Chapter 2

The role of soil and water conservation in the transition to green growth

This chapter examines soil and water farm management practices and their impact on resource productivity and efficiency. Soil-related problems are interlinked and there is generally no single solution, but rather a wide range of solutions that address multifaceted soil problems. The attempt to institutionalise these solutions and address nation-wide soil problems, however, has led many countries to adopt mandatory soil conservation policies that are often linked to their agricultural policies and support payments. Several land management practices as they affect water conservation are also considered. The practices examined include the preparation of fields for efficient irrigation and management of excess water, on-farm water delivery systems and the application of irrigation practices, irrigation water use management, and protecting water from non-point source pollution and sedimentation. The empirical challenges of assessing these impacts on productivity, efficiency and innovation are discussed.

Key messages

- The evidence concerning traditional economic productivity growth of soil or water conservation practices as compared to those using conventional farming methods shows mixed results.
- Yields are generally lower on farms that use conservation practices, but there are significant differences in yields between OECD countries, agricultural products and over time. Yields on farms that have adopted soil conservation practices improve under rain-fed agro-systems in dry climates.
- The effects of soil or water conservation practices on resource productivity are positive overall, Soil-conservation practices generally reduce the use of non-energy materials and waste, and the management of nutrients is more environmentally sound.
- There is limited but contrasting evidence on how soil and water conservation practices influence employment rates; soil conservation practices seem to have lower labour requirements, while conservation efforts that include the displacement of crops tend to be labour intensive.

Soil conservation practices

A quiet revolution?

Soil erosion is a global environmental issue. Much of this erosion, as well as the degradation of soil in general, is due to poor soil management practices, including slash and burn management, deforestation, and overgrazing. The extreme climatic and topographic conditions, and climate changes occurring today only increase soil erosion. Current rates of land and soil degradation are considered to be unsustainable. UNEP (2012) argues that 24% of the global land area has suffered declines in health and productivity over the past quarter-century as a result of unsustainable land-use. Since the 19^{th} century, worldwide damage to organic matter due to land-clearing for agriculture and urban development accounts for an estimated 60% loss of the carbon stored in soils and vegetation.

Increasing amounts of land are being cultivated using intensive farming methods. These methods place great strain on the natural resources upon which they rely and are jeopardising the future of agriculture. Indeed, a study co-authored by the European Commission’s Joint Research Centre found that diminished soil biodiversity in the European Union is primarily due to intense use of land for agriculture (Gardi, Jeffery and Salteli, 2013).[1]

Most OECD countries have programmes in place to encourage farm practices that specifically seek to reduce the risk of soil erosion. This includes transferring arable land to grassland, extensive use of pastures, green cover (mainly during the winter period), and promoting soil conservation practices such as tillage conservation, conservation crop rotation, and crop nutrient management practices.

The amount and type of tillage used in crop residue management systems are critical issues for farm managers and policy makers alike, as tillage practices affect nutrient availability, soil structure and aggregate stability, soil strength and temperature, the soil-water relationship, and the crop residue cover. Tillage consumes energy and affects soil carbon sequestration capacity with implications for GHG emissions. Loss of Soil Organic Carbon (SOC) has been primarily attributed to tillage, and tilled soils are viewed as a depleted carbon reservoir (Reicosky, 2003). Likewise, crop rotation practices affect the risk of soil erosion, water runoff, and the chemical and physical properties of the soil.

Conservation tillage methods, which make up some of the most dramatic technological revolutions in crop management, are considered a sustainable alternative to conventional tillage because by maintaining residue cover, it can improve both agronomic and economic efficiency while providing environmental benefits. Moreover, given that fewer tillage field passages are needed, reduced machinery costs, fuel and labour expenditures can boost farm profits. This may, however, be offset by increased pest management costs in some climates and for some crops (Ebel, 2012).

Conservation crop rotation practices can reduce the risk of soil erosion, help prevent water runoff, and improve the chemical and physical properties of soil. These practices can provide supplementary forage and act as a substitute for some agricultural inputs – including fertilisers, herbicides and water – given the significant nitrogen storage capacity and improvement in soil fertility, the suppression of weeds, and soil moisture retention.

Farms that use crop residue management retain more moisture by trapping snow, decreasing water evaporation from the top layer of soil, and improving water infiltration to plant root systems. Environmental benefits include reduced soil erosion and water pollution (via reduced sediment, fertiliser and pesticide runoff), and improved air quality (as soil particulates do not become airborne).

Conservation agriculture is based on the simultaneous application of the following three principles that underpin agricultural production systems: i) continuous minimum mechanical soil disturbance; ii) protection of the soil through permanent maintenance of plant soil cover with crop residues and green manure crops, particularly legumes; and iii) the diversification of rotations and intercropping (Box 2.1). The diversity of production conditions and farmers' needs have led to a wide diversification of practices in the application of these three principles. Conservation agriculture, which integrates ecological management with modern agricultural techniques, corresponds to a family of cropping systems rather than to a single technology or system. In some cases, seeds are sown directly through the crop residues (drilling directly through the stubble), while in others, the soil receives some light preparation to facilitate crops planting. In all cases, changes related to the introduction of conservation agriculture go beyond a mere change in soil tillage techniques and must be considered in a broader context that includes other innovations, such as the use of cover crops and intercropping.

Box 2.1. What is conservation agriculture?

FAO defines conservation agriculture as "an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment" (www.fao.org/ag/ca/1a.html; FAO, 2001). It comprises the following conservation farm practices.

Conservation tillage: Any method of soil cultivation that leaves the previous year's crop residue (such as maize stalks or wheat stubble) on the fields before and after planting the next crop in order to reduce soil erosion and runoff. It minimises (or eliminates) tillage and maintains crop residues as ground cover (practices include no-till, strip-till, ridge-till and mulch-till) (Minnesota Department of Agriculture, 2012). Each of these four methods requires different types of specialised or modified equipment and adaptations in management. No-till and strip-till require that crops are planted crops directly into the residue. With the no-till method, the residue is not tilled at all. With the strip-till method the soil is tilled along narrow strips (zones) with the rest of the field left untilled. With ridge-till method, row crops are planted on permanent ridges about 4-6 inches high, with the previous year's crop residue cleared off the ridge-tops into adjacent furrows, thus making way for the new crop to be planted on the ridges. (However, maintaining the ridges is essential and requires modified or specialised equipment). Mulch-till is any other reduced tillage system that leaves at least one-third of the soil surface covered with crop residue.

Conservation crop rotation: A farm practice whereby several crops are planted in succession in the same field. These crops should include at least one soil-conserving crop, such as perennial hay, or nitrate-trapping and nutrient-enriching crops, such as various legumes. Conservation crop rotation is similar, and frequently practised with, crop cover activities.

Cover crops: All crops that are planted to provide seasonal soil cover on land when the soil would otherwise be bare. Cover crops include various grasses, legumes or forbs and are planted before the main cash crop emerges in spring or after harvest in the autumn. The term "cover crops" includes various practices, such as winter cover crops, catch crops, smother crops, green manure and short-rotation forage crops. Winter cover crops aim to provide the soil with cover over winter in order to reduce water and wind erosion. Catch crops are planted immediately after harvesting the cash crop in order to reduce nutrient leaching. Smother crops are used as an environmentally friendly weed control practice. These crops, such as buckwheat and rye are able to out-compete major weeds. Other cover crops are used as green manure because they are incorporated into the soil in order to improve soil fertility. Finally, cover crops may be used for grazing or green chop to provide forage and are called short-rotation forage crops.

There are clear benefits to conservation agriculture, including evidence that topsoil organic matter increases as do other soil properties and processes involved in the delivery of related ecosystem services. Soil conservation practices protect the soil surface with residue retention, and increase water infiltration and decrease runoff with no tillage, thus reducing erosion due to water and wind (Palm et al., 2014; Verhulst et al., 2012). Water-holding capacity and storage are also improved (reducing the risk of floods) when conservation practices provide a buffer to crop production during drought conditions (Friedrich, Kassam and Shaxson, 2009; Kassam et al., 2009). Finally, conservation agriculture allows for greater precision and timeliness of farm operations, and greater efficiency of inputs. Table 2.1 summarises the effects and benefits of conservation agriculture contrasted with no-tillage (Hobbs et al., 2008).

