**Cover Crops for Sustainable Water Management in Agriculture**

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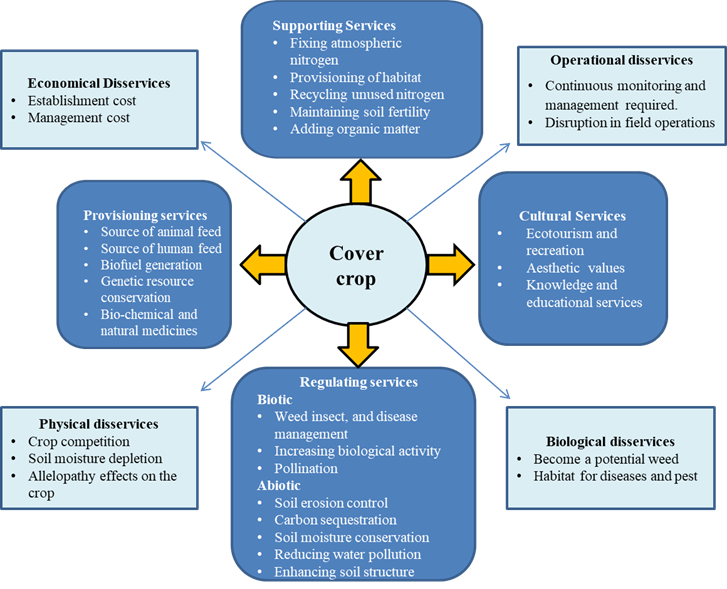
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**Abstract**

This article discusses the use of cover crops for water conservation in agriculture. Cover crops are non-cash crops that are planted between or during cash crops. They offer several benefits, including improved soil health, reduced evaporation, and controlled erosion. These benefits can lead to more efficient water use and healthier farmlands. It also discusses the technical considerations for selecting and managing cover crops for water conservation, such as climate, planting time, termination timing, and residue management. The article then highlights the economic benefits of using cover crops for water conservation, such as reduced irrigation costs, improved crop yields, and reduced fertilization costs. It concludes with a call to action for farmers and ranchers to adopt cover crops as a way to protect their land, their water resources, and their future. Finally, the article discusses the future of cover crops for water conservation and the challenges and opportunities that lie ahead. One challenge is that cover crops might compete with cash crops for water and nutrients. Another challenge is that cover crops can be expensive to plant and manage. However, there are many opportunities to expand the use of cover crops for water conservation, such as developing new cover crop varieties that are better adapted to specific regions and creating new cover crop management practices that are more efficient and cost-effective.

**Introduction**

Climate change is a major threat to agriculture. It lowers crop yields, reduces water availability, damages soil health, and contributes to the emission of greenhouse gases. (Khose *et al.*, 2023). To control and manage the devastating effect of climate change on a small-scale basis, sustainable measures for agriculture, and water conservation needs to be adopted. In this article focuses on water conservation methods using cover crop techniques. This approach not only align with sustainability goal but also feasible and well received by farmers. Cover cropping is an agro-environmental technique for groundwater and soil protection. Choosing the right cover crops for dry regions requires data on their water usage compared to bare soil, ensuring efficient water management (Bodner *et al*., 2007). Cover crops, non-cash plants grown between or during cash crops, offer numerous benefits, like improved soil health, reduced evaporation, and controlled erosion. These benefits can lead to more efficient water use and healthier farmlands. Water conservation is a crucial aspect of sustainable farming, and cover crops play a significant role in addressing this challenge. These non-cash plants cover and protect the soil during periods when primary crops are not in the ground, reducing erosion, suppressing weeds, and enhancing nutrient retention. Cover crops also play a prominent role in water conservation, as they contribute to soil health improvement, reduce evaporation, suppress weeds, and enhance nutrient retention. Thus, cover crops play a crucial role in promoting water conservation in agriculture. Figure 1 shows the schematic view of the benefits offered by cover crops in environmental aspects.



