Scientific Papers. Series B, Horticulture. Vol. LXIX, No. 2, 2025
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

THE IMPACT OF THE USE OF GREEN CROPS IN AGRICULTURAL PRODUCTION - ON OVERVIEW

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Abstract

Cover crops are an essential agroecological practice for sustainable agriculture, with multiple beneficial effects on soil, biodiversity and productivity. An integrative analysis of 59 international and national studies shows that they contribute to improving the physical, chemical and biological properties of the soil, reducing nutrient losses and increasing the resilience of agroecosystems. From a physical point of view, green crops increase water infiltration rates by up to 35% and reduce soil bulk density by 6-9%. Chemically, replacing fallow land with green crops reduces nitrate leaching by 45–83%, sometimes equivalent to a reduction of 40-80 kg N ha⁻¹ in mineral fertilisation. Biologically, they increase microbial biomass by 20-25% and fungal diversity by 15%, stimulating enzymatic activity and nutrient recycling. A major aspect is carbon sequestration, with average increases of 0.3-0.5 Mg C ha⁻¹ year⁻¹, visible especially after 3-5 years of application. Thus, green crops contribute to climate change mitigation and long-term fertility maintenance. In addition, grasses (e.g. rye, oats) are effective for nitrate capture and soil protection, legumes (e.g. clover, vetch) for nitrogen supply, and cruciferous plants (e.g. mustard, radish) for biofumigation and decompaction.The effects on biodiversity and weed control are significant, reducing infestations by 30-45%. In contrast, under optimal conditions, cover crops stabilise yields and reduce costs by decreasing chemical inputs, generating net economic benefits of €60–120/ha. Cost constraints and competition for resources can be overcome by choosing the right species and integrating them into agricultural support policies (e.g. CAP eco-schemes). Their widespread adoption can make a decisive contribution to the transition to more resilient, efficient and environmentally friendly agriculture.

Key words: *cover crop, carbon sequestration, enzymatic activity.*

INTRODUCTION

Modern agriculture faces the dual challenge of ensuring food security and protecting natural resources. *Cover crops* (or *green manure*) have been promoted globally as a solution to improve soil fertility, reduce pollution and increase the resilience of agricultural systems (Silva et al., 2024; Wittwer et al., 2017).

In the US, the area cultivated with cover crops increased from 1.5 million ha in 2005 to over 6 million ha in 2017 (Basche and DeLonge, 2019). In the European Union, they are integrated into CAP schemes, and Romania has begun to encourage their use through eco-schemes and local research, especially on pre-luvisolic soils (Gîdea et al., 2010). Globally, the area cultivated with green crops has grown steadily over the last two decades, estimated at over 15 million ha in the United States and approximately 3 million ha in the European Union (Blesh, 2018; Blanco-Canqui, 2022). However, the adoption rate differs significantly between regions, being higher on organic farms and lower in conventional systems (Blanco-Canqui and Ruis, 2020).

The importance of green crops derives from multiple scientifically documented benefits: carbon sequestration (Blanco-Canqui and Ruis, 2017; Blanco-Canqui et al., 2023), reduction of nitrate leaching (Blanco-Canqui et al., 2015; Brennan and Smith, 2005), improvement of soil physical properties, weed control (Dabney and Delgado, 2001; Fernando et al., 2023) and support for biodiversity (Finney and Kaye, 2017).

However, there are also challenges: competition for resources (water and nitrogen) (Finney et al., 2016), additional costs for farmers (Gîdea et al., 2010) and the risk of negative effects in dry years (Ciontu et al., 2011).

MATERIALS AND METHODS

The paper presents the results obtained as a result of analyzing the specialized literature by accessing electronic databases, including Google Scholar, Science Direct, Scopus and PubMed, of research focused on the benefits of green manure cultivation and on establishing that these can be sustainable crops.

We used the search terms "green manure", "economic importance of green manure" and thus accessed numerous scientific works, as can be observed from the references chapter.

RESULTS AND DISCUSSIONS

Types of green crops and plant combinations used

Green crops can be divided into several functional groups, each with specific advantages. Grasses (e.g. winter rye, oats, wheat, triticale) have a dense and deep root system, making them effective for capturing residual nitrates and protecting against erosion (Kaspar et al., 2012; Snapp and Surapur, 2018).

