LANDSCAPE POSITION AND CLIMATIC GRDIENT IMPACTS ON CARBON TURNOVER IN COLORADO

G.A. Peterson[1], D.G. Westfall[1], and L.A. Sherrod[2]

[1]*Department of Soil and Crop Sciences,*
Colorado State University, Fort Collins, CO 80523
[2]*Great Plains Systems Res. Unit, USDA-ARS, Fort Collins, CO*

ABSTRACT

Soil organic carbon has decreased in cultivated wheat-fallow (WF) systems due to increased carbon (C) oxidation, low carbon input and soil erosion. Implementation of more intensive cropping with no-till management has reversed the trend in soil C loss. Our objective in this presentation is to review the effects of landscape position on soil C status as related to intensification of cropping system over a climatic gradient. Our analysis will be based on 12 years of data from a long-term cropping system experiment conducted in semi-arid eastern CO under dryland conditions. In summary, climatic gradient affected SOC levels while the high potential evapotranspiration (PET) site having approximately half the level found in the low and medium PET sites. Decreases in summer fallow frequency resulted in improved C budgets. Landscape position impacted soil C content as would be expected, in that slope positions that received the most water had the highest soil C levels because plant productivity was highest at these positions. However, cropping system intensification effects were independent of slope position effects in terms of soil carbon budget over the 12-year period that these data encompass.

INTRODUCTION

The WF production system managed under stubble-mulch tillage has been the backbone of dryland agriculture in the semi-arid environment of Colorado for years. Over the years this system has resulted in a stabilization of yields due to stored soil moisture during the fallow period. Typically less than 25% of the precipitation that is received during the 14-month fallow period is stored in the soil for use by the next wheat crop. Associated with this system has been a dramatic decline in soil organic carbon (SOC) in the range of 30 to 50% of the original SOC levels under native grass (Campbell and Souster, 1982; Mann, 1985; Peterson et al., 1998). The implementation of no-tillage systems associated with increased cropping intensity has been proposed as a mechanism to increase the SOC levels of these degraded soils. Precipitation storage of 40-60% can be achieved under no-till management which will allow producers to shift from the traditional WF system to more intensive cropping systems that result in increased crop production and crop residue return to the soil. Crop residues are the precursor of C inputs into agricultural soils. Unfortunately, crop residues are transitory in nature because of natural decomposition processes and tillage management strategies.

Many studies have been conducted to determine the effect of different tillage systems on SOC. However, the literature has little information on the affect of increasing cropping intensity on levels of SOC and the effects of landscape position. There is little research focusing on SOC as affected by long term (>10y) cropping systems which represent increases in cropping intensity on soils previously managed under conventional tillage and then converted to no-till management. This presentation summarizes the research previously reported by Sherrod, et al., (2003) that was carried out in the semi-arid Great Plains of eastern Colorado with the objective to determine the effect of cropping intensity under no-till management on SOC after 12 years of no-till management of a range of cropping systems across a PET gradient and across a gradient of soils along a topographic sequence. We hypothesized that soils that support intensive cropping, which produce greater amounts of biomass, and C inputs, and maintain greater amounts of surface residues, will support higher levels of SOC. Specifically, cropping systems that have reduced fallow frequencies under cooler climates and depositional slopes (toeslopes) will produce the largest amounts of SOC followed by summit soils and finally the sideslope soils.

MATERIALS AND METHODS

This study combines four major variables, each with a gradient, which consist of 1) PET location, 2) slope position, 3) cropping systems, and 4) time,. A brief description of the experiment is presented below but greater details can be found in Peterson et al. (1993) and Sherrod et al. (2003).

PET Locations

The study sites are located in the Great Plains of eastern Colorado along a north to south gradient of increasing PET with all three sites having a long-term average annual precipitation of 420 mm. The long-term average PET of the three sites was 1015 mm yr^{-1} of open pan evaporation (Sterling; low PET), 1270 mm yr^{-1} (Stratton; medium PET) and 1900 mm yr^{-1} (Wash; high PET).

Slope Position

The soil variable is represented by slope positions of summit, side, and toeslope positions along a catenary sequence. Each slope represents a unique soil series common to the geographic area.

