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Nutrient Management

Long-Term Effects of Tillage, Nitrogen and Rainfall on Winter Wheat Yields in the Pacific Northwest

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The inland Pacific Northwest (PNW) has some of the highest soil erosion rates in the U.S. Residue maintained by conservation tillage systems reduces erosion, but historically most farmers have been wary of adopting such systems due to such perceived drawbacks as poor weed control, inadequate planting equipment and lower crop yield. The development of new farming equipment and chemicals since the 1980s has increased the probability of obtaining crop yields similar to those of conventional clean-tillage systems and of lowering input costs. However, there are conflicting results on yield response of winter wheat to reduced-tillage systems in the PNW.

One difficulty in interpreting apparently conflicting results is that many studies have drawn conclusions based on only a few years' data. Long-term studies provide perhaps the only way to determine whether agricultural practices will sustain or degrade the productive capability of the soil and allow insight into larger trends in crop production.

Historically, few if any technologies have increased winter wheat yield more than N fertilization. However, recommending optimum N rates is not an exact science, especially under dryland conditions. Recent concerns over environmental quality, energy conservation and economics have increased the need to maximize crop utilization of applied fertilizer N and to reduce excess application that may contribute to stream or ground water contamination. Determination of optimum N rates is best done with yield records over a period of time that includes a range of weather conditions.

Soon after its inception in 1928, Oregon State University's Columbia Basin Agricultural Experiment Station, located near Pendleton, OR, initiated a number of long-term cropping system studies. One of the oldest experiments, which continues to this day, originated in 1940 to determine the effects of tillage, crop residue management and N application on the sustainability and profitability of winter wheat–summer fallow cropping systems.

The objective of this study is to use yield data from this experiment to evaluate the long-term effects of tillage, N, soil depth and precipitation on yield in a winter wheat–summer fallow rotation.

Materials and Methods

Field design. This experiment was conducted at the Columbia Basin Agricultural Research Center near Pendleton, OR. The climate is characterized by cool, moist winters and hot, dry summers. The mean annual precipitation is approximately 420 mm, of which 70 percent is generally received between Sept. 1 and April 11. The soil is classified as Walla Walla silt loam.

The experiment consisted of a winter wheat–summer fallow rotation with one set of plots; thus, yield was obtained only in odd years. Plots were arranged in a split-plot design with three replications. The main plot treatments were three primary tillage systems (moldboard plow, subsurface sweep and offset disk) and six fertility subplots. The moldboard plow had a tillage depth of approximately 23 cm and approximately 7 percent residue cover at seeding. The subsurface sweep had a tillage depth of approximately 15 cm and approximately 43 percent residue cover at seeding. The offset disk tilled at a depth of approximately 15 cm and had approximately 34 percent residue cover at seeding. Individual plot size was 5.5 by 140 m.

Replication 1 had an average depth to bedrock of 210 cm on a slope of 3 percent; Replication 2 had an average depth to bedrock of 130 cm on a slope of 0 to 2 percent; and Replication 3 had an average depth to bedrock of 110 cm on a slope of 2 percent.

Primary tillage operations (plow, disk and sweep) were performed in late March on stubble left undisturbed since the previous harvest. All plots were subsequently smoothed to a depth of 10 to 15 cm deep with a field cultivator and harrow and rod-weeded four to five times between April and October to control weeds and to reduce soil moisture loss. Nitrogen fertilizer was normally applied around Oct. 1, and winter wheat seeded around Oct. 10 with a semideep furrow drill. Medium-tall soft white winter wheat was grown from 1940 to 1962, and semidwarf soft white winter wheat varieties since.

Grain yield was determined for 27 of 29 crops grown in alternate years during the 1941 to 1997 period. Due to a lack of scientific personnel at the station during the Great Depression and World War II, data collected for 1941 and 1943 were considered unreliable and excluded from this study.

The experimental design has remained relatively unaltered since inception, but the fertility treatments, timing and tillage depth have been modified four times to maintain their relevance to contemporary agriculture. Therefore, the data were divided into four time periods, described below, in which treatments remained consistent.