Table 2.1. Effects of traditional tillage, conservation tillage and conservation agriculture

Issue	Traditional tillage (TT)	Conservation tillage (CT)	Conservation agriculture (CA)
Practice	Disturbs the soil and leaves a bare surface	Reduces the soil disturbance in TT and keeps the soil covered	Minimal soil disturbance and soil surface permanently covered
Erosion	Wind and soil erosion: maximum	Wind and soil erosion: reduced significantly	Wind and soil erosion: the least of the three
Soil physical health	The lowest of the three	Significantly improved	The best practice of the three
Compaction	Used to reduce compaction and can also induce it by destroying biological pores	Reduced tillage is used to reduce compaction	Compaction can be a problem but use of mulch and promotion of biological tillage helps reduce this problem
Soil biological health	The lowest of the three owing to frequent disturbance	Moderately better soil biological health	More diverse and healthy biological properties and populations
Water infiltration	Lowest after soil pores clogged	Good water infiltration	Best water infiltration
Soil organic matter	Oxidizes soil organic matter and causes its loss	Soil organic build-up possible in the surface layers	Soil organic build-up in the surface layers even better than CT
Weeds	Controls weeds and also causes more weed seeds to germinate	Reduced tillage controls weeds and also exposes other weed seeds for germination	Weeds are a problem especially in the early stages of adoption, but problems are reduced with time and residues can help suppress weed growth
Soil temperature	Surface soil temperature: more variable	Surface soil temperature: intermediate in variability	Surface soil temperature: moderated the most
Diesel use and costs	Diesel use: high	Diesel use: intermediate	Diesel use: much reduced
Production costs	Highest costs	Intermediate costs	Lowest costs
Timeliness	Operations can be delayed	Intermediate timeliness of operations	Timeliness of operations more optimal
Yield	Can be lower where planting delayed	Yields same as TT	Yields same as TT but can be higher if planting done more timely

Source: Table 2 in Hobbs, P., K. Sayre and R. Gupta (2008).

Adoption of conservation agriculture and no-tillage techniques is rising rapidly in several countries. According to data collected by the FAO, conservation agriculture has expanded at an average rate of around 7 million hectares per year (from 45 to 125 million) over the period 1999-2013. Since 1990, the rate of adoption globally has been growing exponentially, mainly in North and South America, Australia and New Zealand. The main drivers are stagnating productivity due to soil erosion, loss of soil organic matter and soil structure, soil compaction, the rising costs of production, government policies, the adoption of herbicide-tolerant crops and the potential impacts of climate change (Kassam, Derpsch and Friedrich, 2014).[2]

There are concerted efforts to promote conservation agriculture in smallholder farming systems in South Asia and Sub-Saharan Africa (Hobbs et al., 2008; Valbuena et al., 2012), but whether it is suitable to smallholder systems in the tropics and subtropical countries is unclear (Box 2.2).

It was estimated in 2013 that 10% of the world's cropland area was farmed under conservation agriculture, with the largest areas found in South America (Table A2.1). Five countries account for more than 80% of the total global area under conservation agriculture: the United States (23%); Argentina and Brazil (20%); Australia (11%); and Canada (12%) (Table A1.1). In six countries, the share of cultivated area under conservation agriculture is equal to or larger than 30% (Argentina, Brazil, Australia, Canada, Paraguay and Uruguay) (Figure 2.1 and Table A2.1).

Box 2.2. Innovative approaches to enhance green growth potential in smallholder farming systems

Whilst conservation agriculture has been successfully introduced in high-input and high-yielding smallholder farms in the rice-wheat region of South Asia, this is more challenging in the low-input, low productivity smallholder farm systems of the tropics and subtropics. The most significant obstacles here are the lack of residue produced and the competition from alternate, higher value use.

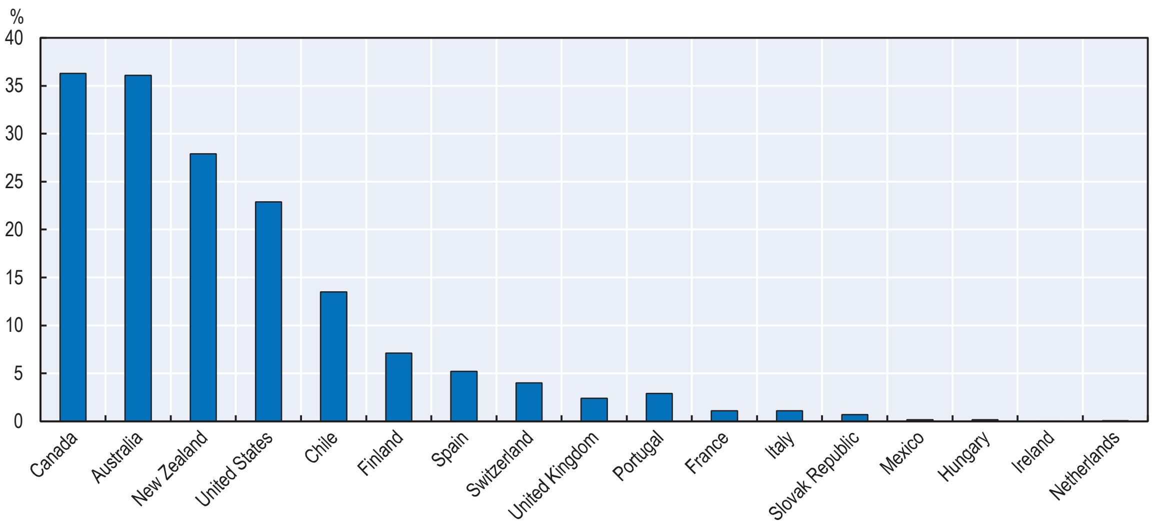
The amount of crop residue retained after harvest, either on the soil surface or incorporated, is a key factor of conservation agriculture. Unlike most temperate zone agriculture and other large-scale farming systems where zero (or reduced) till results in high production and retention of crop residues, that produced by many small scale farms in Sub Saharan Africa, parts of Latin America, and South Asia is low due to low productivity (Palm, et al., 2014; Paul et al., 2013; Thierfelder et al., 2013; Dube et al., 2012; Lahmar et al., 2012; Ngwira, Thierfelder and Lambert, 2012; Giller et al., 2009).

Competing, alternative uses of residues are another constraint. The majority of smallholders are mixed crop-livestock farmers who use most crop residues as animal feed. In some areas, crop residues are burned to clear agricultural fields, while in other areas residues are removed from fields by termites. In many regions of Sub-Saharan Africa, there is also a cultural norm that residues may be grazed by any animal in the community (Wall, 2007). Given that residues provide an important source of animal feed, changing this cultural norm will be difficult.

These limitations point to the need for nuanced approach in the promotion of different conservation agriculture practices. For example, a series of interventions may be more appropriate (Lahmar et al., 2012). The first step would be to increase crop production through nutrient management, followed by soil and water management practices that improve soil quality and water retention, followed by a gradual introduction of conservation agriculture practices if and where appropriate to the soil, climate and socioeconomic conditions. These steps must be based on evidence that the practice or suite of practices result in increased ecosystem services without compromising increased yields.

Sources: Pannell, D., R. Llewellyn and M. Corbeels (2014), "The farm-level economics of conservation agriculture for resource-poor farmers", *Agriculture, Ecosystems and Environment*; Palm, C., H. Blanco-Canqui, F. DeClerck, L. Gatere and P. Grace (2014), "Conservation agriculture and ecosystem services: An overview", *Ecosystems and Environment*,; Brouder, S. and H. Gomez-Macpherson (2014), "The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence", *Agriculture, Ecosystems and Environment*,.

