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Tillage and Stubble Management: On-going Research in USA

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Abstract

There is considerable emphasis on conservation tillage research in the U.S. in response to growing concern over soil erosion and its adverse effects on productivity and environmental quality. Conservation tillage can reduce erosion by 50% or more and at the same time conserve water which has significantly increased crop yields and reduced farming risks in the dryland areas. U.S. farmers are now applying conservation tillage practices to about one-third of the nation's croplands. Approaches to conservation systems receiving more emphasis include no-till fallow, increased cropping intensity for more soil cover, no-till into cover or sod crops, and ridge-till. Adaptive research on tillage methods include slot mulching, paraplowing, and basin pitting. Studies of fertilizer placement with conservation planting show generally that banding the fertilizer near the seed row of crops is superior to broadcasting or banding some distance away from the row. A new combination seed-fertilizer drill opener termed "cross-slot" has been developed that is capable of efficiently operating over a wide range of conservation tillage conditions. Yields with the cross-slot opener were comparable or superior to those with standard double disc or hoe-type openers. Conservation tillage alone as used with many conventional cropping systems will probably not change the current status of nitrate leaching and thus, the potential for groundwater contamination. The status with pesticide contamination of water is less certain and no clear cut distinction between conventional and conservation tillage yet exists.

Water Conservation and Erosion Control

Tillage and crop residue management are high priority research objectives in U.S. agriculture because of their important impacts on the nationally prominent issues of soil and water conservation, and water quality. Soil erosion is regarded as the greatest single threat to sustaining the productivity of the nation's 170 million hectares of croplands. A national survey conducted in 1982 estimated that wind and water erosion on U.S. croplands exceeded 2 billion tons annually (Soil Conservation Service 1982). If this erosion is allowed to continue it is expected to undermine steadily the productivity of many soils. Inefficient use of precipitation in dryland areas and impairment of surface and groundwater quality by agrochemicals and/or sediment are also major national problems that are often associated with improper management practices.

In recent years much research emphasis has been given to both technology development and adaption of conservation tillage systems for water conservation and erosion control. The Conservation Technology Information Center (CTIC) in West Lafayette, Indiana, USA, defines conservation tillage as "any tillage and planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce soil erosion by water. Where soil erosion by wind is the primary concern, at least 1000 pounds of flat small grain residue per acre (1120 kg/ha) is on the surface during the critical erosion period". Five types of conservation tillage systems are now identified: no-till, reduced tillage, mulch tillage, strip tillage, and ridge till. The first three types, and to a lesser extent strip tillage, have application to dryland farming systems. Ridge till is mostly being applied to the more humid northern climates with row cropping of maize (*Zea mays)* and soybeans (*Glycine max*) for example.

According to estimates determined by CTIC, conservation tillage results in an average 50% reduction in soil erosion compared with many conventional tillage practices (Brosten 1988). However, the range may vary from 30 to 90% depending on the specific form of conservation practice and other factors including soil type and the tillage system formerly in use. For example, no-till with a good residue cover may reduce erosion by 90% or more, whereas stubble mulching may reduce it considerably less (e.g. 30 to 40%), compared with clean cultivation. It is apparent that broad-scale adoption of conservation tillage could have significant impact in reducing erosion, especially if applied to highly erodible lands.

Conservation tillage has also been shown to benefit water conservation markedly, and enhance crop yields in dry farming systems. Table 1 presents water storage efficiencies for different fallow systems at Akron, Colorado, USA. Storage efficiency is defined as the percent of the precipitation that is stored during the fallow period (in this case 12 months) and

Table 1. Effect of different tillage systems on the efficiency of water storage in fallow, Akron, Colorado, USA (Greb *et al* 1979)

Tillage system	Years in use	Number of tillage operations	Efficiency*
Maximum tillage. Plow and Harrow	1915-30	7 to 10	16 to 22
Conventional bare. Shallow disc, rodweed or harrow	1931-45	5 to 7	20 to 24
Modified conventional. Disc (once) chisel, rodweeder	1946-56	4 to 6	24 to 27
Stubble mulch. Sweep, rodweeder	1957-70	4 to 6	27 to 33
Minimum tillage. Herbicide to replace one or more tillages	1968-77	2 to 3	33 to 38
No-till	1975-77	0	45 to 55

* Defined as the percentage of precipitation stored in the soil

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made available to the subsequent crop. Storage efficiencies increase as the number of tillage operations decrease and more crop residues are retained on the soil surface. Water storage with the minimum tillage and no-till systems was also improved through better weed control with herbicides. The average wheat (*Triticum aestivum*) yields have doubled over the 45-year period during which improvements in fallow systems were occurring (Table 2). Some of the yield increase was attributed to improved varieties, and planting and harvesting methods, but most was due to increased fallow efficiency (Greb 1979).

