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DEVELOPMENT OF A REDUCED TILLAGE PLANTER FOR THE SEMI-ARID GREAT PLAINS REGION

by

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INTRODUCTION

The practice of minimum tillage as a profitable crop production practice has become a frequently discussed topic among government policy makers, environmentalists, land grant university personnel, and farmers. Interest in the subject has been aroused by a variety of recent events. Rapidly rising energy prices, declining farm product prices, recent drought and subsequent erosion problems, as well as proposed public laws regulating effluents from agricultural lands have all served to stimulate interest in minimum tillage farming. For the purpose of this investigation and the ensuing discussion minimum tillage will be defined as: The production of an economically attractive crop with a minimum amount of tillage.

In January of 1976 the Agricultural Engineering Departments of Kansas State University and University of Nebraska - Lincoln undertook an 18 month program to study and develop a model energy conservation program for production agriculture in the respective states. Emphasis in the Kansas plan was broken down into five major areas, one of which dealt with field operations. A significant amount of effort in the field operations area was devoted to evaluating and implementing minimum tillage practices with interested farmer-cooperators. In the spring of 1976 a 6-row Buffalo Flex-Planter was leased from Fleischer, Mfg. Co., Columbus, Nebraska. This planter was equipped with the various openers and accessories available from the manufacturer for use in minimum tillage planting.

The planter was used under varying conditions by 7 farmers in the western 2/3 of Kansas to plant approximately 500 acres of grain sorghum and soybeans during the summer of 1976. This experience indicated that while there were certain management problems associated with minimizing tillage operations it was practical and feasible from both an economic and an energy standpoint. It was also felt that while the Buffalo Till-Plant system and the Buffalo planter were well suited to some conditions they were not well suited to a majority of conditions normally existent in the western 2/3 of Kansas and in fact a majority of the Great Plains region.

Three primary problems were easily identified; (1) The Buffalo planter was sensitive to varying soil types and in particular to varying soil firmness which may be common to minimum tillage fields. (2) The Buffalo planter did not perform well under heavy residue conditions due to inadequate residue clearance and slippage or stoppage of the depth band and stalk cutter combination used to drive the planter. (3) The planter had many moving parts; some which would not withstand extended use under field conditions. In addition the Buffalo planter design utilized nine adjustments per row; five were major adjustments requiring frequent attention. Many of these were located in poorly accessible areas and generally required considerable physical effort. The combined result of the design was a machine requiring considerable operator patience and skill with a projected high repair cost. Field efficiency would possibly be low due to frequent repairs and time consuming adjustments.

Assessment of the foregoing considerations led to the conclusion that a need existed for a planter designed primarily for conditions existent in the High Plains region of Kansas. In evaluating the needs and current equipment available it became obvious that a unit with residue clearance comparable to the V-blade or stubble mulch plow and a low degree of sensitivity to varying soil firmness would have desirable characteristics for a minimum tillage planter. Such a machine would also have the potential of killing weeds existing at the time of planting.

Between 1968 and 1975 (years without severe or prolonged drought) an average of 2.9 million acres in the 10 Great Plains States received emergency tillage annually to control wind erosion. While farmers in the Great Plains area generally depend upon vegetative growth, crop residue, or mechanically roughened soil surfaces to control wind erosion, the large acreages emergency tilled each year indicate that current practices are not adequate to establish erosion control via. the two desired methods, vegetative growth or crop residue. Careful evaluation of current cultural practices reveals that in practically all cases some tillage is performed for the purpose of reducing residues to levels which will allow satisfactory planter operation. This is particularly true for small grains planted in narrow rows (7-14 inches). Development of a high residue planter would offer an attractive alternative to yield losses and emergency tillage resulting from wind erosion.

REVIEW OF LITERATURE

Development of Minimum or Reduced Tillage Practices in the Great Plains

Reduced tillage farming in the U.S. Great Plains today can be traced back to 1938 and two Soil Conservation Service researchers at Lincoln, Nebraska. The two were Dr. F.L. Duley and Professor J.C. Russel. Their incentitive to develop new farming techniques came as a result of the disastrous dust bowl of the 1930's. Professor Russel (1976) stated that the premise on which they began work was "a soil somehow should be protected against the disruptive pattern of raindrops with joint consequences of reduced intake and enhanced runoff". The logical procedure seemed to them to leave all crop residues on the surface.

The question at that time was, "how to leave residues on the surface to enhance intake and reduce evaporation, and at the same time reduce soil losses through the agency of wind", Russel (1976). Since that time there have been researchers in the Great Plains dedicated to the concept of subsurface or stubble mulch tillage as it is commonly refered.

In 1938 subsurface tillage machines using V-shaped sweeps pulled beneath the surface were being produced by the Chase Plow Company of Lincoln, Nebraska and a blacksmith, Charlie Smelzer, who lived near Canton, Kansas. Both of these machines were being sold as Bindweed eradicators. Shortly thereafter Duley and Russel made the adquaintance of a Mr. C.S. Noble of Nobleford, Alberta, Canada (Founder of Nobel Cultivators Limited which today is a prominent name in stubble mulch tillage equipment). Within two years, Mr. Noble introduced the V-shaped Noble blade which is the basic tillage tool of most systems in use today.

In addition to demonstrations of stubble mulch tillage, Duley and Russel experimented with planting corn into subtilled legumes. The practice of planting in unturned crop residue had begun. Duley and Russel were successful in using this system which practically eliminated runoff and wind erosion. One problem which they were unable to surmount though was, "how to get rid of downy brome and cheat grass with subtillage in western Nebraska" (Russel, 1976). The only reliable method to keep such weeds in check was plowing, which buried each crop of seed.

The concept of stubble mulch characterized by subsurface tillage spread throughout the Great Plains. Until the 1960's, when chemical herbicides achieved widespread usage, stubble mulch was plagued by weed problems. This is not to say that stubble mulch did not work; it only meant that most tillage programs it was necessary to use some inverting tillage to keep certain weed species under control.

With the advent of chemical weed control, new crop production tillage-planting systems evolved. No-Till, a system that eliminates tillage, was initiated. In the Great Plains region however another practice, Ecofallow, has gained broader acceptance although total acreage to date is low. Ecofallow, as the name implies, is a method of fallow in which weeds are chemically controlled throughout a major portion of the fallow period with only a limited amount of mechanical tillage. The basic objectives of Ecofallow are control of weeds and preservation of crop residues.

The advantages of minimized tillage systems are usually listed as: reduced production costs, reduced energy consumption, increased yields, and reduced capital investments. There are however two indisputable advantages of reducing tillage that are paramount. These are: 1) moisture conservation and 2) soil conservation. Expenditure of resources to develop farming practices with these two benefits needs no further justification for anyone familiar with agriculture in the U.S. Great Plains.

Soil and Moisture Conservation Potentials of Minimum Tillage

Minimum Tillage or Ecofallow have all of the conservation benefits of stubble mulch; however substitution of chemicals for tillage in weed control preserves additional crop residues. Chemical weed control hence increases the benefits of stubble mulch tillage.

In an eight-year study at Alliance, Nebraska, Fenster (1960) evaluated stubble mulch fallow, one-way disk fallow and bare fallow in a wheat-fallow rotation system. In this study, Fenster and McCalla found average wind erosion losses for the 8-year period were .86, 1.4, and 2.9 tons per acre for stubble mulch tillage, one-way fallow, and bare fallow, respectively. This reduction in soil loss was due to increased residue levels, 2620 pounds per acre for stubble mulch versus 610 pounds per acre for clean tillage.

In another study of stubble mulch farming at Alliance, Nebraska, Fenster (1960) compared water erosion under stubble mulch fallow and bare fallow in a wheat-fallow rotation. This study (on a very fine sandy loam, 4 percent slope) showed that maintenance of residues on the soil surface reduced soil loss by 86 percent and runoff by 60 percent during the fallow period. In growing wheat, stubble mulch fallow reduced soil loss 74 percent and runoff 43 percent compared with the losses on bare fallow.

Numerous studies have also shown that surface residues greatly increase water intake. In a Wyoming study by Barnes and Bohmont (1958) intake for bare fallow and stubble mulch fallow was 0.30 and 2.26 inches respectively. Other studies in Colorado, Montana, and Nebraska by Fenster and McCalla (1970) and Greb, Smika, and Black (1967) also showed significant increases in moisture storage during fallow with 1500 to 6000 pounds per acre of wheat residue on the surface.

In emphasizing the importance of mulches on soil structure, McCalla and Fenster showed that surface mulch is more important than soil organic matter in increasing water infiltration. The test involved sprinkling mulched and unmulched subsoil for three hours. Infiltration rates of 0.76 and 0.44 inch per hour were found for the two respectively. In the same test mulched and unmulched topsoil had infiltration rates of 1.62 and 0.55 inches per hour respectively, Fenster and McCalla (1970). In addition to reducing soil erosion, increased infiltration rates enhance soil moisture storage by reducing runoff. Increased moisture storage resulting from enhanced infiltration rates is of greater importance in areas with high intensity rainfall such as the U.S. Great Plains region than in low intensity rainfall areas such as the U.S. Pacific Northwest.

Another important advantage of residue cover is snow entrapment in areas with significant snowfall, particularly when the snowfall is accompanied by wind causing blowing and drifting (a common condition in the Northern U.S. Great Plains). This is an important factor since, the storage efficiency of snow melt has been found to be 66 percent effective compared with 0 to 15 percent effectiveness of moisture from a July storm, (Greb, Smika, and Black, 1967).

Yield reduction is probably the most effective way to express the importance of soil moisture storage. In the Great Plains it has been found that the loss or shortage of one inch soil moisture will reduce the yield of wheat by 4 to 6 bushels per acre and associated straw yield by 420 to 660 pounds per acre, Greb (1978). The following research results give a more detailed view of the long term advantages of reduced tillage and mulch farming practices which may be expected when such practices are implemented. (Table 1, 2, and 3)

Table 1: Net soil water gain at end of fallow for bare and conservation mulch fallow systems at 7 Central Great Plains locations. Smika (1976)

Location	Soil Surface Conditions	
	Bare	Mulch
	inches	
Akron, Colo. (6)*	5.61	6.72
Colby, Kans. (4)	4.52	5.56
Garden City, Kans. (6)	3.39	3.53
Oakley, Kans. (4)	3.24	5.14
N. Platte, Nebr. (8)	5.75	7.99
Alliance, Nebr. (8)	1.13	1.24
Archer, Wyo. (2)	1.10	1.67
Avg. All Locations	3.53	4.56

*Denotes years of experimental results.

Table 2: Grain yield at 8 Central Great Plains locations with bare and conservation mulch fallow systems. Smika (1976)

Location	Fallow System	
	Bare	Mulch
	bu/ac.	
Akron, Colo. (4)*	35.3	43.8
Colby, Kans. (4)	27.1	28.2
Garden City, Kans. (6)	19.8	23.6
Oakley, Kans. (4)	36.0	39.0
Alliance, Nebr. (8)	21.9	21.6
N. Platte, Nebr. (8)	40.0	43.0
Sidney, Nebr. (6)	38.3	38.8
Archer, Wyo. (2)	19.2	19.2
Avg. All Locations	29.7	32.2

*Denotes number of years of results.

Table 3: Net benefits of fall herbicide weed control in a fallow-wheat rotation compared with conventional spring tillags. Akron, Colorado. Greb (1976)

Fallow and Crop Year	Fall Weeds Suppressed	Extra Fallow Soil Water	Extra Fallow Nitrogen	Fewer Tillages	Extra Wheat Yield Components			
					Grain	Straw	TDM[c]	Protein Grain
Exp. No.	Lb/Acre(%)	Inches	Lb/A	No.	B/A	Lb/A	Lb/A	%
Colo. A-67-1								
1968-69	490, (51)	.92	15	2	3.8	545	775	0.3
1969-70	1049, (85)	2.34	46	2	13.7	1180	2000	1.7
1970-71	590, (61)	1.71	39	2	5.5	1030	1360	1.2
1971-72[a]	500, (70)	1.38	10	2	4.7	515	795	0.0
1972-73[b]	580, (75)	.72	27	2	6.9	565	930	0.8
Colo. A-72-2								
1973-74	920, (73)	1.41	41	1	8.3	980	1480	1.9
1974-75	550, (65)	1.76	25	2	11.0	800	1460	0.6
1975-76	520, (62)	1.52	14	1	5.6	760	1095	0.0
1976-77	1000, (82)	1.80	25	2	4.1[d]	235[d]	480[d]	0.5
Avg.	700, (69)	1.50	27	1.8	7.1	735	1150	0.8

[a] East field [b] West field [c] Total dry matter [d] Hail damage 30%

Nst bushels/acre = $\frac{7.1}{1.5}$ = 4.73 bu/acre/in. Net dry matter = $\frac{1150}{1.5}$ lb/acre = 765 lb/acre/in.

Note: Herbicide combinations included: atrazine + amitrol T, atraxine + paraquat, atrazine + roundup.

The Practice of Minimum Tillage

There are many definitions of minimum tillage; however, all are concerned with the production of an economically attractive crop using a minimum amount of tillage. In most cases, chemicals are substituted for some or all mechanical tillage operations. Because minimum tillage is concerned with reducing tillage operations and their severity, the practice leads to a high residue or mulch system of farming.

There are a variety of reasons for tillage operations. In general, these can be categorized as: (1) weed control, (2) residue elimination, (3) seedbed preparation (loosening and forming), and (4) erosion control (wind and water). In evaluating a tillage program, these general requirements should be considered and priorities determined. In the past, mechanical tillage has been necessary to control weed growth; however in recent years, herbicides have developed into viable controls and can be substituted for some tillage operations. In most tillage programs, residue elimination has been a necessity because planting equipment currently in use does not perform satisfactorily in high residue conditions. In some cases, mechanical tillage may be necessary for incorporation of fertilizer or chemicals. For conventional tillage programs, a good deal of effort is expended on seedbed "preparation". The ideal seedbed, however, is one with the appropriate firmness and adequate moisture close to the surface. This is almost exactly what nature will provide in the spring if weed growth does not occur. When good residue cover is maintained erosion control is much better than where residues have been destroyed by tillage operations. If, however, sufficient residue for control of wind and water erosion cannot be grown, mechanical tillage is the only alternative.