**Figure 1.** Schematic diagram depicting interdependency of cover crop and other environmental aspects.

Cover crops serve multiple purposes that contribute positively to their productivity. These functions encompass control of soil erosion, retention of soil nutrients, weed suppression, and the addition of organic matter. Although cover crops have been a longstanding practice for improving soil and crop health, the adoption of diverse mixtures is a more recent development. The idea is that increasing the diversity of cover crop mixtures can enhance and stabilize their various functions. Table 1 shows the choice of cover crops based on family, season, and benefits offered by them.

**Table 1.** Choice of cover crops based on family, season, and benefits.

|  |  |  |
| --- | --- | --- |
| **Types** | **Cover Crops** | **Benefits** |
| Summer | Buckwheat, Cowpea, Sunhemp, Sudan grass | Reduce erosion, enhance soil microbes, improves organic matter, weed suppression |
| Winter | Red cloves, oats, hairy vetch, brassica, and rye | Nitrogen fixation, Erosion control, improvement of soil texture, organic matter addition, |
| Leguminous cover crop | Field pea, Pea Bean, hairy vetch, and field pea | Erosion prevention, nitrogen fixation, attracts beneficial insects |
| Non- Leguminous cover crop | Wheat, Mustard, Brassica, Oat and Barley | Nutrient scavenging, weed suppressor, reduced soil erosion |

*Source: Sharma et al. (2018)*

1. **Benefits of Cover Crops for Water Conservation**

**2.1 Improved soil health:**

Cover crops improves soil health by adding organic matter, increasing water infiltration, and reducing runoff. They also improve soil structure, creating a favourable environment for plant growth and water retention. Healthy soils have higher infiltration rates and water holding capacity due to more organic matter acting as a sponge. Additionally, healthy soils have better soil structure, allowing water to move more easily through the soil. This also affects the tillage practices that are to be adopted by farmers in agricultural farms. In the study conducted by Abdollahi *et al.,* (2014) assessed that growing a cover crop usually increases pore organization and air permeability, air-filled porosity, and reduces the amount of blocked air porosity at all depths for all tillage treatments. In addition, the cover crop improved the environment for gas and water movement and root growth by continuously forming macropores. Thus, in all tillage treatments, the cover crop reduced the impact of tillage pan compaction. Farmers are widely adopting cover crop-centered, organic rotational conservation tillage systems to maximize benefits in both the short term, such as weed management and nutrient supply through cover crop mulches, and the long term, including soil carbon sequestration, replenishment of soil health, and improved soil nutrient cycling facilitated by conservation tillage practicesTop of Form and cover crops (Mirsky *et al*., 2012). Cover crops offer a powerful tool for boosting carbon sequestration in agriculture. They actively capture carbon through above-ground biomass and extensive root systems. Cover crops not only grab carbon from the air but also create conditions that encourage the soil to hold onto it more effectively. ([Kätterer](https://www.sciencedirect.com/science/article/pii/S0167880921000608" \l "bib0220) *[et al](https://www.sciencedirect.com/science/article/pii/S0167880921000608" \l "bib0220)*[., 2011](https://www.sciencedirect.com/science/article/pii/S0167880921000608" \l "bib0220); Kaye et al., 2017; [Lal, 2001](https://www.sciencedirect.com/science/article/pii/S0167880921000608#bib0250); Kaspar and Singer, 2015; [Poeplau and Don, 2015](https://www.sciencedirect.com/science/article/pii/S0167880921000608" \l "bib0335)). Overall, cover crops play a crucial role in improving water conservation.

To meet short-term nutrient and weed management goals for optimal crop yields, it is necessary to simultaneously implement other best management practices (BMPs), like cover crops, to reap the benefits of conservation tillage techniques on organic fields concerning soil health. The introduction of cover crops had a net beneficial effect on soil organic carbon (SOC) concentrations in this study, but only at 0–15 cm depths (10% increase). Nevertheless, cover cropping had no discernible impact on the depth-weighted SOC concentrations. Additionally, studies have indicated that the addition of cover crops to other BMPs, such as conservation tillage may improve soil health even more (Kimble et al., 2000). Unfortunately, there isn't enough research in organic systems that examine the results of mixing cover crops with other BMPs.

**2.2 Reduced evaporation:**

Cover crops shade the soil surface, reducing the rate of evaporation, a major source of water loss in arid and semi-arid regions. This can reduce water loss by up to 50%. Additionally, cover crops help reduce wind speed, further reducing evaporation.