Table 2. Wheat yields for 2 locations in the Central Great Plains as a result of improved technology. (Greb *et al* 1979)

	Average of Akron, CO and Colby, KS	
Decades	Average precipitation mm	Wheat yield Mg/ha
1926-35	432	1.2
1936-45	455	1.6
1946-55	472	2.0
1956-65	472	2.2
1966-75	427	2.7

Another example showing the effect of improved tillage and residue management on water conservation and wheat yields is demonstrated by changes in fallow practices in the western Nebraska drylands. Wheat yields doubled (from 0.7 to 1.5 t/ha) during the late 1930s when stubble grazing was eliminated and mulch tillage and improved weed control were introduced in the wheat-fallow cropping system (Fenster 1989). Fertilizer usage was an important but secondary factor contributing to this yield increase. The change in farming practice amounted to a "snowball" effect, i.e. without grazing there was more surface cover and this, coupled with good weed control, substantially increased the available water, which in turn produced more crop residues for additional water conservation benefits and higher yield. The increase in yield was sufficient to justify separating the production of livestock and grain on the same land in many USA dryland areas. This to a large extent is the practice today. Moreover, retention of surface stubble reduces wind and water erosion, which improves the long-term sustainability of the soil.

Current Research and Farmer Adoption

Much research and development on soil and crop management is currently directed towards no-till and minimum tillage systems. Economics has been the major incentive in promoting

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their use on croplands. Though the use of no-till is increasing, farmer adoption of this practice has been relatively slow. According to the 1988 CTIC survey, no-till is being applied to about 10% of the 88 million hectares of croplands that are presently under some form of conservation tillage. Some of the limitations of no-till include poorly understood biological factors that retard crop growth in surface residue systems; increased weed infestations and costs of controlling weeds; increased plant diseases associated with residues on the surface; and problems with equipment and stand establishment with seeding in badly prepared seedbeds and hard soil.

Long-term no-till promotes a build-up of organic matter on the soil surface. This helps to reduce surface crusting and increase the infiltration rate of many soils. Some researchers also report increased worm and insect activity with continuous no-till or limited tillage which improves intake of rain or irrigation water (Griffith *et al.* 1986). The increase in surface organic matter is accompanied by an increase in soil organic nitrogen. Some researchers report that although less nitrogen may be available for crop uptake with no-till, at any one time the season-long availability is improved compared with conventional tillage systems (Conservation Impact 1988).

Cropping/residue Management Systems

Chemical fallow

There has been considerable research on technology development for complete no-till (chemical) fallow in the dryland areas. The potential benefits of no-till fallow are near-elimination of soil erosion, higher water storage and grain yields, and lower energy costs per unit of production. Most success with chemical fallow has been achieved in summer rainfall areas such as the Great Plains. In the winter precipitation zones such as the Pacific Northwest, without tillage there is substantial loss of seedzone moisture during the summer (Lindstrom *et al.* 1974). This reduces the chances of early autumn establishment of wheat, and the farmer must then rely on late planting with lower yield potential. Under these conditions the greatest potential for no-till fallow is on sandy soils (Hammel *et al.* 1981). These soils tend to self-mulch upon drying, making the effect of tillage in reducing water loss less important than for finer-textured soils.

Annual or double cropping systems

Conservation tillage is increasing the potential for double cropping, and increased annual cropping in traditional wheat-fallow areas. For example, maintaining standing stubble during the overwinter noncrop period may increase water storage enough from snow catch and reduced evaporative loss to permit annual cropping in the transition zones between subhumid and semiarid areas. The practice may also allow annual cropping in years of above-normal precipitation in the semiarid areas.

No-till is also moving the potential for double cropping, e.g. soybeans after wheat, into the subhumid northern areas with shorter growing seasons. With no-till, soybeans can be successfully seeded into wheat stubble immediately after harvest, which minimizes moisture loss, and assures quicker stand establishment from residual moisture than can be accomplished with a tilled seedbed, which tends to dry out.

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Cover crops

In some of the more southern regions cold-tolerant crops such as rye (*Secale cereale*), crownvetch (*Coronilla varia*), or Austrian winter peas (*Pisum sativum*) are grown during the winter months to reduce runoff, erosion, and nutrient loss. These are especially beneficial in preventing erosion on steep land which would otherwise lack cover in winter. The vegetation is chemically killed in early spring to control moisture use and a crop such as maize is later no-till seeded into the mulch which helps prevent runoff and evaporation. A limitation to the use of cover crops is moisture use, which may reduce the amount of water available for the succeeding crop, especially in water-deficient areas or in dry years. Another practice being adopted by farmers in some areas is no-till seeding of grain crops in sod following take-out of a grass or legume crop grown for seed or forage. One example is in eastern Washington where pulses are no-till seeded into killed sod of bluegrass after several years of seed production.

