FARM MACHINERY DEVELOPMENT FOR NO-TILLAGE AGRICULTURE

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INTRODUCTION

No-tillage agriculture is a viable philosophy and practice for 1980's agriculture in the United States because of the interaction of many factors, illustrated by the following circle of interrelated needs, technologies, and results:

> → Needed erosion control for continued agriculture → Residues provide for erosion control → No-Till to maintain the residues → Reduced energy requirements because of No-till → Lower equipment costs from reduced energy requirements → More economical production because of lower equipment costs → Continued agriculture is possible with more economical production →

Agriculture is a business and agricultural management is driven by economic decisions. With no forseable trends toward sustained higher prices for agricultural products relative to the costs of production items, it appears that more economical production is required for continued agriculture in its present form. Such production economy must be for total farming enterprises and not just for one crop within an enterprise.

Unlike land, insurance, available family labor, seed, and fertilizer costs, farm machinery inventory and management are highly variable costs within an enterprise budget. With equal production, reductions in machinery-related costs produce increased profits. With re-evaluated production goals set to maximize net profits rather than yields, machinery-related costs might be reduced further.

Please note that herbicide weed control has not been mentioned. For this paper, weed control is considered to be part of the functional machine system with the application of herbicides being mechanical operations substituting for mechanical weed control. This is but one of several machinery selection and management options which must be evaluated to maximize the farm enterprise profits.

Farm machine systems are substantially based upon approaches to four basic functions:

1) Residue Management,
2) Fertilizer Application,
3) Crop Establishment,
4) Weed Control.

Conventional tillage philosophy says that residues must be completely buried so that a broadcast field surface can be tilled until the desired surface layer soil structure is produced for a seedbed. Weed control by mechanical cultivation is compatible with conventional residue management and seedbed preparation.

In contrast with conventional tillage, no-tillage philosophy says that residues must be kept on the soil surface year-around to conserve soil moisture and to protect soil from erosion. (At this point, we should admit that few farmers are going to make any change in production practices if there are not economic incentives; items such as "erosion control," reduced "groundwater pollution," and minimum "offsite impacts" are laudable environmental protection goals, but they will only be pursued if the practices which achieve them are also sensible, practical, manageable, and profitable). Therefore, the objective for development of farm machinery for no-tillage is to make available machines for the maintenance of surface residues while establishing crops, applying fertilizers, and controlling insects and weeds.

Machines For Residue Management

No-tillage field machines must be conceived and designed to either manipulate residues or minimize residue disturbance so that the following separate goals are achieved:

1) Soil cover is maintained for required level of conservation,

2) Subsequent machine operations which contact the residue and soil may be accomplished with reliable, uniform results,

3) Crop response and weed control are uniform.

Residue manipulation includes straw and stover chopper/spreaders on wide combines, shredders, and planter strip-tillers or strip-cleaners. Standard straw spreaders on combines will not spread evenly across the width of cut and actually separate the material according to size and weight, Fig. 1. This situation commonly results in high concentrations of chaff, spilled grain, and weed seed in the center of the combine path and only large, coarse pieces of residue at the outer edges (Allmaras et al., 1985). After making such a nonuniform residue distribution with a combine, no one would expect uniform performance by subsequent machines, fertilizers, herbicides, or crop plants. Machines adapted to and adjusted for one residue condition will encounter different types and sizes of residues across the field and different soil moisture contents under the different amounts of soil cover. Fertilizer performance will be different across the field depending upon the levels of nutrient availability resulting from various amounts of residues, soil moistures, and soil temperatures (Lohry, 1985). Volunteer crop plants will be concentrated in the path of the combine. Weed pressure and herbicide contact with the soil will vary with nonuniform residue spreading. Crop response, without row clearing, will vary between different soil moistures and temperatures as well as between different levels of available nutrients across the field. These influences on system performance should be sufficient to convince almost anyone that residues must be uniformly distributed over the surface of the field by harvesters. Chopper/spreader attachments should be adjusted to throw residues the full width of cut for each combine.