Figure 2.1. Adoption of soil conservation agriculture in OECD countries: Share in total cultivated area,



Source: FAO, AQUASTAT database, website accessed on 2 July 2015.

The initial impetus to reduce soil disturbance and adopt no-till farming in the United States arose in response to the devastation caused by the prolonged drought of the mid-1930s (the dust bowls years). In Canada and Australia, the initial drivers were wind and water erosion, but subsequently factors such as greater productivity and profit, expansion of cropping diversity in sub-tropical and cool temperate environments, and the reduced cost of fertiliser, pesticides, energy and time became important. In the case of countries such as Brazil, Argentina and Paraguay, where no-till farming started in the 1970s and 1980s, the main initial driver was soil degradation due to devastating soil erosion from intense tropical and sub-tropical storms, and from exposed and loose top soil due to intensive tillage.

With the exception of a few countries (e.g. the United States, Canada, Australia, Brazil, Argentina, Paraguay and Uruguay), conservation agriculture has not been "mainstreamed" by farmers or policy makers, and the total arable area under conservation agriculture worldwide remains relatively small (about 9%). The main factors hindering greater adoption, as cited in the literature, include: i) insufficient knowledge (or know-how); ii) farmer attitudes and aspirations; iii) lack of adequate machines; iv) lack of suitable herbicides to facilitate weed management; v) the high opportunity cost of crop residues for feed; vi) lack of herbicide-tolerant crop varieties for some crops and climates; and vii) inappropriate policies (e.g. commodity-based support in some OECD countries) (Kassam, Derpsch and Friedrich, 2014; D'Emden, Llewellyn and Burton, 2008; Thomas et al., 2007; Pannell et al., 2006; Prokopy et al., 2008; Gedikoglou and McCann, 2010; Gedikoglou et al., 2011).[3]

Australia is an example of a country that has largely adopted conservation farm practices. Since the late 1990s, these practices have been used by the majority of crop farmers, driven primarily by the anticipated benefits of higher crop yields resulting from managing soil moisture and improved fertility. In particular, such practices (involving reduced tillage and crop residue retention) have been a key management tool to improve productivity in the dryer inland grain-producing areas, which cover 80% of cropping land. Farmer experimentation with conservation agriculture began in the 1960s; today,of the country's 23.5 million hectares of winter crops, 80-90% are cultivated using conservation agriculture practices (Belloti and Rochecouste, 2014).

The hot, arid conditions in Australia have created a major impetus for the expansion of moisture conservation through direct seeding and stubble retention after harvest. The economic benefits from yield increases through no-till systems in the cereal grains sector is 1 tonne per hectare, with increased planting opportunities in prolonged dry years. Other sectors (cotton and sugar) have followed suit. A national survey conducted in 2012 by the Conservation Agriculture Alliance of Australia and New Zealand (CAAANZ) indicates that the main catalyst for changing tillage practices included the perceived risks stemming from soil erosion and drought that farmers believed threatened the viability of their farms. In addition, the changes in conservation farming practices and the success gained in terms of yield led to further research into productivity gains and the need to reduce cost input resources. Although this research was primarily productivity-driven, it was to provide significant complementary benefits to the environment, in particular the emergence of precision agriculture (Chapter 6).

In the United States, agricultural land devoted to "no-till" farming has increased across all major crops. In 2010, approximately 35.5% of US cropland planted to eight major crops had no tillage operations (Ebel, 2012; Horowitz, Ebel and Ueda, 2010). Soybean farmers had the highest percentage of planted area with no-till (almost 50%), followed by maize (around 30%) and cotton farmers (24%). More area is planted to maize than to any other field crop in the United States. Of all the major crops analysed, rice farmers had the lowest percentage of planted acres with no-till (16.3%).

Crop nutrient management is an important conservation strategy that has implications on production costs. Crop nutrient management refers to the type, quantity and time of application of major nutrients. Farmers are frequently unaware of the nutrient needs of their soils; the continued application of fertilisers does not increase yields, but does increase contamination and production costs. It is estimated that the over-application of inorganic and organic fertilisers has boosted nutrient capacity in the soil by about 2 000 kg of nitrogen, 700 kg of phosphorus, and 1 000 kg of potassium per hectare of arable land in Europe and North America in the last 30 years (World Bank, 1996). Integrated nutrient management is related to precision agriculture and is discussed in Chapter 6.

It is evident that all soil-related problems are interlinked and there is no single solution – or rather, there is a wide range of solutions addressing the multifaceted soil problems. The attempt to institutionalise these solutions and address nation-wide soil problems has led many countries to adopt mandatory soil conservation policies linked, or not, to their agricultural policies.

In the European Union, an integrated soil conservation directive was proposed in 2006, but has not progressed since. However, the cross compliance regulations in the European Union provide a coherent soil conservation policy for agriculture. Cross compliance is the set of conditions which must be met by farmers who claim direct payments under the Common Agricultural Policy (e.g. the Single Farm Payment Scheme). These conditions constitute the minimum farming requirements and for which the farmer is not compensated. Additional requirements and their associated payment may be covered by agri-environmental schemes. Good Agricultural and Environmental Conditions (GAECs) are legal requirements made up of either existing laws or existing good practices in EU member states before the introduction of cross compliance. Concerning soil conservation, GAECs requirements relate to soil erosion, soil organic matter, soil structure, and ensuring a minimum level of maintenance.

For soil erosion, GAECs require minimum soil cover, minimum land management reflecting site-specific conditions and the retention of terraces when possible. For soil organic matter, standards are set for crop rotations and arable stubble management. Soil structure recommendations include appropriate use of machinery and minimum livestock stocking rates. Finally, cross compliance requirements in the European Union ensure that the ratio of permanent pasture to total agricultural area is maintained at the 2003 level. Permanent pasture is defined as land that has been under grass for at least five years and has not been ploughed for other crops during that time. There are also many voluntary agri-environmental programmes which compensate farmers for agreeing to produce further environmental and conservation public benefits, in addition to what is envisaged through cross compliance.

In the United States, the Food Security Act (1985 Farm Bill) introduced two important compliance conservation practices to preserve soil and water resources (collectively referred to as conservation compliance). These two provisions, still in force, require that in exchange for certain US Department of Agriculture (USDA) programme benefits, producers agree to maintain a minimum level of conservation on highly erodible land and not to convert wetlands into cultivated land. In addition, many voluntary programmes exist for soil and water conservation.

The Agricultural Management Assistance Program provides financial and technical assistance to agricultural producers who voluntarily want to adopt water management, water quality, and erosion control practices by incorporating conservation into their farming operations. The Environmental Quality Incentives Program is a voluntary programme that provides financial and technical assistance to agricultural producers through contracts of up to a maximum term of ten years. Assistance is provided to help plan and implement conservation practices that address natural resource concerns and for opportunities to improve soil, water, plant, animal, air and related resources on agricultural land and non-industrial private forestland.

The Conservation Stewardship Program (CSP) is a voluntary conservation programme that encourages producers to address resource concerns in a comprehensive manner by: undertaking additional conservation activities, and improving, maintaining, and managing existing conservation activities. Two types of payments are provided through five-year contracts: annual payments for installing new conservation activities and maintaining existing practices; and supplemental payments for adopting a resource-conserving crop rotation. Participants are paid for conservation performance: the higher the operational performance, the higher their payment.[4]

Productivity and efficiency gains, but types of soil and crops critical to the overall gains

Economic outcomes are context specific

Soil is an asset, whose returns are composed of three elements: i) the value of soil as an input to agricultural production; ii) the value of soil as a capital element which − depending on the amount and productivity − affects the potential resale value of the land; and iii) the value that soil provides above and beyond production (i.e. provision of ecosystem services). These elements determine the potential resale value of the farmland.

