CEMA
European Agricultural
Machinery Association

Position Paper

# CEMA supports science-based Regenerative Agriculture

September 2024

# Index

## Acknowledgments

The CEMA Strategic Committee and the CEMA Secretariat would like to extend their heartfelt thanks for their reviews and contributions to this position paper to:

The CEMA President,
The CEMA Board Members,
The CEMA Strategic Committee Members,
The CEMA National Association Members,
The Member Company experts.

# Introduction

**CEMA**, is the association representing the European agricultural machinery industry. With 11 national member associations, the CEMA network represents both large multinational companies and numerous European SMEs active in the sector.

CEMA represents about 1,300 manufacturers, producing more than 450 different types of machines with an annual industry turnover of about €40 billion and 150,000 direct employees. CEMA companies produce a large range of machines that cover any activity in the field from seeding to harvesting, as well as equipment for livestock management. Our industry offers a wide range of machinery and technology solutions for sustainable farming and is dedicated to enhancing the vitality of agricultural soils across Europe.

This paper aims to contribute positively to the ongoing debate on regenerative agriculture. It will first serve to identify the problem linked to the very definition of the concept of regenerative agriculture. Next, the main advantages of this type of agriculture will be summarized before highlighting its limits. Finally, we will propose some avenues for the dissemination of regenerative agriculture, and in conclusion some policy recommendations.

# 1. What is Regenerative Agriculture?

## 1.1 Many definitions for one concept

Exploring the literature on regenerative agriculture reveals numerous definitions of the concept. While these definitions are generally aligned, they differ on some important points. This observation was also noted in the study conducted by the Forum for the Future of Agriculture on the same subject[i].


(Source: Forum for the Future of Agriculture: https://forumforag..com/wp-content/uploads/2023/10/RegenAg-final.pdf)

A study which includes, as examples, the two definitions provided by the Boston Consulting Group and the Wageningen University:

*"An adaptive farming approach applying practically proven and science-based practices, focused on soil and crop health aimed at yield resilience and a positive impact on carbon, water, and biodiversity."* [ii]

*"RegenAg is an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production."* [iii]

To these definitions we could add the FAO's one:

*"Regenerative agriculture describes holistic farming systems that, among other benefits, improve water and air quality, enhance ecosystem biodiversity, produce nutrient-dense food, and store carbon to help mitigate the effects of climate change."* [iv]

Or the approach provided by the company Bayer:

*"While there is no commonly agreed definition of regenerative agriculture, the term generally refers to farming principles or practices aimed at improving the overall environment with a strong focus on improving soil health and enhancing the ecosystem services provided by agricultural systems.".* [v]

The European Commission also acknowledges that:

*"There is no single definition of "regenerative agriculture", with interpretations varying between practitioners; but it can broadly be defined as "an approach to farming that uses soil conservation as the entry point to regenerate and contribute to the delivery of food production and other ecosystem services."* [vi]

## 1.2 CEMA's approach to Regenerative Agriculture

One of the least considered aspects of regenerative agriculture is that it offers a more inclusive approach to sustainability.

According to the *Sustainable Market Initiative*: Regenerative agriculture can be adopted by numerous farms, regardless of the type of crops. Globally, it is estimated that nearly 15% of farms practice regenerative agriculture, with many more engaging in it partially.[vii]

This is an important aspect to emphasize because, for CEMA, regenerative agriculture, if well designed and equipped with the right tools, appears as an adaptive process rather than a challenge to the agricultural practices that ensure the food security of the European Union.

This inclusive nature is particularly evident in the fact that livestock management is partially integrated into regenerative agricultural practices. Integrating livestock into crop production systems is a practice as old as agriculture itself, but it has gained renewed interest in sustainable farming circles. Livestock can provide numerous benefits to crop systems, including natural fertilization through manure, pest control, and land management through grazing. This integration fosters a symbiotic relationship between crops and animals, creating a more efficient and self-sustaining system. This involves energy generation as a part of the ecosystem, where livestock contribute to field fertilization and biogas plants are converted into energy on the farms[viii].

Furthermore, encouraging diverse crop rotations and integrating livestock into farming systems are crucial steps towards creating balanced agricultural ecosystems. These practices not only support a variety of flora and fauna but also enhance the sustainability and resilience of farming systems. By aligning more closely with natural ecological processes, these methods offer a hopeful pathway for harmonizing agricultural production with environmental conservation.

CEMA supports this holistic approach, which includes conventional farming, crop rotations, livestock and more broadly the dairy farm sector. Such an approach is undeniably beneficial for the environment and sustainability of agriculture.

**CEMA believes that <u>regenerative agriculture should be a science-based approach to farming</u> that prioritizes the restoration and preservation of soil health as necessary. It encompasses a wide range of farming techniques and empirical evidences aimed at replenishing the organic matter in soil, thereby improving water cycles and enhancing resilience to climate change. These practices vary from one country to another and must be site-specific and appropriate for the local soil types and prevailing climate.**

CEMA does not subscribe to the idea that there would be one-size-fits-all approach to regenerative agriculture, but fully acknowledges its potential as a leading paradigm for voluntary schemes supporting sustainable farming.

## 2. The benefits of Regenerative Agriculture

In this section, we will mention the most significant benefits of regenerative agriculture. There are numerous reference studies on this subject. This paper is not a detailed study of the practices associated with regenerative agriculture, but a contribution to the debate on how our industry can share its experience and technologies for the implementation of these practices.

### 2.1 Enhancing soils' health

Soil health serves as a crucial measure of agricultural sustainability. Employing sustainable farming techniques - such as varied crop rotation, minimal soil cultivation, organic fertilization, and cover cropping-, plays a significant role in enhancing soil structure and fertility. These practices lead to elevated levels of soil organic matter, enhanced microbial activity, soil structure and moisture retention and improved nutrient cycling, culminating in the creation of robust and fertile soil. Healthy soil serves as the foundation for producing high-quality crops and is essential for long-term agricultural sustainability and food security. This is because healthy soils enhance crop resilience against pests, diseases, and climate fluctuations, potentially leading to more dependable yields in the future, despite the possibility of these crops being more susceptible to pest infestations. Improving soil physics and biology is a basic prerequisite for good soil structure also for minimizing tillage.

## 2.2 Water management and conservation

Innovative water management practices are essential components of regenerative agriculture. Methods such as rainwater harvesting, topographic and on-contour field activities, and keyline design are utilized to maximize water usage and mitigate erosion. Additionally, drip irrigation, cover cropping, crop residue incorporation, retention, cover and the application of living mulches, where possible, aid in water conservation and reducing evaporation, allowing for the efficient utilization of this vital resource. Shallow stubble cultivation is another tool for reducing evaporation.

All these practices lead to improved water retention and increased resilience against gully rid or erosion. In some specific areas, new breeding techniques and crops could have a positive impact on the demand for water.

## 2.3 Carbon sequestration and climate change mitigation

Regenerative agriculture appears to be a promising response to climate change. There are several key regenerative practices that contribute to the sequestration of carbon in the soil:

Firstly, the minimization of soil disturbance plays a crucial role in maintaining soil structure and organic matter, thereby creating an environment conducive to increased carbon storage.

Secondly, the practice of cover cropping, especially during off-season periods, serves to introduce organic matter into the soil, retaining nutrients left by the crop, and further capturing carbon by extending post-harvest photosynthesis on the arable portion of the landscape.

