Soil Conservation Service

Stubble-mulch equipment for soil and water conservation in the Great Plains

By R. R. Allen
and
C. R. Fenster

RAPID settlement combined with cyclical precipitation patterns in the semiarid Great Plains of North America resulted in periods of boom and bust for agriculture during the early part of this century. Wind erosion often ravaged the land, especially when the soil surface remained unprotected during fallow or drought. These conditions reached a critical stage during the 1930s with the compounding effects of drought and economic depression. Suitable equipment to manage semiarid land was not yet available.

Widely separated attempts took place in Alberta, Nebraska, and Oklahoma to develop equipment and test tillage methods that would stop erosion and allow some vegetative cover to remain on the soil for protection from the wind. These initial efforts to develop conservation machines had three distinct goals in mind that would later interrelate to bring about stubble-mulch culture. First was a method to perform emergency tillage by bringing clods to the surface to stop on-going soil movement by wind. Second was a method to kill weeds and volunteer plants by shallow tillage while leaving plant residue on the surface to protect the soil from erosion. Third was the concept of leaving plant residue on the soil surface to reduce runoff and soil water loss from evaporation during fallow and thus preserve more soil water for use by the succeeding crop.

The emergency tillage cultivator

In 1933 Fred Hoeme, a Kansas-born farmer who had moved to Hooker, Oklahoma, was searching for a way to control wind erosion on his Oklahoma Panhandle farm (personal communication, 1984, Roland Hoeme). Hoeme had noticed that road-building scarifiers could rip up large clods with their heavy, pointed shanks. Wheel-mounted, spring-tooth cultivators were already on the market, such as the Faulkner[1], but these were too lightly constructed for emergency tillage or deep primary tillage.

Hoeme set out to build a cultivator that was sturdy enough to penetrate the drought-parched soils of the Plains. His first prototypes were made from truck frames. Leaves from truck springs served as the tillage shanks.

After testing three prototypes, he arranged to produce the heavy-duty cultivators for sale. Heavy H-beams for frame members came from the Colorado Fuel and Iron steel mill in Pueblo, where special rolls were set up to form the H-beams. Tillage shanks, made from recently developed, tough manganese steel, came from California.

Some 2,000 Hoeme cultivators were distributed by Fred Hoeme and his son Roland from the family farm near Hooker before the production and distribution rights were sold to W. T. Graham in 1937. Graham then established a manufacturing plant in Amarillo, Texas. During this depression era, the Hoemes sold 15-foot-wide machines for as little as $250 with cash-in-advance orders.

Similar plows were soon marketed by others, such as the Jeoffroys of Amarillo, Texas. The versatile machines, forerunners of present-day chisel plows, could also be equipped with sweeps for sub-tillage.

Noble's blade

C. S. Noble was born in Iowa in 1873, homesteaded briefly in North Dakota, then moved to southern Alberta where he was engaged in land development and farming and later in farm equipment development and manufacturing (22). This Alberta

R. R. Allen is an agricultural engineer at the Conservation and Production Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Bushland, Texas 79012. C. R. Fenster is a professor of agronomy, emeritus, at the University of Nebraska Panhandle Station, 4502 Avenue I, Scottsbluff, 69361. This article is a contribution from ARS, USDA, and the University of Nebraska Panhandle Station.

[1]Mention of brand names or manufacturers is for information only and does not constitute special endorsement or treatment.

Reprinted from the Journal of Soil and Water Conservation
January-February 1986, Volume 41, Number 1

farmer and agricultural leader was concerned about wind erosion on fallow land. So-called "plowless" farming, introduced in 1916 by Edward Bohannon, another Alberta farmer, was being practiced to a limited extent in wheat-fallow farming systems in the province (*34*). "Paul Bunyan" cultivators (moldboard plowframes with duckfoot sweeps replacing the moldboards) were being tested as a means of undercutting wheat stubble and leaving the residue on the surface for protection from wind erosion. But these cultivators did not have sufficient clearance to permit large amounts of residue to pass through.

On a trip to southern California in 1936 Noble witnessed the harvesting of carrots by a machine that undercut the rows to simplify harvesting. With this undercutter idea in mind, he immediately built the first Noble blade, a straight undercutting blade, in a friend's workshop in Garden Grove, California. He tested the new implement in nearby fields, then towed it to Nobleford, Alberta, behind his car.

After further testing the new implement on his farm, he constructed three more of the machines in his farm shop. Some neighbors wanted blade machines as well, so Noble set up manufacturing. About two years later the U.S. Soil Conservation Service bought 19 machines for testing and distribution spread into the United States.

Noble was nearing 65 years of age when he built his first blade, a time when most people consider retirement. But he shunned retirement and actively promoted his blade throughout the Great Plains, often towing a machine with his car to demonstrations as far north as Peace River, Alberta, and as far south as the Texas Panhandle.

