weeks, the time saved by eliminating unnecessary seedbed tillage can be critical. This becomes more important in years with above average spring rainfall.

In addition to the time saved in land fitting and planting operations, additional time can be saved with some minimum tillage methods by increasing cultivation speed. Height of corn is one of the factors determining speed of travel. With wheel track planting and pre-emergence band spray for weeds, the first cultivation can be done rapidly because weeds seldom emerge until corn is 6 to 10 inches tall. At this stage there is little danger of covering corn by cultivating at high speed.

Affects Soil Moisture

In 1959 soil moisture samples were taken to a depth of 5 feet from a minimum tillage experiment in Brookings County. Soil type on the experimental site was Vienna loam. The preceding crop was oats. Available soil water is shown in table 1.

Soil moisture measurements were made on July 1 because minimum tillage treatments required the first cultivation on this date. After the first cultivation, variation in roughness of seedbed of most treatments was less and the expected difference in infiltration would be less. There was an interval of 34

Table 1. Effect of Method of Planting Corn on Available Water in 5-Foot Profile, Brookings County, July 1, 1959.

Planting Method	Inches of Available Water
Conventional	1.8
Strip processed with straw mulch on surface	1.4
Hard ground listed	1.6
Wheel track	2.2

days between planting and soil sampling in which different tillage methods could influence water stored in soil. Since only 2 inches of rain fell in this period, there were only minor differences in soil water due to tillage treatments. The small differences that were found could be attributed largely to weed growth. Strip processed and hard ground listed plots had more weeds and less moisture. Wheel track plots had remarkably few weeds in the loose plowing between corn rows. These plots also had the most water on July 1.

The soil at this location was medium in texture, high in organic matter, excellent in structure, and on nearly level topography. All of these soil characteristics are favorable for rapid water infiltration.

Research in Indiana, Ohio, and Wisconsin indicates that minimum tillage can increase water infiltration especially on sloping terrain. With heavy, slowly permeable soils on steeper slopes, the rough seedbed associated with minimum tillage methods would be expected to reduce run-off, especially if the tillage followed contour lines.

Table 2 shows available water in a 5-foot profile of a Kranzburg silt loam on nearly level topography at the Southeast Research Farm near Centerville.

Between planting date, May 2, and first sampling date, May 16, 1.91 inches of rain fell. Rainfall between May 16 and July 15 totaled 5.6 inches and between July 15 and Aug. 23, 3.49 inches.

On the first sampling date, slightly more available soil water was present in minimum tillage plots than conventionally tilled plots.

By July 15, mulched plots contained more water than the other two treatments. Evidently the straw mulch was effective in reducing

Table 2. Effect of Method of Planting Corn on Available Water in 5-Foot Profile, Southeast Research Farm 1963.*

Planting Method	Inches of Available Water (average of 2 replications)		
	May 16	July 15	Aug. 23
Hard ground listing	9.5	5.0	1.7
Conventional planting fall plow	8.1	4.4	1.4
Strip processed with straw mulch on surface	9.0	6.9	1.1

*All three treatments were fertilized with 60 pounds of 18-46-0[3] starter (18-20.2-0 elemental basis) and 70 pounds of nitrogen per acre applied as a side dressing.

[3]18% N, 46% P_2O_5, 0% K_2O. To convert to elemental basis multiply percent P_2O_5 by 0.44 to get percent of P. Multiply percent K_2O by 0.83 to get percent of K.

Table 3. Effect of Corn Planting Method on Soil Bulk Density at Southeast Research Farm August 23, 1963.

	Bulk density of soil between corn rows		
Depth in inches	Hard ground listing	Conventional planting fall plow	Mulch planting
0-6	1.4	1.2	1.2
6-12	1.2	1.2	1.2
12-24	1.3	1.3	1.3

evaporation and run-off of the 5.6 inches of rain that fell during this period.

On August 23, mulched plots had slightly less water than the other two planting methods because only a small amount of straw remained on the soil surface to increase infiltration and because there were more weeds in mulched plots which used large quantities of moisture. Several combinations of shovels, disks, and sweeps were tried in the mulch plots to control weeds without covering the straw mulch. These methods were moderately successful.

Affects Soil Compaction

Bulk density can be used as an indication of a soil's compaction, oxygen availability, and mechanical impedance to plant roots.* Critical limits of bulk density have been estimated in order to evaluate tillage practices for corn. For the seedling environment zone, the upper bulk density limit was estimated to be 1.4 and the lower limit to be 1.0.* Bulk density samples were taken at the Southeast Research Farm in 1963. Soils from three different planting methods were sampled (table 3).

These samples were taken between rows on August 23, more than 3 months after planting. Bulk density of only the upper 6 inches of soil was affected by different tillage and planting procedures.

Bulk density was greatest in unplowed hard ground listed plots. Lister shovels did not loosen the soil or increase its pore space be-tween rows as much as the [illegible] board plow. Stubble m[illegible] were not plowed but their b[illegible] sities were about the same [illegible] of plowed plots. This may [illegible] to the 30-inches-wide sweeps used for cultivating mulched plots. These sweeps ran a little deeper in the soil than conventional cultivator shovels and apparently had a greater loosening effect.

Bulk density between corn rows in hard ground listed plots was at the maximum limit of the optimum range estimated for seedling environmental zone.* This may explain in part, why yields from hard ground listing occasionally fell below those from conventional method. In addition, it indicates why

*Larson, W. E. Soil Parameters for Evaluating Tillage Needs and Operations. Soil Science Soc. of Am. Proceedings Vol. 28, pp. 118-122. Jan.-Feb. 1964.

yields from minimum tillage methods that use the plow are more easily kept equal to or above those from conventional methods.

The following discussion points out the specific advantages and disadvantages of each minimum tillage method—wheel track planting, hard ground listing, plow plant, and strip processing. A discussion of roto tilling is also included.

