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Review

Conservation Agriculture and its contribution to the achievement of agri-environmental and economic challenges in Europe

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Abstract: Conservation Agriculture is an ecosystem approach to farming capable of providing solutions for numerous of the agri-environmental concerns in Europe. Certainly, most of the challenges addressed in the Common Agriculture Policy (CAP) could be tackled through Conservation Agriculture (CA). Not only the agri-environmental ones, but also those concerning farmer and rural communities' prosperity. The optimisation of inputs and similar yields than conventional tillage, make Conservation Agriculture a profitable system compared to the tillage based agriculture. Whereas this sustainable agricultural system was conceived for protecting agrarian soils from its degradation, the numerous collateral benefits that emanate from soil conservation, i.e., climate change mitigation and adaptation, have raised Conservation Agriculture as one of the global emerging agrosciences, being adopted by an increasing number of farmers worldwide, including Europe.

Keywords: no tillage; erosion; climate change; groundcovers; environmental policy; CAP

1. Introduction. Sustainability and Conservation Agriculture

The Sustainable Crop Production Intensification approach proposed by the Plant Production and Protection Division (AGP) of the Food and Agriculture Organization of the United Nations [1] focuses on the need to feed a growing population while coping with an increasingly degraded environment and uncertainties resulting from climate change. This concept provides "opportunities for optimizing crop production per unit area, taking into consideration the range of sustainability aspects including potential and/or real social, political, economic and environmental impacts". Needless to say that Europe has a great capacity to deliver food security as an important long term choice. Preserving the food production potential on a sustainable basis throughout the European Union (EU) will help to achieve this global goal for society in general. But what does this mean in practice and how can the proposed CAP 2020 objectives be made compatible?

Indeed, the European Commission tries to head EU agriculture towards sustainability, in its holistic sense, through different European policies implementation more focused on environmental objectives; such as the new requirements and measures established in the greening of the CAP reform (2014–2020) contributing to achieve the Europe 2020 Strategy objectives. In the prescient words of a farmer from Iowa (anonymous) "Sustainability is a journey, not a destination". It also appears to be the search for the best compromise between the different dimensions of sustainability, which are economy, ecology and community (farmers and consumers). The concept of agriculture sustainability should be understood as a three-legged table; economic, social and environmental aspects of production systems. For example, INSPIA project "European Index for Sustainable Productive Agriculture" which is a European project aiming to achieve sustainability in cropped farming by providing farmers a European Index based on monitoring different types of indicators—basically economic, social and environmental indicators—since this is what needs to be balanced to achieve sustainability. Today, in commercial farming there probably will be no single production system that can claim to be the "sustainable system". Obviously, the definition of the aforementioned best compromise depends on the priorities established. With regard to priorities defined in the revision of the CAP, what requirements should agricultural production systems meet to provide not only the optimal but the best solution?

In practical terms these requirements should be productive with regard to total production per unit land area. They are expected to be resource efficient, which means to produce more with less, primarily with regard to soil and water, but also other inputs such as fertilizers, plant protection products, energy and labour. The realisation of these two goals would not only contribute to competitiveness and economic sustainability but would also enhance environmental protection and biodiversity [2,3]. Furthermore, sustainable production systems have to reduce as much as possible off-site transport of soil and water and the nutrients and plant protection products contained in eroded sediments and surface runoff. Diversity and maintenance of agricultural activity in less favoured regions is more achievable if production systems are competitive in terms of cost [4].

A concurrent approach to realise all the objectives outlined in the Communication from the Commission "The CAP towards 2020" [5] requires a production process which respects natural capital and uses available knowledge and technology to optimise production, while enhancing and improving the environment and the production base for future generations. This is reminiscent of the meaning of agricultural sustainability and Sustainable Crop Production Intensification and is reflected in the concept of Conservation Agriculture. Figure 1 resumes the basic principles of this concept which are:

minimum or no soil disturbance, permanent soil cover by leaving the soil covered with residues or establishing a cover crop, and increasing plant diversity in the form of well balanced and wide crop rotations.

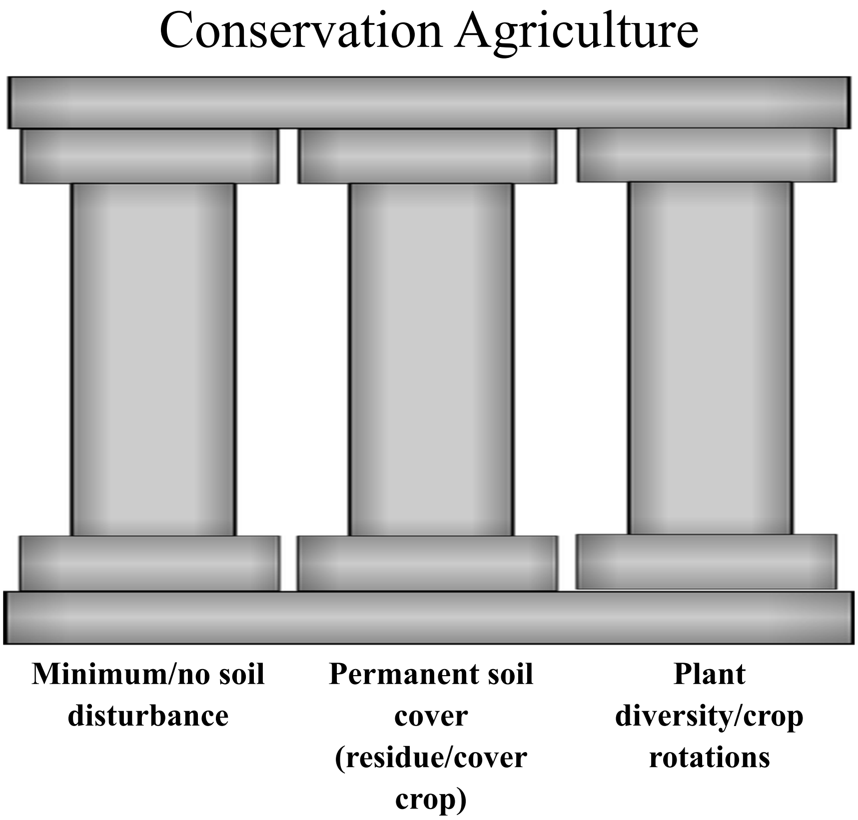

Figure 1. Principles of Conservation Agriculture.

