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# Impacts of direct seeding into mulch on the $CO_2$ mitigation

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**Abstract.** The development of agricultural systems with low energy input could help to reduce agricultural greenhouse gas emissions. Tillage consumes nearby 50% of the direct energy in a 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 conservation tillage, in which tillage will be reduced or even completely eliminated, such as direct seeding into mulch (DSM). Conservation tillage can both reduce diesel consumption and sequestrate C into soil, resulting in $CO_2$ mitigation. The present study assessed the impact of DSM on $CO_2$ 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 also measured. $CO_2$ emission was calculated considering $CO_2$ 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 increased C content of soil (1,671 kg. $ha^{-1}$ $year^{-1}$). The consequence of these two positive impacts of DSM resulted in considerable $CO_2$ mitigation.

**Key words:** direct seeding into mulch, $CO_2$ emission, conventional tillage

## INTRODUCTION

Demands to produce more and more food, feed, and renewable energies are strongly increasing in the agricultural sector, whereas the accessibility of arable land and fossil energy resources are limited (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 & Pieri, 2000; Deike et al., 2008). Hence, sustainable farming systems should achieve 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 ($CO_2$) from a specific agricultural system (Dyer & 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 (Dalgaard et al. 2001; Pimentel & Pimentel, 2008; 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 & Johnson (1993) the greater organic matter content in the soil is linked to less mineralization and consequently lower release of $CO_2$ into the atmosphere. In this sense, until the soil reaches a new equilibrium, the positive impact of DSM can be both a reduction in $CO_2$ 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 & Lindstrom, 1993; Franzluebbers et al., 1994; Ismail et al., 1994; Borin et al., 1997).

EU imports almost of its fossil energy so a rational use of energy in the agricultural sector contributes towards reducing its energy 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 an energy input for society ever since the introduction of steam engines. In recent decades, oil has become, by far, the most important source of energy used, directly or indirectly, in all economic sectors (Hall et al., 1986; Gever et al., 1991). Its use causes a one-way transfer of carbon (C) from the geosphere to the atmosphere in the form of $CO_2$, $CH_4$, 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 & Giampietro, 1997).

Although some works have been done to date, more studies need to be conducted to ascertain the effects of DSM on environmental protection. The purpose of this study was to determine the impacts of DSM on the $CO_2$ 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 environmental protection.

## MATERIALS AND METHODS

A study has been carried out at Lavalette experimental station of the Irstea Institute (43° 40’N, 3° 50’E, altitude 30 m) in Montpellier in south-east France to determine $CO_2$ mitigation of DSM compared with CT system. The annual average rainfall is 789 mm year$^{-1}$ (a 17-year average). The annual evapotranspiration calculated by the Penman equation exceeds annual rainfall under this Mediterranean climate (859 mm year$^{-1}$). 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.** Average monthly climatic data, Lavalette meteorological station (1991–2007).

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum temperature, °C | 12 | 14 | 17 | 19 | 23 | 28 | 31 | 30 | 25 | 21 | 16 | 13 |
| Minimum temperature, °C | 2 | 1 | 4 | 7 | 11 | 14 | 16 | 17 | 13 | 11 | 5 | 2 |
| ETo, mm | 12 | 27 | 57 | 86 | 122 | 153 | 108 | 141 | 84 | 42 | 18 | 9 |
| Rainfall, mm | 73 | 41 | 36 | 62 | 46 | 36 | 24 | 50 | 145 | 107 | 80 | 89 |

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.** Some soil physical and chemical properties at Lavalette in 2007 (after 7 years of DSM).

| Treatment | Organic matter (%) | N total (%) | C/N | Clay (%) | Silt (%) | Sand (%) | Texture (in 0–120 cm) |
|---|---|---|---|---|---|---|---|
| CT | 1.34 | 0.08 | 10 | 18 | 47 | 35 | loam |
| DSM | 1.79 | 0.09 | 11.8 | 17 | 39 | 44 | loam |

Besides texture (according to USDA), other soil properties presented here are for 0–30 cm layer.