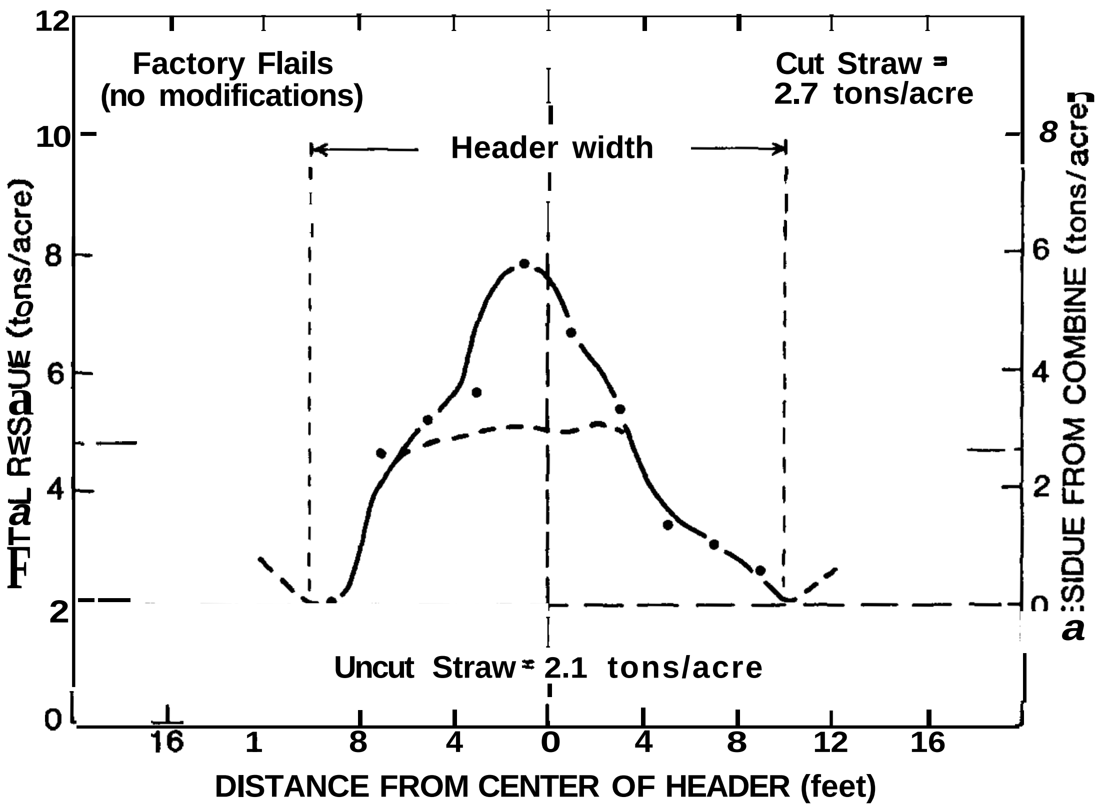

Figure 1. Combine straw spreader and chopper distributions of residues across the cut swath. Residues above the dashed curve line are chaff. (Unpublished, USDA-ARS, Pendleton, OR.)

Shredding of stalks and stubble remaining after harvest is one method used to produce the appearance of uniform residue spreading, but materials previously deposited on the soil surface by a combine are not measurably redistributed, only covered. Shredding may not be a desirable practice. When no-tillage field operations have been reduced to 5 or 6 trips per year the elimination of the stubble shredding operation is a significant reduction in the total machine operation budget. I will admit that we use a stalk shredder, but only once in 3 or 4 years and then only for the special case of immediately after cotton planting, so that standing residues will not be gathered by the cotton strippers at harvest, lowering lint quality.

Standing stubble remains intact longer, doesn't float away with overland water flow, and provides more protection from raindrop-impact induced erosion (Morrison et al., 1985). Fertilizer application and planting operations are much more reliable if the residues are anchored and are not lying on the soil surface requiring positive cutting for soil opening (Erbach et al., 1983).

Planter strip-tillers and strip-cleaners use powered tillers to incorporate residues into the soil or discs, shovels, or sweeps to move surface soil and residues out of the path of individual row planting units, Fig. 2. These devices are used both on the flat and on ridge-tillage. Strip tillage is used to improve planting performance and crop response uniformity.

In some ways, strip tillage is a "fix-it" approach to obtaining our goals. If residue distribution, weeds, and field traffic can not be adequately controlled to provide uniform conditions at planting time, then strip tillage may be necessary until those problems can be corrected. The limitations to strip tillage are accented when we need to effectively establish narrow-row or solid-seeded crops such as wheat or soybeans, within a particular residue management program. Strip-tillage with solid-seeding becomes total tillage and row cleaners deposit removed residues on adjacent rows; in short, it doesn't work. Narrow-row crops require as favorable growing conditions as do wide-row crops and narrow-row fertilizing and planting machines must perform adequately, therefore, we must use residue management technologies which do not limit profitable rotations and management of crops.

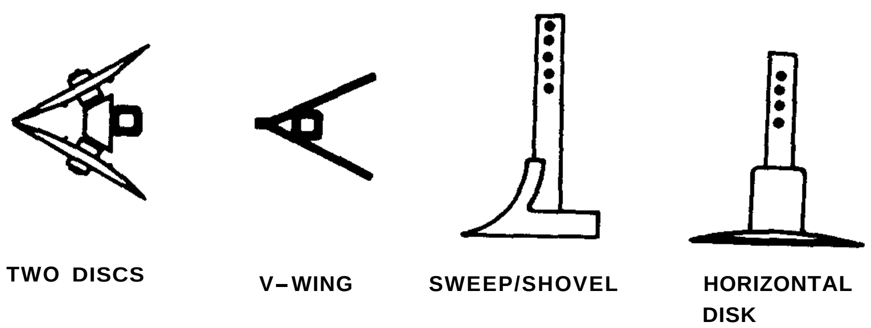

Figure 2. Strip tillage residue strip-cleaning tools for wide row crops.

Machines For Fertilizer Application

No-tillage fertilizer applicators can be grouped into four classes:

1) Applicators which place liquid or dry fertilizer materials on top of the soil and residue,

2) Applicators which penetrate the soil surface and place liquid and/or dry fertilizer materials in a slot,

3) Applicators which place dry, liquid, and/or vaporious fertilizer materials at predetermined subsurface depths,

4) Applicators which are in combination with individual planter row units to place fertilizer materials in, under, or beside the seed furrow.

The first three classes of applicators may be separate machines for pre- or post-planting operations, or mounted on planters, drills, or air seeders. The major differences in the various uses of these applicators are the applicable field and residue conditions and the expected crop utilization efficiency.

Surface fertilizer application is the most popular and the most inappropriate method for no-tillage fertilization. Surface broadcast application was developed for the distribution of fertilizers prior to incorporation by primary or secondary tillage. Without tillage incorporation, the fertilizer use efficiency is reduced, residues are prematurely decomposed, and surface soils become progressively more acidic (Mengel et a1., 1982; Blevins et a1., 1977). Surface dribble of concentrated bands of urea-ammonium nitrate solution were found to be 58% to 77% more efficient for plant N uptake than broadcast fertilization (Touchton and Hargrove, 1982). Both of these surface methods deposit fertilizer materials where they are vulnerable to losses by volatilization and runoff water flow, and also, contribute to offsite water pollution. Dribble banding is currently the better choice of surface fertilizer application techniques if subsurface application equipment is not available. Dribble banding may be the only appropriate method for spring topdressing of winter cereals. Dribbled liquid fertilizers are dispensed from tubes spaced along a lateral boom. Squeeze pumps, pressure pumps and nozzles, or elevated distribution manifolds are the liquid meters. Dry fertilizers may be dribbled from metering boxes, lateral auger tubes, or air-delivery tubes.