Cropping Systems

The cropping systems with various cropping intensities were imposed across the soil sequences at each location in two replications. Cropping systems include: wheat-fallow (WF), wheat-corn-fallow (WCF), wheat-corn-millet-fallow (WCMF), continuous cropping (CC) which included corn/sorghum, wheat, hay millet and sunflower in order of frequency and planted warm and cool season grass species (G) to be used as a “reference” for C inputs. Grain sorghum replaces corn in the cropping systems at Walsh and at Stratton prior to 1990. Corn replaced sorghum after 1990 at Stratton. All phases of each cropping system are present each year in each of the replications. No-till management was used thought the study. These cropping systems represent a gradient of cropping intensities with WF having an intensity factor of 0.50 (one crop every two years) with increasing intensity factors of WCF, WCMF, and CC are 0.67, 0.75, and 1.0, respectively.

Time

The time component of the study of 12 years was chosen because all of the cropping systems were back to the phase which they started out with in the fall of 1985. The WF cropping system completed 6 cycles, while the WCF and WCMF systems completed 4 and 3 complete cycles, respectively, after 12 years. The CC and G systems both completed 12 years as there is only 1 year in the rotation cycle.

At the end of the 12-year cycle soil cores were taken from all cropping systems including G at all three sites and at all three slopes from 0-2.5, 2.5-5, 5-10, and 10-20 cm depth increments for each of the two replications. Soils were air dried for several days and then ground to pass a 2 mm sieve size and all visible plant material larger than 2mm sieve size; roots or surface residues, were removed. A sub-sample was powder ground and analyzed for SOC using the wet oxidation method (Nelson and Sommers, 1982).

Experimental Design and Sampling

Details of the Analysis of Variance and experimental design are reported by Sherrod, et al. 2003.

RESULTS AND DISCUSSION

Soil Organic Carbon

Cropping intensification increased SOC (Figure 1) in both the 0-2.5 and 2.5-5 cm soil depths. Evaluation of WF and WCMF on summit soils after 8 years in these no-till rotations by Ortega et al. (2002) also found a trend (P=0.16) in SOC levels to be highest in the more intensive system. The SOC level in 0-2.5 cm depth of the CC treatment actually approached the amounts found in the G reference. This is remarkable in that the perennial G treatment is returning large amounts of root biomass relative to the CC or other cropping systems. An average annual above ground biomass yield from G at the low, medium and high PET locations were 1700, 1930, and 1240 kg/ha, respectively.

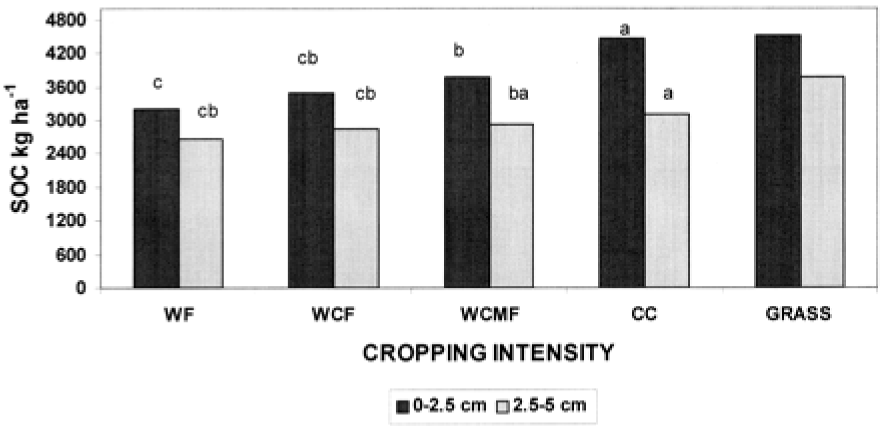

Figure 1. Soil organic C in the 0- to 2.5- and 2.5- to 5-cm depths after 12 yr under no-till management as affected by cropping intensity with grass as a reference point (averaged over locations and slopes). Means followed by a different letter within depths are statistically different ($P < 0.05$) using Fisher's LSD. (from Sherrod et al., 2003)

Cropping system effects on SOC did not interact with site (PET gradient) and/or soil position. However, as one would expect, site and soil position did affect SOC, and SOC was less in summit and sideslope soils than in soils on the toeslope position.

