# Long-term Nitrogen Fertilization Benefits Soil Carbon Sequestration

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Positive effects of nitrogen (N) fertilization on soil organic carbon (SOC) were clearly demonstrated in a long-term dryland annual cropping study under no-till (NT) conditions in Colorado.

The potential to sequester more carbon (C) in soils by increasing cropping intensity and N fertilization in semi arid, dryland areas could contribute positively to mitigating agriculture's effect on atmospheric carbon dioxide ($CO_2$) levels and its effect on global climate change. The value of SOC is more than improving soil quality and fertility. Its hidden value is in its ability to help moderate the greenhouse effect on the environment by reducing atmospheric enrichment of $CO_2$. Thus we need to understand how management practices, such as N and phosphorus (P) fertilization, affect SOC. Converting to a NT system and cropping more intensively can potentially enhance environmental quality.

Utilization of NT systems to conserve more water for crop production makes it feasible to crop more frequently than is done with the conventional crop-fallow system in the central Great Plains area. Increased cropping frequency and low N mineralization capacity of the soils in this region make N fertilization a requirement for economical yield levels.

As yearly residue production is increased within a cropping system and/or tillage frequency is decreased, SOC levels will probably remain constant or increase with time, depending on the quantity and types of residue input to the soil.

Available information on the long-term effects of N fertilization rates on crop residue

**TABLE 1.** Grain or forage yield (lb/A) of each crop from 1984 through 1994 as a function of N rate.

| | | N fertilization rate, lb/A | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Crop** | **0** | **20** | **40** | **60** | **80** | **120[1]** |
| 1984 | Barley | 2,304 | 3,360 | 3,312 | 3,696 | 3,648 | 3,120 |
| 1985 | Corn | 3,696 | 4,200 | 5,376 | 5,656 | 5,432 | 5,936 |
| 1986 | Barley | 384 | 1,056 | 1,824 | 2,112 | 2,544 | 2,832 |
| 1987 | Corn | Hailed out on Aug. 5, 1987 | | | | | |
| 1988[2] | Wheat | 2,340 | 2,700 | 2,880 | 3,240 | 3,060 | 2,820 |
| 1989 | Corn | 2,296 | 2,912 | 2,968 | 3,360 | 2,968 | 3,696 |
| 1990 | Barley | 144 | 384 | 864 | 1,008 | 864 | 768 |
| 1991 | Corn | 3,808 | 4,312 | 5,208 | 5,712 | 5,432 | 5,376 |
| 1992[3] | Oat hay | 654 | 1,619 | 2,742 | 3,238 | 3,908 | 4,433 |
| 1993 | Corn | 2,240 | 2,576 | 3,528 | 4,648 | 4,368 | 4,704 |
| 1994[3] | Oat/Pea hay | 760 | 1,471 | 1,727 | 2,379 | 2,175 | 2,129 |
| Total (11 crops) | | 18,626 | 24,588 | 30,429 | 35,049 | 34,399 | 35,813 |

[1]Actual N rate was 160 lb/A in 1984 and 1985.
[2]N rates were reduced by 50 percent due to loss of 1987 corn crop to hail and no N removal.
[3]All above-ground biomass was harvested as hay and removed from plots except for 2- to 3-inch standing stubble.

production and its subsequent effects on SOC and total soil nitrogen (TSN) in NT dryland cropping systems in the central Great Plains is limited. Therefore, we evaluated the long-term effects of N fertilization rates on crop residue production in a NT annual cropping system and determined the subsequent effects of returning this crop residue to the soil on SOC and TSN.

## Study Approach

We conducted the study at the Central Great Plains Research Station, Akron, Colorado, on a Weld silt loam soil with an initial pH of 7.2 and SOC concentration of 0.69 percent (0 to 6 inch depth) or 1.2 percent soil organic matter in 1984. The sodium bicarbonate ($NaHCO_3$)-extractable soil P level (0 to 6 inch depth) was 22 parts per million (ppm)...very high...at initiation. Nitrogen as ammonium nitrate ($NH_4NO_3$; 34-0-0) was broadcast at planting of each crop at rates of 0, 20, 40, 60, 80, and 120 lb N/A. The 120 lb N/A rate plots received 160 lb N/A in 1984 and 1985. This N rate was reduced in 1986 because of a significant increase in residual soil nitrate-N ($NO_3$-N). Nitrogen rates were reduced 50 percent in 1988 because of crop failure in 1987 that resulted in no measurable N removal. Initially the N plots were split, with application of 69 lb $P_2O_5$/A to half of each plot in 1984. The P treatment was discontinued after the first year. A NT system of farming was used. Spring barley, corn, winter wheat, and oat-pea hay were grown in rotation (**Table 1**).