Soils such as the loamy soils found in the High Plains region of the Midwest require 1200 to 1500 pounds per acre of wheat straw and approximately 2400 to 3000 pounds of sorghum stover for adequate protection from wind erosion. In estimating the amount of residue present at harvest time one can use approximately 100 pounds wheat residue/acre for each bushel harvested and likewise approximately 55 pounds sorghum residue/acre for each bushel harvested, Hays (1971). The percent residue reduction with each tillage operation is dependent upon numerous factors; however, Table 4 can serve as a guideline.

Table 4: Effect of Tillage Equipment on Surface Residue (Anderson, 1976)

Tillage Machine	Residue Reduction per operation (%)
Subsurface Machines	
Wide-Blades and Rodweeders	10
Mixing-Type Machines	
Heavy Duty Cultivators and Field Conditioners	25
Mixing and Inverting Disk Machines	
One-Way Disk, Tandem Disk, Offset Disk	50
Inverting Machines	
Moldboard and Inclined Disk Plow	90

Adaptibility of minimum tillage is based upon soil drainage, climatic conditions, crop rotation program, and weed problems present. Although minimum tillage has been made to work on nearly every type of soil, it is more readily adapted to lighter, well drained soils than to heavier, poorly drained soils which may experience water ponding problems.

Practically all minimum tillage systems rely on chemicals to aid weed control. Consequently not all crop rotations can be practiced without danger of herbicide carry-over damage. A planned crop rotation however can be a bonus in controlling weeds. By growing crops with different growing seasons and herbicide tolerances, it is possible to control weeds which develop under continuous cropping (Example: Shattercane in continuous sorghum versus a sorghum-wheat-soybean rotation or cheat in continuous wheat versus a wheat-sorghum-fallow rotation). If perennial weed problems such as bindweed or Johnson grass are serious, minimum tillage probably has few advantages if any over conventional practices.

Many people have the mistaken concept that minimum tillage farming requires considerably more chemicals than conventional programs. While this may be true in some instances, most farmers today are using a herbicide program on their row crops which uses chemicals such as Atrazine, Igran, Milogard, Bladex, Ramrod, 2,4-D, Lasso, or Treflan depending upon the particular crop. Where such herbicides are already in use, a change to minimum tillage will not generally require a significant change in application rate. There may, however, be a change in method of application and probably in timing of the application. Another common misconception is that herbicide programs eliminate the need for cultivation. Numerous test plots in Kansas have shown that in practically all cases, a light lay-by cultivation performed as late as possible (before root pruning becomes a hazard) results in positive yield responses for grain sorghum on both chemical treated and untreated soils (Table 7).

Recent advertising has been directed toward the sale of nonselective contact herbicides for use in minimum tillage farming. In the past, contact herbicides (herbicides which kill all types of plant material upon contact) have had two basic problems: (1) cost ($6.00 to $32.50 per acre)[1], and (2) erratic results due to slightly less than ideal application conditions.

Where possible, application of commonly used residual chemicals (chemicals which remain active in the soil for a period of time after application) prior to seedling weed emergence has the potential of good control prior to planting and throughout the growing season, thus eliminating the need for contact herbicides and pre-plant tillage. When using early season residual herbicide applications, the degree of control should be evaluated immediately prior to planting and thoughout the season. Should rainfall or soil type influence control in an unexpected fashion, one has the alternatives of applying an additional residual herbicide treatment, pre-plant or pre-emerge, using a chemical such as 2,4-D and/or mechanical cultivation during the growing season. Care should be exercised not to exceed the total recommended application rates during a growing season or apply chemicals not cleared for use in combination. Considering present costs and performance records, it seems difficult to justify the use of contact herbicides in programs other than double-cropping and when weather has prevented the timely use of tillage or residual chemicals.

When using preplant chemical applications, care must be exercised to minimize disturbance of the treated soil layer during planting, which could result in poor control within the crop row. In evaluating a herbicide program, one should keep in mind that the life and degree of control are dependent upon having a uniformily treated layer of soil near the surface. Chemical applications are thus sensitive to application method, rainfall, tillage, and amount of residue on the soil surface (which may intercept the herbicide before

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[1]Paraquat (1 pt./ac.) + X-77 Spreader (.4 qt./ac.) = $6.08/ac.
Roundup (2 qts./ac.) + Spreader = $32.50/ac.
(Paraquat CL - $39.50, X-77 Spreader - $11.45/gal. and Roundup - $62.20/gal)

reaching the soil). The importance of having a well calibrated and adjusted sprayer cannot be over emphasized. Properly spaced flat fan nozzles usually perform much better than the common flood jet nozzles. A good way to check uniformity of spray application is to spray across a road or other bare flat surface and compare surface wetness across the swath width. Another key to good weed control is knowing what weeds are present and using a chemical capable of controlling them.

Although this discussion focuses primarily upon row crop programs, minimum tillage concepts are applicable to small grains such as wheat. In fact, a type of reduced tillage known as stubble mulch has been practiced in some localities for several years.

Programs are currently under development to substitute chemicals for mechanical tillage in the initial fallow period of fallow-wheat rotations. These programs utilize chemicals for weed control during the initial 4 to 11 months of the approximately 16 month fallow period and rely upon conventional tillage to control undesireable vegetation during the fallow period and are usually refered to as "Ecofallow". In such programs seedling injury from residual carry-over has been a problem in years with less than normal rainfall.

As in row crop programs, the inability of planting equipment to operate under heavy residue levels governs in part the number of tillage operations and in particular their severity. Another factor is the limited number of residual herbicides available for weed control in small grains thus limiting the substitution of chemicals for mechanical tillage. Future developments in both of these areas will probably make true minimum tillage for small grains a reality at some time in the future.

Problems also rise in crop rotations such as fallow-wheat-sorghum when the herbicides used for sorghum carry-over and cause stand reduction in the following wheat crop. Should herbicide carry-over be suspected it can be checked prior to seeding by planting the intended crop in a greenhouse flat of the soil and evaluating the herbicide influence if any by comparing with a similar planting in untreated soil. If such a test is performed sufficiently ahead of planting the alternatives may be to perform a mixing tillage operation such as plowing or to plant a less susceptable crop (Doanes Agricultural Report, 1977).

Planting Methods

Since minimum tillage is concerned with a minimum amount of soil manipulation, the surface profile is an important factor in the overall success of a minimum tillage program. The two basic systems in use today for row crop are the Ridge Planting system and the Slot Planting system.

The Ridge Planting system (Figure 1) uses a surface profile with the past years crop growth standing on ridges 4 to 6 inches above the center of the crop rows. Planting of the successive crop involves cutting away the top 2 inches or so of the ridge and moving this down into the furrow placing the seed atop the old ridge. This system is best suited to early seeded crops where planting occurs while weeds are small enough to be removed from the ridge and buried along with those in the furrow. A residual herbicide can be banded onto the crop row at planting time and a reridging or furrowing cultivation used to reshape ridges and control weeds after the crop is large enough to shade most of the area between rows.

Important factors in the Ridge System are the surface profile and an early planting date if early season weeds are to be controlled without the use of chemicals. This system works quite well in both dryland and furrow irrigated cropping systems depending upon the exact practice used. However, under irrigation it may not be possible to irrigate between planting and the lay-by or reridging cultivation which should be made as late as possible (12-18 inch crop height). Consequently it is important to have adequate moisture in the soil profile at planting time to carry the crop until furrows are reopened.

The Slot Planting system (Figure 2) strives to achieve a minimum amount of soil disturbance and is generally better suited to a nearly level surface profile. When Slot Planting, the new crop is usually seeded directly into old residue. This provides excellent protection for the newly seeded crop. Since this system performs little or no tillage for weed control, planting date is not an important factor as it is in the Ridge Plant System. Slot planting is also well adapted to double-cropping where existing vegetation is either not a problem or is chemically controlled. In double-cropping programs, a contact herbicide is often used for control of existing weeds and volunteer; a residual type of herbicide is applied if necessary for extending control. For full season crops, residual herbicide application prior to early weed emergence has the potential for preplant weed control as well as growing season control thus avoiding the need for a contact herbicide at planting time. The Slot Planting system should also make use of a light cultivation such as cultivator sweeps when the crop reaches a size sufficient to shade most of the ground. Slot planting is well adapted to wheat-row crop-fallow rotations, to sprinkler irrigation, and double-cropping practices. There are some variations of Slot Planting commonly referred to as Strip Till which perform some tillage in the immediate seed placement zone. The tillage is usually accomplished by using a 2 to 3 inch wide fluted "Till-Coulter", a small duckfoot or cultivator sweep, or a modified rotary tiller with most of the knives or tines removed. The primary purpose of such tillage is to provide sufficient loose soil for covering the seed and establishing adequate seed-soil contact which can be a problem when slot planting in firm soils.

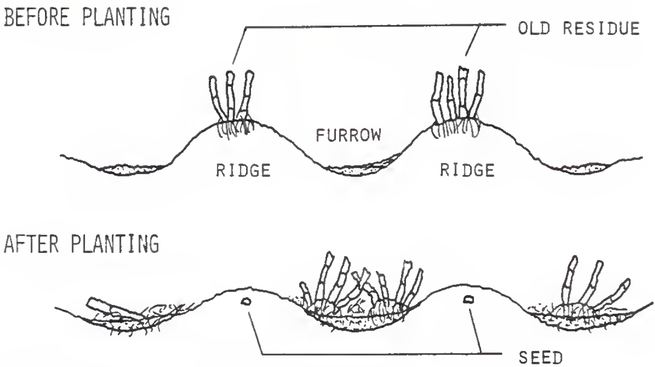


Figure 1: Ridge Planting

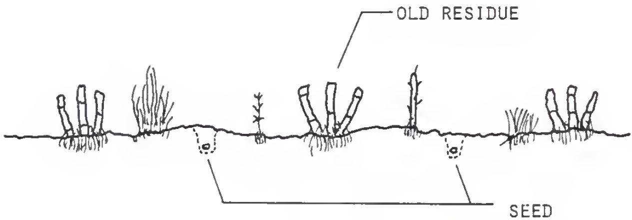


Figure 2: Slot Planting

Evaluating Minimum Tillage

The following discussion and sample farming operations can be used as a guide in evaluating minimum tillage. When evaluating minimum tillage for a particular farming operation, the following points should be analyzed: (1) time, fuel and power requirements; (2) crop rotation program; (3) weed problems; (4) possible differences in herbicide cost, and (5) decreased weather dependence when using only one field operation instead of several. If records on time and fuel requirements are not available, the sample operations and farming programs given here for production of grain sorghum in a fallow-wheat-grain sorghum rotation can be used or modified to evaluate energy, and time requirements, along with representative custom rates (Table 5 and 6).

Comparing Reduced and Conventional Tillage Systems

Advantages of Reduced Tillage

1) Fuel, Labor and Machinery savings - Less trips over the field mean less of these inputs are required.
2) Moisture Conservation - Reduced tillage depths and operations combine with higher residue levels for less soil moisture loss. The moisture conservation aspects of reduced tillage can add up to sizeable savings and under irrigation, may eliminate the need for pre-irrigation.
3) Soil Conservation - Less tillage leaves soil less susceptible to wind and water erosion.
4) Reduced Soil Compaction - Less trips across fields plus lower draft loads will reduce overall compaction.
5) Improved Water Intake Rates - Increased organic matter and reduced

soil compaction combine to enhance water intake rates.

6) Better Soil Tilth - Soil structure will improve as a result of less tillage, reduced compaction, and increased organic matter.

7) Reduced Weather Dependency - Elimination of tillage operations normally performed just prior to planting allows one to plant during the entire period left open by the weather.

<u>Points of Caution</u>

1) Possible Increased Chemical Costs - If a present program does not include herbicides, a switch to minimum tillage with a herbicide program may mean substantial costs for herbicides. Contrary to a popular concept, minimum tillage and herbicide programs should be accompanied by a light cultivation for best results.

2) Need for Better Management -

   A. Crop Residue must be managed to leave the desired amount of residue at planting in a condition compatible with fertilizer and herbicide programs. Chemical performance may be affected by surface residue, preventing herbicide materials from reaching the soil. Uniform residue distribution at harvest is essential. Whenever possible it is best for residue to remain anchored to the soil.

   B. Some unexpected or previously insignificant pest and weed problems may become quite severe with changes in farming practices unless the program can be changed to control them.

   C. Planting and cultivation equipment designed for use in high residue levels may be more difficult to set and maintain than other more conventional units.

3) Transition Period for Farmer and Land -

A. Farmer must learn how to farm using new methods and new types of equipment as well as the response of different soils to chemicals used. It would seem reasonable to expect from 3-5 years for a farmer to make these adjustments.

B. Soil will undergo a change in structure as tillage decreases and organic matter increases.

4) Soil Type - Minimum tillage is more readily adapted to well drained medium and coarse textured soils than to heavy textured soils which sometimes experience ponding problems and are more difficult to manage.

5) A minimum tillage program should start at or before harvest of the previous crop.

Table 5: Sample Operations

	Kansas Averages (1976)			
Operation	Fuel Consumption[1] (gal./ac.)	Work Rate[1] (ac./hr.)	(hr./ac.)	Custom Rate[2] ($/ac.)
Flowing	1.94	2.50	.40	6.18
Disking	.90	5.93	.17	3.50
Cultivating	.46	5.69	.18	2.75
Planting (Row Crop)	.54	6.24	.16	3.44
Field Conditioning/Springtooth	.63	8.88	.11	2.31
Harvesting	1.04	3.90	.26	9.28
Chiseling	1.03	6.18	.16	4.34
Oneway	.52	10.61	.09	3.60
Drilling (Small Grain)	.41	7.97	.13	2.70
Rod Weeding	.57	11.11	.09	2.00*
Undercutter	.65	8.78	.11	3.83
Spraying Chemicals	.29	7.67	.13	1.95
Shredding Residue	1.12	2.89	.35	5.50*

[1]Data obtained from compilation of Energy use records from 55 farms throughout Kansas in 1976.

[2]Average 1976 Kansas Custom Rates, Kansas Crop and Livestock Reporting Service

*Estimates

Note: Assume additional charge of $.50/ac. and .05 hr./ac. for any operation when fertilizer or herbicide is applied in conjunction with the operation. Add $1.00/ac. and .1 hr./ac. when both fertilizer and herbicides are applied.

