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Review

Controlled traffic farming: A review of the environmental impacts

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ABSTRACT

Controlled traffic farming (CTF) is a strategy to minimise soil compaction, which is being implemented worldwide. The aim of this study was to review and analyse the state-of-the-art regarding the environmental impacts of CTF. CTF, when compared with random traffic farming (RTF), was able to reduce environmental issues, such as soil emissions of nitrous oxide (21–45%) and methane (372–2100%), water runoff (27–42%), in-field operations direct emissions (23%), and indirect impacts associated with fertilisers (1–26%), pesticides (1–26%), seeds (11–36%), and fuels (23%). CTF, in addition, is likely to cause reductions on environmental issues, such as ammonia emissions, and runoff of soil, nutrients, and agrochemicals. Effects of CTF on soil-C balance, leaching of nutrients and agrochemicals, and in-field-machinery indirect impacts cannot be determined by the currently available literature. Research on the non-determined environmental issues and a quantitative environmental impact assessment, such as life cycle assessment, would contribute to advance agriculture towards more environmentally-friendly systems.

Contents

1. Introduction

Agricultural machinery, such as tractors or combines, are essential tools in specialised arable farming systems. The in-field traffic intensity and the size and weight of agricultural machinery have increased as a result of the agricultural specialisation (Arvidsson, 2001) and the pursuit of a higher operations efficiency and capacity. In Denmark, for instance, the average tractor weight has increased from 2.6 tonnes, in 1970, to 6.6 tonnes, in 2000 (Høj, 2011). The risk of traffic-induced soil compaction, consequently, has also increased (Raper, 2005).

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Traffic-induced soil compaction is known as the process induced by wheeling of mobile farming units in which the soil particles are spatially rearranged increasing the soil bulk density (Hamza and Anderson, 2005). As a result, reductions in the soil gas diffusivity and the hydraulic conductivity, and increases in the soil mechanical strength are induced (Arvidsson and Hakansson, 1991; Bhandral et al., 2007; Horn et al., 1995). Compaction restricts crop-root functions and growth, consequently reducing the crop yield (e.g. Chan et al., 2006; Hakansson and Reeder, 1994; Lipiec et al., 1991; Nevens and Reheul, 2003; Tardieu, 1994). Compaction, in addition, increase emissions of soil greenhouse gases (GHGs) and losses of nutrients and agrochemicals through runoff (Soane and van Ouwerkerk, 1995). Although biotic and abiotic processes are quite efficient in regenerating topsoil compaction (Bullock et al., 1985), subsoil compaction (i.e. compaction below the normal cultivation depth) can last over many years, decades or even centuries (Etana and Hakansson, 1994; Hakansson and Reeder, 1994). The agricultural worldwide area of detrimental soil compaction was estimated in 1991 to amount to 68 million hectares, of which nearly 50% (i.e. 33 million ha) was located in Europe (Oldeman et al., 1991).

Controlled traffic farming (CTF) is a management strategy to minimise traffic-induced soil compaction, which is being implemented worldwide (Raper, 2005). CTF is defined as a "crop production system in which the crop zone and the traffic-lanes are distinctly and permanently separated" (Taylor, 1983) by the use of in-field machinery equipped with navigation-aids and auto-steering systems (Bochtis and Vougioukas, 2008; Raper, 2005). CTF, consequently, keeps the crop zone unaffected by the wheels, while the traffic-lanes become compacted improving the draught efficiency (Taylor, 1992). CTF reduces the trafficked area when compared with conventional traffic practices, known as random traffic farming (RTF). RTF, in one cropping season, can cause a trafficked area of 80–100% of the total field area in intensive tillage practices, and 30–60% in conservation tillage practices (i.e. reduced and zero tillage practices) (Radford et al., 2000; Soane et al., 1982; Soane and van Ouwerkerk, 1994; Tullberg et al., 2007). CTF fields, in contrast, cause a trafficked area of 10–20% of the total field area (Soane and van Ouwerkerk, 1994; Tullberg, 2010; Wang et al., 2009).

The implementation of a specific in-field traffic practice can influence additional environmental issues besides the ones influenced by traffic-induced soil compaction. For instance, emissions from different in-field operations which depend on factors such as in-field travelled distance (Bochtis et al., 2010) and draught force requirements (Chen et al., 2010; Tullberg, 2000), and different use of farm resources (e.g. fertilisers, pesticides, seeds, and fuels) (Birch, 1999; Nielsen and Sørensen, 1994).

