EIP-AGRI Focus Group

Water & agriculture: adaptive strategies at farm level

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1. Summary

This report presents the results of the EIP-AGRI Focus Group (FG) on **"Water & Agriculture: adaptive strategies at farm level"**. Water is an essential resource for crop and livestock production. Climate change is generating variations in temperature and rainfall, forcing farmers to rethink how to produce their crops, breed their animals or manage their farms. To counteract the negative impacts of climate change on agriculture due to water scarcity, management strategies at the farm level need to be identified. Channels and mechanisms to make this information available must be established so as to foster implementation by farmers. This Focus Group has collected innovative approaches and adaptive strategies to counteract water scarcity at farm level and has discussed the related challenges and opportunities.

The EIP Focus Group on Water and Agriculture brought together 19 experts, who started their work in June 2015 and delivered their report in March 2016.

Discussions were framed by an initial document written by the coordinating expert, partly based on a survey circulated to the group's members before the first meeting. In agreement with this document, the main strategies to tackle under water scarcity have been identified. They include measures currently applied at farm level or promising ones.

The group chose to classify these strategies into three main categories:

i) practices to increase water availability for crops and livestock,
ii) the efficient use of water (including irrigation efficiency), and
iii) farm resilience under water scarcity.

Many other factors than water affect productivity in both rainfed and irrigated commercial farms, and the causes of these factors must be understood.

Water availability may be increased by strategies that reduce water losses or increase the capacity to store the water to be used by crops or livestock. Among the identified strategies, conservation agriculture and covering the soil surface by residues or mulching were considered the most effective for conserving water.

Given the available water, there are strategies aimed at increasing crop production using that water:

i) choosing a cultivar or species with high water productivity,
ii) using available water more efficiently and,
iii) in the case of irrigation, increasing irrigation efficiency.

Any improvement in crop, pasture and grazing management, and in feeding or in crop and animal health will thus result in an increase in water productivity and output of the system. Four strategies were identified as potentially more effective: choosing crops with high rooting ability, improved cropping management (fertilisers, pest and diseases, crop rotation, irrigation) aided by decision support systems, and precision irrigation monitored by remote sensing.

Some strategies **profit from farm spatial differences to increase resilience under water scarcity**. In these terms, large farms have more scope for zone diversification and timely operations and can afford their own equipment and labour. Among the discussed on-farm strategies, crop diversification and linking to networks were identified as potentially more effective.

Some strategies require fine-tuning for adaptation to local conditions, may not be economically viable, or pose environmental problems. Some of these strategies require research to make them viable on-farm. Although not specifically addressed by this FG, a major concern of many of its members is that **on-farm strategies must be combined with efforts at a higher scale than the farm** to be really effective at conserving water and using it efficiently.

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Some general failure factors and barriers for adoption were common to several strategies. Little is known about the **economic implications** of farmers adopting most of the proposed strategies, particularly if these are recently introduced or uncommon. Similarly, there is a lack of evaluation of strategies at farm level to show the **impact on water conservation and the return to investments**. There is also a lack of knowledge regarding **long-term or environmental benefits** of strategies in local conditions. This type of demonstration or research is rare as most public agricultural research is focused on frontier knowledge. Additionally, there is little institutional and policy support when **significant training, technical advice or fine-tuning research** are required.

Research needs from practice (Annex 5: List of research needs from practice**)**

For most strategies, their effectiveness in water conservation at farm level and the economic return are unknown. Clear **protocols for systematic on-farm research to evaluate strategies** are needed; and often, **understanding the impact at higher scales than the farm** (e.g. watershed) will be required to have a global significant impact on water conservation. Similarly, **economic and environmental risks** associated to any strategy must be studied and well understood. Transparent **cost-benefit analyses** are required before any promotion among farmers. Some strategies require **long-term studies** to show agronomic benefits, in particular those aimed at improving water holding capacity and water infiltration by **increasing soil organic matter**: conservation agriculture and maintaining soil surface covered with residues, mulching, cover cops or green manure, and crop rotation.
Decision Support Systems (DSSs) can be used to improve crop and irrigation management but should be **calibrated and evaluated for local conditions**. They also need further tests and research to widen their applicability in a **range of environments and crops**; to make them **more user-friendly**; and to show **clear benefits in practice**.

Regarding irrigation efficiency, there is a need to develop and refine **cost-effective, easy to use plant-based sensors** to monitor the actual crop water use, as well as their implementation in DSSs to provide real time recommendations for irrigation scheduling in different crop species. The interpretation of the sensor data should be based on a thorough understanding of the crop physiology to ensure that the DSS are reliable. Research is also needed to improve **regulated deficit irrigation** (RDI) strategies to broaden the number of species, environments and soils where they can be applied. Furthermore, studies are needed to **validate and fine-tune the application of online services, RDI protocols and precision irrigation approaches**.

In precision irrigation, field crop variability is identified and quantified using remote sensing images or in-field measurements; however, research is needed to **develop protocols and clear prescriptions** for taking decisions regarding water depth of applications. Site-specific variable rate irrigation systems must be tested and evaluated for local conditions.

Ideas for operational groups (Annex 6: Suggestions for Operational Groups)

Focus Group members proposed several ideas for Operational Groups to develop viable strategies: local adaptation of conservation agriculture; increasing soil organic matter; proper tillage to reduce soil compaction; improving crop rotation and increasing crop diversification within farm and within plot; identifying spring-summer crops less sensitive to low temperatures for earlier sowing; determining local benchmarks as references for irrigation performance and crop productivity and identifying sources of on-farm yield gaps; optimising irrigation with crop water balance and soil sensors, supplemental irrigation or adoption of regulated deficit irrigation considering yield or quality; precision irrigation aided by remote sensing; site-specific variable rate irrigation; use of alternative water sources; and use of poor quality water and innovative solutions for improving or managing it.

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Water Focus Group Experts

Which farm-level adaptation strategies exist or can be developed to deal with water scarcity and how to make them more effective and viable in farmers' terms?

Although there are many strategies to deal with water scarcity, few have been assessed on-farm in terms of effectiveness, practicability and economic return under local conditions. Demonstrations are needed to show the benefits, and for some strategies, these activities should be maintained for years to show effectiveness and environmental benefits for local conditions. Above all, farmers should first learn whether there are other limitations than water in their systems. Additionally, understanding the impact at higher scales than the farm and strategies at these higher levels will be required to have a globally significant impact.

2. Structure of this report

This reports starts with the motivation, tasks and a brief description of the process. This is followed by the definition of water scarcity at farm level used by the FG and the questions considered while systematising the strategies identified to deal with water scarcity at farm level:

i) How to increase water availability on the farm?
ii) How to increase water use efficiency?
iii) How to increase resilience under water scarcity?

From this perspective, this report subsequently looks at:

- Existing strategies at farm level
- Potential strategies under development or not yet adopted
- How to improve the implementation of innovative strategies in relation to:
    - research
    - setting up Operational Groups
    - knowledge exchange

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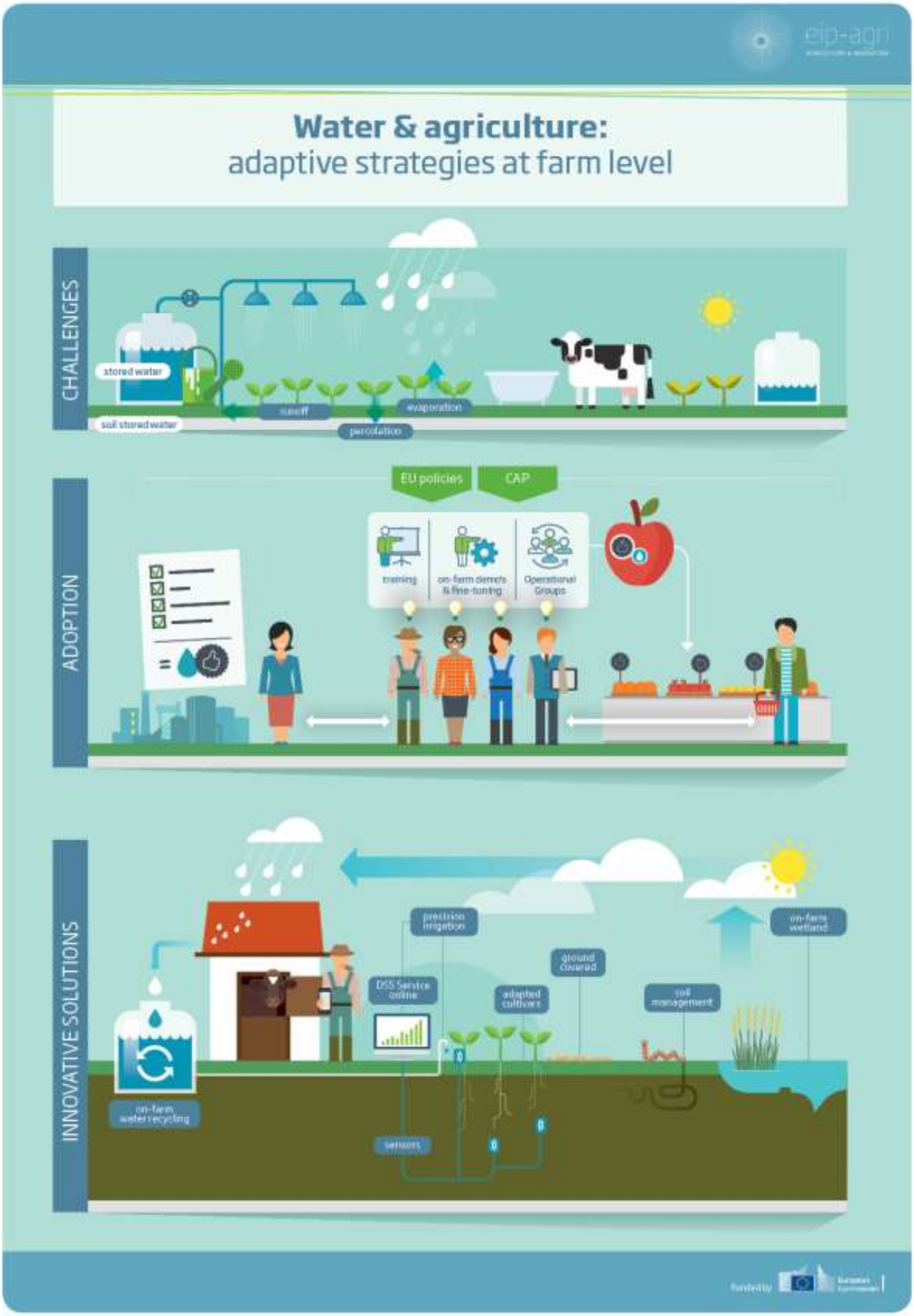