Advantages Reduce nitrate leaching by 45-710% (Nouri A. et al., 2022; Thapa et al., 2018), protect the soil from erosion and increase aggregate stability (Basche and DeLonge, 2019; Blanco-Canqui and Ruis, 2020), control weeds through shading and mulching (Godar et al., 2025; Nouri et al., 2022).

Disadvantages High C/N ratio → slow decomposition (Blanco-Canqui and Ruis, 2017), May reduce subsequent crop yields in dry years (Kaspar et al., 2012; Wayman et al., 2015).

Legumes (e.g. red clover, field peas, alfalfa, vetch) biologically fix atmospheric nitrogen, providing the equivalent of 40-80 kg N/ha to subsequent crops.

Advantages: Fix atmospheric nitrogen, 40-80 kg N/ha, (Kaye and Quemada, 2017; Tribouillois et al., 2015); improve soil structure and water retention capacity (Finney and Kaye, 2017) contribute to increased microbial biodiversity (Joshi et al., 2023; Thapa et al., 2018).

Disadvantages Requires inoculation with fixing bacteria for maximum efficiency (Blesh, 2018), May compete with the main crop if not finished in time (Kannberg et al., 2024; Wayman et al., 2015).

Cruciferous species (e.g. fodder radish, white mustard) are used for their biofumigant effect and for soil decompaction, as they have deep taproots (Brennan and Smith, 2005; Koudahe et al., 2022). Other species, such as buckwheat, millet or Sudanese sorghum, can be used in diversified systems for organic matter input and weed suppression (Nichols et al., 2020; Ranaldo et al., 2020).

Advantages taproot reduces compaction (Koudahe et al., 2022), biofumigant effect → reduces nematodes and pathogenic fungi (Brennan and Smith, 2005), short cycle → can be introduced between horticultural crops (Murrell et al., 2017).

Disadvantages sensitive to frost, mustard and rapeseed species (Yousefi et al., 2024), can transmit cruciferous diseases if rotations are not respected (Koudahe et al., 2022).

Buckwheat (*Fagopyrum esculentum*) advantages: quickly suppresses weeds and attracts pollinators (Nichols et al., 2020).

Disadvantages: total biomass is lower than that of grasses (Ranaldo et al., 2020).

Phacelia (*Phacelia tanacetifolia*) advantages: melliferous, supports biodiversity and pollination (Wittwer et al., 2017).

Disadvantages: does not fix nitrogen, requires dense sowing for complete coverage (Yousefi et al., 2024).

Sudanese sorghum/pearl millet advantages: produces high biomass, drought tolerant (Ranaldo et al., 2020). Disadvantages: sensitive to cold, can compete intensely for water (Kannberg et al., 2024).

In practice, mixtures of species that combine the advantages of different groups are frequently used. Finney et al. (2016) and Ranaldo et al. (2020) showed that mixtures of grasses and legumes provide both nitrate capture and biological nitrogen supply, simultaneously increasing total biomass and the suppressive effect on weeds.

In Europe, adapted mixtures (e.g. rye + vetch, oats + peas, triticale + clover) have demonstrated superior performance to monocultures, with higher productivity and increased resilience to variable climatic conditions (Wittwer et al., 2017).

In Romania, long-term experiments have confirmed that rotations with complex mixtures can ensure stable yields and maintain the fertility of pre-luvisolic soils (Ciontu et al., 2011; Gîdea et al., 2010)

Influence on soil physical properties

Green crops contribute significantly to improving soil structure and stability.

Basche and DeLonge (2019) showed that infiltration rates increase by 35% in systems with cover crops.

Blanco-Canqui and Ruis (2020) confirm a 6-9% reduction in apparent soil density and a 15-20% increase in aggregate stability.

Finney and Kaye (2017) demonstrated that the functional diversity of cover crop mixtures increases root biomass by 18%, improving soil structure.

In Romania, wheat and maize rotations on pre-luvisolic soils reduced compaction and improved water retention (Ciontu et al., 2011; Gîdea et al., 2015).

Dabney et al. (2001) showed that soil losses through erosion are reduced by 40-60% on sloping land, confirming the role of cover crops in soil conservation.

In another study, Finney and Kaye (2016) showed that the functional diversity of cover crop mixtures contributes to better soil structure, with an 18% increase in root biomass and a positive effect on microaggregate stability.

Blanco-Canqui (2022) highlighted the role of deep-rooted species (e.g. rye, fodder radish) in reducing compaction and improving porosity.