Several studies have analysed the environmental impacts of CTF, but only focusing on specific environmental issues and stages of the agricultural production system. There is a need, therefore, to review and analyse these impacts following a system approach.

The aim of this study was to review and analyse the state-of-the-art regarding the environmental impacts of CTF, when compared with RTF, considering all relevant environmental issues and stages of the production system.

2. Methods

The method approach consisted of the analysis of the currently available studies regarding the environmental issues associated with CTF as compared with RTF, and was based on scientific peer-reviewed articles and dissertations.

The environmental issues analysed included the main issues associated with arable crop production (Nemecek and Kagi, 2007), and consisted of soil gaseous fluxes, runoff of soil, nutrients and agrochemicals, leaching of nutrients and agrochemicals, in-field operations emissions, and indirect impacts associated with the farm resources (Fig. 1).

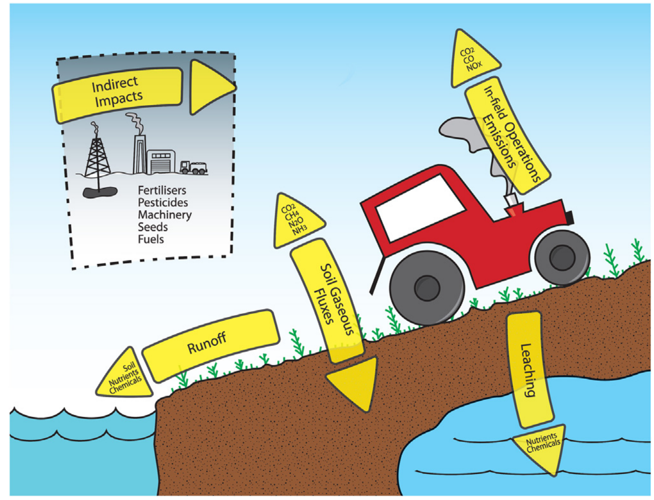

Fig. 1. Main environmental issues associated with crop production.

System conditions such as climate, soil, crop, fertilisation, tillage, and operations type, which can influence the environmental issues (e.g. Mari and Changying, 2008; Sidhu and Duiker, 2006; Soane, 1990; Torbert and Reeves, 1995), were analysed to avoid misleading literature comparisons. These data, however, have been reported only when necessary to interpret the reviewed results.

3. Environmental issues review

3.1. Soil gaseous fluxes

3.1.1. Carbon dioxide (CO_2)

Carbon (C) is absorbed by crops in the form of CO_2 through photosynthesis. A fraction of this C is incorporated in the soil as organic matter, i.e. soil C sequestration. The sequestered C is mineralised by microorganisms and released into the atmosphere in the form of CO_2, i.e. microbial respiration (West and Marland, 2001). Soil respiration consists of the soil CO_2 emissions arising not only from microbial respiration, but also from roots respiration (Hu et al., 2009).

Some agricultural practices can reduce soil C inputs (e.g. harvest and residues removal) or increase soil C outputs (e.g. intensive tillage practices, which enhance microbial respiration (Regina and Alakukku, 2010)). These practices, therefore, can deplete soil C stocks and consequently contribute to climate change (Ciais et al., 2010).

Addressing the inputs, it is known that the lower biomass production found in compacted soils can reduce the soil C inputs (Brevik et al., 2002). Addressing the outputs, several studies reported lower microbial respiration rates in compacted soils (Ball et al., 1999; Beare et al., 2009; Jensen et al., 1996a,b; Toth et al., 2009). Reductions in soil gas diffusivity and water drainage caused by soil compaction create anaerobic conditions that are unfavourable for the microbial community responsible for the microbial respiration (Beare et al., 2009; Pengthamkeerati et al., 2005). Some studies, however, found that after an intensive compaction, reductions in soil respiration rates were not related to influences on the microbial community, but rather to reductions in the soil gas diffusivity, which limited the transport of CO_2 into the atmosphere (Shestak and Busse, 2006). Other studies, moreover, suggest that the reductions in soil respiration rates can also be influenced by reductions in root respiration rates, as a result of a root size reduction in compacted soils (Hu et al., 2009).