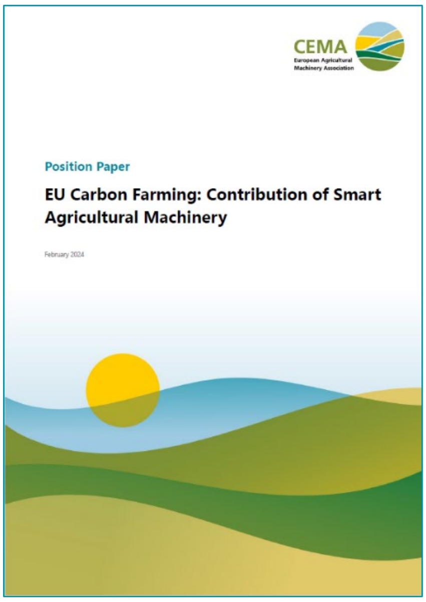
Thirdly, the implementation of diverse crop rotations supports a spectrum of soil organisms, each of which contributes to the storage of carbon in unique and complementary ways.

Fourthly, the adoption of agroforestry and perennial crops provides deep-root systems that are particularly effective in storing carbon beneath the soil surface.

Finally, the utilization of organic amendments, such as compost and other organic materials, serves to enrich the soil's carbon content, thereby contributing to the overall sequestration effort.

These practices directly facilitate the removal of CO2 from the atmosphere. The improvement of soil health engenders better nutrient use efficiency, thereby reducing the reliance on synthetic fertilizers, which are a significant source of nitrous oxide, another potent GHG.

In line with these practices, CEMA published a dedicated Position Paper[ix], emphasizing the importance of considering broader carbon reduction opportunities:




CEMA: https://cema-agri.org/images/publications/position-papers/CEMA-EU_Carbon_Farming-_Position_Paper_2024-02.pdf

## 2.4 Boosting biodiversity

Biodiversity is a vital element of regenerative agriculture, representing the complex relationships among flora and fauna in natural ecosystems.

In agriculture, biodiversity refers to the rich variety of plant, animal, and insect species that play a vital role in the ecological balance of food production. More biodiversity enhances ecological resilience and agricultural system health. Diverse crop rotation and plant communities enrich the soil with nutrients and contribute to ecological balance, while cover crops provide additional nutrition and income.

Livestock, birds, and insects play key roles in nutrient cycling, pest management, and pollination, bolstering agricultural productivity. Regenerative agriculture employs various techniques, such as catch rotation, to maintain biodiversity and soil health. Additionally, strategic crop rotation and cover crop integration enhance soil fertility and protect soil resources. Livestock rotation prevents overgrazing and soil compaction, ensuring even nutrient distribution. These integrated approaches highlight regenerative agriculture's benefits for biodiversity and ecological resilience, especially across mixed landscapes that include forests and riparian zones.

## 2.5 Other benefits

Some social science research indicates that regenerative agriculture increases resilience of farming communities. They are less susceptible to market fluctuations and climate extremes.[x] Furthermore, regenerative agriculture practices are well-aligned with the increasing consumer demand for sustainably and ethically produced food, creating new opportunities for farmers. As a result, products from regeneratively farmed land could potentially be preferred to command premium prices in the market. However, inflation shifted consumers priorities and the demand for organic food fell substantially in 2023.[xi]

So, while organic food and food from regenerative practices are different, both are subject to the forces of supply and demand.

As mentioned earlier, this review of the benefits associated with regenerative agriculture is not intended to be exhaustive. Similarly, this list of advantages should not overlook the obstacles to the adoption of this type of agriculture. These obstacles deserve to be identified.

# 3. Potential obstacles to Regenerative Agriculture

In the same way that we have limited the scope of the main advantages related to regenerative agriculture, we will limit the scope of the main obstacles to its adoption. Once again, the aim here is not to compile a catalogue, but to provide a dynamic perspective to formulate constructive proposals for the expansion of this type of agriculture. The first of these obstacles that comes to mind is the cost of adopting regenerative agriculture.

## 3.1 Absence of clear metrics and goals

Within the realm of regenerative agriculture, some farmers have expressed concerns about the absence of universally agreed-upon metrics and alignment regarding desired outcomes. This uncertainty has led to fears that the expectations and standards could constantly be in flux. Additionally, there is apprehension that off-takers and NGOs may advocate for different or even conflicting outcomes, potentially adding to the complexity and challenges faced by farmers seeking to transition to regenerative practices. This lack of consensus on metrics and outcomes underscores the need for greater collaboration and communication within the agricultural community to ensure a cohesive approach towards regenerative agriculture practices. Trust and consumer alignment should prevail in shaping this cohesive approach.

One of the inherent challenges in defining universal criteria to qualify the objectives to be achieved in regenerative agriculture is that each farm has different geological, ecological, and climatic characteristics. In our view, policy flexibility supporting regenerative agricultural practices should account for the diverse production factors and conditions encountered. In addition, solutions should be market driven, yet flexible enough to encourage adoption by agricultural advisors, producers, and the like. In this sense, the training of independent agricultural advisors capable of supporting farmers in their transition appears as a necessity.

## 3.2 Impact on yields and farmers' income

Even though different studies lead to different results, there is some consensus that agricultural yields decrease during the initial years of transitioning to regenerative agriculture. According to *Elsevier Agricultural Systems* yields drop by as much as 29% for cereals:

*"Regenerative farms produced 29% less corn grain than conventional operations (8,481 ± 684 kg/ha vs. 11,884 ± 648 kg/ha; ANOVA; $F_{1,70} = 8.39$, $P = 0.01$). Yield reductions are commonly reported in more ecologically based food production systems relative to conventional systems."*[xii]

Some studies suggest that the economic impact is either neutral or positive, while others indicate it is negative.

For instance, a study from LaCanne and Lundgren (2018) comes to the same findings as *Elsevier* but underlines that the drop in yields is compensated by higher profits: *Regenerative fields had 29% lower grain production but 78% higher profits over traditional corn production system*[xiii].

We believe that the impact differs from one farm to another depending on its marketing position and the types of contracts linking these operations to major purchasers of agricultural products. Merely considering yields is insufficient when evaluating the viability of regenerative agriculture. In instances where yields decrease, the use of inputs also typically decreases. Therefore, both economic and ecological performances must be considered in this context.

The feedback CEMA members have received from their customers tends to confirm that, in the European Union, the decline in agricultural yields during the transition period is indeed accompanied by a decrease in profitability, particularly in the third and fourth years.

The transition phase represents one of the main barriers to widespread adoption of regenerative agriculture. This is especially true given that the agricultural sector is characterized by narrow profit margins subject to the vagaries of market cycles and price fluctuations. Without external financial support, it is particularly difficult for EU farmers to adopt different agricultural practices, especially if they are facing cash flow difficulties and anticipate a market downturn. Therefore, there is a general concern that the new revenue streams may be diminished or not sustainable, potentially resulting in farmers facing ongoing costs that outweigh any agronomic benefits. This is especially true given that this transition requires access to new technologies and types of equipment.

It is worth noting that certain studies, such as the one by Peter Breunig and Marcus Mergenthaler, published in March 2024, clearly show that the greatest carbon sequestration benefit is attained through increased agricultural production. Their conclusion highlights that decreasing pork and dairy production would result in a reduction in carbon benefits[xiv]. This study emphasizes how critical it is to keep or increase European agriculture's yields and output.