WHEEL TRACK PLANTING

Wheel track planting is probably the most "foolproof" of the four minimum tillage systems because fewer problems are encountered and those are easily overcome. Planter shoes run in tracks made by packer or tractor wheels. Even though disking and harrowing can be eliminated, time and expense savings are smaller than with other minimum tillage methods.

Several commerical machines are available which eliminate one or more trips over the field. Some are to be used with plowing and some without plowing. Their performance has been very satisfactory when used in the soil environment they were build for. For those farmers who would like to use their existing machinery, machinery modification is discussed.

Wheel Track Planting

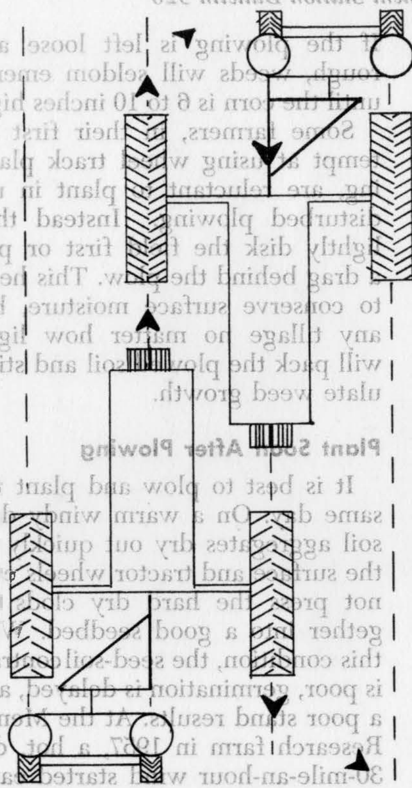


Figure 2. Use of a 2-row planter and tricycle tractor for wheel track planting.

Machinery Modification for Wheel Track Planting

For a 2-row planter and a utility type tractor (wide front end), the front and rear tractor wheels of some models can be set in enough to plant 40-inch rows. Tractor wheel spacing need not match exactly the spacing of corn planter wheels but it is desirable. Planter wheels can track 2 to 4 inches left or right of the tractor wheel track center with no serious trouble unless part of the planter wheel rides up on unpacked plowing. When tractor wheels are set in, the tractor is more easily tipped over.

For a 2-row planter and tricycle tractor, the planter hitch can be offset to the left so the left planter shoe goes in the left rear tire mark and the right shoe goes in the front tricycle tire mark (figure 2). On the return trip, the right rear tractor wheel will track in the row previously planted in the front tire tracks.

With a 4-row planter and utility tractor, set the two rear wheels close enough to make tracks for the two inside rows. The front tractor wheels can be extended to pack the 2 outside rows.

Another way is to bolt a second pair of wheels to the rear tractor wheels, use metal drums or pipes as spacers to keep the extra wheels at the proper distance.

Still another method is to offset the planter hitch to the right and adjust tractor wheels so they track for row 1 and 3 (figure 3). Then change the frame work on the planter so the carrying wheels track for rows 2 and 4. A packer wheel for each row could be mounted in front of the planter. Then the off-set hitch would not be necessary.

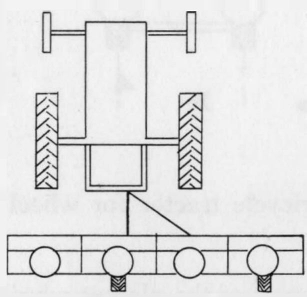


Figure 3. Use of a wide front end tractor and off-set hitch on a 4-row planter for wheel track planting.

No Extra Wheel Tracks

Corn planters with carrier wheels that make additional tracks to those in the row are not well suited for wheel track planting. The extra wheel tracks pack the soil and stimulate weed growth, nullifying the major advantages of the system. If the plowing is left loose and rough, weeds will seldom emerge until the corn is 6 to 10 inches high.

Some farmers, in their first attempt at using wheel track planting, are reluctant to plant in undisturbed plowing. Instead they lightly disk the field first or pull a drag behind the plow. This helps to conserve surface moisture, but any tillage no matter how light, will pack the plowed soil and stimulate weed growth.

Plant Soon After Plowing

It is best to plow and plant the same day. On a warm windy day, soil aggregates dry out quickly on the surface and tractor wheels cannot press the hard dry clods together into a good seedbed. With this condition, the seed-soilcontract is poor, germination is delayed, and a poor stand results. At the Menno Research farm in 1957, a hot, dry 30-mile-an-hour wind started early in the morning shortly after the plots were plowed. By evening the silty clay loam surface soil was so hard and cloddy that the tractor wheels could not press aggregates together to make a good seedbed. The optimum soil moisture content for wheel track planting is about the same as that for optimum plowing conditions.

By plowing and planting the same day, weeds will not have the opportunity to germinate ahead of the corn.

Wheel Track Planting and Weeds

Weeds are generally easier to control with wheel track planting than with other minimum tillage

methods. Corn may be 6 to 10 inches high before cultivation is needed between rows.

One weed problem associated with wheel track planting should be noted. Weeds are slow to germinate in the loose plowing between rows but quick to germinate in the packed wheel tracks in the corn row where they are more difficult to control. This calls for an early tillage to control weeds in the wheel track when there is no need for cultivation between rows.

Starter fertilizer placed in a band near the seed is not the answer to this problem because weed seeds in the wheel track are stimulated by fertilizer and grow about as fast as the corn. A spike tooth or flextine harrow used to kill early weeds in the row, packs the soil between rows and minimizes advantages of the system. Early tillage with a tractor mounted cultivator has the same effect. With cloddy soils and sites infested with quack grass, an early cultivation with a tractor cultivator is difficult because cloddy soil in rough plowing makes it unsuitable for rolling in small amounts of soil to cover weeds in the row without covering corn.

