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Dryland Conservation Technologies: Enhancing Agricultural Profitability and Sustainability

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Abstract: The adoption of dryland conservation technologies can significantly increase productivity and profitability in dryland agriculture. These technologies are based on maintaining surface residue cover and conserving as much water as possible for use by marketable crops. Dryland conservation technologies involve: (i) reducing soil water evaporation, (ii) eliminating water use by weeds, (iii) reducing water runoff (and soil erosion), (iv) increasing water infiltration, and (v) increasing snow catch. These critical components involve maintaining crop residues on the soil surface throughout the year. Although storing additional water is essential, changing the cropping system to utilize the additional water will dramatically increase profitability. Therefore, producers must reduce tillage intensity to increase the quantity of soil water stored; however, to increase profitability producers must reduce their dependency on fallow by increasing their cropping intensity with alternative spring and summer row crops. As a result of interdisciplinary technology transfer programmes, the number of acres managed with conservation technologies has increased five-fold over the last five years. Producers understand that the dryland conservation technologies provide the greatest opportunity to achieve agricultural sustainability and profitability in the Great Plains.

Key words: Conservation technologies, profitability, sustainability, residues, weeds, water used.

The Great Plains region represents one of the most important agricultural regions in the U.S. With approximately 280 million hectares in ten states (31% of the total U.S. land area), the Great Plains produces over 50% of the beef and 66% of the wheat. The Great Plains has the highest proportion of its population directly involved in production agriculture. Despite its contributions to production agriculture, the traditional dryland wheat-fallow rotation is generally not profitable and, thus, many producers diversify through cattle and irrigated crop production to increase profitability. The primary reason for marginal dryland crop productivity and profitability is limited available water. In the semi-arid Great Plains environment, total precipitation is less than the evapotranspiration demand; thus, yields are frequently limited by plant available water. At the same time, excessive water loss can occur through intensive tillage and poor weed control practices.

Another water related problem is low water-use efficiency. The water-use efficiency is extremely low in wheat-fallow, which indicates that fallow is an inefficient

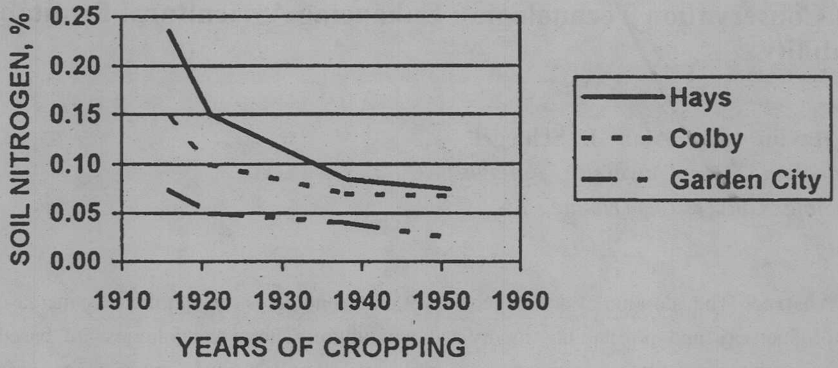

Fig. 1. Decrease in soil nitrogen content (0-15 cm depth) with years of cropping in conventional tillage dryland wheat in western Kansas (Haas and Evans, 1957).

way of storing and using water. Water-use efficiency in dryland cropping systems can be doubled if producers adopt dryland conservation technologies. Instead of producing 1600 kg of grain per 50 cm of plant available water, production of 3000 kg of grain with the same amount of water is possible.

The last problem associated with dryland agriculture is declining productivity related to soil erosion and oxidation of soil organic matter. The concerns about declining soil productivity under fallow cropping systems are not new (Fig. 1). These data show that from 1910 to 1946, total soil nitrogen decreased 50% in just 40 years. Similar results have been reported throughout the U.S. and Canadian prairie regions and confirm that intensive tillage in dryland cropping systems reduces soil organic matter by 50% during the first 50 years of cultivation.

