CARBON CREDIT AND SEQUESTRATION IN AGROECOSYSTEMS; LESSONS FROM TRIALS IN SOUTHERN ILLINOIS

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ABSTRACT

A carbon (C) credit is the attribution of net CO_2-C equivalent which can be used to decrease climate forcing through a given practice or farming system for a given unit time. Carbon credits allow industries to purchase C that is produced on a farm (i.e., offsets). Carbon can be captured in two ways; (i) by capturing and reducing greenhouse gasses (on a CO_2-C equivalent basis), and/or (ii) by increasing soil organic C stocks. Therefore, to enable C credits in the agricultural sector, we must measure and track CO_2-C equivalent flow in and out of the soil. Management practices that are in line with C increase in soil range from proper nitrogen (N) fertilization to a shift from tillage-based to no-till systems and increasing C inputs via cover crops (with different management scenarios like late termination), manure, etc. In Southern Illinois, results of a long-term tillage by fertility trial in a corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation indicates that a shift from tillage to no-till increases surface (0-5 cm) soil C, and provides protection for the sequestered C through increase in soil aggregation and aggregate stability but benefits do not go beyond 0-5 cm depth. Also, no-till benefits decrease significantly with no fertilization (control) reflecting lower C inputs by crop yields compared to tillage treatments. We observe a significant reduction in nitrous oxide (300 times more potent that CO_2) by no-till practice compared to a chisel-disk that could be considered for C capture. In a five-yr trial, adding cover crops into a corn-soybean rotation increased soil C stocks but only in 0-5 cm depth. Potentially, longer than five years of cover cropping is needed to build soil C stocks beyond topsoil. There are also tradeoffs in terms of greenhouse gas emissions with cover crop management practices. For example, in a winter wheat (*Triticum aestivum* L.)-corn trial, we observed significantly higher N_2O losses with wheat as a cover crop (especially when terminated late) than a no-cover crop reflecting increased soil volumetric water content during the corn growing season. Overall, based on our results, a first step is to ensure a continuous no-till practice in corn-soybean systems with proper N fertilization. Other practices require further assessments. Our results also indicate that quantifying CO_2-C equivalent inputs and outputs is difficult and tradeoffs between these must be considered for C credits. These results call for unified North Central trials to assess the effects of these diverse agricultural practices on soil C sequestration and C crediting and to find best solutions for mitigating climate change.

INTRODUCTION

A carbon (C) credit is the attribution of net CO_2-C equivalent which can be used to decrease climate forcing through a given practice or farming system for a given unit time. Carbon credits allow industries to purchase C that is produced on a farm (i.e., offsets). Carbon can be captured in two ways; (i) by capturing and reducing greenhouse gasses (on a CO_2-C equivalent basis), and/or (ii) by increasing soil organic C stocks[1]. Therefore, to enable C credits in the agricultural sector, we must measure and track CO_2-C equivalent flow in and out of the soil[2]. Management practices that are in line with C increase in soil range from proper nitrogen (N) fertilization to a shift from tillage-based to no-till systems and increasing C inputs via cover crops (with different management scenarios like late termination), manure, and many other sources.

An important approach to increase soil C is to increase net primary productivity (NPP)[2]. Optimizing cash crop growth and production requires proper N fertilization to ensure no N limitation[3]. In a long-term corn (*Zea mays* L.)-corn and corn-soybean (*Glycine max* L.) trial, Poffenbarger et al. found reported that at optimum N rate, SOC maximized which was mainly due to optimization of corn grain yield and returned crop residue[4]. In a recent 10-yr trial however, Bailey indicated that when soil N supplying capacity is high, at limited N rate, crop residue return could be similar to the optimum N rates and thus, SOC in the soil remained similar among N rates[5].