Total above-ground biomass yield (grain plus residue or forage) was determined. Grain yield was subtracted from total biomass to get an estimate of the above-ground crop residue returned to the soil surface for grain crops. Total corn biomass was estimated for 1985 using the average stover/grain ratio from other years of corn production. Because of hail in 1987, an estimate of 1987 biomass production was made by using an average of corn stover returned to the soil for the other four corn years. No above-ground crop residue was returned to the soil surface except the remaining stubble for the hay crops in 1992 and 1994. Estimates of below-ground (root) residue C in the soil were made by assuming that root C equaled grain yield times 0.57. (This method of estimating root C was obtained from published research from the central Great Plains). Hay crop contributions to root C were estimated from a linear relationship of above-ground residue C to root C for the wheat, barley, and corn crops.

Six random soil cores per plot were collected and composited after hay harvest in 1994 to assess TSN and SOC in the 0 to 3 and 3 to 6 inch soil depths. Loose surface crop residue was brushed aside before taking the samples. Soil bulk density was determined for each sampling depth. Soil samples collected in April 1985 from the 0 to 3 inch and 3 to 6 inch soil depths were also analyzed for soil C.

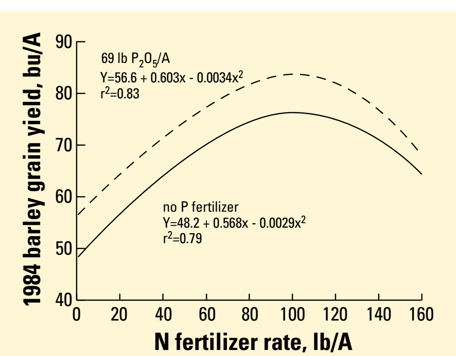



**Figure 1.** Barley grain yields as a function of N and P fertilizer rates in 1984.

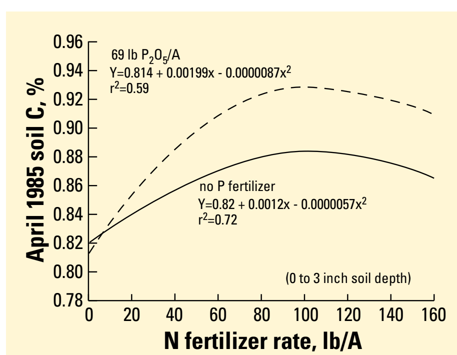
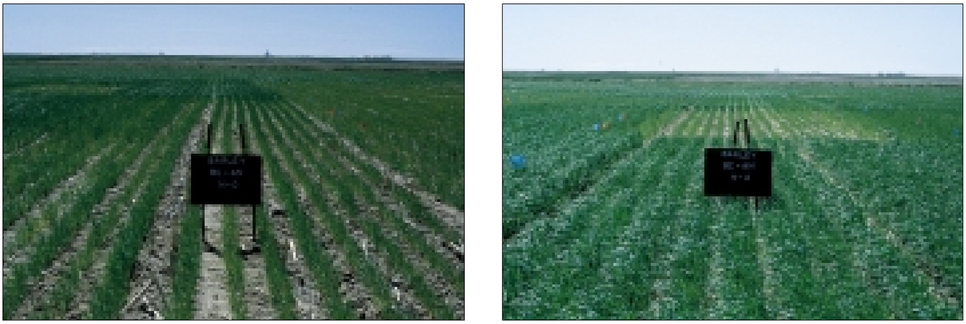



**Figure 2.** Soil C in 0 to 3 inch soil depth in April 1985 as a function of N and P fertilizer rates.



**Barley in plot** with no N added (left) had limited growth in May, compared to plot with 60 lb N/A (right).

However, soil bulk density was not determined.

Carbon sequestration efficiency for each N rate was calculated by dividing the estimated total (11 crops) residue C returned to the soil above that without N fertilization by the change in SOC above that without N fertilization.