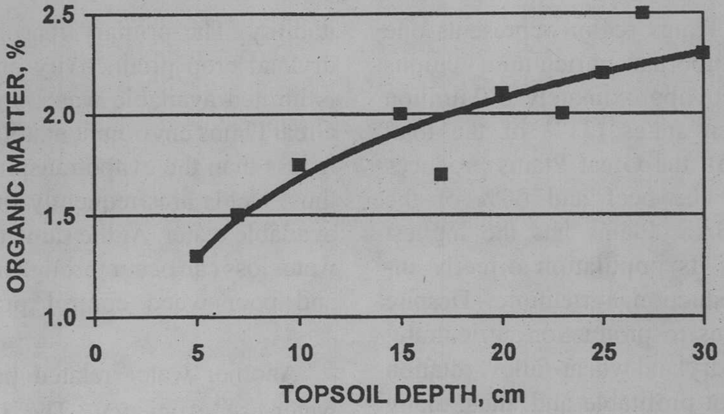

Fig. 2. Influence of soil erosion on soil organic matter (0-15 cm depth) of a Ulysses silt loam soil in western Kansas (Havlin et al., 1992).

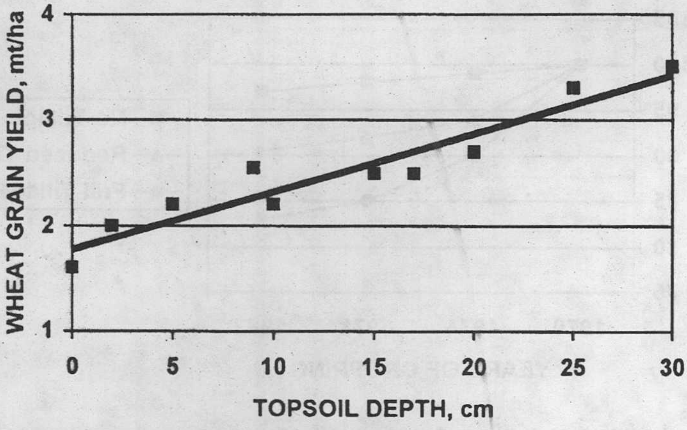

Fig. 3. Influence of soil erosion on wheat grain yield produced on a Ulysses silt loam soil in western Kansas (Havlin et al., 1992).

Soil Erosion and Conservation

Recent studies in Kansas have quantified the relationship between erosion of topsoil and wheat productivity. In a Ulysses silt loam soil, organic matter decreased by 0.05% for every cm of topsoil eroded (Fig. 2). More importantly, wheat yield decreased 48 kg ha^{-1} cm^{-1} of topsoil loss (Fig. 3). With 25 cm of top soil erosion, wheat yield potential would have decreased 1200 kg ha^{-1}, which represents a significant loss in soil productivity. Thus, soil erosion and loss of soil organic matter can reduce soil productivity and it is essential that producers understand these relationships.

Reducing soil productivity through top soil erosion by wind and water significantly impacts profit potential. Erosion-productivity relationships were quantified for dryland winter wheat, grain sorghum and soybean grown on five Kansas soils over five or six years (Table 1). Relationships between topsoil depth and yield showed that the average yield loss was 30, 54 and 40 kg ha^{-1} cm^{-1} of topsoil loss for wheat, grain sorghum and soybean, respectively. These losses represent \$2.89, \$4.18 and \$8.31 ha^{-1} cm^{-1} of top soil loss for wheat, grain sorghum and soybean, respectively. The cumulative effects of annual soil loss from erosion can be substantial (Table 1). These data show that, depending on crop, lost revenue ranged between \$871 and \$2490 ha^{-1}, which represents the approximate average purchase price for the

Table 1. Influence of soil erosion on annual and cumulative yields and profit loss (Havlin et al., 1992)

Crop	Annual yield loss		Market price	Annual profit loss		40 year cumulative loss[1]	
	kg/ha/cm	kg/ha/15 cm	\$/kg	\$/ha/cm	\$/ha/15 cm	kg/ha	\$/ha
Wheat	30.2	453.5	0.096	2.89	43.40	9070	871
Sorghum	53.6	803.6	0.078	4.18	62.76	16072	1254
Soybean	39.5	592.7	0.210	8.31	124.75	11855	2490

[1] Assumption of 15 cm soil loss over 40 years.