Cover crops play a dual role in affecting soil water dynamics. During their establishment and growth, they transpire water, reducing soil water content for the subsequent crop (Unger and Vigil, 1998; Sharma and Irmak, 2017; Wang et al. 2021). Conversely, the residue of cover crops accumulated on the soil surface contributes to water conservation. This is achieved by minimizing evaporation loss (Delpuech and Metay, 2018) and enhancing soil infiltration and water-holding capacities (Blanco-Canqui *et al*., 2011; Basche *et al*., 2016; Basche and DeLonge, 2019; Wang et al., 2021). Changes in soil water storage throughout cover crop growth and post-termination calculates the Plant Available Soil Water (PSE) and Soil Water Storage at Planting (SWSP). These factors play a role in determining yields, water use efficiency (WUE), and evapotranspiration (ET). However, the impact of cover crops on WUE and ET is inconsistent in the literature (Zhang *et al.,* 2013, 2015; Nielsen *et al*., 2015; Deng *et al*., 2017; Frasier *et al.,* 2017; Xue *et al.,* 2017; Wang et al., 2021).

Cover crops are widely embraced for various agricultural benefits, including enhancing soil carbon sequestration and soil aggregation, reducing nutrient leaching, preventing erosion, and serving as effective tools for weed and insect control when compared to fields without cover crops (De Baets *et al*., 2011; Gabriel *et al*., 2012; Poeplau and Don, 2015; Damien *et al.,* 2017; Osipitan *et al.*, 2019).Top of Form

**2.3 Controlled erosion:**

Cover crops play a crucial role in governing erosion by protecting the soil from the effects of raindrops and wind. This is essential as erosion can reduce the water available to plants. Raindrops can break up soil particles, causing them to detach from the surface, leading to runoff. Cover crops intercept raindrops and break their momentum, allowing water to infiltrate the soil more easily. They also help to reduce wind erosion by holding soil particles in place with their roots. In general, cover crops play an essential role in balancing soil health and nutrient availability.

In soil water conservation practices, cover crops serve to reduce water erosion and runoff. They offer a surface cover (permanent) between main crop growing seasons, providing ongoing protection against erosion even after termination. Adding cover crops to the soil, especially in the form of green manure, is a good fit for no-till and intensive cropping systems. These crops contribute to various ecosystem services, such as improving soil fertility, properties, water quality, and biological diversity. Cover crops also enhance soil infiltration, organic matter content, and aggregate stability, promoting better water management. Their roots play a crucial role in reducing soil erodibility, strengthening soil aggregates, and preventing concentrated flow erosion. Despite challenges in water-limited regions, proper management, species selection, and early termination make cover crops a valuable addition to sustainable agricultural practices. They boost infiltration, create macro pores, increase soil organic matter, and improve aggregate stability and soil microbial biomass. The roots and microbial processes contribute to improving water infiltration and active carbon, reducing soil erosion and susceptibility, and promoting aggregate formation and stabilization. The surface of cover crops (canopy and residue cover) acts as a buffer against erosivity of raindrops, intercepting runoff and supporting water infiltration. These crops also augment below-ground biomass and interact with the soil under no-till, reducing soil erodibility. Different cover crops have different densities of roots; rye and oats have extensive, fine roots that prevent concentrated flow erosion. In semi-humid or humid climates, cover crops are being integrated into advanced cropping systems with conservation tillage. They can be cultivated as summer/fall-after-winter crops like winter wheat or as winter-after-summer crops.Top of Form

**2.4 Increased snowpack and suppressed weeds**

Cover crops trap snow on the soil surface, increasing snowpack and facilitating increased water availability in spring and summer. Snowpack is a crucial source of water for irrigation and drinking in many regions, and cover crops provide a surface for snow to accumulate on, contributing to the overall increase in the snowpack.

Cover crops might contribute to increasing winter albedo by mitigating wind erosion and preventing the deposition of soil particles on snow, commonly known as "snirt." While research is needed to quantify this effect, cover crop impacts on snow accumulation level (depth) and winter wind erosion could moderate reductions in albedo. Existing studies focusing on boreal winter may only partially capture countervailing impacts beyond snowy periods when exposed soil generally reflects less light than cover crop foliage. Further investigation is required to precisely determine the season-long net albedo effects resulting from the relationship among cover crops, soil colour, and snowpack in various regions. (Hunter *et al*., 2019).