The returns to soil conservation practices and their effects on farm productivity and efficiency have been a widely discussed in agricultural economics.[5] At the farm level, the economic impacts of soil erosion and soil degradation are often related to productivity slowdown and decreasing returns observed in some countries.

Changes in prices (input or output) may have contradictory effects on soil erosion. An increase in the output price creates an incentive for increased soil erosion due to the fact that higher output price could encourage farmers to expand production to less productive land or to shift less productive agricultural land to other uses. Policies that increase incentives for stimulating production on economically marginal land may have disproportionately large and unintended consequences for the environment (OECD, 2009). Lubowski et al. (2006) found that in the United States land brought into or retained in cultivation due to crop insurance policies is, on average, less productive, more vulnerable to erosion, and more likely to include wetlands and imperilled species habitats than cultivated cropland.

Input costs are likely to vary under soil conservation practices relative to conventional ones. Conservation tillage has a small cost advantage over conventional tillage, although site-specific conditions could alter this in various ways. Adoption of conservation (or zero) tillage implies that farmers can use smaller tractors and make fewer passes over the field, resulting in lower fuel and repair costs. Conservation tillage also reduces the cost of machine ownership (i.e. interest and depreciation) because some machines are no longer needed. Similarly, most findings confirm the expectation that fuel costs are lower than those incurred under conventional tillage.

Reduced input costs, however, might not be observed because reducing tillage can lead to greater use of pesticides to combat weeds, pests and diseases. Herbicide costs could be higher, at least initially, and thus offset any cost savings associated with less labour, fuel, machine repairs and overhead. Most developed-country studies find, nevertheless, that conservation agriculture demonstrates at least minor cost savings (FAO, 2001).

Uri (1999) found that that in the United States, while the real price of crude oil does not affect the rate of adoption of conservation tillage, it does impact the extent to which it is used. In general, conservation tillage is more profitable in steep-sloping, high rainfall tropical regions (e.g. Latin America) than in flatter temperate areas (e.g. Canada and the United States), since the former would be subject to a higher risk of erosion under conventional tillage (FAO, 2001).

A comparative study of conservation agriculture and conventional tillage in Wisconsin (United States) found that short-run average costs under conservation agriculture exceeded long-run average costs by about 7% (Mueller et al., 1985). The short-run average costs per hectare for conservation tillage were greater than for conventional tillage. However, after adjustments to capital, conservation tillage costs fell below those of conventional tillage in the long run.

Concerning the impact on fertiliser use, Uri (1997) finds there is some increase in fertiliser use by maize farmers adopting conservation tillage in the United States. Additionally, if the application of fertilisers under conservation tillage requires greater management skill, then application costs could rise even if application rates do not.

FAO (2001) reviewed 40 studies of the financial net present values (NPVs) for conservation agriculture and related agronomic approaches (intercropping, contour farming, green manure), almost all in developed countries. Of these, 34 studies indicated that the NPV of conservation agriculture would be positive. Knowler and Bradshaw (2007) reported that 10 out of 11 reviewed studies of the economics of conservation agriculture for Sub-Saharan Africa found a positive NPV.

Erenstein and Laxmi (2008) reviewed several studies (a mix of on-farm trials, field station trials, and farmer surveys) of the economics of zero tillage in the Indo-Gangetic Plains. The authors noted that "cost and profitability comparisons are sometimes complicated by site specificity and methodological differences". Nevertheless, the results consistently showed benefits, both cost savings and increased yields. On average, slightly more than half of the benefits were due to cost savings and slightly less than half to yield increases.

Overall, results from the literature tend to indicate that, in most cases, it would be profitable to adopt conservation agriculture or parts of it (Pannell et al., 2014). There appears to be a small cost advantage over conventional soil farm practices (5-10%), although results vary widely from site to site, with many studies showing soil conservation practices as less profitable. There are also differences in analysing cases in developed versus developing countries (Pannell et al., 2014; FAO, 2001; Uri, 1999).

There are a number of possible explanations for the diverse results. The approaches adopted may be too simplistic or partial, and the opportunity costs of resources used in conservation agriculture are not taken into account. For example, the analysis includes only the direct financial cost of inputs, while agronomic and management factors, such as the opportunity cost of mulching crop residues – which may have a non-cash value for feeding livestock or for burning to enhance pest control that would be lost if the residues are used for soil cover – or the opportunity cost of labour used for weed control are omitted. Secondly, assumptions about agronomic impacts may be overly optimistic. For example, data are obtained from field stations under well-controlled conditions rather than directly from farms. Finally, issues of risk and uncertainty are overlooked (Pannell et al., 2014). The published literature highlights the high level of heterogeneity and the need for case-specific analysis (Pannell et al., 2014).

Higher yields are attained under rain-fed agro-systems in dry climates

It is difficult to establish a robust conclusion as to whether conservation agriculture can maintain crop yields as well as be effectively applied in widely differing farming contexts. For example, although soil moisture retention can be higher with conservation agriculture, resulting in higher and more stable yields during dry seasons, the amounts of residues and soil organic matter levels required to attain higher soil moisture content remains unknown. Empirical evidence suggests that, overall, the effects on yields are mixed, depending on prevailing environmental conditions, including types of soil and crops, and could vary over time.

Evidence on yield effects of zero tillage is highly variable (Giller et al., 2009). Where zero tillage is combined with mulching, a commonly described pattern is for yields to fall initially and then to increase over the subsequent decade or so, eventually exceeding yields in conventional tillage-based agriculture (Pittelkow et al., 2015; Giller et al., 2009; Rusinamhodzi et al., 2011). However, trial data also reveal cases where yield is largely unaffected, and some survey data indicate increases and decreases in different cases.

The economic impact of crop residue management is also highly context-specific, depending on such factors as human population and livestock density, cropping intensity, access to alternative feed sources, land and markets, and non-agricultural income. Apart from the long-term yield effect of mulching with zero tillage, mulching can generate higher soil moisture content in the immediate following year, resulting in higher yields, especially in dry years. However, there is evidence that if mulching is important for high yields in dry areas, yields after mulching can be lower in high-rainfall conditions. It is clear that agro-ecological conditions play a major role in determining the benefits of conservation agriculture.

Pittelkow et al. (2015) have synthesised information from more than 5 000 observations obtained from 610 studies. They show that farming which uses a combination of conservation agriculture techniques can produce equivalent or greater yields than conventional farming under certain conditions. In particular, key finds are as follows: i) the use of "no-till" alone negatively impacts yields (-11.9%);[6] ii) yield decline is minimised when all three principles are applied, as compared to only a single principle applied; iii) no-till significantly enhances yields (7.3%) under rain-fed agriculture in dry climates when the other two conservation agriculture principles are also implemented due to improved water infiltration and greater soil moisture conservation; iv) no-till reduces yields in the first few years following adoption, regardless of whether the other two conservation agriculture principles are implemented; v) no-till yield losses tend to diminish with time, although it does not outperforms conventional tillage after ten years; and vi) there is no evidence that one principle outperforms the other.[7]

The results presented by Pittelkow et al. (2015) have important policy implications. First, to maximise yields, conservation tillage should be implemented in cropping systems which employ residue retention and crop rotation. The transition to no-till integrated with the other two conservation agriculture principles is challenging as it represents a holistic change in management requiring adaptation at the individual farm-level and crop residues can have significant feed value. Second, conservation agriculture could become an important climate-change adaptation strategy in ever-drier regions of the world. However, expansion of conservation agriculture in these areas should be done with caution, as implementation of the other two principles is often challenging in resource-poor and vulnerable smallholder farming systems, thereby increasing the likelihood of yield losses rather than gains.