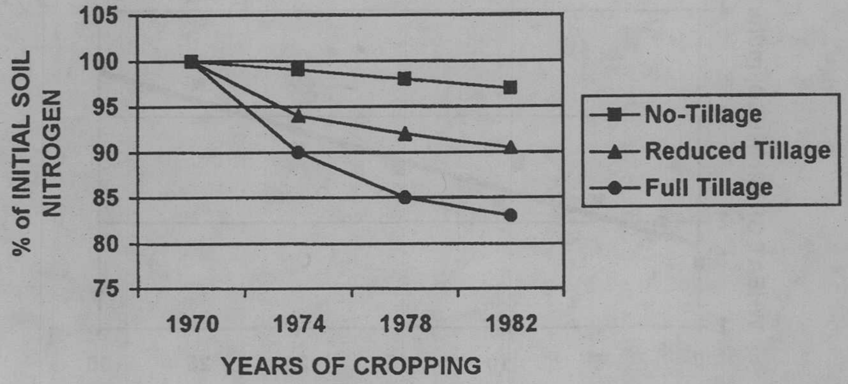

Fig. 4. Influence of tillage system on soil nitrogen in a dryland wheat-fallow system in western Nebraska. Soil nitrogen is expressed as a per cent of the original soil nitrogen content (Lamb et al., 1985).

land. In this region, the value of the lost yield is nearly equal to the purchase price of the land.

The most practical approach to increasing or conserving soil organic matter (or loss of carbon) is to reduce organic matter oxidation by reducing tillage intensity and increasing the carbon input through cropping systems that produce more residues. In a wheat-fallow system (Fig. 4), organic matter (measured as per cent of the original sod or native soil nitrogen) declined 2% after 12 years under no tillage, whereas organic matter decreased 9% and 15% with stubble mulch and conventional tillage, respectively. These results confirm that conventional tillage wheat-fallow rapidly reduces soil organic matter. Therefore, minimizing soil disturbance by tillage will maintain soil organic matter (conserve soil carbon) and ultimately enhance soil productivity.

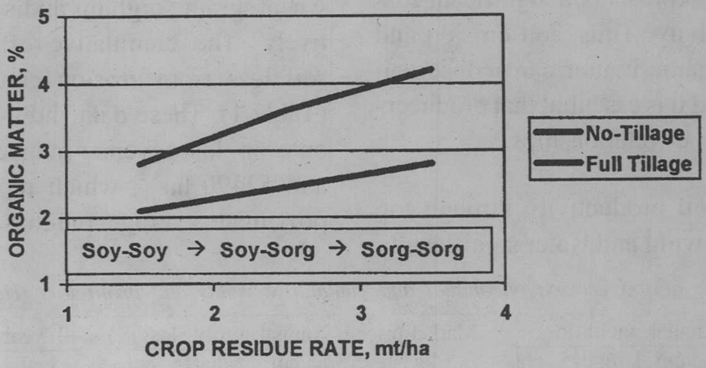

Fig. 5. Crop rotation and tillage system effect on soil organic matter. Crop residue increased in the order continuous soybean (soy-soy) <soybean - sorghum (soy-sorg) <continuous sorghum (sorg-sorg) (Havlin et al., 1990).

Organic matter actually increased with higher levels of residue produced over 13 years (1975-87) with soybean-soybean, sorghum-soybean, and sorghum-sorghum rotations in North Central Kansas (Fig. 5). However, the increase in organic matter was significantly greater when all the residue was left undisturbed on the soil surface (no tillage) compared to conventional tillage. These data demonstrate how managing carbon can influence soil organic matter. Increasing the quantity of total carbon input (increasing residue produced) and decreasing the quantity of carbon oxidized or lost (decreasing tillage intensity) will conserve or increase soil organic matter.

Although producers are sensitive to long term erosion-productivity issues, their primary short-term concern is profitability. Producers will readily adopt new technologies provided profit potential is maintained or enhanced. Therefore, dryland conservation technologies designed to enhance or sustain agricultural productivity also must be profitable. Enhancing productivity and profitability in dryland farming demands that yield limiting factors be reduced or eliminated.

Water Management

Water is the most limiting resource to attaining maximum dryland crop yield potential. Unfortunately, producers seldom give water management their highest priority, whereas most would indicate variety selection, fertility, etc., as their most important management input. After water, fertility, pests, etc., become the next most limiting factors. Dryland conservation technologies that reduce water stress also enhance yield response to other inputs. Therefore, producers that manage for water conservation will enhance dryland agricultural productivity and profitability.