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

Each season the cover crop of the 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 no cover crops 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, there was not enough time for a cover crop, i.e. just one month, and for the second season, a flood between harvest and sowing prevented a cover crop, as well.

In CT plots, primary tillage used a disc harrow to chop and bury the residue, followed by secondary tillage with plough. Depth of the tillage was 25 cm on average. By using a harrow, the seedbed was prepared and crop sowing was performed by a seeder. In DSM plots crop and cover crop sowing was performed with the specific seeder at 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. Fertilizer amounts were applied in order to fully satisfy plant requirements 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 closely as possible the conditions of production in commercial farms. Hence, farm scale equipment was fixed and repeated on the same plot during the experimental period. A HI-955-XL tractor with 70 kW (kilowatt) was used in this experiment. There was no significant slope in any of the plots. The equipments used in this study were neither recent nor worn. The necessary maintenance was performed by technicians, e.g. the replacement of filters. The diesel consumption of each field operation was determined by measuring the diesel tank reserve of the tractor before and after each field operation with a graduated measuring cylinder. For more details please read Khaledian et al. (2010).

**Table 3.** The crop rotation at Lavalette research station in conventional tillage (CT) and direct seeding into mulch (DSM).

| Season | Cover crop in DSM | Main crop in CT and DSM |
|---|---|---|
| 2000/01 | oat[1] | corn[2] |
| 2001/02 | oat | corn |
| 2002/03 | durum wheat[3] | sorghum[4] |
| 2003/04 | mix of oat and vetch[5] | sorghum |
| 2004/05 | - | durum wheat |
| 2005/06 | - | durum wheat |
| 2006/07 | mix of oat, vetch and rape[6] | corn |
| 2007/08 | mix of oat and vetch | corn |
| 2008/09 | mix of oat and vetch | corn |

[1] *Avena sativa L.*, [2] *Zea mays L.*, [3]*Triticum turgidum L. var durum.*, [4]*Sorghum bicolor L. Moench,*[5]*Vicia sativa L.*, [6]*Brassica napus L.*

The DSM impact on $CO_2$ 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 mitigation of $CO_2$ related to diesel combustion (mitigated $CO_{2[diesel]}$), the following formula was employed:

$$\text{mitigated } CO_{2[diesel]} = 3.106\ dQ \qquad (1)$$

where dQ is:

$$dQ = Q_{CT} - Q_{DSM} \qquad (2)$$

where, $Q_{CT}$ and $Q_{DSM}$ are the average diesel consumption (kg ha$^{-1}$) 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 bulk density were measured at the end of the 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 (sequestrated $CO_{2[soil]}$) was calculated as in Borin et al. (1997). Using Walkeley and Black's method, soil organic C concentration was determined. From soil organic C and 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):

$$SOC = 100\ \text{'SOC'}\rho_b d \qquad (3)$$

where SOC is soil organic C content (Mg ha$^{-1}$); 'SOC' is soil organic C concentration (g hg$^{-1}$), $\rho_b$ is bulk density (Mg m$^{-3}$), 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 the 2007 crop season was calculated as:

$$dC = \frac{SOC_{DSM} - SOC_{CT}}{7} \qquad (4)$$

where dC is the yearly average increase of soil organic C content in 0–30 cm soil layer in DSM compared with CT (in Mg ha$^{-1}$year$^{-1}$).

The stored $CO_2$ in the soil was determined as:

$$\text{sequestrated } CO_{2[soil]} = \frac{44}{12} dC \qquad (5)$$

where 44 and 12 are the molecular weights of $CO_2$ and C, respectively. The overall impact of DSM (saved $CO_{2[total]}$) was determined as:

$$\text{saved } CO_{2[total]} = \text{mitigated } CO_{2[diesel]} + \text{sequestrated } CO_{2[soil]} \qquad (6)$$

## RESULTS AND DISCUSSION

A lower diesel consumption and better C sequestration in soil led us to the hypothesis that DSM would mitigate $CO_2$ emission compared with CT. The findings support that hypothesis.

