

Perspective

No-till is challenged: Complementary management is crucial to improve its environmental benefits under a changing climate

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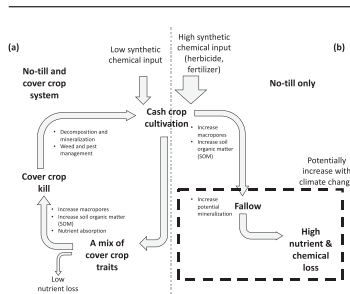
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HIGHLIGHTS

- No-till alone is not sufficient as a management practice to improve environmental quality.
- No-till should be integrated with cover crops to improve its environmental quality benefits.
- Cover crops tighten nutrient cycling in no-till system.
- Cover crops may reduce herbicide needs and absorb residual chemicals.

GRAPHICAL ABSTRACT



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ABSTRACT

Tillage is the most common agricultural practice dating back to the origin of agriculture. In recent decades, no-tillage (NT) has been introduced to improve soil and water quality. However, changes in soil properties resulting from long-term NT can increase losses of dissolved phosphorus, nitrate and some classes of pesticides, and NT effect on nitrous oxide (N_2O) emission remains controversial. Complementary management that enhances the overall environmental benefits of NT is therefore crucial. By incorporating cover crops, nutrient cycling and nutrient use efficiency in NT fields could be improved given the nutrient supplying capacity of some cover crops. Cover crops could also offset the need for occasional tillage of NT cropland, an operation whose effect is only temporary in reducing, for example, soil compaction associated with NT management. When used in combination with NT, cover crop termination methods, using agrochemicals, should be carefully considered to prevent further jeopardy to water quality. Compared to herbicides, the use of roller crimping could potentially result in production cost saving while minimizing soil disturbance and export of agrochemicals. Future research should focus on various combinations of cover crop traits (e.g., decomposition rate) and management (e.g., timing of cover crop termination) that account for site- and cash crop-specific requirements.

1. Introduction

Tillage practice has been a foundation of agriculture for thousands of years, but it also creates unwanted consequences such as soil erosion and soil compaction (Triplett and Dick, 2008). In line with the need to achieve Sustainable Development Goals, restoring degraded agricultural landscapes is important (UNEP/FAO, 2020) to address the twin goals of improving environmental quality and ensuring sustainable food production. In recent decades, no-tillage (NT or zero tillage) manage-

ment has been introduced to improve soil and water quality, i.e., to reduce soil erosion and reduce loss of nutrients that are attached to soil particles (Lal, 1974). So far, the soil erosion control benefits of NT are well documented and have spurred its widespread adoption (Cassao et al., 2012). In the United States alone, no-till was used on roughly 56% of the total acreage of soybean (2012), 42% of corn (2016), and 67% of wheat (2017) (Claassen et al., 2018). However, recent meta-analyses showed that NT, as a single management practice, carried unintended consequences as it increases nitrate (NO_3^-) and dissolved phosphorus (P) export from agricultural fields (Daryanto et al., 2017a, Daryanto et al., 2017b), as well as the loss of pesticides (Elias et al., 2018). NT has also been found to increase N_2O emission in humid regions, fine-textured and acidic soils, but not in dry regions, coarse-

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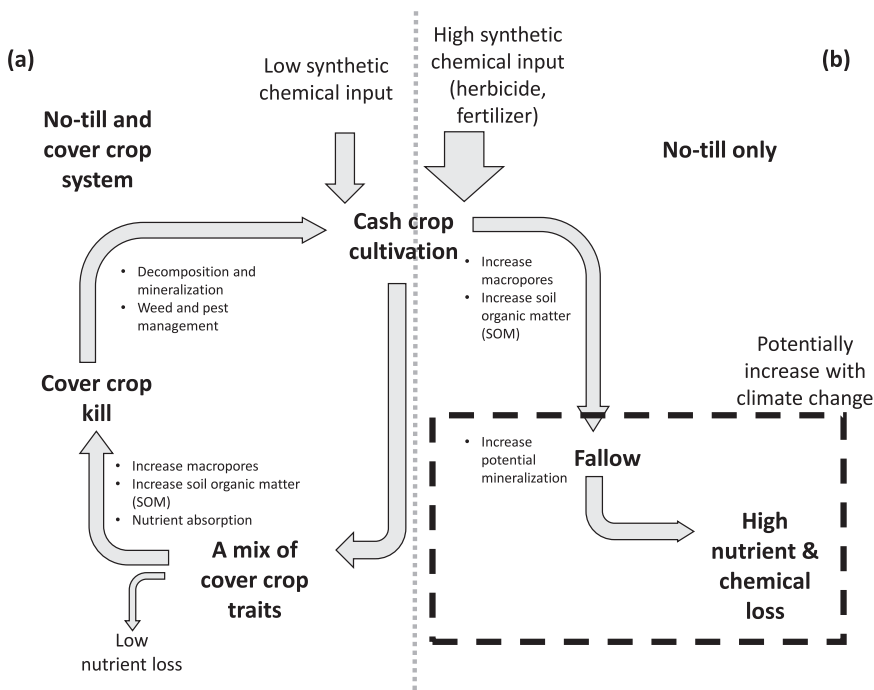