Period 1 (1944-1951). Four of the six subplots received N in the form of ammonium sulfate at a rate of 11 kg N ha^{-1}. Although this is a very low rate by modern standards, at the time many felt that the use of N in dryland wheat systems would depress yield. The N was applied to two of these plots at seeding and to the other two at plowing. The last two subplots received no N fertilizer. Two of the fertilized plots and one of the unfertilized plots were tilled to a depth of 13 cm. The other three were tilled to a depth of 20 cm. The experiment was seeded to the winter wheat variety Rex M-1 in 1945, spring wheat in 1947 and the winter wheat variety Elgin in 1949 and 1951.

Period 2 (1953-1961). In 1953 the rate of ammonium sulfate was increased from 11 to 34 kg N ha^{-1}. The tillage methods and depths, and the timing of fertilizer application remained unaltered. The plots were seeded to the winter wheat varieties Elgin in 1953, Elmar in 1955 and Omar from 1957 to 1961.

Period 3 (1962-1987). Important changes were made to the experimental design in 1962, reflecting the introduction of high-yielding, N-responsive semidwarf varieties into regional farming systems. The initial tillage treatments, including the moldboard plow, subsurface sweep and offset disk, continued. However, tillage depth was discontinued as a treatment, and all plots were tilled to a depth of 15 cm. Fertility treatments were also revised. The four plots that previously received 34 kg N ha^{-1} as ammonium sulfate (two plots at plowing and two at seeding) were fertilized only at seeding. Newly introduced fertilizer treatments were 45, 90, 135 and 180 kg N ha^{-1} as ammonium nitrate. The two plots, which had previously received no N fertilizer, began receiving 45 and 90 kg N ha^{-1}. The plots were seeded to the winter wheat varieties Gaines from 1963 to 1967, Nugaines from 1969 to 1973, McDermid in 1975, Hyslop in 1977 and Stephens from 1979 to 1997.

Period 4 (1988-1997). In 1988 the subplot that had received 0 kg N ha^{-1} from 1945 to 1961 and 45 kg N ha^{-1} from 1962 to 1987 was designated as the control, receiving 0 kg N ha^{-1}. Nitrogen rates on all other plots remained unmodified. The form and placement of N changed from broadcast ammonium nitrate to urea ammonium nitrate (32–0–0) and shanked 15 cm deep with 25-cm band spacing.

Results

Tillage. There was no interactive effect between tillage and N for any year except 1997. When 1997 data were combined with those from other years in Period 4, there was no interactive effect.

Tillage had a significant effect in each time period. In all four periods, the moldboard plow treatment had approximately 300 to 400 kg ha^{-1} greater yield than the subsurface sweep treatment. Winter wheat yield depression under conservation tillage systems when compared with conventional tillage practices was also reported in three other studies. In the present study, yield reduction was probably due largely to poor control of the invasive grass species downy brome. Field notes dating back to 1961 repeatedly report severe downy brome infestations in subsurface sweep plots. These qualitative observations nearly always described downy brome infestation as less severe in the offset disk treatment than in the subsurface sweep treatment, and as negligible in the moldboard plow treatment. The importance of weed control to the success of conservation tillage systems in the PNW has been well documented. Similarly, a 1971 study found that a stubble–mulch tillage system increased weed populations by two to three times compared with moldboard plowing, and a study in 1969 found that downy brome control with stubble–mulch tillage systems was not as consistent as with a one-way disk or moldboard plow.

It is also possible that lower yields were in part due to decreased N mineralization associated with conservation tillage. A study in 1985 found that soils of a stubble–mulch tillage system accumulated only about 70 percent as much NO_3–N as plowed soils at two sites, and a study in 1963 found soil NO_3–N accumulations to be depressed under stubble–mulch tillage at seeding time in the Great Plains. A study in 2000 reported that wheat grain N content was significantly reduced in conservation tillage treatments in a wheat–dry pea rotation experiment, suggesting possibly reduced N mineralization. Reduced mineralization may be caused by increased N immobilization associated with higher-residue systems. However, the lack of a tillage x N interaction in this study suggests that greater N immobilization was not a factor in grain yield reduction with conservation tillage. Furthermore, this was unlikely, as the 135 and 180 kg N ha^{-1} rates should have provided sufficient N to eliminate any N deficiency and alleviate yield differences between tillage treatments.

Yields with the moldboard plow system were significantly higher than with the offset disk tillage treatment in Periods 3 and 4. The same trend was evident for mean yield in Periods 1 and 2, but differences were not statistically significant. Mean yields tended to be higher, although only significantly in Period 2, for plots tilled with the offset disk than for plots tilled with the subsurface sweep, except in Period 4. In this last period, this trend reversed, and mean yield with the subsurface sweep was approximately 200 kg ha^{-1} greater than with the offset disk. This may be due to improved chemical herbicides, which provide greater control of downy brome than was possible during Period 3.