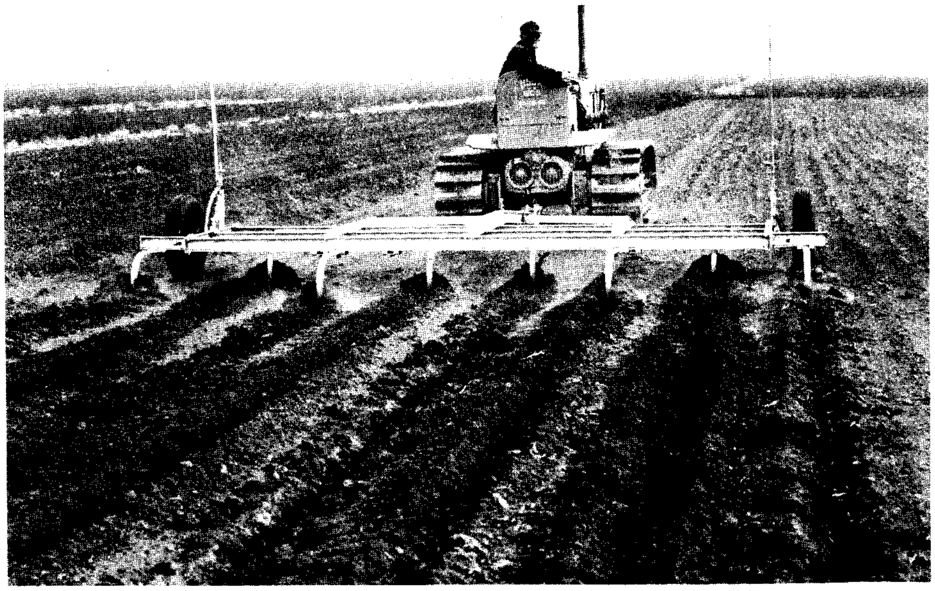
An account of a soil erosion control meeting at Lethbridge, Alberta, in 1943 reveals that other enterprising farmers were also producing blade undercutting tillers (*25*). Among those farmers were P. Kooy (Williamson blade) of Nobleford, Alberta, and V. Erdman of Barons, Alberta.

The stubble-mulch concept

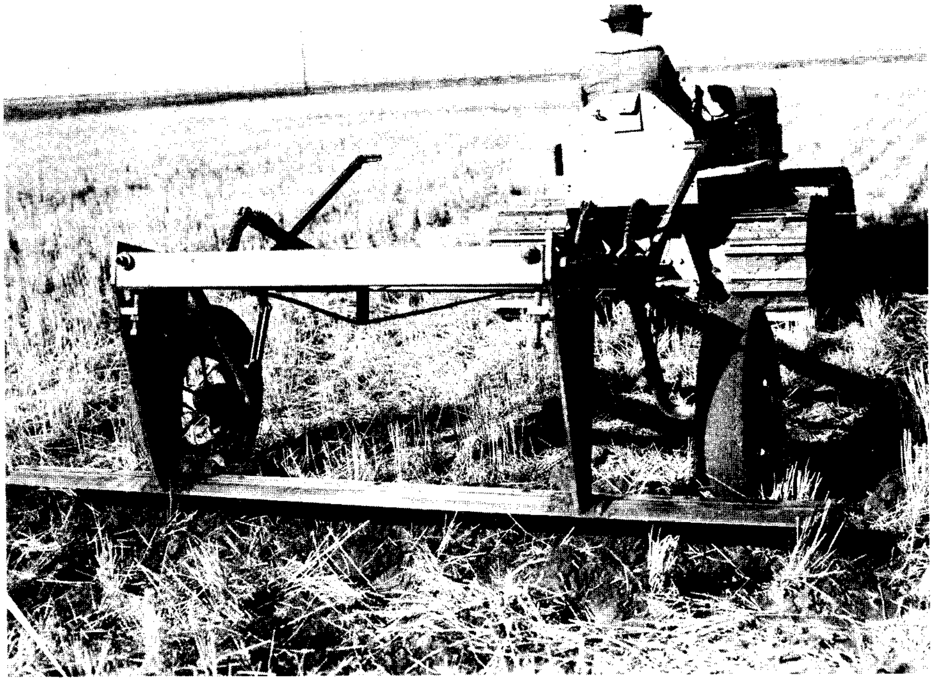
In July 1938, Professor J. C. Russel joined Dr. F. L. Duley at Lincoln, Nebraska, to form a team destined to make soil and water conservation history (*27*). Duley had left the staff at Kansas State University to become the first director of the U.S. Department of Agriculture's Soil Conservation Research Station in Lincoln. Russel was a joint employee of SCS research and the University of Nebraska Agronomy Department. Their early work dealt with leaving a protective cover of crop residue on the soil surface to enhance infiltration and reduce runoff and evaporation.

Leaving straw on the surface did conserve soil water, but weed control in the moist, mulched soil proved to be a problem. They were aware of a new bindweed eradicator with cultivator sweeps being manufactured by the Chase Plow Company of Lincoln that might help solve their weed control problem by cutting off the weeds and leaving the straw on the surface.

They approached L. W. Chase, president of Chase Plow Company, who later became a professor and head of the Agricultural Engineering Department at the University of Nebraska. Chase and his son (*5*) modified some bindweed eradicator sweeps for Duley and Russel to test. These were 22 inches wide with a 85-degree V-angle. When mounted with a 22-inch, vertical-shank clearance, they proved successful in undercutting weeds while leaving residue on the soil surface. Subsurface tillage was a reality!



Soil Conservation Service



Chiseling with a Graham-Hoeme cultivator (top) to stop wind erosion, February 1941, Bushland, Texas. A Noble straight-blade cultivator (bottom) operating in wheat stubble, January 1941, Bushland.