Fig. 1. Processes and nutrient flow that occurs in cover crop and no-till (NT) combination (a) compared to NT alone (b) separated by dotted line. Arrows indicate processes and nutrient flow while dashed line indicate processes that may be exacerbated with climate change.

medium-textured soils and in neutral or alkaline soils (Huang et al., 2018). Although soil organic matter build-up is widely viewed as beneficial, accumulation of nitrogen (N) and P on NT soil surface, in combination with increased bulk density and soil compaction, could increase nutrient loss. Decline in soil pH, which often accompanies organic matter accumulation, can increase the solubility of some classes of pesticides, and thus their propensity for loss via runoff (Elias et al., 2018). Further, the installation of subsurface tile drainage networks commonly found in clay-rich and poorly drained soils can exacerbate these adverse impacts on water quality.

Occasional tillage has been proposed as a potential remedial action to reduce the aforementioned undesirable effects of long-term NT. However, this action alone is likely inadequate and can be counterproductive. First, this action could reverse improvement in soil biology and remove the protection against soil loss and evaporation provided by crop residue on land surface. These considerations are important in light of projected changes in climate and hydrological conditions (e.g., more frequent droughts and floods) (Jiao et al., 2019), and their expected impact on nutrient mobility. Greater rates of organic N and P mineralization are observed in soils subjected to repeated drying and moistening cycles (Smith and Jacinthe, 2014), leading to high nutrient and pesticide load in runoff during subsequent rainfall events (Elias et al., 2018). Changing in precipitation patterns from snow to rain during periods when soils are uncovered is also expected to enhance nutrient loss (Berghuijs et al., 2014). Instead of using occasional tillage, cover crops act as “natural tillage” (i.e., those with large taproot diameter such as fodder radish and oilseed rape) (Chen and Weil, 2010). These large taproots allow the development of macropores and reduce soil compaction (Chen and Weil, 2010). The schematic diagram in Fig. 1 illustrates how cover crops can foster a reduction in agro-chemicals use and greater tightening of nutrients cycling (i.e., uptake of accumulated nutrients and re-use, and timely release of nutrients to subsequent growing crops) (Daryanto et al., 2018) —attributes that are crucial to resolve the water quality problems associated with NT management under a changing climate. We also showed an example of combined NT and cover crop practices in the Midwest in the United States (Fig. 2). Further details on how cover crops can improve water quality under NT management are available in Section 2 below.



Fig. 2. An example of agricultural field under combined cover crop and no-till practices in Indiana in the United States. Cover crop is annual rye standing in the previous crop corn residue, and cover crop is terminated using glyphosate.

2. The environmental benefits of incorporating cover crops to no-till system

The use of cover crops to reduce nutrient loss through reduction in soil and water loss (Daryanto et al., 2018) as well as their nutrient scavenging ability (Kristensen and Thorup-Kristensen, 2004) is nothing new. Our argument that a combination of NT and cover crops could be highly beneficial to the overall environmental quality (i.e., reduced N_2O and NO_3^-) through tightened nutrient cycling and reduction in synthetic fertilizer application (Fig. 1), is consistent with some recent findings (Basche et al., 2016; Gelfand et al., 2016; Fiorini et al., 2020). While there are multiple other benefits of cover crops (Daryanto et al., 2018), in this article we focused on the benefits associated with water quality. The fate of dissolved N (e.g., NO_3^- and NH_4^+) in groundwater systems, rivers and estuaries is considered the single largest source of uncertainty in the global N_2O inventory (Turner et al., 2015). With the increase in

synthetic N fertilizer consumption during the last half-century, there has been a parallel increase in N₂O emission (Millar et al., 2010), which is projected to reach upward of 7×10^6 ton N₂O yr⁻¹ in 2030, an equivalent to 17% increase relative to 1990 emission (Reay et al., 2012).