Nitrogen. Fertilizer application affected wheat grain yield for 19 of the 27 years of the study. When annual grain yield data were pooled within the four time periods, fertilizer was a statistically significant variable for all periods but the first, when the maximum N rate was only 11 kg N ha^{-1}. Even at this low N rate, however, there was a tendency for yield to increase compared with the unfertilized treatment. For Period 2, grain yield increased significantly with the addition of 34 kg N ha^{-1}.

For Period 3, grain yield did not significantly increase with the addition of more than 45 kg N ha^{-1}. Insignificant yield differences between fertility Subplot 1 and 2 (which received 45 kg N ha^{-1}) and Subplots 3 and 4 (which received 90 kg N ha^{-1}) could be attributed to the use of ammonium sulfate fertilizer during Periods 1 and 2. A residual sulfur or N response may be responsible for slightly higher yields for Plots 2 and 4. Maximum mean yield was obtained at an application rate of 135 kg N ha^{-1}.

For Period 4, average grain yield increased with the addition of 45 and 90 kg N ha^{-1}. There were no significant yield increases at greater rates of N. While yields were not significantly different between 90 and 135 kg N ha^{-1}, maximum mean yield was obtained at an application rate of 135 kg N ha^{-1}.

Precipitation. Total precipitation was a significant covariate for all time periods except Period 4. Growing season (April 1-June 30) and winter precipitation (Oct. 1-March 31) were significant covariates for all periods except Period 1. Grain yield was positively correlated with annual precipitation and with the 9-month growing season precipitation, as expected under dryland conditions. Similar correlations were seen for growing-season and winter precipitation.

Interaction between soil depth and precipitation. There was a significant ($p < 0.01$) interaction between the covariates soil depth and annual precipitation in all but the fourth time period when growing-season precipitation was the highest. In very dry years, yield was approximately 1000 kg ha^{-1} greater in relatively deep soils (>2.8 m) compared with shallow soils (<1.3 m). However, as precipitation increased to approximately 400 mm or more, the effect of soil depth diminished. Similarly, a 1991 study concluded that wheat yield was not affected by soil depth when growing season precipitation was above average, but was 10 to 20 percent less in shallow soils when growing season precipitation was below average. Shallow soils store less water and thus have a lower yield capability than deep soils in dry years. A study in 1981 found that a 210 cm deep soil produced a maximum yield of 5,034 kg ha^{-1}, while a nearby 110 cm deep soil reached a maximum yield of only 4,026 kg ha^{-1}.

When precipitation was >500 mm, yield decreased by approximately 1,500 kg ha^{-1}, regardless of soil depth. The decrease in yield was potentially due to disease, lodging or N fertilizer leaching.

Yield evolution. Wheat yield has improved since the 1940s with the introduction of new technology. Yield increase was minimal at first, and became more rapid soon after 1960 due primarily to the introduction of semidwarf varieties that were responsive to increasing rates of fertilizer application. The new semidwarf varieties also matured earlier, and therefore were less susceptible to drought.

Data since 1980 serve to illustrate that the rate of yield increase, and therefore our ability to keep pace with rising global demand for wheat, has fallen considerably since the period 1960-1980.

Discussion

The consistently depressed yields associated with conservation tillage illustrate why, we believe, there has been minimal adoption of this practice in eastern Oregon and other parts of the Columbia Basin despite well-documented beneficial effects of such systems on soil properties. For example, a 1989 study found that after 50 years of stubble–mulch tillage, soils in eastern Oregon had 33 percent more soil organic matter (SOM) in the top 7.5 cm than those that were conventionally plowed. A study in 1988 found that organic N and C in the top 75 mm of soil were 26 and 32 percent higher, respectively, in two stubble–mulch systems than in conventional-plow tillage.

We believe the main reason for yield decrease under conservation tillage, in our experiment, was inadequate weed control. Similarly, after examining 80 years of data at Lethbridge, AB, a study in 1982 suggested the main factor contributing to increased wheat yield since 1963 was chemical weed control. It follows that further reduction in herbicide costs and increased efficiency of weed control would go a long way toward making reduced-tillage systems more practical in the PNW.