The adoption of these principles in locally adapted production systems for the growth of annual and perennial crops, pastures and forages, together with good quality seeds and optimally integrated nutrient, water and pest management, would realise the goals outlined in the CAP by:

– providing similar or even higher yields through improvements in soil structure, organic matter and overall soil fertility [6];
– lowering production costs through reduced inputs of energy, labour, machinery, fertilizers, water and pesticides, thus raising related productivity and efficiency [7];
– mitigating CO_2 emissions through reduced fuel consumption and sequestration of atmospheric carbon into soil organic matter, and reducing N_2O and CH_4 emissions through reduced use of mineral nitrogen and improved soil drainage [7,8];
– reducing runoff and erosion through better soil aggregate stability and improved water infiltration, and protective cover of the soil by crops and/or crop residues [9];
– diminishing off-site damage of infrastructures and pollution of water bodies through less runoff with a much reduced sediment load;
– maintaining in-field and off-site biodiversity through the absence of destructive soil disturbance, protective soil shelter and less off-site transport of contaminants [10];
– maintaining the diversity of rural landscape through enhanced crop and species diversity and cover crops;

- maintaining less favoured rural areas under production through adoption of economically and environmentally viable production methods [4];

The characteristics of locally adapted CA production systems together with the rational and responsible use of external inputs will optimize crop yields, farm income, competitiveness and biodiversity, and minimize some negative ecological impacts associated with intensive farming. The use of herbicides to facilitate weed control and soil cover management is an option to reduce production costs and to avoid the aforementioned negative effects associated with soil tillage, including the stimulation of further weed emergence and spread. There is no evidence of an increase in the use of herbicides under CA systems when compared to conventional tillage farming. Instead, there is a shift in application timing and towards the use of contact herbicides. The latter are less persistent in the environment than the more frequently used residual herbicides in conventional farming. In some West European countries [11] and some areas in Australia [12], which have agroecological conditions similar to Europe, herbicide use per tonne of output is lower in CA systems with integrated weed management than in conventional tillage farming [13].

When CA systems are adopted over large areas, it is possible to harness much needed ecosystem services such as water, erosion prevention, climate regulation, maintenance of soil fertility, moderation of risk events, etc., that have heretofore not been fully possible with conventional intensive tillage-based agricultural land uses in Europe [3]. Thus, CA principles and systems would provide a solid bridge between the two Pillars of CAP and make cross-compliance environmentally and financially meaningful on an EU-wide basis. Adoption of CA will also provide a foundation for developing environmental service schemes such as carbon sequestration and trading, clean water provision, soil erosion control, and biodiversity enhancement [14,15], etc., in which incentives and payments can be linked to specific production systems and services. Such schemes exist elsewhere such as in Canada where a cap and trade scheme, started in 2007, enables regulated industries to purchase carbon offsets from agriculture sector based on a CA (no-till) production protocol adopted by farmers.

Today CA is practiced on some 156 Mha around the world [16] across all continents where agriculture takes place and in all agroecologies, with some 50% of the area located in the developing world. The spread of CA has been increasing at annual rate of 10 Mha during the past decade. This widespread adoption of CA is direct proof of its viability and sustainability, especially in some South American countries where there is no subsidy support for primary producers, and where CA is used on more than 60% of the arable land [17]. In addition, the fact that CA is successfully applied under very different climate conditions strongly indicates that there is great potential for the adoption of CA principles on a Europe-wide basis. Since its foundation in 1999 the European Conservation Agriculture Federation (ECAF) has advocated for the widespread adoption of CA in its 12 member countries. Its main objective is to integrate CA as the basic principle in mainstream agriculture in Europe including EU member states. At the same time, other tillage-based production systems such as horticulture, organic farming, agroforestry, irrigated flooded rice, would equally benefit from adopting these principles. In some EU countries, notably Spain, Finland, and France, moderate success has been achieved while other member states lag far behind in terms of CA adoption [18]. The reasons are manifold and range from the cultural entrenchment of soil tillage over the wrongly perceived need for increased herbicide inputs to the missing recognition of CA as an overall framework for sustainable production systems and for sustainable production intensification.

ECAF actively participated in the discussion and development of the Soil Thematic Strategy. The implementation of the Soil Framework Directive [19] was supposed to promote the adoption of CA throughout Europe. Unfortunately, it was blocked by a few member states. Now, ECAF will attempt to inform stakeholders during the revision process of the CAP, in order to obtain recognition and administrative and political support for the concept of CA as a sustainable crop production system capable meeting the wide ranging objectives of CAP 2020.

2. Conservation Agriculture and ecosystem services

To remain competitive, farming must be able to produce the required volume of biological products efficiently, which means at least cost, and socially sustainably which mean that the productive capacity of the resource base and ecosystem functions that generate and regulate ecosystem services must be maintained in the social-ecological system [20]. In tillage agriculture, many ecosystem services are disrupted and degraded because of the loss in soil organic matter and soil structure leading to compaction, waterlogging, run-off and erosion. Productivity and economic advantages from CA include similar or higher yields as the new system transforms and reaches a new equilibrium, improved productivity which means more output with less inputs, and system resilience which involves adaptation to climate change due to increased infiltration and soil moisture storage and availability of soil moisture to crops, reduced risks of runoff and flooding, and improved drought and heat tolerance by crops. Advantages also include climate change mitigation through reduced emissions due to 60–70% lower fuel use, 20–50% lower fertilizer and pesticides use, 50% reduction in machinery and labour requirement [21], C-sequestration 0.85 t ha^{-1} y^{-1} or more [22], and no CO_2 release as a result of no burning of residues. These advantages of greater soil health and productive capacity and lower cost of production leads to higher crop yields and factor productivities. Also, lower costs of production with CA leads to greater profit margins and competitiveness. To the mechanised farmers in Europe, CA offers reduced fuel use, lower capital outlay on machinery and decreased maintenance costs. Overall, CA has a much lower carbon foot print than tillage agriculture [23], and greenhouse gas (GHG) emissions of CO_2, CH_4 and NO_2 are all reduced with CA [22,24].

For any agricultural system to remain productive and sustainable over the long term, the rate of soil formation—from the surface downwards—must exceed the rate of any degradation due to loss of organic matter (living and/or non-living), and of soil porosity, as evidenced by consequent soil erosion. In the majority of agro-ecosystems this is not possible if the soil is mechanically disturbed [25]. For this reason the avoidance of unwarranted mechanical soil disturbance is a starting point for sustainable production and the reversal of soil degradation, leading to higher soil carbon levels and microorganism activity over time, reduction in soil compaction, minimisation or avoidance of soil erosion and runoff, improved soil moisture storage due to improved soil porosity, and increased aquifer recharge due to greater density of soil biopores due to more earthworms and more extensive rooting [9]. Not tilling the soil is therefore a necessary condition for stopping land degradation and maintaining ecosystem functions. For high output ecological and economic sustainability, other complementary techniques including mulch cover, crop rotations and legume cover crops are also required to create a sufficient condition for enhancing and sustaining soil productive capacity and ecosystem services, and for efficient integration and management of production inputs of seeds, land, labour, energy, plant nutrients, pesticides and water in CA production systems [26].