Van de Puttea et al. (2010) present a meta-regression analysis (47 European studies, 563 observations) that compares crop yields under conventional tillage, reduced tillage, and no-tillage practices. Their analysis shows that while the introduction of conservation tillage in Europe may indeed have some negative effect on yields, these effects can be expected to be limited. Surprisingly, they find that no-tillage performs worse under drier climatic conditions. They argue that this is due to the fact that in wetter climatic conditions negative effects, such as an increased prevalence of pests, seem to outweigh possible gains stemming from increased water availability. On clay and sandy soils, however, this negative effect of no-tillage is counteracted and all conservation tillage techniques perform better under drier climatic conditions. Another important finding concerns cereals-only rotations, where relative yields under conservation tillage tend to decrease with time. The authors suggest that conservation tillage can be a viable option for European agriculture from the viewpoint of agricultural productivity. Potential negative effects on agricultural productivity can be strongly reduced by applying sufficiently deep tillage and by practicing crop rotation, including crops other than cereals.

deVita et al. (2007) examined the effect of no-tillage and conventional tillage on durum wheat under rainfed Mediterranean conditions over a three-year period (2000-02) at two locations (Foggia and Vasto) in southern Italy. Higher yields were obtained in Foggia with no tillage (rather than conventional tillage) in the first two years. In contrast, mean yield and quality parameters in Vasto were similar for the two treatments during the first two years and higher for conventional tillage during the third year. This was attributed to the high correlation between rainfall and yields, with a system of no-tillage supporting higher levels of soil moisture. In this case, soil conservation practices are more productive (more output and less input) than conventional practices. In contrast, a study for wheat and maize in the Pampas, Argentina, found that although the adoption of limited tillage systems leads to soil improvement, it also generates the necessity to increase the use of nitrogen fertilisers in order to sustain yields (Alvarez and Steinbach, 2009).

Li et al. (2007) present a 15-year field experiment conducted in Shanxi, the People's Republic of China (hereafter "China") that compares the long-term effects of no-till and residue cover with conventional tillage in a winter wheat monoculture. Crop yield and water use efficiency tended to be higher under no-tillage than under conventional tillage, especially in the years of low rainfall. This suggests that the change in soil structure provided a better environment for crop development. Thus, no-tillage is a more sustainable farming system which can improve soil structure and increase productivity with positive environmental impacts in the rain-fed, dry farming areas of northern China.

Farooq et al. (2011) plotted the yield difference between the full conservation agriculture package and conventional treatments against rainfall using results from 25 studies and found a declining trend in yield advantage of conservation agriculture as rainfall increased, with yields of conservation agriculture being mostly higher than conventional systems where annual rainfall was below 560 mm. In their meta-analysis of maize production under conservation agriculture, Rusinamhodzi et al. (2011) found that conservation agriculture led to no difference in yield stability under conditions of drought or excess rainfall.

Brouder's and Gomez-Macpherson's (2014) review of the evidence study also finds that the very few studies that fully reported critical data or meta-data show that in the short-term zero tillage generally resulted in lower yields than did conventional tillage. Occasionally, these decreases could be linked to direct effects (e.g. increased soil compaction in rice), but failure to adapt other management tools (e.g. weed control) to the conservation agriculture system was a common and confounding indirect effect. The authors argue that it is not possible to make strong general conclusions about benefits of conservation agriculture and zero tillage on yields and resource use efficiency of smallholder farmers as there too few field studies.

Greater precision and timeliness of farm operations result in higher efficiencies of input use

Soil conservation practices allow large farms to use technological advances, such as controlled traffic farming and GPS-based precision farming that lead to higher levels of efficiency of energy and input use. These efficiencies have led some countries to implement policy initiatives such as the carbon credit scheme for offset markets from conservation tillage that has been operating in Alberta, Canada for several years. The scheme, based on conservation agriculture, is in the process of integrating controlled traffic farming and GPS-based precision farming (Lindwall and Sonntag, 2010).Soil conservation practices, which increase soil water content by increasing infiltration and reducing runoff and evaporation, improve water use efficiency and buffers crops against drought. Mulch cover also buffers the soil against temperature extremes. For example, in rain-fed semi-arid highlands of Mexico, soil water content during dry periods was 10-20 mm higher in maize fields under conservation agriculture than in those with conventional tillage and residue removal. There is clear evidence that mulch reduces soil erosion (Giller et al., 2009).

Concerning nutrient productivity, Moussa-Machraouia et al. (2010) conducted a study in Tunisia where they found that no-tillage significantly improved soil content, especially for K, K_2O, P_2O5 and N, while Soil Organic Matter (SOM) and Soil Carbon (SOC) are enhanced but not to a significant extent.

Moussa-Machraouia et al. (2009) found that long-term conservation tillage increased soil organic matter in the top 20 cm by 21.4%, total N by 31.8% and P by 34.5% in the 0–5 cm layer, compared with traditional tillage. The authors also found that the largest yield improvements coupled with greatest water use efficiency were achieved by no-tillage with straw cover.

Loke et al. (2012), in a long-term (32 years) study of wheat production in semi-arid South Africa, found that no-tillage had higher SOC levels than the stubble mulch and ploughing treatments in the 0–50 mm soil layer, but the ploughed plots recorded higher SOC levels below 100 mm of soil depth. No-tillage and stubble mulch enhanced Soil Total Nitrogen (STN) throughout the soil profile, compared with ploughing. The authors suggest that to maintain or improve SOM in specific soil types (Plinthosol), priority should be given to no-tillage and stubble mulch management practices.

Hobbs et al. (2008) review the role of conservation agriculture in sustainable agriculture and present the benefits of conservation agriculture as an improvement on conservation tillage. Their paper concludes that conservation agriculture is a more sustainable and environment-friendly management system for cultivating crops. Case studies from Asia and Mexico show that agricultural conservation practices in these two different environments have raised production sustainably and profitably.

The potential of soil conservation farm practices to mitigate climate change is uncertain

Soil conservation practices, particularly no-till, have been promoted as a means to potentially mitigate climate change by sequestering carbon (West and Post, 2002; Lal, 2004). However, this optimistic view has been challenged and it is now recognised that soil carbon storage with soil conservation practices compared to conventional ones shows considerable variation (Govaerts et al., 2009; Luo et al., 2010). The potential of soil conservation farm practices for storing carbon depends on a variety of factors including, antecedent soil carbon concentration, cropping system, management, soil type, and climate.

There are many uncertainties remaining in understanding the relationship between tillage, soil carbon, and other greenhouse gases (Vanden Bygaart et al., 2003). Reduced-tillage or no tillage may increase soil carbon compared with conventional tillage, but these increases are often confined to near-surface layers (<10 cm) and, as such, the observed increase is a redistribution of organic carbon, not a net accumulation.

Baker et al. (2007) argue that reduced tillage has not been shown to cause a consistent increase in soil organic carbon. Boddey et al. (2010) and Franzluebbers (2009), however, argue against the claims made by Baker et al. Blanco-Canqui and Lal (2008) found that the impact of no-tillage farming on soil organic carbon and nitrous oxide were soil specific: no-tillage farming increases soil organic carbon concentrations in the upper layers of some soils, but it does not store soil organic carbon more than plough tillage soils for the whole soil profile.

Palm et al. (2014) review of global literature found that there is clear evidence that topsoil organic matter increases with conservation agriculture and with it other soil properties and processes that reduce erosion and runoff and increase water quality. However, the impacts on other ecosystem services are less clear. Only about half of the 100+ studies that compare soil carbon sequestration with no-till and conventional tillage indicate increased sequestration with no till. Combining no-till with residue retention increases the potential for carbon sequestration by increasing biomass inputs to the soil. The study by Govaerts et al. (2009) found that out of 100 comparisons, soil carbon stock in no till was lower in seven cases, higher in 54 cases, and equal in 39 cases as compared to conventional tillage in the 0- to 30 cm soil depth after five years or more of no till implementation. These studies were primarily from Canada and the United States, and to a lesser extent from Brazil, Mexico, Spain, Switzerland, Australia and China.