This objectionable feature was minimized in experimental plots by applying a pre-emergence weed spray in a band equal to the width of the wheel track. The spray controlled weeds in the row close to corn plants and eliminated the necessity for an early, slow cultivation. By applying spray in a band, costs were materially reduced and cultivation could be delayed until weeds began to emerge in plowing between rows.

When the soil was not previously infested with weeds and no spray used, corn planted with minimum tillage methods had fewer weeds than corn planted with conventional methods (table 4).

This location was unusually free of weeds from the beginning of the experiment in 1956 so no weed spray was used. Yellow and green fox tail were the predominant weeds present. Application of nitrogen usually increased amount of weed growth.

Table 4. Effect of Planting Methods on Weeds at Harvest, Menno Research Farm.

Pounds per acre*				Weeds reported in tons per acre at 15% moisture	
N	P	K	Method of planting	1958	1959
0	17.6	0	Conventional	0.22	0.75
60	17.6	0	Conventional	0.73	1.08
0	17.6	0	Wheel track	0.12	0.41
60	17.6	0	Wheel track	0.04	0.56
0	17.6	0	Hard ground listing	0.09	0.46
60	17.6	0	Hard ground listing	0.12	0.50

*Applied by broadcasting before plowing or listing.

Wheel Track Planting and Perennial Weeds

Three perennial weeds were encountered in minimum tillage experimental plots: field bindweed, Canada thistle, and quack grass. In fields infested with quack grass, wheel track planting combined with a pre-emergence band spray was fairly successful. Weedkillers used were Simazine 80 W and Atrazine 80 W at 3 pounds of material per acre actually covered by the spray. When applied in 13-inch bands on 40-inch rows, this amounts to 1 pound of material per acre of corn. Nozzles used were 8003E (TeeJet). The 80 refers to number of degrees in angle measuring spray width, the 03 to size of orifice in nozzle tip; E indicates an even flat spray pattern rather than oval or cone shape.

Plots were sprayed the first year by making a separate trip over the field with a spray rig after planting but driving in the corn planter tracks. After the first year, spraying equipment was mounted on the planter with the nozzles behind the packer wheels. Both systems gave satisfactory results, but the latter is preferred because of saving in time and expense.

When the planting season was dry, plowing gave quack grass a severe setback, and it was slow to recover in loose dry plowing between corn rows. The pre-emergence band spray applied over the rows effectively held quack grass in check in the wheel tracks. First cultivation was sometimes difficult because conventional shovels pushed clumps of quack grass sod to one side instead of breaking up the clods and pulling out quack grass roots. Narrow shovels without wings were more effective for penetration and pulling quack grass roots to the surface to dry out and die.

Canadian thistle and field bindweed were difficult to control. At the 3 pound rate of application, Simazine and Atrazine applied in a band had little or no effect on these weeds. The use of 2,4-D with drop nozzles and leaf lifters should give some measure of control.

Do a Good Job of Plowing

All weeds and organic matter should be well turned under. Deep plowing is desirable because plant residues will be buried more completely. If this is not carefully done, weeds and debris catch on planter shoes.

Adjust the plow so it will stay at a uniform depth. If it has a tendency to "pull out" and run shallow in hard dry areas or "scratch the surface" in solonetz spots, depth of seeding with wheel track planting will be variable. This leads to an uneven stand which makes it difficult to adjust the cultivator.

All plow bottoms should cut at uniform depths. If one bottom runs deep making a ridge in the turned furrow and the other shallow making a trough, it is difficult to adjust the cultivator to kill all weeds.

Wheel Track Planting and Corn Stands

Wheel track planting done properly gave good germination and excellent stands. If plowed soil was

allowed to dry before planting, poor stands resulted. Freshly plowed soil usually has enough moisture for rapid germination. Good seed-soil contact is necessary. To achieve this, additional weight on packer wheels will sometimes be neccessary to firm the seedbed over the row.

Soil Types Suited for Wheel Track Planting

Wheel track planting works well on a wide range of soil textural classes. Greatest benefits and yield increases would normally be expected on heavy wet soils where compaction and rate of moisture infiltration are serious problems. Soils high in silt appeared to withstand abuse from heavy machinery traffic better than those high in clay. Expected benefits from wheel track planting on silty loess soils would be less than on heavy wet alluvial soils.

With sandy soils, the large aggregates in rough plowing between wheel track planted rows are more resistant to wind erosion than the small aggregates which result from conventional methods where several trips are made over the field with disk and drag.

HARD GROUND LISTING

Hard ground listing refers to listing in unplowed ground. It is a true "once-over" planting method

Hard Ground Listing after Chopping Corn Stalks

because the seedbed is prepared and corn planted in one operation. It is a quick, easy, and inexpensive way to plant corn. The problems usually occur after the corn is planted.

Machinery

A rotary bottom lister with 15-inch saucer shaped disk moldboards was used in all experimental plots. Penetration was good and it worked well in wet sticky soils. It planted corn without trouble in a wide range of soil types and plant residues. More weight on the packer wheel would have been helpful under some conditions to insure good seed-soil contact.

Cultivation and Weed Problems

In eastern South Dakota experimental plots, weed control was the most serious problem associated with hard ground listing. This problem can be overcome, but it is a potential hazard on fields heavily infested with weeds. "Kill weeds before they emerge, when their roots are tender and white" is old but good advice and especially applicable to hard ground listing. If weeds get a good start in hard ground listed corn, they are usually more difficult to control than in conventionally planted corn.