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3. Introduction of the EIP-AGRI Focus Group Water and Agriculture

This Focus Group was established to answer these main questions:

- **Which farm level adaptation strategies exist or can be developed to deal with water scarcity?**
- **How to make them more effective and viable in farmers' terms?**

3.1. Motivation

Water is an essential resource for crop and livestock production. Climate change is generating variations in temperature and rainfall according to the latest IPCC report (Kovats et al. 2014), forcing farmers to rethink how to produce their crops, breed their animals or manage their farms. To counteract negative impacts of climate change on agriculture due to water scarcity, management strategies at the farm level need to be identified. Channels and mechanisms to make this information available must be established so as to foster implementation by farmers.

3.2. Tasks

The Focus Group was assigned to carry out the following tasks:

- Making an inventory of competitive farm management practices and strategies that are currently available or adopted to tackle water scarcity at farm/local level in the EU. How will they cushion against feed and food insecurity and rural vulnerability? What working examples can be found in the EU?
- Listing promising alternative and cost-effective, competitive (novel) crops or cropping/livestock/agricultural systems able to deal with water scarcity. Assessing the potential for soil and landscape management to improve water holding capacity.
- Identifying the success (or failure) factors (financial, environmental, societal…) concerning the transferability of adaptive strategies beyond the farm or local boundaries as well as to farms in different European regions.
- Identifying needs from practice and possible gaps in knowledge on particular issues concerning adaptation(s) to water scarcity which may be solved by further research.
- Identifying the main challenges farmers will face when changing "business as usual" to counter the effects of water scarcity due to changing rainfall regimes.
- Discussing the following questions: Are the local Agricultural and Innovation Systems sufficiently equipped to discuss adaptation strategies with farmers? Which active role must be played by extension services, training systems, information campaigns? Who shall initiate an "adaptation strategy"? What role for the (innovative) farmer? Can advisors play a role? How and when can they provide support?
- Proposing potential innovative actions to stimulate the knowledge and use of adaptation measures or strategies to water scarcity and to multiply positive effects within the agricultural sector.
- Proposing directions for future research work.
- Proposing priorities for relevant innovative actions, including practical ideas for EIP-AGRI Operational Groups.

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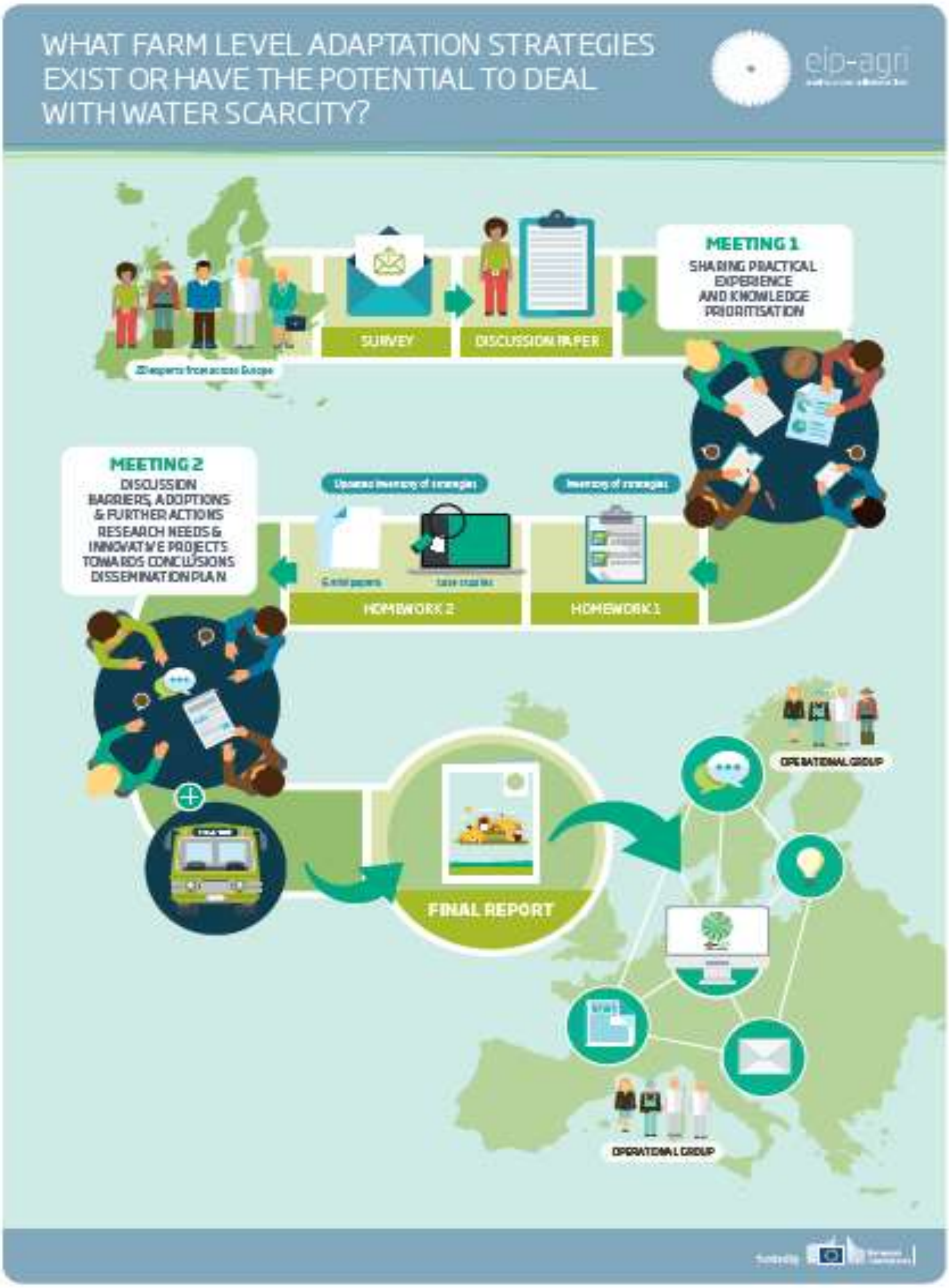
3.3. Brief description of the process

The Focus Group consisted of a team of 19 experts from practice, extension and research backgrounds, working in different EU regions (Annex 1: Members of the Focus Group). Helena Gómez-Macpherson was appointed as coordinating expert to write a starting paper, to facilitate the technical discussions in the groups, and to assist in reporting tasks. The starting paper helped to establish a common understanding about the purpose of the Focus Group, provided background on water at crop and farm level, presented the state of play in adaptive strategies at farm level to reduce the impact of water scarcity on farm productivity, considering on-line contributions by Focus Group members, and identified key questions for discussion at the first meeting.



The **first meeting** (Fiumicino, Italy, 25-26 June 2015) addressed the first five tasks. Members focused on identifying and describing strategies or practices to deal with water scarcity. The discussions clarified that many of these options are not ready to be adopted straight away because of technical, economic, environmental or regulatory limitations. Topics for mini papers were selected to further explore key questions around these strategies and limitations. These mini papers (Annex 2: Mini papers on prioritised topics) were prepared by the Focus Group members between the first and second meetings.

The **second meeting** (Ciudad Real, Spain, 4-5 November 2015) addressed the last four tasks, mostly concerned with improving adoption and identifying Operational Groups and research needs. During the second meeting, a field visit was organised to the "Misión Posible" project in Daimiel. The main purpose was to meet project leaders, stakeholders engaged in water management in the Daimiel Water Users Association and farmers, to discuss constraints on adopting new strategies, and how to lift these barriers.