## 3.3 Access to innovation and equipment

Transitioning to regenerative practices frequently necessitates acquiring new or alternative resources. These encompass access to premium seeds, organic fertilizers, training/education/consulting, suitable tools, and equipment for cover cropping and handling of cover crops. Financial resources play a pivotal role as well, as farmers may encounter initial expenses when integrating new practices or endure temporary reductions in yield throughout the transition phase.

Several cases have highlighted the limited availability of specialized machinery, such as lightweight direct seed drills or planters, at an affordable cost, particularly concerning the expected profits from regenerative practices. The same applies to some current technologies linked to weed control inputs or carbon-fixing cover crops, for instance.

In the next part of this paper, we will delve further into the equipment needed for the transition to regenerative agriculture and the practices it entails. However, it must be acknowledged that there is a clear paradox here: Farmers are required to invest in a transition project that, initially, will lead to a decrease in profitability, and unknown outcomes for their crops whereas the logic behind any investment is to increase the profitability of the business and certainly not increase the level of risks.

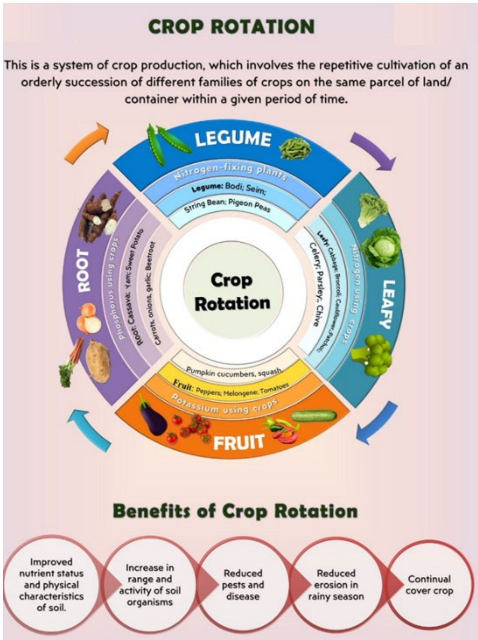
# 4. Avenues for the dissemination of Regenerative Agriculture

In this section, we will illustrate some of the practices and machinery commonly associated with regenerative agriculture using existing or protype technologies. These technologies are provided as simple examples. Other solutions may exist, and many are still to be developed. The priority focus should be on crops.

## 4.1 Crops

### 4.1.1 Crop rotation

Worldwide it is very well-known that crop rotation offers numerous benefits to soil health.




Source: Ministry of Agriculture, Land of Fisheries, Trinidad and Tobago

By diversifying the types of crops grown in a field over successive seasons, crop rotations help improve soil fertility, reduce the build-up of pests and diseases specific to a particular crop, and enhance the overall structure and quality of the soil. The practice of rotating crops also aids in the replenishment of essential nutrients in the soil, reduces erosion, promotes better water retention, and contributes to the long-term sustainability of agricultural land. Crop rotation is clearly addressed by the EU Common Agricultural Policy but certainly needs to be reviewed.

In this respect CEMA supports the EU Commission's proposal from March 2024 to: *"ease administrative burden for EU farmers, [and] review certain provisions of the Common Agricultural Policy (CAP), aiming to deliver simplifications while maintaining a strong, sustainable and competitive policy for EU agriculture and food",* [including] *good agricultural and environmental conditions" (GAECs).*

The proposal from the EU Commission to review GAEC 7, supports the science-based and freedom of farming approaches promoted in this policy paper. Indeed: the amendment of GAEC 7 will allow EU farmers to meet the crop rotation requirement by either rotating their crops or diversifying them. The flexibility to opt for crop diversification instead of rotation is welcomed and will be beneficial for farmers dealing with challenges like regular drought or excessive rainfall. This adaptation will provide farmers with more options to comply with the regulation based on their specific conditions and the choices made by their country in the CAP Strategic Plan[xv].

### 4.1.2 Intercropping systems

Intercropping holds a crucial position in the realm of regenerative agriculture. Intercropping stands apart from other strategies employed by farmers to enhance diversity in cropping systems, such as crop rotation, insectary strips, and buffer plantings. Crop rotation, a more prevalent practice in large-scale agriculture, involves cultivating different crops sequentially in the same field to achieve temporal diversification. The central concept behind intercropping is habitat partitioning, where multiple species utilize light, water, nutrients, and other resources in distinct ways, leading to an overall increase in productivity. For instance, clover legumes can act as living mulches, providing fixed nitrogen to a complementary grain like corn. The legumes can thrive despite corn's competitive advantage for sunlight due to its taller growth. As the corn matures, its canopy opens up, allowing the legumes to gain a competitive edge. A crucial aspect of this system is to ensure that the corn is well-established early in the growing season, either mechanically or through other methods; otherwise, corn grain yields may decline. Other intercropping strategies include aerial seeding, multiple plantings of annual crops, and various alternative solutions.

Intercropping implies different crops to be grown side by side alternating rows and strips in the same field (spatial diversification), one needs smart planters connected to GNSS which can plant different crops at different time, like the multi hopper seed drill shown below:


(Photo Credit: courtesy of CEMA member)

Furthermore, specialized machinery tailored for inter-seeding, such as high clearance drills suited to different terrain types and seed varieties, may be necessary. In the below example, the equipment traverses over a young soybean crop to sow a cover crop during the middle of summer.

(Photo Credit, Pennsylvania State University, AgroEcology Lab)[xvi]

Combine harvesters need to be modified for intercropping purposes as they are typically designed to harvest a single crop type at a time. While certain companies provide adaptable solutions allowing for the swift attachment and removal of blades, crop pickers, and rock lifters to and from the combine's main frame, there is currently no universal solution available to accommodate the diverse configurations required for relay intercropping. Selecting species for intercropping that involve diverse plant stature can help mitigate the harvesting challenge.

(Photo credit: AgriExpo, https://www.agriexpo.online/prod/flexxifinger-qd-industries-inc/product-169042-127435.html)

### 4.1.3 Cover crops

In conventional farming circles, monoculture has historically been seen as a hallmark of a skilled farmer. Similarly, winter fallowed fields have traditionally been left bare without any vegetation, reflecting a mindset that is now evolving. The most rapidly growing trend in agriculture today is the adoption of cover crops and strip-till soil management.

(Photo Credit: USDA, Cover Crops for Climate Resilience,
https://www.climatehubs.usda.gov/hubs/northwest/topic/northwest-cover-crops-climate-resilience)

Cover crops play a crucial role in soil health by reducing erosion, enhancing water quality, managing weeds, attracting beneficial insects, and decreasing nutrient-laden runoff into surface water bodies. Suitable cover crops include various legumes, grains, crucifers (like mustard, linum, etc.), and grasses, are cultivated primarily to improve soil health rather than for commercial harvest. They are either mechanically or chemically terminated so as not to adversely affect the subsequent crop in the rotation.

Cover crops not only offer economic benefits by boosting yields but also provide ecological advantages by sequestering carbon and enhancing soil fertility and hosting wildlife. As weather patterns become more extreme and unpredictable, the benefits of cover crops become more pronounced, particularly when compared to fields lacking cover crops.