Chase began manufacturing sweep plows and sold them as subsurface tillers in 1939. Other manufacturers, such as Deere, Dempster, International Harvester, and Minneapolis Moline, modified machines, mostly cultivators or listers, to accommodate sweeps and to perform subsurface tillage (*7, 8*). International Harvester offered experimental models with 24-inch V-sweeps on tractor-mounted, hydraulic-lift tool bars or on wheel-mounted wheatland lister frames (*21*).

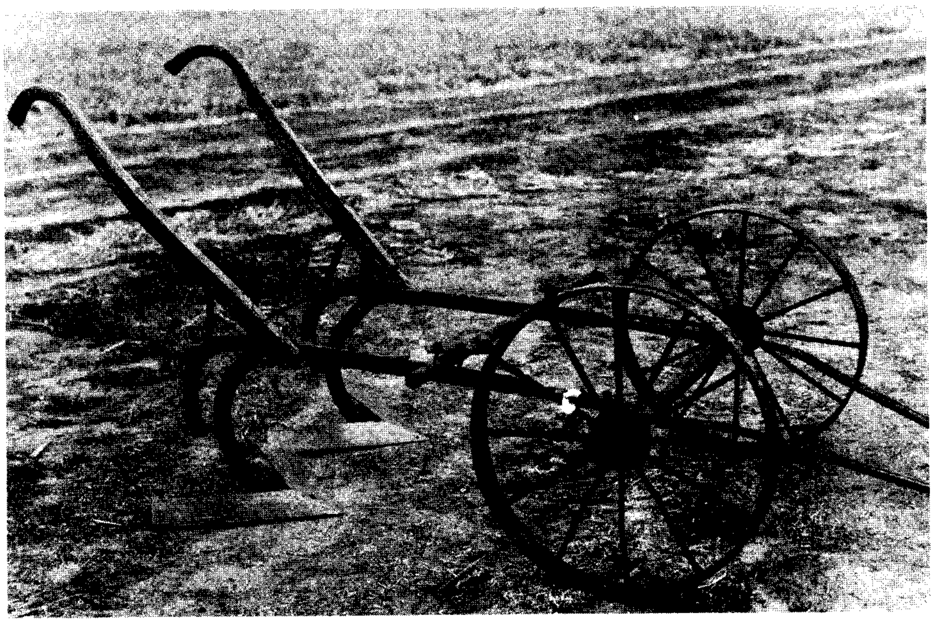
Duley and Russel began more experiments with subtillage. In their first manuscript on the new subject, they debated what to call it—"noninversion tillage," "subtillage," or "subsurface tillage." When they sent the manuscript to Washington, D.C., for approval, SCS Director Hugh Hammond Bennett changed the name to "stubble-mulch tillage," which naturally resolved the "name" question.

In 1939 Duley and Russel learned of a subsurface tiller other than the Chase (*7*). It was the Noble blade, conceived a year or two before the work by Duley, Russel, and Chase. Duley and Russel soon visited Noble in Alberta. This began an exchange of information and visits that continued for several years.

Noble liked the performance of the V-shaped sweeps used by Duley and Russel, and he proceeded to make some large V-sweeps (about 6 feet wide) that could be used (two per carrier frame) in place of his 10-foot straight blades. The V-sweeps, which required less draft, became popular quickly. Noble also provided V-weeder sweeps. These featured rounded forward edges for use on land that had already been loosened with the straight blade or cultivator sweeps.

In 1939 also Duley and Russel learned of another subtillage implement development, that of Oscar E. Miller in Stratton, Nebraska. Miller, a farmer, conceived the idea of attaching a chisel bar to a rodweeder to improve soil penetration in firm soils. He built the first machine in July 1939 and began manufacturing and marketing in early 1940. His idea was to loosen the soil yet leave the plant residue for protection (*17*). The semi-chisel rodweeder gave a big boost to fallow-season weed control options in the new stubble-mulch farming system. This type of rodweeder could be used in conjunction with or in place of sweep tillage machines on most soils.

Shortly after starting their work on V-blade subtillage, Duley and Russel became concerned about firming the seedbed in subtilled soil. They reversed the frame of a Dunham rotary hoe so that the wheels rotated in the opposite direction. This had been Russel's discovery in the early 1930s. They called this altered implement a "treader." When two units were pulled, one behind another working at an angle, they were called "skew treaders." Treaders effectively flick out weed and volunteer seedlings while firming the soil and anchoring residue.

