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# EFFECTS OF SUNFLOWER ON SOIL QUALITY INDICATORS AND SUBSEQUENT WHEAT YIELD

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**Sunflower (*Helianthus annuus L*) production has increased in the central Great Plains, but little is known regarding how this crop will affect surface biomass production, various soil quality indicators, and subsequent winter wheat (*Triticum aestivum L.*) yields. We hypothesized that sunflower production was reducing soil quality relative to other summer crops because of the need for tillage to incorporate herbicide, thus reducing surface residue. Our objectives were to quantify on a Weld silt loam (fine, smectitic, mesic, Aridic Argiustolls) surface crop residue levels immediately after seeding wheat, subsequent wheat grain yield, soil organic carbon (SOC), particulate organic matter-carbon (POM-C), aggregate stability, and texture in 3- or 4-year rotation. A randomized complete block design with three replications was used to compare rotations both with and without sunflower. Our data showed 13% lower SOC content and 26% lower POM-C content at the 0- to 5-cm depth in rotations with sunflower versus those without. At the 5- to 15- cm depths, differences were not significant ($P < 0.05$). Crop residue by mass was 5 times lower and wheat yields 33% lower in rotations with sunflower, but no differences were measured for wind erodible aggregates or texture. Tillage to incorporate herbicides for sunflower and low amounts of residue after sunflower in the 3-year rotation contributed to reduced SOC and POM-C, decreased residue at wheat planting, and reduced wheat yield. If sunflower is to be included in the central Great Plains, efforts should be made to use no-till production practices and 4-year rotations with corn. (Soil Science 2000;165:516–522)**

**Key words: Corn, proso millet, tillage, soil organic carbon, erosion.**

SUNFLOWER production in the central Great Plains has increased steadily over the last several years (Lyon and Meyer, 1995), from a few hectares in 1988 to nearly 50,000 hectares in 1997. There are many reasons for this dramatic increase, among them sunflower's competitive profitability with other crops, the opening of a processing plant in Goodland, Kansas, and easier marketing and transportation. A warm-season, broadleaf crop has long been desirable in a cereal-based cropping system as a hedge against increased weed infestation in a wheat-fallow system (Lyon and Baltensperger, 1995). The presence of a tap root crop may also, in some instances, alleviate surface compaction generated through long-term, clean-tillage wheat-fallow. The need to capture "escaped nitrates" and water after harvest of shallow-rooted crops such as proso millet (*Panicum miliaceum L.*) is another advantage of the deep-rooted sunflower crop.

Since much of the research and data for this crop was obtained in the Northern Plains, where climatic conditions are cooler, frost-free periods are shorter, and residues persist longer, researchers and producers in the central Great Plains need to develop their own management database on sunflower production for their soil types and climatic conditions. Investigations in western Kansas, the panhandle of Nebraska, and eastern Colorado are beginning to address concerns about low residue levels, erosion potential, and water use after a sunflower-fallow sequence (Nielsen, 1995;

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Lyon, 1998; Sunderman, 1995). There are also concerns about the effects of tillage used to incorporate herbicides on crop residue persistence, soil organic matter (SOM) decomposition, soil erosion, and water availability (Lyles and Tatarko, 1986; Anderson et al., 1996).

Our overall research objective was to develop sound agronomic practices for sustainable dryland rotations that provided economic stability with minimal environmental risk. The introduction and testing of a broad-leaf summer crop (sunflower) is crucial to this objective. The specific objectives for this portion of the study were to compare the effects of sunflower in rotations with fallow with that of similar length rotations with corn (*Zea mays L.*) and millet for differences in: (i) erosion potential as measured by amounts of surface crop residue cover and mass immediately following winter wheat seeding; (ii) soil quality indicators including total SOC, POM-C, stable aggregates, and soil texture; and (iii) wheat grain yield.