Slot injections are the newest fertilization technologies for conservation-tillage systems, Fig. 3. They all involve the creation of a cut, depression, or "slot" in the soil surface for deposition of liquid or dry fertilizer materials in a concentrated band. Advantages are minimum soil and residue disturbance, adaptation to a wide range of soil and residue conditions, protection from major volatilization and runoff losses, and subsurface placement below the highly biologically active soil surface layer. Each slot injection method achieves portions of these goals, as described below.

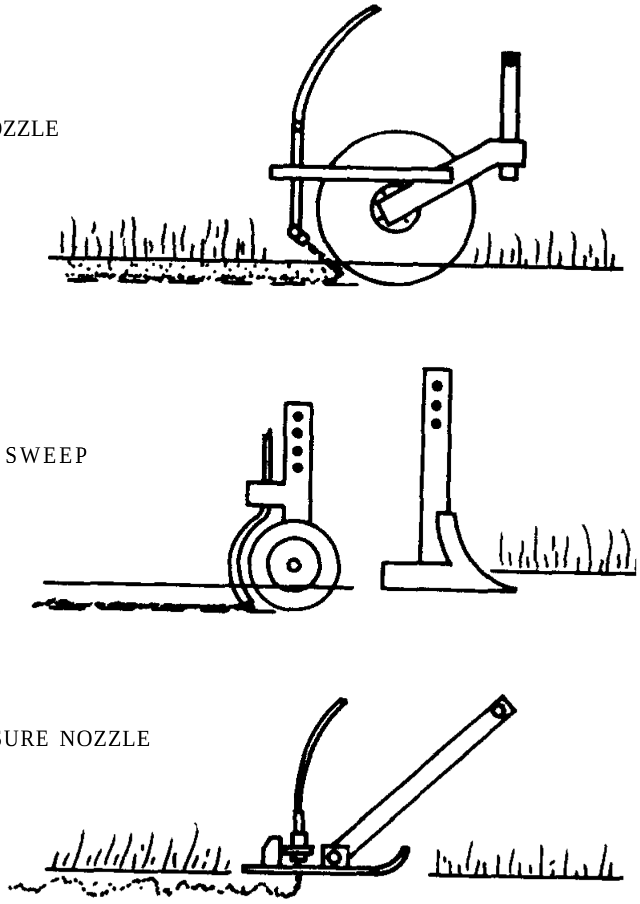

Figure 3. Slot injectors for no-tillage fertilization.

Rolling coulters with solid stream spray nozzles are slot injectors which shoot liquid fertilizer materials into the partially open slot directly behind the coulter. These "coulter/nozzle" applicators are relatively inexpensive, durable, and reliable devices. They can be mounted on a toolbar as a separate machine or on planters or drills to place fertilizer beside or between rows. We use coulter/nozzles as one alternative on our experimental applicators and include dual angled rear presswheels to close the fertilized slot, Fig. 4. The vertical distribution of the fertilizers and resulting plant use efficiency are under study at several locations, including Temple, Texas.

V-wheel type slot injectors have been introduced by one company to operate in residue-free conditions behind row trash cleaners. Their units are equipped with tubes to deliver metered liquid fertilizers into the slot pressed open by the thin V-wheel. We visualize the potential use of such V-wheels behind rolling coulters to cut no-tillage residues, penetrate firm soil surfaces, and open a wider slot than achieved with coulter/nozzles. V-wheel slot injectors deliver all of the fertilizer material below the soil surface and might also be adaptable to deliver dry materials.