Indeed, societies benefit from the many resources and processes supplied by nature which are collectively known as ecosystem services [27]. Under CA systems, it is possible to harness many of the ecosystem services mainly because the ecosystem functions that generate these services are enhanced and protected by CA practices, so that production on agricultural land is not in competition with nature but works in harmony with it. In tillage systems without mulch cover and reduced functional crop diversity, ecosystem functions are disrupted and do not deliver the required ecosystem services.

Ecosystem services are derived in CA systems as a result of improved conditions in the soil volume used by plant roots, and by enhanced functional agrobiodiversity. Avoidance or minimisation of soil disturbance leads to increase in soil organic matter and improvements in soil structure and porosity which is brought about by the actions of the soil biota that are present in greater abundance in the soil under CA. The organic mulch on the soil surface in CA systems protects against the compacting and erosive effects of heavy rain, buffers temperature fluctuations, and provides energy and nutrients to the organisms below the soil surface. The co-benefits of more water infiltrating into the ground beyond the depth of plant roots is perceptible in terms of more regular stream flow from groundwater through the year, and/or more reliable yields of water from wells and boreholes. The benefits of carbon capture become apparent in terms of improvements in crop growth, plus less erosion and hence less deposition of sediment in adjacent waterways. Legumes in CA rotations provide increased in situ availability of nitrogen, thus diminishing the need for large amounts of applied nitrogenous fertilizers. In CA systems, the sequences and rotations of crops also encourage agrobiodiversity as each crop will attract different overlapping spectra of microorganisms. The optimization of populations, range of species and effects of the soil-inhabiting biota is encouraged by the recycling of crop residues and other organic matter that provides the substrate for their metabolism, and to drive the food webs of natural enemies of pests. Rotations of crops inhibit the build-up of weeds, insect pests and pathogens by interrupting their life cycles, making them more vulnerable to natural predator species, and contributing development-inhibiting allelochemicals. Crop mixtures, sequences and rotations also provide above-ground mixed habitats for insects, mammals and birds [28,29].

CA facilitates the delivery of better ecosystem services initially at the farm level. When the effects are reproduced across farms in a contiguous landscape, the ecosystem services provided become more apparent and cumulative. At the landscape level, CA offers the advantages of better ecosystem services including: provision of clean water, regulation of climate and reduced pests/diseases, supporting nutrient cycles, pollination, cultural recreation, and conserving biodiversity and erosion control. To the community and society, CA offers public goods that include: less pollution, lower cost for water treatment, stable river flows with reduced flooding and maintenance, and cleaner air. At the global level, the public goods are: improvements in groundwater resources, soil resources, biodiversity and adaptation to and mitigation of climate change.

3. Mainstreaming Conservation Agriculture in Europe

Conservation Agriculture is being widely practiced outside Europe, including in areas with similar agro-climatic conditions, particularly in North America [2,30]. There is now a growing consensus amongst many agricultural development experts that CA has an important role in transforming agriculture everywhere towards a more sustainable and efficient system [31]. Currently, however, CA is not being popularised in the EU. The lack of knowledge on CA systems and their management, and the absence of dynamic and effective innovation systems and lack of policy support, make it difficult and socio-economically risky for European farmers to give up tillage-based farming, including mouldboard ploughing which is a practice rooted in their cultural traditions.

Currently, there are some 2.3 Mha of arable cropland under CA system in Europe, mainly in Spain, France, Finland, UK, Italy, Portugal and Switzerland, and 1.8 Mha in woody crops. The adoption process seems mainly farmer-driven, motivated by the reduction in the cost of fuel, labour and machinery. This adoption trend is expected to grow in the future in response to increasing energy and input costs. In a wheat-sunflower crop rotation in southern Spain, reported €234.82 extra benefits for no-tillage farms in comparison to the conventional system based on soil tillage [32]. However, farmers need to be made aware of the possibility of higher productivity and profit potential with CA as well as of improved soil health and ecosystem services including soil and water conservation so that these advantages are also considered amongst the main drivers in the European farmers' decision to shift to CA or not. At the same time, farmers wishing to switch to CA systems should be encouraged and offered financial and institutional support to minimize transitional risks.

4. Climate change and Conservation Agriculture

European soils are an important pool of active carbon and play a major role in the global carbon cycle and have contributed to changes in the concentration of GHGs in the atmosphere. Indeed, agricultural ecosystems can play a significant role in the production and consumption of GHGs, especially carbon dioxide (CO_2). Agriculture contributes approximately 10% to total EU GHG emissions. Fuel burning by agricultural machinery is often regarded as the main source of CO_2 emissions in the primary sector, neglecting the CO_2 fluxes derived from agricultural land caused by the "burning" of organic litter left after harvest and soil organic carbon (SOC) losses caused by intensive plough based tillage, which is still considered "normal" and "good agricultural practice". Intensification of agricultural production is an important factor influencing GHG emissions, particularly the relationship between intensive tillage and soil carbon loss [33].

According to estimates over decades of measurement, soil organic matter (SOM) levels have decreased considerably due to agricultural land use [34]. A 1% reduction of SOC in the 30 cm topsoil layer results in losses of approximately 45 t of carbon, or 166 t of CO_2/ha (3.7 t CO_2/1 t carbon), to the atmosphere. This calculation clearly illustrates the impact that agriculture has on the release of CO_2 to the atmosphere where land use practices lead to a depletion of SOC.

On the other hand, it also reveals the potential for carbon sequestration, which a change of the agricultural practice could have, if it succeeds in restoring at least some of the SOC lost over decades of traditional tillage. This would increase not only the levels of SOM but also soil fertility and the long-term sustainability of agriculture and food production. The reduction of CO_2 emissions would be due to the reduction in energy use through the manufacture and utilization of agricultural machinery and the adoption of CA to reduce CO_2 emissions from soils. Methane production could be reduced through composting of manure and a widespread implementation of grass-based grazing systems. Finally, the release of nitrous oxides could be lowered through the reduced application of inorganic fertilizers as a result of improved soil fertility through the increase of SOM, and the use of targeted and slow release fertilizers.

It is widely accepted that both emission reductions and an increase in potential sinks would have to occur if there is to be a positive effect on climate change. Numerous sinks have been identified by many authors and assessments are being made to quantify their potential in terms of carbon sequestration. With regard to agricultural land, reduced tillage and especially zero or no-tillage, coverage of the soil surface with straw residue, cover crops and rotations, and improved management practices, which result in increased crop and biomass productivity, are recognized as the main practices necessary to turn agricultural soil into a significant carbon sink. The advantage of promoting carbon sequestration is that it can be achieved in the short term using technologies that are readily available while at the same time there are also considerable production and environmental benefits.