The meta-analysis by (Luo et al., 2010) found increased soil carbon in the topsoil (0-10 cm) on conversion of conventional tillage to no tillage, but no significant difference over the soil profile to 40 cm due to a redistribution of carbon in the profile (Luo et al., 2010). Eve et al. (2002) reported that, on average, a farmer in the US Corn Belt who changes from conventional tillage to reduced tillage would sequester only 0.33 more metric tons of CO_2 per acre per year over a 20-year period, while the change from conventional tillage to the more restrictive no-till would sequester 0.64 more metric tons of CO_2 per acre per year.

In addition to minimum soil disturbance, the level of carbon sequestration depend on suitable crop rotations or associations, and on the amount of the biomass from the production system that is retained as surface mulch and is being incorporated or sequestered into the soil. Crop rotations effects on soil carbon are often mixed (Corsi et al., 2012). High-residue producing crops may sequester more carbon than crops with low residue input. Intensification of cropping systems such as increased number of crops per year, double cropping, and addition of cover crops can result in increased soil carbon storage under no tillage (West and Post, 2002; Luo et al., 2010). West and Post (2002) found interactions with crop rotations and tillage practice; in general, crop rotations sequestered more carbon than monocultures on conversion to no tillage, though there were notable exceptions with corn-soybean rotations with less soil carbon than monoculture maize.

A review study was undertaken by FAO of the scientific literature concerning the impacts and benefits of the two most common types of agriculture, "traditional tillage agriculture" and "conservation agriculture, a no-till system", with respect to their effects on soil carbon pools (Corsi et al., 2012). The results on carbon sequestration in tillage agriculture were compared with conservation agriculture. The review shows that conservation agriculture permits higher rates of carbon sequestration in the soil compared with tillage agriculture. When no carbon sequestration or carbon loss is reported in agricultural systems, this is most frequently associated with any one, or with a combination, of the following reasons: i) soil disturbance; ii) mono-cropping; iii) specific crop rotations; iv) poor management of crop residues; and v) soil sampling extended deeper than 30 cm.

Although the amount of residues retained in the system is a key component to the amount of carbon stored in the soil, there is little indication of the amount of residues needed to maintain or increase soil carbon. In fact, insufficient levels of surface residue combined with no till does not result in increased soil organic matter, soil moisture or related ecosystem services and can even result in decreased yield (Palm et al., 2014). The amount of residues required to increase soil carbon and benefits derived from it depends on the crop types, yields obtained, and the balance between carbon inputs and decomposition which vary with soils and climate.

The effects of these three types of soil practices on soil carbon stocks are generally analysed separately in the literature. Nevertheless, these conservation agriculture components interact. For example, the types of crops, intensity of cropping and duration of the cropping systems determine the amount of inputs and thus the ability of conservation agriculture to store more carbon than conventional tillage. Intensification of cropping systems with high above and below ground biomass (i.e. deep-rooted plant species) input may allow conservation agriculture systems to store more soil carbon relative to conventional tillage (Luo et al., 2010).

Conservation agriculture also reduces power and energy requirements. Not tilling the soil decreases fuel consumption, requires less working hours, and slows the depreciation rate of equipment per unit of output. Not only do these factors contribute to emission reductions of farm operations, but also from the machinery manufacturing processes. In addition, crop residues left on fields return the carbon fixed in crops to the soil through photosynthesis, thereby improving soil health and fertility. This, in turn, lowers fertiliser use and CO_2 emissions.

Several studies report higher GHGs emissions (nitrous oxide and methane) with conservation farm practices compared to conventional, while others find lower emissions. With no till, residues are returned to the soil resulting in surface mulches that may lower evaporation rates, and hence increase soil moisture and labile organic carbon (Galbally et al., 2005). This consequently increases N_2O emissions compared to conventional till. Increased bulk density with conservation agriculture compared to conventional till may also increase emissions.

However, lower soil temperatures and better soil structure under no till may reduce the incidence of soil saturation and reduce emissions of N_2O. There are no definitive conclusions but rather contradictory findings on N_2O emissions from conservation agriculture compared to conventional practices. The inconsistent results of N2O emissions with conservation agriculture practices are potentially due to the lack of comparability of studies and methodological issues on the measurement of N_2O in the field (Palm, et al., 2014).

There are very few studies that examine the impact of different conservation agriculture practices on all relevant GHGs, including soil carbon sequestration and the resulting net global warming potential. One of the few comprehensive studies conducted over multiple years found no differences in either N_2O or CH_4 emissions between conservation agriculture and conventional till in a long-term dryland cropping trial in central Mexico (Dendooven et al., 2012a and Dendooven et al., 2012b). Conservation agriculture was found to have a significantly lower global warming potential in comparison to conventional till due solely to changes in soil carbon.

West and Marland (2002) estimate the carbon dioxide emissions from the use of machinery and other agricultural inputs (fertilisers, pesticides, seeds, etc.) for three tillage practices in the non-irrigated areas of the United States. The authors undertake a full carbon cycle analysis on US agriculture and find that changing from conventional tillage to no-tillage does not increase CO_2 emissions, and in most cases contributes to a decrease. They also find that changing from conventional tillage to no-tillage offers an opportunity to both increase carbon sequestration and simultaneously reduce carbon emissions from agriculture.

Lower labour requirements, but availability of off-farm labour critical to adoption

Much attention has focused on the apparent reduction in labour requirements under conservation agriculture due to decreased demand for labour to prepare land at the beginning of the growing season. Some estimates put this reduction at 50-60% during this time period. In the case of smallholders, conservation tillage is more likely to lead to labour savings in cases where herbicides are used for weed control, but less likely where farmers employ manual weeding. In the latter case, conservation tillage could even require more labour than conventional tillage agriculture.

Herren et al. (2012) report that most no-till farm operations have lower labour requirements per productive unit of output and per unit of land. Overall, due to the fact that yields from no-till farms were consistently greater than those from conventional farms, the economic return to no-till farm labour was significantly higher.

The level of a farm household's off-farm income is a factor influencing their decision to adopt new technologies. The existing literature, however, seems to suggest that the effect of off-farm income on adoption is ambiguous – increasing the adoption of some practices while decreasing the adoption of others. Off-farm employment would be expected to decrease the availability of labour and could thus impede the adoption of labour-intensive conservation farm practices.

A study by Gedikoglu et al. (2011), based on a survey of 3 104 livestock farmers in Iowa and Missouri (United States), found that the off-farm employment of farm operators has a significantly positive impact on the adoption of capital-intensive practices at the expense of more labour-intensive practices. In particular, adopting the practice of injecting manure into the soil, which is a capital-intensive procedure (and which contributes to the compaction of topsoil due to the use of heavy machinery) is preferred to non-mechanical (and more soil-conserving) spreading due to its time-saving advantages. The same results are supported by previous studies which found that in regions where off-farm employment plays a major role, farmers are less likely to divert labour to conservation practices if the economic returns from off-farm labour are higher than the perceived benefits from investing scarce labour in soil conservation (Neill and Lee, 2001; Moser and Barrett, 2003; Jansen et al., 2006; Lee et al., 2006; Wollni et al., 2010).

At a watershed or even higher spatial-level, the application of soil and water conservation practices can be very beneficial for the rural economy and for job creation. Pincus and Moseley (2013) analyse the impact of watershed restoration practices on Oregon's (United States) economy using input-output analysis. They find that the sustained programme of restoration work conferred significant benefits to the economy. They also note that these impacts largely accrue to rural areas in need of economic development opportunities due to the decline in traditional resource management activities. They estimate that in addition to approximately 16 jobs that are supported per million dollars invested in ecological restoration, a sustained investment in restoration has created both new local organisational capacity in watershed councils and other community-based partners and business opportunities, especially in rural areas.

In a more "holistic" investigation, Herren et al. (2012) apply an integrated dynamic global modelling approach to assess the job-creation capacity of green agriculture. The authors specified the adoption of actions such as sustainable management practices (e.g. no-till cultivation, natural fertilisation), research and development, integrated pest control and rural value-added food processing, and assumed that investments of initially USD 100 billion and subsequently USD 180 billion per annum, to facilitate these actions will be induced through subsidies and shifts in taxation. These investments were assumed to be directed either to green agriculture or to conventional agriculture. Projections showed that if the green agriculture option is chosen, farm and food employment in 2050 is 3% higher than that associated with the conventional agriculture option.