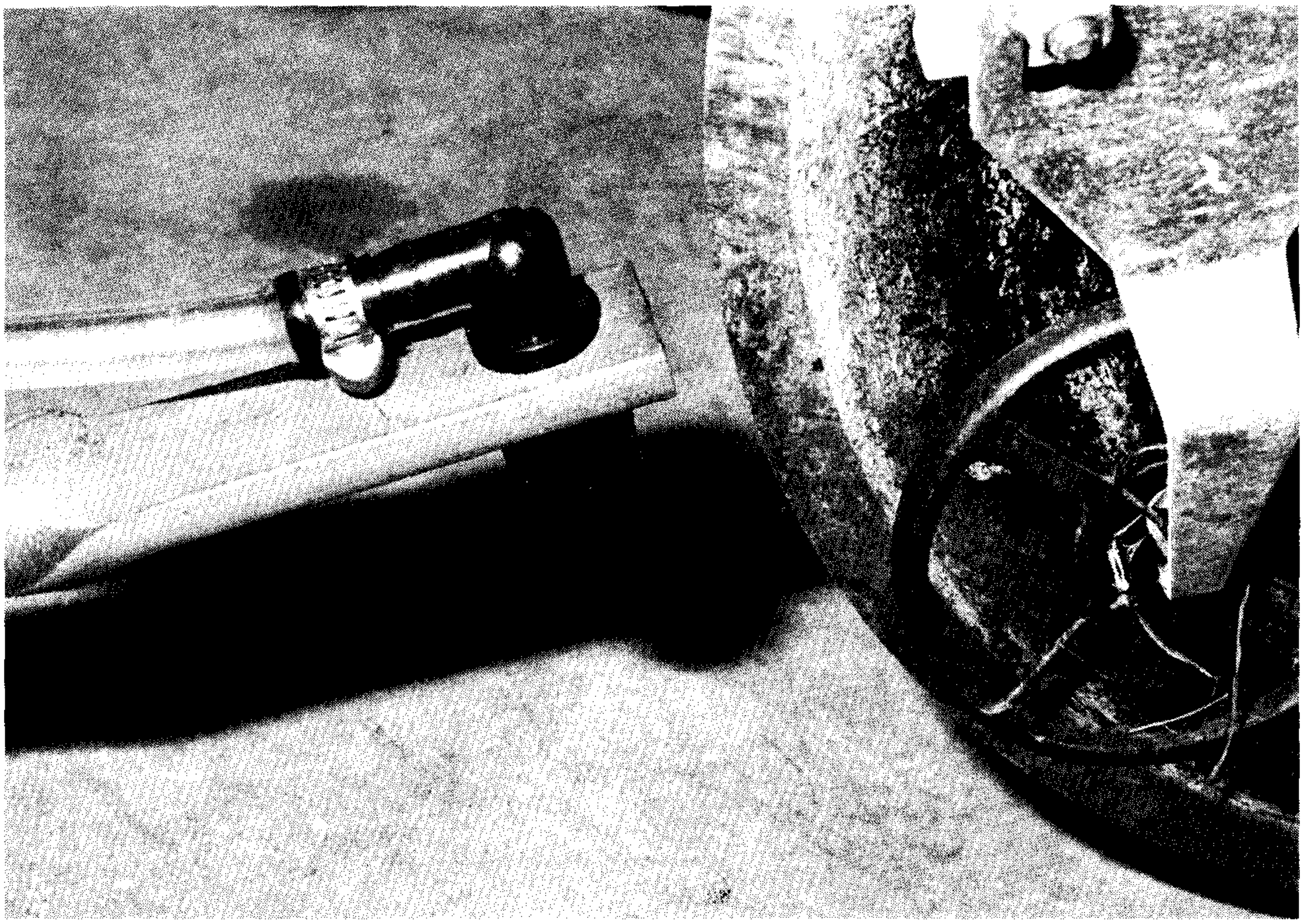

Figure 4. Experimental fertilizer application unit with a solid-stream nozzle directing a jet of solution into the slot behind the smooth rolling coulter. The nozzle replaces an applicator knife in this unit. (Unpublished, USDA-ARS, Temple, TX).

High pressure nozzle slot injection has been developed for no-tillage conditions. A trailing sled moves over the soil surface with a solid stream nozzle positioned just above the surface directing a stream of liquid fertilizer at pressures around 2,000 psi. The goal is to use the high pressure stream to cut a slot in the soil to place the bulk of the fertilizer material subsurface. Residue and hard surface soil reflect portions of the fertilizer material. In 1984 tests at Colby, Kansas, 50 to 70% of the fertilizer remained in the top 0.4 inch of surface soil (Sunderman, 1984). Performance was dependent on pressure, flow rate, and filtration of the liquid fertilizer.

Subsurface fertilizer applicators may be acceptable for no-tillage or they may be totally worthless, causing more damage than benefits. Benefits from subsurface applications include utilization of lower cost anhydrous ammonia nitrogen source. The materials are placed below the biologically active surface layer and into soil which may be moist enough for continued crop root uptake as the growing season progresses. This is due to surface residues maintaining higher soil moistures closer to the soil surface than in conventional bare soils (Lal, 1978), so that sub-surface depths of 3 to 4 inches may be adequate.

Subsurface application problems occur when the surface residues are not completely cut and machine plugging causes stoppages. Problems also occur when applicator tools displace significant amounts of soil in their paths leaving deep, wide furrows (Chichester et al., 1985). These conditions occur during typical preplant and planting seasons when soils are moist, at low strengths, and adhesive. The wide bands of disturbed soil interfere with subsequent planting operations, cover needed surface residues, leave loosened soil more susceptible to erosion and micro-gully channeling of runoff, and expose buried weed seed for germination. Soil disturbance can be reduced by depth control and by selection of appropriate applicator designs (Chichester et al., 1985).

Several applicator knife designs are available for subsurface applicators. Conventional, thick, forward curved knives displace too much soil for no-tillage, especially at speeds above 4 mph, Table 1. Thin back-swept knives minimize soil disturbance, but require significant down-pressure and release fertilizers higher in the furrow than forward shanks. Shallow release may be unacceptable for sealing-in anhydrous ammonia vapors. Thin forward knives are a good compromise on knife designs.

Spoked-wheel point-injectors penetrate residues and surface soil layers to deposit pockets of fertilizer every 8 inches at Iowa State University (Baker et al., 1985), Fig 5. They can be used either as a separate machine or mounted on a planter. Experiments continue with both liquid and anhydrous ammonia applications. This applicator minimizes disturbances of both surface residue and soil.

Table 1. Eight fertilizer applicator knives ranked in order of minimum disturbance of soil surface cover (Chichester et al., 1985).

Knife Type	Shank Width	Toe Width	Mean Width of Soil Cover Disturbance†
	cm	cm	cm
Thick Backswept	1.5	1.5	20a
Thin Backswept	1.0	1.0	30b
Forward w/sealer	1.3	2.0	33bc
Thin Forward	1.1	2.4	36cd
Forward	1.3	2.0	38d
Thick Forward	1.5	3.6	40d
Forward w/point	1.0	4.5	46e
Thick Forward w/point	1.6	5.1	47e

† Data averaged overall treatment comparisons. Means assigned the same letter are not different by Duncan multiple range test at the 5% level of significance.

