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The impacts of direct seeding into mulch on the CO₂ mitigation

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Abstract

The development of agricultural systems with low input of energy could help to reduce agricultural greenhouse gas emissions. Tillage consumes nearby 50% of the direct energy in conventional tillage system (CT). Current agricultural policies seek to promote crop production systems that minimize fossil energy input for a high level of output. One possible solution can be the conservation tillage, where tillage will be reduced or even completely eliminated such as direct seeding into mulch (DSM). Conservation tillage can both reduce diesel consumption and sequester C into soil, resulting CO₂ mitigation. The present study assessed the impact of DSM on CO₂ mitigation compared with CT. An experimental study has been carried out at Lavalette experimental station in Montpellier in south-east France. The diesel consumption for field operations was measured in both DSM and CT. Soil C concentration was measured too. CO₂ emission was calculated considering CO₂ emission from diesel combustion and organic carbon variations in soil during the field trial. The results showed that using DSM resulted in less diesel consumption compared with CT (about 50%). Furthermore, DSM did increase C content of soil (1671 kg/year/ha). The consequence of these two positive impacts of DSM ended up in a considerable CO₂ mitigation.

Keywords: Direct seeding into mulch, CO₂ emission, conventional tillage

Introduction

Demands to producing more and more food, feed, and renewable energies are strongly increasing in agricultural sector, whereas the accessibility of arable land and fossil energy resources are limited (Kelm et al., 2003; Deike et al., 2008). These growing demands for services are menacing the quality and the natural regulating functions of limited resources on which sustainability depends (Bindraban et al., 2000; Dumanski and Pieri, 2000; Deike et al., 2008). Hence, sustainable farming systems should gain high production while minimizing negative environmental impacts.

We need relevant indicators to assess environmental impacts of different agricultural systems. Agri-environmental indicators should be clear, straightforward, concise and, furthermore, well-founded regarding ecological issues and applicable in rapid evaluations (Hülsbergen, 2003). The necessary data for assessing should be as far as possible derivable from regular farm records. Several studies have demonstrated that the quantity of fossil energy input is closely related to the release of carbon dioxide (CO₂) from a specific agricultural system (Dyer and Desjardin, 2003; Tzilivakis et al., 2005; Deike et al., 2008). Energy use in agriculture can be divided into two components: (1) indirect consumption, necessary for production and delivery of farm inputs e.g. fertilizers, pesticides, etc. (2) direct consumption of diesel in the various cropping operations (Borin et al., 1997). The direct energy used is around 30-40% of total energy consumption (Biondi et al., 1989). Tillage is one of the operations that consume 55-65% of the direct energy in arable production (Pelizzi et al., 1988). Hence the development of conservation tillage systems such as direct seeding

into mulch (DSM) may be one possibility to save energy (Pimentel and Pimentel, 1996; Dalgaard et al. 2001; Khaledian et al., 2009).

Conventional tillage (CT) comprises all tillage types that leave less than 15% of crop residues on the soil surface after planting the next crop, and includes ploughing. But in DSM, the soil is left undisturbed from harvest to planting with 30% or more residues remaining after sowing (El Titi, 2002). Planting is accomplished in a narrow seedbed with a specific direct-seeding machine. DSM contributes to environmental conservation as well as enhanced and sustained agricultural production (Derpsch, 2001). According to Kern and Johnson (1993) the greater organic matter content in the soil is linked to less mineralization and consequently less release of CO₂ into the atmosphere. In this sense, until the soil reaches a new equilibrium, the positive impact of DSM can be both a reduction in CO₂ emissions owing to the use of less fossil energy and a greater accumulation of C in the soil as a consequence of reduced mineralization of the organic matter (Balesdent et al., 1990; Reicosky and Lindstrom, 1993; Franzluebbers et al., 1994; Ismail et al., 1994; Borin et al., 1997).