Shifting from tillage practices including moldboard plow and chisel-disk to no-till has been shown to increase SOC over time. This is mainly due to increase in soil C inputs than C outputs and thus, positive C balances[6]. Weidhuner et al.[7] reported an increase in soil SOC in a long-term tillage trial which was in line with a recent meta-analysis report by Liptzin et al.[8] suggesting decreased tillage increased SOC and such increase was more pronounced at sites with higher precipitation.

Cover crops especially in no-till systems have the potential to increase SOC over time. The increase in SOC by cover crops especially in no-till systems follows the similar greater N inputs than outputs scenario where no-till decreases C loss and cover crops increase the C inputs leading to positive net C balances. Liptzin et al.[8] suggested that SOC responded to integrating cover crops into cropping systems and that increase in soil C was higher in no-till systems. Literature suggests that a reasonable C input (0.9 tons ac^{-1}) from cover crops over at least a five-yr span is needed significantly increase SOC in top 12” of soil[9].

In this paper, we assessed trials in Southern Illinois and identified whether conservation practices could increase the SOC in long- and short-term trials and if nitrous oxide emissions could be decrease or increase in some of those studies which could influence C crediting scenarios.

MATERIALS AND METHODS

Several trials were conducted in Southern Illinois and ranged from short term studies (three to five years) to a long-term (49-50 years) tillage by fertility trial (currently in 52nd year).

Trial 1 (Tillage by Fertility Trial)

A long-term tillage by fertility trial field experiment was initiated in 1970 at the Belleville Research Center in Belleville, IL (38.519179° N, 89.843248° W). The randomized split-plot trial is located on a somewhat-poorly drained Bethalto silt loam (fine-silty, mixed, superactive, mesic Udollic Endoaqualf). Tillage treatments were laid out in a Randomized Complete Block Design. Four tillage treatments, applied at the same time were (i) MP using moldboard plow to 8-12”; (ii) CD using spring disking to 6” followed by chisel-point cultivator to 8”; (iii) AT which was 2-yr of no-till followed by a moldboard plow for 1 yr.; and (iv) continuous NT without disturbance of the soil excluding a standard planter. The main experimental design is split-plot with tillage as main plots (randomized strips) and five fertility treatments as subplots (randomized within tillage strips). Each tillage treatment was repeated four times. Soil samples were collected in 2019 (49 years into the trial) for soil C assessment. Protocols for the soil analysis are reported in Weidhuner et al.[7]. Soil nitrous oxide emission during the corn years was also assessed to calculate CO_2-C equivalent of nitrous oxide. The protocol for nitrous oxide measurement and analysis are reported in Weidhuner et al.[10].

Trial 2 (Manure by Winter Rye Double Crop)

A three-yr trial was conducted from 2019 to 2022 in a dairy farm located in Breese IL (38.60888° N, 89.9579706° W). The soil was Oconee-Darmstadt silt loam (fine, smectitic, mesic Udollic Endoaqualfs). Treatments were (1) corn for silage fertilized with 180 lbs UAN ac^{-1}; (2) phosphorus-removal-based liquid manure (12900 gal ac^{-1}) plus supplemental N fertilizer; (3) Nitrogen-based liquid manure (16500 gal ac^{-1}); (4) phosphorus-removal-based liquid manure (12900 gal ac^{-1}) plus supplemental N fertilizer and double cropping with winter rye (*Secale cereale* L.); (5) Nitrogen-based liquid manure (16500 gal ac^{-1}) double cropping with winter rye. The treatments were laid out in a Randomized Complete Block Design with four replicates. Soil samples were collected in 2019 and 2022 for soil C assessment. Protocols for the soil analysis are reported in Weidhuner et al.[7].

Trial 3 (Precision Cover Cropping in a Corn-Soybean Rotation)

A five-yr trial was conducted from 2016 to 2021 at a farm in Springerton, IL (38.16598° N, 88.41070° W). The soil was Edwardsville silt loam (fine-silty, mixed, superactive, mesic Aquic Argiudolls). The trial is in corn-soybean rotation with three treatments including (1) a no-cover crop control (NOCC); (2) NOCC on the corn row, vetch on the middle row, and winter rye on the side row (NOVR); and (3) Oat and radishes on the corn row, vetch on the middle row, and winter rye on the side row (ORVR). Figure 1 shows an example of precision planted cover crops. Similar soil indicators to Weidhuner et al.[7] including deep core (0-36”) SOC and bulk density were collected and measured in 2021.