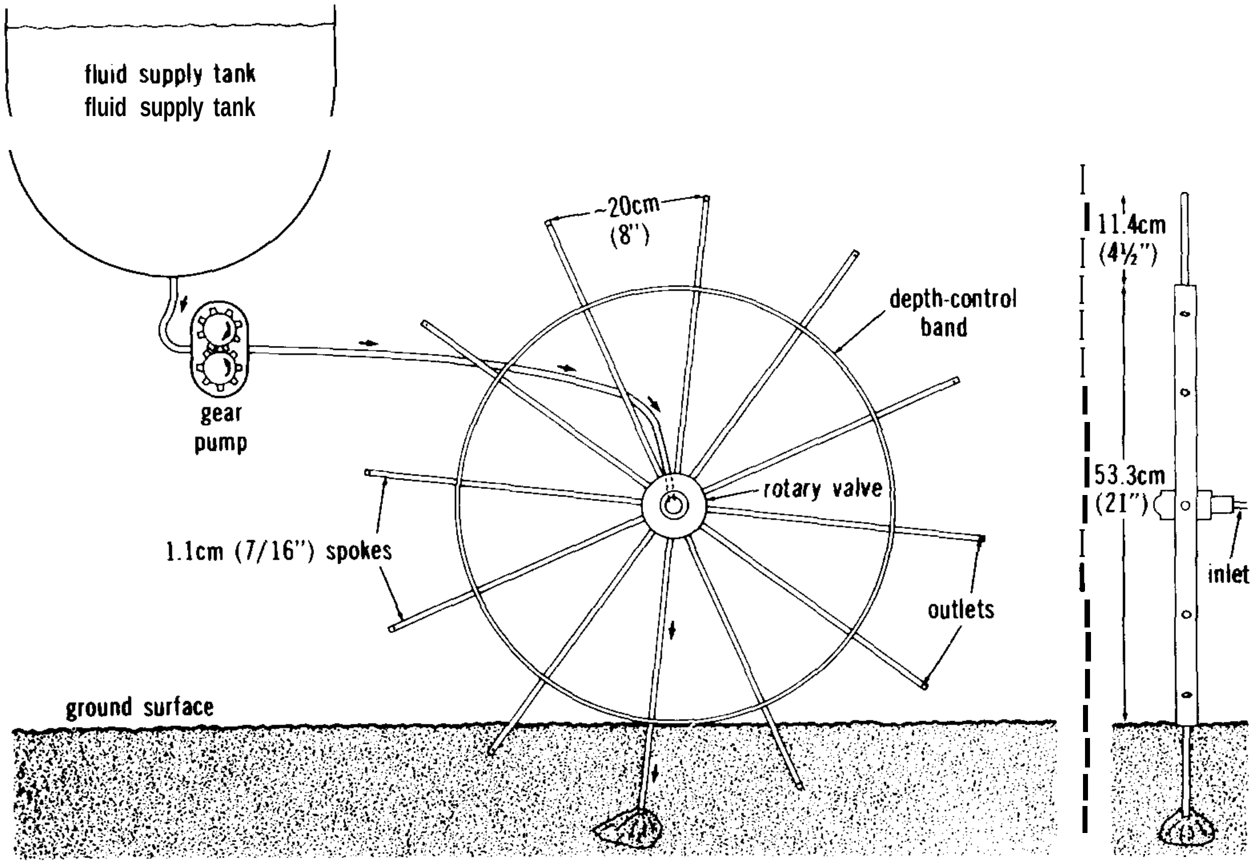

Figure 5. Experimental Iowa State University spoked-wheel applicator. (Baker et al., 1985).

Single and double discs have been used for years as subsurface fertilizer banding applicators on planters. Their main use has been for dry fertilizers, but liquids can also be used. These applicators require as much downpressure for soil penetration as do planter openers, so that their use as side banding attachments double the downpressure requirements for no-tillage planters. Total available downpressure for all openers is limited by the empty weight of the planter. The effect of shallow fertilization is not as damaging as crop stand establishnent failures due to shallow planting from inadequate downpressure. When such planting hazards are common, it would be better to eliminate such applicators from the planter and use them attached to a toolbar for a separate machine operation as either pre-plant or post-plant sidedress. We rarely see it done, but single or double disc openers can be used on a separate toolbar just like knife applicators.

Deep placement of fertilizers may be used when in-row deep chiseling or subsoiling is being conducted ahead of the planter opener to address a root or water penetration problem in the lower soil horizons. In these cases, any of the various fertilizer materials may be delivered down the backside of the deep tillage tool shank. This places fertilizer in soil zones which will be at higher moisture contents longer into the growing season and, therefore, should be more available for late season plant uptake than with any other method.

In-row starter, "pop-up," fertilizers are being overlooked by many no-tillers as an appropriate technology. We use liquid 10-34-0 starter fertilizer at 100 to 150 lbs/A with all of our no-tillage wheat, corn, grain sorghum, and cotton. We add liquid systemic insecticides for control of pests such as cutworms. In-row starter can provide part or all of the crop's phosphorous requirement, which is reported to enhance emergence and early growth during cool soil conditions (Moncrief and Schulte, 1979). Starter fertilizers are easily applied through a tube placed in the furrow opener, Fig. 6. Applicators such as split-boots and winged coulters are really starter fertilizer devices because most of them can not be used to apply the complete plant requirement rates. It may be just as good to limit the rate of application to allowable in-row values and deliver the materials directly into the seed furrow to avoid the cost, maintenance, and extra soil disturbing width of split-boots.