Maximizing water conservation requires knowledge of the water budget or the inputs (gains) and outputs (losses) of the limited precipitation.

In the central Great Plains, about 80% to 90% of the total precipitation received is rainfall, while snowfall represents about 10% to 20% of the total. The water outputs or losses are runoff, snow loss by wind, evaporation, percolation, and water use by crops and weeds. Weeds are non-marketable crops that use water intended for marketable crops. Again, the goal should be storage of all water received with efficient water use only by a marketable crop.

Evaluating the different sources for plant available water is important in understanding where the investment in water conservation provides the greatest return (Table 2). Water stored in the soil profile is potentially 100% available to the next crop. Therefore, any soil profile water left after harvest must not be lost. The major losses of stored soil water occur through weed growth, transpiration, and soil evaporation. About 80% of snowfall will become plant available water in the soil profile.

Table 2. Relative value or efficiency of water sources in providing plant available water (Greb, 1983)

Water source	Relative efficiency (%)
Stored soil water wheat	100
Snowmelt	70-85
Runoff	50-65
Cool season rainfall	25-30
Warm season rainfall	20-25

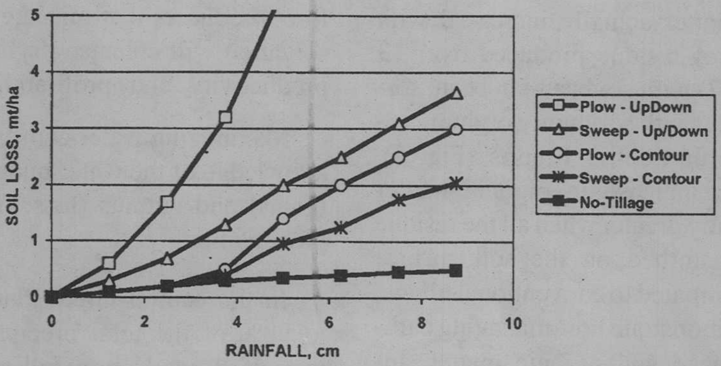

Fig. 6. Effect of tillage practice and rainfall intensity on soil erosion on a Richfield silt loam soil in western Nebraska (4% slope). Sweep represents a subsurface tillage implement or 20% residue incorporation, and plow represents full residue incorporation (Dickey, et al., 1981).

Approximately 60% of runoff water from other parts of field can be stored as plant available water. Unfortunately, only about 30% of growing season rainfall is plant available water. The low rainfall efficiency is related to higher evaporation loss during spring and summer months. If, for example, we receive 25 cm of rainfall in the spring/summer and efficiency is 25%, only 6.3 cm is stored as plant available water in the soil profile. In contrast, if we receive an average of 60 cm of snow (5 cm of water), at 80% efficiency, 4 cm of water (from the snow) enters the soil profile as plant available water. Comparing the two sources, plant available water from snow (4 cm) represents two-thirds of that obtained from rainfall (6.25 cm). Storage of additional soil water from snowfall can increase yield potential through increased plant available water. Therefore, snowfall is an extremely valuable source of plant available water and collecting snow on the soil surface over winter is critical for increasing plant available water and eliminating water as a limiting factor to crop productivity. Thus, leaving wheat stubble standing after harvest will enable collection of additional snow. Increasing stubble height also can increase snow catch.

Maintaining surface crop residue cover (reducing tillage intensity) is important for reducing runoff and evaporation and increasing water infiltration which are essential to increasing stored soil water. Rain falling on a bare soil will seal off the soil surface within the first 30 minutes (depending on soil texture/structure and rainfall intensity). Experiments in Kansas showed sealing of bare soil with 1 cm of rainfall, where the additional rainfall would runoff. Once sealed, infiltration slows or ceases and water begins to move off the field. Surface residue cover can increase the time period for infiltration by 2 or 3 fold, which greatly increases the quantity of rainfall infiltration (reduced runoff).