Water conservation practices

Agriculture accounts for around 70% of the water used in the world today (45% in the OECD area). Rapidly growing water demand from cities, industry and energy suppliers, and the effects of climate change will make less water available for irrigation in the future. Farmers must receive the right signals to increase water use efficiency and improve agricultural water management, while preserving aquatic ecosystems.

The scope for the sustainable management of water resources in agriculture concerns the responsibility of water managers and users to ensure that such resources are allocated efficiently and equitably, and used to achieve socially, environmentally and economically beneficial outcomes. This includes: irrigation to smooth water supply across the production seasons; water management in rain-fed agriculture; management of floods, droughts, and drainage; and conservation of ecosystems and associated cultural and recreational values.

Conservation water management practices include land management practices to prepare fields for efficient irrigation and management of excess water, on-farm water delivery systems and the application of irrigation practices, irrigation water use management, and protecting water from non-point source pollution and sedimentation. Non-point source pollution comprises constituents such as nutrients, and organic and toxic substances from diffuse sources, such as runoff from agricultural land development and use. Soil conservation practices, especially conservation tillage and conservation crop rotation are also considered water conservation practices because they enhance soil water content due to minimum soil disturbance and maintenance of soil cover, reduction of water runoff and improved infiltration.

Correct initial land levelling conserves water by reducing runoff and allowing uniform distribution of rainfall and irrigation water. For example, in Texas (United States), correct levelling can reduce water use-by 20-30% and increase crop yields by 10-20% (Texas Water Development Board). Furrow diking conserves water by capturing precipitation or irrigation water in small dams made by earth in the furrows. Knowledge about weather conditions, the capacity of the soil to absorb and retain water, and the capacity of crops to utilise water, depending on root depth and soil properties at different depths, can provide crucial information for water conservation.

There are three basic types of water delivery: surface (gravity), sprinkler, and drip irrigation. The highest levels of water conservation are attained through drip irrigation, which can be very effective with certain crops and on uneven terrain. Sprinklers, especially those of the older high-pressure technology, are not efficient, particulary under conditions of high temperatures and windy conditions. For this reason, modifications to low-energy precision application and low-elevation spray application have been introduced. The case of Israel offers a unique insight into what an integrated water management system looks like in practice, in addition to providing lessons on how to efficiently manage a scare resource (Box 2.3).

Farming practices that seek to minimise non-point source pollution and sedimentation include the creation of various types of buffer areas, grass filter strips, grass waterways, forested riparian buffers, terraces, diversions, water and sediment control basins, etc. A buffer area (buffer strip or buffer zone) is an area of natural or established vegetation managed to protect critical resource areas, such as wetlands, water bodies, waterways or even wells, from significant degradation due to land disturbance and nutrient chemical runoff.

Grass filter strips are planted between the field and surface water (rivers, streams, lakes and drainage ditches) to protect water quality. They slow the runoff from fields, trapping and filtering sediment, nutrients, pesticides and other potential pollutants before they reach surface waters. Filter strips also are planted around drainage tiles. Grass waterways are a type of broad and shallow conservation buffer designed to prevent soil erosion while draining runoff water from adjacent cropland. Grass waterways also help prevent gully erosion in areas of concentrated flow.

Forested riparian buffers are rows of trees or shrubs or maintained grass that is planted alongside rivers, streams, lakes or wetlands and are designed primarily for water quality and wildlife habitat purposes. Forested riparian buffers prevent potential pollutants in agricultural runoff (sediment, nutrients, pesticides, pathogens) from reaching surface waters. Terraces are earthen or stone embankments, channels, or combined ridges and channels built across the slope of the field (USEPA, 1993). They may reduce the topsoil erosion rate and lessen the sediment and pollutants content in surface water runoff. In the United States, terraces have been reported to reduce soil loss by 94 to 95%, nutrient losses by 56 to 92% and runoff by 73 to 88% (Cestti, Srivastava and Jung, 2003).

A diversion is similar to a terrace but its purpose is to direct or divert surface water runoff away from an area, or to collect and direct water to a pond. Diversions are used with filter strips above them in order to trap sediments and protect the diversion, and with vegetative cover in the diversion ridge. A water and sediment control basin is a small earthen ridge-and-channel or embankment built across a small watercourse or area of concentrated flow within a field.

A good example of integrated water conservation policy with direct implications for agriculture is the European Union's Water Framework Directive (WFD) introduced by "Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy". The WFD classification scheme for the ecological status of surface water includes five categories: high, good, moderate, poor and bad. The WFD requires river, lakes, ground and coastal waters to reach good ecological and chemical status by 2015. Thus, the WFD has very serious implications for farming practices and land management as well as water management concerning diffuse pollution and water consumption. One of the most important measures to achieve this goal includes reducing emissions of nitrogen (N) and phosphates (P_2O_5) from manure and mineral fertilisers into the environment. This action incurs a considerable cost to the farming sector and, in certain cases, the cost is far beyond what can be achieved within the budget of agri-environmental measures (OECD, 2012).

Box 2.3. The efficient management of water resources in Israel

A notable feature of Israeli agriculture has been its capacity to increase the efficiency of water-use in agriculture. Efficiency has been improved in physical (technical) terms of water use per tonne of output (or hectare irrigated), in terms of economic water-use efficiency (value of output per unit of water used and through reducing the sector's use of fresh drinking quality water while increasing use of recycled water).

Efficient water management has been the foundation of much of Israel's success in agriculture in arid, semi-arid and dry sub-humid zones. The invention and development of drip irrigation in Israel from the 1960s has been the key innovation behind the rise in technical water-use efficiency, as well as shift towards other pressurised irrigation systems (i.e. sprinklers, micro-sprinklers, micro-jets) with flood irrigation no longer being used. Water-use efficiency is increased through lowering runoff and evaporation losses and reducing leaching of water and contaminants below the root zone. The success of drip irrigation lies in the provision of optimum conditions for plant uptake of water and nutrients. Drip systems also facilitate the more efficient agronomic use of saline, brackish and marginal water.

Initially, drip irrigation met with limited interest and was not without problems, such as pipe clogging and breakage. This changed in the 1980s with further refinements to drip systems, including developments towards the next generation of drip technology including computerised systems and pressurised drippers, which enable the stable distribution of water. In Israel over half the irrigated area is now under drip irrigation.

A more recent development has been sub-surface drip irrigation (SDI), with about 5-10% of the irrigated area currently under SDI systems. These systems are positioned within the soil to: conserve water; control weeds; minimise runoff and evaporation (reducing evaporation by up to 20%); increase longevity of piping and emitters; ease use of heavy equipment in the field; and prevent human contact with low-quality water. Additional motivation for SDI comes in the form of savings, as the extensive labour costs involved with the seasonal installation and collection of surface drip system piping is eliminated. SDI also provides the opportunity to manipulate root distribution and soil conditions in arid climates in order to better manage environmental variables including nutrients, salinity, oxygen and temperature.

Source: OECD (2010), *Review of Agricultural Policies: Israel*, http://dx.doi.org/10.1787/9789264079397-en.

High productivity, efficiency and innovation impacts, but empirical assessment is challenging

Water-conservation practices target the quantity and quality of water and can be implemented at all stages of water storage, delivery and use both on- and off-farm. In principle, water conservation measures are resource-efficient because they attain their yields by managing the water-retention capacity of soil. Water conservation practices work best in rain-fed cultivations. Almost all types of buffer zones attain a significant reduction in pesticide and nutrient concentrations in water and are thus environmentally efficient.

Water-conservation techniques are also energy-efficient because water-saving practices reduce energy needs and emissions. Such practices contribute to the production of public goods. They reduce negative externalities mainly by reducing sedimentation as well as through the associated reduction of flood risks, the protection of watercourses, and the supply of cleaner water.

