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Tillage and wind effects on soil CO_2 concentrations in muck soils

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Abstract

Rising atmospheric carbon dioxide (CO_2) concentrations from agricultural activities prompted the need to quantify greenhouse gas emissions to better understand carbon (C) cycling and its role in environmental quality. The specific objective of this work was to determine the effect of no-tillage, deep plowing and wind speeds on the soil CO_2 concentration in muck (organic) soils of the Florida Everglades. Miniature infrared gas analyzers were installed at 30 cm and recorded every 15 min in muck soil plowed with the Harrell Switch Plow (HSP) to 41 cm and in soil Not Tilled (NT), i.e., not plowed in last 9 months. The soil CO_2 concentration exhibited temporal dynamics independent of barometric pressure fluctuations. Loosening the soil resulted in a very rapid decline in CO_2 concentration as a result of ‘‘wind-induced’’ gas exchange from the soil surface. Higher wind speeds during mid-day resulted in a more rapid loss of CO_2 from the HSP than from the NT plots. The subtle trend in the NT plots was similar, but lower in magnitude. Tillage-induced change in soil air porosity enabled wind speed to affect the gas exchange and soil CO_2 concentration at 30 cm, literally drawing the CO_2 out of the soil resulting in a rapid decline in the CO_2 concentration, indicating more rapid soil carbon loss with tillage. At the end of the study, CO_2 concentrations in the NT plots averaged about 3.3% while that in the plowed plots was about 1.4%. Wind and associated aerodynamic pressure fluctuations affect gas exchange from soils, especially tilled muck soils with low bulk densities and high soil air porosity following tillage.
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Keywords: Organic soils; Soil subsidence; Carbon dioxide fluxes; Soil carbon; Aerodynamic pressure effects; Soil air porosity

1. Introduction

The increasing importance of global climate change issues reflects the need for direct measurements to quantify greenhouse gas emissions, especially carbon dioxide (CO_2), influenced by agricultural management practices (Houghton et al., 1983; Schlesinger, 1985). Understanding these processes will lead to enhanced soil management techniques and new technology for increased food production efficiency with a minimum impact on environmental quality and greenhouse gas emissions (Paustian et al., 1997; Lal et al., 1998). Studies involving tillage methods indicate major gaseous losses of carbon (C) immediately after tillage (Ellert and Janzen, 1999; Reicosky and Lindstrom, 1993; Rochette and Angers, 1999). The interaction of

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combined meteorological and tillage impacts on soil gas fluxes is creating a new awareness of agricultural impacts.

Diffusion has long been considered the dominant process by which trace gases moved from the subsurface source to the soil surface; however, there has been indication that atmospheric pressure fluctuations also might play a role (Kimball, 1983; Nazaroff, 1992; Clarke and Waddington, 1991; Massman et al., 1997; Auer et al., 1996). Takle et al. (2003) measured CO_2 fluxes from the soil surface under conditions of natural and artificial pressure pumping at the soil surface. They showed that pressure changes due to fluctuations in wind speed and direction, interacting with a wind barrier, penetrated to at least 60 cm in bare, nearly dry clay loam soil. Takle et al. (2003) found that the CO_2 fluxes at the surface to be approximately three times as large as would be expected from calculations based on diffusional flux rates, in agreement with Kimball (1973). There is a strong suggestion that diffusion alone is not sufficient to explain the flux of CO_2 from the soil surface, but that increasing the magnitude of the pressure fluctuations will enhance soil CO_2 flux.

Wind and pressure forces were first identified as important determinants of the rate of gas exchange from the tilled soil surface by F.H. King (1891) as cited in Tanner and Simonson (1993). The influence of wind on soil water evaporation has been studied extensively (Hanks and Woodruff, 1958; Benoit and Kirkham, 1963; Scotter and Raats, 1969; Farrell et al., 1966). Increased wind speed increases water vapor transfer from soil through gravel and straw mulches, and is somewhat less effective in vapor transfer through soil mulches. Kimball and Lemon (1971) provided early insights about the effect of wind speed on heptane evaporation and exchange from the soil surface. They concluded that air turbulence increased the transport of water vapor through coarse mulches or through very shallow depths of soil. Kanemasu et al. (1974) and Kimball and Lemon (1971, 1972) showed that pressure deficits of 1 Pa resulted in significant mass flow from soils. The importance of mass flow induced by pressure deficits can be evaluated by determining if the flux from the soil differs for different flow rates of gas through a dynamic chamber as observed by Hanson et al. (1993). Varying the speed of the chamber-mixing fan showed that increased wind speeds up to 0.6 m s^{-1} inside the chamber can enhance the measured flux. They attributed this effect to the disruption of the normal high boundary layer by excessive turbulence. Denmead (1979) used a much smaller-scale chamber for measuring trace gases; a pressure deficit of 100 Pa caused a 10-fold increase in measured N_2O emissions.

Wind and associated pressure effects must always be considered in studies of soil gas exchange. The meteorological techniques for measuring CO_2 fluxes require a critical assumption of mass airflow to analyze high frequency wind fluctuations to quantify turbulent transport (Baldochi et al., 1988). Evidence suggests that convection can contribute, in certain circumstances following intensive tillage, to gas exchange and soil aeration, particularly at shallow depths and in soils with tillage-induced large pores (Renault et al., 1998). Kanemasu et al. (1974), Nakayama and Kimball (1988) and Nakayama (1990) showed that "blowing" air (positive air pressure) through a chamber gives flux results very different than "sucking" the air (negative air pressure) through the same chamber over the same soil. Nakayama and Kimball (1988) showed a 50–80% reduction in soil CO_2 flux at pressures in the range of 1–4 Pa above ambient. Apparently, the aerodynamic forces that yield net positive or negative pressures will affect the magnitude of the flux based on the wind speed and direction. The tillage-induced change in soil air porosity showed that convection contributes to gas exchange (Reicosky and Lindstrom, 1993).

Soil subsidence and C loss have become concerns for soil resources in the Florida Everglades sugarcane (*Saccharum* ssp.) area as a result of depleting muck (organic) soils. The relationship between land subsidence and drainage of wetland or marsh lands has been studied, but work has concentrated on laboratory measurements. In the laboratory, soil CO_2 evolution increased with temperature (between 10 °C and 60 °C) and soil organic C content, but decreased with increasing moisture content (Knipling et al., 1970; Volk, 1973; Tate, 1979, 1980a, 1980b). The rate of CO_2 evolution in the laboratory, a measure of soil C loss, agreed qualitatively with the rates of field measured subsidence and this suggests most subsidence in the Florida organic soils was a result of biochemical oxidation (Stevens and Stewart, 1976). Direct field measurements of gas exchange may lead to improved management practices and decreased C loss from these fragile soils. This cooperative study was developed with the broad goal to determine the short-term effects of various tillage methods on the soil oxidation potentials and evolution of CO_2 (soil C loss) from the intensively tilled muck soils used for sugarcane production in the Florida Everglades (Morris et al., 2004; Gesch et al., 2007). As part of a larger study, the specific objective of this work was to determine the effect of Not Tilled (NT), tillage with a Harrell Switch