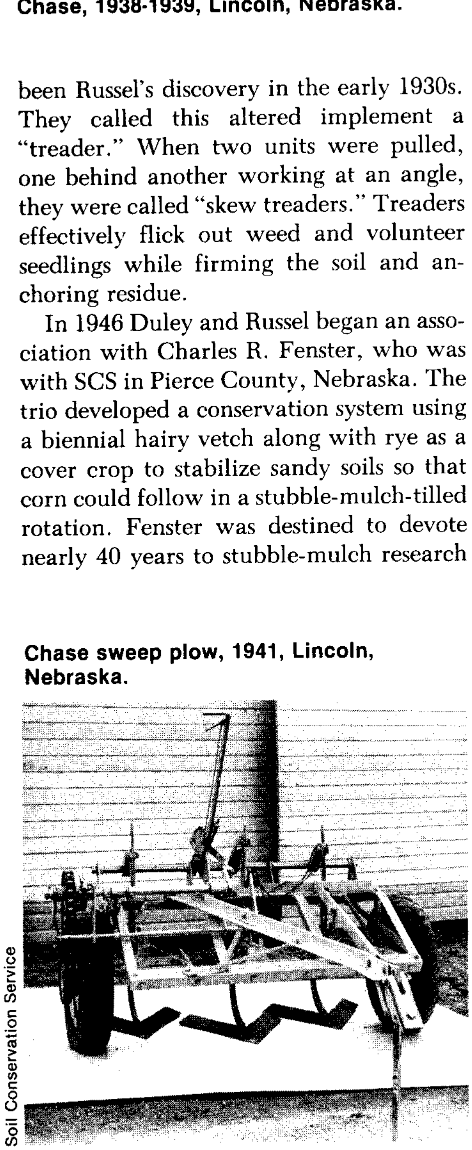


Soil Conservation Service

Horse-drawn sweep cultivator developed by Duley and Russel for use on experimental plots. V-blades were supplied by L. W. Chase, 1938-1939, Lincoln, Nebraska.

In 1946 Duley and Russel began an association with Charles R. Fenster, who was with SCS in Pierce County, Nebraska. The trio developed a conservation system using a biennial hairy vetch along with rye as a cover crop to stabilize sandy soils so that corn could follow in a stubble-mulch-tilled rotation. Fenster was destined to devote nearly 40 years to stubble-mulch research and application, after 1956 as an agronomist with the University of Nebraska.

Chase sweep plow, 1941, Lincoln, Nebraska.



Soil Conservation Service

Experimentation spreads

Stubble-mulch experiments were established by SCS researchers throughout the Great Plains by 1941-1942. Many of these experiments began after harvest of the 1941 wheat crop. Among the locations was one in the southern High Plains at Bushland, Texas, a site with a so-called "hardland" clay loam soil.

C. J. Whitfield led a group of USDA researchers at Bushland who were attempting to adapt the new stubble-mulch concept to that hardland soil. The group included F. G. Ackerman, W. C. Johnson, and C. E. Van Doren. The researchers tested various equipment to undercut stubble and to roughen the surface soil in emergency situations to stop erosion. Noble demonstrated his blade for undercutting wheat stubble on January 14, 1941. Kelley sweeps, 36 inches and 42 inches wide, were tested on three-row lister frames. A Graham-Hoeme cultivator, with chisel points spaced 30 inches apart, was tested for emergency surface roughening in February 1941.

Formal stubble-mulch experiments were established in the summer of 1941. The Graham-Hoeme cultivator with 18-inch sweeps and the Noble straight blade were included in the studies. The straight blade and field cultivator proved efficient under most conditions, but the straight blade did not always scour well at shallow depths, especially where sedge roots were present in the soil during the final cultivation before seeding the next crop. Researchers preferred something heavier than the field cultivator for the first cultivation after harvest on the hardland soil (*19*).

The Bushland group decided to develop a single-implement tillage system that could be used under all hardland soil conditions. Most stubble-mulch plows lacked sufficient weight and strength for the hardland soils (*1*). Sweep blade designs were tested in cooperation with I. F. Reed at USDA's National Tillage Machinery Laboratory. The sweeps chosen were four inches across the blade with a one-and-three-eighths-inch (20-degree) pitch. The cutting width was 30 inches with a 60-degree V-angle. Earlier, L. W. Chase had tested blade pitch, choosing a one-and-three-sixteenths-inch pitch (17 degrees) with a four-inch blade section (5).

In 1945 a reinforced and supplementary weighted carrier frame was constructed at Bushland. The unit included features suggested by Akerman and Ebersole (*1*). Five 30-inch sweep blades were mounted on a modified Dempster 101 carrier, allowing a four-inch blade overlap as Chase (5) had suggested. Fifteen-inch-diameter rolling coulters were mounted ahead of each shank to cut through residue. The power lift linkage was improved to enhance depth control. This unit was successful, and Dempster Manufacturing Company began supplying heavier commercial sweep machines including many features of the Bushland USDA machine. Dempster also supplied sweep blades to mount on chisel-plow frames.

Average residue reduction per tillage operation (*12, 13*).

Tillage Operation	*Residue Reduction per Operation (%)*
V-sweep (30 inches or larger)	10
Shovel sweeps (16-18 inches) mounted on chisel plows	20
Chisel plows	25
Rodweeders	5-10
One-way, tandem, or offset disks	
Operated 3 inches deep	30
Operated 6 inches deep	70