Focus Group experts in the field

4. Dealing with water scarcity at farm level

4.1. Defining water scarcity at farm level

Water shortage is a major abiotic factor limiting crop and livestock production in Europe; its incidence is expected to increase with climate change, particularly negative in southern Europe (Falloon and Betts, 2010). Mediterranean areas are likely to suffer higher temperatures, more rainfall variability and greater frequency of extreme events according to the IPCC (Kovats et al. 2014). The arid regions face the double burden of less and more erratic rainfall, and higher temperatures that surpass the threshold for major staple crops. In northern Europe, an increased global water supply is expected (Falloon and Betts, 2010); however, this increase will occur in winter while there will be significantly less summer rainfall. This shortage is particularly relevant in sandy soils growing vegetables, not only because of the effect on yield, but also because of the effect on quality. Overall, it appears that rainfall will be more erratic with long drought periods combined with heavy rain showers. The impact on farm production will depend on farm characteristics and on farmers' capacity to change management and adapt to new conditions (Reidsma et al. 2010).

The Commission carried out an assessment of water scarcity and droughts in the EU and, based on this assessment, presented and adopted the communication **Addressing the challenge of water scarcity and droughts** (COM/2007/0414) in 2007. Water scarcity was defined as a human-driven phenomenon occurring when water demand for human activities exceeds available water resources and natural recharge, while drought referred to a temporary decrease in water availability due to natural phenomena like rainfall deficiency. The Water Framework Directive (WFD) also considers water ecosystem services and the need to protect water for the future. In this general context, agriculture is considered a major player and has been included in most policies addressing water.

The Focus Group defines **water scarcity at farm level** as the excess of water demand over available supply to produce agriculture outputs of acceptable quality without damaging the environment. Under these conditions of scarcity, farmers' common objective is using available water most productively and profitably while complying with environmental regulations. Water scarcity is often associated with low quality water and growers are then forced to use it even though it might have high salt concentrations. Additionally, illegal abstractions are relatively widespread in some EU member states. Only by protecting the natural resources on which agriculture relies can the future of this activity be assured.

Previous studies have identified ways to reduce the negative impact of climate change on water scarcity (Turral et al. 2011; Olesen et al. 2011; OECD 2014; Iglesias and Garrote 2015). In general, strategies identified in the literature coincide with those proposed for current drought-prone areas (Parry et al. 2005; Passioura 2006; Blum, 2015) as it is assumed that these strategies will continue to be effective in relative terms under future climate change scenarios (Turral et al. 2011). Proposed actions range from molecular transformation of crops (e.g. transforming rice plants into C4 plants) to the construction of new irrigation facilities (organisational solutions). This FG was asked to focus on adaptive strategies at farm level, i.e. changes in crop and livestock management practices that lead to a reduction of the impact of water scarcity on farm productivity. Therefore, research strategies at molecular to plant level are not discussed, although some aspects are mentioned when referring to choice of species or cultivars by farmers. Similarly, strategies at scales above the farm level are not included, even though there are several situations where on-farm strategies are effective when coordinated at a higher scale, particularly in irrigated systems. On the other hand, impact of strategies on water quality and environmental implications of strategies are considered. For example, water scarcity is often associated with low water quality in irrigated systems, particularly due to salinity.

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4.2. Conditions and aspects to keep in mind while considering strategies to deal with water scarcity at farm level

Farm water inputs and outputs. Water sources for crop production are rainfall and irrigation. Water is essential to extract nutrients from the soil and transport them to the parts of the plant that are growing. Water evaporates from the plant into the air through the stomata (**transpiration**). The hotter, drier and windier the air, (higher evaporative demand), the faster the water is lost through transpiration. Not all rainfall is effectively used in plant growth and transpiration. Part of the stored water in the soil is lost through **evaporation** from bare soil between the plants and part of the rain or irrigation water is lost by **runoff** and **deep percolation**, although it may be used down-stream by other farmers. The water that remains stored in the soil is available to roots for crop growth and transpiration. The damaging effect of a drought will depend on its timing, duration, on how much water is stored in the soil and the proportion of it that the crop can access, on how fast it is used or lost, and on the development stage of the crop.

Farm water productivity is defined as the combined farm outputs (yield of crops, orchards and livestock) expressed in economic units per unit of available water (rainfall plus irrigation) and year. Irrigation efficiency is defined as the ratio of the output and the irrigation watersupplied. Because water productivity estimates on their own do not consider environmental performance, other indicators are necessary for this, e.g. emission of greenhouse gases, sequestered soil organic carbon, soil erosion or water quality (salinity, sediments, pollutants). Additionally, the efficiency at farm scale may disappear at a larger scale, e.g. higher irrigation efficiency on one farm may not be effective at scheme scale (Berbel and Mateos 2014). Although not specifically addressed by this FG, strategies at higher scales than farm level can be more effective in terms on conserving water at regional level. The case studies 'UEA Agritech water cluster, An irrigation strategy for the East of England' and 'How to motivate farmers to use water more efficiently' present information at higher scales than the farm (Annex 7: List of Case Studies).

Often, other causes than drought reduce productivity. Given non-limiting radiation and temperature, there is a direct link between water used and biomass produced by an adapted crop. However, studies in commercial farms have shown that crop yield is often affected by rainfall distribution and by many other factors than water in both rain-fed and irrigated conditions (Angus and van Herwaarden, 2001; Grassini et al. 2011, 2015). For example, poor weed control results in less water and nutrients for the crop. It is necessary to understand the causes of this yield gap before designing or introducing any strategy. The causes could range from socioeconomic constraints to poor management because of lack of knowledge. Part of this yield gap may be also due to farmers' strategies to minimise risks related to erratic weather.

The most effective adaptation strategies aim to maximise water availability because of the close link between water used and biomass produced by the crop. Other strategies focus on using the water more efficiently or on increasing farm resilience under water scarcity and linking to off-farm strategies. The first two approaches focus on plot scale while the third one profits from farm characteristics. All three are based on improving management and aim to close the yield gap. Rainfall provides an important part of the water consumed by irrigated crops (unless grown under cover) and most strategies increasing water availability and efficient use of water also apply to irrigated conditions. Some strategies related to irrigation management and design are specific to irrigated systems, not only to supplement rainfall to achieve yield and quality targets, but also to deal with water quality and other environmental issues.

5. Existing practices at farm level

The FG has identified strategies to deal with on-farm water scarcity that are already available in European countries (Annex 3: List of documented current strategies).

5.1. Strategies to increase water availability for crops and livestock

Water availability may be increased by strategies that (i) reduce water losses or (ii) increase the capacity to store the water to be used by crops or livestock. Among the strategies identified, **conservation agriculture**[1]and **covering the soil surface by residues or mulching**[2]were considered the most effective at conserving water according to FG members.

5.1.1. Strategies to reduce water losses

Conservation agriculture (CA), defined as a combination of minimum soil disturbance (preferably no tillage), permanent organic soil cover (retention of residues on the ground) and crop rotation, improves water infiltration (less runoff) and reduces evaporation from the soil thanks to the residues cover. CA is partly addressed in the Minipaper **Soil management for improved water availability** (Annex 2: Mini papers on prioritised topics). Having less runoff reduces soil erosion and some countries promote CA in fields with high risk of runoff. CA is widely adopted in America but comparatively little in Europe (except in permanent crops) in spite of extensive research and promotion. On the one hand, most benefits are shown in the long term, on the other, there are technical problems at farm scale not appreciated in experiments on-station (difficulties in managing crop residues, disease carry-over in the absence of crop rotation, deficient crop establishment and weed control, or specialised machinery not locally adapted), lack of knowledge and inadequate extension (Soane et al. 2012). A major problem is that no-tillage by itself may cause runoff unless crop residues are left in the field (Brouder and Gómez-Macpherson 2014). However, many farmers sell the residues for extra cash, biogas or construction. Many sell only part of the residues but they do not know the optimum amount that should remain on the ground to increase soil organic matter and improve their soil. On the other hand, crop establishment in undisturbed soil and through residues is a major challenge and specific drills, often more expensive than conventional, are required. Sporadic tillage may be applied, especially during transition periods from conventional to CA. Weed control requires much attention from farmers. Because soil must not be disturbed, weeds are controlled with herbicides only and some resistance to the most common herbicides has already been observed; an integrated approach is required to reduce dependency on these products. CA is often associated to herbicide-resistant GMOs (as commonly cultivated in America) but these cultivars are not allowed in Europe and CA should be practised without the use of those cultivars. Adopting CA is not a simple action; it is complex and requires adjusting many elements of the system: specific machinery, management of residues, rotation of crops, etc. In Europe, CA has been successfully developed in olive and fruit orchards, and vineyards, but its adoption is slowly increasing in annual cropping systems as it is difficult for farmers to combine the required elements.

In annual crops, **early ground cover crop establishment** reduces soil evaporation and improves water infiltration; additionally, it reduces soil erosion and nutrient leaching. Early ground cover can be obtained by early sowing, dry sowing, seed priming (pre-soaking seeds to enhance germination), sowing cultivars with early vigour, or optimising plant density through crop establishment and fertilisation management (Passioura and Angus 2010; Fletcher et al. 2015). Early crop establishment has a higher risk of early weed infestation and of early drought (and frosts in northern Europe).

Depending on the soil and timing of operations, tillage often results in a hard pan that limits root growth and water storage, increasing the chances of waterlogging. **Deep tillage** may then be required to increase water infiltration and root growth (Chamen et al. 2015; and **Soil management for improved water availability**.