Table 6: Chemicals

Fertilizer	Formulation	Price ($/ton)	Energy Content (gal Diesel/100 lb Prod.)
Anhydrous Ammonia	82-0-0	175.00	18.50
Ammonium Nitrate (Urea)	28-0-0	109.00	6.61
Ammonium Nitrate	34-0-0	130.00	8.82
Ammonium Phosphate	18-46-0	180.00	6.83
	10-34-0	181.00	3.88
	4-10-10	90.00	

Herbicides	Price ($/lb. formulated product)	Energy Content (gal. Diesel/lb. formulated prod.)
Atrazine 80W	2.25	.9
Milogard 80W	2.95	.9
Bladex 80W	2.75	.9
Ramrod 65WP	1.90	.9
Igran 80W	3.00	.9
2,4-D 4 lb. A.I./gal.	8.80/gal.	.15 gal Diesel/lb
Paraquat CL	39.50/gal.	.42 gal Diesel/lb
X-77 Spreader	11.45/gal.	
Roundup	63.20/gal.	

Retail price effective June 1, 1977 in Manhattan, Kansas. Energy values of chemical product obtained through personal communication, February 15, 1977 with Earle E. Gavett, Coordinator of Energy Related Research, USDA Economic Research Service, National Economic Analysis Division, Washington, D.C. 20250.

The following comparison of different tillage systems assumes these application rates per acre when application of the particular material is indicated.

Herbicide: 5.17 pounds Ramrod 65WP + 1.75 pounds Atrazine 80W.

1½ pt. Paraquat CL + .4 qt. X-77 spreader

1 pt. 2,4-D.

Fertilizer: 75 pounds N + 25 pounds P_2O_5.

Sample Farming System for Production of Grain Sorghum after Wheat in a Fallow-Wheat-Grain Sorghum Rotation

"Conventional" Tillage Systems

Program 1:	Cost ($/Ac.)	Energy (Gal. Diesel)	Time (Hr./Ac.)
Plow (Post Harvest)	6.18	1.94	.40
Disk (Fall)	3.50	.90	.17
Disk (Spring)	3.50	.90	.17
Field Condition + 65 lb./ac. 82-0-0	2.31	.63	.16
Plant	3.94	.54	.21
Spray-Ramrod/Atrazine	1.95	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	33.42	6.70	1.68
Fertilizer	11.87	15.72	
	45.29	22.42	
Herbicide	13.76	4.28	
	59.05	26.70	

Program 2:	Cost ($/Ac.)	Energy (Gal. Diesel)	Time (Hr./Ac.)
Disk (Post Harvest)	3.50	.90	.17
Chisel (Fall or Spring)+65 lb/ac. 82-0-0	4.84	1.03	.21
Disk (Spring)	3.50	.90	.17
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Spray Ramrod/Atrazine	1.94	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	29.76	5.16	1.33
Fertilizer	11.87	15.72	
	41.63	20.70	
Herbicide	13.76	4.28	
	55.39	25.16	

Program 3:			
Undercut (Fall)	3.83	.65	.11
Chisel (Spring) + 65 lb./ac. 82-0-0	4.84	1.03	.21
Disk	3.50	.90	.17
Springtooth	2.31	.63	.11
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Spray - Ramrod/Atrazine	1.95	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	32.40	5.54	1.38
Fertilizer	11.87	15.72	
	44.27	21.26	
Herbicide	13.76	4.28	
	58.03	25.54	

Program 4:	Cost ($/Ac.)	Energy (Gal. Diesel)	Time (Hr./Ac.)
Undercut (Post Harvest)	3.83	.65	.11
Undercut (Fall)	3.83	.65	.11
Undercut (Spring) + 65 lb./ac. 82-0-0	4.33	.65	.16
Rodweed	2.00	.57	.09
Springtooth	2.31	.63	.11
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Cultivate	2.75	.46	.18
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total- Field Operations	35.02	5.65	1.41
Fertilizer	11.87	15.72	
	46.89	21.37	

Program 5:			
Undercut (Post Harvest)	3.83	.65	.11
Undercut (Fall)	3.83	.65	.11
Undercut (Spring) + 65 lb./ac. 82-0-0	4.33	.65	.16
Rodweed	2.00	.57	.09
Springtooth	2.31	.63	.11
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Spray - Ramrod/Atrazine	1.95	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	34.22	5.48	1.36
Fertilizer	11.87	15.72	
	46.09	21.20	
Herbicide	13.76	4.28	
	59.85	25.48	

Program 6:	Cost ($/Ac.)	Energy (Gal. Diesel)	Time (Hr./Ac.)
Undercut (Post Harvest)	3.83	.65	.11
Undercut (Spring) + 65 lb./ac. 82-0-0	4.33	.65	.16
Rodweed	2.00	.57	.09
Springtooth	2.31	.63	.11
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Spray (1 pt. 2, 4-D)	1.95	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	30.39	4.83	1.25
Fertilizer	11.87	20.55	
	42.26	25.38	
Herbicide	1.10	.15	
	43.36	25.53	

"Reduced" Tillage Systems

Program 7:			
Chisel (Fall) + 65 lb./ac. 82-0-0	4.34	1.03	.21
Disk (Spring)	3.50	.90	.17
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Spray - Ramrod/Atrazine	1.95	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	25.76	4.26	1.16
Fertilizer	11.87	15.72	
	37.63	19.98	
Herbicide	13.76	4.28	
	51.39	24.26	

Program 8:	Cost ($/Ac.)	Energy (Gal. Diesel)	Time (Hr./Ac.)
Disk (Post Harvest)	3.50	.90	.17
Spray (Spring) 1.4 lb. Atrazine 80W + 233 lb./ac. 28-0-0	1.95	.29	.13
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Spray 5.2 lb. Ramrod 65WP	1.95	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	23.37	3.52	1.21
Fertilizer	17.58	19.03	
	40.95	22.52	
Herbicide	13.76	4.28	
	54.71	26.83	

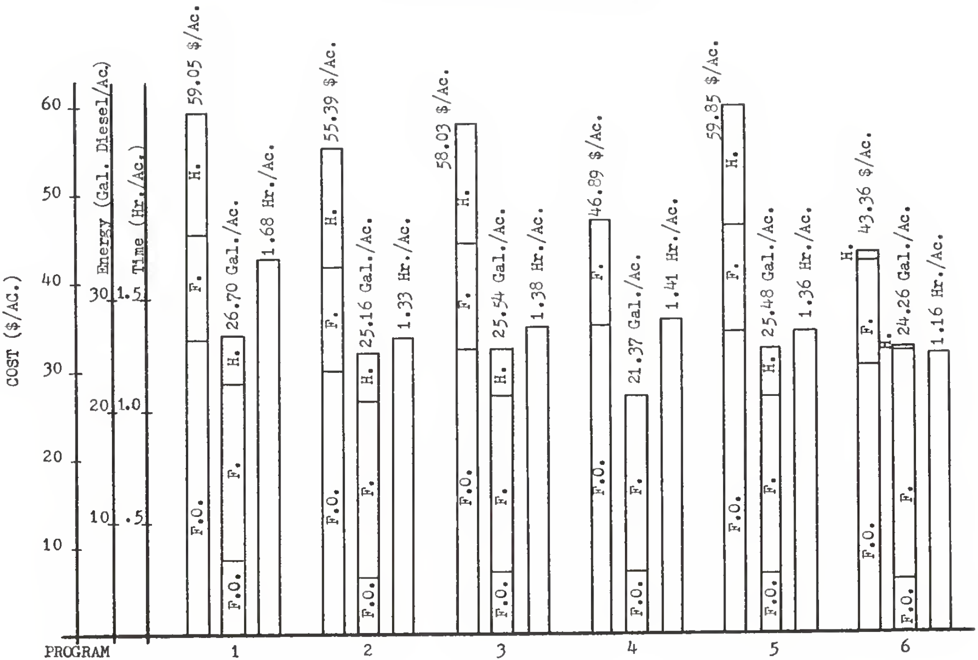
Program 9:	Cost ($/Ac.)	Energy (Gal. Diesel)	Time (Hr./Ac.)
Undercut (Post Harvest) + 65 lb./ac 82-0-0	4.33	.65	.16
Spray (Post Harvest) - 1.4 lb. Atrazine 80W	1.95	.29	.13
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Spray 5.2 lb. Ramrod 65WP	1.95	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	24.20	3.27	1.07
Fertilizer	11.87	15.72	
	36.07	18.99	
Herbicide	13.67	4.28	
	49.74	23.27	

Program 10:	Cost ($/Ac.)	Energy (Gal. Diesel)	Time (Hr./Ac.)
Undercut (Post Harvest) + 65 lb./ac. 82-0-0	4.33	.65	.16
Spray (Post Harvest) - 1 lb. Atrazine 80W	1.95	.29	.13
Spray (Spring) - .4 lb. Atrazine 80W	1.95	.29	.13
Plant + 54 lb./ac. 18-46-0	3.94	.54	.21
Spray - 5.2 lb. Ramrod 65WP	1.95	.29	.13
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	26.15	3.55	1.20
Fertilizer	11.87	15.72	
	38.02	19.28	
Herbicide	13.76	4.28	
	51.78	23.56	

Program 11:			
Undercut (Post Harvest), Spray 1.4 lb. Atrazine 80W + 65 lb./ac. 82-0-0	4.83	.65	.21
Plant + 54 lb./ac. 18-46-0 + Spray 5.2 lb. Ramrod 65WP	4.44	.54	.26
Cultivate	2.75	.46	.18
Combine	9.28	1.04	.26
Total - Field Operations	21.30	2.69	.91
Fertilizer	11.87	15.72	
	33.17	18.41	
Herbicide	13.76	4.28	
	46.96	22.69	

Program 12:	Cost ($/Ac.)	Energy (Gal. Diesel)	Time (Hr./Ac.)
Spray (Preplant) 1.4 lb Atrazine 80W + 1½ pt. Paraquat CL + X-77 Spreader + 233 lb./ac. 28-0-0	1.95	.29	.13
Plant + Spray 5.2 lb. Ramrod 65WP + 54 lb./ac. 18-46-0	4.44	.54	.26
Combine	9.28	1.04	.26
Total - Field Operations	15.67	1.87	.65
Fertilizer	17.58	19.03	
	33.25	20.90	
Herbicide	22.31	4.91	
	55.56	25.81	

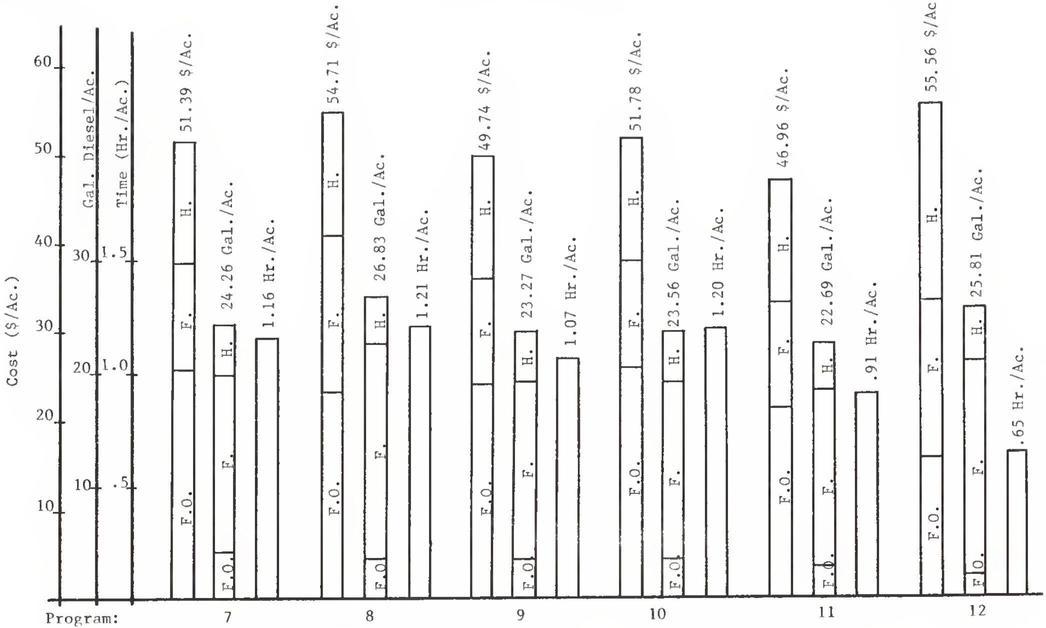
Conventional Tillage Systems



F.O. - Field Operations F. - Fertilizer H. - Herbicide

Figure 3.

Reduced Tillage Systems



F.O. - Field Operations F. - Fertilizer H. - Herbicide

Figure 4.

Table 7: Effect of weed control treatments on weeds and yield of sorghum, 1976, and multi-year yield averages, Minneola, Lundquist (1977).

Treatment	Active Ingredient lb/a	When* Applied	Cultivation	Yield bu/ac 1976	2-yr avg	3-yr avg	Weed Control % Broadleaf	Grassy
Propazine	2.0	PPI	1	49	--	--	100	95
Propazine	2.0	PPI	0	36	--	--	100	95
Propazine	2.0	PRE	1	46	46	--	87	95
Propazine	2.0	PRE	0	48	51	52	80	95
Igran	2.0	PRE	1	36	37	--	83	95
Igran	2.0	PRE	0	38	26	38	73	95
Igran + Propazine	1.6 + 0.4	PRE	1	45	43	--	83	95
Igran + Propazine	1.6 + 0.4	PRE	0	40	34	42	70	95
Ramrod	4.0	PRE	1	44	47	--	77	95
Ramrod	4.0	PRE	0	37	44	52	57	95
Ramrod/Atrazine	3.45	PRE	1	58	53	--	80	95
Ramrod/Atrazine	3.45	PRE	0	41	45	49	73	95
Ramrod + 2,4-D	4.0 + 0.5	PRE	1	40	41	--	87	95
Ramrod + 2,4-D	4.0 + 0.5	PRE	0	42	38	41	73	95
2,4-D	0.5	EP	1	50	45	--	87	95
2,4-D	0.5	EP	0	33	29	--	60	95
Banvel	0.25	EP	1	50	44	--	90	95
Banvel	0.25	EP	0	45	31	38	73	95
Atrazine + Oil	1.5 + 1.0 qt.	EP	1	49	48	--	83	95
Atrazine + Oil	1.5 + 1.0 qt.	EP	0	49	48	--	63	95
Handweed			1	53	51	--	100	100
Handweed			0	49	49	55	100	100
No Treatment			1	38	34	--	73	0
No Treatment			0	34	20	35	47	0
Bladex + Ramrod	1.5 + 2.0	PRE	0	45	--	--	80	0
Test Average				43			81	89
LSD .05				NS			16	NS

*PPI = Preplant -- incorporated prior to planting; PRE = Pre-emergence -- before sorghum or weeds emerged; EP = Early postemergence -- soon after sorghum and weeds emerged.