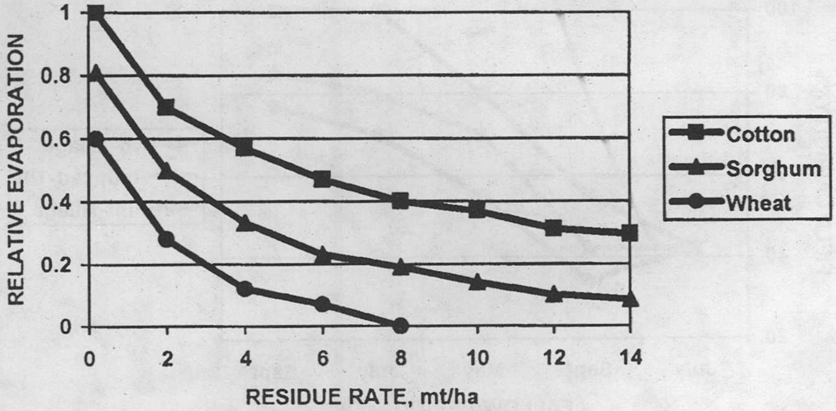

Fig. 7. Influence of surface residue cover on relative soil surface evaporation (Steiner, 1989).

Increasing infiltration and reducing runoff will greatly reduce soil loss by erosion (Fig. 6). In a wheat-fallow field (4% slope), maintaining standing wheat residue (no tillage) significantly reduced soil loss compared to full tillage (no residue cover) or stubble mulch tillage (20 to 30% residue cover). In the two tillage systems, tilling on the contour also reduced soil loss compared to tillage with the slope. Reduced soil loss means that water runoff was reduced and water infiltration was increased.

Evaporation of water from the soil surface constitutes a major loss of plant available water. While evaporation loss can not be eliminated, significant reductions are possible (Fig. 7). To reduce evaporation from bare soil by 70%, 2 tons ha^{-1} of wheat residue are needed compared to 4 tons ha^{-1} of sorghum residue. Much greater quantities of cotton, soybean or sunflower residue would be required to obtain the same reduction in evaporation.

Weeds and Weed Control

Another major source of water loss is water use by weeds. The dramatic effects of weeds on water loss can be frequently observed in fields throughout the Great Plains. Water use data from the Great Plains shows that 900 to 3000 kg ha^{-1} of weed residue are produced after harvest. Total water use by weeds after wheat harvest often ranges between 5 and 15 cm of water. Eliminating weed growth in the dryland cropping system is essential for maximizing the soil water accumulation. Technologies used to reduce evaporation and runoff, increase infiltration, and increase snow catch are useless if weeds are allowed to use the additional water stored.

Tillage has been the traditional method of controlling weeds in fallow; however, tillage deplete soil moisture through evaporation and destroys standing crop residue. Therefore, herbicides need to be used for weed control in conservation cropping

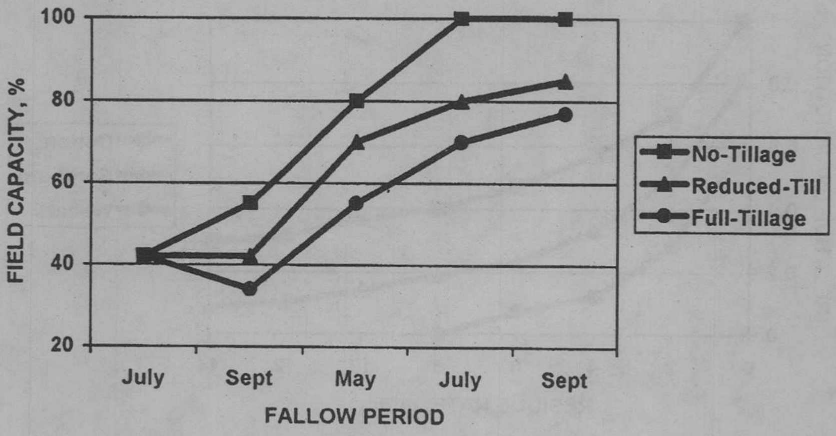

Fig. 8. Soil water accumulation during a typical 14-month fallow period in dryland wheat-fallow cropping system (Greb, 1993).

systems to conserve moisture and maintain surface crop residue cover.

Weed control in fallow begins with effective weed control in the previous crop. For example, judicious weed control in the growing wheat, combined with a good stand of wheat, will likely result in weed free stubble after harvest. Several herbicides can provide post-emergence control of weeds in the growing crops, as well as residual weed control through harvest. Burndown and/or residual herbicides can be used to control weeds through the fallow period as needed, but residual herbicides (e.g., atrazine, etc.) must be used with good judgment to avoid herbicide carry-over to the following crop.