Cover crops are crucial in enhancing water use efficiency by suppressing weeds, thereby reducing competition for water with cash crops. The motives for growing cover crops are to enhance aboveground diversity, weed suppression, decrease herbicide use and wildlife habitat improvement, and disrupt insect pest cycles and disease. Also, cover crops enhance soil quality, improve microbial biomass, and reduce soil erosion and growth efficiency. By reducing nitrogen leaching and storing excess fertilizer, they lower the need for additional fertilizer in cash crop production. A higher water-holding capacity can result from changes in soil quality, such as improved texture, soil aggregation, porosity, infiltration, and organic matter. This can help the cash crop's productivity during seasonal aridity (Frye *et al.,* 1988; Keisling *et al.,* 1994; Letter *et al.,* 2003; Blanco-Canqui *et al.,* 2015; Lal, 2020). Cover crops, however, could utilize water that the cash crop needs in dry areas. Farmers primarily adopt cover crops because of the local benefits they offer, however, the benefits vary depending on various factors, such as management techniques, climate, type of soil, and plant. (Unger & Vigil, 1998; Meisinger *et al.,* 1991; Sainju *et al.,* 2003; Tonitto *et al.,* 2006; Kaspar & Singer, 2011).

Concerning weed management, the residues of cover crops have been stated to have a detrimental impact on the establishment and germination of weed seeds. Additionally, crop residues may alter soil physical properties, such as improving moisture conservation (Liebl *et al.* 1992; Weston 1996; Ohno *et al*. 2000; Kruidhof *et al*. 2008b;). Residues that remain on the soil surface can result in reduced soil temperature variations and diminished light penetration, both proven to suppress weed germination (Teasdale and Mohler 1993; Liebman and Mohler 2001). Winter oilseed rape and rye are two cover crops that grow well in temperate areas; they both contain allelochemicals, but quite different kinds. In addition to their allelopathic effects, crop residues can affect weed germination and establishment by a variety of other methods. The release of nutrients from the residues can promote weed germination, while the breakdown of high C/N residues can also temporarily immobilize nutrients in the soil, inhibiting germination. (Stevenson 1986; Palm et al., 1997; Liebman and Mohler, 2001; Teasdale and Pillai, 2005). Crop leftovers may also have an impact on the soil's physical characteristics. For example, soil modified with residue may be better at retaining moisture (Liebl *et al*. 1992; Sarkar et al., 2020). The residues remain on the soil's surface can reduce the variations in soil temperature and less evaporation.

**2.5 Carbon sequestration**

Cropland soils suffer from depleted soil organic carbon (SOC) due to cultivation, resulting in 30–40% SOC losses compared to semi-natural or natural vegetation (Don *et al*., 2011; Poeplau *et al*., 2011). Integrating cover crops into cropping systems presents a compelling solution for carbon sequestration. Unlike extensification or organic manure applications, cover crops neither decrease yields nor cause carbon losses. Cover crops, or intercrops or catch crops, are crops that are planted in place of bare fallow throughout the winter and then turned over as green manure prior to the main crop being sown. Beyond increasing carbon input, cover crops reduce soil erosion, enhance biodiversity, and abate drought stress for subsequent crops when used as mulch cover. Cultivated in autumn and winter, they uptake excess nitrogen, reducing N leaching. Despite their known benefits, comprehensive quantitative data are deficient regarding the mid-to-long-term impacts of cover crops on the storage of soil organic carbon (SOC). Comprehensive analysis is needed to evaluate their impact on SOC stocks comprehensively. The inclusion of cover crops instead of fallow periods increases cropland SOC stocks, offering an effective measure to offset human-caused greenhouse gas emissions (Lal, 2004). By adding more carbon assimilation during periods of bare fallow, cover crops enhance the net ecosystem carbon balance. In contrast to other organic supplements, a large amount of carbon is added to roots from cover crops, and research has shown that this method of adding carbon is more successful than adding it above ground. Furthermore, higher SOC may have a positive impact on plant growth, raising the primary crop carbon input (Brock *et al*., 2011; Kätterer *et al.*, 2011).Top of Form