While both cultivation and herbicides add to the cost of production, information such as the experiment field study in Table 7 should be examined closely before making conclusions regarding the value of cultivation and herbicides. In comparing the different systems illustrated, the economics and energy efficiency of using anhydrous ammonia (82-0-0) as a source of nitrogen as opposed to other materials is quite evident. (Compare programs 7 and 8 or 9 and 12.) The advantages of combined operations are also evident if one compares programs 9 and 10 to 11. Such comparisons point out that in the future anhydrous ammonia will be the primary source of nitrogen and wherever possible spraying operations will be combined with other trips across the field.

Guidelines To a Successful Minimum Tillage Program

1) Pre-Plant Weed Control --

Weed control prior to planting is essential to conserve moisture and nutrients. There are many alternatives which can be used to achieve preplant weed control. Some of these are early planting date, mechanical tillage, contact herbicides, application of residual herbicides prior to weed emergence, or combinations of the above.

2) Herbicide Compatibility with Cropping Program --

Herbicides used must be compatible with the cropping rotation practiced. The best guide to selection and usage of label cleared herbicides is past experience and a general understanding of chemical weed control.

3) Management of Crop Residue --

The condition and amount of residue must permit acceptable performance of chemicals and planting equipment. Whenever possible, crop residue should remain attached to the soil and standing to facilitate ease of planter and cultivator operation as well as maximizing erosion control. Harvesting operations should leave residue uniformly distributed over the field and in a condition which will allow chemicals applied to reach the soil. In heavy residues use of high per acre gallonage of carrier may aid in getting chemicals down through heavy cover to the soil surface.

4) Soil Firmness --

The last cultivation or tillage operation should result in the desired soil firmness for planting the succeeding crop.

5) Surface Profile Determined at Previous Crop Harvest --

The surface profile should be determined by harvest time of the previous crop. Example: When using the ridge plant system the ridge profile should be formed by the lay-by cultivation.

6) Make Use of a Light Lay-by Cultivation --

Research in Kansas has shown that a light lay-by cultivation as late as possible usually results in a positive yield response. This cultivation should be light to avoid disturbing the herbicide treated soil layer. Cultivator sweeps or rolling cultivators are generally adequate.

7) Planned Crop Rotation Program --

Because minimum tillage relies on chemicals and one or two strategic tillage operations for weed control, weeds with growth pattern and herbicide tolerances very similar to those of the growing crop may become serious problems. A crop rotation program where similar crops are not grown more than two consecutive years can be quite effective in controlling such problem weeds.

8) Continual Program Evaluation --

As with any farming program, fields should be checked periodically to evaluate weed control, insect infestations, and crop development. A notebook of brief comments on these items can prove a very beneficial source of information when making future plans. To date there is no long-term conclusive evidence to indicate that insects and plant diseases are more or less of a problem with reduced tillage farming than conventional systems. Like conventional systems, careful evaluation and a plan will allow timely control of insect problems and diseases.

9) Program Flexibility --

In planning a minimum tillage program, one should continually evaluate the alternatives available to cope with unexpected problems which may arise throughout the crop year. Any alternative enabling a farmer to economically produce a crop is viable and should be considered. Example: If chemical weed control fails due to conditions such as excess rainfall some alternatives are: 1) supplemental application of a label registered residual herbicide; 2) use of a herbicide such as 2,4-D or Banvel on corn or sorghum and 3) mechanical cultivation.

INVESTIGATION

The concept of planting behind an undercutter plow began taking shape as work continued with a modified Buffalo planter. The modification involved adding a number of Buffalo cultivator parts to the basic Buffalo planter unit. The final version consisted of a slot shoe with 6 inch long cultivator sweep wings welded on both sides and a 24-26 inch cultivator sweep mounted between and to the rear of the slot shoes. (Figure 5) As ideas developed the logical concept seemed to be a planter which would till the entire field killing weeds and simultaneously planting a crop. Such a machine would have trash handling capability and the tolerance for varying soil firmness common to an undercutter plow. The machine would also be capable of conforming to the terrain in a manner very similar to existing flexibly framed undercutter plows.

A number of concepts utilizing compaction openers, disc openers, and etc. were developed into sketchs. All of these consisted of mounting presently available furrow openers and seed placement devices on the undercutter frame to operate 2-5 ft. behind the V-blades. Two major problems existed with all of these ideas. The first was depth control. Because the seed placement device was some distance behind the undercutter plow gage wheels, depth regulation from the plow frame would have been impractical. This left a choice of numerous depth gaging means dependent upon soil firmness. The second problem occurring with attachments mounted behind the plow frame, was the necessity of castering all items to allow turning while planting. Because of such problems, an unproven and rather radical idea was developed which would attempt to place seed in the void present beneath an operating undercutter blade. Although the outcome was doubtful, the promise of eliminating many of the problems encountered when adding existing

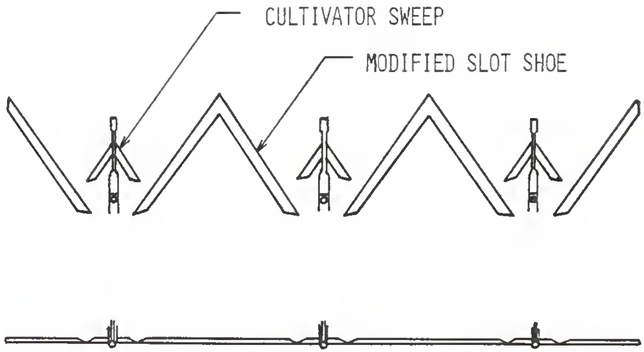


Figure 5. Modified Buffalo Planter

planter hardware to an undercutter plow made the idea attractive.

A preliminary discussion of the concept with Ray Richardson; Chief Engineer - Richardson Manufacturing Company, Incorporated, Cawker City, Kansas led to a cooperative agreement between Richardson Manufacturing Company and the Kansas State University Department of Agricultural Engineering. This agreement was signed December 30, 1976 and work began immediately.

DESIGN OBJECTIVES

The objectives of this project were to design, construct, and test on a production scale a minimum tillage planter adapted for use under conditions common to the High Plains region of the United States. This planter would perform as well as or better than existing minimum tillage planters while embodying meaningful design improvements over currently available planters. The basic design objective was to: build a planter capable of operating under any condition in which an undercutter plow would perform satisfactorily and also establish satisfactory crop stands under such conditions given adequate moisture for seed germination.

Specific design objectives were to build a planter with the following features:

1. Combine a mechanical tillage operation capable of killing existing vegetation with the planting operation.
2. Minimize the number of parts subject to wear and replacement.
3. Minimize the number of machine adjustments necessary to adapt to varying field conditions.
4. Perform equally well under cultural practices ranging from "Clean-Till" to "No-Tillage".
5. Operate in as much residue as an undercutter plow.
6. Having no greater sensitivity to varying soil firmness than an undercutter plow.

Because the testing was to be done in conjunction with the Federal Energy Administration Energy Conservation project scheduled to end July 29, 1977, the planter had to be field ready for spring planting.

DESIGN AND CONSTRUCTION

Design work for this project was informal and applied rather than theoretical in nature. Due to the time limitations of this project, it was imperative to use proven components where possible and to select only concepts which appeared to have a good chance of working.

A design size of 6-row with a 30-inch spacing was selected because of its popularity, transportability, and a size compatible with production scale operations. The Richardson AE 4-15-1 undercutter plow which is built on 60 inch centers worked quite well with the 30 inch row spacing allowing symmetrical spacing of seed drops on the undercutter blades.

While this machine used a nonconventional means of planting, it performed the basic four functions of any planting machine:

1. Metering and distribution of seed.
2. Placement of seed into soil with adequate moisture for germination.
3. Covering the seed with the proper amount of soil for existing conditions to prevent drying out and to allow emergence of a vigorous plant.
4. Establishing soil to seed contact adequate for quick germination and vigorous emergence.

No attempt was made in the investigation to develop or improve an existing seed metering and distribution system since the primary concern was seed placement.

Seed Metering

An International Harvester Model 500 Cyclo planter was selected as the metering and distribution system of this planter. The IHC Cyclo unit was selected because of its suitability for a wide variety of crops and a wide range of seeding rates. The hydraulically driven air supply system also allowed easy variation of air volume for the distribution system. (Figure 7)

The IHC Cyclo unit was mounted on the center frame of the three section plow and 250 gallon liquid fertilizer tanks were mounted on the right and left wing sections. Liquid starter fertilizer was chosen over granular materials in spite of slightly higher cost for ease of handling, calibration, metering and distribution.

John Blue liquid fertilizer squeeze pump was used for fertilizer metering and distribution. The fertilizer pump was mounted beneath the Cyclo unit and driven by the same drive (taken from the left inside gage wheel of the plow). A clutch was installed on the drive system to stop seed and fertilizer delivery when the plow was lifted out of the ground.

The Richardson AE-4-15-1 V-plow was modified to facilitate the addition of accessory attachments ahead of and behind the main machine frame. A 4 x 4 inch beam was mounted on the front of the right and left wing sections of the machine for mounting the coulter blade and compaction runner openers when the V-blades were not used. Special mounting pads were welded in place on the center section since the hitch frame prevented addition of the 4 x 4 inch beam. Two 4 x 4 inch beams were mounted on the rear of the plow frame for use in mounting openers and press wheels behind the machine blades. These beams were built as a frame with a front to back spacing of approximately 20 inches and were fastened to the plow frame by hinges which allowed floating or clamping for rigid operation. These frames were folded upward 90° for highway transport on a low-boy implement trailer. The plow hitch was modified as shown in Figure 6 for removal. This modification was necessary to allow an overall width of less than 8 foot for highway transport on the implement trailer. (Figure 8)

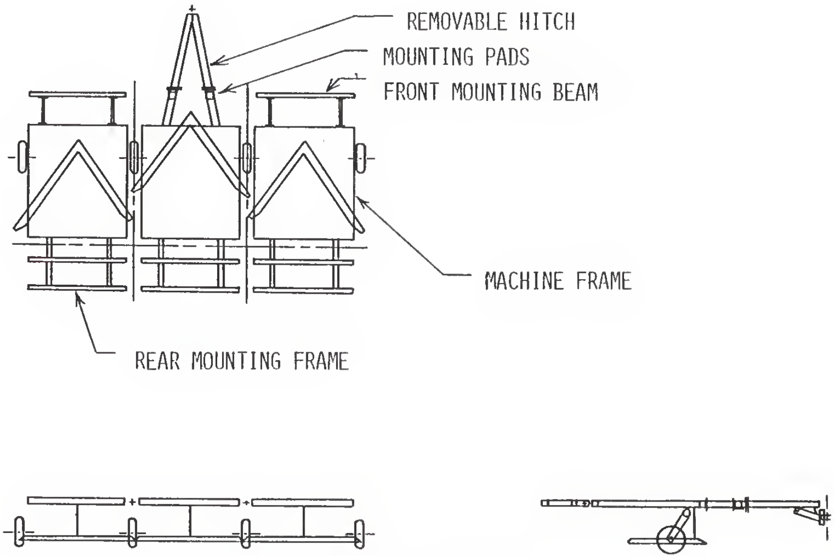


Figure 6. Modified Richardson AE-4-15-1 Undercutter Plow

Figure 7. Planter Unit - Field Ready.


Figure 8. Planter on Transport Trailer.

Seed Placement

Placement of the seed in moist soil is an essential function of all planters which rely on existing soil moisture to germinate the seed. In the High Plains region of the United States spring planted crops are usually planted in soils with adequate moisture for germination and emergence of the crop. There are, however, seasons when the soil moisture is marginal for germination and emergence of a crop. A number of practices have been employed to make the best of such marginal conditions. The application of supplemental water in the immediate seed zone at planting time and the practice of increasing soil bulk density in the immediate vicinity of the seed to insure capillary action and draw additional moisture into the seed zone are examples of such practices. Increasing the bulk density in the vicinity of the seed is accomplished by using compaction runners to form a small seed trench and/or the application of pressure by press wheels to the soil immediately adjacent the seed. The use of compaction runners is generally the best way to achieve this soil compaction and the press wheels are then relied upon primarily to establish good soil to seed contact.

Although provision was made for the use of water injection on this planter, it was never used. A good deal of time and effort was devoted to the design of a compaction opener which mounted below the blade and made a small trench for the seed about 1/4 to 1/2 inch below the cutting plane of the blade and 1/2 to 3/4 inch in width. The openers were attached to the blade support with brackets welded to the blade support and connected to the openers by 5/16 inch diameter roll pins which allowed quick removal and height adjustment of the openers. The brackets were designed to give three mounting locations with 1/4 inch vertical adjustment between holes for a total of 1/2 inch adjustment. (Figures 9, 10, 11, and 13)

Figure 9. Compaction opener mounted below V-blade.

Figure 10. Seed trench formed by compaction openers.

Figure 11. Compaction opener, fertilizer delivery tube, and cover control rods.

Figure 12. Press wheel assembly mounted on planter.