In the experimental plots, grassy weeds were especially troublesome. In one plot, volunteer rye growing on top of ridges was quite a problem. Ridge-top weeds were usually difficult to control unless the field was disked before planting. With tap rooted weeds 2 or more inches in height at planting time, it was best to disk the seedbed before listing. If this was not done, the lister moldboards could not throw enough soil to cover weeds in the center of the ridges. If these ridge top weeds do get an early start, a spike tooth harrow will kill some of them, but if the weeds are too tall to cover with the lister, they are usually too well established to kill with a drag. A rotary hoe or lister cultivator set to throw soil away from the corn row for the first cultivation were not very effective. If the disks were set to split the ridges and throw soil toward the row, it would kill the weeds, but this cannot be done until the corn is several inches high or the corn would be covered. A front mounted cultivator with 12- to 14-inch sweeps running in the center of the ridges was successful for controlling these weeds. It was more difficult to keep sweeps in the ridge centers with a rear mounted cultivator. Weeds down in the trench were not so difficult to control, but a pre-emergence band spray was very helpful.

The second cultivation with a lister cultivator, when soil was thrown in toward the plant by breaking the center ridges, was sometimes troublesome in heavier soils. The disks penetrated satisfactorily, but the hard packed, unplowed soil in the ridges made it difficult to keep the disks running in the center of the ridge, to throw soil equally toward each corn row.

Rocky soils were objectionable because as the lister shovels slid around a rock so did the corn rows, making them crooked. When this

occurred, a section of the row was often close enough to an adjoining straight row to be cultivated out. In rocky fields, speed of planting must be reduced or equipment will be damaged.

Noxious weeds presented a special hazard. If quack grass was present, hard ground listing was not very successful without an effective pre-emergence weed spray. The reduced number of tillage operations offered little or no control of noxious weeds. There was an inverse relationship between the need for weed sprays and amount of tillage. With tillage held to a minimum, as with hard ground listing, there was a greater need for weed sprays to control weeds and maintain yields.

Getting a Stand

Several farmers and research workers have reported difficulties in obtaining good stands of corn with the lister. In some instances this is due to lack of compaction of the soil over the seed by the lister press wheels. With poor seed-soil contact, germination is slow and stands are uneven. A light rain is usually sufficient to firm up the seedbed and establish satisfactory seed-soil contact. A heavy rain may wash soil down from the ridges and bury small seedlings, or wash them out completely if lister furrows are up and down hill.

In the experimental trials on level land, getting a good stand was not a serious problem. Good stands were obtained every year for 8 consecutive years of this investigation.

At the Southeast Research Farm in 1963 stands with listed corn were better than with surface planted corn. A late spring frost occurred which killed surface planted corn, but it did relatively little damage to listed corn.

Slow Start

Early growth of listed corn is sometimes slow. This is more noticeable in cold wet springs and in shallow top soils that decrease sharply in fertility with depth. Fertilizer, placed correctly, will help overcome this disadvantage.

Fertilizer Placement

Broadcasting phosphorus prior to listing has not been a satisfactory way of fertilizing hard ground listed corn. When phosphorus is broadcast on the soil surface, lister moldboards push it high into the middle ridges where the plants are unable to use it early in the season. Phosphorus does not readily move from this location down into the root zone. It is one of the most immobile of macronutrients required by plants.

In one experimental plot in Brookings County, the top 4 inches of soil were deficient in phosphorus and the soil below was even more deficient. Phosphorus fertilizer was broadcast on the surface, the lister shovels pushed it to the center ridges and corn was planted 4 to 6 inches below the surface in soil that had the lowest possible phosphorus supplying ability. As a result, every corn plant was stunted in growth and purplish in color indicating a severe phosphorus deficiency. Young corn plants were severly re-

tarded until the second week in July. By this time roots were evidently able to recover more phosphorus.

This problem was not so serious for soils high in phosphorus or for those that receive phosphorus fertilizer applications every year. With annual applications, residual carry-over may be enough to satisfy early needs of plants.

Nitrogen moves through soil more rapidly than phosphorus so placement is not such a serious problem. If supplemental nitrogen is needed, it can be sidedressed early in the season. Nitrogen fertilizer requirements are often a little greater for hard ground listing because the expected release of nitrogen from breakdown of soil organic matter by soil micro-organisms will be less. With fewer tillage operations and less soil aeration, activity of these micro-organisms that break down organic matter to release its nitrogen will be limited.

Fertilizer Applicator Problems

Most conventional furrow openers for application of fertilizer were not satisfactory for hard ground listing. Single disk, double disk, shoe and disk-shoe combinations were tried. It was difficult to penetrate 2 inches below the seed in unplowed soil. Crop residues and moist soil collected in front of the openers, plugging fertilizer delivery tubes. An experimental opener was devised that worked well in 1962 and 1963. It consisted of a solid shank curved forward at the bottom with a small metal point welded at the tip, resembling a minature subsoiler. The fertilizer boot was attached at the rear of the shank. This penetrated easily in hard unplowed soil and gave less trouble from collecting debris. Fertilizer was funneled through the boot and fell in place behind the opener point which was 2 inches to the side and 2 inches below the seed. It was attached by removing one of the seed covering disks and and bolting the fertilizer applicator to the bracket originally intended for the seed covering disk shank. Seed was covered adequately with the remaining covering disk by increasing the angle of approach so that it threw more soil on the seed.

Cropping Sequence

Corn can be hard ground listed after any crop, but in some instances the extra trouble and work make this practice undesirable.

Hard ground listing works well with continuous corn. At the Menno Substation, corn was grown continuously for 5 years. There was less trouble when old stalks were either disked or chopped. Each year corn was listed in the center between rows of the previous years corn stalks. No important difficulties were encountered during planting and good stands were obtained every year. However, old corn stalks and roots were troublesome for the first cultivation. Conventional cultivator shovels pulled up old corn roots and covered new corn seedlings. A combination of disk hillers and shovels worked better. A rotary hoe did not penetrate far enough into the hard unplowed ground to be effective. A lister cul-

tivator worked fairly well for the first cultivation. In the second cultivation, when disks were reversed and ridges split, some root clumps were brought to the surface but this was not very serious. A spike tooth or flextine harrow worked quite well for early cultivation to break up old corn roots, level center ridges, and drag down soil to cover small weeds in the furrows. With this method old corn roots were not pulled up with shovels until the new corn was fairly well along.