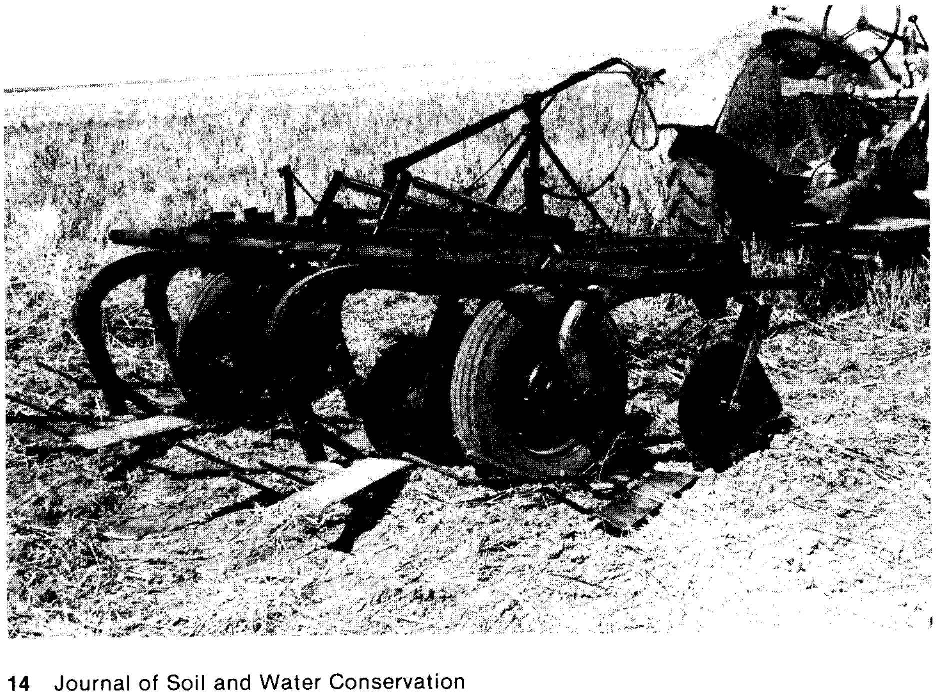
Central Plains research

In 1956 Fenster began research on stubble-mulch tillage and equipment in western Nebraska, first at Alliance, later at Scottsbluff. Fenster (*11*), as did Johnson and Davis (*19*), emphasized proper adjustment and weighting, up to 250 pounds per foot of width, to provide adequate sweep penetration without ridging the soil.

Fenster and cooperators were interested in multi-implement residue management systems. Various combinations of sweep tillers, field cultivators, oneway tillers, rodweeders, and treaders were evaluated for managing wheat residue during fallow. Personnel from USDA's Wind Erosion Laboratory at Manhattan, Kansas, cooperated in some of the studies (*15, 36*). Stubble-mulch tillage power requirements were evaluated relative to tillage effects and residue retention (*6*). Disk implements covered 30 to 70 percent of the residue for each operation, while larger sweeps and rodweeders covered only about 10 percent (*12, 13*). D. T. Anderson of Alberta experienced similar results of residue coverage with tillage (*4*).

Dempster sweep plow with frame strengthened for hardland soils, 1949, Bushland, Texas.

Soil Conservation Service



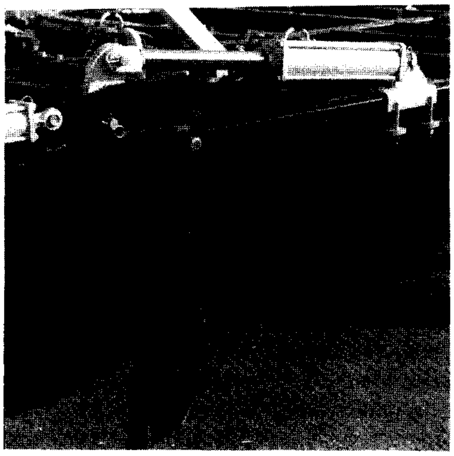
During a visit with J. C. Fleming of the Sunflower Manufacturing Company in 1960, Fenster encouraged Fleming to consider developing a "flex-sweep" tiller with two or more blades on one machine. Until that time, the large five- to seven-foot V-blades were individually mounted and connected by multiple "squadron-type" hitches for large tractors. Fleming then designed a hinged-frame flex-tiller, and the Sunflower Company in Beloit, Kansas, began producing the machines in early 1961.

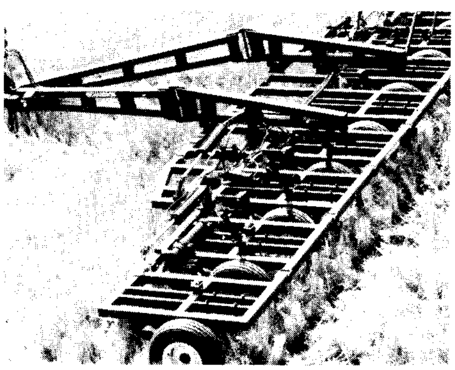
The flex-frame arrangement caught on quickly among farmers, and the concept continues to be used today throughout the industry. The older, separately hitched V-blades worked well, especially in rocky and stumpy soils. But the new hinged-frame plows appealed to farmers because they could be hydraulically folded into compact units for transport. Modern hinged-frame sweep tillers may have as many as 9 to 11 blades. Some extend beyond 50 feet in width.

Most large V-blades for these modern sweep tillers are still supplied to various manufacturers by Versatile-Noble. A survey of current models indicates that new square-tubing, heavy-frame plows still range in weight from 150 to 250 pounds per foot of width as recommended by Fenster nearly 25 years ago. The hinged-frame sweep tillers are popular in the central and northern Great Plains and are excellent for terrace contours. Treaders and flex-tine harrows are a popular accessory. Rigid-frame, three-point mounted sweep tillers are popular in flat areas of the southern Great Plains, but machine widths are limited to about 20 feet.