1. **Technical Considerations for Selecting and Managing Cover Crops for Water Conservation**

When choosing and managing cover crops for water conservation, a number of factors are considered, including:

**3.1 Climate:**

Choosing cover crops adapted to the local climate, considering factors like temperature, precipitation, and soil type, is crucial. Cover crops can be incorporated with cropping systems by cultivating them during the lean period and terminating them before growing the primary crop or by incorporating them as living mulches throughout the primary cropping season. Choosing cover crops that efficiently suppress weeds over prolonged periods and align well with perennial production systems is crucial. Cover crops create unfavourable conditions for weed germination by competing for nutrients, water, light, and allelopathic effects. The selection of cover crops depends on factors like crop rotation patterns, primary crop duration, fallow periods, and tillage practices. Successful primary crop/cover crop associations require appropriate management practices, including suitable sowing dates, planting patterns, mowing/cutting strategies, and effective methods for terminating cover crops when no longer needed. Annual cover crops are often preferred in intensive vegetable rotations, while in perennial cropping systems, adaptation to low light conditions and easy management are essential for cover crops between rows in vineyards and orchards. The selection process should involve an in-depth analysis of existing cropping systems and management systems at the field scale to ensure compatibility and maximize benefits.

**3.2 Planting time:**

Cover crops should be grown at the appropriate time of year to confirm that they have adequate time to establish themselves before the onset of hot weather or drought conditions.

**3.3 Termination timing:**

Terminating cover crops at the right seasonal juncture is crucial to prevent them from competing with the cash crop for nutrients and water. Various methods, such as tillage, crimping, or herbicide application, can be employed before planting the spring crop to terminate the cover crop. Selecting the precise moment for controlling the vegetative cover crop is essential, as many commonly used species like rye, oats, chickpeas, vetches, and forage radishes can germinate if allowed to mature.

**3.4 Top of Form**

**Residue management:**

Cover crop residue should be managed in a way that protects the soil from erosion and evaporation. Achieving this can involve either leaving the residue on the soil surface or mixing it into the soil.

To mitigate the devastating impact on young plant growth, it's crucial to manipulate the timing of cover crop residue placement concerning seed sowing (Kalinova, 2010). The effectiveness of surface mulches in prompting weed seed development and seedling growth depends on mulch type, quantity, and structure. Cover crop residue quality, determined by C/N ratio, decomposability, and allelochemical composition, is a critical factor. Quantity matters too; high amounts optimize weed suppression, while lower amounts may stimulate weed emergence due to insufficient inhibition or provide uniform moisture conditions, promoting germination. Creating densely packed, multi-layered cover crop residue mulch enhances weed suppression, with management practices maximizing mulch area and volume proving effective. Tissue disruption and residue placement methods influence decomposition rates and allelochemical release. Chopping increases decomposition speed, and residues mixed with the soil decompose faster than those on the surface, leading to a quicker release of allelochemicals (Kruidhof *et al.* 2009).

1. **Economic Benefits of Using Cover Crops for Water Conservation**

The expenses associated with cover crop seeds exhibit significant fluctuations annually and regionally. Historically, establishing legume cover crops has incurred approximately twice the cost of small grain covers. However, the higher establishment cost of legumes can be balanced by their ability to replace nitrogen (N). Utilizing cover crops for water conservation yields economic advantages, notably in reducing irrigation expenses. Improved soil water infiltration and retention attributed to cover crops contribute to the mitigation of irrigation costs. This means that farmers can use less water to irrigate their crops. Improve crop yields as cover crops can help to improve crop yields by improving soil health and suppressing weeds. Healthy soils produce higher yields than unhealthy soils. Cover crops can also help reduce weed competition, which can lead to improved yields. Reduced fertilization costs as cover crops can help reduce fertilizer costs in several ways. First, they can enhance nitrogen in the soil (Suryawanshi *et al.* 2023). Nitrogen is a vital nutrient for plant growth, and it can be expensive to purchase fertilizer nitrogen. Second, cover crops reduce the nutrient leaching from the soil. Nutrient leaching is the loss of nutrients from the soil through runoff or drainage. When nutrients leach from the soil, they are no longer available to crops, and farmers must apply more fertilizer to compensate.