## MATERIALS AND METHODS

Research plots were established on a Weld silt loam near Akron, Colorado, in 1990 and 1991 (Table 1). Mean long-term (> 80 years) annual precipitation in the area is 420 mm, with 80% occurring from April to September. Mean open pan evaporation for April to September is 1400 mm, and the frost-free period is 120 days. Site elevation is 1400 m.

The experimental design was a randomized complete block with three replications. Plot size was 30 m by 9 m. All phases of each rotation with sunflower and the corresponding non-sunflower summer crop were present every year. Fertilizer N and P were applied to each plot according to soil test results and projected crop yields. The crops used in the rotations were corn (C), winter wheat (W), sunflower (S), and proso millet (M). Selected 3-year, and 4-year rotations containing sunflower (W-S-F, W-C-S-F) and matching rotations without sunflower (W-C-F, W-C-M-F) (Table 2) were used for soil and surface residue comparisons in 1998 and wheat yield comparisons from 1995 to 1998.

For weed control in the rotations, the residual herbicide atrazine, [6-chloro-N-ethyl-N′-(1-methylene)-1,3,5-triazine-2,4-diamine, plus clomazone, {2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidione} and contact herbicide glyphosate [N-(phosphonomethyl)glycine] were used during the fallow (F) period for all crops. For sunflower, two shallow (0–5 cm) tillage operations with a sweep plow before seeding were performed for herbicide (granular ethal-fluralin, N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-triflurometyl)benzenamine) incorporation (Anderson et al., 1999). No attempt was made to separate tillage and crop sequencing in the sunflower rotations (W-S-F, W-M-S-F) from that of no-tillage and crop sequencing in the non-sunflower rotations (W-C-F, W-C-M-F) relative to contributions to soil changes and crop yield.

### *Plant Data Collection*

Crop residue cover (percentage by line transect, Laflen et al., 1981) and surface residue biomass (mass per unit area) were measured within 1 to 2 weeks after wheat seeding in September and October 1998 for sunflower and matched non-sunflower plots. A 1-m square was chosen by tossing a meter stick to the middle of the plot, but by subjectively choosing the more representative of residue side of the meter stick (visually) for the square meter assessment of residue. Surface residue in the quadrants was washed to remove soil, dried, and weighed. Winter wheat grain yield after sunflower (W-S-F, W-C-S-F) or after the matched non-sunflower crops (W-C-F, W-C-M-F) was also quantified from the appropriate plots during 1996, 1997, and 1998.

Crop varieties, planting dates, rates, and general cultural practices are given in Table 3. Although planting and harvesting dates may differ only slightly among producers, greater variability may be expected for seeding rates, fertilizer applications, and tillage intensity.

TABLE 1

Selected physical and chemical characteristics of the study site for the 0 to 5 and 5 to 15 cm depths

| Soil Depth | pH | Db† | SOC† | Total N | $NaHCO_3$-P | Silt | Clay | CEC† |
|---|---|---|---|---|---|---|---|---|
| cm | (0.01 M $CaCl_2$) | Mg $m^{-3}$ | —— g $kg^{-1}$ —— | | mg $kg^{-1}$ | — g $kg^{-1}$ — | | Cmol 100 $g^{-1}$ |
| 0–5.0 | 5.4 | 1.25 | 11.0 | 1.2 | 26.0 | 420 | 200 | 14.0 |
| 5.0–15.0 | 6.5 | 1.38 | 8.0 | 0.8 | 14.0 | 400 | 220 | 14.0 |

†Db is soil bulk density; SOC is total soil organic carbon; CEC is cation exchange capacity.

TABLE 2

Description of number of measurements from rotations with and without sunflower

| Property measured | Rotation comparison | | | |
|---|---|---|---|---|
| | Sunflower | n† | No sunflower | n† |
| SOC, POM-C | W-S-F | 9 | W-C-F | 9 |
| | W-C-S-F | 12 | W-C-M-F | 12 |
| Cover at wheat seeding‡, texture, aggregate stability | F-W-S | 3 | F-W-C | 3 |
| | F-W-C-S | 3 | F-W-C-M | 3 |

†Twenty-one soil samples (7 entry points in two rotations with 3 replications); 6 soil samples (1 entry point prior to wheat in 2 rotations with 3 replications).
SOC, total soil organic C; POM-C, particulate organic matter-C.
W = wheat; S = sunflower; C = corn; M = proso millet, F = summer fallow.
‡Cover in previous sunflower plot before fall wheat seeding.