Water conservation practices are associated with well-known green innovations in the irrigation industry, such as drip irrigation. They also utilise a rich knowledge base to develop promising water management innovation systems for rain-fed agriculture, including a broad array of water-harvesting practices, conservation farming systems, water conservation techniques, and integrated soil fertility management.

Despite these positive developments, empirical assessment of the economic productivity gains in terms of yields from applying water conservation practices is difficult. The complexity involved in making simple predictions of water savings (on the field level) and yield increases, as illustrated by Burt and O'Neill (2007, and referred to by Perry et al., 2009), have been highlighted in the literature. The authors, using information from a large-scale study undertaken by the Irrigation Training and Research Centre of the California Polytechnic State University (United States) examined the methods of growing tomatoes (and the yields attained) on 187 furrow-irrigated fields and 164 drip irrigated-fields, with typical field sizes of 50 ha. After comparing yields and applied water depth, the authors argued that it would be risky to assume that drip irrigation confers immediate major benefits across-the-board.

Warda and Pulido-Velazquez (2008) consider irrigation conservation practices at the basin level and reach a controversial conclusion. They suggest that "where return flows are an important source of downstream water supply, reduced deliveries from the adoption of more efficient irrigation measures will redistribute the basin's water supply, which could impair existing water right holders who depend on that return flow".

This would indicate that water conservation subsidies will not provide farmers with the economic incentives to reduce water depletion, and it is therefore unlikely that new water will be made available for alternative uses. In fact, depletion is likely to increase as a result of subsidies. For example, drip irrigation is important for many reasons, including greater water productivity and food security, but it does not necessarily save water when considered from a basin level. Subsidies for irrigation efficiency have been found to increase water use as higher crop yields lead to higher evapotranspiration with no return flow or recharge in aquifers (OECD, 2015).

At the farm level, improved irrigation methods reduce water use per cultivated area and thus energy needs, which results in lower emissions.[8] Improved irrigation techniques produce higher levels of resource (water), environmental and energy productivity than conventional irrigation methods. But increased water productivity may result in a "slippage effect", where saved water may be used to irrigate previously non-irrigated land. For example, while it is generally acknowledged that an improved irrigation infrastructure has the potential to deliver significant water savings to the farmer, the adoption of "green innovations", such as drippers, may not necessarily lead to a net environmental benefit if the farmer opts to direct these water savings into increased production or to sell the saved water to other producers (assuming the existence of a water-trading system).

In addition, some water conservation methods are associated with resource costs including (at times prohibitive) increases in energy demand. For example, evidence from Australia suggests that if adopting a pressurised system would undoubtedly result in a reduction of inefficiencies such as evaporation and seepage, changing to a new system would result in increased energy demand compared to existing gravity-fed channel delivery systems. Evidence shows that certain Australian irrigators are opting not to update their irrigation and delivery systems due to the increased energy costs of pressurised water systems.

Off-farm water conservation

Non-irrigation water conservation measures such as buffer zones and terraces have significant resource productivity impacts because they increase infiltration and reduce runoff while protecting the nearby environment from non-point source pollution and sedimentation. Moreover, buffer zones and grass waterways support habitats and biodiversity.

Kay et al. (2009) provide a comprehensive review of the literature and present the efficiency of buffer strips and wetlands in removing nutrients (total nitrogen, nitrates, total phosphorus and soluble phosphorus) contained in runoff agricultural water. The reported percentages show a large deviation, ranging from 5% to 100%. The same results, with less variation, are reported for pesticide substances as (Table 2.2) (Kay et al., 2009).

These results indicate the need to change the way in which herbaceous riparian buffers are implemented adjacent to channelized headwater streams, and also suggest that their use should be paired with upland management practices, riparian wetland creation, and/or in-stream habitat practices that are capable of addressing the chemical and physical habitat degradation exhibited by channelled agricultural headwater streams. Their research highlights the risk embedded in fragmented approaches versus integrated watershed management practices.

Table 2.2. Changes in pesticide concentrations in runoff due to the creation of buffer zones

Pesticide	Effect of buffer zone	Reference
Atrazine	53% reduction	Arora et al. (2003)
	25–49% reduction	Popov et al. (2006)
Chlorpyriphos	83% reduction	Arora et al. (2003)
Metolachlor	54% reduction	Arora et al. (2003)
	30–61% reduction	Popov et al. (2006

Notes

1. The study states that in 56% of EU territory there is a varying degree of potential threats, with intense land exploitation estimated as the main pressure on soil biodiversity. More specifically, using information from the European Soil Data Centre (ESDAC) and other European databases the study found that 1% of EU land is exposed to "extremely high" threats, 4% to "very high" and 9% to "high" threats. Intense farming, based on nitrogen load, is identified as the most significant menace, followed by organic carbon losses, invasive species, compaction, erosion and contamination. Due the combined effect of high intensity agriculture, many invasive species and an increased risk of organic carbon loss, the potential pressures were found to be particularly high in the United Kingdom and central Europe.
2. Moreover, there has been more extensive adoption of some the components, particularly conservation tillage, although not in association with the other two components of the conservation agriculture "package" (Friedrich, Derpsch and Kassam, 2014).
3. A voluminous literature, both theoretical and empirical, exists on the adoption of agricultural practices and technologies. Recent reviews with emphasis on adoption of conservation practices include Pannel, et al. 2006, Prokopy et al., 2008; Gedikoglou and McCann, 2010.
4. See: www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/ama/
5. For example, in 1947 Ciriacy-Wantrup examined the capital returns to soil conservation practices.
6. Pittelkow et al. (2015) that the largest yield declines occur when no-till is implemented alone (-9.9%) or with only one other conservation agriculture principle (-5.2 and -6.2% for residue retention and crop rotation, respectively.
7. On average, the individual effects of residue retention and crop rotation reduce the negative impacts of no-till by 4.8% and 3.8%, respectively. However, in dry climates these principles each have a much stronger effect on rainfed crop yields, reducing yield losses by 10% and 11%, respectively.
8. A comprehensive experimental study with mathematical modelling to carried out to investigate the effects of cropping practices on water balance variables in California (United States) found that cropping practices do not significantly affect soil water content; rather crop rotation and soil spatial variability largely influence water distribution and availability in the sub-surface system Islam et al. (2006).

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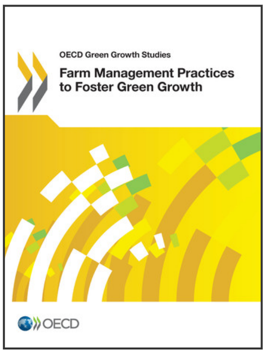
Annex 2A

Adoption of conservation agriculture

Table A2.1. Extent of the adoption of conservation agriculture, more recent year

	Total ('000 ha)	As % of cultivated area (%)
OECD countries		
Australia	17695	36.1
Canada	18313	36.3
New Zealand	162	27.9
United States	35613	22.9
Chile	180	13.5
Finland	200	7.1
Spain	792	5.2
Switzerland	17	4.0
United Kingdom	150	2.4
Portugal	32	2.9
France	200	1.1
Italy	380	1.1
Slovak Republic	35	0.7
Mexico	41	0.2
Hungary	5	0.2
Germany	200	n.a.
Ireland	0.2	0.0
Netherlands	0.5	0.0
Non-OECD countries		
Argentina	29181	68.7
Paraguay	3000	54.4
Uruguay	1072	37.3
Brazil	31811	43.8
Bolivia	706	18.4
Kazakhtan	2000	7.9
Zambia	200	5.3
Russia	4500	3.8
Colombia	127	8.0
South Africa	368	3.0
Mozambique	152	2.7
China	6670	2.9
Ukraine	7100	1.8
World	157434	10.9

Source: FAO, AQUASTAT database, website accessed on 2 July 2015.



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