[1] Annex 3, Strategy Nº1 and Annex 4, Strategy Nº P2
[2]Annex 3, Strategy Nº7

It is an expensive operation, in economic and energetic terms, and its effect is rapidly lost with successive tillage. A more permanent solution is conservation agriculture, avoiding the adverse effects of tillage.

Effective weed control in crops and orchards prevents the use of water by competing plants. Crop roots will also be able to explore more soil. Weed control requires attentive management and should consider the full crop rotation. Usually, an integrated approach of combined methods is more effective and environmentally safer than fully relying on the same type of herbicides. There are roundup-ready GMO cultivars of some species that facilitate weed control; however, these are NOT approved in Europe.

In **contour farming**, crop sowing or tree establishment following contour lines to increase infiltration and reduce runoff (and erosion). This is not possible on steep slopes because of the risk of accidents during operations requiring driving machinery. In gently sloping landscapes, runoff may be stored in small-scale reservoirs. Contour farming requires a good design to facilitate field operations, especially when only large tractors are available, and will depend on plot size.

Plastic mulch reduces soil evaporation and increases soil temperature favouring early establishment (faster growth and higher root density in topsoil); Black plastic alsomakes weed control easier and can result in higher crop yield (Taparauskiene and Miseckaite, 2014). Plastic mulchmay extend the crop growing season because crops that are sensitive to low temperatures may be sown earlier (and thus increase yield). Easy to install and manage, it is mostly used in horticultural crops due to cost. Getting products to the market earlier may make it more cost effective. A major problem is the pollution due to plastic disposal (and manufacturing).

5.1.2. Strategies to increase soil capacity to store water and to improve access to that water

Soil capacity to store water depends greatly on soil texture and structure. The texture is fixed but the structure can be improved by **increasing soil organic matter** or by reducing soil compaction. The EIP-AGRI FG report Soil organic matter in Mediterranean conditions provides several strategies to increase soil organic matter; most of them are also relevant for northern Europe. Keeping the soil surface covered by organic products increases soil organic matter in the top layer, improves water infiltration and reduces soil evaporation (Hatfield et al. 2001), as in CA. The transformation rate into soil organic matter will depend on the C input amount, local conditions and soil management. The ground cover also favours soil biodiversity and bird nesting, and helps to suppress weeds, although it may reduce herbicide effectiveness. Soil may be covered by **stubble/crop residues, application of mulch** (stubble or residues from external sources or organic processed inputs, e.g. livestock manure or compost), or by cover crops. Applying (expensive) water-retaining hydrogel will also increase soil capacity to retain water. In annual crops, stubble may be kept until just before sowing when it will be incorporated into the soil during seedbed preparation. Stubble is quite effective at retaining snow. In orchards, the space between trees can be protected by mulching, natural vegetation or by establishing a cover crop. Cover crop management is well known in olive orchards, vineyards and organic horticultural cropping systems. In these systems special attention should be paid to the timing of killing the cover crop to avoid water competition with the main crop. External application of mulch can be expensive depending on transport cost, nutrient content and spreading method.

Reducing compaction or avoiding it will increase water stored in the soil and will also favour root growth to colonise the soil. In **controlled traffic** systems, wheels always pass over the same lines in the field, leaving the space in between with higher soil porosity to fill in with water (Chamen et al. 2015). Controlled traffic requires the use of GPS-guided tractors and may be expensive if the wheel distance of all used machinery has to be made uniform. Soil compaction may also be avoided by carrying out mechanical operations when the soil is dry (although this is not possible in many occasions) and using **high flotation tyres**.

In annual crops, a plot may left **fallow** during one season to store rainwater of that season in the soil to be used in the following season (Cantero et al. 1995). Its efficacy depends mostly on soil water holding capacity. Fallows also help to control weeds. Yearly fallows were common in the Mediterranean region but nowadays they are rarely used except in the driest environments or in organic farming. Whenever possible, fallows are substituted by cropping with improved systems.

5.1.3. Strategies to increase water supply for irrigation and livestock

Within a farm, new sources of water may be developed **by treating waste water or harvesting water** from roofs or from drainage systems. Treatment of waste water following international standards is necessary to avoid health hazards (some food processors may even have higher standards). Treatments can be too expensive and not economically viable. Water harvesting from roofs may be cost-effective if large areas of roof are available, e.g. glasshouses or poultry houses. The case study 'Using alternative water sources for livestock' (Annex 7: List of Case Studies) helps farmers to find the right way to purify 'alternative' water sources. Tertiary treatment of water may be more efficient and economically viable when developed at zone or regional scales, as shown in the case study 'Waste water reuse for quality crop production' (Annex 7: List of Case Studies). Access to underground water by constructing private wells may be possible if permitted by water authorities (the Water Framework Directive includes regulations on managing and licensing of private wells). Depending on water table depth and local hydrology this can be an option but it is not recommended when there is risk of depleting the resources. In cold environments, it is recommended to keep the water in a pond for a while to increase its temperature and ensure sufficient flow rate for the envisaged use.

In **level-controlled drainage**, the drainage level can be changed to keep water in the field without damaging the system. It requires permission of and co-ordination with drainage authorities. Although simple to introduce, farmers need training to learn how to work with level-controlled drainage. Its feasibility will depend mostly on the distance between drains, field slope and soil texture. This option is used in Flanders, UK, Netherlands, and a few places in Sweden, Lithuania and Finland.

Runoff on the farm may be stored in **farm ponds**. It is an expensive option as it requires soil movement but might cost little if favoured by the landscape. It has to follow the regulations of water management authorities. Interest for this option is higher in environments with erratic storm rainfall.

Good maintenance or renovation of irrigation systems and animal drinking systems on the farm will reduce water losses, particularly if the systems are in bad shape. Water monitoring systems may be installed to control the use, losses and potential problems. For example if milch cows drink too much, there is a risk that they may eat too little, which impairs milk production.

5.2. Strategies to increase water use efficiency

Given the water available, there are strategies aimed at increasing crop production using this water: i) choosing a cultivar or species with high water productivity; ii) using available water more efficiently and, iii) in the case of irrigation, increasing irrigation efficiency. Among the strategies identified, FG members considered the following potentially more effective: **crops with high rooting ability**[3], **improved cropping management (fertilisers, pest and disease, crop rotation, irrigation, etc.) aided or not by decision support systems**[4] and **precision irrigation aided or not by remote sensing**[5].

5.2.1. Strategies to profit from cultivars or species with high water productivity

Crops and cultivars differ in their **rooting ability** to colonise the soil and reach water in deeper zones. This also applies to rootstocks of perennial crops. Crops can colonise more soil by having denser root systems or by reaching deeper horizons, thus increasing water availability for the crop and reducing the risk of losing water through drainage. Agroforestry may combine annual crops with permanent species with deeper root systems. In general, little information is available on rooting ability of cultivars and species and the benefits may not be clear for local conditions. Research is needed to characterise and quantify benefits of the various options.

In recent decades there have been strong research programs aimed at identifying and incorporating traits conferring drought resistance into cultivars of annual crops, but so far most have had limited success. Nevertheless, some traits in improved cultivars have shown higher water productivity in the field (Richards et al. 2007; Passioura and Angus 2010; Turner et al. 2014; Blum 2015): "stay-green" in sorghum; low discrimination against carbon 13 during photosynthesis (high transpiration efficiency) in wheat grown on stored water; osmotic adjustment in wheat; short anthesis-to-silking interval (ASI) in maize; barley landraces. The farmer, however, does not know whether any of the locally available cultivars has any of these traits. On the other hand, breeding programs aimed at increasing drought tolerance in perennial crops have been lacking; drought tolerant varieties for perennial crops (e.g. fruits) are still missing. Although strategies at plant level or below were not part of the Focus Group, the minipaper **Improved varieties and crops** presents some of the current efforts in breeding crops for drought resistance and tolerance.

5.2.2. Strategies to use available water more efficiently

Understanding and closing yield gaps

Any improvement in crop, pasture and grazing management and feeding, or in crop and animal health, and therefore an increase in the system's output will increase water productivity. In regions with high inter-annual rainfall variability, tactical management refers to taking management decisions to adapt to the season and to profit from best years (higher rainfall than average). Depending on the development of the season and the potential yield, the farmer can decide on which cultivar cycle type to use, on applying nitrogen, on adjusting the crop load (for perennials) or other treatments. For livestock, mating time or mating populations can be programmed. In general, **Decision Support Systems** (DSSs) are mathematical descriptions of agricultural systems that facilitate taking tactical crop and water management decisions (Minipaper **Tools for improving crop/farm management**). To be effective, DSSs should be previously calibrated and tested for local conditions. Several DSSs are available for crop management, but mostly at research level, and adoption by farmers is quite limited. More commonly used in farms are DSSs for irrigation scheduling (Minipaper **Irrigation management**), most work through on-line services. The case study "*Misión Posible*" shows an example of calculating irrigation recommendations and access to information on-line or via sms (Annex 7: List of Case Studies). Many other DSSs represent promising results of EU funded research projects but they are yet to be adopted (for examples see Minipaper Tools for improving crop/farm management). There are several reasons for the limited use of DSSs: costs, complexity, risks of failures/mistakes, knowledge needed, unfamiliarity, and lack of professional, continuous support. To change this trend focus is required on improving the tools available, on proving benefits and on efficient and comprehensive knowledge dissemination to reach the target audience. Further tests and research are needed to widen their applicability

[3] Annex 3, Strategy Nº 17 and Annex 4, Strategy Nº P4
[4] Annex 3, Strategy Nº 18
[5] Annex 3, Strategy Nº 22 and Annex 4, Strategy Nº P9

in a wider range of environments and crops. Information, training material and activities are needed to show farmers and advisors DSSs' functioning and benefits in their environment.