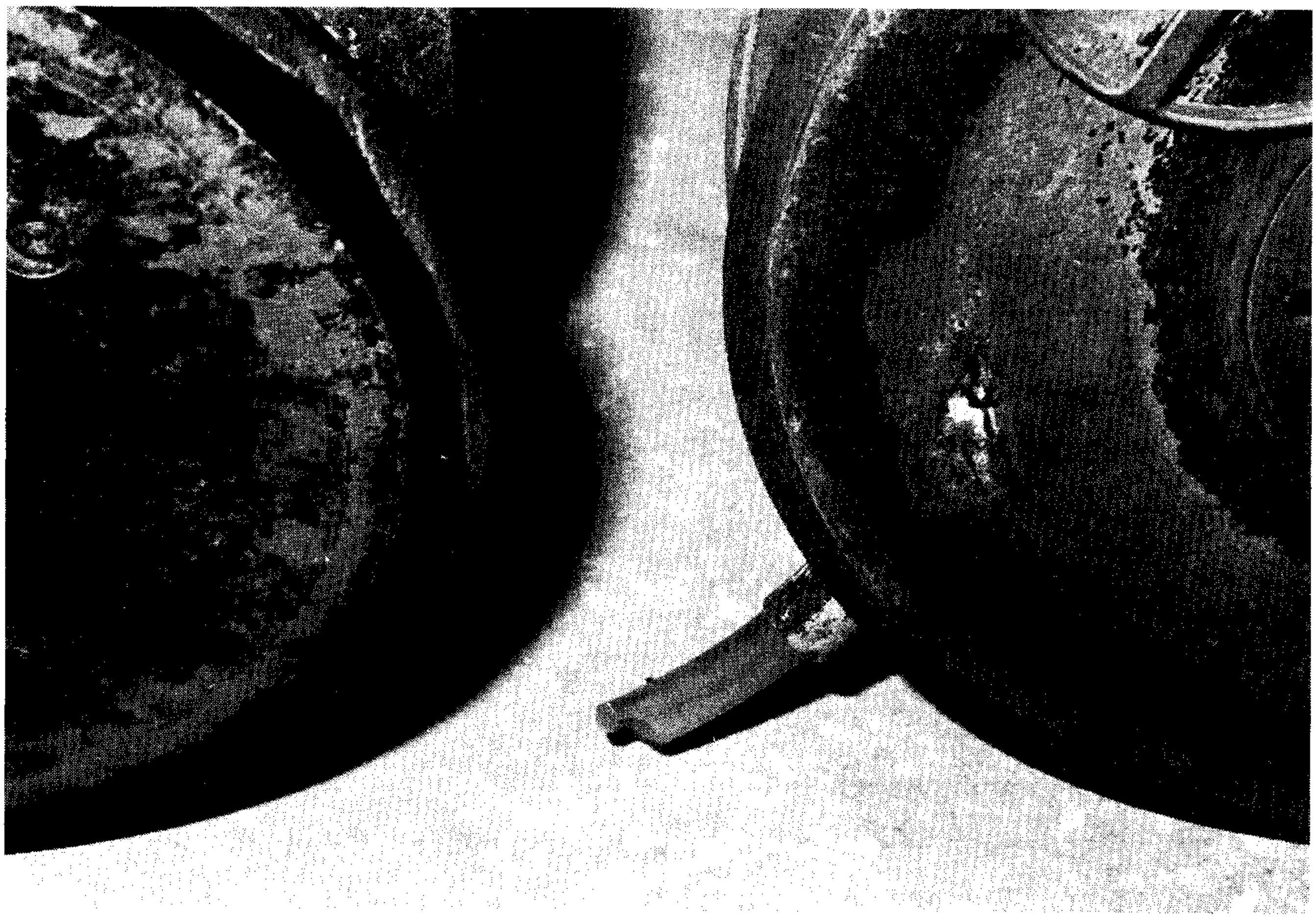

Figure 6. Starter fertilizer tube mounted in rear of a double-disc opener on an experimental no-tillage planter. (Unpublished, USOA-ARS, Temple, TX).

Machines for Crop Establishment

No-tillage crop establishment involves one pass of a planting machine. That machine may do several things in addition to depositing seed in the soil, including cutting residue, clearing a path, and applying fertilizers, insecticides, and herbicides. Performances of these machines have been closely linked to successes and failures of attempts at no-tillage cropping (Erbach et al., 1983).

Research and development efforts have concentrated on improving planting technology for row crops. Many innovations have been incorporated into machines which are quite acceptable for some no-tillage planting conditions. These machines are available with many options as seen in Table 2. Of course, only a limited number of these options are available or needed for the intended use of different machines. Comprehensive strategies for selection of appropriate planter types and options are now being developed by the American Society of Agricultural Engineers and our laboratory at Temple. An "expert system" computer software package is being developed to serve as a guide to the selection of conservation-tillage planters, drills, and air seeders, Fig. 7.