Ridge-till with surface residues for maize and soybeans

Ridge till (planting row crops on a preformed ridge) has been gaining popularity as a conservation practice for maize and soybean production in the midwest states. Advantages are decreased erosion, water conservation, reduced fuel and equipment costs, and faster seedbed warmup in the spring. The row crops are sown in the spring on ridges formed by cultivation of the crop during the previous growing season. The ridges and residues which are usually shredded in the autumn are left intact overwinter.

The planting operation moves 2 to 3 cm of soil, weeds, manures, and crop residues from the ridge top where seed and starter fertilizer are placed into the interrow or wheel track area. As the corn or soybeans grow a later cultivation is used to control weeds and preform the ridges for the next year's cropping. The mulch in the interrow area helps prevent runoff and erosion.

Tillage Methods

No-till planting can result in water runoff, especially from frozen or eroded soils, and where residue amounts are low. This is also of concern where soil compaction results from the continued use of heavy no-till drills which require large powerful tractors. Where these conditions exist it may be necessary to use a supporting practice to enhance water infiltration into the soil. Some special form of tillage and residue management may also be necessary on parts of the landscape where topsoils are thin and erosion continues to expose the less permeable subsoils.

Slot mulch

A concept of tillage and residue management termed "slot mulch" has been under test in the Pacific Northwest wheat region as a supporting practice for no-till to control runoff (Saxton *et al.* 1981). Conceptually, the approach is to compact loose residues and chaff from the harvested grain crop into a narrow slot approximately 7 to 13 cm wide and 20 cm or more deep, formed on the hillside with the loose soil forming a berm on the downslope side. The practical

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distance between slots might range from 6 to 8 m. The straw in the slot is left exposed at the surface. The straw mulch maintains macroporosity for intercepting runoff from rain or melting snow and also insulates the slot so that the bottom remains unfrozen during the winter. Theory and field experiments have confirmed that the slot mulch prevents runoff on steeply sloping land over a wide range of conditions. The operation also facilitates no-till planting because the loose residues that may interfere with planting and crop establishment are removed and packed into the slot.

Paraplow

The paraplow is a subsurface tillage implement that shows promise for water conservation by reducing runoff. The design is a slant-shank chisel plow with tools mounted on a frame much like that of a moldboard plow. The purpose of the paraplow is to loosen the soil to a depth of 30-40 cm while leaving the surface residues mostly intact. The tillage operation creates large fractures and macropores which help maintain high infiltration rates even after heavy rains or while the soil is frozen. It has the potential for improving water infiltration on steep slopes where there is little surface residue and water intake is slow.

Research in a 350 mm precipitation area in eastern Washington shows an additional 30-60 mm of water is stored overwinter with autumn paraplowing as compared with no-tillage (Table 3). Maximum benefits were achieved during a winter when several runoff events

Table 3. Overwinter soil water storage (mm) as affected by paraplow tillage and residues (180 cm depth)*

Residue management	Tillage		Gain with paraplow
	Paraplow	No-till	
Standing Stubble	165a	123bc	42
Chopped Stubble	150ab	119bc	31
Burned stubble	95dc	65d	30
LSD	35		

* Average of 3 years

occurred on frozen soils. Highest water gains were with surface residues present. Field demonstration tests in Ohio showed that maize yields with paraplowing equaled or surpassed those with moldboard plowing, chisel plowing, and no-till (Conservation Impact 1987). The tillage benefit in this case enabled the farmer to reduce erosion sufficiently and remain in compliance with the erosion control requirements of the 1985 Food Security Act for highly erodible lands. The paraplow requires about 50 horsepower per chisel which covers a width of approximately 50 cm. The beneficial effects of paraplowing for infiltration may last for several seasons which makes it work well for a minimum tillage system.

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Basin pitters

Furrow dammers, or basin pitters, are increasing in use as a means for enhancing water infiltration and storage in soil. The operation consists of forming small furrows or miniature basins that hold water on sloping positions during rain or snowmelt events. For example, the basin pitter can be used on tilled or untilled stubble as a means to improve infiltration or hold snow. Field testing has included sowing winter wheat with a disc drill following pitting, or pitting after the sowing operation. More research is needed to determine the feasibility of this tillage practice over a range of soil, slope, and cropping conditions.