The effect of cropping intensity on SOC, summed to a 10 cm depth, was independent of slope position and PET site effects and no significant interactions existed. However, SOC was greatest in the CC and WCMF systems and least in WF. The CC system, without any summer fallow, had a 20 % increase in SOC compared to WF over the 12-year period. The WF and WCF cropping systems did not differ in SOC levels.

The low and medium PET sites had equal SOC levels while the high PET site had approximately half the level found in the low and medium PET sites (Figure 2). The fact that the medium PET site had SOC equal to the low PET site was not unexpected. This location historically produces the slightly greater yields and had an initial, at initiation of study, SOC level of 2.05 g kg^{-1} greater than the low PET site, when averaged over slope position.

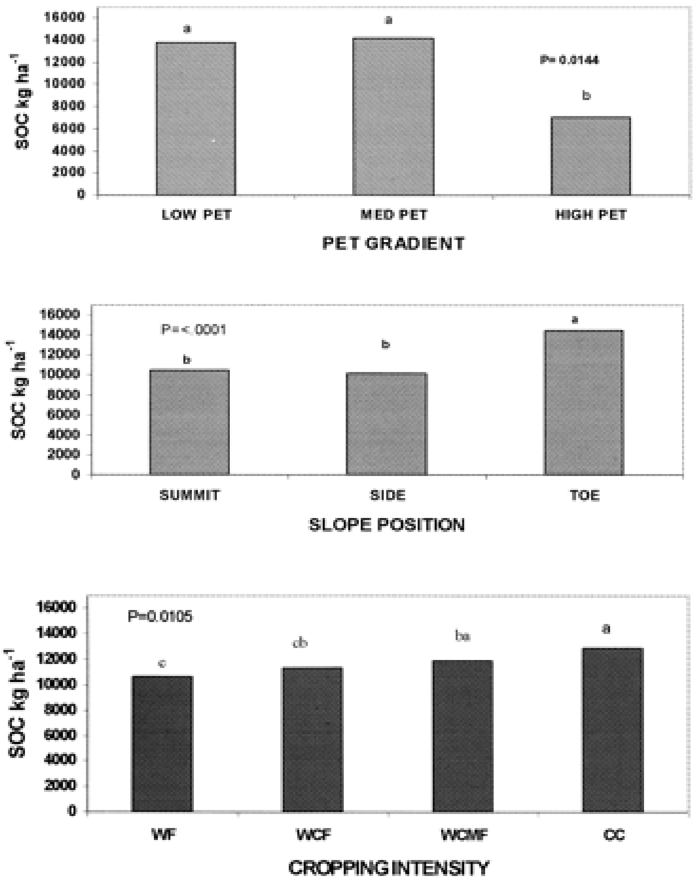

Fig. 2. Soil organic C as affected by PET gradient, slope position, and cropping intensity in the 0- to 10-cm depth. Means followed by a different letter are statistically different (*P* < 0.05) using Fisher's LSD. (from Sherrod et al., 2003)

Stover Production and SOC

Annualized stover (crop residue) production over the 12 years is the driving input for all changes in SOC. (Figure 3). Increased cropping intensity increased stover production and interacted strongly with PET, which was driven by the reduced stover production in the CC cropping system at the high PET site. This site is the most water-stressed location, and the CC cropping system experienced three years of failure in the 12 yr period. Generally, stover production increased as system intensity increased, with CC producing approximately 70% more stover than the WF cropping system.

Stover inputs, averaged over all cropping systems, PET sites, and slope positions had a strong relationship with SOC levels in the 0-10 cm depth with a $r^2 = 0.80$. This shows the importance of residue retention, since 80 percent of the variability in SOC was accounted for by the annualized stover production. Paustian et al. (1998) states that if we view organic matter decomposition as a series of first order reactions then the amount of soil organic matter maintained is directly proportional to the rate of C inputs, which our results demonstrate.