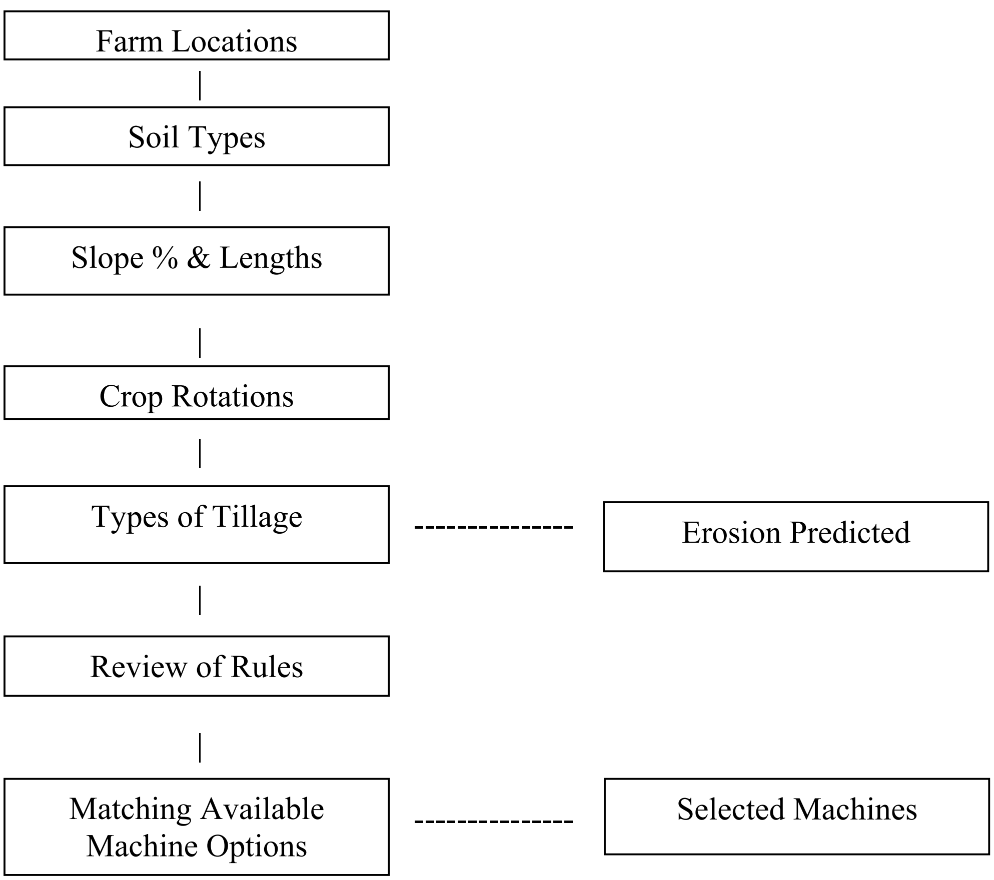

Figure 7. "Expert System" computer flow chart for selecting appropriate machines and available options for conservation planting. (Unpublished, USDA-ARS, Temple, TX).

Table 2. Component options for conservation planters, drills, and air drills.

Initial Penetration Components	Row Preparation Components	Depth Control Components	Soil Opening for Seeding Components	Seed Firming Components	Seed Covering Components	Seed Slot Closure Components
Smooth coulter	*Sweep	Rear presswheels	Double disc	Rubber-tired wheel	Single covering disc	*Wide zero pressure wheel
Notched coulter	*V-Wing	*Side gauge wheels	Staggered double disc	Steel-plate wheel	Double covering disc	Single rib wheel
Rippled coulter	*Two-disc row cleaner	Skid plate on each opener	Runner		Paddles	Double rib wheel
Bubble coulter	*Horizontal disc row cleaner	Tandemed front wheels and rear presswheels	Stub runner			Narrow rubber wheel
Narrow fluted coulter	Wide fluted coulter	Frame lifting/guage wheels	Hoe			Narrow steel wheel
Wide fluted coulter	Ripple chisel	Depth rings on front leading coulter	Single disc			Dual angled rubber wheels
Powered blade or coulter	*Subsoil ripper		Coulter-boot			Dual angled steel wheels
Staggered double disc	*Dual angled residue-cullers		Chisel-boot			Split steel wheels
*Strip rotary tiller						Double covering discs
Smooth coulter w/depth bands						*Dual wide flat wheels

*Components which are too wide or which disturb too much soil to be effectively used on narrow-row, solid-seeding conservation drills.

There is no justification for using more exacting specifications for no-tillage row planting than for no-tillage drilling or solid-seeding. However, no-tillage drills remain crude and ineffective compared to current no-tillage row planters (Erbach et al., 1983). The drills generally have lower technology residue cutting, trash clearance, depth control, seed firming, furrow closure, flotation, and downpressure systems than do the best no-tillage planters. Air-drills only differ from conventional drills by using air delivery rather than gravity delivery of seed to the furrow openers. Drill component options are the same as for planters, Table 2, if applicable to narrow rows.

Air seeders deliver centrally metered seed to wide sweeps with multiple discharge ports. They can be used as conservation machines, but the use of full-width sweep tillage removes them from no-tillage practice.

Crop rows are getting narrower and narrower as fanners change from old technologies. The 30-inch minimum corn row spacing for combine corn headers is a major constraint to the use of narrow rows, approaching solid-seeded for all other major crops. At Temple, we plant no-tillage corn on 16-inch spaced rows and harvest at half speed with combine grain headers. Better harvesting solutions are needed for corn to allow narrower rows, so that the narrow row fertilizing, seeding, and spraying equipment for other crops on a farm will also fit corn rows.

General guidelines for the selection of planter and drills for no-tillage agriculture are as follows:

a) Use rolling components as much as possible to achieve self-cleaning and to minimize stoppages,

b) Cut residues with a rolling coulter or a staggered double disc opener,

c) Control the depth of the coulter in sticky soils,

d) Control planting depth as close to the location of seed drop as possible or by tandem front and back wheels,

e) Minimum disturbance of the soil surrounding the seed furrow is preferred,

f) Positive seed slot covering or closure is a must,

g) Use fertilizer, insecticide, and herbicide attachments only if they do not degrade seeding performance,

h) Use downpressure systems which allow individual row unit flotation,

i) Use downpressure systems which automatically adjust to changing field conditions,

j) Flotation and downpressure should be independent of variations in the weight of seed and fertilizer hoppers and tanks.

Machines for Weed Control

No-tillage weed control machines are herbicide sprayers. Sweep cultivators, rod weeders, and herbicide incorporation devices all perform tillage and are excluded from no-tillage systems. No-tillage herbicide sprayers are of five general types;

1) Band sprayers behind planter row units,

2) Broadcast spray booms on the rear of planters or drills,

3) Tractor-mounted or towed boom sprayers,

4) Self-propelled boom sprayers,

5) Directed sprayers for "chemical cultivation" of weeds.

Band sprayers only treat row areas and are more common for reduced tillage systems where mechanical cultivation is used for weed control between rows.

Broadcast sprayer attachments on planters and drills are very common and practical management tools. Herbicides are applied up to the end of the planting period eliminating the extra labor required to have a separate spraying rig following the planter and the hazard of leaving portions of a field without treatment. Conversely, on-board herbicide spraying requires additional down-time for refilling and mixing, and a large tank, pump, and controls on the planting tractor. If the mounted tank and pumps are being used for coincident fertilizer applications and the additional loads will require the purchase of a larger tractor, then separate planting and spraying operations may be the most economical procedures.