A cropping sequence of corn and small grain was satisfactory, but weeds in the stubble can cause trouble if they are not disked down before listing. Usually large crops of straw should be chopped, disked, or baled and removed.

A soybean and corn sequence is good because beans do not have large root clumps that make cultivating difficult in continuously listed corn. Less plant residue remains after beans than after corn, which makes it easier to plant and cultivate the corn.

Hard ground listing has not been successful after grasses and legumes under limited moisture. Grasses and legumes are not killed with the lister and they compete with corn for moisture and nutrients. It is best to plow and disk these forage crops before listing.

Soil Type for Hard Ground Listing

Experimental plots have been located on a range of soil textural classes from loam to silty clay. Satisfactory stands and yields were obtained on all the different soil textures in this range. Since the soil was not "fluffed-up" or loosened by the plow in hard ground listing, bulk density between rows was sometimes quite high (table 3). For this reason oxygen availability, micro-organism activity, and mechanical impedance to roots may be adversely effected on the heavier soils.

Well drained, moderately well drained, and somewhat poorly drained soils have been investigated. In one experimental plot on a somewhat poorly drained soil, water collected in the trenches, retarded plant growth, and reduced yield. On poorly drained soils it may be worth while to try "ridge planting" where the corn is planted on the ridge tops instead of down in the trench.

Most experimental plots were on slopes of less than 3%. Considerable soil washing occurred in one plot on only a 2% slope when lister furrows were up and down hill. If listing follows contour lines, furrows will act as dams to collect water and prevent runoff. This can be dangerous, however, because if water washes over just one ridge on the slope, then all ridges below will probably wash out and cause serious erosion, unless terraces are constructed to take care of extra water.

Plow Plant Machine with Fertilizer Applicator

PLOW PLANT

This method refers to plowing and planting in a once over operation. Packer wheels are used to firm the seedbed in rough plowing. This method is not as popular as wheel track planting because most farm tractors are not large enough to plow and plant more than one row at a time.

Machinery Modifications for a One Row Unit

An elaborate combination of machinery is not necessary for the plow plant method. An experimental 1-row model was placed on a mounted plow at nominal cost. Construction was simple, yet it worked fairly well. A tool bar was bolted on top of the plow beams at right angles to direction of travel. Point of attachment was approximately 2 feet behind rear edge of the leading moldboard. A single row planter was bolted on the tool bar and adjusted laterally to plant in the turned over furrow of the right hand or most forward bottom. Object was to mount the planting unit as far forward as possible to reduce lateral or whip action which will be accentuated if the planter is mounted far to the rear on a free floating plow and to reduce strain on the hydraulic pump which lifts plow and planter out of the ground. Side movement may be enough to damage planter drive wheel if the plow slides around a rock. When a corn planter is added

to weight of the plow plus an applicator for weed and insect chemicals, plus a fertilizer applicator with drive wheel, hopper and furrow opener, the additional weight may be beyond the capacity of the hydraulic system. The mechanical advantage will be more favorable if most of the weight is mounted forward, close to the hitch. Newer tractors have more rugged hydraulic systems that will handle this extra weight quite easily.

The experimental model had double disk furrow openers which cut through trash and clods with a minimum of plugging. No packing device was used ahead of openers the first year. The next year a tillage attachment that looked like a miniature section of a flextine harrow was bolted on in front of the openers. This helped to break up clods and to firm a narrow band of soil ahead of the planter, but old stalks and straw would occasionally bunch up in front of this unit. A small packer wheel with a compression spring would probably do a better job of rolling overthe trash and clods without plugging.

Machinery Modifications for a 2-Row Unit

A little more ingenuity is sometimes required to put a 2-row unit together. If the plow is large enough to turn a swath 80 inches wide, then merely bolt on another planting unit (figure 4). This would take a 5-bottom plow with 16-inch bottoms. It is not necessary to buy a plow exactly this width to assemble a 2-row plow-plant unit because the plow width need not be exactly 80 inches for two 40-inch rows. For example, a plow with six 14-inch bottoms could be used. This

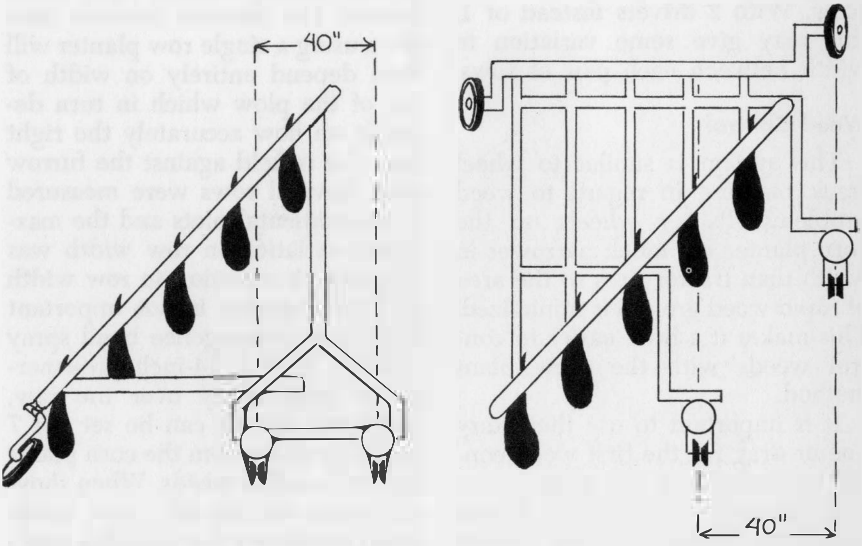


Figure 4. Examples of how tool bar planters can be attached on a 5-bottom plow for a 2-row unit.

totals 84 inches. To take care of the extra 4 inches, merely adjust the plow so that the right hand bottom takes a 10-inch cut instead of a 14-inch cut.