### Soil Organic Carbon and POM-C

For SOC and POM-C changes, representative soil samples (five composites from each plot) were taken in the spring of 1998 from the 0- to 5- and 5- to 15-cm depths. Four rotations (seven different sequencings) were used for plots with and without sunflower (21 samples each) (Table 2). Soil organic carbon was assessed with a C-N analyzer or by chromic acid digestion where carbonates were present (Bowman, 1998). The POM-C was measured according to the procedure by Gregorich and Ellert (1993) as modified by Bowman et al. (1999). Bulk density (Db) by the core method (Blake and Hartge, 1986) and pH in 0.01 M $CaCl_2$ (McLean, 1986) were also measured for these depth increments. Soil data for SOC were assessed on a mass and volumetric basis for both depth increments.

### Soil Erosion Potential

To evaluate the potential for wind erosion in plots being planted to wheat in 1998, soil samples were taken from the 0- to 2-cm depth and analyzed for texture and stable aggregates as suggested by Skidmore (1994). This was done primarily to confirm crop residue compliance for deficiency payments and to quantify the potential for wind erosion during the winter. Therefore, evaluations were actually made on six plots. Stable aggregates were measured by dry sieving the top 2.0 cm of soil (Chepil, 1962; Kemper and Rosenau, 1986). Two 15 × 15-cm samples were collected, air-dried, composited, and run through the rotary (Chepil) screens. The various aggregate fractions were collected and weighed, but only the wind erodible fraction (< 0.850 mm) and the >2.000-mm fraction are reported. Soil texture was determined by the hydrometer method (Gee and Bauder, 1986) for the same plots on an area adjacent to where aggregate samples were taken. Only the sum of the "fines" (silt plus clay) is reported.

### Statistical Analyses

Statistical analyses included analysis of variance and Tukey's mean difference test ($P \leq 0.05$) for wheat yield evaluation. Differences were compared by treatments (post-sunflower vs. no-sunflower) and by years (1995 to 1998). Soil data and surface residue evaluations for the 1998 soil sampling were evaluated using *t* tests ($P \leq 0.05$) on mean differences between the 3- and 4-year rotations with and without sunflower.

## RESULTS AND DISCUSSIONS

### Plant Data

Adequate residue cover (generated through no tillage and continuous cropping) is crucial to protect the soil from wind erosion and from evaporative water loss (Skidmore and Siddoway, 1978). However, sunflower production in the central Great Plains generally requires tillage and fallow (Lyon, 1998; Anderson et al., 1996). The physical incorporation of herbicide to control weeds in sunflower and the use of fallow after sunflower have been the predominant protocol

TABLE 3

Cultivation practices for establishing wheat, corn, proso millet, and sunflower at Akron, Colorado

| Cultivation data | Wheat | Corn | Proso millet | Sunflower |
|---|---|---|---|---|
| Variety | TAM 107 | P-3732† | Sunup | T-546† |
| Planting date range | Sept 18–28 | May 3–12 | June 5–12 | June 1–5 |
| Seeding rate (seeds/ha) | 2 million | 37,600 | 2 million | 39,500 |
| Row spacing (cm) | 20 | 76 | 20 | 76 |
| Nitrogen rate (kg ha$^{-1}$) | 45 | 65 | 35 | 45 |
| Phosphorus (kg ha$^{-1}$) | 8 | 8 | 8 | 8 |

†P represents Pioneer Hi-Bred Seed International; T represents Triumph Seed Company Inc.

and are still practiced widely today although trends toward no-till sunflower production are emerging. Anderson et al. (1996) found a 10% increase in residue at Akron before sunflower seeding with no tillage versus sweep tillage. Results presented here, however, reflect sweep tillage practices being used for sunflower and the subsequent impact of including the crop on winter wheat production.