EU imports almost of its fossil energy needs so a rational use of energy in agricultural sector contributes towards reducing its dependence and also helps limit production costs and negative environmental impacts. The sources of energy currently used for manufacturing farm inputs and running machinery are mainly of fossil origin. Fossil energy sources have continued to increase their importance as energy input for society since the introduction of steam engines. In recent decades, oil has become, by far, the most important source of energy applied, directly or indirectly, in all economic sectors (Hall et al., 1986; Geveer et al., 1991). Their use causes a one-way transfer of carbon (C) from the geosphere to the atmosphere in the form of CO₂, CH₄, and other greenhouse gases, contributing to the 'greenhouse effect' in the atmosphere (Borin et al., 1997).

The main problem with the increasing dependency of food production on fossil energy is related to the fact that the rate of consumption of fossil energy is certainly faster than that of its production (Martinez-Alier, 1987). This implies that current agricultural techniques are unsustainable in the long term, since present consumption of fossil energy has the effect of reducing energy accessibility for future generations. Moreover, alternative energy sources that could be discovered in the future may not have the same convenient characteristics of oil (Conforti and Giampietro, 1997).

Although some works have been done to date, more studies need to be conducted to ascertain the effects of DSM on the environment protection. The purpose of this study was to determine the impacts of DSM on the CO₂ mitigation compared with CT in south-east France. This topic was identified as being of importance to determine whether DSM is a reliable alternative for CT in south-east France regarding environment protection.

Material and methods

An experimental study has been carried out at Lavalette experimental station of the Cemagref Institute (43° 40'N, 3° 50'E, altitude 30 m) in Montpellier in south-east France to determine CO₂ mitigation of DSM compared with CT system. The average annual rainfall is 789 mm/year (a 17-year average). The annual evapotranspiration calculated by the Penman equation exceeds annual rainfall under this Mediterranean climate (859 mm/year). Those climate data were monitored at a weather station situated in the experimental station. Some climatic characteristics of Lavalette station are presented in Table 1.

Table 1

According to the USDA soil classification (Hillel, 1980); the soil under the CT and DSM plots belongs to the loamy soil category. The soil is an Inceptisols related to USDA soil taxonomy. Some physical and chemical properties of the soil are given in Table 2.

Table 2

In CT plots, plough, disc harrow, harrow, and seeder were used in the tillage sequence whereas in DSM plots just a specific direct-seeding machine (SEMEATO[®]) was employed.

Each season the cover crop of DSM system was destroyed by glyphosat approximately two weeks before sowing the main crop in CT and DSM. The crop rotation in the form of cover crop in DSM as well as main crop in CT and DSM is presented in Table 3. After a 4-year study on summer crops i.e. corn (*Zea mays L.*) and sorghum (*Sorghum bicolor L. Moench*), durum wheat (*Triticum turgidum L. var durum*) was sown for the two cropping seasons i.e. 2004/2005 and 2005/2006. For these two seasons there were not any cover crop in DSM, but there were enough residues on the soil surface to form mulch. For the first season after sorghum harvest in September and before sowing in November, we had not enough time to have a cover crop i.e. just one month and for the second season there was a flood between harvest and sowing and we could not have a cover crop too.

In CT plots, primary tillage with disc harrow was done to chop and bury the residue. Secondary tillage with plough was performed afterwards. Depth of the tillage was 25 cm in average. By using a harrow, seedbed was prepared and crop sowing was performed by a seeder. In DSM plots crop sowing, as well as cover crop, was performed with the specific seeder in the same time as in CT. The agronomic practices and the use of plant protection agents were in accordance with local practices, official recommendations and expert advice.

Fertilizers amount are applied in order to fully satisfy plant requirement as soon as N, P, K soil profiles i.e. the amount of those nutrients in the maximum root depth, were established just before sowing.

The goal was to mimic as close as possible the conditions of production in commercial farms. Hence, farm scale equipments were fixed and repeated on the same plot during the experiment period. A HI-955-XL tractor with 70 kW (kilowatt) was used in this experiment. There was not any significant slope in all plots. The equipments used in this study were neither recent nor worn. The necessary maintenances were done by technicians e.g. the replacement of filters. The diesel consumption of each field operations was determined by measuring the diesel tank reserve of tractor before and after each field operations with a graduated measuring cylinder.