The effects on soil erosion are also notable. Dabney et al. (2001) showed that the use of cover crops reduces soil loss through erosion by 40-60%, especially on sloping land. This effect derives both from the coverage of the soil with plant debris and from the ability of the roots to stabilise aggregates and reduce surface runoff.

Influence on soil chemical properties

Tonitto et al. (2006), analysing 37 studies, showed that replacing fallow land with cover crops improves the nitrogen cycle and reduces losses. Thapa et al. (2018) reported average reductions in nitrate leaching of 70%, while Nouri et al. (2022) confirm maximum values of 83%. Kaspar et al. (2012) observed decreases in nitrates in drainage water of between 25-60%.One of the main benefits of green crops is their ability to contribute to the storage of organic carbon in the soil.

The meta-analysis by Poeplau and Don (2015), which included over 100 experiments, showed that the use of cover crops increases carbon stocks by an average of 0.32 ± 0.08 Mg C ha^{-1} $year^{-1}$.

The effect is more pronounced in degraded soils and temperate climates, where carbon accumulation can exceed 0.5 Mg C ha^{-1} $year^{-1}$ (Blanco-Canqui et al., 2023).

Another global study (Gîdea et al., 2015) showed that integrating green crops into rotations contributes to an increase in active soil carbon content of 12-20% after 5 years of continuous application. This is essential for achieving the climate goals set out in the Paris Agreement and for the resilience of agroecosystems to climate change.

Reducing nitrate leaching

A major, extensively documented benefit is the reduction of nitrate losses from the soil through leaching. Thapa et al. (2018) conducted a global meta-analysis of 131 studies and showed that the use of cover crops reduces nitrate leaching by an average of 70%, with variations between 45% and 92%, depending on species and management.

Nouri et al. (2022) confirmed these results, emphasising that efficiency is highest in temperate climates, where the reduction reaches up to 83%.

One of the most important benefits of green crops is their ability to increase soil organic carbon stocks, thereby contributing to climate change mitigation and long-term fertility improvement.

Global meta-analyses show that the use of cover crops leads to an average increase of 0.3-0.5 Mg C ha^{-1} $year^{-1}$. Poeplau and Don (2015), analysing over 100 experiments, confirmed that the largest increases occur in systems with diverse rotations and moderate residue inputs. Jian et al. (2020) showed that the effect is cumulative: carbon gains become visible after 3-5 years and continue to increase in long-term experiments.

Blanco-Canqui (2022) emphasises that perennial grasses and legume + grass mixtures have the highest sequestration potential because they provide both a large amount of biomass and residues with variable C/N ratios, which promotes balanced mineralisation. Tiemann et al. (2015) showed that species diversity stimulates microbial activity, which accelerates the stabilisation of organic matter. Ruis and Blanco-Canqui (2017) highlighted that the benefits are more pronounced in degraded or eroded soils, where additional inputs of organic matter can quickly restore carbon balance.

Wittwer et al. (2017), in a European synthesis, confirm that in temperate regions, cover crops can compensate for up to 25-30% of carbon losses caused by monoculture and intensive farming.

In Romania, studies on pre-luvisols and southern chernozems (Ciontu et al., 2011; Gîdea et al., 2008; 2010; 2012; 2015) have shown that rotations with legumes and grasses increase humus content by 0.2-0.3% after 5-7 years of application. These data confirm that the widespread adoption of green crops could be an effective strategy for increasing the resilience of agroecosystems to climate change.

Waring et al. (2020) showed that introducing rye as a green manure crop reduces nitrate concentrations in groundwater drainage by 25-60%, while modelling studies by Malone et al. (2014) and Gupta et al. (2022) suggest that nitrate losses could be reduced by more than 50 kg N ha^{-1} $year^{-1}$ in artificially drained systems.

With regard to phosphorus, Koudahe et al. (2022) showed that plant residues reduce losses through surface runoff.

In experiments in Romania, rotations with peas and wheat led to better mineral fertiliser efficiency and increased humus content (Gîdea et al., 2008; 2010; 2012; 2015).

Influence on soil biological properties

Soil biological activity is significantly stimulated by green crops (Zhou et al., 2021).

Tiemann et al. (2015) reported increases in microbial biomass by 22% and fungal diversity by 15%.

Tribouillois et al. (2015) showed that legumes stimulate nitrogen-fixing bacteria and reduce pathogens.