Chemical fallow

The availability of new triazine herbicides during the 1960s, such as propazine


Agricultural Research Service


Richardson Manufacturing Company

Hinged-frame plow with large V-blades and hydraulic folding mechanism (top). Forty-five-foot-wide hinged-frame plow with V-blades operating in stubble (bottom).

and atrazine, offered new flexibility for fallow-season residue management in the Great Plains. The chemicals could be used in place of or in combination with sweep tillage in wheat-fallow-sorghum-fallow and wheat-fallow rotations. The cost of equipment and mechanical tillage has increased more rapidly than has the cost of herbicides, so chemical fallow or combinations of chemical and machine fallow (ecofallow) have become popular. These methods increase fallow-season storage of soil water beyond that achieved with stubble-mulch tillage alone. The result has been higher and more stable crop production in the Great Plains (*14, 16, 26, 29, 33, 35*). Ecofallow methods have reduced production costs as well as time and energy requirements (3, *14*).

Seeding through residue

Introduction of stubble-mulch tillage produced another challenge, that of seeding through residue. Duley and Russel found that 10-inch-spaced, semi-deep furrow disk drills mixed too much residue with the seed (9). They turned to the King drill, which had been developed in Nebraska before stubble-mulch tillage was introduced (*27*). The King drill featured an angled, flat-disk opener with an adjacent seed boot. The angled disk cut through residue and opened a seed slot in the soil. This basic design is available on some no-till drills today.

Attention was quickly directed to shovel drills, also called lister and hoe drills, which had more residue-clearing ability than ordinary grain drills. Some lister drills by Deere and Company had been used in Montana as early as the 1920s (personal communication, 1984, with Warren Ten Pas). The Dempster Company of Beatrice, Nebraska, had shovel press drills available by 1927. During the 1930s, C. T. Peacock, an Arriba, Colorado, farmer, developed a lister drill that formed furrows about 20 inches apart for snow trapping; this drill would also handle residue (*23*). By 1940 International Harvester had double-disk-opener press drills and plow (shovel) press drills featuring staggered openers, power lifts, and pneumatic front caster wheels (*24*). Such designs are still common in the industry. Noble started producing heavy-duty, high-clearance shovel press drills during the early 1940s, in addition to the blade cultivators. Minneapolis Moline offered a unique tool-bar seeder that could seed in rows 12 to 20 inches apart. The unit could be used to seed small grains through residue or row crops.

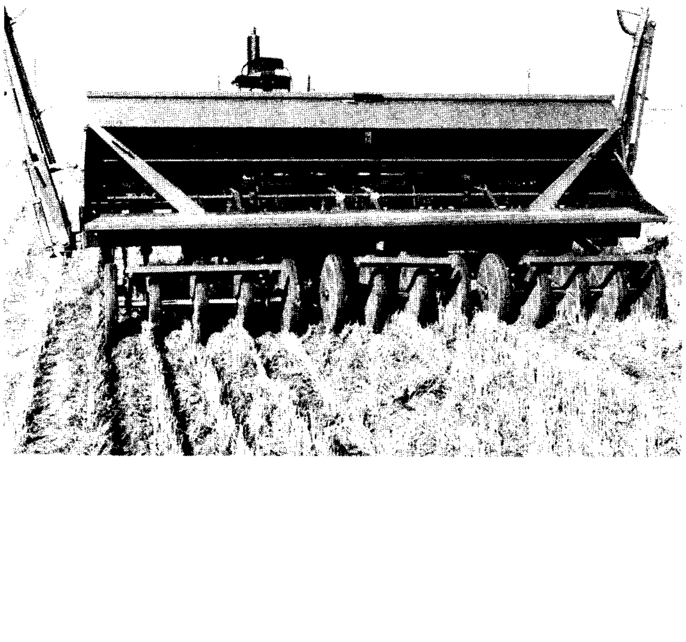
The shovel press drills, in which the relatively large-diameter rear press wheels carried much of the weight of the machine, proved effective in stubble mulch. The shovel opener penetrated deep enough to reach moist soil without covering seed too deeply. Shovel seed openers were arranged in two or three staggered rows for residue clearance. Fenster (*11*) noted that there should be at least 20 inches of space between shovels and that the vertical clearance between the frame and shovel tip should be at least 17 inches.

A wide range of shovel openers are available for drills (*30*) that can be used for stubble-mulch seeding. Ray Throckmorton and others worked with Fenster in developing and refining shovel press drills (personal communication, 1984, with Throckmorton). Narrow, light draft points, called eagle-beak or spear points, were introduced. These disturb little residue and work well with narrow press wheels.