In annual crops, **improved crop sequences** that result in an overall increase in production also improve water productivity. Including legumes or oilseed crops will benefit the following cereal crop in certain conditions by fixing some nitrogen, reducing soil diseases and facilitating weed control. Additionally, the rotation with these species will increase soil biodiversity. The challenge is to make these crops economically attractive and to find seed in the market. The Final Report of the EIP-AGRI Focus Group **Protein crops** discusses how to make legume farming competitive.

Some zones or plots may have extremely acid or sodic soils. Soil rehabilitation (applying lime to control acidity or gypsum in sodic soil) will favour soil aggregation and denser and deeper rooting, and will thus improve access to water and crop growth. Applications can be expensive depending on volume and transport distance. Other costs result from the need to study field conditions prior to any application.

In irrigated systems, **fertirrigation** facilitates nutrient application in key demand stages and the absorption by roots. In general, fertiliser losses are reduced and their efficiency increased resulting in environmental and economic benefits. When fertirrigation is used, soil compaction due to traffic of tractors and fertiliser spreaders is avoided. On the other hand, clogging of pipelines or emitters may increase maintenance costs of the irrigation system.
Growing feed under controlled environment helps to intensify livestock production using less arable land and water. Locally produced grain can be used as part of feed mixes. These feed products are of high nutritional value so animals are healthier and more productive. On the other hand, extra costs are derived for establishment of greenhouses as feed growing areas. As a whole the system may be too expensive. The case study 'Hydroponic green fodder production technology shows an example of this strategy (Annex 7: List of Case Studies).

Growing crops when the evaporative demand is lower

Growing an annual crop when the evaporative demand is lower (e.g. during the rainfall season from autumn to spring in Mediterranean conditions) increases crop output per unit of water used. **Matching the cropping season to the rainfall season** reduces water losses by evaporation, runoff and deep percolation. Matching crop and rainfall requires first the characterisation of the rainfall and temperature pattern and soil capacity to store water. Based on historical weather data, it is possible to estimate the start and end of the rainfall season and the prevalent droughts. Additionally, changes in past decades due to climate change (particularly, risk of frosts) can also be detected enabling selection of cultivars best matching this pattern. Crop models can also be used to define agro-ecological zones (which crops/cultivars, climate, soils, others) using historical weather data. The minipaper **Tools for improving crop/farm management** presents tools that can help in this characterisation.

In southern Europe (sunny and warm environments), where radiation is high, trellised orchards or vineyards following **east-west row orientation** intercept less radiation and reduce transpiration without compromising yield. The decision on the orientation must be taken when designing the plantation. It costs the same as a north-south orientation but it may increase erosion risk if the slope orientation is also east-west. **Shading nets** also reduce canopy light interception, temperature and evapotranspiration. They are simple and easy to implement and commonly used in vegetable production. Most nets commonly available on the market already let through sufficient radiation for crop growth. For some crops, the shading effect of commercial hail nets can also be increased up to 40%, with no yield losses and benefits in terms of water savings. Special covering materials are also used to prevent damage caused by hail and rains of high intensity. Spreading **kaolin** (inert, white clay) over fruit crops increases radiation reflection and reduces leaf temperature and transpiration while avoiding heat stress. The kaolin cover prevents sunburn of fruits (resulting in a better price) and it can be a barrier to pests. It is an environmentally friendly product but its cost is high, quite expensive if repeated applications are needed. It cannot be used in areas with high risk of storms because rain will wash it off.

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5.2.3. Strategies to increase irrigation efficiency

The minipapers **Irrigation management** and **Tools for improving crop/farm management** discuss specific strategies to deal with water scarcity in irrigated agriculture. Irrigation efficiency is related to **irrigation systems** and their maintenance, and it may be increased by improving **distribution uniformity** or **application efficiency** (Pereira et al. 2002; Playan and Mateos 2006). Distribution uniformity and water depth should be appropriate to cover crop water demand while avoiding runoff and percolation. In the last decades, modernisation of irrigated systems at farm and scheme levels in the Mediterranean countries has increased irrigation efficiency significantly but, rather than resulting in more reliable annual allocation (the general objective), the saved water has led to the intensification of farming practices or an expansion of the irrigated area. The modernisation often includes the introduction of water distribution on demand and farmers **paying** for water according to volume used, and to tiered water tariff (cheaper at night).

Precision irrigation aided by remote sensing (satellite, planes, drones & sensors in machinery) adjusts irrigation management to spatial variation, avoiding local yield depressions or waste of irrigation water. With images, field crop variability is identified and quantified; however, prescriptions for taking decisions are not clear (if the crop in zone A is growing poorly, should it receive less or more water?). Furthermore, precision irrigation requires an irrigation system that allows applying different amounts of water in different zones within the plot (**Variable Rate Irrigation, VRI**). This is available for central pivots (very expensive systems). Once the irrigated system is designed and installed, it is difficult to apply different amounts of water in different zones unless already catered for in the system design. Thus, together with the farmer expertise, remote sensing may be used before acquiring the irrigation system to identify zones performing differently and then design the system accordingly so that different zones can receive a different amount of water. From then on images can help to decide about managing zones. Data availability (images) depends on weather conditions as, in general, it requires a clear day. Obtaining the images and their analysis (advisory service) can be expensive; the practicability and profitability of these strategies are questioned. Access to soil maps (case study 'Soil/water variable mapping and distribution in an App format' in Annex 7: List of Case Studies) and understanding spatial variability will help taking decisions.

Water pollution and soil salinity are major risks for the future of irrigated agriculture in many countries suffering increasing water scarcity. Practising environmentally friendly and economically sound agriculture in the above situations is a challenge. Nevertheless, management practices can often be modified to obtain a more favourable distribution of salts in the soil profile, assuring better crop yields and water quality maintenance. Several on-farm strategies are discussed in the minipaper Water quality and salinity. Successful practices are only possible with adequate saline water irrigation management policies.

Efficiency of irrigation systems

With **drip irrigation** farmers can achieve high irrigation uniformity. Automation, scheduling and fertirrigation are possible. It requires some energy for applying low water pressures and can help farmers to control salinity problems and weeds. However, it requires water on demand and careful maintenance to avoid clogging of emitters by hard (high-calcium) water or fertirrigation and chewing damage to thin distribution lines. It is expensive to buy and install but worthwhile in several conditions (high water price, good quality products and hilly terrain). It is commonly used in horticultural crops, and particularly in permanent crops such as olives, vines and fruit orchards. In general, with **drip irrigation farmers use less water and more energy than with flood irrigation, but less energy than with sprinkler systems**.

Subsurface irrigation is a drip irrigation system buried under the crop to reduce evaporation from the soil surface while increasing distribution efficiency. It requires higher initial investments than traditional drip irrigation but uses less water and facilitates farm operations. Its correct functioning may be impaired by hard-to-detect problems, such as common hidden leaks due to chewing by rodents.

In **sprinkler systems** (rain guns, central pivots, lateral move systems and set of sprinklers), irrigation uniformity depends largely on the system's characteristics, and high irrigation uniformity is possible except with wind and in hilly terrain. This method is widely used because it is easy to install, maintain and manage, and irrigation scheduling is possible (if water on demand is available). However, it is expensive, evaporation may be significant, it requires energy for high water pressure and, in some conditions, it may result in higher risk of fungus attacks and soil erosion.

Flood irrigation is still widely used in Europe, mostly in flat lands in traditional irrigated areas. Reviled by many because of the large amounts of applied water and environmental risks (water contamination), it has recovered attention because of its low energy consumption and costs compared to other systems. In general, irrigation scheduling is not possible as water is received by farmer following turns. In saline soils, some of the water applied leaches salts out of the rooting zone and increases yields. **Furrow irrigation** improves the distribution uniformity of flood irrigation (even more with intermediate dykes), but often below the level obtained with sprinkler or drip systems. On the other hand, furrow irrigation consumes less energy than these two systems. **Laser levelling** is the best operation to improve distribution uniformity in flood and furrow irrigation systems, reducing water application rate, percolation losses and nutrient leaching. It is expensive but the levelling effect can last several years. It is relatively common in rice fields. Before transformation from flood or furrow irrigation systems to sprinkler or drip systems the cost to transform the main infrastructures and the availability and cost of energy should be considered. As discussed before, this transformation may result in less water applied per crop but not necessarily in more water conservation at farm or watershed levels.