Every no-tillage farm is going to have broadcast spraying equipment. It will be used for insecticide as well as herbicide treatment. For those with front or saddle tanks on a tractor, the most economical sprayer is a 40-ft wide folding boom mounted on the tractor 3-point hitch. Alternatives are 3-point hitch mounted boom sprayers with tanks, and towed boom sprayers with a tank on a trailer.

Self-propelled boom sprayers are very convenient machines, but can be justified only if a tractor is not available, or if special chemical treatments must be made to tall crops and aerial spraying is not available or practical for those situations. Care should be taken in selecting a self-propelled sprayer so that the wheel tread widths match future needs. For controlled-traffic considerations and solid-seeded crops, four-wheel sprayers are preferable over three-wheel machines to confine all machine traffic to the same interrow traffic lanes.

A directed sprayer should be in every no-tillage farmer's shed, Fig. 8. Hopefully, he will never need to use it because his broadcast weed control programs will be adequate. But, for the times when the planting-time herbicides are not effective and there are no appropriate over-the-top herbicides, directed spraying between crop rows may be the only method of control. These machines consist of a toolbar with trailing sleds which position nozzles between rows. The nozzles are aimed at the base of the crop plants and the row middles, depending on the weed problem and the crop susceptibility to the herbicide. One nozzle is adequate between narrow rows. Users argue as to the merits of crop shields on directed sprayers. Shields may not be needed if low pressure, coarse sprays are used to avoid swirling herbicide mists in the plant canopy.

Manufacture's directions should be followed for matching sprayer tank, pumps, and plumbing sizes and materials for personal needs. Most no-tillage sprayers end up being used to pump corrosive fertilizers, so stainless steel fittings and nozzles are good investments. New easy-off sprayer nozzle caps and color-coded nozzles from several manufacturers aid good sprayer management. Electronic sprayer rate control and monitoring equipment may be practical investments for large acreage operators, especially for those who do all of their spraying and liquid fertilizer application work with one machine.

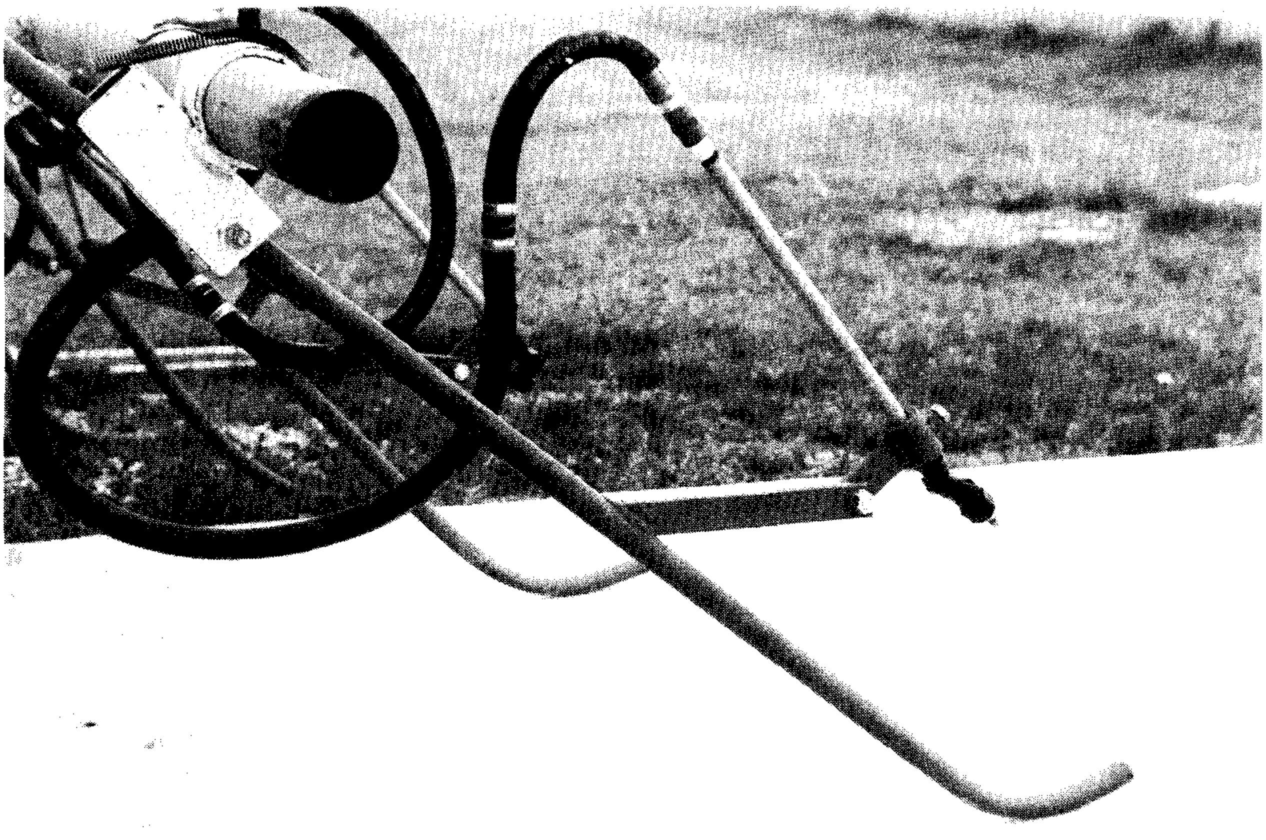

Figure 8. Simple sled-type directed sprayer unit without crop shields to operate between crop rows.

Other Machines

The only other field machines used in no-tillage agriculture are mostly connected with crop harvesting. In general, harvesting machines are interacting with above-ground plant material and do not require special specifications due to surface residue and undisturbed soil conditions. However, harvesting operations can impose objectionable soil compaction and wheel traffic ruts from random machine and truck traffic. For continued no-tillage, it is advisable to establish a common wheel track width for all machines and vehicles, eliminate dual wheels on tractors and combines, and manage year around controlled-traffic (Morrison, 1985).

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