## Study Results

Despite the high soil test P level, a barley response to P fertilization was obtained in 1984, as shown in **Figure 1**. The decline in barley grain yields at the 160 lb N/A rate was the result of severe lodging at this N level. A significant N x P interaction was present in the 0 to 3 inch depth for SOC concentration following the 1984 barley crop (**Figure 2**). Phosphorus also significantly increased the level of SOC in the 3 to 6 inch depth when averaged over N rates. These data indicate that P probably stimulated root growth as evidenced by the increase in measured SOC since surface residue from 1984 had not been incorporated into the soil. Unfortunately, soil samples from subsequent years were not available to further evaluate this influence of P on SOC.

When averaged over all years, optimum grain yield was obtained with the application of 60 lb N/A (**Table 1**). Total above-ground biomass production (11 crops) increased significantly with increasing N rate to near maximum with the application of 60 lb N/A and then tended to level off with increasing N rates. Total crop residue returned to the soil surface followed similar trends (**Figure 3**).

Soil bulk density within the 0 to 3 inch depth after 11 years decreased significantly with increasing N rate (**Figure 4**), with

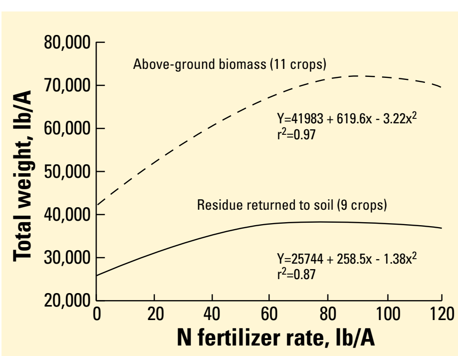



**Figure 3.** Total above-ground biomass production by 11 crops and total residue returned to soil surface by nine crops as a function of N fertilizer rate.

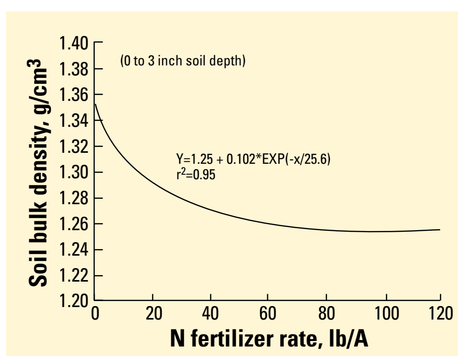



**Figure 4.** Soil bulk density in the 0 to 3 inch depth as a function of N fertilizer rate in 1994.

no influence of N on soil bulk density at the 3 to 6 inch depth. The decline in soil bulk density reflects the increase in crop residue returned to the soil surface with increasing N rate. There was a significant linear inverse relationship ($r^2$=0.88) between soil bulk density and increasing amounts of residue returned to the soil. The lower bulk density in the surface 0 to 3 inch soil depth enhances the performance of disk type drills in seed placement and water infiltration. These data show the positive influence of increasing amounts of crop residue returned to the soil on soil bulk density in the NT system.

Total N uptake in the total above-ground biomass of the 11 crops and the total crop residue N returned to the soil increased with increasing N rate (**Figure 5**). The total amount of N removed in the harvested grain or forage is the difference between total biomass N uptake and the N in the residue returned to the soil surface. An average of about 28 percent of the total N uptake was returned to the soil in the residue for the N fertilized plots. The increase in crop residue N returned to the soil with added N was reflected in a significant increase in TSN in the 0 to 6 inch depth with increasing N rate (**Figure 6**).

The significant increase in SOC mass with increasing N rate (**Figure 6**) reflects the response of crop biomass production to added N and the quantity of residue returned to the soil. Based on regression analyses, 1,790 lb/A more SOC had accumulated in the 0 to 6 inch soil depth after 11 crops in the 120 lb/A N rate than with the zero N rate. This equates to an annual increase in SOC of 163 lb C/A per year. At the 60 lb/A N rate, the annual increase in SOC was estimated to be 125 lb C/A per year. The annual SOC accumulation rate for the 40 lb/A N rate was 84 lb C/A per year. The soil C/N ratio was not influenced by N fertilization in this study, remaining constant across all N rates at 9.0.