Certain weeds that are similar to the crop, such as jointed goatgrass and cheatgrass in wheat, can become unmanageable in reduced tillage, mono-cropping systems. These weeds can not be controlled effectively in wheat with herbicides. However, rotation with summer crops changes the growing environment and disrupts the weeds' life cycle thereby greatly reducing the weed pressure.

Alternative Dryland Cropping Systems

In summary, increasing the amount of plant available water requires that we: (i) increase snow catch, (ii) increase infiltration, (iii) reduce runoff, (iv) reduce evaporation, (v) eliminate water use by weeds, and (vi) save all stored soil water in fallow periods. With conventional tillage, only 75% of the field capacity is attained after the fallow period (14 months) (Fig. 8). Field capacity is the maximum amount of plant available water that can be stored in a soil. In contrast, with full residue cover (no tillage), 100% of field capacity is attained by late June (only 12 months). Once the soil is at 100% field capacity, it can not store additional water, thus, a full 14 month fallow period is not needed.

Surface residue cover increases fallow efficiency (Fig. 9). As plant available soil water increases, grain sorghum yield potential increases. With 50% fallow efficiency,

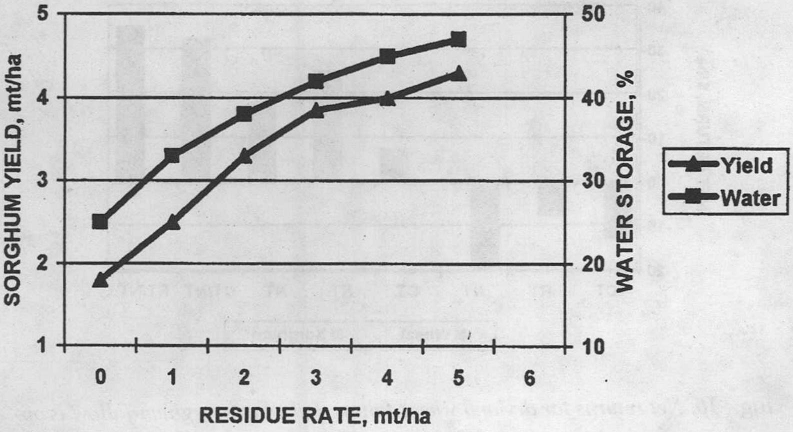

Fig. 9. Increasing surface residue cover increases soil water storage and dryland grain sorghum yield in Texas (Unger, 1983).

3 to 4 tons ha^{-1} sorghum yields are possible, in the year following wheat harvest.

In the typical wheat-fallow system, 14 out of 24 months are fallow (1 crop in 2 years). However, with additional water stored, a spring crop can be inserted into the fallow period so that 2 crops are produced in 3 years (increased cropping intensity). Many producers ask why they can't remain in wheat-fallow if dryland conservation practices are adopted? Simply, winter wheat will not respond in yield to the additional stored water so there is little opportunity to recover the additional input costs. Therefore, increasing the cropping intensity (reducing dependency on fallowing) by producing 2 crops in 3 years or 3 crops in 4 years is necessary to increase profitability.

Several alternatives are possible in the central Great Plains. Sorghum, corn, and sunflower have been demonstrated to be profitable crop alternatives. Sorghum is more suitable for the west central regions, whereas corn is more productive in northern regions. Sunflower is adapted in most regions except for the extreme southwest. Rotations with 2 crops in 3 years are the most common, but with sufficient soil water, 3 crops in 4 years or more frequent croppings are possible. For example, continuous no tillage grain sorghum is a profitable alternative in the southern regions. The important concept relative to alternative crop options is for the producer to take economic advantage of the additional stored moisture. There will be drought years where fallowing is necessary; however, if soil moisture is adequate at planting time to insure a profitable yield, then producers should plant. In Kansas, for example, if 3 or more feet of soil moisture are present at planting time (late April) then corn or sunflower could be planted. If there are less than 3 feet of soil moisture, the producer might wait until the end of May or early June and plant grain sorghum if additional water was stored during May. If not, the producer should continue fallowing until September and plant wheat. Thus, to increase pro-