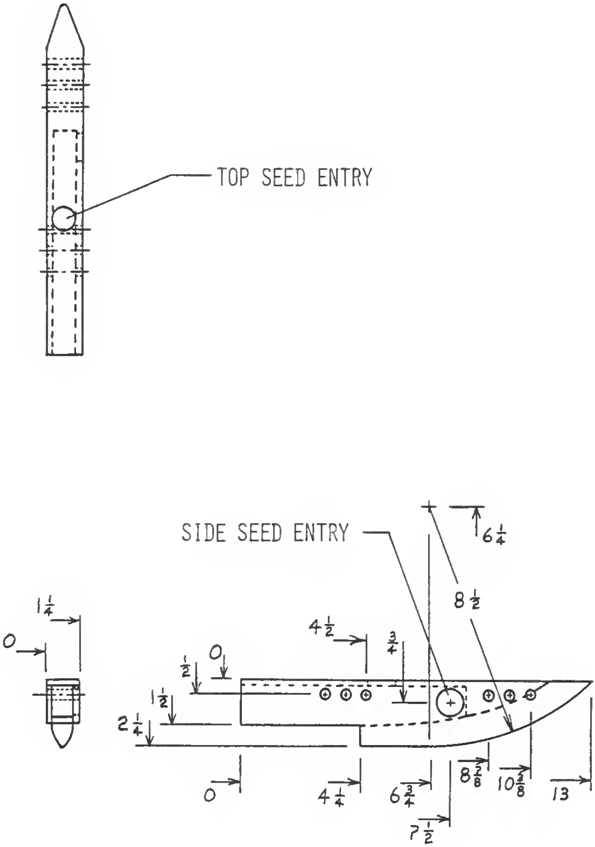


Figure 13. Compaction Opener

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Cover Depth

Because the V-plow is a soil cutting tool dependent upon cutting resistance of the soil to shear off roots and other plant materials in the soil, it has a practical minimum depth of 2 1/2 to 3 1/2 inches under most conditions. Optimum cover depths for most spring planted crops are from 1 to 2 1/2 inches. This means that if seed is placed at or below the cutting depth of the V-blade some steps must be taken to reduce the depth of soil covering the seed. When using this method of planting, cover depth control requires moving aside a portion of the soil overburden. This can be done by directing the flow of soil as it flows over the blades or by using a press wheel to compact and force aside excess soil over the seed row. Of the two, controlling the flow of soil after it leaves the blade is most desireable.

Two rods 14-16 inches long were attached to the blade support and extended upward, rearward, and away from the seed row on each side to control cover depth as shown in Figure 11. Although in operation, the soil could be seen to have lateral movement when passing over the rods, the final effect was inadequate and cover depth was usually on the deep side.

Press Wheel Assembly

The press wheel assembly for this machine was designed based upon previous experience with the Buffalo Flex planter and other planters. The design utilized three press wheels and a tine harrow drag. The press wheel assembly used a 1 x 12 inch press wheel running vertically between and about 8 inches ahead of two 1.25 x 13 inch press wheels angled about 45 degrees (22.5 degrees out at the top) and about 3 inches apart center to center at the bottom. (Figure 14) The objective was to establish good seed to soil contact with the front press wheel and to close the trench left by the center

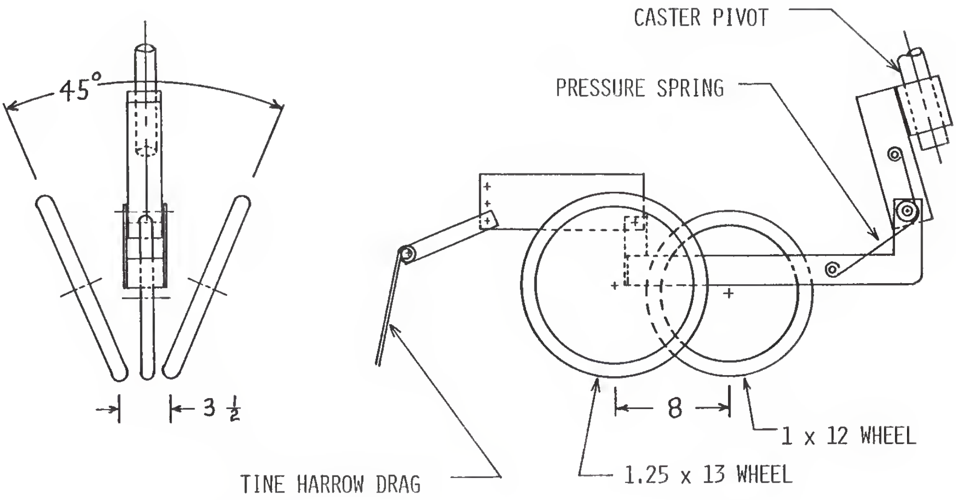

Figure 14. Triple press wheel assembly

press wheel using the two angled press wheels. A tine harrow drag behind the press wheels then passed over the row breaking clods and mulching to retard moisture loss. A chief advantage of the two angled press wheels used to close and firm the seed trench is that, unlike disc covers and drags, the wheels were practically insensitive to crop residue and varying soil moisture. These are major problems when setting and operating planters equipped with covering discs or drags (Figures 12, 14).

Seed Delivery System

Initially the seed delivery tubes were of 5/8 inch I.D. vinyl tubing. These were routed down the back of the blade support standard and underneath the blade support to the compaction runner. Other parts mounted under the blade support were the monitor sensors and a section of screen wire tubing making up the last 10 inches or so of the delivery tube. The purpose of the screen wire tubing was to allow relief of the conveying air and to deaccelerate the seed before it left the tube reducing the tendency to bounce out of the row - a common problem with planters such as the Cyclo which use air to convey seed to the seed discharge (Figure 15).

Coulter Blade and Compaction Runner Openers

As mentioned earlier a set of openers was built for use of the machine without V-blades. High moisture conditions or the lack of growing vegetation can make the use of blades either impractical or undesireable in which case the blades could be removed and the coulter blade and compaction runner installed. This particular opener was made by extending the arm on which the coulter spindle is welded and mounting an Acra-Plant cutting edge on a specially designed body immediately behind the coulter blade. When mounted on the 4 x 4 inch beam added to the front of the plow

Figure 15. 5/8 I.D. vinyl seed tube, monitor, screen wire tube.

Figure 16. Coulter and compaction runner opener.

frame, these units would place seed about 24 inches in front of the plow gage wheels. The flexible plow frame provided conformability to lateral terrain variations and good depth regulation across the width of the machine. Time did not permit testing of these openers (Figures 16 and 17).

Figure 17. Top view of coulter and compaction opener.

Figure 18. Compaction opener and side entry of seed delivery tube.

TESTING AND REDESIGN

The original opener design used side entry of the seed delivery tube which allowed mounting the seed delivery tube below the blade support as shown in Figure 18. Problems were encountered with this design since soil wedged between the seed tube, the compaction runner, and the blade support created a buildup of soil and plant material beneath the blade support which kept the machine from penetrating the soil (Figure 19).

The first problem encountered with the side entry, was soil building up alongside the opener ahead of the seed delivery tube pinching it off, stopping seed delivery. An angle iron shield was fastened to the blade support and opener mounting brackets immediately in front of the seed delivery tube (Figure 20). The shield, which extended down to within 1/2 to 3/4 inch of the blade cutting depth, kept soil from closing the seed tubes off but soil buildup continued forcing the blades out of the ground after only 1 or 2 acres of operation. Although the protective shield was 1/2 to 3/4 inch above the blade cutting depth which would appear to clear the sheared soil surface, the problem seemed to be generated by the opener. As the opener passed through the soil it forced the soil immediately adjacent outward and upward accumulating in front of the shield.

The succeeding revision involved removing the shield, altering the opener to allow delivery of the seed from above, and moving the seed delivery tube from below the blade support to a location above and behind the support as shown in Figure 21. In this particular situation, the rear edge of the blade was extended 3 inches upward and rearward extending the plane of the blade. This extension of the blade increased the soil lift by about 1 1/2 inches. This was not really necessary to provide protection of the seed tubes. An extension of the blade support to the rear would have provided adequate

Figure 19. Soil buildup below blade caused by compaction openers.

Figure 20. Angle iron shield to protect seed tube.

protection of the tubes from above.

Moving the seed tube and air diffuser to the top of the blade support eliminated problems with plugging caused by restrictions, but the soil build-up below the blade on either side of the opener continued to be a problem. Operating under conditions very similiar to those previously encountered, the machine was now able to plant 3 to 5 acres with the angle iron shield removed before the soil buildup below the blade and support held it out of the ground (Figure 19).

After trying several alternatives for mounting an opener below the blade, a decision was made to remove the opener. Obviously, compaction and the resulting increase in soil bulk density below the cutting plane is less than than that below a compaction opener. It was hypothesized that this might still be better than no compaction and proven to be adequate for establishing a stand when press wheels are used. Based upon this reasoning, the opener was removed and the seed delivery tube extended to reach within about 1/2 inch of the cutting plane. This configuration was used to plant the last four plots with good results where soil moisture was adequate for planting by any other method (Figure 22).

Seed Delivery Tube

As previously mentioned, the initial selection of seed delivery tubing was 5/8 inch I.D. clear vinyl tubing. This worked reasonably well for sorghum; however, difficulties were encountered where the tubing laid across square corners on the machine frame or made abrupt bends. When ambient temperatures climbed, the tubing was dimensionally unstable and flattened restricting seed flow. After the first two field trials (where corn was planted) the vinyl tubes were replaced by 3/4 inch I.D. SAE 100R7 hydraulic hose with a polymeric inner tube (Synflex 3130). This material had excellent

Figure 21. Extended blade with seed tubes mounted above the blade support and entering the compaction opener from above.

Figure 22. Seed delivery tubes with compaction openers removed.

dimensional stability and was never plugged in the remainder of the tests. The bends required in routing the seed tubes behind the blade support were sharper than could be made without crushing the hydraulic hose. Three-fourths inch I.D. sweat copper pipe fittings were used to make the sharp bends. The use of 90 degree street ells allowed making corners with smooth radi. The copper tubing was used from the vertical shank to the air diffuser and from the diffuser through the final bend preceeding the discharge. After making this bend a piece of 5/8 inch I.D. vinyl tubing was used to convey the seed to within 1/2 inch of the ground. The tubing was slit into several strips for the last two inches or so to prevent plugging with soil and to allow further diffusion of the air (Figure 21,22).

Press Wheels

The triple press wheel design like many designs was better in concept than actual field performance. Although the design was used on a majority of the acres planted, it did not have adequate trash handling characteristics. Under drier clody conditions, it did not adequately firm and mulch the seed row.

The most troublesome type of crop residue encountered was corn and sorghum stalks. The plugging was such a problem at the Kansas River Valley Field that it was necessary to raise the front press wheel about 2 inches to allow passage of the corn stalks. Some problems were also encountered with tumble weeds which lodged in front of the press wheel frame.

The 50 pound load on the press wheels was adequate for mellow soils; however, when planting firmer soils or sodded ground this pressure was inadequate to break up clods and establish good soil to seed contact (press wheel pressure was measured at the center of the rear press wheel).

Figure 23. Testing of 7 x 20 zero pressure, 3 1/2 x 26 convex steel, and the triple press wheel design.

Figure 24. 3 1/2 x 26 convex steel press wheel

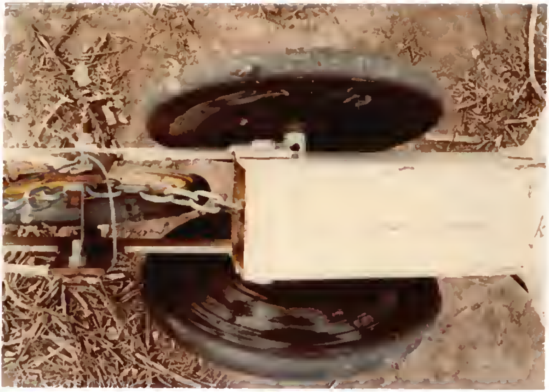

Figure 27. Top view of triple press wheel design.

Figure 28. Laboratory testing of seed placement.

The press wheels were mounted on casters and pressure springs were used to apply additional force. Tine harrow drags were installed on all of the press wheels very much like those on the triple design. The spring tension on all press wheels was adjusted to produce a force of approximately 90 pounds at the center of the single press wheels and at the center of the rear wheels on the triple design.

As testing of the planter progressed the potential for using press wheels to control the cover depth became apparent. The original press wheel design did not include using the press wheels to control cover depth. Consequently the triple press wheel design had very little effect on depth of soil covering the seed.

One consideration in selection of the 3 1/2 inch convex steel press wheel was its potential for controlling cover depth. One of the ways the convex press wheel controls cover is by acting as a wedge in the soil above the seed. If pressure on the press wheel is increased, the soil over the seed is compacted more and forced aside reducing the cover depth. Another way in which press wheels can be used to control cover depth is by using the press wheels to control the flow of soil which has been disturbed by an opener. All press wheels used in the comparison tests were mounted behind the blades far enough so that soil passing over the blades had come to rest before reaching the press wheels. Because of this the press wheels controlled cover depth only by varying the pressure applied to the soil.

Evaluation of the three press wheel types was subjective rather than objective in nature and was made on the basis of:

1. Soil firmness over and adjacent to the seed
2. Residue handling ability
3. Depth of soil covering the seed

Comparisons of the three press wheel designs were made only on the Larry Walker farm. Weather conditions for the one month period following planting were quite dry followed by a severe hail about August 1, 1977 prior to re-examination of the plots on August 12, 1977. The dry weather conditions prevented emergence of all but a small percentage of the grain sorghum and the severe hail on both sorghum and soybeans planted at the location rendered population counts made August 12, 1977 only estimates at best.

Observations however indicated that the triple press wheel design and the 26 inch diameter deep furrow drill press wheel gave adequate soil compaction and left a desireable seed cover. The large diameter convex shaped press wheel performed noticeably better than the other two designs. The convex shaped press wheel had excellent trash clearance characteristics and did an excellent job of reducing cover depth by 1 to 1 1/2 inches when operating the V-blades at a 3-3 1/2 inch depth.

The triple press wheel design had problems clearing heavy trash residue and Russian thistles due to its small diameter. This design had some effect on reducing the cover depth. Examination of press wheel performance by digging behind the rows indicated that soil in the row was firmest directly over the seed in all plots using the triple design. This firm area of soil was usually from 1 to 1 1/2 inches deep.

While not fully investigated or understood in this investigation the features of the triple press wheel concept appear to warrant further investigation. The design was intended to provide a firmly packed zone 1/2 to 1 1/2 inches deep over the seed and the remainder of the cover depth loosely packed above this zone. Examination by digging indicated that performance was approximately as desired (Figure 29).