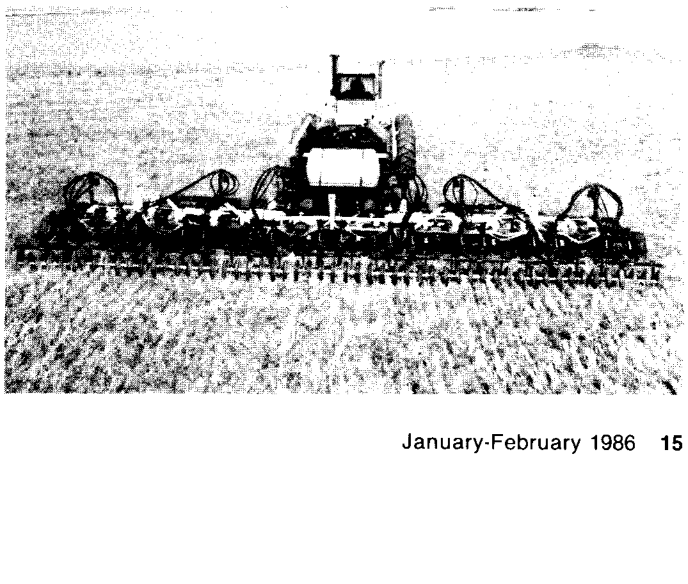
Improved management practices and better wheat varieties resulted in consistently higher wheat yields, which produced more residue. Drills were needed to handle the extra residue. Farmers, including Vance Ehmke of Healy, Kansas, complained that drills were plugging with residue in years when straw amounts were above average or when the residue was damp (*10*).

So-called no-till drills, usually with coulters mounted ahead of double-disk

Agricultural Research Service



Flex-King Corporation



A modern narrow-point, shovel-press drill (left) that seeds with a minimum of soil and residue disturbance. An air seeder mounted on a 45-foot, hinged-frame V-blade plow (right). Trailing seed press wheels are attached.

openers, have proliferated in soybean and small grain areas east of the Great Plains. These drills cut through residue, but they were not built to penetrate the soil to a depth of three or more inches to reach moist soil without covering seed too deeply.

Montana studies compared coulters mounted in front of double-disk openers, slot openers, and shovel openers (*20*). Generally, the double-disk openers caused the least soil disturbance, and all openers operated through wheat stubble without plugging when coulters were used. Smooth coulters worked best. Disk-opener drills could not penetrate firm soil without the help of a coulter cutting a slot.

In Manitoba, coulters were added to an International Harvester Model 620 disk-opener press drill with a six-inch seed row spacing to successfully seed cereal and oilseed crops through residue (*32*). Ron and Erve Friehe of Red Willow County, Nebraska, lengthened the frame of a Noble shovel drill by 24 inches and added 22-inch coulters plus weight for penetration to seed through ecofallow stubble (*2*).

Some specialized, very heavy no-till drills have been developed in the Palouse area of the Pacific Northwest. Each disk opener carries about 1,700 pounds of weight to force penetration. Separate disk openers place fertilizer between seed rows. Morton Swanson built the first prototype in 1974. The heavy drills are frequently pulled with four-wheel drive tractors.

Air seeders

Another development during the late 1970s has helped to resolve the problem of seeding through large amounts of residue. Two enterprising farmers from Antler, Saskatchewan, Preston Davies and Art Ross, developed an air-seeding system to distribute seed behind field cultivators or chisel plows (*34*). Their unit was manufactured as the Prasco. Other manufacturers quickly developed similar seeders. Distribution tubes release seed behind the cultivator shanks. These units operate through large amounts of residue, and the larger units, 50 to 60 feet in width, can cover large areas. Fertilizer distribution tubes can also be added.

One shortcoming of this type of air seeder is uneven seed depth placement (*28*). Mark Schrock of Kansas State University has suggested use of individual parallel linkage and press wheels for each opener to improve seed placement depth.

Kansas State University agricultural engineers introduced air seeding directly behind five-foot V-sweeps for seeding row crops, such as sorghum, into wheat stubble (*18, 31*). The Flex-King Corporation of Quinter, Kansas, acquired production rights to the KSU planter system and now markets air distribution systems for seeding in 10-inch rows behind five-foot V-blades or wider spacing for row crops. Tests at Bushland, Texas, seeding wheat behind a wide V-blade on a clay loam soil, indicate that the seed depth is more variable than with press drills (unpublished data).

Other chisel-plow and sweep-plow manufacturers offer air seeders, some for seeding behind blades, others for seeding behind point openers. Many of these feature press wheels.

In summary

Stubble-mulch culture is a reality in the Great Plains. Development of stubble-mulch equipment and systems in North America spanned a period of 70 years. The combined efforts of farmers, scientists, and extension personnel were involved.

Improvements continue, of course, but the early developments proved to be the catalyst for improved farming practices that reduce soil erosion and more efficiently use limited supplies of water.