Carbon sequestration is very important when considering the effects of farming practices on greenhouse gas emissions, such as $CO_2$. Cropping systems and practices that enhance C sequestration of atmospheric $CO_2$ are beneficial. In this study, N fertilization increased SOC. The percent change in C sequestration above that of the zero N rate is shown in **Figure 7**. Carbon sequestration efficiency, when based on only mass of above-ground residue C, indicates an increase of about 30 percent at the highest N rate above that of the zero N rate. However, when estimated root C was included with above-ground residue C in the total plant C estimate, C sequestration efficiency was about 11 percent higher at the highest N rate than for the zero N rate. These calculations illustrate that knowledge about the mass of C in plant roots that are incorporated into the SOC pool is critical to the calculation of plant-residue C storage efficiency. The 1985 sample

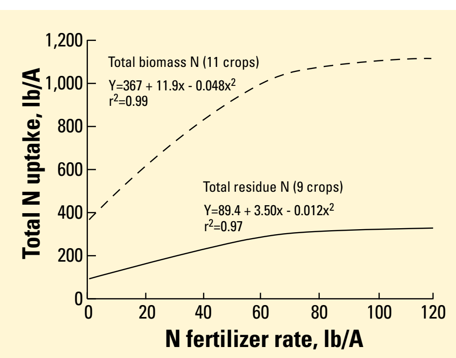



**Figure 5.** Total N uptake in above-ground biomass of 11 crops and total N returned to soil surface in residue of nine crops as a function of N fertilizer rate.

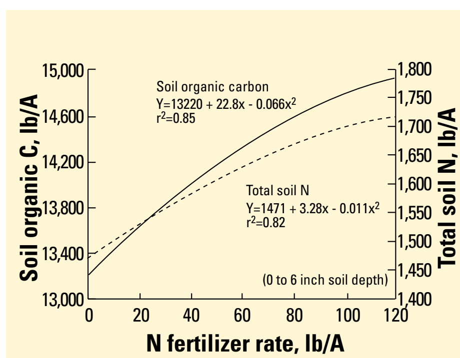



**Figure 6.** Total SOC and TSN in the 0 to 6 inch soil depth in the fall of 1994 as a function of N fertilizer rate.

analyses suggest that P fertilization may also play an important role in C sequestration.

There is a lack of research knowledge concerning the mass of below-ground residue C produced by plant roots from various crops. This information is extremely important when addressing the effects of cropping practices on C sequestration as it is related to concerns about global climate change.

The positive effects of N fertilization on SOC were clearly demonstrated in this long-term dryland annual cropping study under NT conditions. Nitrogen fertilization significantly increased crop residue inputs to the soil, resulting in increases in TSN and SOC after 11 crops. The increase in SOC with increasing N fertilization rate decreased soil bulk density and contributed to improving soil quality. Carbon sequestration efficiency was improved by N fertilization. This study shows that managing NT cropping systems for optimum yield with adequate N fertility will have positive environmental impacts and that N fertilization will enhance SOC accumulation and productivity in the central Great Plains. A good fertility program helps sequester atmospheric $CO_2$ into SOC by increasing plant growth and, subsequently, returning more organic C to the soil for storage as soil organic matter in a NT system. BC

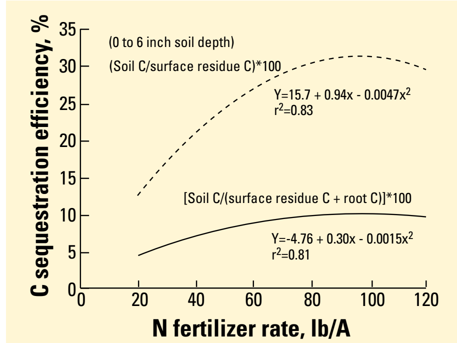



**Figure 7.** Estimates of C sequestration efficiency in the 0 to 6 inch soil depth as a function of N rate after 11 crop years when considering surface residue C inputs only and surface residue C plus estimated root residue C inputs.

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## World Population Reaches 6 Billion

The world's population increased to over 6 billion people on October 12, 1999, according to the United Nations (U.N.). While the population growth appears to be slowing, it is still adding more than twice as many people as were added annually at the middle of the 20th century.

In 1950, world population reached a total of 2.556 billion. The graph shown here tracks the number at each decade since then. While tremendous progress in food and fiber production has eased concerns in many areas of the world, the challenge of improving practices and developing more efficient crop and soil management systems continues. BC