4.1. Dual benefits of carbon sequestration and soil conservation

Lands under agriculture and forestry production systems are important pools in the global carbon cycle and the land management practices used can determine whether these lands are sources or sinks of carbon.

For example:

- Management factors to increase SOC must increase organic matter inputs to the soil, and decrease decomposition of SOM and oxidation of SOC. Such practices include: reduced tillage intensity, decreased bare or cultivated fallow periods, the use of winter cover crops, increased rotation cropping with the inclusion of legumes, balanced nutrient management and efficient nutrient management [35,36].

Increasing the level of soil carbon or soil organic matter can provide considerable dual environmental and production benefits:

- Increased organic matter improves soil aggregation which in turn improves soil aeration, soil water storage, reduces soil erosion, improves infiltration, and generally improves surface and groundwater quality [22,37].
- Increasing the SOC content of soil through sequestration improves nutrient cycling by stimulating soil biology and biodiversity. This stimulates the decomposition rate, enhances the nutrient supplying power of the soil, and reduces the need for inputs such as mineral fertilizers.
- In addition, increased water storage capacity and improved soil fertility provides some degree of mitigation against droughts and crop failures in dry years.

4.2. Potential of CA to reduce CO_2 emissions and increase C-sequestration in Europe

Assessing the potential for carbon sequestration through the adoption of CA requires an estimate of the potential land area which could be converted to this form of soil conservation, and the rate with which carbon is accumulated per unit of time and area following uptake. There are several studies available from a number of countries with the main focus being on the USA. However, with regard to Europe, information is available on the extent to which CA could contribute to carbon sequestration and less CO_2 emissions [22,35,36,38]. Results are in agreement with what assessed about carbon sequestration [39]. The authors estimated that through no-tillage C sequestration was approximately 0.4 t ha^{-1} yr^{-1}. According to the authors the maintenance of 2 to 10 tons of straw would have an additional effect on carbon sequestration of approximately 0.2 to 0.7 t C ha^{-1} yr^{-1}. Based on this information and the conservative estimate that 30% of the total arable area in EU countries (EU-27) would be suitable for the adoption of CA practices (no-tillage with crop residue retention) the potential CO_2 mitigation for EU member states through uptake of CA is shown in Figure 2. The key values used in this calculation are: Carbon sequestration (reduced CO_2 emissions) under CA: 0.77 t C ha^{-1} yr^{-1} [40] reduced fuel consumption under CA: 44.2 L ha^{-1} yr^{-1}, percentage of arable land suitable for NT: 30%.

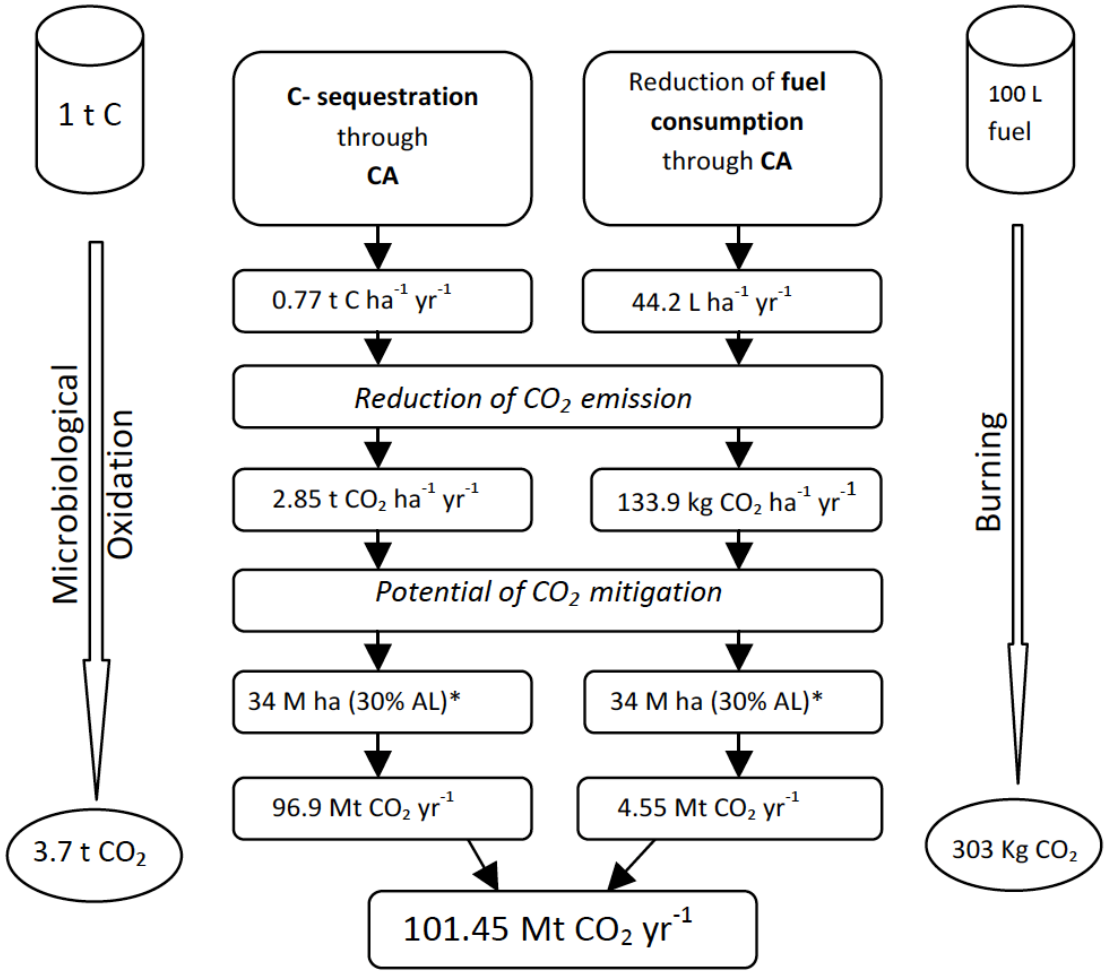

Figure 2. Estimation of the potential reduction CO_2 emissions through the application of Conservation Agriculture in Europe (EU-27). *When applied on 30% of total European Arable Land (AL), 113.4 Mha [41].

Similar calculations were conducted for the USA, resulting in a potential carbon sequestration of between 0.45 and 1.0 t ha^{-1} per annum giving an average annual agricultural soil sink of 180 Mt of carbon. Thus, soils sinks could offset about 30% of the CO_2 emission reduction target of the USA [42].