The adoption of cover crops signifies a shift in farming practices from chemical-dependent approaches to biological strategies. By harnessing the power of photosynthesis and plant decomposition, cover crops emulate nature's natural processes for cycling carbon and other nutrients, fostering synergies with an intricate network of organisms in the soil food web. These practices involve shifting from strict monoculture, where a single species achieves maximum canopy growth during the optimal part of the growing season, to promoting extended canopy growth (and/or residual non-live canopy) through the use of multiple successive or coexisting species.

In non-living mulching, a layer of material such as straw, leaves, plastic film, or biodegradable materials is placed on the soil surface around plants to provide various benefits. Mulching helps to retain soil moisture by reducing evaporation, regulating soil temperature, suppressing weed growth, and preventing soil erosion. Additionally, mulch can improve soil structure and fertility over time as it decomposes, adding organic matter to the soil. In this respect, care must be taken so that single-use plastics do not enter surface waterbodies, as they are harmful to fish, birds, turtles, and other animal classes.

Mulching and cover crops can further enhance the benefits to the soil and overall agroecosystem. For instance, using cover crops as living mulch can provide continuous soil coverage, weed suppression, and nutrient cycling throughout the growing season. Mulching with organic materials can complement the benefits of cover crops by adding additional organic matter to the soil, promoting microbial activity, and improving soil moisture retention.

Some common equipment used for mulching include:

**Mulching Mowers:** These are specialized mowers designed to cut grass, weeds, and small vegetation into fine pieces that are then distributed evenly over the ground as mulch. They are commonly used for maintaining grassy areas, orchards, vineyards, and roadsides.

**Flail Mowers:** Flail mowers have rows of small metal knives (flails) that rotate at high speeds to chop vegetation into small pieces. They are often used for mulching heavy grass, brush, and small trees.

**Compact discs harrow:** equipped with two rows of concave discs, to cut and incorporate organic matter before planting or after harvest.

(Photo Credit: courtesy of CEMA member)


(Photo Credit: courtesy of CEMA member)

(Photo Credit: courtesy of CEMA member)

Thatching could also be performed by this type of equipment steered by precision agriculture technologies:

(Photo credit: courtesy of CEMA member)

Mechanical weeding is also another way to minimize the use of chemical weeding products.

Below is an example of a mechanical weeder including a front tank for spot fertilizer application:


(Photo Credit: Courtesy of CEMA member)

## 4.2 Minimum tillage system

Minimum tillage involves less aggressive shallower cultivations, limited to a depth of 15 cm, without turning over the soil. This approach aids in preserving soil structure by reducing the number of cultivations passes. Implementing lighter cultivation methods such as tines and discs instead of ploughs and power harrows can significantly boost soil health and preserve soil structure.

Enhancing soil health through reduced tillage practices can lead to faster crop establishment and less damage to soil structure over time. By refraining from soil inversion, moisture retention is improved, surface runoff risk is reduced, and the land is better protected against flooding drought. and accelerated eutrophication of surface waterbodies.

Adopting a minimum tillage system in farming not only helps retain nutrients in the soil but also reduces the reliance on fertilizers by preserving organic matter and enhancing soil quality. This, in turn, promotes the proliferation of beneficial organisms like earthworms, crucial residue cycling via bioturbation, improving soil fertility, structure, and microporosity, and aiding in soil regeneration.

Minimum tillage is well-suited for a wide range of soils, particularly drier, stable, and well-drained soils. It is particularly beneficial for soils prone to compaction, such as heavy clay soils, and can also help reduce water runoff in sandy soils. Mixing minimum tillage with strip tillage or cover crops can further enhance soil health and crop yields. To enhance weed control, a light cultivation post-harvest can create a "stale seedbed," encouraging weed germination that can then be targeted before sowing.

The following equipment combination features tractors outfitted with a minimum tillage “compact-disc” harrow systems:

(Photo Credit: courtesy of CEMA member)

(Photo Credit: courtesy of CEMA member)

## 4.3 Meliorative tillage for carbon farming

Member companies of CEMA have developed a plough designed for meliorative tillage, specifically aimed at alleviating soil compaction and enhancing soil quality. This implement features bodies that plough at varying depths, creating wells below the tillage level in alternating furrows, which are then filled with humus-rich topsoil. Historical analyses conducted by the Leibniz Centre for Agricultural Landscape Research indicate that over half of the humus introduced in this way is retained, contributing to long-term CO2 storage in the soil. The lower soil layers, which contain minimal humus and are brought to the surface during the ploughing process, are mixed with the topsoil, resulting in the formation of new humus-rich topsoil within just a few years, as carbon is added from crops. Consequently, the overall humus content of soils treated in this manner increases, leading to improved soil fertility.

Additionally, this sustainable approach not only enhances soil quality but also establishes a new business model centered around carbon farming. By breaking up compacted soils and integrating humus-rich topsoil into the wells, plant roots can penetrate deeper soil layers, accessing water and nutrients stored there. This method has been shown to boost yields by up to five percent, even in the first year. Such benefits were recognized as early as the 1960s and 1980s and have been reaffirmed by recent field trials conducted the Leibniz Centre for Agricultural Landscape Research. This technique can be reapplied diagonally to the primary direction of work every five to ten years.

Beyond these advantages, this innovative carbon farming technology provides farmers with new income opportunities through the trading of CO2 certificates. As a result, potential future taxes on CO2 emissions can be mitigated, thereby enhancing the competitiveness of agricultural operations.


(Photo credit: courtesy of CEMA member)

## 4.4 Soil compaction

Rubber tracks offer significant advantages in minimizing soil compaction compared to traditional wheeled equipment in agricultural operations. The larger surface area of rubber tracks distributes the machine's weight more evenly, reducing ground pressure and minimizing soil compaction. This is particularly beneficial in wet or sensitive soil conditions where compaction can negatively impact soil structure, root growth, and overall soil health.

Research has shown that rubber tracks can help reduce soil compaction by up to 50% compared to wheeled equipment. For example, a study conducted in Germany found that the use of rubber tracks on agricultural machinery resulted in a soil compaction depth of only 15-20 cm, compared to 30-40 cm with wheeled machinery. Additionally, the study reported that soil bulk density was lower with rubber tracks, indicating less soil compaction and better soil porosity.

The study measured soil compaction using a penetrometer and reported a penetrometer resistance of 2.5 MPa with rubber tracks compared to 4.5 MPa with wheeled equipment. Soil bulk density was recorded at 1.3 g/cm$^3$ with rubber tracks and 1.5 g/cm$^3$ with wheeled machinery. These metrics demonstrate the tangible benefits of using rubber tracks to minimize soil compaction and preserve soil health in agricultural operations.

Rubber tracks are especially meaningful for heavy equipment:

(Photo Credit: courtesy of CEMA member)

(Photo Credit: courtesy of CEMA member)

It could also be well adapted to smaller equipment depending on the type of application:

(Photo Credit: courtesy of CEMA member)

Central Tyre Inflation Systems (CTI) and Low Ground Pressure (LGP) tyres are established technologies that have been utilized by farmers for many years to minimize soil compaction. CTI allows operators to adjust tyre pressure on-the-go, optimizing traction and reducing the impact on soil structure during various field operations. By lowering tyre pressure when driving on soft or wet ground, farmers can distribute the weight of their machinery more evenly, thereby reducing soil compaction and promoting healthier soil conditions. LGP tyres complement this system by providing a larger footprint, further aiding in weight distribution. As a result, these technologies have become standard on many modern agricultural machines, enabling more sustainable farming practices and improving overall soil health[xvii].