On the experimental 1-row unit, a plow was tried that could cut a swath 8 inches wider than necessary. The plow was adjusted so that 8 inches of the right hand bottom extended out in the dead furrow and did not turn any soil. The plowing looked a little uneven and the first cultivation was more difficult but a good stand was obtained.

A 2-row unit is not limited to large equipment. It can be done with 2 average size tractors and plows, provided total width of cut is wide enough for 2 corn rows. Plowing units can operate independently but the 2-row planter would be mounted on the second plow. With 2 drivers instead of 1, this may give some variation in width between each pair of rows.

Weed Control

This system is similar to wheel track planting in regard to weed problems. Packer wheels on the corn planter are much narrower in width than tractor tires so the area of rapid weed growth is minimized. This makes it a little easier to control weeds with the plow plant method.

It is important to use the rotary hoe or drag for the first weed control tillage when soil moisture is just right to break up clods. When clods are broken up, weed control will be easier with subsequent cultivations.

A band spray over the row for weed control is desirable to kill hard-to-get weeds in the row and forestall the first cultivation. This will allow the loose porous plowing to remain between rows longer.

Row Spacing

The first question usually asked is "Can rows be spaced accurately enough with a one-row planter to cultivate with a 2-row cultivator?" The first thing to do is to adjust the right rear tractor wheel so that the tire side wall is just touching the furrow wall when the plow is cutting a 40-inch swath. With this arrangement there was very little side draft in the experimental model because the center of draft was fairly close to the center of pull. The planter unit can be moved left or right on the tool bar until it plants in the freshly turned right hand furrow. The distance between corn rows using a single row planter will then depend entirely on width of cut of the plow which in turn depends on how accurately the right rear tire is held against the furrow wall. Several rows were measured in experimental plots and the maximum variation in row width was 2 inches. A variation in row width of 2 or 3 inches is not important when a pre-emergence band spray is used. With a 14-inch pre-emergence band spray over the row, cultivator shovels can be set out 7 inches or more from the corn plants and still control weeds. When shovels are set out this far, a row width could easilyvary 2 or 3 inches without danger of covering corn or pruning roots.

Soil Compaction and Plow Plant

With the plow plant method, there are no trips over the field with a tractor for seedbed preparation after it is plowed. With narrow corn planter packer wheels, compaction in the row is minimized. Therefore, more of the surface soil is loose and open for rapid intake of water and better aeration.

Obtaining Stands

Excellent stands were obtained in experimental plots every year. The most important thing to insure good stands is a firm seedbed that will establish good seed-soil contact. With 2-row plow plant units, additional weight on the planter wheels is sometimes necessary to compress loose soil and bring it in contact with the seed.

Soil Types for Plow Plant

The plow-plant method is well adapted to a wide range in soil types. Its use would have maximum advantage in heavy wet fields where soil structure breaks down under heavy machinery traffic.

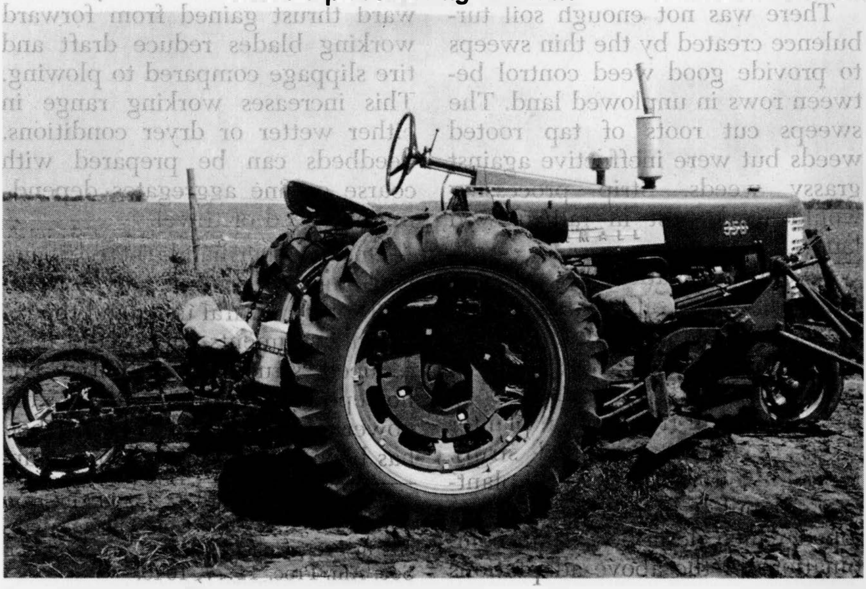
It could also be used on sandy soils subject to wind erosion. With conventional methods the extra disking and dragging break down soil aggregates making them more easily moved by wind.

From field observations of plow-plant experimental plots on gentle slopes, it is apparent that this method is more suited to steeper slopes than some of the other minimum tillage methods.

STRIP PROCESSING

Strip processing refers to any method where only a narrow strip

Strip Processing Machine



of soil is thoroughly worked. Advantages of this method are similar to those of hard ground listing.

Machinery Adaptations

The strip processing machine used in experimental plots consisted of a narrow blade running deep to loosen the soil, a wide blade running shallow to kill weeds between rows and a narrow section of rotary hoe to work up soil in the row. Planting units were mounted at the rear.

It was difficult to hold tillage sections at a uniform depth if the soil was hard, dry, or stony. In unplowed ground, straw and weeds collected and bunched in front of tillage units. On disked cornstalks and stubble this was not a problem. The combination of rotary hoe and blades made a satisfactory seedbed in the strips and good stands were usually obtained.