Table 4 shows the amount of diesel consumption in CT and DSM during 2001–08 periods. DSM clearly could decrease diesel consumption in all nine crop seasons. The results, related to both economic benefits and environmental protection, are interesting.

**Table 4.** Consumption of diesel (lit $ha^{-1}season^{-1}$) in DSM and CT systems.

| Crop season | DSM | CT | Saved diesel in DSM |
|---|---|---|---|
| 2001 | 40 | 86 | 46 |
| 2002 | 44 | 84 | 40 |
| 2003 | 40 | 76 | 36 |
| 2004 | 48 | 76 | 28 |
| 2004/05 | 41 | 83 | 42 |
| 2005/06 | 43 | 79 | 36 |
| 2007 | 40 | 76 | 36 |
| 2008 | 40 | 78 | 38 |
| 2009 | 42 | 80 | 38 |
| Average | 42 | 79.78 | 37.78 |
| S.D.* | 2.69 | 3.77 | 4.94 |
| C.V.* | 0.17 | 0.18 | 0.65 |

* S.D. and C.V. are standard deviation and coefficient of variation, respectively.

Table 5 presents soil organic C (g $hg^{-1}$) in CT and DSM in 2000 and 2007. DSM increases C in soil, whereas soil C concentration decreases in CT from 2000 to 2007. Montanaro et al., (2011) found that using conservation tillage, i.e. cover crop, no-tillage and mulching, can increase the mean annual carbon soil inputs from about 1.5 to 9 Mg $ha^{-1}$ per year; our findings in this study are in agreement with the results of Montanaro et al., (2011).

**Table 5.** Soil organic carbon concentration (g $hg^{-1}$) in DSM and CT systems in 0–30 cm layer.

| Year | DSM | CT |
|---|---|---|
| 2000 | 0.87 | 0.87 |
| 2007 | 1.04 | 0.78 |

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 2000–07. DSM clearly mitigated more than 6 Mg $ha^{-1}year^{-1}$ $CO_2$ compared with CT in south-east France. It can be said that DSM has mitigated 54 Mg $ha^{-1}$ in nine years.

**Table 6.** Saved $CO_{2[diesel]}$, stored $CO_{2[soil]}$ and saved $CO_{2[total]}$ in DSM compared with CT in kg $ha^{-1}$ $year^{-1}$.

| Crop season | Saved $CO_{2[diesel]}$ | Stored $CO_{2[soil]}$ | Saved $CO_{2[total]}$ |
|---|---|---|---|
| 2001 | 123 | 6127 | 6250 |
| 2002 | 107 | 6127 | 6234 |
| 2003 | 96 | 6127 | 6223 |
| 2004 | 75 | 6127 | 6202 |
| 2004/05 | 112 | 6127 | 6239 |
| 2005/06 | 96 | 6127 | 6223 |
| 2007 | 96 | 6127 | 6223 |
| 2008 | 102 | 6127 | 6229 |
| 2009 | 102 | 6127 | 6229 |

Further improvements to the soil C content could be achieved by sowing a mix of a cover crop producing more organic matter resulting in increased soil organic C. DSM can contribute to $CO_2$ mitigation in two ways, first, by improving C sequestration in the soil, and secondly, by reducing diesel consumption during the crop season. A return to CT after some years of DSM practice could cause an additional release of $CO_2$ 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 substantial $CO_2$ mitigation. Increasing soil C sequestration and decreasing diesel combustion in DSM results in an important $CO_2$ mitigation compared with CT. It should be noted that in DSM, the share of C sequestration is more important in $CO_2$ mitigation than saving diesel. The annual sum of these two $CO_2$ savings per hectare is equivalent to the annual $CO_2$ emission from a medium-size car. Decreasing diesel consumption is important not only from an 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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