4.3. Climate change and future CA adoption

The agronomic, environmental, and economic feasibility of CA systems has been proven under many soil and climatic conditions. It has been well established that SOM and SOC levels can reach a new higher equilibrium with the application of conservation practices, especially where crop residues are maintained on the field and permanent crop and soil cover is achieved. The adoption of these sustainable management practices on a substantial part of the EU arable land area could reverse the continuous decline of soil organic matter and soil fertility and contribute decisively to the necessary reduction in CO_2 emissions and CO_2 levels in the atmosphere as agreed under the international agreements on the subject, such as the COP21 Paris agreement in 2015.

5. Farm income and competitiveness

Along its history the European CAP pursued several objectives with reasonable consistency. The improvement of farm incomes is certainly one of the more persistent objectives in CAP history, going back to the 70's, when a gap opened up between the incomes in the secondary and tertiary sectors and those in the primary sector. Today, however, the validity of this objective is being strongly questioned, and the "Declaration on CAP reform 2009" even recommends the abolishment of the CAP income objective as it is not attainable in the long run and not coherent with EU social policy, namely the objective of equal opportunities and treatment across sectors. The objective of competitiveness of EU agriculture only gained support during the discussion of Agenda 2000.

Despite a change in the definition of the priorities in the legal proposal for the CAP reform [43] with regard to the economic challenges, prioritizing food security, price volatility and economic crisis, CAP will continue to guarantee a basic income support through direct payments, as disparity in incomes between the agricultural sector and the rest of the economy persists (Figure 3), and the downward pressure on agricultural income is expected to continue, as a consequence of a slowdown in productivity gains and a margin squeeze due to a rising gap between input costs and output prices (Figure 4). Therefore the achievement of the viable food production objective will strongly depend on further improvements in competitiveness of the European agricultural sector. This can only be achieved if certain core practices in the current tillage-based farming systems in Europe that are responsible for lowering production factor productivities are transformed and underpinned by a more efficient ecosystem approach to sustainable production intensification as explained in the following sections.

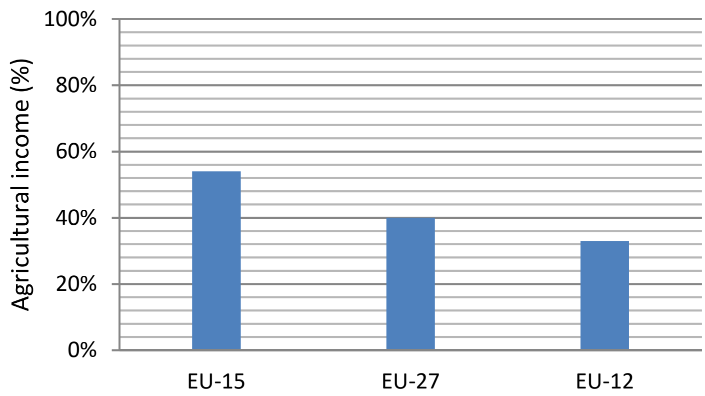

Figure 3. Agricultural income as % of average income in the total economy (average 2008–2010) [41].

The EU support via CAP over the last decades has been crucial, not only for maintaining the quantity and quality of agricultural commodities for European and foreign markets, but also for helping farmers to be gainfully employed and live in rural areas. Nevertheless, from outside the EU, CAP is generally considered to be a distorting support mechanism for the EU agricultural sector. Indeed, WTO continues to put strong pressure on EU to drastically reduce its internal market and farmer support. In its defence EU alleges that the existing high environmental and food safety and quality standards "justify" the large transfers of funds from taxpayers and consumers to the agricultural production sector.

However, both globalization and the agreed ceiling and restructuring of EU expenditures for CAP will force EU farmers to become more competitive and more resource efficient, i.e., to produce more from less, in order to reverse the income disparity (Figure 3) and stagnating (Figure 5) agricultural incomes.

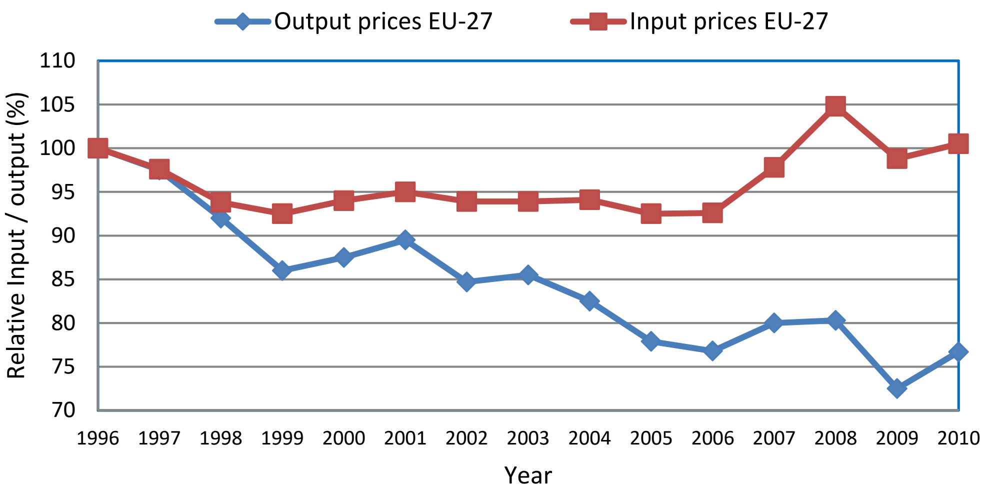

Figure 4. EU-27 developments in agricultural input and output prices in real terms (1996 = 100) [41].

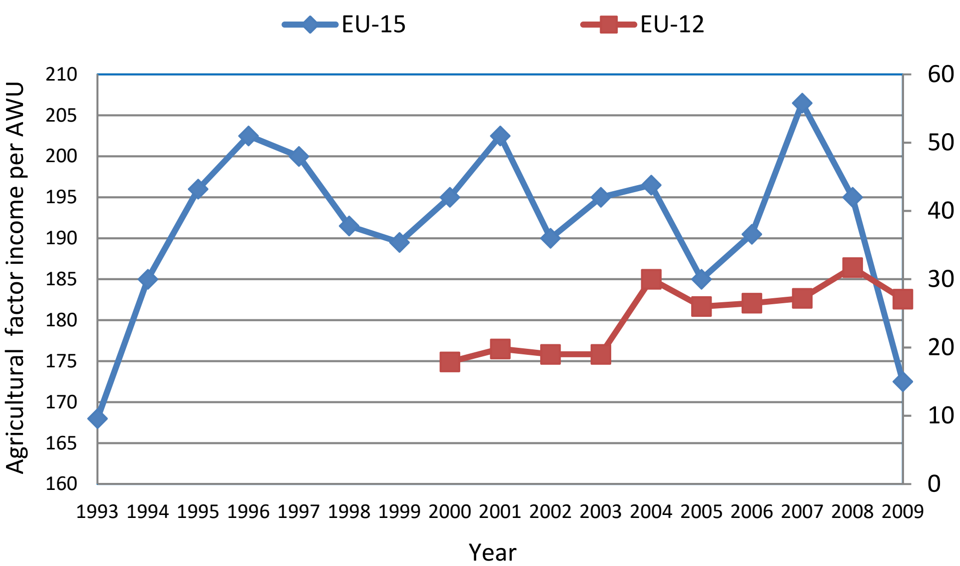

Figure 5. Development of agricultural factor income per AWU in the EU-15 and EU-12, 1993–2009, EU-27 in 2000 = 100, in real terms. Economic Accounts for Agriculture — Elaboration DG AGRI) [41].