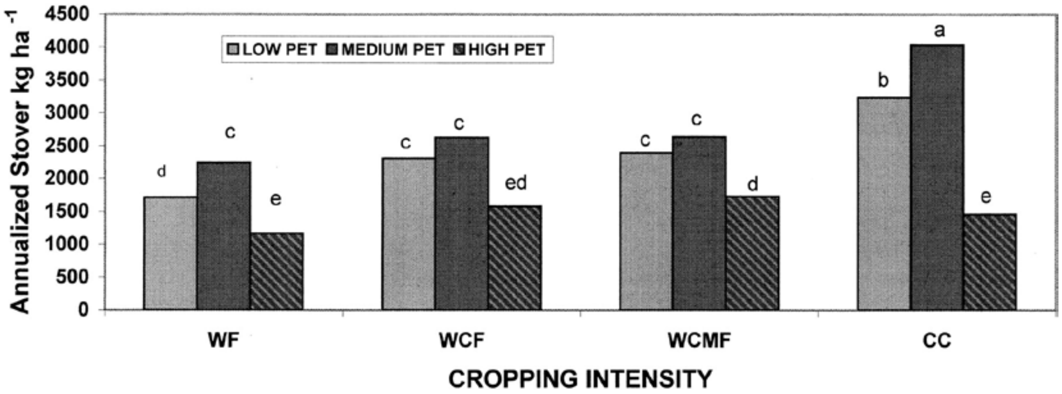

Fig. 3. Annualized stover inputs over a 12-yr period in no-till management as affected by the interaction of cropping intensity and location (PET gradient). Means followed by a different letter are statistically different ($P < 0.05$) using Fisher's LSD. (from Sherrod et al., 2003)

SUMMARY AND CONCLUSIONS

We found that the after 12 yr of no-till management of cropping systems the SOC could be increased by increasing cropping intensity and decreasing summer fallow frequency. The CC systems produced SOC levels equal to about 88% of a G reference system and 35% greater than in the WF system. Continuous cropping minimizes the opportunity for accelerated rates of SOC oxidation and most closely simulates perennial systems in which the balance between nutrient immobilization and mineralization processes results in minimum nutrient loss and maximum accumulation of SOC. However, if crop failures occur due to limited moisture, these levels may not be achieved. Summer fallow disrupts this balance between immobilization and mineralization processes, and the greater soil moisture and temperature conditions that occur under summer fallow result in an accelerated rate of SOC oxidation. Overall, toeslope soils had 30% more SOC as compared to the side or summit soils. Slope position, and location (PET gradient) independently impacted SOC. The impact of PET gradient also was evident because the high PET site had 50% of the amounts found at the low and medium PET sites.

Our study demonstrates that minimizing summer fallow is essential to the increase in SOC. Increased C sequestration is driven by increased cropping intensity, which returns more crop residue to the soil. Avoiding soil disturbance also is a major factor in reducing SOC oxidation and must be avoided if C sequestration is to occur in this semi-arid environment.

ACKNOWLEDGMENTS

This work was accomplished through the long-term cooperative research commitment between the Great Plains System Research unit, USDA-ARS Northern Plains Area, the Department of Soil and Crop Sciences, and the Colorado Agricultural Experiment Station.

REFERENCES

Campbell, C.A., and W. Souster. 1982. Loss of organic matter and potentially mineralizable nitrogen from Saskatchewan soils due to cropping. Can. J. Soil Sci. 62:651-656.

Mann, L.K. 1985. Changes in soil carbon storage after cultivation. Soil Sci. 142:279–288.

Ortega, R.A., G.A. Peterson, and D.G. Westfall. 2002. Residue accumulation and changes in soil organic matter as affected by cropping intensity in no-till agroecosystems. Agron. J. 94:944-954.

Paustian, K., E.T. Elliott, M. R. Carter. 1998. Tillage and crop management impacts on soil C storage: use of long-term experimental data. Soil Tillage Res. 47:vii-xii.

Peterson, G. A. and D. G. Westfall. 1996. Management of dryland agroecosystems in the central Great Plains of Colorado. In: Paul, E. A., Paustian, K. A., Elliot, E.T., Cole, C. V. (Eds.), Soil Organic Matter in Temperate Agroecosystems. Lewis Publishers, Boca Raton, FL, pp. 371-380.

Peterson, G.A., D.G. Westfall, and C.V. Cole. 1993. Agroecosystem approach to soil and crop management research. Soil Sci. Soc. Am. J. 57:1354-1360.

Sherrod, L. A., G. A. Peterson, D. G. Westfall, and L. R. Ahuja, 2003. Cropping intensity enhances soil organic carbon and nitrogen in no-till agroecosystems. Soil Sci. Soc. Am. J.67:1533-1543.