Our data showed that crop residue mass and percent cover at wheat planting was significantly lower in sunflower rotations than in rotations without sunflower (Table 4). The W-S-F rotation had the lowest percentage cover, whereas the W-C-M-F had the greatest. Wheat, corn, and proso millet without tillage produced the greatest percent cover, but low residue inputs (no corn and proso) and mechanical tillage produced the lowest residue cover in the W-S-F rotation. These data were consistent with residue cover data in Nebraska (Lyon, 1998). The Nebraska research, however, did not have a 4-year rotation and utilized much more tillage following sunflower. In our study, both rotations showed a trend for increased cover as rotation length increased. With sunflower, the greatest cover was obtained by using the 4-year rotation (W-C-S-F).

Total above-ground biomass for sunflower is a direct function of seeding density and stalk length at harvest (Nielsen et al., 1999) along with older residues. Surface crop residue for the W-C-F rotation was much greater than the comparable rotation with sunflower (W-S-F) (Table 4). This decline is a function of both tillage (residue being covered and decomposed), and crop (corn producing more cover than sunflower.

TABLE 4

Wheat grain yields, residue production (surface biomass and % cover at wheat seeding) for 3- and 4-year rotations with and without sunflower. Values represent means and standard deviations

| Rotation† | Cover | Surface biomass | Grain yield |
|---|---|---|---|
| | % | ---------- kg ha$^{-1}$ ---------- | |
| W-C-F | 74 ± 6 | 4010 ± 950 | 2880 ± 615 |
| W-S-F | 23 ± 11 | 460 ± 20 | 1810 ± 635 |
| W-C-M-F | 83 ± 4 | 2230 ± 100 | 3040 ± 630 |
| W-C-S-F | 50 ± 14 | 905 ± 280 | 2230 ± 900 |
| Mean (no S) | 75 ± 8‡ | 3040 ± 90† | 2960 ± 110‡ |
| Mean (S) | 36 ± 14 | 625 ± 240 | 2020 ± 290 |

†W is winter wheat; C is corn; S is sunflower; M is proso millet.

‡Means for no sunflower plots significantly higher than for sunflower plots at $P \leq 0.05$, according to Tukey's mean separation procedure.

Lyon (1998) obtained similar values for W-S-F studies where residue declined drastically from early spring (3380 kg/ha) to late spring (1450 kg/ha) and then to wheat seeding (570 kg/ha). The W-C-S-F rotation had nearly twice as much surface residue biomass as the W-S-F, presumably because of less fallow and the increased biomass contribution from corn.

For wheat grain yields, no differences were found by years so data for the same treatments were composited. Yields were significantly lower after sunflower (Table 4). Water use by sunflower was greater than use by other summer crops (Nielsen et al., 1999). Average available water measurements by Nielsen et al. (1999) for the 1.8-m profile at wheat planting were 92 mm for W-S-F, 191 mm for W-C-F, 134 mm for W-C-S-F, and 198 mm for W-C-M-F. Depleted soil water along with reduced residue cover following sunflower increased evaporation during the subsequent fallow and, therefore, decreased wheat yield. In semiarid regions, surface cover, evaporation, and subsequent available water are the primary factors affecting wheat yield (Nielsen et al., 1999). The 3-year average grain yield for rotations without sunflower was about 40% greater than with sunflower. In areas of greater rainfall (>500 mm), or in years when rainfall in our area is abundant during grain formation, sunflower water extraction may not affect subsequent wheat yield or may do so minimally (Anderson et al., 1999).

Our data and those obtained by Nielsen et al. (1999) and Anderson et al. (1996) suggest that a good management option for sunflower production would be to include water-saving practices such as no tillage, leaving greater sunflower stalk length at harvest, and using a 4-year rotation with corn.