Seeding and Fertilizer Methods

Considerable progress has been made on the development of no-till drills that can simultaneously apply seed and fertilizer, and current research is underway on herbicide banding, all in a single pass. Machines are now available that can operate in heavy residues and hard soil, and deep band all or part of the crop fertilizer requirement between or below the seed rows. The commercial machines currently in use are equipped with either hoe-type or heavy-duty double disc openers, the latter sometimes being offset to facilitate cutting through crop residues or penetrating hard, dry soil.

Fertilizer placement

There has been considerable research to develop fertilizer placement technology for conservation tillage systems. Although crop response to fertilizer placement depends on a number of factors, early access to nutrients by roots of seedlings has been shown to be particularly important. In general, banding fertilizer in proximity to the seedzone produces greater yields for most grain crops than broadcasting the fertilizer. Banding the fertilizer some distance away from the seed row can reduce the fertilizer response compared with banding closer to the row (Table 4). As a result, a method of seed-fertilizer placement

Table 4. Effect of fertilizer band placement on wheat yield in a no-till winter wheat - spring wheat rotation with 41 cm row spacing

Fertilizer placement	Wheat yield	
	Winter wheat	Spring wheat
	Mg/ha	
5 cm below seed row	3.8	2.9
5 cm below and 20.5 cm to side of seed row	2.9	2.2

Source: G.M. Hyde, Washington State University, Pullman, WA, USA. Unpublished results.

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emerged in commercial practice with double disc drills and is referred to as "paired row" planting. The seeds are placed in pairs of rows 10 to 18 cm apart with a wider space of 33 to 40 cm between the next pair. This configuration allows a single band of fertilizer to supply nutrients efficiently to two closely spaced rows of the small grain crop. With paired row planting the fertilizer is placed 6 to 9 cm below and only 5 to 9 cm to the side of the seed row. In this particular arrangement the crop roots tend to envelop the fertilizer band, thereby increasing fertilizer use efficiency, and possible crop competition against weeds. Recent research indicates that the paired row fertilizer placement does not give a greater fertilizer response in wheat than banding directly below each wheat row. The main advantage with paired row seed-fertilizer placement is that one fertilizer band can be used to supply two rows of the crop. It also allows for improved trash clearance with no-till seeding.

Cross-slot seed-fertilizer placement technology

A new combination seed-fertilizer drill opener termed "cross-slot" has been developed that is capable of planting a range of crops in tilled and untilled soil. The opener, first developed in New Zealand and followed by adaptive research in the U.S., features a single 56 cm diameter sharp disc to penetrate residues and soil (Baker and Saxton 1988). Two winged side blades situated on opposite sides of the disc create a cavity at the seeding depth for simultaneous placement of the seed and fertilizer. Two packer wheels running at a slight angle flank the rear of the disc and both close the disc slot and firm the soil over the seed. The wheels also maintain the seed opener depth. Performance of this opener with regard to seed placement is significantly different from conventional double-disc or hoe-type openers. Unique advantages include minimal disturbance of surface residues and soil, minimum plugging problems, superior stand establishment under marginal moisture conditions compared with disc or hoe openers, and lower horsepower requirements than most other no-till drills that place seed and fertilizer. Field tests show that the full complement of fertilizer can be placed with this opener at seeding time without adversely affecting stand establishment of cereal crops. Yields of wheat, peas (*Pisum sativum*), and barley (*Hordeum vulgare*) from plantings with this opener are equal to or greater than with standard double disc or hoe-type openers that are commonly used.

Conservation Tillage and Water Quality

Contamination of water by runoff or chemical leaching is a growing nationwide concern. Baker and Johnson (1983) report that conservation tillage reduces the volume of runoff by 25%, but the degree of reduction is highly variable and site specific. This means that there is a greater potential for increased infiltration and hence, movement of water and soluble chemicals through the profile. Fox and Bandel (1986) concluded that there is a greater potential for nitrate leaching in no-till than in tilled soils. The greater loss in no-till was explained on the basis of increased drainage losses in the undisturbed soil. However, other studies indicate lower nitrate concentrations with no-till as a result of greater denitrification and immobilization than in tilled soil (Doran 1980; Rice and Smith 1984; Fox and Bandel 1986). This compensating effect would offset the greater leaching potential with no-till.

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The effect of conservation tillage on pesticide leaching is complex with many confounding factors. On the one hand the increased infiltration along with increased use of pesticides with conservation tillage could increase the risk of pesticide leaching. On the other hand a moister soil environment associated with conservation tillage could increase the microbial degradation rate of pesticides in soil compared with conventional clean tillage. Much research yet remains to be done to establish the impact of conservation tillage on the quality of surface and groundwater.

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