5.1. How to enhance farm income and competitiveness?

Whereas the answer to this question might seem rather obvious, its achievement requires the adoption of a more complex and holistically sustainable ecosystem management approach. This is because the easy-to-achieve productivity gains of the past, obtained largely through modern varieties and intensive use of agro-chemical inputs, mechanization, fossil energy etc., have already been exploited to a maximum degree and further intensification through this paradigm carries unacceptably high levels of negative externalities and financial costs to the producers and society alike [7,44,45]. Certainly, there are still considerable potential productivity gains that are attainable in some EU regions and in certain production sectors through structural and operational improvements. However, the major contribution to enhancing farm incomes and competitiveness in the future must be attained through: (i) a reduction of production factor inputs and costs, i.e., an improved efficiency of the resources used, and (ii) an improvement of the quality of the resource base that can maintain or improve farm output and also harness a range of ecosystem services needed by the society. Both outcomes are achievable concomitantly only through farming practices based on an alternate paradigm that enhances soil quality and its productive capacity, while maintaining or improving yield levels at reduced input levels. Any farming approach capable of satisfying all these conditions can only do so if it is based on the principles and practices of CA, described elsewhere in this article, and which is a successful and workable ecosystem approach to agricultural sustainable land management that has been tested in other parts of the world in environments similar to those in Europe.

5.2. Reduction of production inputs and costs

In arable farming systems costs for soil tillage both in terms of machinery (purchase, depreciation, maintenance) and fuel consumption can make up a considerable part of the variable production costs. CA systems, instead, rely on crop establishment without soil tillage, using appropriate no-till seeding equipment for the placement of seeds into undisturbed soil. Depending on farm type and size, labour may also represent a restrictive factor when it comes to cost efficient management or when a farmer could spend his time with other activities instead of driving a tractor tilling his fields.

Apart from machinery repair and fuel costs, the inputs of agro-chemicals in the form of fertilizers and plant protection products account for a large share of the variable production costs. Especially, the prices for fertilizers that depend on the cost of energy and minerals have soared over the last few years, requiring their reduced and efficient use to be an imperative for the financial and economic viability of farms. Therefore, the enhancements of soil fertility, based on adequate levels of SOM that guarantee efficient nutrient cycling, and the integration of leguminous crops to take advantage of biological nitrogen fixation, represent key elements to achieve the objective of reduced use of purchased mineral nutrients and optimization of overall nutrient efficiency leading to minimization of production costs for crop nutrition. The principles of CA safeguard both soil organic matter build-up through minimum soil disturbance and maintenance of crop residues, and the introduction of legumes to comply with the demand for diverse crop rotations. In the medium and longer-term, after the build-up of more favourable soil physical and chemical (SOM) conditions, CA systems have shown to require considerably less (up to 50%) mineral fertilizer inputs for the same or even higher yields [46,47].

This very aspect of the principle of diverse crop rotations, proposed also as one of the "greening" measures introduced in the CAP 2020, allows CA farmers to keep the need for the application of chemical plant protection products within ecologically sustainable levels. Even with regard to weed control, crop rotation in combination with absence of soil disturbance (which avoids protective burial of weed seeds) and soil cover (which serves as an effective physical barrier to weed emergence) provides an integrated weed management approach applicable also in commercial farming. Therefore, the general perception that no-tillage farming requires increased herbicide rates does not correspond to reality on the ground [48,49]. Instead, an optimisation of all inputs is what CA provides.

5.3. Reduction of negative externalities and environmental costs

Although farming ideally should be practiced in a manner commensurate with its stewardship role in land husbandry, the negative externalities from the ecologically unsustainable current production systems do also negatively impact the on-site and off-site ecosystem functions, the environment and resources in ways that cause large-scale damage and substantial public expenses for repeated remediation needs arising there from. The "polluter-payer" principle is difficult to apply when the nature of the origin of land degradation and pollution of soil, water and air is diffuse, thus leading to high external costs upon the society. Especially the off-site transport of water, soil, minerals, microorganisms and agro-chemicals may cause severe damage to infrastructures such as roads and surface water bodies, or high costs for the removal of minerals, microorganisms and toxic agro-chemicals in water treatment stations.

Again, the essential means to minimize the risk of negative on-site and off-site environmental impacts of farming and to improve productivity (efficiency) and ecological sustainability are delivered by the practices that implement the principles underlying the concept of CA [3,9]. Apart from the benefits of CA in terms of environmental costs reduction, the provision of public goods and ecosystem services such as the enhancement of below and aboveground biodiversity and climate change mitigation through carbon sequestration in the soil and reduced CO_2 emission through less fuel consumption, reduced N_2O emission through reduced mineral nitrogen application and better soil aeration, as well as reduced CH_4 emission due to improved soil drainage and aeration, should also economically be accounted for.

5.4. Farm income

The revenues and profit of a farm depend strongly on the level of output and productivity as well as the expenses of inputs and management associated with the production activity. Both aspects have already been highlighted in detail in the current chapter. Long-term empirical evidence and scientific results [50] allow the conclusion that (a) crop yields under CA are similar to those obtained under traditional cultivation right after shifting to CA, (b) there is a tendency for yield to increase under CA over time, and (c) the benefits in terms of increased profits are even more pronounced than yield differences (Figure 6) because of higher factor productivity.

5.5. Transition and risk management

As shown above, CA-based farming systems provide economic benefits both on-farm and off-farm, which become more pronounced the longer they are practiced. However, the adoption of CA on a farm involves some additional initial costs due to the need for appropriate seeding equipment and some possible risks of initial drawbacks for those farmers who are not familiar with the new technology. The compensation for these additional costs and economic risks should be covered through initial but temporary incentives or support, corresponding to a real investment in the improvement of competitiveness and farm income, and in longer-term positive effects on a range of ecosystem services and the delivery of public goods which could be assessed and valued based measurable results or performance indicators. Such temporary support mechanisms have been successfully piloted in some European countries such as Spain [51], Germany [52], Italy [53] and Switzerland [54].