Figure 1. Example of a no-cover crop control (A), when corn row is skipped (B), and oat on the corn row with cover crop mixtures (C); Courtesy of John Pike.

Trial 4 (Wheat Cover Cropping in a Corn-Soybean Rotation)

A five-yr trial was conducted from 2017 to 2022 at the Agriculture Research Center (ARC) in Carbondale, IL (37.75° N, 89.06° W). The dominant soil type was Weir silt loam (fine, smectitic, mesic Typic Endoaqualfs). The trial lay out was split plot in a Randomized Complete Block Design with four replicates. Treatments were (1) a no-cover crop control (NOCC); (2) early termination of winter wheat as CC (ET); late-termination of wheat as CC (LT); and removing winter wheat residue (RR). During the corn years a split application of 130 lbs ac^{-1} at planting plus a sidedress rate of 100 lbs ac^{-1} was applied to corn (230 lbs N ac^{-1}). In this trial, we measured soil nitrous oxide emissions during the corn years (2019-2020) and (2020-2021). All sample handling and analyses were similar to those reported in Weidhuner et al.[10].

RESULTS and DISCUSSION

Trial 1 (Tillage by Fertility Trial)

Aggregate associated C and C by depth

Soil C in the NT system were higher in both large (2-4.75 mm) and small (0.25-2 mm) aggregate sizes than other tillage treatments. In small aggregates (0.25-2 mm) soil C was found to be 17.5 for NT, 12.9 for CD, 11.5 for AT, and 11.6 g kg^{-1} for MP (Fig. 2a).

In large aggregates soil C was 17.5 for NT, 11.7 for CD, 10.7 for AT, and 11.9 g kg^{-1} for MP (Fig. 3b). These results for AT indicate that disturbing the soil after two years of NT will reduce the soil C and N benefits that could be achieved by continuous NT practices. Less soil disturbance protects and accumulates C due to the formation of micro and macro-aggregates. There was a positive linear relation between C concentrations in dry small aggregates (0.25-2 mm) and C concentrations in water stable aggregates (r^2 = 0.57, $P \leq 0.01$) at 0.25-2 mm sizes (data not shown). Slower decomposition of crop residues in the surface of NT was likely the reason for greater percentage of water stable aggregates in NT. While water stable aggregates are related to the amount of SOC, greater C additions from increased crop residues increase the formation of soil aggregates.