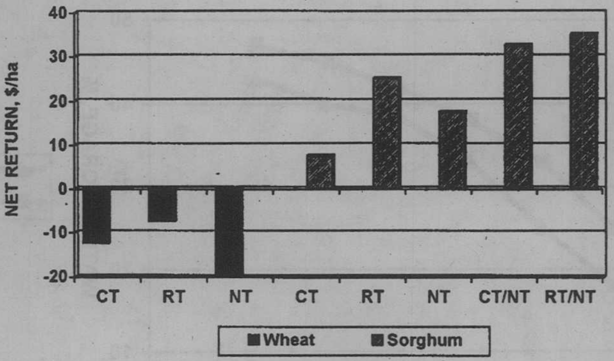

Fig. 10. Net returns for dryland wheat-fallow and wheat-sorghum-fallow cropping system managed under conventional tillage (CT), reduced tillage (RT), no-tillage (NT), and selected combination (CT/NT or RT/NT: tillage for wheat/tillage for sorghum) (Dhyuvetter and Norwood, 1994).

ductivity and profitability producers must evaluate cropping opportunities based on soil water availability.

Two important responses occur when producers change from wheat-fallow to wheat-sorghum-fallow. First, wheat productivity is maintained even when more water is used in the wheat-sorghum-fallow system. Therefore, producers with 2800 kg ha^{-1} wheat yield potential in wheat-fallow will maintain their wheat yield potential in wheat-sorghum-fallow-sorghum-fallow. Second, increased profit potential is realized through the spring crops because of more efficient water storage and utilization.

Profitability

Producers should adopt dryland technologies if they maintain or enhance agricultural profitability. Profitability will be enhanced if returns are increased and, thus, producers must determine the most profitable tillage system and crop rotations for their individual farm and management skills. Producers need to consider how alternative dryland cropping system affect profit, capital requirements, financial risks and management requirements.

To illustrate, an economic analysis was conducted to compare the returns from wheat-fallow (WF) and wheat-sorghum-fallow (WSF) rotations in western Kansas (1987-93 data). Alternative tillage regimes were evaluated for each crop rotation. Crops are produced in WF and WFS rotations on 50 and 67% of tillable acres, respectively, on an annual basis. Returns from WF were not sufficient to cover all costs of production regardless of tillage method (Fig. 10). Returns with no-till wheat were the lowest due to additional herbicide costs. Returns from conventional tillage were not much lower than returns from reduced tillage, indicating there is little economic incentive to reduce or eliminate tillage in a WF rotation. Net returns in the WSF rotation were all positive, because of the

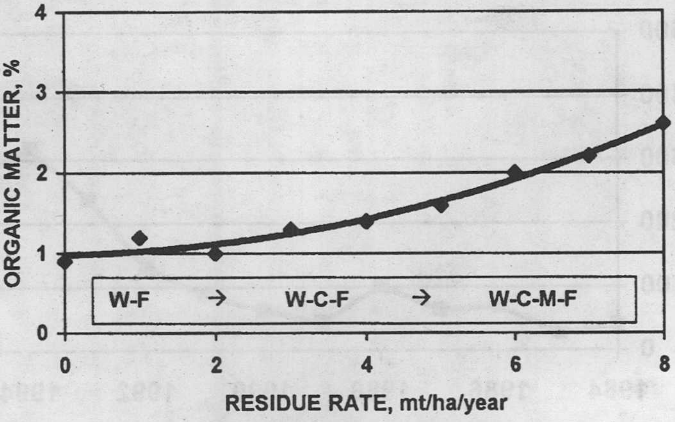

Fig. 11. Soil organic matter increase with increasing dryland cropping intensity. W-F = wheat-fallow, W-C-F = wheat-corn-fallow; W-C-M-F = wheat-corn-millet-fallow (Peterson and Westfall, 1990).

additional revenue generated from the sorghum crop (Fig. 10). Returns for WSF rotations were higher for reduced tillage predominately because of the lower input costs compared to NT. As in the WF rotation, returns from conventional tillage were slightly less than the reduced tillage, indicating there is little economic incentive to reduce tillage on both wheat and sorghum crops. However, returns of the sorghum portion of the WSF rotation were highest for no-till and lowest for conventional tillage. Sorghum yields increase significantly as the amount of tillage is reduced. The most profitable tillage method in the WSF rotation was reduced-till wheat and no-till sorghum.