REFERENCES CITED

1. Ackerman, F. G., and J. C. Ebersole. 1945. *Prerequisites of a sweep stubble-mulch implement for the Southern High Plains.* Agr. Eng. 26(6): 249-250.
2. Alleman, Roy. 1982. *Ecofallow catches on in wheat country.* Farm J. (May 1982): D-4.
3. Allen, R. R., B. A. Stewart, and P. W. Unger. 1977. *Conservation tillage and energy.* J. Soil and Water Cons. 32(2): 84-87.
4. Anderson, D. T. 1961. *Surface trash conservation with tillage machines.* Can. J. Soil Sci. 41: 99-114.
5. Chase, L. W. 1942. *A study of subsurface tiller blades.* Agr. Eng. 23(2): 43-45, 50.
6. Dickerson, J. D., N. P. Woodruff, and C. R. Fenster. 1967. *Power requirements, cloddiness, and residue conservation characteristics of some stubble-mulch tillage implements.* Tech. Bull. No. 152. Kans. Agr. Exp. Sta., Manhattan.
7. Duley, F. L., and J. C. Russel. 1939. *Annual research report.* U.S. Dept. Agr., Lincoln, Nebr.
8. Duley, F. L., and J. C. Russel. 1942. *Annual research report.* U.S. Dept. Agr., Lincoln, Nebr.
9. Duley, F. L., and J. C. Russel. 1942. *Machinery requirements for farming through crop residues.* Agr. Eng. 23(2): 39-42.
10. Ehmke, Vance. 1980. *Drills just can't handle heavy stubble.* No-Till Farmer 8(3): 6-7.
11. Fenster, C. R. 1960. *Stubble-mulching with various types of machinery.* Soil Sci. Soc. Am. Proc. 24: 518-523.
12. Fenster, C. R. 1973. *Stubble mulching.* In *Conservation Tillage.* Soil Cons. Soc. Am., Ankeny, Iowa. pp. 202-207.
13. Fenster, C. R. 1977. *Conservation tillage in the Northern Plains.* J. Soil and Water Cons. 32(1): 37-42.
14. Fenster, C. R., G. A. Wicks, and D. E. Smika. 1973. *The role of ecofallow for reducing energy requirements for crop production.* Agron. Abstrs. 64: 122.
15. Fenster, C. R., N. P. Woodruff, W. S. Chepil, and F. H. Siddoway. 1965. *Performance of tillage implements in a stubble mulch system: III. Effects of tillage sequences on residues, soil cloddiness, weed control, and wheat yield.* Agron. J. 57: 22-55.
16. Greb, B. W., D. E. Smika, and A. L. Black. 1967. *Effect of straw mulch rates on soil water storage during summer fallow period in the Great Plains.* Soil Sci. Soc. Am. Proc. 31: 556-559.
17. Harrington, Preston. 1963. *A farmers inventions and ingenuity make rural industry for Stratton.* The Electric Farmer (June 1963): 10-11.
18. Herron, M. M. 1978. *Development of a reduced tillage planter for the semi-arid Great Plains region.* Masters thesis. Dept. Agr. Eng., Kansas State University. Manhattan.
19. Johnson, W. C., and R. G. Davis. 1972. *Research on stubble-mulch farming of winter wheat.* Cons. Res. Rpt. No. 16. U.S. Dept. Agr., Washington, D.C. 32 pp.
20. Krall, J. L., W. E. Larsen, and A. L. Dubbs. 1978. *No-till drill studies for seeding small grains.* Paper No. 78-1514. Am. Soc. Agr. Eng., St. Joseph, Mich.
21. Morehead, H. A. 1942. *Equipment for subsurface tillage.* Agr. Eng. 23(2): 46, 64.
22. Mount, R. 1979. *History of Noble.* Noble Cultivators Co., Nobleford, Alberta.
23. Musick, J. T. 1981. *Precipitation management techniques—new and old.* Proc., Eighth Ann. Conf. Groundwater Mgt. Dist. Assn., Lubbock, Texas.
24. Otten, S. K. 1984. *International Harvester archives.* Oak Brook, Ill.
25. Palmer, A. E., and J. J. Paterson. 1943. *Tour of inspection of the Dominion Experiment Station at Lethbridge and visits to several prominent farms in the district in regard to soil drifting control methods.* In Report of the Meeting, Reg. Committee on Soil Drifting. Dominion Exp. Sta., Lethbridge, Alberta.
26. Phillips, W. M. 1969. *Dryland sorghum production and weed control with minimum tillage.* Weed Sci. 17: 451-454.
27. Russel, J. C. 1976. *Some historical aspects of stubble mulch tillage.* Publ. 77. Great Plains Agr. Council, Lincoln, Nebr. 12 pp.
28. Schrock, M. 1982. *Ideal reduced tillage drill)* We're getting much closer! No-Till Farmer 10(12): 4.
29. Smika, D. E., and G. A. Wicks. 1968. *Soil water storage during fallow in the Central Great Plains as influenced by tillage and herbicide treatments.* Soil Sci. Soc. Am. Proc. 32: 591-595.
30. Stickler, Fred, and Warren Ten Pas. 1970. *Mechanization of seeding practices* In Proc., Int. Conf. on Mechanized Dryland Farming. Deere & Co., Moline, Ill. pp. 286-289.
31. Suderman, D., and S. J. Clark. 1981. *The KSU underplanter—development and testing.* Paper No. 81-1509. Am. Soc. Agr. Eng., St. Joseph, Mich.
32. Townsend, J. S., and W. Chinsuwan. 1976. *Zero-tillage planting equipment for heavy trash conditions.* Paper No. 76-1022. Am. Soc. Agr. Eng., St. Joseph, Mich.
33. Unger, P. W., A. F. Wiese, and R. R. Allen. 1977. *Conservation tillage in the Southern Plains.* J. Soil and Water Cons. 32(1): 43-48.
34. Walker, John D. 1982. *A brief history of small grain minimum tillage practices.* Min. Till. Series No. 430. Ricks College, Rexburg, Idaho.
35. Wiese, A. F., E. Burnett, and J. E. Box, Jr. 1967. *Chemical fallow in dryland cropping sequences.* Agron. J. 59: 175-177.
36. Woodruff, N. P., C. R. Fenster, W. W. Harris, and Marvin Lundquist. 1966. *Stubble mulch tillage and planting in crop residue in the Great Plains.* Trans., ASAE 9: 849-853. □