There was not enough soil turbulence created by the thin sweeps to provide good weed control between rows in unplowed land. The sweeps cut roots of tap rooted weeds but were ineffective against grassy weeds. Strip processing would work best in fall plowed land.

Several adaptations of the machine described above have been improvised. Different types of tools such as rototillers, hoes, knives, sweeps, and flexible tines have been placed in front of the planter shoes to prepare seedbed strips. Descriptive terms such as till planter and mulch planter have developed which describe certain combinations of the above adaptations for strip processing. A mulch planter was assembled at the Southeast Research farm which prepared a narrow strip for seeding and left a straw mulch on the surface. It consisted of conventional planter shoes with V-shaped metal straps bolted on to push away the trash. Penetration was obtained by sweeps bolted to planter shoes. The seedbed was worked with a Noble blade prior to planting to loosen the soil and kill weeds yet maintain a straw mulch on the surface.

ROTOTILLER

This could not be classified as a minimum tillage method because the soil is quite thoroughly tilled. However, it is a "once-over" method for seedbed preparation and has some advantages. For example, plant residues are mixed with the soil, not turned over in a layer. Forward thrust gained from forward working blades reduce draft and tire slippage compared to plowing. This increases working range in either wetter or dryer conditions. Seedbeds can be prepared with coarse or fine aggregates depending on speed of travel.

On the other hand, rotary tillage is claimed to be destructive of natural soil structural units and the resulting fragments supposedly have reduced structural stability.[7] The horsepower requirement for the power take off is high. This method has been included in the minimum

[7]Page, J. B., Willard, C. J. and McCuen, G. W. Progress Report on Tillage Methods in Preparing Land for Corn. Soil Sci. Soc. Am. Proc. 11:77, 1946.

tillage trials at the Southeast Research farm for 2 years. Weed problems were about the same as those with conventional seedbed preparation with plow, disk, and drag. the seedbed was light, fluffy and mellow. Good stands were obtained each year.

YIELD COMPARISONS

Minimum tillage experiments werestarted at the Menno Research Farm in 1956 and carried on through 1960. After 3 years of preliminary work at Menno, it was obvious that this tillage principle had considerable merit and work was expanded in 1959. Investigations were also conducted in Brookings County from 1959 through 1961. Two new methods of planting were added and pre-emergence weed spray combinations were investigated. In 1962 this work was again expanded to include 10 treatments at the Southeast Research Farm.

Investigations at Menno Research Farm

Corn yields obtained at the Menno Research Farm are shown in table 5. No yields were reported for 1960 because the corn in some replicates was flooded, causing erratic yield data.

Plants were hand thinned to 10,668 per acre in all plots. Four replications of continuous corn were grown each year. In 1956, fertilizer was broadcast on top of the ground before any tillage was performed. In 1957, 1958, and 1959 fertilizer was broadcast before plowing for conventional and wheel track plots but after listing in the listed plots. This changewas made to determine if early dragging, in listed plots, would pull fertilizer down from the ridges to furrow bottoms and facilitate its uptake by plant roots. Listed corn yields in 1957 and 1958 indicate that this practice combined with residual fertilizer effect had a slightly beneficial influence on yield.

In general, yields from minimum tillage methods held up very well over the 4-year period. Yield increases from nitrogen werevariable. In 1959, a dry year, nitrogen appeared to decrease yields with all methods of planting. A larger increase from nitrogen was expected in hard ground listed plots.

Table 5. Effect of Minimum Tillage on Yield of Corn, Menno Research Farm.

Pounds per acre of				Bushels of corn per acre				
N	P	K	Planting Method	1956	1957	1958	1959	4 yr. ave.
0	17.6	0	Conventional	43	76	52	22	48
60	17.6	0	Conventional	52	82	63	19	54
0	17.6	0	Wheel track	46	74	54	21	49
60	17.6	0	Wheel track	32	75	54	11	43
0	17.6	0	Hard ground list	43	81	63	26	53
60	17.6	0	Hard ground list	43	84	66	19	53

Table 6. Effect of Tillage Method and Pre-emergence Spray on Corn Yield, Brookings County, 1959.

Planting Method	Spray treatment*	Previous Crop small grain bu of corn/acre	Previous Crop corn bu of corn/acre
Conventional	spray	32	44
Conventional	no spray	24	29
Strip processed	spray	17	31
Strip processed	no spray	12	18
Hard ground listed	spray	18	47
Hard ground listed	no spray	17	44
Wheel track	spray	32	40
Wheel track	no spray	29	32

*Simazine 50 W applied in a 13-inch band over the row at time of seeding at the rate of 2 lbs. active ingredient (4 lbs. of product) per acre actually covered by the spray.

Investigations in Brookings County

In 1959 two experiments were performed in Brookings County; one followed corn, and one followed small grain (table 6).

In corn plots that followed small grain, there were several unfavorable conditions. Soil moisture and phosphorus were deficient; quack grass and rocks were prevalent. Twenty pounds of nitrogen and 20 pounds of P_2O_5 (8.8 lbs. of P) per acre were broadcast on the surface. In spite of these limitations, corn yields with wheel track planting were comparable to those with conventional methods. Other minimum tillage methods were not as successful. This was due in part to improper phosphate placement and lack of weed control. The spray treatment for weed control increased corn yields with all methods of planting.

In plots where corn followed corn, yields were higher than where corn followed small grain. This was due to better soil moisture conditions and higher level of fertility from heavy manure applications. With soil moisture and fertility more favorable, both wheel track planting and hard ground listing resulted in yields comparable to those with conventional methods. Strip processing yields were not as high as with other methods. A striking increase was noted on yield from the pre-emergence band spray with strip processing in the corn after corn plots.

In 1960 the plow plant method was substituted for strip processing (table 7).