An example of centrally deflated tyres in the field:


(Photo credit: courtesy of CEMA member)

Another potential and future approach to avoid soil compaction is the use of a fleet of robots. These robots have a considerably lower weight than agricultural machines capable of performing similar tasks, such as seeding. They weigh between 50 and 100 kilograms depending on the models used.

At this stage, the equipment available for large-scale crops are prototypes. There are still various technical and economic barriers preventing their widespread adoption.


(Photo Credit: courtesy of CEMA member)

Larger prototype robots equipped with tracks are also being tested for being placed on the market:


(Photo Credit: courtesy of CEMA member)

For this type of equipment, as well as many others discussed in this paper, a technological step change is necessary for broader dissemination.

## 4.5 Precision nutrient management

Precision manure management supports regenerative agriculture.

The three main nutrients are nitrogen (N), phosphorus (P) and potassium (K). Together they make up the trio known as NPK. Other important nutrients are calcium, magnesium and sulphur.. Fertilizers feed the plants but also soil bacteria which also use nitrogen to produce the energy they need to live and multiply. As a result, soils dependent solely on inorganic fertilizer sources, sometimes receive an overapplication of N to overcome the short-term N tie-up due to accumulation of soil microbial biomass, especially in continuous non-legume rotations.

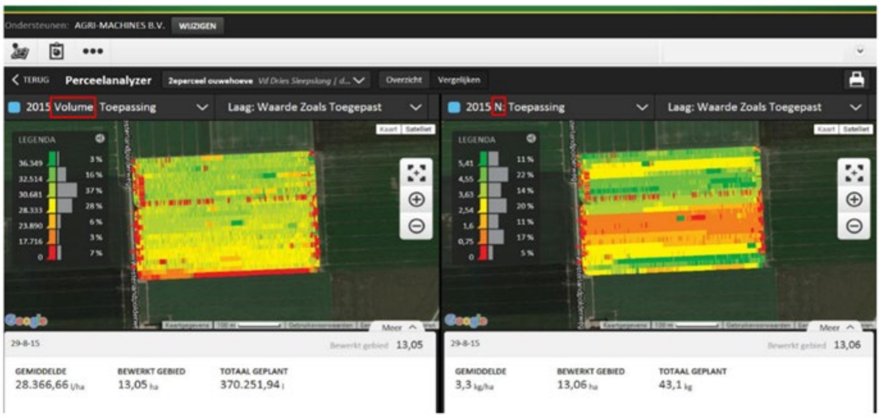
The need to cut anthropogenic nutrient and phosphorus inputs to ecosystems has been widely recognized. According to the EU Seventh Environment Action Programme:

*"High nitrogen losses from agricultural land to the environment have a significant negative impact on biodiversity and ecosystems". (...) Excessive nutrient losses affect soil, air and water quality, have a negative impact on ecosystems".*

Precision manure spreading allows farmers to focus on building soil health and fertility by delivering nutrients in a targeted manner, promoting microbial activity, and improving soil structure. Healthy soils support diverse soil life and increase the capacity of soils to sequester carbon, which is a key aspect of regenerative agriculture.

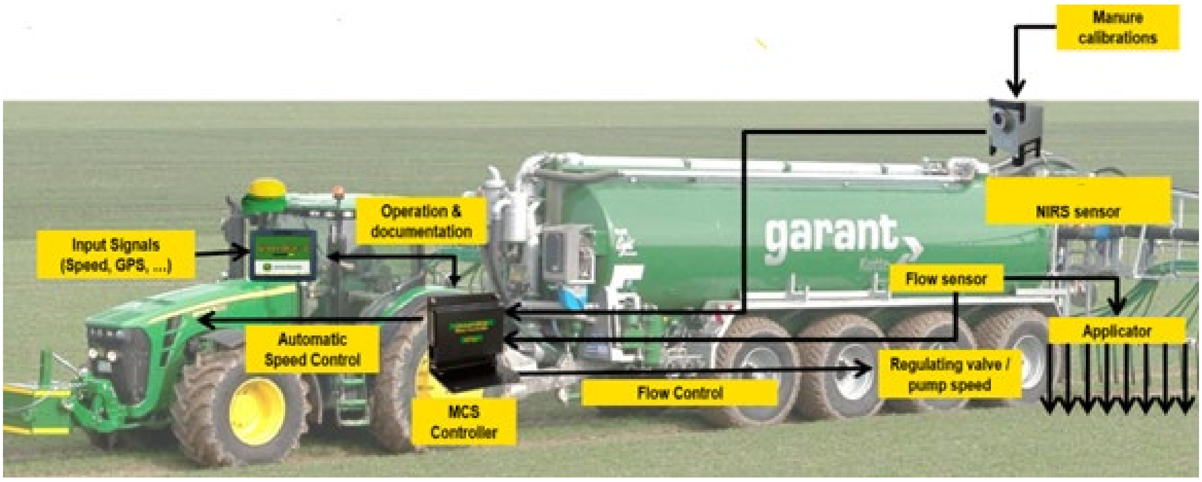
Using near-infrared (NIR) sensors capable of measuring 4000 points per second and the main components of manure such as total nitrogen, ammonium nitrogen, P2O5, K2O and dry matter during field application manure can now be used on the basis for the first time of a target amount (kg / ha) of a nutrient and an optional maximum amount of a second ingredient and, if desired, also based on a given prescription map.

<u>Applied volume and nutrient ingredients</u>




(Photo credit: courtesy of CEMA member)

The system allows a very precise application of organic nutrients with an agronomical optimized, site-specific fertilizer quantity in kg / ha instead of relying on an estimated average nutrient content by applying a certain amount of $m^3$ / ha. This allows significant savings in the cost of mineral fertilizer, maximizing yield and soils' health, while ensuring environmentally friendly and sustainable agriculture. This technology also offers new possibilities for optimizing site-specific nutrient balances. Based on the nutrients, soil fertility status and soil nutrient supplies, the required application rate of the organic fertilizer is regulated and documented fully automatically depending on the continuously measured nutrient content via the tractor speed, valve control and / or pump speed. The scheme below shows how the system is integrated in a slurry tanker:




(Photo Credit: courtesy of CEMA member)

## 4.6 Paludiculture

Paludiculture is the cultivation of biomass on wet and rewetted peatlands. Paludiculture thus combines peatland and climate protection with agriculture. The biomass obtained in this way can primarily provide renewable raw materials for construction and insulation materials, paper and packaging, wood-based materials, and plastics. A traditional example of this is the cultivation of reeds for roofing thatch.

Within the European Union, there are significant peat reserves in Finland, Sweden, Estonia, Latvia, and Ireland. Finland has 9.4 million hectares of peatland, which is about 30% of its total land area. Half of this peatland is drained for agriculture and forestry, while only 0.6% is used for peat production. The energy potential of Finnish peatlands is 58,000 terawatt-hours, which is 6-7 times more than its forests. Sweden has around 10 million hectares of peatlands, and Estonia has 1 million hectares, both offering promising prospects for peat plants as a biofuel feedstock.