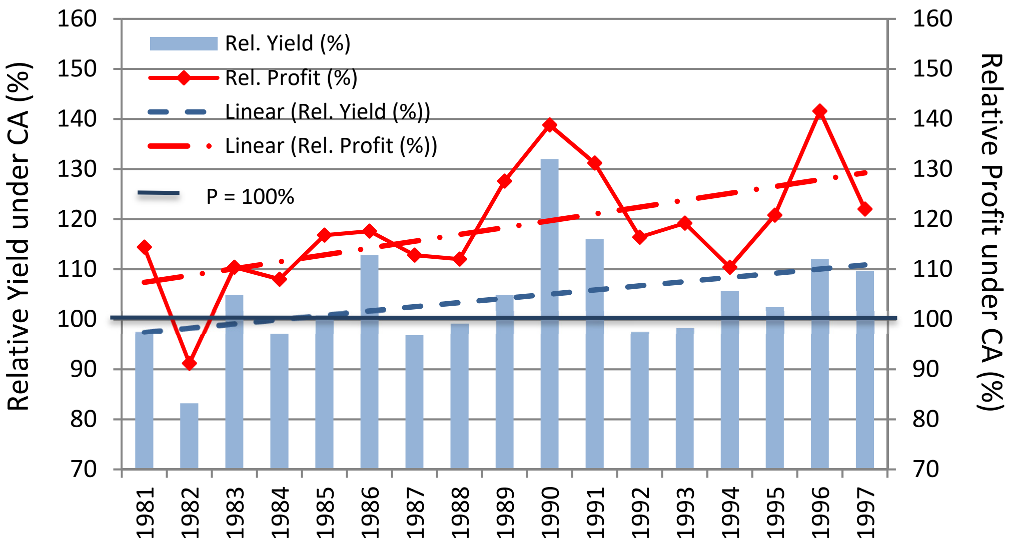

Figure 6. Relative yield and profit (including their trend) of different crops under Conservation Agriculture compared to conventional soil management (mouldboard plough—P) [50].

6. Structural diversity of rural areas and natural constraints

Within the complexity of objectives of CAP 2020, the EU Commission stresses on several occasions the need for territorially balanced agriculture thereby maintaining and promoting diversified farming systems and land use.

To ensure sustainable and integrated rural development, thus maintaining the structural diversity of predominantly rural areas, a functioning and active agricultural sector is required. However, this goal cannot be achieved without substantially improving the competitiveness of an agricultural sector that is subject to a more competitive environment, as the global economy becomes increasingly liberalized. It is therefore essential to either reduce production costs or produce more from the same inputs. Ideally, the achievement of both goals would boost competitiveness and avoid land abandonment and standardization of agricultural activities. How CA is able to contribute to the improvement of competitiveness both through the reduction of production costs and the increase in productivity (efficiency) and thus farm income is explained in detail in the respective subchapters of this publication.

A contribution to balanced territorial development of rural areas in the EU can be achieved, not only through the establishment of links between rural and urban areas, but also, through the reduction of the effects of natural constraints in agriculture. Natural constraints, or Less Favoured Areas [55], suffering from climate, soil, and terrain induced constraints, will always lag behind regions with favourable natural conditions in terms of agricultural activity and competitiveness. Nonetheless, the use of CA can counteract and alleviate the effects of some of these constraints and help reduce the risk associated with them.

In regions with pronounced seasonal water scarcity or low and erratic rainfall water use efficiency can be dramatically improved by the practice of CA, mainly through the adoption of low soil disturbance with and soil organic matter cover, both of which contribute to increased infiltration and the reduction of unproductive water loss through soil evaporation. Higher and more stable crop yields have frequently been observed under CA, in dryland areas and in drought affected years [56,57]. This improved water use efficiency may reduce water requirements for a crop by about 30%, regardless of whether crops are under irrigation or rain fed [58]. Similarly, there is improved nutrient use efficiency under CA which is known to reduce nitrogen application by 30–50% [57].

Natural soil constraints are often considered as being restricted to deficient drainage, extreme soil texture (sands or heavy clays), effective soil or rooting depth, or chemical properties such as salinity, sodicity, acidity, or other forms of toxicity. Although identified in the Soil Thematic Strategy [59] as one of the major threats for European soils, the decline and the low levels of soil organic matter are generally not being addressed as one of the major natural constraints. However, the soil's fertility and capacity to produce are intrinsically linked to its level of organic matter as all important soil properties and functions (water retention, nutrient cycling and availability, microbial activity, filtering and buffering capacity, degradation of organic compounds, etc.) improve with the amount of organic carbon retained therein. Higher levels of soil organic matter may even compensate, to some extent, for other soil constraints and allow for a reduction in mineral fertilizers inputs.

Conservation Agriculture has proven to be the most promising practice capable of reversing SOM decline and the associated loss of soil fertility [31,60]. Therefore, the continuous payment of "unproductive" compensation for production difficulties in areas with specific natural constraints could be replaced by an investment in incentives to improve natural soil resources through the increase of SOM, providing both a physical and economic return in the medium to longer term.

The slope of land terrain can also present an impediment for agricultural land use, either through increased difficulty with mechanized field operations, or through an increased rate of surface runoff combined with the risk of soil erosion or landslides. Regarding the latter, the practice of CA is capable of reducing the risk of soil erosion and landslides even on heavily undulated land, thus allowing for crop production instead of marginal or extensive land use through permanent pastures.

This indicates that the impact of natural constraints, whether regarded in isolation or in combination, may vary according to the production system and technological practices used. The application of the principles of CA, together with good agricultural practices such as adapted seeds, integrated pest, nutrient, and water management, timeliness of and trafficability for field operations, enable the farmer to counteract conditions perceived as natural constraints under the conventional tillage system [61]. For example, the time available after harvest under cool and moist conditions may not allow the establishment of a winter crop using conventional soil tillage for seed bed preparation. The conservation or loss of soil moisture in spring through no-till or conventional seedbed preparation can often be decisive for the success or failure of a spring crop under rainfed conditions. Another, often neglected aspect with regard to overcoming natural constraints, results from the soil's bearing capacity under CA conditions. Whereas under the conventional system crop establishment and field operations may have to be delayed or even cancelled mainly due to unfavourable soil moisture conditions, CA allows farm traffic almost continuously thereby allowing for the optimal use of inputs such as fertilizers and plant protection products [62].