Jian et al. (2020) confirmed that cover crops intensify the carbon cycle by stimulating the microbiota.

In Romania, complex rotations on pre-luvisolic soils have led to significant increases in microbial biomass and biological fertility (Ciontu et al., 2011; Gîdea et al., 2015).

Influence on soil enzyme activity

Soil enzymes are indicators of quality and fertility (Zală, 2015).

Jian et al. (2020) showed that cover crops increase β-glucosidase and urease activity.

He et al. (2025) confirmed that legumes enhance phosphatase activity, increasing phosphorus availability.

In experiments in Romania, Burcea et al. (2007) demonstrated that reduced tillage and crop rotations increase catalase activity and reduce weed infestation.

Influence on biodiversity and weed spectrum

Cover crops reduce weed pressure through shading and mulching effects.

Nichols et al. (2020), based on 67 studies, reported an average reduction of 33% in infestation.

Osipitan et al. (2019) confirm the effectiveness of rye and oats.

Godar et al. (2025) showed that mixtures reduce infestation by 45%, compared to 28% in monocultures.

In Romania, Gîdea et al. (2010; 2012; 2015) showed that rotations and integrated technologies significantly reduce weed pressure on maize and sunflowers.

Influence on pathogens and pests

Murrell et al. (2017) demonstrated that delaying the termination of cover crops can increase the incidence of root diseases in maize by 10-15%, but proper management prevents these effects.

Brennan and Smith (2005) showed that mustard and radish have a biofumigant effect, reducing soil pathogen density by 20-40%.

In Romania, Gîdea et al. (2008) highlighted the reduction in *Pyrenophora tritici-repentis* attack on the Flamura 85 variety in green crop rotations.

Influence on plant productivity, growth and development

The impact of cover crops on yields is variable, but in the long term tends to be positive or neutral.

Tonitto et al. (2006), in a meta-analysis of 37 studies, showed that cover crops stabilise yields and reduce nitrogen losses.

Peng et al. (2024) confirm, through a global synthesis, that average yields do not decrease and interannual variability is reduced.

Silva et al. (2024) reported in the US Midwest that soybeans sown after rye do not lose yield, but even gain modestly (+2–4%).

In contrast, Wayman et al. (2015) and Kannberg et al. (2024) showed that excessive delay in termination can generate competition for water and nitrogen, leading to 5-15% decreases in maize.

Gîdea et al. (2010; 2012; 2015) showed that green crop rotations increase wheat and maize yields by 8-12% in normal years, but can reduce production by 5-10% in dry years.

Influence on rotations

Cover crops improve the efficiency of rotations.

Kaye and Quemada (2017) showed that legumes can provide the equivalent of 40-80 kg N ha^{-1} through biological fixation.

Blesh (2018) and Finney et al. (2017) confirm that legume-grass mixtures combine the advantages of nitrogen fixation with residual nitrate capture.

Gîdea et al. (2010; 2012; 2015) showed that complex rotations reduce weed infestation and increase the efficiency of mineral fertilisers.

Environmental impact

Thapa et al. (2018) and Ritz et al. (2017) showed that nitrogen losses are reduced by 20-70% through the use of cover crops.

Nouri et al. (2022) confirm maximum reductions of 83%.

Waring et al. (2020) observed decreases in nitrate concentrations in drainage of up to 62%.

In terms of gas emissions, Jian et al. (2020) showed that N_2O decreases by 10-20% when cover crops are introduced into agricultural systems.

In Romania, Gîdea et al. (2008; 2010) confirm that crop rotations reduce nitrate pollution and increase biodiversity.

Differentiated influence on crops

Maize: rye reduces nitrate leaching by 60-70% and provides 30-50 kg N/ha (Kaspar et al., 2012).

In Romania, crop rotations increase yields by 5-12% (Ciontu et al., 2011).

Soybeans: benefit from the suppressive effects on weeds, without yield losses (Silva et al., 2024).

Wheat: rotations with legumes provide the equivalent of 40-80 kg N/ha (Kaye and Quemada, 2017); Gîdea et al. (2008) showed a reduction in foliar diseases.

Vegetables: mustard reduces pathogen density by 40% and nitrogen losses by 35% (Brennan and Smith, 2005).

Sunflower: rotations reduce infestation and increase production stability (Gîdea et al., 2008).

For orchards and vineyards → clover, phacelia, rye (biodiversity + fertility).