Despite the yield disadvantage of the conservation tillage system suggested by this study and by farmer reluctance to adopt conservation or zero-tillage systems in the inland Northwest, current rates of soil degradation will eventually render the presently used system unsustainable in terms of long-term soil productivity. Previous research on this experimental plot showed 26 and 32 percent higher organic N and C, respectively, in the top 75 mm of soil in the two stubble mulch systems than with the moldboard plow. This was recognized long ago by scientists in the region.

Most farmers presently continue to sacrifice long-term sustainability for the sake of shorter-term profitability because of the low-to-negative profitability of dryland wheat-based systems. Reductions in herbicide costs, increased efficiency of weed control and further understanding of the influence of surface residue on seed germination, N mineralization and immobilization, and weed populations will perhaps eventually result in greater yields and greater adoption of conservation tillage systems in the PNW.

The degree to which results from our study can be extrapolated to other sites is unclear because of its uniqueness. Of all the long-term experiments in North America reviewed in a 1991 report, the tillage/fertility experiment (the focus of this study) was the only one in which the study of tillage effects on productivity was an objective.

Editor's note: *Content was adapted from the paper "Long-Term Effects of Tillage, Nitrogen and Rainfall on Winter Wheat Yields in the Pacific Northwest," which was published in Agronomy Journal Vol. 95, July-August 2003, and is courtesy of K.M. Camara, W. A. Payne and P. E. Rasmussen.*

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February Self-Study Examination

DETACH HERE

1. Some of the highest soil erosion rates in the U.S. are found in the:
[ ] a. Southeast.
[ ] b. Midwest.
[ ] c. Pacific Northwest.
[ ] d. Mid-Atlantic.

2. Use of a conservation tillage system:
[ ] a. historically, has been widely accepted by farmers.
[ ] b. historically, has been slowly accepted by farmers.
[ ] c. has not been proven effective in reducing erosion.
[ ] d. has shown consistent results on yield response in winter wheat.

3. Interpreting conflicting results from conservation tillage systems:
[ ] a. is difficult because there is so much long-term data to analyze.
[ ] b. is difficult because conclusions have been drawn based on data of only a few years.
[ ] c. has been very easy because of the Soil Survey erosion tables.
[ ] d. has been easy because all the studies have been conducted at one location.

4. One of the oldest experiments to determine the effect of tillage, crop residue management and N application on the sustainability and profitability of the winter wheat–summer fallow cropping system originated at the Oregon State University's Columbia Basin Agricultural Experiment Station in:
[ ] a. 1940.
[ ] b. 1938.
[ ] c. 1930.
[ ] d. 1928.

5. The soil texture of the long-term experiment site is classified as:
[ ] a. clay loam.
[ ] b. loam.
[ ] c. silty clay loam.
[ ] d. silt loam.

6. In all four periods, the moldboard plow treatment had a greater yield than the subsurface sweep treatment by:
[ ] a. 100 to 200 kg ha^{-1}.
[ ] b. 200 to 300 kg ha^{-1}.
[ ] c. 300 to 400 kg ha^{-1}.
[ ] d. 400 to 500 kg ha^{-1}.

7. Examining the interaction between soil depth and precipitation found that:
[ ] a. as precipitation increased to 400 mm, yield decreased.
[ ] b. shallow soils store water more efficiently and therefore have higher yield capability in dry years compared to deeper soils.
[ ] c. a 110 cm deep soil reached a maximum yield of 5,034 kg ha^{-1}.
[ ] d. when precipitation was greater than 500 mm, yield decreased by approximately 1,500 kg ha^{-1} regardless of soil depth.

8. Data since 1980 show that the rate of yield increase:
[ ] a. has fallen considerably since the period between 1960 and 1980.
[ ] b. has increased considerably since the period between 1960 and 1980.
[ ] c. has stayed the same.
[ ] a. could not be determined.

Over

9. A 1989 study found that after 50 years of stubble-mulch tillage, soils in eastern Oregon have:

[ ] a. 13% more soil organic matter.
[ ] b. 23% more soil organic matter.
[ ] c. 33% more soil organic matter.
[ ] d. 43% more soil organic matter.

10. The authors believe the main reason for yield decrease under conservation tillage, in this experiment, was:

[ ] a. inadequate weed control.
[ ] b. inadequate soil organic matter.
[ ] c. excessive N application.
[ ] d. low precipitation.

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