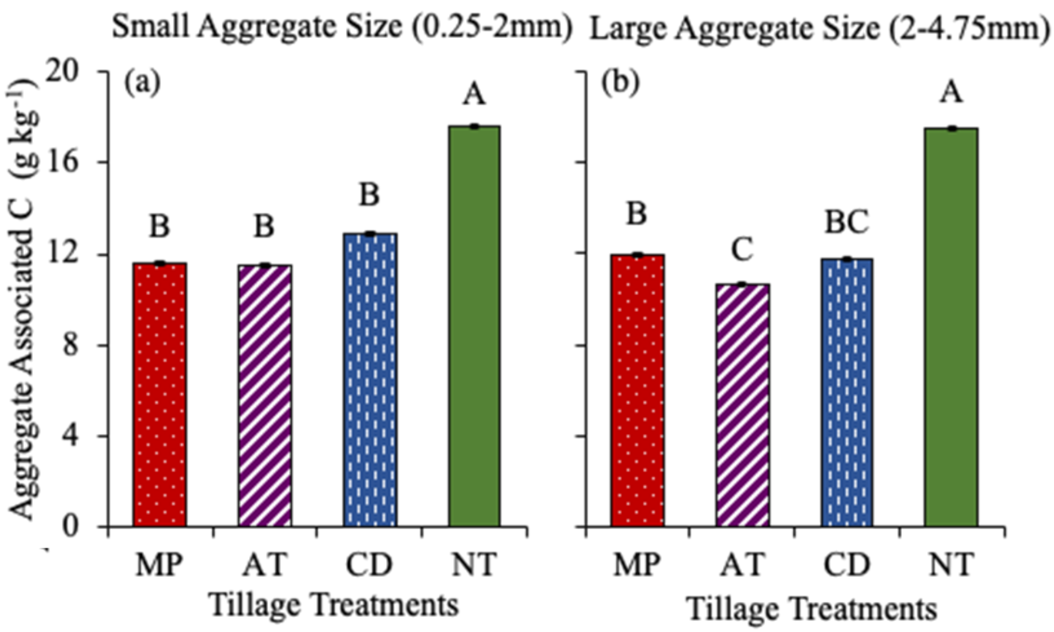

Figure 2. Tillage effect on dry, small (a) and large (b) aggregate associated C after 49 years. Yearly tillage treatments include: moldboard plow (MP); 2-yr no-till and 1 yr MP (AT); chisel-disk (CD); and no-till (NT). Similar letters indicate no statistical significance at 0.05.

Percent SOC by depth was much higher in the NT treatment at 0-2" (19.4 g kg^{-1}) than CD (12.3 g kg^{-1}), MP (10.7 g kg^{-1}) and AT (10.5 g kg^{-1}) (Fig. 3). This indicated that only two years of no-till followed by tillage (AT) does not benefit C build-up in the 0-2" depth compared to continuous MP treatment. All treatments had similar SOC beyond topsoil (0-2") which indicated that NT benefits of soil C were limited to the topsoil and additional practices such as inclusion of cover crops are needed to increase SOC.

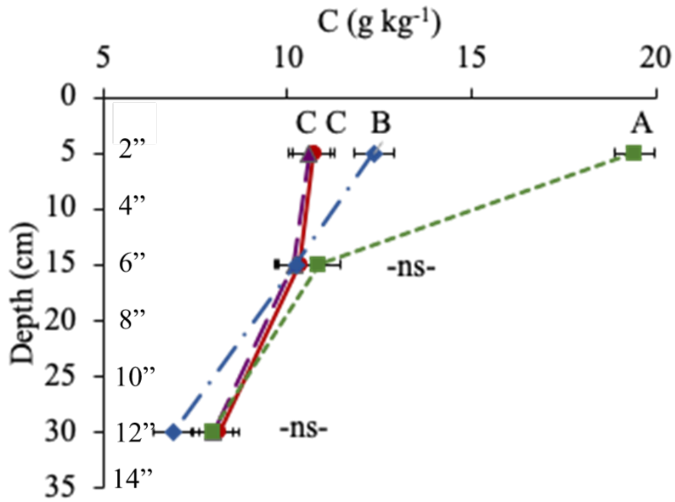

Figure 3. Tillage effect SOC in top 12” of soil after 49 years. Yearly tillage treatments include: moldboard plow (MP); 2-yr no-till and 1 yr MP (AT); chisel-disk (CD); and no-till (NT). Similar letters indicate no statistical significance at 0.05.

Trial 2 (Manure by Winter Rye Double Crop)

Coarse (> 0.25 mm) and light fractions of soil organic matter (0.053-0.25 mm) were higher in double cropped treatments (INJPCC and INJNCC) at 0-2” depth but at a depth beyond 0-2”, winter rye did not increase soil organic matter fractions (Figure 4) perhaps reflecting on C inputs that is higher in 0-2” than 2-8” (data not shown; Burkett et al. unpublished data).