The 7 inch wide, 20 inch diameter zero pressure press wheel had

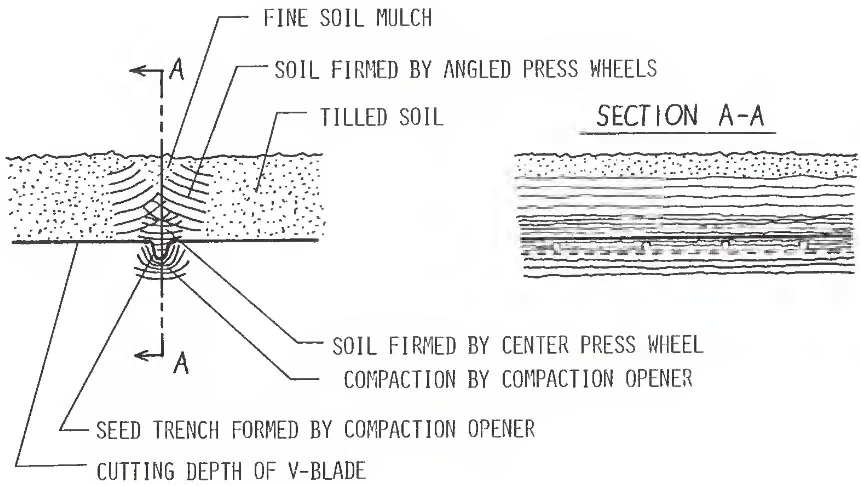

Figure 29. Theortical performance of triple press wheel design and the compaction opener.

adequate trash clearance and performed acceptably in the sandy soil; however, its performance did not indicate desireable characteristics for tighter soils which often require press wheels to brake up clods left in the row to provide an adequately firmed and mulched seed cover. This design had practically no effect upon reducing cover depth. The press wheels ranked in order of performance as indicated by observations while testing are: (1) 26 inch diameter convex steel press wheel, (2) triple design, and (3) the 7 inch wide 20 inch diameter zero pressure press wheel.

Seed Placement

Initial testing of the seed distribution and placement means was made in the laboratory using a planter test track designed to evaluate seed placement of planters (Figure 28). The track speed could be varied from about 2 to 8.8 fps. (1.5 to 6 mph.). The purpose of this laboratory test was to develop an opener which would confine seed to the row after leaving the seed tube.

The test was begun with the track running approximately 7.5 fps. (5 mph.) and the planter air supply set at a pressure of 8 inches (water column). The top and sides of the opener were covered with canvas extending down to the test track and rearward about 10 inches behind the point of discharge as shown in Figure 30. Thie would have been replaced by a steel fender attached to the rear of the opener if it had proven acceptable. This confinement shield made only a small improvement over the unshielded opener. The next step was to reduce the air supply pressure. Using an air supply pressure of 4-5 inches of water, it was possible to confine both corn and soybeans to an acceptable row width on the track. Even with the reduced pressure, it was impossible to confine sorghum seed to a row.

The decision was then made to install a section of screen wire tube as the final 10 to 12 inches of the delivery tube (Figure 15). This tube was made of 3/32 inch mesh fly screen. When this means of pressure relief was used it was possible to get an acceptable row width of sorghum, corn, and soybeans using the minimum recommended air pressure of 8 inches of water and the canvas confinement shields. The next approach used was to partially slow the seed using the air release tube and chain links hung at the rear of the opener to stop the seed (Figure 31).

The screen wire air diffuser proved an unacceptable design because it was easily crushed by soil plugging ahead of the opener. It was also easily crushed when lowering the planter into the ground without forward motion. The screen wire tubes were replaced by IHC Cyclo Diffuser (a perforated section of plastic pipe) shown in Figure 21. Although it was possible to confine the seed to a row using the air diffusers and chain links described, the seed velocity was high enough to damage some delicate seeds such as soybeans.

In a telephone conversation with Mr. Duey Davis of the International Harvester Kansas City Branch office, he stated that the Cyclo unit would accurately meter seed at air pressures as low as 2 inches of water. However, he had no experience to indicate the effect on seed spacing in the row.

Field testing at pressures of 4 to 5 inches of water indicated a reduced seed velocity and relatively even seed spacing for sorghum even when the openers were removed and seed discharged into the seed tube without confinement.

In order to test the effect of air pressure upon seed spacing a test was made by running the planter on a smooth road and evaluating the seed spacing. Tests were also conducted to prove that seeding rates did not vary from row to row with decreased air pressures. The placement test was run at a ground speed of 5 mph. and a seeding rate of 13,000 seeds per acre.

Figure 30. Testing of seed confinement methods on planter test track.

Figure 31. Chain links hung in opener to confine seed to the row.

The tests were made at air pressures of 2 and 7 inches (water column). The planter was operated with the blades approximately 1/2 inch above the road surface (Approximating actual seed placement upon the shear plane as shown by Figures 32, 33, and 34). See Table 8 and 9 for seed placement and seeding rates.

Figure 32. Testing seed placement on a smooth road surface.

Figure 33. Seed placement with 7 inches (water column) air supply pressure.

Figure 34. Seed placement with 2 inches (water column) air supply pressure.

Table 8: In Row Seed Placement With Varying Air Pressure

Pressure: 2 inches water column
Length of Run: 20 feet
Ground Speed: 5 mph.
Seeding Rate: 13,000 seeds/acre

Row #	Total Seeds Deposited	Singles	Doubles	Triples
1	20	13	2	1
2	22	16	3	0
3	22	16	3	0
4	20	15	1	1
5	22	18	2	0
6	23	17	0	2

Mean: 21.5
Standard Deviation: 1.22
26% Multiple Deposition

Pressure: 7 inches water column
Length of Run: 20 feet
Ground Speed: 5 mph.
Seeding Rate: 13,000 seeds/acre

Row #	Total Seeds Deposited	Singles	Doubles	Triples	Four
1	23	19	2	0	0
2	24	16	2	0	1
3	23	14	3	1	0
4	19	13	3	0	0
5	22	18	2	0	0
6	21	15	3	0	0

Mean: 22
Standard Deviation: 1.79
28% Multiple Deposition

Note: Multiple seed deposition indicates seed spacing of less than 2 inches between seeds.

Table 9: Row to Row Planter Calibration With Varying Air Pressure

36 Hole Seed Drum

1029 ACCO Sorghum Seed

Rate: 13,000 seeds/acre

Ground Speed: 5 mph.

Row #	5 inches water column Seeds	2 inches water column Seeds
1	285	269
2	271	275
3	284	267
4	262	268
5	288	268
6	286	271
Mean:	279.33	269.67
Standard Deviation:	10.43	2.94

Power Requirements

A John Deere tractor loaned to Kansas State University Department of Agricultural Engineering by Deere and Company for use in energy conservation demonstrations was used to plant the plots for Bob Bohannon and Jim Welker.

This tractor was instrumented to measure fuel consumption, draft, wheel slippage, and travel speed while operating under field conditions. Although this datum is fairly accurate (commensurate with field conditions) descretion should be exercised in applying the numbers to other cases since it is representative only of conditions encountered on particular plots. Of the measurements taken, the draft is probably the least accurate since problems were present resulting in some unstability although no more than 10% drift was ever indicated. Draft measurements are time integrated values not peak or averaged values (Figure 35).

The data indicate the realitive draft of both the Buffalo planter equipped with modified slot shoes and the undercutter planter.

See draft data in Tables 10, 11, 12, and 13.

Figure 35. Testing power requirements of undercutter planter with instrumented John Deere 4630 tractor.

Table 10: Planter Power Requirements in Alfalfa Sod

	Draft (lb.)	Fuel (Gal)	% Slippage	MPH	Ac/Hr	Gal/Ac
Undercutter:	4850	.37	17.55	4.71	8.56	1.48
	5300	.29	18.05	4.51	8.20	1.44
	6000	.36	15.43	5.05	9.18	1.30
	5100	.34	18.71	4.49	8.16	1.40
	4800	.39	16.96	4.72	8.58	1.34
	5000	.34	17.63	4.66	8.47	1.31
	5400	.23	18.21			1.45
	5700	.37	18.88	4.58	8.33	1.42
Mean ---------------	5269		17.68			1.38
Standard Deviation -	420		1.10			.06
Buffalo:		.32	6.49	5.30	9.64	.796
		.51	3.29	5.29	9.62	.796
		.42	4.90	5.28	9.60	.714
		.25	4.99	5.50	10.00	.692
		.48	4.62	5.43	9.87	.706
Mean ---------------			4.86			.73
Standard Deviation -------			1.14			.04

Table 11: Planter Power Requirements in Brome Sod

	Draft (lb.)	Fuel (Gal)	% Slippage	MPH	Ac/Hr	Gal/Ac
<u>Undercutter</u>:	5550	.17	15.84	3.46	6.29	1.68
	5690	.20	13.0			1.77
Mean -----------			14.42			
<u>Buffalo</u>:		.20	4.63	4.42	8.04	.82
		.14	6.76	3.93	7.15	1.12
		.22	5.65	4.24	7.71	.84
Mean ----------------------------------			5.68			.93
Standard Deviation -------------------			1.07			.17

Table 12: Planter Power Requirements in Wheat Stubble

	Draft (lb.)	Fuel (Gal)	% Slippage	MPH	Ac/Hr	Gal/Ac
<u>Undercutter</u>:	2550	.02	4.50	4.01	7.29	1.14
	3610	.24	8.72	3.88	7.05	1.06
	3850	.39	7.46	3.92	7.13	1.17
	4050	.44	11.45	3.76	6.84	1.21
	4750	.45	13.79	3.63	6.60	1.25
	3850	.43	10.67	3.78	6.87	1.18
Mean ------------	3777		9.43			1.17
Standard Deviation	716		3.27			.06
<u>Buffalo</u>:		.27	3.15	4.17	7.58	.69
		.26	4.98	3.73	6.78	.74
		.23	2.85	4.33	7.87	.62
Mean -------------------------------			3.66			.68
Standard Deviation -----------------			1.15			.06

Table 13: Planter Power Requirements in Sorghum Stubble

	Draft (lb.)	Fuel (Gal)	% Slippage	MPH	Ac/Hr	Gal/Ac
Undercutter:	4500	.26	9.64	5.33	9.69	.99
	4300	.27	10.39	5.23	9.51	.99
	4400	.25	10.15	4.95	9.00	1.01
	4300	.23	11.66	5.25	9.55	1.07
	4300	.12	8.75	5.80	10.55	.97
	4600	.14	10.26	5.14	9.35	1.01
	4500	.31	9.81	4.18	7.60	1.09
	4300	.34	11.57	4.12	7.49	1.16
	4500	.34	10.78	4.09	7.44	1.11
	5000	.17	13.18	4.12	7.49	1.17
	4500	.16	12.17	5.19	9.44	1.02
Mean ------------	4473		10.76			1.05
Standard Deviation	205		1.28			.07
Buffalo:		.22	3.24	5.58	10.15	.59
		.21	2.54	5.65	10.27	.58
		.23	3.62	5.58	10.15	.62
		.23	2.99	5.61	10.20	.60
		.23	3.28	4.41	8.02	.67
Mean ------------------------------			3.13			.61
Standard Deviation ----------------			.40			.04

DISCUSSION OF RESULTS

Results of the investigation are manifest in the final design of the planter. Investigation and development was in the four general areas of: (1) Seed Distribution, (2) Seed Placement, (3) Seed Cover, and (4) Soil Firming.

Seed Distribution

An IHC Model 500 Cyclo planter unit was used for seed metering and distribution. Both testing and crop emergence in plots indicated that seed spacing was as uniform as with other planters although not perfect. At the outset, farmers and dealers familiar with the Cyclo planter expressed concern that seed distribution would be bunched and uneven if the seed tubes were routed in a serpentine manner as required by this design.

Some problems with seed bunching did occur using the original 5/8 inch I.D. vinyl tubing. However after switching to a 3/4 inch I.D. polymeric tubing (Synflex 3130-12 hydraulic hose) and eliminating other restricted areas in the delivery tube, no further problems were experienced with seed bunching or with the seed tubes plugging when planting sorghum or soybeans. Testing of the seed distribution system using sorghum at the rate of 13,000 seeds/acre and a ground speed of 5 mph., indicated bunching or uneven distribution was no more of a problem than with other planters. These tests were conducted with air pressures ranging from 2-7 inches (water column).

Original concerns over the irregular path of seed tubes were found to be unjustified. Based upon the tests conducted and actual field usage, the seed distribution system requirements can be met with smooth non-collapsing 3/4 I.D. seed tube and an air supply with a pressure of 2-4 inches (water column) at the seed tube inlet. With this combination, seed tube routing should have very minimal effects on distribution.

Cover Depth

As indicated by prior experience with undercutter plows, it is impractical if not impossible to operate at depths of less than 2 1/2 to 3 inches; however, under most conditions, undercutter plows can be set to maintain a depth of 3 to 4 inches. Under conditions normally encountered in spring planting in the Great Plains region, optimum seed cover depth is usually from 1 1/2 to 2 1/2 inches. Since seed is placed at the level where the V-blade cuts through the soil, it is necessary to reduce the soil overburden to achieve optimum cover depth.

Regulation of cover depth was attempted though the use of press wheels and 1/2 inch diameter rods about 16 inches in length fastened about 2 inches to each side of the row and angled upward and outward. Although the rods did pick up the soil after it cleared the rear edge of the blade, they were unable to direct a significant amount of soil away from the seed row.

The triple press wheel arrangement had very little effect on the depth of cover; however, the 3 1/2 x 26 inch convex shaped press wheel (with 90 pounds of soil to wheel pressure) did have a noticeable tendency to reduce the cover depth.