2.1. Cover crops can reduce nitrogen and phosphorus fertilizer application for the subsequent cash crop

Cover crops have been considered the best management practice for vegetable production systems which are notoriously known to require significant N input (Brennan, 2017). Cover crops are not only selected based on climate and production systems, but also on their nutrient uptake and releasing ability. While legume cover crops can be attractive from a N-supplying perspective, they are generally not as efficient as non-legume cover crops at scavenging residual nutrients from soils (Valkama et al., 2015). Recent studies suggested that the right mixture of cover crops (e.g., legume and non-legume) can tighten nutrient cycling by providing nutrients for the subsequent cash crop and at the same time minimizing nutrient loss (Frasier et al., 2017; Couedel et al., 2018). While it is well known that the decomposition of residues from N₂-fixing plant species can supply N to the subsequent crops, it has also been demonstrated that the residues of cereal rye (*Secale cereale* L.), faba bean (*Vicia faba* L.), purple vetch (*Vicia benghalensis* L.), oat (*Avena sativa* L.), and white mustard (*Sinapis alba* L.) can also release plant-available P in amounts comparable to mineral fertilizers (Maltais-Landry and Frossard, 2015). Incorporation of cover crops may also induce P re-distribution in the topsoil as well as reduction in residual available P (Daryanto et al., 2018). The use of tropical grasses from the genus *Urochloa* or *Brachiaria* has been found to improve plant-available P in Oxisols and Ultisols due to their ability to mobilize and take up P from recalcitrant pools such as P bound to Fe or Al oxides (Almeida et al., 2018). Compared to synthetic mineral fertilizers, slow-degrading cover crop materials can release available nutrients in synchrony with the demand of the growing crops, thus enhancing both nutrient uptake and use efficiency (Ladan and Jacinthe, 2017).

2.2. Cover crops can reduce herbicide needs

With cover cropping, farmers can spend less on herbicides, and reduce their production costs. Proper selection of cover crops (e.g., planting date, density, species) can put competitive pressure on weeds, including those that are herbicide-resistant (Travlos et al., 2017). Studies have suggested that a combination of cover crops (cocktail) can have N-supplying and pest control benefits given the insect-repellent properties of some cover crops (e.g., *Desmodium* spp., effective against stem-borer while supplying N) (Pickett et al., 2014). However, much remains to be learned about the phytosanitary benefits of cover crops, including pest control (Furlan et al., 2017) and suppression of some soil pathogens (Wen et al., 2017). In addition, residues of some cover crops appear to be effective at absorbing residual pesticides (Cassigneul et al., 2015), and thus can be a promising approach to reduce the concentration and load of organic chemicals from NT soils, especially those with low affinity for the solid phase (Elias et al., 2018).

3. Challenges with incorporating cover crops and directions for future research

Despite evidence of the water quality benefits of cover crops, their incorporation into large-scale intensive agricultural production systems remains limited, although the general trend in adoption rates is encouraging (SARE, 2017). Farmers' decision to implement a sustainable practice can be motivated by a range of factors, including agronomic and socio-economic considerations as well as complex internal values or beliefs (Silva and Moore, 2017). Uncertainties in regard to the yield of the subsequent cash crops, and perceived increase in production costs (to

purchase cover crop seeds and new equipment for cover crops termination) could greatly affect such a decision. In addition, by introducing cover crops, the production system become more complex in its management, and that could be a deterrent for some producers. Further, in order to improve nutrient-use efficiency, it is important to understand the synchrony between nutrient need of the subsequent crop and the timing of nutrient release from cover crop biomass. With better knowledge of cover crops decomposition patterns, reduction in synthetic N fertilizer input and the emergence of a tighter soil N cycle, N loss as gaseous emission or via runoff and leaching can be minimized, as indicated by recent regional models (Basche et al., 2016; Necpalova et al., 2018). Further research on these topics should help determine how NT farming and cover cropping can be integrated into a sustainable production system that maintains agricultural productivity, improves soil health, and protects water quality. These considerations provide a strong rationale for additional research involving the combination of NT with different types of cover crops. It is also crucial that detailed economic analyses are conducted to determine potential impact on farm economy, and thus the likelihood of adoption (Daryanto et al., 2019). For different production systems, these analyses should account for local edaphic factors and other constraints that could be imposed by a changing climate.

4. Conclusions

Overall, NT needs to be complemented with cover crops to harness its environmental benefits. If, as projected for several world eco-regions that dry-wet cycles are to become more frequent (Knapp et al., 2017), it seems that leakage of nutrients from NT agroecosystems could become more significant. It should be noted, however, that the method used for cover crop termination could affect the extent to which water quality benefits are realized. Using roller crimping will be an example of recommended method to terminate cover crops, while minimizing soil disturbance and the use of chemicals (Davis, 2010). Recent advances of the technology (e.g., sickle-bar mowing, roller crimper, or their combination with flaming) allow: (i) faster and cheaper cover crop termination (Frasconi et al., 2019), (ii) more uniform residue cover which enhances weed suppression, moisture retention, and soil conservation, without affecting ground-dwelling predator communities (Navarro-Miró et al., 2017).

Declaration of Competing Interest

No potential conflict of interest was reported by the authors.

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