Rainfall was more favorable and corn yields were higher in most plots than those in 1959. Plow plant and wheel track methods gave yields similar to those with conventional methods. Hard ground listing was not as successful this year primarily due to a weed problem and to volunteer rye. If these plots had been disked before planting, the weed problem would not have been so severe.

A pre-emergence band spray was again effective for increasing corn yields. Each plot received 3 cultivations. The treatment with the least amount of tillage had the greatest need for a pre-emergence spray.

In 1961 the same methods of planting were used as in 1960 but a change was made in the spraytreatments. In previous years most differences attributed to planting method were actually due to different degrees of weed control. Therefore, an over-all spray treatment was included in 1961 in an attempt to measure differences in yield due to planting method itself rather than to different degrees of weed control. Soil fertility was adequate from previous applications of manure and commercial fertilizer. All plots received two cultivations.

Very little difference was noted in yield between the different minimum tillage methods with an over-all spray treatment (table 8). A band spray was nearly as effective in increasing yields as the over-all spray with all treatments except hard ground listing. Unsprayed plots yielded less than sprayed plots.

In 1962 the minimum tillage work was expanded to include mulch planting and rototilling at the Southeast Research Farm. Fertilizer application machinery was improvised or adapted so that a starter fertilizer could be applied with each planting method. Some of these adaptations were not perfect, but they did work satisfactorily. Starter was placed 2 inches to the side and 2 inches below the seed.

All treatments were hand thinned to 12,000 plants per acre. The cropping sequence was corn and oats with 4 replications. Randox T was applied in a band over the row at the time of seeding at the rate of 1.75 pounds of active ingredient

Table 7. Effect of Tillage Method and Pre-emergence Band Spray on Corn Yields Brookings County, 1960.

Planting Method	Spray treatment*	Bushels of corn per acre
Conventional	spray	74
Conventional	no spray	71
Plow plant	spray	74
Plow plant	no spray	69
Hard ground listing	spray	53
Hard ground listing	no spray	37
Wheel track	spray	77
Wheel track	no spray	68

*Atrazine 80 W applied in a 13-inch band over the row at time of seeding at the rate of 2.4 pounds active ingredients (3 pounds of product) per acre actually covered by the spray.

Table 8. Effect of Tillage Method and Spray Treatments on Yield of Corn, Brookings County, 1961.

Planting Method	Spray treatment*	Bushels of corn per acre
Conventional	No spray	58
Conventional	Band spray	84
Conventional	Over-all spray	85
Plow plant	No spray	78
Plow plant	Band spray	86
Plow plant	Over-all spray	83
Wheel track	No spray	68
Wheel track	Band spray	86
Wheel track	Over-all spray	81
Hard ground list	No spray	61
Hard ground list	Band spray	72
Hard ground list	Over-all spray	81

*Atrazine 80 W applied at 2.4 pounds active ingredient (3 pounds of product) per acre actually covered by the spray.

(5 pounds of product) per acre actually covered by the band.

Hard ground listed plots had no seedbed preparation prior to listing. Mulch plots were planted with an experimental planter (for description of planter see section on machinery adaptations under strip processing). For cultivation in mulch plots, a wide V-shaped blade was used instead of the usual cultivator shovels in order to keep as much plant residue on the soil surface as possible. A conventional sub-soiler was used on the chiseled plots. The chisel point ran approxi-

Table 9. Comparison of Corn Yields with Minimum Tillage to Yields with Conventional Methods, Southeast Research Farm.

Planting Method	Fertilizer* N P K	Bushels of Corn per Acre 1962	1963
Hard ground listing	80 -12.3- 0	95	82
Wheel track planting	80 -12.3- 0	102	79
Conventional plant, spring plow	0 - 0 - 0	95	89
Mulch planting	80 -12.3- 0	104	73
Spring list after fall subsoiling	80 -12.3- 0	94	84
Plow plant	80 -12.3- 0	116	86
Loose ground listing, fall plow	80 -12.3- 0	86	87
Conventional plant, fall plow	80 -12.3- 0	108	88
Rototiller, conventional plant	80 -12.3- 0	96	80
Conventional plant, spring plow	80 -12.3- 0	104	92

*80-12.3-0 is total fertility applied (elemental basis). This included 60 pounds of 18-20.6-0 applied in a band as starter and 70 pounds of liquid nitrogen as sidedress.

mately 22 inches beneath the surface. Corn yields for 1962 and 1963 are presented in table 9.

Corn yields with most minimum tillage methods were excellent in 1962, a year of favorable weather. Water accumulated in lister furrows in early spring and remained for several days. This is probably one of the reasons why yields from listing were generally lower than those from conventional planting.

In 1963, the lowest yielding treatment was mulch planting. This was due in part to difficulties in controlling weeds while maintaining a straw mulch cover on the surface. In listed plots, subsoiling in the fall did not increase yields appreciably. Corn in listed plots survived a late spring freeze with no apparent damage, but corn in surface planted plots required extensive replanting to bring stands back up to 12,000 plants per acre.

SUMMARY

Minimum tillage methods for growing corn can be grouped into four systems: wheel track planting, hard ground listing, plow plant, and strip processing. There are several combinations and variations of the above 4 methods.

Minimum tillage is not a panacea for all the problems encountered in growing corn. Each method has its own merits, its own problems, and its own limitations. The advantages for using these methods are definite and substantial. Operating costs can be reduced, time saved, moisture conserved, and soil compaction lessened.

Disadvantages are usually associated with machinery adaptations, weed control, fertilizer placement, obtaining good stands, and maintenance of yields. Under most conditions these disadvantages can be minimized or overcome.

Minimum tillage methods that included use of the plow were usually easier to perfect and were usually more successful in maintaining yields. Minimum tillage can be used in a wide range of soil types, but some methods are better adapted to adverse soil conditions.

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