1. **Call to Action**

For farmers and ranchers, the adoption of cover crops is strongly recommended. The integration of cover crops plays a vital role in water conservation, soil health improvement, and enhanced crop yields. Numerous resources exist to deepen understanding of cover crops and their application in farming. Local extension offices offer valuable information on cover crop selection, planting techniques, and effective management practices.

There are also several financial assistance programs available to help farmers and ranchers adopt cover crops. These programs can help cover seed, planting, and termination costs. By using cover crops, you can help to protect your land, your water resources, and your future.

1. **The Future of Cover Crops for Water Conservation**

Cover crops are quite innovative practice in many regions, but they are quickly advancing in popularity as farmers and ranchers realize the many benefits they can provide. As cover crops become more widely adopted, we can expect to see even greater benefits for water conservation and other aspects of agricultural sustainability. One of the most exciting trends in cover crop research is the innovation of new cover crop varieties that are specifically designed to improve water conservation. For example, scientists at the University of California, Davis have developed a new variety of ryegrass that is able to use water more efficiently than traditional ryegrass varieties.

Another promising area of research is the utilization of cover crops in conjunction with other water conservation practices, such as drip irrigation and no-till farming. Studies have revealed that combining cover crops with other water conservation practices can lead to even greater water savings. As cover crops become more widely adopted and as new cover crop varieties and management practices are developed, we can expect to see even greater benefits for water conservation in agriculture.

1. **Challenges and Opportunities**

The establishment and management of cover crops pose significant challenges in certain soils, primarily due to nitrogen immobilization. Inadequate residue management can lead to planter residue accumulation, uneven soil drying, delayed seedbed warming, and interference with sowing and fertilizing activities, ultimately impeding seedling emergence. Issues such as hair pinning and allelopathic effects on the primary crop can arise under residue-laden conditions. In semiarid or water-inadequate regions, the implementation of cover crops is limited due to the potential decrease in plant-available water for the primary crop. Challenges, including labor requirements, cover crop timelines, and limited machinery, further complicate the task for farmers in growing cover crops.

Despite the many benefits of cover crops, some challenges still need to be addressed before they can be more widely adopted. One challenge is that cover crops might compete with cash crops for nutrients and water. This can be a problem in regions where water resources are limited. Another challenge is that cover crops can be expensive to plant and manage. However, several financial assistance programs are available to help farmers and ranchers adopt cover crops.

Despite these challenges, there are many opportunities to expand the use of cover crops for water conservation. One possibility is to develop new cover crop varieties better adapted to specific regions requiring less water and nutrients. Another opportunity is to create new cover crop management practices that are more efficient and cost-effective. For example, researchers are developing new ways to terminate cover crops without using herbicides. By addressing the challenges and seizing the opportunities, we can make cover crops a more viable option for water conservation in agriculture.

**Conclusion**

Global Population is predicted to reach nine billion by year 2050, posing a serious challenge to agriculture, which must simultaneously meet future food demands and mitigate the risks of environmental pollution, natural resource depletion, and climate change. Its correction is urgently needed, and a lot of focus has been placed on improving soil health and addressing other negative effects of agriculture, such as nutrient leaching, soil erosion, and water pollution, by implementing crop rotations or reduced tillage. Due to enormous advantages, including reduced soil erosion, weed suppression, soil aggregate stability, improved soil organic carbons, carbon sequestration, improved soil hydraulic characteristics, and reduced soil erosion, cover crops are recognized as a practical and sustainable agriculture technique.

Cover crops offer a promising solution for sustainable water conservation in agriculture. Their ability to enhance soil health, reduce evaporation, control erosion, and suppress weeds leads to more efficient water use and healthier farmlands. While challenges like competition with cash crops and higher costs exist, ongoing research and improved management practices hold immense potential for expanding cover crop adoption and their positive impact on water conservation in the future. The call to action for farmers and ranchers to embrace cover crops is a crucial step toward securing a more sustainable and water-resilient agricultural landscape.

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