Technology Transfer

The adoption of dryland conservation technologies can significantly increase productivity and profitability in dryland agriculture. These technologies are based on maintaining surface residue cover and conserving as much water as possible for use by marketable crops. To summarize, dryland conservation technologies involve: (i) reducing soil water evaporation, (ii) eliminating water use by weeds, (iii) reducing water runoff (and soil erosion), (iv) increasing water infiltration, and (v) increasing snow catch. These critical components primarily involve maintaining crop residue on the soil surface throughout the year.

Increasing the quantity of residue (or carbon) added to the soil and reducing organic matter oxidation (by reducing tillage) will increase soil organic matter, and subsequently soil productivity. Research results confirm that increasing the quantity of residue produced and left undisturbed on the soil surface dramatically increased soil organic matter (Fig. 11). The more intensive the crop rotation, the more productive the soil becomes.

Two major benefits are realized when producers adopt dryland conservation technologies. First, producers realize increased

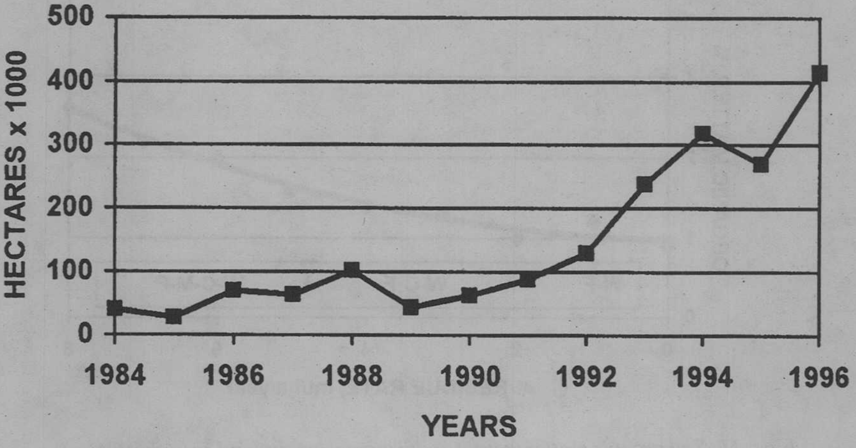

Fig. 12. Increase in dryland wheat-corn-fallow area in western Kansas.

profitability, which improves the standard of living and increases the cash flow through the rural community (producer has more disposable income to purchase local goods and services). Second, soil erosion is dramatically reduced as a dryland production problem. Producers should adopt dryland conservation practices because of increased profit potential and enhanced productivity.

Extensive technology transfer programmes were initiated in 1988 that represented a cooperative effort between professionals in agricultural extension and industry. The multidimensional effort comprised on-farm field demonstrations of dryland conservation technologies, producers and agricultural dealer meetings and seminars, and publication of written materials, slide sets, and videos. For example, in Kansas between 1988 and 1995, over 15 field demonstrations and 400 county and dealer meetings were held. The best measure of success of any technology transfer effort is monitoring the rate of adoption over time (increase in land area with dryland conservation technologies). Figure 12 shows the rapid increase in producer adoption of dryland corn, planted predominately in a reduced or no-till wheat-corn-fallow rotation. Dryland corn production has tripled between 1993 and 1996. These data provide convincing evidence that new technologies that enhance productivity of the land will be readily adopted by producers, provided profit potential is enhanced.

Surveys were conducted in 1995 to assess the primary reasons why producers did or did not adopt dryland conservation technologies. The major reasons provided by producers unwilling to accept the new technology were: (i) insufficient water availability or rainfall for intensive cropping, (ii) too expensive (no-till equipment and herbicides), and (iii) tradition (always have farmed wheat-fallow).

In contrast, the major reasons provided by producers who adopted wheat-corn-fallow or other dryland conservation technologies were: (i) dryland conservation technologies were more profitable, (ii) available water or precipitation was adequate for intensive cropping, and (iii) reduced and no-till cropping systems required less time and labor.

Clearly the primary motivation for adoption of dryland conservation technologies was enhanced profit potential and their understanding of how to manage limited available water for enhanced crop production.

The future and viability of the Great Plains agriculture depends on sustaining the soil resource base and increasing producer profitability. Dryland conservation technologies provide the greatest opportunity to achieve agricultural sustainability and profitability in the Great Plains. It is essential that dryland producers adopt proven technologies that insure the future productive capacity of our fragile soils.

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