The testing fostered three untried ideas which should be superior to the ideas tested even if they are inadequate when used by themselves. These were (1) Replacement of the 1/2 inch diameter rods by 1/4 by 2 1/2 hot rolled flat mounted edgewise on each side of the seed row angling upward and away, should move a good deal of soil away from the seed row. (2) Increasing the soil to wheel pressure on the 3 1/2 x 26 inch convex shaped press wheel from 90 to 150 to 200 pounds. This was tested by standing on the press wheel support frame and

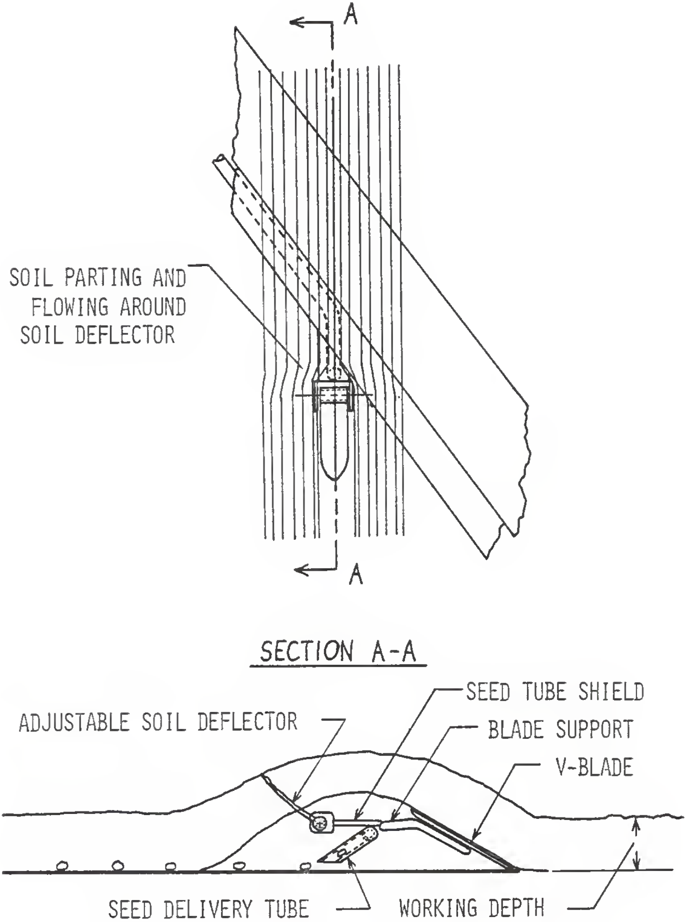

Figure 36. Proposed cover depth control.

had the effect of reducing soil cover depth by 1/2 to 1 inch. (3) An obstruction mounted on the rear edge of the blade angled upward and rearward. This device would cause the soil to part and flow to either side of the crop row. See Figure 36 for illustration of this concept. Although crop emergence on all plots was acceptable, better depth control is needed for a planter of this type than was achieved in the limited testing.

Seed Placement

Considerable time and effort was devoted to developing a small compaction runner mounted below the blade support and extending below the cutting edge of the blade. The idea was to form a small trench below the V-blade shear surface for accurate seed placement allowing very little lateral variation along the row.

The compaction runners were designed with enclosed top and sides extending 6 to 8 inches behind the forming edge of the runners to insure that the seed came to rest in the trench. Placement of seed in the formed trench was very good with the openers even at air pressures of 6 to 8 inches (water column). The concept of an opener mounted behind and below the blade was finally abandoned because a way for preventing soil build up in front and to either side of the opener was not found. While testing the openers, it was not possible to plant more than about 3 acres before soil would build up enough to hold blades out of the ground.

After removing the openers the seed tubes were extended back at the seed drop locations and downward to within about 1/2 inch of the shear plane level. The air pressure was also reduced to between 3 and 4 inches (water column). This arrangement performed just as well as the previous opener device and eliminated the problems with soil build up allowing non-stop operation. Examination of the soil in the seed row immediately following planting revealed no noticeable difference in soil to seed contact between the two methods. Likewise no difference in crop emergence was noted between the two methods of seed placement.

Testing the seed spacing within the row revealed no difference when using air supply pressures of 2 and 7 inches (water column). The seed spacing was not extremely uniform at any of the pressure levels which was apparently due to the long tubes between the metering device and final discharge point. This non-uniformity should not be unacceptable for field crops such as grain sorghum, soybeans, and corn. If it were critical to obtain nearly uniform seed spacing, it would probably be necessary to use a metering device located much closer to the discharge point - possibly a plate type planter with no more than 2 feet between metering device and discharge.

Soil Firming - Press Wheels

The selection and use of press wheels on grain drills and row crop planters varies widely between crops, geographical location, and individual operators. Press wheels on most planting machines function to some degree in four general areas. These are: (1) establishing soil to seed contact, (2) breaking up clods and mulching soil above the seed to prevent rapid moisture evaporation, (3) reducing covering depth to a relatively uniform depth, and (4) increasing soil bulk density immediately adjacent the seed to enhance capillary movement of moisture to the seed zone.

In the High Plains region of the U.S. the use of press wheels is considered by most farmers to be more important for spring planted row crops than for fall planted small grains. While practically all farmers feel that press wheels are a necessity for row crop planters, there are some who feel that press wheels have no real advantage for fall planted small grains and a few who don't even use them. Grain drills not equipped with press wheels often employ a 12 to 18 inch long "drag" made of chain and two or three large diameter rings (3 to 4 inches in diameter of 3/8 to 1/2 inch diameter rod) which serve to cover the seed with a layer of mulched soil.

Most important of these functions is the establishment of good soil to seed contact which promotes soil to seed moisture transfer promoting rapid germination and vigorous emergence. The importance of press wheels to mulch soil and eliminate voids in the soil covering the seed is reflected in the emphasis placed upon press wheels for spring planted crops. The rate of evaporation is usually much higher in the spring planting season than in the fall and consequently it is more important to mulch the soil cover to minimize evaporation.

A six toothed tine harrow drag about 12 inches wide was used behind the press wheels to leave a mulched soil cover over the row. The drag harrows did a good job of mulching however they usually had a tendency to add to the already adequate cover.

The triple press wheel design performed the intended function of providing a firm seed cover about 1 inch deep and 1 inch to each side of the seed covered by a loose soil mulch 1 to 2 inches deep. This developed excellent soil to seed contact, increasing the capillary action immediately adjacent to the seed, and the loose soil cover served to restrict evaporation. In firmer soils the press wheel loads of approximately 60 pounds were inadequate to break up clods and leave a well mulched soil cover. In mellower soils the small diameter press wheels sank deeper into the soil causing them to slide when they encountered residue such as corn stalks or tumble weeds. When press wheel pressure was increased for firmer soils, the sinkage and trash clogging problems were worsened. Performance of the triple press wheel arrangement in mellow soils without heavy residue was excellent and from all indications the same arrangement with about 20 inch diameter wheels would give excellent performance under a wide range of conditions. The triple design had only a small effect on the cover depth. If it is necessary to control cover depth with press wheels, selection of a press wheel such as the convex wheels tested would be a much better choice than the three narrow wheels.

The 26 inch diameter, 3 1/2 inch wide convex steel press wheels tested gave excellent results; however, they should be followed by some type of drag in most cases to break up the smooth surface which they leave to prevent soil baking and crusting. While the concave furrow left by convex faced press wheels is helpful in reducing cover depth, it may be an undesireable feature in some cases. Some research has indicated that damage may occur to sorghum seedlings if certain herbicides are applied post-plant pre-emergent where seed is placed in the bottom of furrows. Damage in these instances occurs when rainfall concentrates the herbicide applied to furrow sidewalls in the bottom of furrows directly over the crop row.

Bearing in mind the possibility of crusting and herbicide concentration as a result of rainfall, the large diameter convex press wheels appear to be an excellent all around choice as well as an economical selection over the triple wheel design.

Based upon the testing experience, requirements for a successful press wheel selection should include: (1) capability to develop at least 100 pounds per wheel reaction under any operating condition, (When using wheels of 20 inches or greater in diameter, capability of 200 pounds per wheel would be desireable. This should approximate a soil pressure of 10 to 15 psi. in the seed row.) (2) diameters of at least 20 inches will greatly aid the trash clearance capabilities of press wheels, and (3) a means such as a drag to break up any smooth compacted surface which might be left by the press wheels to become baked and crusted. This device should also be capable of adding or developing a shallow cover of loose soil mulch over the row.

CONCLUSIONS

The design objective (a planter capable of operating and establishing a satisfactory crop stand, given adequate moisture, under any condition in which a stubble mulch plow would perform acceptably) was realized. This design represents meaningful improvements over existing minimum tillage planters in the areas of residue clearance and decreased sensitivity to varying soil firmness. Testing of the machine indicates that it can be expected to perform very nearly like the stubble mulch plow and should be adaptable to the same conditions. The planter concept also has the potential for reducing crop production costs by eliminating the need for a preplant tillage or spraying to kill weeds present at planting time.

Conclusions of the findings can probably be summarized best by outlining the requirements which were found to be necessary and desireable for such a planter. Similar planters of future design should manifest the following design features in the areas of seed metering, seed distribution, seed placement, cover depth control and soil firming.

Seed Metering

A planter of this type will not be capable of accurately spacing seeds in the row. Because of this, one need not be overly concerned with uniform seed metering. Results of testing indicate that metering devices such as double run cups or fluted feeds can be expected to give results comparable to more precise metering devices such as the IHC Cyclo drum or plate type planters when long seed tubes and air pressure are used for seed delivery.

Seed Distribution

A. Seed tubes: Placement of seed below V-blades requires the use of conduits or tubes to carry seed from the metering device to the point of discharge. The use of such tubes prevents accurate spacing of seed in the row precluding the need for extremely accurate seed metering devices. Testing indicated that a smooth noncollapsing tube of 3/4 inch I.D. would adequately serve the purpose.

B. Seed Tube Routing: Initial concerns over routing of the seed tubes were proven to be unfounded. Testing of the planter indicated no effect upon seed placement with different seed tube lengths and routing. The concern most often voiced by farmers who have used the Cyclo planter was that the tubes should have a minimum of bends and should move progressively downward toward the point of discharge. Seed tubes on the planter had both numerous bends and sections which were horizontal and sloping upward. No effects of this routing were observed in the seed placement and therefore the conclusion can be drawn that, seed tube routing has little effect upon the distribution and placement of seed.

Routing was for the most part arbitrary above the plow frame; however, seed tube routing below the frame was restricted to a small area behind the blade support. A rearward, extending shield was fastened to each side of the vertical portion of the shank. The seed tubes were run inside of this shield down to blade level where they ran along the back edge of the blade support out to the row location. A shield should be mounted above the seed tubes extending horizontally rearward from the back of the blade to provide protection for seed tubes from above. The use of seeding monitors is almost mandatory on this type of machine. When used they should be located as near the discharge as possible. It appears that an air escape should be provided in the last 6 to 18 inches of the seed tube to slow the seed velocity (reducing the tendency for seed bouncing). 3/4 inch copper tubing sweat fittings were found to work very well for routing of the seed tube where bends sharper than the minimum allowable bends for the tubing material were necessary.

Seed Placement

The two methods of seed placement tested (compaction runner and discharge from a tube onto the shear surface below the blade) worked quite well. These were concerned with the lateral placement of seed in the row and had no effect upon spacing in the row.

The first, utilized a compaction runner which formed a trench below the shear plane level into which the seed was placed. This gave very good lateral spacing of the row; however, the compaction runner was finally abandoned because it caused soil build up under the blade holding them out of the ground.

The second placement method tested consisted simply of curving the seed tubes straight back and downward at about 45 degrees to within 1/2 inch of the shear plane at the row location. While the lateral spacing with this design was slightly wider than that of the compaction runner, it still gave a row width of 2 to 3 inches and proved to be a virtually trouble free design making it a much better choice than the compaction runner.

Cover Depth Control

The 26 1/2 x 3 1/2 inch steel press wheels with about 100 pounds of weight per wheel were the only reasonably effective cover-depth control tested and they too were less than acceptable. Based upon the field tests, the idea which appears to hold the most promise for regulating cover depth is a combination of the 26 1/2 x 3 1/2 inch convex press wheel and a rearward and upward extension of the blade. This would cause soil passing over the blade to part and move to either side of the row. If the blade extension is provided with sufficient adjustment it should be possible to maintain the desired cover depth under a wide variety of conditions.

Soil Firming

Testing of the planter demonstrated the benefits of soil firming in the seed row which resulted in faster emergence and reduced chances of drying out before plant emergence.

Press wheel selection for this type of planter should have the capability of firming a zone 2 to 3 inches wide over the seed row and have a minimum vertical force of 100 pounds/row. Press wheel diameters of 20 inches or greater should be selected to facilitate residue clearance. Selection of convex shaped wheels should have a beneficial tendency for breaking up clods in the row and reducing seed cover in the row. If the press wheels selected have a tendency to leave a smooth slick surface, a drag of some sort (either chain or harrow) should be provided to eliminate this condition which can often lead to baking and crusting.

RECOMMENDATIONS FOR FURTHER INVESTIGATION

Further investigations appear warranted in the areas of: (1) cover depth control and press wheels, (2) application of anhydrous ammonia concurrent with planting and (3) seeding of small grains such as wheat in narrow rows.

Although some testing was conducted on cover depth control and press wheels, no satisfactory combination was found which promised to perform well under a variety of conditions.

Conversations with Dr. Larry Murphy of the K.S.U. Agronomy department indicated a strong possibility that crop nitrogen requirements could be applied at planting time in the form of anhydrous ammonia. Although questions exist regarding the possibility of seedling damage from ammonia applied at seeding time (in proximity to the seed), Dr. Murphy stated that he had made some investigations which indicated this would not be a problem if the ammonia were applied to the center of alternate crop rows (i.e. directly below the blade centers and 15 inches away from the crop row when using 30 inch rows and 60 inch wide blades.) Application of fertilizer concurrent with planting could eliminate one trip across the field and the accompanying cost and detrimental effects upon the soil and residue cover.

The seeding of small grains such as wheat with this type of planter holds the potential for seeding wheat into heavy crop residues. Seeding of wheat into sizeable amounts of residue has definite advantages in the wheat growing areas of the Great Plains. Heavy crop residues, especially standing crop residues, can provide much needed wind protection for young seedlings and will also trap blowing snow to supplement the often too short moisture supplies.

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APPENDIX

TEST PLOTS

Date: April 25, 1977

Location: Garden City Branch Experiment Station

Crop: Corn

Rate: 24,000 seeds/acre

Soil Condition: Irrigated Brome Sod Pasture with soil moisture above 75% of field capacity.

Emergence: Plant spacing erratic

Yield: No yield check however, emerged plants had large well filled ears.

Comments: Soil moisture was too high at planting time to acheive weed kill by the tillage. Existing vegetation was killed with Paraquat applied post plant.

Cover depth on this plot was 3 to 3 1/2 inches. This depth was a practical minimum because it was impossible to operate the blades shallower and keep them in the ground. Only about one acre was planted at this location. Considerable difficulties were encountered with the seed tubes plugging. This was caused by the seed tubes being flattened where they laid across square edges of the machine frame or made abrupt bends.

Date: May 5, 1977

Location: Kansas River Valley Experiment Field, Rossville, Kansas

Crop: Corn

Rate: 24,000 seeds/acre

Soil Condition: Soil at the experiment field is a fine sandy loam. The plots had been untilled except for an anhydrous ammonia application made with anhydrous knives running in the center of old rows. The soil surface was covered by last year's corn stalks which had not been chopped or otherwise reduced. Soil moisture content was between 75% and field capacity.