Improving irrigation scheduling

Irrigation scheduling must match crop water requirements during the growing season to reach target yield and quality while minimising water losses by evaporation, runoff or percolation. When irrigation water is available on demand, i.e. farmers can decide when and how much water is applied, several techniques are available to improve irrigation scheduling: water balance, soil sensors, models, setting the crop load, etc. Calculating the **crop water balance** and the required water needs (Allen et al. 1998) is the most common and effective crop-tailored irrigation strategy. The crop water balance can be calculated daily at field scale and adapted to the crop management and evolution. After the farmer enters crop and soil parameters, the expert system provides weather data and optimal irrigation volumes and intervals, via web or cell phone text message. Several expert systems are available on-line; the minipaper **Irrigation management** explains in detail some of these options in southern Europe. Some are public services free of charge, others require a fee.

Soil sensors detect when soil dries to levels causing plant damage. In general, the software allows choosing the recording time and elaborates the data to show the trend of soil moisture over time. Information can be retrieved in situ or via cell phone. The cost will depend on the number of sensors required to provide representative information on the plot, and this will depend on soil spatial variability; heterogeneous soils are not suitable for this system because of the large number of probes required. Soil sensors are widely used in glasshouse crops but in many other systems the cost may be too high considering the farmer's revenues. The case study "*Misión Posible*" shows an example of applying soil sensors commercially (Annex 7: List of Case Studies).

In **supplemental irrigation**, water is applied during drought periods only, particularly if coinciding with critical crop phases. The objective is not to achieve the maximum possible yield under full irrigation but to assure the yield and quality that can be produced during a good rainfall season. Costs must be evaluated for local conditions as this system may not be economically viable. It is a recommended option for areas with limited or unreliable availabilityof water for irrigation.

In **regulated deficit irrigation**, full required water is assured in crop developmental stages when plant yield and quality are most sensitive to water stress but less water is applied during the less drought-sensitive phenological phases of the crop. The system has a maximum production as target but can also help to control excessive vegetative growth or improve quality (higher dry matter content, soluble solids content, storability). To apply regulated deficit irrigation, professional technical advice is required as the risk of negative effects on yields is high if not well managed (protocols are still under development for many conditions).

Tied ridges are micro-basins prepared along the irrigated furrows or between crop rows. Tied ridges retain the water flow and increase infiltration rate resulting in less required water and less soil erosion. Preparing them is a highly time and energy consuming operation and requires specific machinery. Although common in USA it requires development for EU conditions. Compared to conventional furrow irrigation, less water is also required when **alternate furrow irrigation** or **partial root drying** is followed. The last can be successfully applied with drip and subsurface irrigation systems as well. The risk of water percolation and nutrient leaching are reduced. Little infrastructure is required for these two systems and they are cheap and easy to apply. However, not all crop species have been tested and it requires adaptation studies to local conditions.

5.2.4. Strategies to favour farm resilience under water scarcity

Some strategies profit from spatial differences within the farm to increase resilience under water scarcity. Large farms have more scope for zone diversification and timely operations, and can afford their own equipment and labour. Among the on-farm strategies discussed, FG members identified **crop diversification**[6]and **linking to networks**[7] as potentially more effective.

Crop diversification within farm and within the plot reduces the impact of failure of one crop and reduces the risk of failure when rainfall is too erratic. The best soils within the farm can be allocated to the most productive crops while the most drought-adapted crops or natural water retention measures (**NWRM**) can be allocated to the poorer areas. Intercropping can be an association of woody perennials (trees, shrubs, etc.) with annual crops or livestock (agroforestry) or an association of different annual crop species or cultivars. Some agroforestry systems are well developed in the Iberian Peninsula, e.g. the "dehesa" or "montado" association of cork trees, pastures or cropping and livestock. Intercropping of annual crops is rare in Europe because of difficulties to mechanise the system, particularly harvesting co-existing crops/cultivars at different times. Operational costs often increase in mixed systems and the initial investment is high, particularly when planting trees. These strategies require intensive knowledge, good planning and solid evaluation of options, including economic and environmental benefits. Promoting a combination of traditional practices of economic interest can also be a viable option as seen in case study Water conservation through traditional land use practices (Annex 7: List of Case Studies). An initial indication of the suitability for local climatic conditions of a new crop is discussed in minipaper Crop Suitability Index).

The **involvement of farmers in networks**, including water users associations (WUAs), improves access to knowledge and potential benefits provided by the network (e.g. technical assistance, low input prices, high output prices). WUAs are common in current schemes and traditional irrigated areas; but it may be difficult and expensive to promote and create new ones and maintain them in areas without an existing water culture. Acquiring **knowledge** through participation in training, skills development and awareness raising events makes the farmer better prepared for making decisions and planning and for overcoming the inertia of current practices. In regions where WUAs are not implemented, it is vital for farmers to understand the basis of an increasing regulation of water management and to ensure that, by operating in collaboration with others, farmers can improve their own management of water, improve their prospects of obtaining a fair allocation of water for their business, and increase the security of their access to water. The minipaper Co-operative water management addresses this topic and presents best practices and possible forms of cooperation or ways of facilitating cooperation among stakeholders. Most of these strategies work at a scale above the FG working scale target (on-farm); however, they bring in the need of linking efforts at different scales as a means to be most effective in water conservation. Two examples of benefiting collaborations are presented in the case studies 'UEA Agritech water cluster' and 'An irrigation strategy for the East of England' (Annex 7: List of Case Studies).

Natural water retention measures[8](NWRM) refer to different landscape elements in the farm (buffer strips, grasslands, terracing, ponds, etc.) recommended in Europe to intercept runoff and reduce unwanted flooding while recharging aquifers. The best measures will depend on the site characteristics, and the design requires technical support in order to be effective and comply with water resources regulations. They require

[6]Annex 3, Strategy Nº 47
[7]Annex 3, Strategy Nº 48
[8]Annex 3, Strategy Nº 45

viability and environmental studies and may require a high investment, particularly if soil must be moved. The benefits must be clearly understood by the farmer, as a cultural change is required and NWRM often result in part of the land used for the water retention measures.

In the UK, farmers may follow certification standards for efficient water use at the farm (water efficiency, respect of freshwater biodiversity). These standards are required by many retailers because of consumers' demand for sustainable production (case study *How to motivate farmers to use water more efficiently* in Annex 7: List of Case Studies), but to attain them may be hard and expensive. On the other hand, farmers obtain an added value via certified products.

6. New developments in research and practice

Annex 4: List of documented potential strategies presents new strategies, in the pipeline or not yet adopted, that have potential to confront water scarcity. Some strategies require fine-tuning for adaptation to local conditions or may not be economically viable at present, or may have environmental problems. Some require research to make them viable on-farm. Although not specifically addressed by this FG, a major concern of many of its members is that on-farm strategies must be combined with efforts at a higher scale than the farm to be really effective in conserving water and making an efficient use of it. Because of its importance, the FG has looked into this topic (e.g. the case study 'An irrigation strategy for the East of England', Annex 7: List of Case Studies).

Often, current plot yields in the farm are lower than the potential ones, even without water stress. In order to improve the efficient use of water, local benchmarks for water productivity under good agronomic management (**benchmarking of efficiency**) are needed as targets. In this way, the impact on water productivity of any proposed strategy can be evaluated against its benchmark. Farmers can also compare their current systems to the potential ones and then explore what is not functioning in their plots (closing the yield gap due to mismanagement[9]). In the case of wheat and rice, this exploration can be facilitated by using check points of crop production (good cropping benchmarks) in the plot. Calibrated check points help to evaluate crop performance during the season, identify causes of poor performance and decide on actions to overcome those problems. For example, if plant density after crop emergence is below the target, possible problems like presence of crust, deep sowing, bad seed, etc., should be explored and addressed. Adopting this strategy increases knowledge on the interaction between management and crop performance and the environmental impact of farming practices. It is essential to identify the numerous environmental and agro-technical factors with a major effect on the various measures in a systematic manner. **The result of the benchmarking should serve as general guidance for practitioners.**

Using cultivars of spring-summer crops[10] (maize, sugar beet, sunflower, etc.) that are **less sensitive to low temperatures**, allows **early sowing** in the spring and, therefore, for them to grow when the evaporative demand is lower. This procedure can be quite effective and easily adopted once suitable cultivars are identified. This strategy will be a long term and expensive option requiring seed companies and farmers' interest if such cultivars are still to be developed.

Addition of water retaining (**hydrophilic) products** to soil[11] (e.g. hydrogel, zeolite or biochar) increases the water holding capacity of soils. However, it may be too expensive for most cropping systems considering the marginal production gain obtained unless the system includes a relatively high profitable crop or the soil is quite deteriorated. Few products are available in the market and often there is a lack of clear recommendations for local conditions.

New techniques to improve irrigation scheduling[12] include: a) improving soil moisture or drought plant-based sensors (nano-sensors, sap-flow, dendrometers) and reducing their cost to make them more affordable and useful; b) calibration of existing and new models to local conditions and making them compatible with remote sensing data and on-line services; and, c) continuous fruit monitoring. However, most sensors are expensive, the minimum number of sensors for representative measurements is not clear and often they are not very user-friendly. Additionally, the actual best time for irrigation according to crop physiology (not necessarily at night) is not known for many conditions. This is particularly relevant in sandy soils as they have a limited capacity to store water.

