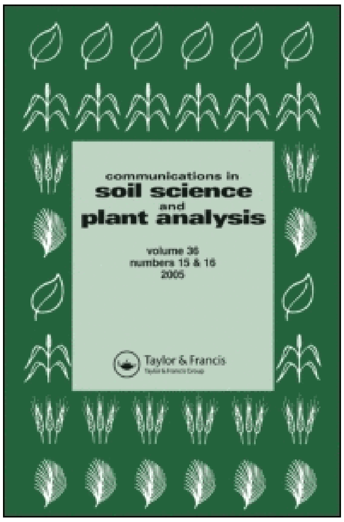

Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597241

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To cite this Article Mullen, R. W., Thomason, W. E. and Raun, W. R.(1999) 'Estimated increase in atmospheric carbon dioxide due to worldwide decrease in soil organic matter', Communications in Soil Science and Plant Analysis, 30: 11, 1713 — 1719

To link to this Article: DOI: 10.1080/00103629909370324

URL: http://dx.doi.org/10.1080/00103629909370324

COMMUN. SOIL SCI. PLANT ANAL., 30(11&12), 1713–1719 (1999)

Estimated Increase in Atmospheric Carbon Dioxide Due to Worldwide Decrease in Soil Organic Matter[1]

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ABSTRACT

Atmospheric carbon dioxide (CO_2) levels have risen from 260 to 340 mg kg^{-1} (ppm) over the last 150 years, largely attributed to worldwide industrialization and continual change in land use. Conventional tillage practices have also added to the atmospheric CO_2 pool via the accelerated decay of soil organic matter. The objective of this work was to derive a simple estimate of CO_2 in the atmosphere that could be attributed to tillage and decomposition of soil organic matter from arable land. The percent increase in atmospheric CO_2 due to a worldwide decrease of 3, 2, and 1% in soil organic matter of arable land was estimated to be 20 mg kg^{-1}, 12.5 mg kg^{-1}, and 5 mg kg^{-1}, respectively. This decrease in soil organic matter would have accounted for 6 to 25% of the 80 mg kg^{-1} (340-260) increase in atmospheric CO_2 over the last 150 years.

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[1]Contribution from the Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, OK 74078. Published with approval of the Director, Oklahoma Agricultural Experiment Station.
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INTRODUCTION

Atmospheric CO_2 has increased over the last 150 years from 260 to 340 mg kg^{-1} (Wittwer, 1985 and Wallace, 1990), and is reported to be the cause of a 0.5°C increase in global temperature (Perry, 1983). The increasing atmospheric CO_2 level is due to the industrial burning of fossil fuels (Wallace, 1990) and changing land use (deforestation and cultivation) (Lal et al., 1997). The amount of carbon (C) released by industrial processes and changing land use was estimated to be 5.0×10^{12} and 2.0×10^{12} kg C yr^{-1}, respectively (Lal et al., 1997).

Scientists believe that by selecting proper soil management practices, soil organic matter can be used as a C sink, decreasing the atmospheric CO_2 pool. Carbon can be sequestered by the crop-root system and redistributed deeper into the soil profile, making it less likely to be converted back to CO_2 (Reicosky and Lindstrom, 1993). Consumption and decay of food and plants naturally recycles C from crops and trees through the ecosystem with C being temporarily stored in soil organic matter (Reicosky, 1995).

Conventional tillage practices (moldboard plow, disk harrow, chisel plow, etc.) can release C as CO_2 via the accelerated decomposition of soil organic matter (Reicosky and Lindstrom, 1993). Reicosky and Lindstrom (1993) also reported that 19 days after tilling wheat stubble in the fall, more organic C was decomposed than was produced all year in wheat straw and roots, while untilled plots lost five times less CO_2. Reicosky (1997) reported that when the soil is tilled, a burst of CO_2 is released to the atmosphere; oxygen (O_2) enters the soil and enhances the organic matter decomposition, releasing more C as CO_2. The objective of this work was to derive a simple estimate of CO_2 in the atmosphere that could be attributed to tillage and decomposition of soil organic matter.