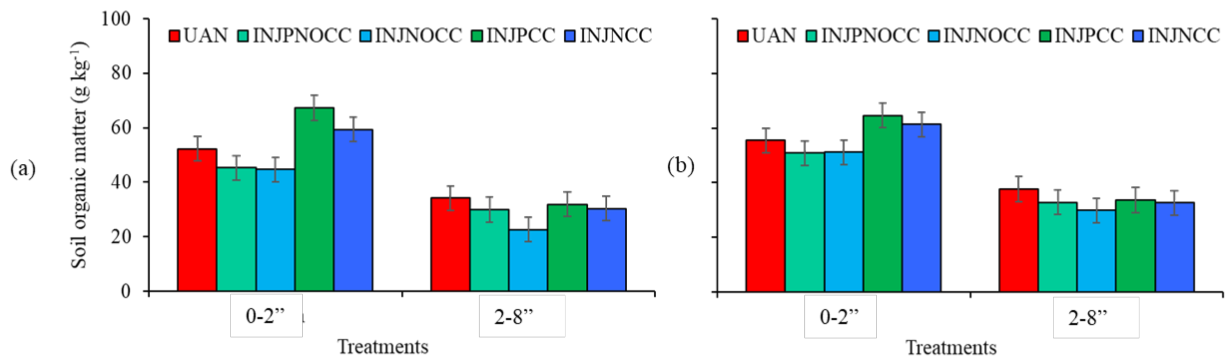

Figure 4. Effect of manure and fertilizer management on coarse (a) and light (b) soil organic matter fractions. (1) UAN: corn for silage fertilized with 180 lbs UAN ac^{-1}; (2) INJPNOCC: phosphorus-removal-based liquid manure (12900 gal ac^{-1}) plus supplemental N fertilizer; (3) INJNOCC: Nitrogen-based liquid manure (16500 gal ac^{-1}); (4) INJPCC: phosphorus-removal-based liquid manure (12900 gal ac^{-1}) plus supplemental N fertilizer and double cropping with winter rye (*Secale cereale* L.); (5) INJNCC: Nitrogen-based liquid manure (16500 gal ac^{-1}) double cropping with winter rye. Bars represent standard error.

Trial 3 (Precision Cover Cropping in a Corn-Soybean Rotation)

Results of a five-yr trial indicated that integrating NOVR and ORVR increased SOC stocks only in the top 2” of soil (data not shown). These findings are in line with our trial 2 that suggest greater root inputs are needed at lower soil depths to increase SOC concentration and stocks. Blaco-Canqui[9] suggested that delaying the termination of cover crops could accumulate more C and therefore, increase C inputs in agroecosystems. This led to our trial 4 to evaluate whether late termination of cover crops result in any tradeoffs in nitrous oxide emissions.

Trial 4 (Wheat Cover Cropping in a Corn-Soybean Rotation)

Assessing C inputs between early vs. late terminated wheat cover crop indicated that C accumulation is highly related to biomass accumulation and that early wheat termination (ET) had 2805 and 2661 lbs ac^{-1} less biomass than a late-terminated winter wheat treatment (LT) in 2020 and 2021, respectively (data not shown). Our data also suggest that inclusion of winter wheat and delaying the termination resulted in increased soil volumetric water content which played a key role in greater nitrous oxide loss in LT than the no-cover crop treatment. Averaged over the two-yrs, LT produced 825 lbs ac^{-1} more CO_2-C than the no-cover crop control (data not shown) suggesting a need to incorporate N_2O losses in the C crediting systems.

CONCLUSIONS

Overall, based on our results, we conclude that a first step is to ensure a continuous no-till practice in corn-soybean systems with proper N fertilization. Other practices require further assessments. Our results also indicate that quantifying CO_2-C equivalent inputs and outputs is difficult and tradeoffs between these must be considered for C credits. For example, a practice such as late termination of cover crops could add more C but increase nitrous oxide emissions and result in tradeoffs in gain and loss of C. These results call for unified North Central trials to assess the effects of these diverse agricultural practices on soil C sequestration and C crediting and to find best solutions for mitigating climate change.

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