Emergence: Not counted

Yield: 67.4 bu./acre

Comments: Plots were quite small on this test plot measuring 12 rows by 100 feet long. Eight plots of this size were planted on the field. The corn stalks on the field gave considerable problems plugging in front of the center press wheel. In order to alleviate the problem the press wheels were raised until the front press wheel was about level with the ground surface. Cover depth on the plot was 3 to 3 1/2 inches. It would have been possible to reduce the cover depth slightly; however, it was decided to cover the seed at this depth to keep it from drying out. (Figures 37, 38, and 39)

Figure 37. Planting No-Till corn at the Rossville Experiment Field.

Figure 38. Planting No-Till corn at the Rossville Experiment Field.

Figure 39. No-Till corn planted with undercutter planter at Rossville Experiment Field.

Figure 40. Wheat stubble after planting with undercutter planter on the Bohannon farm.

Date: May 14, 1977

Location: 8 miles north of Holton, Kansas on highway 75 and 2.7 miles west on north side of road.

Cooperator: Robert A. Bohannon, Manhattan, Kansas 66506

Crop: Grain sorghum

Rate: 65,000 seeds/acre

Soil Condition: The plot consisted of wheat stubble lightly disked after 1976 harvest and brome sod which had been chemically killed. Soil moisture at planting was 50-75% of field capacity. Soil type was Pawnee Silt Loam.

Emergence: Acceptable - uncounted

Yield: 100 bu./acre

Comments: This plot was planted using both the experimental undercutter planter and the Buffalo Flex planter equipped with modified slot shoes. The brome sod was firm enough that a firm step on the heel would not penetrate more than 1/2 inch. The wheat stubble was about the right firmness for reduced tillage planting; a firm step on the heel would penetrate about 1 1/2 inches.

The brome sod was too firm for the undercutter to operate at the 3-4 inch depth necessary for planting. Operating at this depth the upward reaction on the blade, openers, and coulters was great enough to lift the machine out of the ground. The Buffalo planter also did less than acceptable work in the Brome sod.

Both planters did an acceptable job in the wheat stubble covering the seed 3 to 3 1/2 inches deep. (Figures 40 and 41)

Figure 41. Wheat stubble planted with undercutter planter. 15 days after planting and after approximately 10 inches of precipitation on the Bohannon farm.

Figure 42. Planting untilled sorghum stubble with growing weeds on the Welker farm.

Date: May 18 and 28, 1977

Location: Jim Welker farm located 6 miles west of highway 77 on the Washington-Riley county line.

Rate: 65,000 seeds/acre

Soil Condition: The undercutter and Buffalo planters were used to plant untilled alfalfa sod and sorghum stalks. In both plots the soil moisture content was approximately 75% of field capacity. The soil in both plots was about the right firmness for reduced tillage planting; however, the alfalfa sod was somewhat firmer than the sorghum. Soil type was Irwin and Wymore Silty Clay loams.

Emergence: Emergence on all treatments was acceptable although uncounted.

Yield: Unharvested

Comments: Planting of these plots was in soil with moisture content too high for good weed kill. Heavy rains following planting resulted in very little weed kill from the tillage performed at planting. Because of severe weed problems all but check strips of the plots were destroyed and replanted (Figure 42).

Date: June 7, 1977

Location: Southwest Kansas Experiment Field, Minneola, Kansas

Seeding Rate: 21,000 seeds/acre

Soil Condition: The plot was in 1976 sorghum stubble which had been chiseled once. The soil was about the right firmness with approximately 75% field capacity moisture at a depth of 3 to 4 inches. The soil surface had been crusted by heavy rains after chiseling and had cracks 1/8 to 1/4 inch wide in the surface when planted. The planter was also demonstrated in a prepared seedbed with the only adjustment being a reduction in depth by 4 turns of the lift cylinder depth stop. Soil type was Harney Silt loam.

Emergence: Population at Harvest - No-till 10,950 plants/acre

Conventional Till 13,500 plants/acre

Yield: Prepared seedbed - Conventional Till - 97.4 bu./ac.

No-Till - 47.7 bu./ac.

Comments: Soil conditions were almost ideal for operation of a V-plow. Weed kill was good and crop emergence was also good. The cloddy soil condition gave a soil cover slightly cloddier than ideal; however, this did not allow excessive soil desiccation which would have hindered emergence. Soil moisture estimated at 50-75% R.A.M. (Figure 43).

The large difference in yield between No-Till and Conventional Tillage prepared seedbed is primarily due to fallowing. The No-Till plot was planted on continuous grain sorghum while the prepared seedbed or Conventional Tillage plot was planted on fallow-grain sorghum. The No-Till plot experienced a period of drought stress which the Conventional Tillage did not due to moisture storage during fallow.

Figure 43. Planting in a prepared seedbed with the undercutter plow at Minneola.

Figure 44. Sorghum planted in Ecofallowed wheat stubble on the Sandelin farm.

Date: June 8, 1977

Location: John Sandelin farm located 5 miles east and 1 mile north of the northeast corner of Wakeeney, Kansas.

Seeding Rate: 46,500 seeds/acre counted in the row at planting. The planter was calibrated for about 65,000 seeds/acre.

Soil Condition: This field had been undercut approximately 4 inches deep about two weeks after the 1976 wheat crop of 37 bu./acre was harvested. The undercutter plow was equipped with tag-along mulch treaders and 40 pounds/acre of anhydrous ammonia was applied in conjunction with the tillage operation. The field was treated with 3 3/4 pounds/acre Atrazine 80W after the tillage operation. No other operations were performed prior to planting. At planting time the Atrazine had deteriorated enough to allow a heavy infestation of foxtail.

The soil conditions were very good for planting. Soil moisture in the top 3 inches was 50-75% of field capacity with higher moisture content in the soil below. Soil firmness was adequate to slightly soft. A firm step on the heel would make a track 2 - 2 1/2 inches deep. The soil was very mellow without clods leaving a well mulched soil cover.

Emergence: 61,000 plants per acre counted on June 26, 1977.

Yield: 95 bu./acre on the 11 acre plot planted with the undercutter planter. The entire 59 acre field of which the remainder was offset disked and planted with a deep furrow hoe drill on June 6, 1977 yielded 93 bu./acre.

Comments: This plot represented conditions which would be described as ideal for spring planted crops. The weed kill was excellent due to drying weather and the lack of rainfall for approximately 10 days after planting. (Figures 44-50)

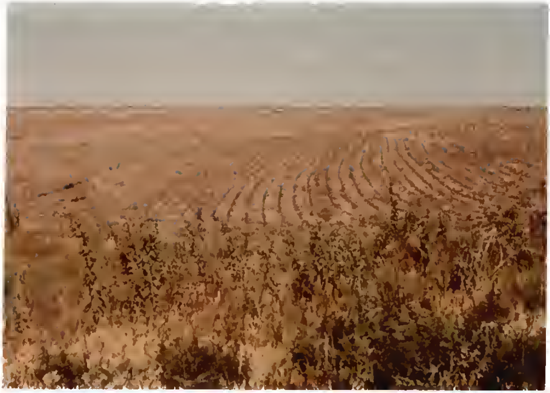

Figure 45. Sorghum planted in Ecofallow wheat stubble with undercutter planter on the Sandelin farm.

Figure 46. Sorghum planted in Ecofallow wheat stubble. Foreground - disked once preplant and planted with deep furrow drill. Background - planted with undercutter planter on the Sandelin farm.

Figure 47. Wheat stubble remaining in Ecofallow sorghum planted with undercutter planter on the Sandelin farm.

Figure 48. Ecofallow sorghum planted with undercutter planter on the Sandelin farm.

Figure 49. Ecofallow sorghum planted with undercutter planter on the Sandelin farm.

Figure 50. Ecofallow sorghum planted with undercutter planter on the Sandelin farm.

Date: June 9 and 10, 1977

Location: The Bill Armfield farm 1 mile east of the northeast corner of Sedgewick, Kansas.

Seeding Rate: 64,000 seeds/acre

Soil Conditions: The field was being used as a minimum tillage demonstration plot. The field was disked once lightly after the 1975 milo crop was harvested. Weeds were controlled with chemicals until planting of the 1976 milo crop. The field was planted in early June and a light lay-by cultivation made in late July. Weed growth was again chemically controlled until planting of the 1977 crop.

Soil firmness was about right to slightly firm and moisture content of the surface 3 inches of soil was approximately 50% of field capacity. The soil surface had begun to crack as the soil dried. After being undercut by the planter the soil surface was broken into clods about 1 inch thick and 2 inches in diameter. This soil condition did not have a well mulched soil cover over the seed.

Emergence: Inspection on June 21, 1977 revealed an average plant population of 38,000 plants/acre. (Figures 51 and 54)

Yield: 80 bu./acre

Comments: The fertilizer system was used on this plot to apply 9 gallon/acre of material. The additional weight of the fertilizer tanks helped to maintain a uniform depth in the slightly firm soil. As the tanks were emptied the depth stop had to be adjusted to increase depth.

The cloddy soil conditions resulted in a poorly mulched soil cover over the seed. This coupled with about 5 days of hot drying weather probably explains the poor crop emergence.

Observations indicated no soil structure problems on the plot after two years of minimized tillage.

Figure 51. Planter in use on the Armfield farm.

Figure 52. No-Till sorghum stubble planted with the undercutter planter on the Armfield farm.

Figure 53. No-Till milo planted with undercutter planter on the Armfield farm.

Figure 54. Stubble of no-till sorghum planted on the Armfield farm with undercutter planter.

Date: June 23, 1977 through July 1, 1977

Location: Larry Walker farm located in the southwest corner of Stanton County, Kansas.

Seeding Rate: Soybeans were planted at rates ranging from 85,000 seeds/acre up to 150,000 seeds/acre. The farmer wanted to plant relatively low populations and then changed his mind and increased the seeding rate as planting proceeded. (Recommended seeding rates are approximately 200,000 seeds/acre for irrigation).

Soil Conditions: Soil type was sandy loam soil. The top soil had been quite dry and virtually without structure as is common with dry sandy soils until a .60 inch rain shower had dampened the top 4-5 inches of top soil about 24 hours prior to planting. This moisture gave sturcture to the top soil increasing its shear strength making it easier to cut through plant roots and cause soil to flow over the blades. This moisture however prevented an effective weed kill which developed into a serious problem later on.

Soil firmness was less than optimum for use of an undercutter even with the moisture; however, the sandy soil did leave a very well mulched soil cover over the seed.

Emergence: Emergence was not checked on the plot since it would have been inconclusive at best in light of other adverse conditions.

Yield: Unharvested; however, inspection in late November of 1977 indicated plants attained a height of about 8 inches with 12 to 15 pods per plant and 2 to 3 beans per pod.

Comments: This particular plot seemed doomed at the outset when the top soil was too wet for a good weed kill and the subsoil was too dry to support plant life. The dry subsoil was not too much of a concern since the farmer was equipped for sprinkler irrigation. Pre-emergent herbicides were applied and sprinkler irrigation began prior to crop emergence. Sprinkler malfunctions caused erratic water distribution leaching chemicals out of the light soil in spots. These problems were further compounded by two severe hail storms in late July and mid-August.

The farmer was quite satisfied with the planter performance and the concept of planting in standing crop residue without prior seedbed preparation. The problems experienced on this plot were for the most part beyond operator control with the weather serving as a major contributor. (Figures 55 and 56)

Figure 55. Planting soybeans after wheat harvest on the Walker farm.

Figure 56. Unharvested soybeans planted with undercutter planter on the Walker farm.

ABSTRACT

DEVELOPMENT OF A REDUCED TILLAGE PLANTER FOR THE SEMI-ARID GREAT PLAINS REGION

by

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ABSTRACT

The objective of this investigation was to design, build, and test a production scale minimum tillage planter. Requirements of the planter were that it must be capable of operating and establishing a satisfactory crop stand under any condition in which a stubble mulch plow would operate satisfactorily given adequate moisture for seed germination. Preservation of the low sensitivity to varying soil firmness and the trash handling ability of the stubble mulch plow were key considerations. A design size of 6 rows (30 inch rows) was selected for compatability with production scale operations. Basic components of the machine were a 3 section 15 foot stubble mulch plow and an IHC Model 500 Cyclo Planter.

Testing of the planter concentrated on proving the concept of using the undercutter plow as a basis for the planter and developing this concept to a level suitable for use on a production scale. The planter was tested at eight different locations around Kansas in varying field conditions between April 25th and July 1st of 1977. Crops planted were corn, grain sorghum, and soybeans. Field conditions varied from untilled grass sod, to untilled stalk fields, double cropping after wheat, and prepared seedbeds. Crop emergence under all of the conditions was acceptable and comparable to other planters operating under similiar conditions. A total of some 200 acres were planted with the machine.

Ability of the planter to operate under widely varying conditions of soil firmness and residue levels with a minimum of adjustment and sensitivity was demonstrated in all of the tests. In addition to excellent trash handling characteristics, the machine was able to perform a weed killing tillage operation while planting. In many cases this would

eliminate a preplant tillage operation or the use of expensive chemicals. Ability of the machine to plant with a minimum of residue disturbance has definite conservation benefits providing excellent protection from wind and water erosion for both soil and young seedlings. Placement of seed in the cavity below the V-blade was shown to give both uniform row width and crop emergence while preserving the residue clearance of the stubble mulch plow by eliminating individual row openers. Seed distribution tubes were routed vertically downward behind the blade supports and horizontally behind the blade and support out to the row location.

Results of the tests indicated that seed distribution could be handled quite well using smooth, non-crushing, plastic tubes of 3/4 inch I.D. and an air supply of 2 to 4 inches (water column) measured at the tube entrance. Press wheel requirements were found to be somewhat different than other planters. In particular, it was found that higher press wheel forces were needed with about 100 pounds per wheel required for adequate soil compaction and clod breakage in the row. Press wheels of less than 20 inches in diameter were found to occassionally clog with residue. Control of seed covering depth was also found to be somewhat troublesome, because the under-cutter plow cannot be operated much shallower than 3 inches. Soil must therefore be moved away from the row if cover depth after firming is to be less than about 2 inches.

While the concept needs some improvement before commercial introduction, results of the tests leave no doubt that the concept has merit and commercial applications will be made where the stubble mulch plow is adapted.