Our industry already provides solutions for harvesting unconventional crops from peatlands like sedge:

(Photo Credit: courtesy of CEMA member)

Or reeds:

(Photo credit: Universität Greiswald, https://www.uni-greifswald.de/universitaet/information/aktuelles/detail/n/paludizentrale-begleitet-nasse-moornutzung-auf-dem-weg-zum-markt-new65b0e8499ca96437930435/)[xviii]

According to Kari Mutka and Timo Nyrönen (2008)[xix], peat is an excellent raw material for biofuel for several reasons. It is a great source for biodiesel and there are abundant reserves of peat in Nordic and Baltic Region countries. Extracting peat from drained peatlands can reduce greenhouse gas emissions by 35%. Harvesting peat from drained areas has minimal impact on biodiversity and the extraction sites are usually small, if peatlands remain protected from mining. Using peat plants as a biofuel does not compete with food production.

## 4.7 Agroforestry

Agroforestry involves the harmonious integration of woody vegetation, crops, and/or livestock within the same land area. Trees can be strategically placed within fields or along boundaries such as hedges.

(Source: Wikipedia, *What is Alley Cropping?* Photo Credit: *USDA National Agroforestry Center.* February 2012 https://en.m.wikipedia.org/wiki/File:Alley_cropping_corn_walnuts.jpg)

This practice can be implemented across all agricultural systems throughout Europe. It encompasses planting trees within agricultural land or incorporating agriculture within existing woodlands or orchards, known as silvopasture.

This type of equipment could plant thousands of poplar trees per hectare in a short time:

(Photo credit: Lingnovis: https://www.lignovis.com/en/services/planting-of-agroforestry-short-rotation-plantations-srp.html)

Europe boasts a rich heritage of traditional agroforestry systems that hold significant environmental and cultural value. Moreover, the continent exhibits great potential for innovative modern agroforestry systems, which have been developed by research institutions over the past two decades. Agroforestry entails the fusion of agricultural and forestry practices to establish cohesive and Europe boasts a rich heritage of traditional agroforestry systems that hold significant environmental and cultural value. Moreover, the continent exhibits great potential for innovative modern agroforestry systems, which have been developed by research institutions over the past two decades. Agroforestry entails the fusion of agricultural and forestry practices to establish cohesive and sustainable land-use systems. Although this concept may seem novel to some, agroforestry has ancient roots and is prevalent in various regions worldwide.

One of the fundamental aspects of agroforestry is its ability to deliver economic and environmental benefits concurrently. These advantages encompass topsoil preservation, soil fertility restoration, protection of crops and livestock, product diversification, mitigation of risks linked to volatile markets, enhancement of wildlife habitats, improved aesthetics, water quality management, waste disposal, and carbon sequestration.

Various types of agroforestry systems are embraced by landowners and managers, such as silvopasture, alley cropping, forest farming, riparian forest buffers, and windbreaks. Additionally, there are specialized applications that deserve attention. While most agroforestry practices are applicable EU-wide, factors like climate, soil composition, and rainfall can influence their suitability.

Agroforestry practices have the potential to significantly reduce carbon dioxide levels in the atmosphere and store carbon. These practices include windbreaks, riparian forest buffers, silvopasture, and short rotation woody crops (SRWC). Well-planned field windbreaks can offer sufficient protection for crops and soil with just 2-3% of the cultivated land dedicated to windbreaks.

(Photo credit: 'Institut national de recherche pour l'agriculture, l'alimentation et l'environnement https://www1.montpellier.inrae.fr/safe/conferences/Paris/1%20Dupraz%202005%20Une%20agroforesterie%20%E0%20la%20fran%E7aise.pdf)

For example, if the agricultural land in the EU, which is approximately 158 million hectares, were to be planted with only 2.5% of 9-meter-wide tree windbreaks, the carbon dioxide absorption from these trees could exceed 170 million metric tons.

There is an opportunity to combine food or energy crops with fast-growing trees such as hybrid poplar, hybrid willow, sweetgum, sycamore, and locust. By using short tree rotation periods of 6 to 9 years, farmers and landowners could establish an alley cropping system. This system aims to grow an annual energy crop (such as switchgrass) alongside a longer rotation energy crop (like willow) or to cultivate an annual cash crop (such as corn) alongside a longer-term energy crop (such as poplar).

(Photo credit: USDA Cooperative State Research Education Extension Service, Forest*A*Syst: https://www.forestasyst.org/agroforestry.html)[xx]

## 4.8 Forestry

One significant environmental concern related to forestry is soil erosion. Tyres that create ruts in the soil can channel rainwater and contribute to erosion. Self-guided machines, operated without a driver on board, fitted with wider wheels and low-pressure tires, can assist in reducing the formation of these channels. This approach can aid in preventing soil erosion by preserving the topsoil's integrity and decreasing the likelihood of water runoff carrying away essential nutrients and topsoil layers. By diminishing erosion, such machines have the potential to help maintain soil fertility and overall soil health. Such machines also support selective logging where only the mature trees are harvested leaving saplings or other species on the landscape.


(Photo credit: Konrad, https://www.vonatzigenag.ch/wp-content/uploads/Konrad-pully.pdf)

Another kind of technology is provided by forestry prototype walking machines. The below prototype was created based on the concept that the larger contact area of each foot on a forestry walking machine, in comparison to a traditional wheel, aids in evenly distributing the load. This even distribution reduces the pressure on the soil, thereby minimizing soil compaction, disturbance and trafficking of the forest substory. By spreading the weight across a greater surface area, walking machines are less prone to causing soil degradation, thus helping to preserve soil structure and foster healthier soil ecosystems.

(Photo Credit: courtesy of CEMA member)

The reduced ground disturbance caused by forestry walking machines can also benefit soil aeration. Compacted soil can impede the flow of air, water, and nutrients to plant roots, negatively impacting plant growth. By minimizing soil compaction and maintaining soil structure, walking machines promote better soil aeration, allowing roots to access oxygen and nutrients more easily. This can enhance plant growth and overall ecosystem health in forested areas.

Another fascinating aspect to consider is the idea of robots that can move between trees without touching the ground. This concept suggests that these robots could work together to clear canopies and fell trees.

However, the advantages of these robots do not account for the soil disruption that may occur when removing fallen trees using this method. In the future, these robots could potentially complement systems like the semi-autonomous steep terrain harvester, which aids in transporting felled trees and was developed partly to enhance soil preservation in highly vulnerable steep areas.

(Photo credit: Tree Swinging Robot Prototype, Scion Research Institute, New-Zealand)[xxi]

By minimizing ground disturbance and preserving. soil structure, forestry walking machines, automated equipment and robots can help maintain a healthy soil environment where diverse soil organisms can thrive. This can contribute to improved nutrient cycling, organic matter decomposition, and overall soil fertility, supporting the long-term health and productivity of forest soils. However, these pieces of equipment, when they are not prototypes, are not yet widely commercialized. They might not have a sufficient cost advantage to spread quickly but there is an obvious safety advantage of forest robots. Indeed, logging is a Class-A industry (meaning a most dangerous activity).

# Conclusions and Policy Recommendations

## 5.1 The need for a European agricultural and forestry soils health-check

In CEMA's views an EU-wide audit of the agricultural and forestry soils is needed to determine clear goals in terms of regenerative agriculture practices. Before considering the organic content of soils, it is important to measure the pollution that agricultural lands in Europe are subjected to. Studies show that certain agricultural lands, particularly those near major roads and tourist areas, are contaminated by external elements such as plastic waste, illegal garbage dumps, aluminum cans, pet waste, and roadkill.