### *Soil Organic Carbon and POM-C*

Soil samples from plots with sunflower (3- and 4-year rotations together) contained significantly less SOC and POM-C than comparable rotations without sunflower (Table 5). When partitioned, samples with sunflower in the 3-year rotation contained significantly less SOC and POM-C at the 0- to 5-cm depth than in the W-C-F rotation, but this was not the case for the 4-year rotation because of the presence of corn, the greatest residue producer. While data for W-S-F and W-C-S-F clearly illustrated a reduction in percent cover and biomass relative to W-C-F and W-C-M-F (Table 4), corn residue in the W-C-S-F rotation was tilled and produced 2 years be-

TABLE 5

Average (weighted mean) total soil organic carbon (SOC) and particulate organic matter-carbon (POM-C) at the 0 to 5 and 5- to 15-cm depths in 1998 for treatments with sunflower (S) and without sunflower (no S). Values represent means and standard deviations

| Rotation | SOC | | POM-C | |
|---|---|---|---|---|
| | 0–5 cm | 5–15 cm | 0–5 cm | 5–15 cm |
| | Mg ha$^{-1}$ | | | |
| W-C-F | 5.75 ± 1.0 | 8.37 ± 1.8 | 3.02 ± 1.2 | 1.76 ± 0.4 |
| W-S-F | 4.75 ± 1.3 | 8.24 ± 1.5 | 1.81 ± 0.7 | 1.48 ± 0.5 |
| W-C-M-F | 5.68 ± 0.7 | 9.32 ± 1.5 | 2.19 ± 0.4 | 1.89 ± 0.7 |
| W-C-S-F | 5.25 ± 1.1 | 8.64 ± 1.5 | 2.00 ± 0.8 | 1.76 ± 0.5 |
| Mean (no S) | 5.72 ± 1.1† | 8.91 ± 1.5 | 2.56 ± 0.8† | 1.83 ± 0.4 |
| Mean (S) | 5.05 ± 1.1 | 8.47 ± 1.5 | 1.92 ± 0.6 | 1.64 ± 0.5 |

†Means for no S plots significantly higher at $P \leq 0.05$.

fore wheat was planted, and the residue was measured. This created greater potential for SOC and POM-C accumulation but less for percent cover. Rotations with less fallow, such as W-C-M-F, had the greatest SOC content, whereas W-S-F had the lowest. In another study at the same site, Bowman et al. (1999) documented the importance of increasing cropping intensity and minimizing summer fallow to increase or maintain SOM content, but direct comparison of sunflower with another crop in a similar rotation was not evaluated. Lyles and Tatarko (1986) measured SOM and textural changes at 10 soil sites on cropland in western Kansas, first measured by Chepil and associates in 1948. Lyles and Tatarko (1986) found a 19% decline in SOM (1.87% to 1.57%), which was accompanied by a 7% decline in silt content. Soil organic matter loss was thus attributable to both erosion and cropping.

For the 0- to 5-cm depth, the W-S-F rotations contained 18% less SOC than the W-C-F rotations. For the 5- to 15-cm depths, these differences were not significant even though this depth contained more carbon by volume (twice as thick) as the 0- to 5-cm depth. Like most no-till studies not in W-F rotation, SOC enrichment occurred primarily from decomposition of surface residues and shallow roots rather than from carbon from roots below 5 cm (Havlin et al., 1990; Bowman et al., 1999).

Data for the POM-C were more variable. The average for W-S-F rotations was 40% less than for W-C-F rotation at the 0- to 5-cm depth. A slight but insignificant decrease (10%) existed for the same comparison at the 5- to 15-cm depth. POM-C for the W-C-S-F treatments was 91% of the W-C-M-F treatments, whereas the W-S-F treatment was only 60% of the W-C-F treatment. These results were consistent with the lower percent cover and residue biomass obtained with the W-S-F treatment. This difference in POM-C can be attributed partly to the production of less residue because of greater decomposition in sunflower plots and the greater residue biomass remaining after harvest in corn (W-C-F) compared with sunflower (W-S-F) (Table 5). Also, tillage in sunflower to incorporate the herbicide may have contributed to this decline by mixing soil and organic material and, consequently, causing faster decomposition (Havlin et al., 1990).