DISCUSSION

Soil organic matter has declined in agricultural soils largely due to cultivation (Boman et al., 1996; Reicosky and Lindstrom, 1994). Untilled upland soils contain between 1 and 6% organic matter (Troeh and Thompson, 1993), and virgin prairie soils can have as much as 8% (Reicosky and Lindstrom, 1994). Estimates on the amount of soil organic matter lost since initial cultivation range from as low as 20% (Schlesinger, 1986) to as high as 54% (Smith et al., 1997). The amount of soil organic matter lost is dependent on the quantity present prior to cultivation, the tillage system, and the number of years the soil was tilled. Native prairie soils in the Central Great Plains contained 4% soil organic matter in the 1800s, and after more than 150 years of cultivation that number is now less than 1% (Boman et al., 1996). For this work, a 3% loss in organic matter from arable soils worldwide will be assumed. Assuming that organic C = [(% organic matter—0.35)/1.80] (Ranney, 1969) and 1 ha of soil (15-cm deep) with a bulk density of 1.49 Mg m^{-3} weighs approximately 2.235×10^{6} kg, the net loss in organic C would be 3.285×10^{4}

TABLE 1. Components used for calculating increased atmospheric CO_2 due to worldwide decreases in soil organic matter, assuming a decrease from 4% to 1% over the past 150 years on worldwide arable land.

Component	Value	Reference and/or calculation
Weight of 1 hectare of soil to a depth of 15 cm (soil bulk density of 1.49 Mg m^{-3})	2,235,000 kg ha^{-1}	10,000 m^2 * 1.49 Mg m^{-3} * 0.15 m
Organic carbon lost	1.47%	Organic carbon=(organic matter - 0.35)/1.8 (Ranney, 1969)
Carbon lost from organic matter per hectare	32,845.5 kg ha^{-1}	2,235,000 kg ha^{-1} * 0.0147
Arable land in the world	1,381,917,000 ha	FAO, 1996
Total carbon lost from all arable land in the world	4.55×10^{-13} kg	32,845.5 kg ha^{-1} * 1,381,917,000 ha
Sixty % of carbon lost from organic matter converted to CO_2	2.73×10^{-13} kg	4.55×10^{-13} kg * 0.60 (Brady and Weil, 1996)
Total CO_2 lost to the atmosphere	1.00×10^{-14} kg	2.73×10^{-13} kg * 3.67 [(44 g mol^{-1} CO_2)/(12 g mol^{-1} C)]
Mass of earth's atmosphere	5.00×10^{-13} kg	Wild, 1993
Change in atmospheric CO_2	0.008%	80 mg kg^{-1} (Lal et al., 1997) change in CO_2/10,000
Increase in atmospheric	4.00×10^{-14} kg	5.00×10^{18} kg * 0.00008
Change in atmospheric CO_2 due to organic matter decay	25.03%	1.00×10^{14} kg/400×10^{14} kg
Increase in atmospheric CO_2 due to 3% loss of organic matter worldwide	20.03 mg kg^{-1}	80 mg kg^{-1} * 0.2503

kg C ha^{-1}, if organic matter decreased by 3%. If all arable land worldwide [1.382x109 ha (FAO, 1998)] lost 3% organic matter over the past 150 years, a total of 4.55×10^{13} kg organic C would be released to the atmosphere. One mole of CO_2 weighs 44 g while one mole of C weighs 12 g. Therefore, the amount of CO_2 released to the atmosphere would be 3.67 times the amount of organic C lost. Only 60% of C is actually converted to CO_2 (Brady and Weil, 1996), so the total amount of CO_2 released worldwide due to a 3% organic matter loss would be 1.00 x 10^{14} kg. Atmospheric CO_2 has increased from 260 to 340 ppm over the last 150 years which translates into an increase in CO_2 concentration of 31%. Multiplying the mass of the earth's atmosphere [5.00 x 10^{18} kg (Wild, 1993)] by the change in CO_2 results in an increase of CO_2 in the atmosphere of 4.00×10^{14} kg over the last 150 years. The amount contributed via soil organic matter decay over the same time period was 1.00×10^{14} kg, thus the increase due to C released from organic matter is 25.03% or 20.03 ppm (Table 1). This value is based on the assumption of a 3% loss of organic matter worldwide. Schlesinger (1984) reported that between 1860 and 1960 3.60×10^{13} kg C was lost from agricultural soils, and later (Schlesinger 1995) determined the current rate of loss to be 8.00×10^{11} kg C yr^{-1}. Based on these values, arable lands worldwide would have lost 4.22% soil organic matter over the last 148 years. The increase due to C lost from organic matter would be 36.55% or 29.24 mg kg^{-1} (Table 2). One possible explanation for the difference between the two values could be the C released from deforestation, which was not considered in this work.