In addition to these external factors, natural elements like stones and animal carcasses are also present. Some agricultural practices contribute to the issue with waste like plastic bag residues. All these elements contribute to the poor health of agricultural soils and require appropriate treatment, possibly using new types of agricultural machinery.

(Photo Credit: courtesy of CEMA member)

## 5.2 Establishing clear criteria for supporting regenerative agriculture

As outlined in paragraph 3.3, the agricultural sector requires universally agreed-upon metrics. These criteria should be developed in collaboration with stakeholders to establish a consensus on the metrics used to assess the results of regenerative agriculture practices, thereby preventing confusion and changing expectations.

These criteria should consider the varied geological, ecological, and climatic features of individual farms, offering customized solutions to address specific on-the-ground conditions.

Enhanced collaboration and communication within the agricultural community are also essential to promote a unified approach to regenerative agriculture practices.

## 5.3 Supporting transition costs to regenerative farming

The pivotal barrier hindering the widespread embrace of regenerative agriculture is the transition phase. This obstacle is particularly significant considering the agricultural industry's slim profit margins that are vulnerable to market fluctuations and price variations. In the absence of external financial assistance, EU farmers encounter significant challenges in transitioning to alternative agricultural methods, particularly when grappling with cash flow constraints and anticipating market downturns. Public support is crucial to facilitate the adoption of regenerative agriculture practices in the EU.

Support for farmers transitioning to regenerative agriculture should not only encompass the transition costs but also the expenses needed to maintain regenerative agricultural practices in the long term. The current CAP 'Eco-schemes' are considered as a potential tool for achieving this objective. Therefore, they would need to be amended, under the next CAP beyond 2028, to tackle this issue.

## 5.4 Skills and training

The fundamental requirement for the successful implementation of regenerative agriculture practices is the presence of knowledgeable and skilled individuals supported by appropriate training programs, as the necessary technologies are readily accessible. While technological advancements offer valuable tools for regenerative agriculture, the effective application of these technologies relies heavily on the expertise and proficiency of the workforce utilizing them. Therefore, investing in education and training tailored to regenerative farming practices is critical to empower agricultural professionals with the skills and knowledge needed to maximize the potential of available technologies.

## 5.5 Precision Agriculture Technology uptake and Innovation

Despite the wide array of solutions provided by Precision Agriculture (PA) to promote regenerative farming practices, only 25% of farms in the EU utilize technologies with a PA component, as indicated by a study published by Elsevier in March 2024[xxii].

In countries like Germany, Finland, and Denmark, 36% of the farmers surveyed have already utilized Precision Agriculture Technologies, highlighting the disparity among EU regions. CEMA believes that prioritizing the adoption of these technologies should be a key focus of the upcoming Common Agricultural Policy supporting voluntary schemes (CAP).

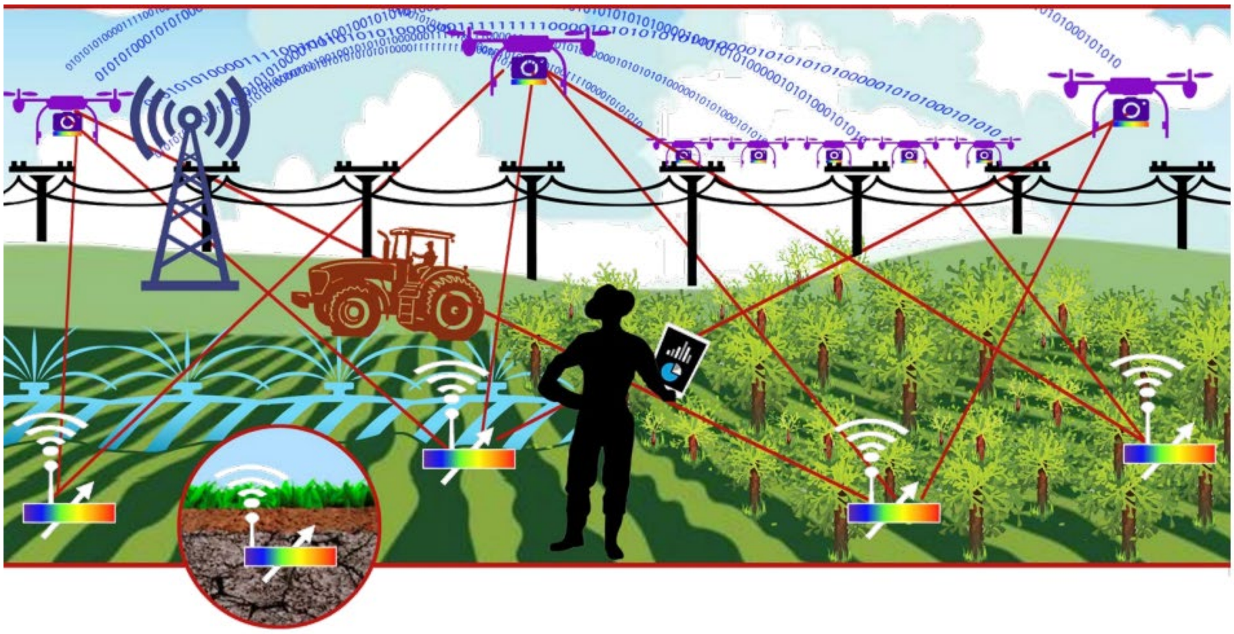
However, Precision Agriculture Technologies and digital platforms can help farmers to plan, implement and document the regenerative agriculture practices. Access to data and technology enables farmers' participation in public-private initiatives that provide financial incentives for practices improving soil health and decarbonizing the agriculture supply chain.

Modern agricultural equipment and digital solutions are leveraging technologies like computer vision, advanced sensing, machine learning, and data analytics. Work is ongoing to enhance the science and technologies that inform the level of greenhouse gas emissions reductions from adoption of regenerative farming practices, including impacts on soil health. Additional investments in soil health measurement technologies are critical to filling data gaps in online farm data management systems and fostering farmers' decision-making.

When it comes to innovation, a promising area that warrants further exploration is the integration of soil sensors with machinery, diagnostic tools, and agricultural advisory services. Currently, these agricultural sensors are not widely available, expensive, and not biodegradable.

As Professor Cherie Kagan's team posted:

*"[We need to] develop miniature sensors designed to be planted alongside crops or placed on top of the soil. These sensors will be considerably less expensive than current systems for monitoring micronutrients and other soil conditions, but be sowed like seeds and even provide data on the scale of an individual plant. They will also develop fleets of robots that will gather data from the air or ground; autonomously monitoring the health of plants with a suite of data-rich sensors, predicting crop yield and quality of produce. (...) Signals will need to travel from below the soil surface, to farm equipment, and from there to the cloud, and do so over long distances in remote locations with no pre-existing cellular networks to rely upon."* [xxiii]



(Source and photo Credit: Pennsylvania State University, https://blog.seas.upenn.edu/penn-purdue-uc-merced-and-uf-partner-on-26m-nsf-engineering-research-center-for-the-internet-of-things-for-precision-agriculture/)[xxiv]

Future soil sensors should adhere to the following criteria:

- They should provide a platform for measuring soil moisture, pH, nutrients, compaction, and organic content. Measuring $CO_2$ absorption and emissions is one of the critical requirements. Alternatively, assessing Total Organic Carbon (TOC) can provide empirical data rather than relying solely on theoretical calculations.
- They should be capable of being installed up to 1 meter below the soil surface.
- They should allow for remote wireless sensor communication from either a drone or agricultural equipment at a distance exceeding 10 meters.
- They must be biodegradable and environmentally friendly.
- They should be cost-effective and scalable in terms of production.