Table 3

The DSM impact on CO₂ emission was assessed by considering the main variables modified by DSM i.e. diesel consumption and C sequestration. Diesel consumption per hectare was determined as mentioned above. To determine the savings of CO₂ related to diesel combustion (saved CO₂_[diesel]), the following formula was employed:

$$\text{saved CO}_{2[\text{diesel}]} = 3.106 \Delta Q \quad (1)$$

where ΔQ is:

$$\Delta Q = Q_{CT} - Q_{DSM} \quad (2)$$

where, Q_{CT} and Q_{DSM} are the average diesel consumption (kg/ha) in CT and DSM, respectively. In equation (1) the constant of 3.106 is the coefficient of transformation of diesel into CO_2 under optimal engine functioning conditions (Srivastava et al., 1993; Borin et al., 1997).

The soil organic C and dry bulk density were measured at the end of 2007 crop season by collecting undisturbed soil cores at depths of 0-10 and 10-30 cm. CO_2 mitigation related to C sequestration in the soil (stored $CO_{2[soil]}$) was calculated as in Borin et al. (1997). Using Walkley and Black method, soil organic C concentration was determined. From soil organic C and dry bulk density, the soil organic C content in CT and DSM in both 0-10 and 10-30 cm per hectare was calculated using equation (3):

$$C=100 C' Bd \quad (3)$$

where C is soil organic C content (Mg/ha); C' is soil organic C concentration (g/hg), B is dry bulk density (Mg/m³), d is depth (m) of sampling. The difference in the average C content in the 0-30 cm layer in CT and DSM at the end of 2007 crop season was calculated as:

$$\Delta C = \frac{C_{DSM} - C_{CT}}{7} \quad (4)$$

where ΔC is the yearly average increase of soil organic C content in 0-30 cm soil layer in DSM compared with CT (in Mg/ha/year).

The stored CO_2 in the soil was determined as:

$$\text{stored CO}_{2[\text{soil}]} = \frac{44}{12} \Delta C \quad (5)$$

where 44 and 12 are the molecular weights of CO₂ and C, respectively. The overall impact of DSM (saved CO_{2[total]}) was determined as:

$$\text{saved CO}_{2[\text{total}]} = \text{saved CO}_{2[\text{diesel}]} + \text{stored CO}_{2[\text{soil}]} \quad (6)$$

Results and discussion

A lower diesel consumption and better C sequestration in soil led us to hypothesis that DSM would mitigate CO₂ emission compared with CT. The findings go with that hypothesis.

Table 4 shows the amount of diesel consumption in CT and DSM during 2001-2008 periods. DSM clearly could decrease diesel consumption in all nine crop seasons. It is interesting related to both economic benefits and environmental protection.

Table 4

Table 5 presents soil organic C (g/hg) in CT and DSM in 2000 and 2007. DSM makes C increase in soil, whereas soil C concentration has decreasing in CT from 2000 to 2007.

Table 5

Table 6 summarizes saved CO_{2[diesel]}, stored CO_{2[soil]} and saved CO_{2[total]} in DSM compared with CT. It was assumed that the amount of stored CO_{2[soil]} in DSM in 2008 and 2009 followed the same trend as in 2000-2007. DSM clearly mitigated over than 6 Mg/ha/year CO₂

compared with CT in south-east France. It can be said that DSM has being mitigated 54 Mg/ha in nine years.

Table 6

Further improvements to the soil C content could be achieved with sowing a mix of cover crop producing more organic matter results in increasing soil organic C. DSM can contribute to CO₂ mitigation in two ways first by improving C sequestration in the soil and secondly by reducing of diesel consumption during the crop season. A return to CT after some years of DSM practice could cause an additional release of CO₂ caused by oxidation of the accumulated organic C (Borin et al., 1997).

Conclusions

Shifting from conventional tillage to direct seeding into mulch in south-east France, allowed a substantial CO₂ mitigation. Increasing soil C sequestration and decreasing diesel combustion in DSM results in an important CO₂ mitigation compared with CT. It should be noted that in DSM, the share of C sequestration is more important in CO₂ mitigation than diesel saving. The annual sum of these two CO₂ saving per hectare is equivalent to the annual CO₂ emission from a medium-size car. Decreasing diesel consumption is important not only regarding economic aspect but also related to environmental protection. However the share of agricultural activities related to other sectors such as industrial activities is smaller but it cannot be disregarded.

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