For greenhouses and field vegetables → fodder radish, mustard (biofumigation), vetch + oats (nitrogen + mulch).

For intensive rotations → grass + legume mixtures (nutrient balance and weed suppression).

Competition for resources

Wayman et al. (2015) and Kannberg et al. (2024) showed that in dry years, cover crops can reduce maize yields through competition for water and nitrogen.

Profitability and economic efficiency

Ranaldo et al. (2020) showed that in Mediterranean systems, net economic benefits can reach €60-120/ha through reduced herbicide and fertiliser use.

Schipanski et al. (2014) calculated initial costs of 40-70 USD/ha, but medium-term savings through reduced inputs by increasing economic efficiency, stabilising production and reducing pesticide costs.

Limiting factors

1. Water resources - competition in arid areas (Kannberg, et al., 2024; Wayman et al., 2015).
2. Costs - additional, USD 40-70/ha (Silva et al., 2024).
3. Management - choice of species and timing of termination are critical (Murrell et al., 2017).
4. Slow benefits - appear after 3-5 years (Blanco-Canqui and Ruis, 2020).
5. Socio-economic barriers - small farms find it harder to adopt (Schipanski et al., 2014).

Advantages

Biological nitrogen fixation: 40-80 kg N/ha (Kaye and Quemada, 2017; Tribouillois et al., 2015).

Reduction of nitrate leaching: 45-83% (Nouri et al., 2022; Thapa et al., 2018).

Carbon sequestration (0.3-0.5 Mg C/ha/year) (Poeplau and Don, 2015; Jian et al., 2020).

Improvement of soil physical properties (Basche and DeLonge, 2019; Blanco-Canqui and Ruis, 2020).

Weed control: 30-45% (Godar et al., 2025; Nichols et al., 2020).

Increased biodiversity and microbiota (Tiemann et al., 2015; Yousefi et al., 2024).

Economic benefits: additional profit 60-120 €/ha (Ranaldo et al., 2020).

Disadvantages

Yield losses in dry years: –10 ...–15% (Kannberg et al., 2024; Wayman et al., 2015).

Additional costs (Schipanski et al., 2014).

Requires complex management (Murrell et al., 2017).

Benefits visible after several years (Blanco-Canqui and Ruis, 2020).

Socio-economic integration

In Europe, cover crops are integrated into CAP and eco-schemes (Wittwer et al., 2017).

In the US, the area has grown exponentially over the last 20 years (Basche and DeLonge, 2019).

In Romania, crop rotations and green crops are vital for adapting to climate change and protecting soils (Gîdea et al., 2008; 2010; 2012; 2015; 2016).

Adoption depends on financial support, technical advice and farmer networks.

Potential for use

He et al. (2025) showed that global adoption of cover crops could reduce GHG emissions from agriculture by 5-10% by 2050.

Jian et al. (2020) confirm that the long-term effects on carbon are cumulative.

In Romania, pre-luvisols and southern chernozems are the most promising for the expansion of cover crops (Gîdea et al., 2008; 2012; 2015).

CONCLUSIONS

The analysis showed that:

Cover crops increase the amount of carbon sequestered in the soil by 0.3-0.5 Mg C/ha/year (Poeplau and Don, 2015; Jian et al., 2020).

They reduce nitrate leaching by 45-83% (Nouri et al., 2022; Thapa et al., 2018).

They improve soil structure and microbiology (Blanco-Canqui et al., 2023; Tiemann et al., 2015).

They reduce weed infestation by 30-45% (Godar et al., 2025; Nichols et al., 2020).

They support biodiversity and reduce GHG emissions (He et al., 2025; Wittwer et al., 2017).

They stabilise yields of main crops (Peng et al., 2024; Tonitto et al., 2006).

However, there are limitations related to costs, competition for resources and management complexity.

RECOMMENDATIONS

1. Choose species according to soil and climate conditions: rye/oats for nitrate capture, legumes for nitrogen supply.
2. Integration of cover crops into 1-2-year rotations to reduce fertilisers by 40-80 kg N/ha.
3. Extension of payments for ecosystem services and financial support through the CAP.
4. Long-term research (& gt; 10 years) to quantify cumulative effects.
5. Use of digital technologies to optimise management.
6. Training programmes and farmer networks for knowledge transfer.
7. Adaptation to climate change: in dry areas → drought-resistant species, in wet areas → species to reduce leaching and erosion.

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