By meeting these requirements, soil sensors will provide EU farmers access to the necessary tools and technologies to regenerate their soils and maintain their health effectively.

## ABOUT CEMA

**CEMA aisbl** (www.cema-agri.org) is the association representing the European agricultural machinery industry. With 11 national member associations, the CEMA network represents both large multinational companies and numerous European SMEs active in this sector.

CEMA represents about 1,300 manufacturers, producing more than 450 different types of machines with an annual industry turnover of about €40 billion and 150,000 direct employees. CEMA companies produce a large range of machines that cover any activity in the field from seeding to harvesting, as well as equipment for livestock management.

## ABOUT THE AUTHOR

Dr. Gilles Dryancour holds a PhD in Economics. He is the Honorary President of CEMA, served as Chair of the Board of Directors from 2009 to 2014 and is the current Chairman of the CEMA Strategic Committee (2024).

For more information, please contact:

**CEMA aisbl**

**European Agricultural Machinery Industry Association**

Bluepoint, Boulevard Auguste Reyers, 80

1030 Brussels

Tel. +32 2 706 81 73

secretariat@cema-agri.org

## References


[i] *Developing & scaling regenerative agriculture in Europe & beyond. Inquiry and workshop series 2022-23, Forum for the Future of Agriculture*, Brussels, October 2023.
Link: https://forumforag.com/wp-content/uploads/2023/10/RegenAg-final.pdf

[ii] Torsten Kurth, Benjamin Subei, Paul Plötner, and Simon Krämer: *"The Case for Regenerative Agriculture in Germany—and Beyond"*, Boston Consulting Group, January 23, 2023.
Link: https://www.bcg.com/publications/2023/regenerative-agriculture-benefits-germany-beyond

[iii] Mark Manshanden, Allard Jellema, Wijnand Sukkel, W.H.G.J. Hennen, Roel Jongeneel, Carlos Brazao Vieira Alho, Ángel de Miguel Garcia, Lotte de Vos, Floor Geerling-Eiff, *Regenerative agriculture in Europe: An overview paper on the state of knowledge and innovation in Europe,* Wageningen Economic Research, 2023.
Link: https://research.wur.nl/en/publications/regenerative-agriculture-in-europe-an-overview-paper-on-the-state

[iv] *Regenerative Agriculture*, FAO, 2022.
Link: https://www.fao.org/family-farming/detail/en/c/1512632/

[v] *Regenerative Agriculture at Bayer*: https://www.bayer.com/en/agriculture/regenerative-agriculture-definition#:~:text=For%20Bayer%2C%20regenerative%20agriculture%20is,which%20leads%20to%20increased%20resilience.

[vi] *Regenerative Agriculture - Opportunities and Challenges*, European Commission, Directorate-General for Agriculture and Rural Development, EU CAP Network, April 2023.
Link: https://eu-cap-network.ec.europa.eu/events/regenerative-agriculture-opportunities-and-challenges_en

[vii] Sustainable Market Initiative, Agribusiness Taskforce report, 2022:
https://a.storyblok.com/f/109506/x/7b102e6831/agribusiness-task-force-white-paper.pdf

[viii] Scaling regenerative farming: an action plan, Sustainable markets initiative, 2022. Link: https://a.storyblok.com/f/109506/x/7b102e6831/agribusiness-task-force-white-paper.pdf

[ix] *EU Carbon Farming: Contribution of Smart Agricultural Machinery*, CEMA, Brussels, February 2024.
Links: https://www.cema-agri.org/publication/press-releases/1050-agricultural-machinery-manufacturers-chime-in-on-carbon-farming
https://cema-agri.org/images/publications/position-papers/CEMA-EU_Carbon_Farming-_Position_Paper_2024-02.pdf

[x] Emily Rehberger et al, *What climate and environmental benefits of regenerative agriculture practices? An evidence review*, Environmental Research Communications, 2023.
Link: https://iopscience.iop.org/article/10.1088/2515-7620/acd6dc/pdf

[xi] https://auris-finance.fr/en/in-supermarkets-organic-food-is-no-longer-in-demand/, October 2023

[xii] Tomek de Ponti, Bert Rijk, Martin K. van Ittersum, *The crop yield gap between organic and conventional agriculture,* Elsevier, Agricultural Systems, Volume 108, April 2012, Pages 1-9.
Link: https://www.sciencedirect.com/science/article/abs/pii/S0308521X1100182X

[xiii] Claire E LaCanne, Jonathan G Lundgren, *Regenerative agriculture: merging farming and natural resource conservation profitably,* National Center for Biotechnology Information, February, 2018 : https://pubmed.ncbi.nlm.nih.gov/29503771/

[xiv] Peter Breunig, Marcus Mergenthaler, *New approach for accounting greenhouse gas emissions in agriculture*, University of Applied Sciences Weihenstephan-Triesdorf & South Westphalia University of Applied Sciences, Department of Agriculture, March 2024.

[xv] https://ec.europa.eu/commission/presscorner/detail/en/ip_24_1493

[xvi] Cara Peterson, *New pub on interseeding legumes into soybean*, September 2022.
Link: https://www.agroecologylab.com/blog/new-pub-on-interseeding-legumes-into-soybean

[xvii] https://www.continental-tyres.co.uk/b2b/agriculture/agricultural-tyre-topics-homepage/agricultural-tyre-topics-part-6/

[xviii] PaludiZentrale begleitet nasse Moornutzung auf dem Weg zum Markt, Universität Greiswald, January 2024.
Link: https://www.uni-greifswald.de/universitaet/information/aktuelles/detail/n/paludizentrale-begleitet-nasse-moornutzung-auf-dem-weg-zum-markt-new65b0e8499ca96437930435/

[xix] Kari Mutka and Timo Nyrönen, *Liquid biofuels, new opportunity for peat*, International Peatland Society, 2008.
Link: https://peatlands.org/assets/uploads/2019/06/ipc2008p130-132-mutka-liquid-biofuels-a-new-opportunity.pdf

[xx] *Introduction to Agroforestry,* Forest*A*Syst, Washington DC, December 2018.
Link: https://www.forestasyst.org/agroforestry.html

[xxi] *Steepland harvesting programme*, Ministry for primary industries, New-Zealand, 2018.
Link: https://www.mpi.govt.nz/dmsdocument/30612/direct

[xxii] Bojana Petrović, Roman Bumbálek, Tomáš Zoubek, Radim Kuneš, Luboš Smutný, Petr Bartoš, *Application of precision agriculture technologies in Central Europe-review,* Elsevier, Journal of Agriculture and Food Research
Volume 15, March 2024.
Link: https://www.sciencedirect.com/science/article/pii/S2666154324000851#bib87

[xxiii] Evan Lerner, *Penn, Purdue, UC Merced and UF Partner on $26M NSF Engineering Research Center for the Internet of Things for Precision Agriculture,* Posts from the School of Engineering and Applied Science,
August 4, 2020.
Link: https://blog.seas.upenn.edu/penn-purdue-uc-merced-and-uf-partner-on-26m-nsf-engineering-research-center-for-the-internet-of-things-for-precision-agriculture/

[xxiv] Ibid.