Particulate organic matter C is usually a function of crop residue, litter, root production, and tillage intensity. Because much of the fine litter passes through the 2-mm screen, part of the total SOC is composed of this labile C pool (Bowman et al., 1999; Cambardella and Elliott, 1992). Sunflower also has a taproot that produces less below-ground biomass to 15 cm depth than do cereal grasses (Paustian et al., 1997). Greater residue and SOC content at the soil surface can increase available water by increasing infiltration and by reducing runoff, soil crusting, and evaporation (Swift, 1991).

### *Soil Erosion Potential*

In relatively level soils not dominated by calcium carbonate or iron oxides, soil erosion is generally less when there is greater plant cover and SOM (Stocking, 1994). These conditions help to form stable aggregates of a certain size that are less apt to erode (Stott et al., 1999). The Natural Resources Conservation Service (NRCS) has determined that >80% of the erosion in the central Great Plains is caused by wind, with severe water erosion occurring infrequently as a result of very intense climatic events. The NRCS has also determined that when seeding wheat, a minimum of 30% surface cover and 1500 kg/ha of surface residue mass are required to minimize erosion. Although the residue cover requirement was barely met by the W-C-S-F rotation and not met by the W-S-F rotation, the residue mass in both was less than a half of that required.

An indirect way of measuring the potential for soil erosion is to determine the level of the erodible fraction and the sand enrichment created by the removal of fines (silt and clay) by wind between rotations with and without sunflower. Bowman et al. (1990) found significant decreases in fines in a sandy loam soil of the central Great Plains after it had been in conventional-till W-F for more than 50 years. Although our plots without sunflower showed a lower percentage of erodible aggregates than the sunflower plots, these differences were not significant because of spatial variability among replications (Table 6). Smika (1990), working with the same soil type, found a greater and significant percentage of erodible aggregates in conventional-tillage compared with reduced- and no-tillage treatments. These results were not unexpected because conventional tillage required three to five more tillage passes than minimum tillage. The data, which were not statistically different (minimum tillage vs. no tillage), were more analogous to our studies. All other fractions to 38 mm in diameter did not differ. The data for texture indicated a trend for increased loss for silt and clay with sunflower, but these differences were not significant (Table 6). Since the data was collected only once, further evaluation of this trend is warranted.

## CONCLUSION

The amount and percent soil cover in rotations with sunflower were less than with corn or with corn and millet. However, because of the presence of corn in both 4-year rotations, SOC and POM-C content did not differ. Consequently, after 8 years, less SOC and POM-C were present only in the W-S-F rotation. Lower amounts of SOC in the sunflower rotations were attributed to lower biomass production by sunflower and lack of a high residue crop such as corn in the rotation. Although the potential for wind erosion existed, evidence for erosion was not supported by the wind erodible aggregates or texture data. Since these soil data were obtained only at wheat seeding, studies will continue to determine long-term changes in these rotations.

To obtain higher wheat yields than provided by the present W-S-F system, it will be necessary to increase the residue cover during the sunflower-fallow period by leaving longer stalks after harvest and minimizing or eliminating tillage to incorporate herbicides to control weeds as well as using a 4-year rotation that includes corn.

TABLE 6

Texture and dry aggregate distribution in matched rotations with and without sunflower

| | | Aggregates | |
|---|---|---|---|
| Rotations | Fines† | < 0.85 mm‡ | > 2.00 mm |
| | $g\ kg^{-1}$ | | |
| Sunflower | 550 | 630 | 230 |
| No sunflower | 600 | 550 | 300 |
| P§ | 0.24 | 0.19 | 0.20 |

†Silt and clay.

‡Wind-erodible fraction.

§Tukey *P* value for level of significance for comparison between data for plots with and without sunflower.

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