Constructed **wetlands on-farm**[13] can serve as multifunctional ecosystems that store water during wet periods and are pasture lands during the dry periods when they are most needed. The quality of such pastures, however, may be reduced. Wetlands can absorb point-source and non-point (diffuse) pollution, but this reduces their water reuse potential. Construction projects require economic analysis, as they will take land out of production, and a hydrological study and good design. It is an expensive option unless favoured by

[9] Annex 4, Strategy Nº P6
[10] Annex 4, Strategy Nº P5
[11] Annex 4, Strategy Nº P3
[12] Annex 4, Strategy Nº P8
[13] Annex 4, Strategy Nº P12

landscape. Wetlands can help to recharge aquifers, increase biodiversity and valorise the land if it is marginal.

Innovative solutions are needed to improve **on-farm water recycling** systems and the use of saline water[14]. Water quality needs to be closely monitored but, if treated appropriately, use of recycled water may reduce the need for mineral fertiliser inputs. High investment is required to develop prototypes and technologies. A careful economic study will be necessary due to the high cost of installation and maintenance. Additionally, consumers fear risks of contaminated products irrigated with these systems.

[14]Annex 4, Strategy Nº P14

7. General failure factors and barriers

In the previous two sections, specific failure factors were identified for each listed strategy. There are some general factors that affect many strategies. These general failure factors and hurdles are:

- Lack of clear cost-benefit analysis before adopting a strategy. Economic returns are a major concern for farmers who are sometimes not convinced by strategies they are not familiar with, particularly complex options with high dependency on advisors.
- Lack of clear evaluation of the impact of strategies on water conservation and thus, lack of knowledge on the return in terms of water savings. Related to this, lack of water productivity benchmarks for comparison of current farming practices with new systems.
- Lack of knowledge and awareness regarding long-term or environmental benefits of strategies for local conditions. Similarly, lack of knowledge on close links between on-farm and higher scales and larger implications.
- Lack of alternative, drought tolerant crops attractive to markets.
- Lacking institutional and policy support when significant training, technical advice or fine-tuning research are required.
- Missing trusted link between farmers and knowledge providers.
- Very little official reward for researchers working on practical issues not leading to research articles and patents, so most public agricultural research focused on frontier knowledge.

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8. How to facilitate adoption of strategies?

Providing benefits transparently

In general farmers have a resistance to change, unless this change results in clear benefits, particularly economic ones, or they understand the importance of non-obvious benefits (e.g. those obtained in the long term). To facilitate adoption of best practices, benefits in water conservation and in economic or environmental terms, in the short and long term, have to be clearly identified and described for each strategy and for the local conditions.

In most countries there are technical advisors within the fertiliser and pesticide companies. Impartial and reliable advice is needed for confronting suppliers' recommendations as well as to cover areas without economic interest for private companies (e.g. environmental issues). Many farmers lack access to trustworthy extension services.

Thinking and acting together

Knowledge exchange among all actors is necessary to identify and understand any technical and operational problem associated with a strategy, proposed or being implemented. An Operational Group project could be set up around such a practical problem involving all necessary actors with different type of knowledge and expertise to find a solution. The extension service, if existing, should be involved in this type of activities.

Some strategies were developed in quite different conditions than in the target area, and require fine-tuning to develop viable options. In such cases, applied research on farm is necessary, maybe accompanied by on-station research. Before that stage, farmers' perceived reality and needs must be clearly expressed and used in defining target research to ensure that the research results are practical and viable.

Some technologies are complex and require an important training effort for farmers and advisors.

"Seeing is believing"

This applies to any new strategy but particularly those requiring a change in the farmers' mindset. Demonstration plots can be developed to show farmers *in situ* how the technology works, its benefits and problems. Farmers should feel that demonstrations are representative of field conditions, and if possible, plots should be under the responsibility of farmers to facilitate communication. If there are early adopters, their practical cases may work better than even farmer-managed demonstrations. Economics and break-even analysis customised for local conditions is desirable.

Long-term demonstrations accompanied by knowledge are the best tools to show benefits related to soil improvements.

Linking partnership and involving stakeholders

Many strategies require the involvement of manufacturers or agro-companies to develop a viable product adapted to local conditions. For example, a cooperative project aiming at the adaptation of machinery to heavy soils. Other strategies may require a produce chain vision, including consumer demand. Through education, this demand can change, favouring some strategies (e.g. labelled water-use-efficient products in UK or organic products).

User-friendly tools

Complex strategies require the development of clear guides to facilitate their use. These guides could be accessible from the internet where self-training could help mastering the strategy.

There are several decision support systems (DSSs) for crop and irrigation management that could be easy to use after training. Once the farmers are familiar with the DSS, it can be hosted in their computers or on line. Often, a DSS can be combined with weather daily data from neighbouring weather stations to be more precise.

Mapping and distribution of soil moisture in an App format can facilitate taking decisions in precision irrigation.

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Using tools available within the Rural Development Programmes

National and Regional Rural Development Programmes of the Common Agricultural Policy (CAP) offer the possibility to create Operational Groups to solve specific practical problems or to test new ideas in agricultural systems. General information on Operational groups is available on the EIP-AGRI website, including inspiring examples. Innovation support services and investment support measures funded by the Rural Development Programmes may also be helpful. National and regional authorities can provide information on these opportunities, and more.

And think outside the box!

9. What needs to be done?

The Focus Group identified the following specific research needs and ideas for Operational Groups that could contribute to the development of innovative and viable strategies and consequently, increase their adoption.

9.1. Research needs from practice

A list of research needs from practice is presented in Annex 5: List of research needs from practice. This list includes all the topics listed in the minipapers, those discussed during the meetings and those uploaded to the EIP online database.

For most strategies, their **effectiveness of conserving water at farm level** and their **economic return** are unknown. Clear protocols for systematic on-farm research to evaluate strategies are needed; and often, understanding the impact at higher scales than the farm (irrigation scheme and watershed) will be required to have a global significant impact. The evaluation will be more practical if results can be compared to benchmarks representing best options for local conditions. **Benchmarking** of water productivity or efficient use of water will help identify the most and less efficient strategies and under which conditions. This theoretical analysis can lead to significant improvements in production processes in the field with less water.

Similarly, **economic and environmental risks** associated to any strategy must be studied and well understood. Farm level measures usually have a positive impact on ecosystem services, therefore benefits not only arise at farm level but for the whole society as well. Transparent **cost-benefit analyses** are required before any promotion among farmers.

Long-term studies / research needed:

Some strategies require long-term studies to show agronomic benefits, in particular those aiming at improving soil water holding capacity and water infiltration by **increasing soil organic matter**: conservation agriculture and maintaining soil surface covered with residues, mulching, cover crops, green manure, and crop rotation. Good application of any tillage operations needed is critical for conserving soil and its quality. However, the precise effects are not well known and evaluated. Complex strategies (in terms of affecting various elements of an agriculture system, e.g. conservation agriculture) may be preferably studied using **participatory research and a multi-actor approach**.

Short-term studies / research needed:

Simpler strategies aiming at increasing water availability (applying hydrophilic products, decompacting soil and deeper rooting) can be fine-tuned with short-term trials. In particular, agronomic research topics should address:

- The **conditions for the success of conservation agriculture practices** (from no-till/minimum tillage to residues and weed management);
- The evaluation of the effect of **alternative organic materials** (digestate, compost from different sources, sewage sludge, reclaimed waters, beached algae) on the soil-water balance and crop-available water;
- The comparison of **new mulching materials**, alternative to plastic, and verifying the mulching effect of the **cover crops**.

Agricultural engineering research topics should address:

- the relationship between reducing soil compaction and increasing porosity and economic benefits;
- methods to avoid deep compaction (as once this is present it is hard to remove);
- design of new ripper machines adapted to small fields;
- the improvement of no-till drilling equipment, especially for high residue and wet or dry soil conditions.

Moreover, special attention is required for the methodology of valuation of specific environmental services, which are the positive externalities of the farm-level measure of this subject.

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Decision Support Systems (DSSs) can be used to study crop responses to rainfall and temperature patterns and for taking tactical crop and water management decisions. Most available crop management DSSs are used in research and have been tested only in the area or region where they were developed.

Research should focus on improving the tools available and this should be accompanied by comprehensive knowledge dissemination to reach the target audience. More specifically:

- before using them, DSSs should be calibrated and evaluated for local conditions;
- DSSs need further tests and research to broaden their applicability in a wider range of environments and crops;
- more user-friendly systems and studies to show clear benefits are required

Quantification of the economic and environmental benefits of the various models could facilitate their dissemination and adoption on a wider scale.

In southern Europe, where non-limiting light irradiance is present, the use of **shading nets** may decrease the water use of some crops. However, research is needed to test this strategy in different cropping systems and define the optimal shading level.

In northern Europe, there is a need to research and develop vertical closed-cycle, such as **hydroponic green fodder**, systems that use little land and water. Similarly, aquaponic systems use rain water from greenhouses for aquaculture, while the waste water out of aquaculture is used as fertigation water in the greenhouses.