Moreover, and as shown in some other studies developed in South Africa farming areas, the implementation of CA techniques can offer substantial positive environmental, financial, social and health benefits not only for these countries but also for the rest of the world [63]. In Southern Africa, the increasing demand for food from limited available land, in light of declining soil fertility and future threats of climate variability and change have increased the need for more sustainable crop management systems, such as CA. CA has been promoted for more than a decade to fight declining soil fertility and to stabilize crop yields [64]. Results from these studies show that despite the benefits CA can offer, conservation practices is not a one-size-fits-all' solution and often needs significant adaptation and flexibility when implementing it across farming systems. However, CA may potentially reduce future soil fertility decline, the effects of seasonal dry-spells and may have a large impact on food security and farmers' livelihoods if the challenges can be overcome.

Finally, farming under natural constraints means an increased risk of crop failure. One of the best strategies to reduce this risk is to minimize expenditure until the farmer has a better idea of the yields that can be expected. Therefore, cost reduction in the establishment phase of a crop is essential to meet the goal of risk reduction.

7. The European agri-environmental policy framework

The EU redefines the CAP on a regular basis. The last revision of the CAP envisages Europe's farmland until 2020. The most notable change in the current approach is the concern about EU and global food security. The revival of the interest in agricultural production already became evident during the CAP's Health Check as a consequence of climbing commodity prices in 2007/08. It is therefore no surprise that *rising concerns regarding both EU and global food security* was the first topic to appear in the list of justifications for the need for a CAP reform. Other challenges mentioned in this list such as sustainable management of natural resources, climate change and its mitigation, improvement of competitiveness to withstand globalization and rising price volatility, etc., while not new are considered worthwhile enough to be maintained and reappraised.

Referring to the concepts of the EU 2020 Strategy, the European Commission wants CAP to contribute to the Smart Growth by increasing resource efficiency and improving competitiveness, to Sustainable Growth by maintaining the food, feed and renewable production base and to Inclusive Growth by unlocking economic potential in rural areas. In its communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, the European Commission defined 3 general objectives for the CAP 2020:

Objective 1: Viable food production
Objective 2: Sustainable management of natural resources and climate action
Objective 3: Balanced territorial development

Figure 7 shows a detailed summary of the objectives of the EU Commission proposal for the new CAP 2020. Viable food production, in simple terms, means that EU farmers are given the means to produce the same or even more food at lower cost to meet the growing demand of food, feed, fibre and biofuels and competition from a globalized world market, while consumers can buy food at acceptable prices and quality. Sustainable management of natural resources and climate action means matching agricultural production with the simultaneous protection of soil, water, biodiversity, etc., and demands that agriculture contributes to the mitigation of GHGs. Finally, balanced territorial development includes the maintenance of the diversity of production and that, despite severe natural constraints, especially in terms of soils and climate, agricultural activity is guaranteed which only seems viable through the adoption of low cost and probably extensive production systems.

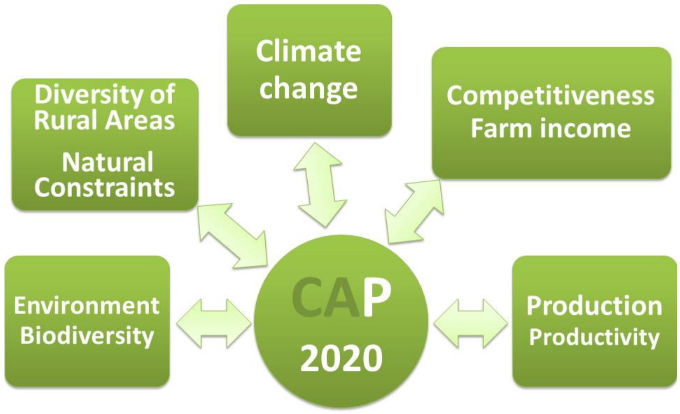

Figure 7. Main objectives to be met by the revision of the Common Agricultural Policy (CAP).

In its CAP towards 2020 reform report, the EU Commission has stressed that the primary role of agriculture is to supply food, and that EU should maintain its productive capacity and improve it [5]. EU agriculture finds itself today in a considerably more competitive environment calling for a continued enhancement of the competitiveness and productivity of the EU agriculture sector as the world economy is increasingly integrated and the trading system more liberalized. The report also calls for a future CAP that contains a greener and more equitably distributed first pillar and a second pillar focussing more on competitiveness and innovation, climate change and the environment. This would allow EU agriculture to release its latent productivity potential. Both production (volume of diversified products produced sustainably) as well as productivity (efficiency) are considered key to competitiveness. This calls for ecologically sustainable and economically efficient "green growth" in the agriculture sector and the rural economy as a way to enhance well-being by pursuing economic growth while preventing environmental degradation.

How can EU address the above challenge? New knowledge and scientific understanding of the principles and practices that underpin sustainable production intensification have been formulated and applied over the past 40 years in many countries outside Europe. There is strong empirical evidence from many parts of the world including in temperate areas that farmers can successfully harness increased production with greater profit and fewer inputs (i.e., greater output with enhanced factor productivities) and at the same time deliver a range of ecosystem services needed by society, as well as by the producers to maintain and improve the productive capacity of their soils.

At present, the predominant form of agriculture in Europe is based on the "interventionist approach", in which most aspects of the production systems are controlled by human technological interventions, such as intensive soil tilling, excessive application of biocides and mineral fertilizers, and heavy machinery. Such interventions are known to degrade ecosystem functions, thus making the crop production systems economically inefficient and environmentally degrading and unsustainable [65,66]. However, there are now a growing number of production systems with a predominantly "ecosystem approach" which seek to enhance ecosystem functions as well as productivity. These systems are underpinned by healthy soils, and characterised as CA that are not only efficient in producing food and other raw materials but also more sustainable in terms of ecosystem services. Their further development and spread in Europe merit deeper support with the development of suitable policies, funding, research, technologies, knowledge-diffusion, and institutional arrangements.

8. Conclusions and key learnings from ECAF

There is a wealth of evidence that appoint conservation agriculture as one of the smarter approaches to sustainability in Europe as well as elsewhere. Some concluding remarks on good strategies for supporting the adoption of CA in Europe follow:

– Effective knowledge and technology transfer for the farming community on CA using a combination of scientific and practical expertise.
– Active involvement of key stakeholders including environment agencies, local authorities, government ministries, farmer organizations and the food industry.
– Incentive programmes to encourage the adoption of CA under existing agri-environmental measures in Member States.
– Long-term agronomic research projects on Conservation Agriculture systems at both farm and research levels throughout the EU.
– Establish an opportunity market for carbon credit trading based on soil carbon sequestration where farmers could participate.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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