Methods to Decrease Atmospheric Carbon Dioxide

One option for increasing organic matter is conservation tillage. Changing to conservation tillage practices could convert many soils from sources of atmospheric C to C sinks (Reicosky and Lindstrom, 1993). Increasing the use of conservation tillage from 25 to 75% of total croplands would substantially enlarge the soil C pool (Kern and Johnson, 1991). A report by Smith (1995) noted that widespread adoption of conservation tillage could offset as much as 16% of worldwide fossil fuel emissions. Some estimates show that as much as 4.00×10^{11} to 8.00×10^{11} kg C yr^{-1} could be sequestered globally using conservation tillage systems (IPCC, 1995). Reicosky et al. (1995) reported a 260%, 160%, and 100% increase in soil organic matter in the surface depths 0-1.27 cm, 1.27-2.54 cm, and 2.54-5.08 cm, respectively, under conservation tillage in a long-term (>10 years) study. Increases in soil organic matter of 0.25% over 10 years in the top 30 cm of soil have also been reported for no-till corn production (Blevins et al., 1983). Conservation tillage not only increases organic matter it also benefits farmers by providing higher quality soil, better yields, and improved sustainability (Fawcett, 1996). It is important to note that increases in soil organic C can also be achieved via the application of high nitrogen (N) rates in grain crop production systems where straw yields are annually high (Raun et al., 1998).

TABLE 2. Components used for calculating increased atmospheric CO_2 due to worldwide decreases in soil organic matter, using Schlesinger (1984, 1985) data.

Component	Value	Reference and/or calculation
Carbon lost from organic	48,052.5 kg	6.64×10^{13} kg (Schlesinger, 1984, 1995)/1,318,917,000 ha
Organic carbon lost	2.15%	48,052.5 kg / 2,235,000,000
Organic carbon matter lost	4.22%	(0.0215 * 180) + 0.35 (Ranney, 1969)
Total carbon lost from world	6.64×10^{13} kg	Schlesinger, 1984, 1995: 3.6×10^{13} kg + (38 yrs * 8.00×10^{11} kg)
Sixty % of carbon lost from organic matter converted to CO_2	3.984×10^{13} kg Weil, 1996)	6.64×10^{13} kg * 0.60 (Brady and
Total CO_2 lost to atmosphere	1.462×10^{14} kg	3.984×10^{13} kg * 3.67
Change in atmospheric CO_2 due to organic matter decay	36.55%	1.462×10^{14} kg/4.00×10^{14} kg
Increase in atmospheric CO_2 due to 3% loss of organic matter worldwide	29.24 mg kg^{-1}	80 mg kg^{-1} * 0.3655

CONCLUSIONS

Atmospheric CO_2 levels have increased 80 mg kg^{-1} over the last 150 years. The continuous tillage of arable land worldwide is likely responsible for 6 to 25% of the increase in atmospheric CO_2 due to decreased soil organic matter. However, it should be noted that the continued use of conservation tillage can increase soil organic matter by as much as 260%. Increasing soil organic matter increases water-holding capacity, decreases erosion, improves sustainability, and increases overall fertility of the soil. The incorporation of a low-till or no-till management system could simultaneously increase soil productivity by increasing organic matter while acting as a sink for atmospheric CO_2.

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