Several irrigation strategies may help farmers **optimise the amount and timing of water supply**; however, currently available options are not suited to conditions of serious water scarcity. Moreover, these systems often rely on the estimation of the crop water balance without taking into account the actual water needs of the plants. The development and refinement of **cost-effective, easy to use plant-based sensors** for monitoring the actual crop water needs is necessary, as well as their implementation in DSSs providing real-time suggestions for irrigation scheduling in different crop species. These sensors should be coupled to a thorough physiological understanding and modelling of the various parameters monitored. Research is also needed to improve **regulated deficit irrigation** (RDI) strategies to broaden the number of species, environments and soils where they can be applied. Furthermore, because of the high heterogeneity in physiology of the different agricultural systems and crops, further studies are needed to **validate and fine-tune the application of online services, RDI protocols and precision irrigation approaches** to a broader range of different species and agricultural systems. Also, most of these strategies may appear too difficult to be adopted by a large number of growers as the use of web platforms, sensors (i.a. for monitoring soil moisture), high technology systems (e.g. for precision irrigation and remote sensing) are envisaged, and the support of professional technical experts, capable to assist the grower with the correct application of the different methodologies may be required. Understanding and responding to the need to **customise solutions** to the preferences (technologies, technical assistance, impact on current practices, etc.) of the grower is essential for adoption of novel technologies.

Treated waste water can be used to increase water availability but research is needed to clarify the effects on cropping (food security, productivity), effect on soil quality, and on fresh water sources. There are situations where good quality water is available for irrigation but not in adequate quantities to meet the evapotranspiration demand by crops. Under these conditions, the strategies for obtaining maximum crop production could include **mixing of saline water with good quality water** to obtain irrigation water of medium salinity for use throughout the cropping season. Alternatively, good quality water could be used for irrigation at the more critical stages of growth, e.g. germination, and the saline water at the stages when the crop has relatively more tolerance. Research is ongoing to define the best options considering the tolerance of crops at different growth stages, critical stages of growth vis-a-vis soil salinity, etc. See Minipaper "Water quality and salinity" for more information on this topic.

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9.2. Priorities for Operational Groups

Ideas for Operational Groups (OGs) were discussed to improve water availability, the efficient use of water and farm resilience. Many other ideas came to light while preparing the mini-papers. Annex 6: Suggestions for Operational Groups presents a list of main ideas and a brief description on the key components to be considered when developing these OGs. In general, most suggestions focus on testing the most relevant options presented in the main text under local conditions, particularly the impact in terms of water conservation and economic benefits.

To increase water availability for crops and livestock, the following activities were proposed:

- i) Adapt Conservation Agriculture to local conditions and cropping systems and establish long term experiences in order to demonstrate to farmers the importance of good agronomic practices on soil fertility and impact on yield stability;
- ii) Evaluate how different methods to maintain soil ground cover influence the increase of soil organic matter, water conservation and economic benefits;
- iii) Study the economics of soil amendments to identify those that produce the best returns;
- iv) Evaluate methods to reduce soil compaction and to improve rooting conditions in intensively managed soils; and,
- v) Assess the effect of controlled drainage on water availability and soil water holding capacity in northern Europe.

To use the available water more efficiently, the following activities were proposed for rainfed and irrigated conditions:

- i) Evaluation of *Brassicaceae* cultivars for resistance/tolerance to drought and salinity;
- ii) Use crop suitability indexing utilising agricultural statistical data, climate data and crop models to propose improved crop rotation and evaluate them for local conditions;
- iii) Test and identify cultivars of spring-summer crops less sensitive to low temperatures to advance sowing time; and
- iv) Close yield gap of local crops by determining benchmarks and identifying reasons behind poor management.

Irrigation efficiency may be also improved by

- i) Optimising irrigation scheduling with crop water balance and soil sensors, supplemental irrigation or regulated deficit irrigation (RDI);
- ii) improving water application with precision irrigation accompanied by remote sensing or Site-specific variable rate irrigation (VRI); and
- iii) Calibrate and test user friendly DSSs for local conditions.

Ideas for improving farm resilience included:

- i) treat farm wastewater or use of poor quality water and new innovative solutions to improve it, to increase water availability in the farm and,
- ii) Evaluate new crops to increase diversification.

For more information on Operational Groups, please see **the EIP-AGRI Brochure on Operational Groups** (available in English, Finnish, French, German, Greek, Hungarian and Italian).

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Annex 1: Members of the Focus Group

Experts

Surname	First name	Profession	Country
Agudelo	Agatha	Expert from agriculture organisation, industry or manufacturing	Spain
Anastasiou	Dimos	Scientist; part time farmer	Greece
Basch	Gottlieb	Expert from NGO; scientist	Portugal
Cabecinha	Liliana	Expert from agriculture organisation, industry or manufacturing	Portugal
Collison	Martin	Farmer; farm advisor; other type of advisor; expert from agriculture organisation, industry or manufacturing	United Kingdom
de Haan	Janjo	Scientist	Netherlands
Fülöp	Bence	Farmer; advisor; scientist	Hungary
Girona	Joan	Scientist	Spain
Hammett	Paul	Farm advisor; expert from agriculture organisation, industry or manufacturing	United Kingdom
Huits	Dominique	Farmer; farm advisor	Belgium
Intrigliolo Molina	Diego	Scientist	Spain
Krysztoforski	Marek	Farm advisor	Poland
Larsson	Linda	Farm advisor	Sweden
Mantovi	Paolo	Farm advisor; scientist	Italy
Mastrorilli	Marcello	Scientist	Italy
Morandi	Brunella	Scientist	Italy
Schmidt	Guido	Advisor	Germany
Takavakoglou	Vasileios	Advisor; scientist	Greece
Taparauskiene	Laima	Expert from agriculture organisation, industry or manufacturing; scientist	Lithuania

Facilitation team

Gómez-Macpherson	Helena	Coordinating expert of Water and Agriculture EIP-AGRI Focus, Researcher at Institute for Sustainable Agriculture (IAS, CSIC) - Spain
Seregélyi	Anikó	Policy officer - European Commission, DG AGRI
Karasinski	Céline	Task manager of Water and Agriculture EIP-AGRI Focus group-Expert of the EIP-AGRI Service Point
García Lamparte	Andrés Manuel	Backup of the Water & Agriculture EIP-AGRI Focus Group, data base officer of the EIP-AGRI Service Point

funded by European Commission

Annex 2: Mini papers on prioritised topics

Themes
ON FARM SCALE
Soil management for improved water availability
Tools for improving crop/farm management
Tools for improving irrigation scheduling: present and future perspectives
Water quality and salinity
OTHER SCALES
Improved Varieties and New Crops
Spatial Crop Suitability Indexing
Co-operative water management

Available on **https://ec.europa.eu/eip/agriculture/en/content/water-agriculture-adaptive-strategies-farm-level**

funded by European Commission

Annex 3: List of documented current strategies

INVENTORY OF CURRENT STRATEGIES

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase water availability for crops and livestock?							
Options to reduce water losses							
1	Conservation Agriculture defined as the combination of: minimum soil disturbance (preferably no tillage) **+** permanent organic soil cover (retention of residues or mulch) (**+** crop rotation in the case of annual crops).	Improves water infiltration (slow runoff) and reduces evaporation losses. Increases soil organic matter (SOM) in superficial soil layers. Yield stability. Requires specific machinery and more vigorous cultivars. Risk of poor crop establishment under certain conditions (wet soils, excessive residues). Hard weed control. Risk of lower yields especially in the first years of application.	Cannot sell residues. Lower machinery and labour costs but increases herbicides. Low price of alternative crops.	Reduces runoff (and nutrient/ pesticide transport) and soil erosion. Increases SOM. In some conditions may sequester carbon. May increase leaching as higher water infiltration (but less production of nitrates in the soil). May increase use of herbicides.	Conserves soil; reduces costs. Active farmers associations for promotion. Part of agri-environmental measure (policy). More effective in low rainfall conditions.	Complex, requires adjusting many elements (machinery, management of residues, rotation of crops…). Expensive machinery. Adapted non-cereal crops to CA must be found. Ploughing culture. Lack of solution oriented research. Subsidies prevent economic pressure to change. Can lead to increased disease carry over between crops. Relatively common direct seeding of cereals but less common in other crops or to maintain ground cover.	America and Australia. Little practice in Europe, except in olive orchards in southern Europe. Obliged in some parts/fields in Flanders.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase water availability for crops and livestock?							
Options to reduce water losses							
2	Early ground cover of crops: a. sowing early; b. dry sowing; c. seed priming (pre-soaking seeds to enhance germination) d. sowing cultivars with early vigour; e. optimising plant density and spacing.	Improves water infiltration (slow runoff) and reduces evaporation losses. Better soil trafficability. Higher yield potential when combined with longer cycle cultivar. More risky crop establishment: early weed infestation; higher risk of early drought (and frosts in northern EU). Requires longer cycle cultivar.	Cheap strategies except (c).	Reduces soil erosion. Reduces nutrient leaching.	Protects the soil. Cheap. Can increase yield when combined with longer cycle cultivar.	Higher risk of early drought. Prediction of break of season and technical support required. Can lead to build up of some weeds – major problem with blackgrass in UK cereals.	(a, b, e) Winter crops in Mediterranean environments. (c) Tropics. (d) Australia.
3	Subsoiling if a hard pan is present.	Increase water infiltration and will favour root growth into deeper layers. If applied, needs to be reapplied systematically. May increase deep drainage.	Expensive operation (less if combined with controlled traffic).	Requires high energy. Degrades soil.	Easy to apply.	Expensive. Timing of operation important, Following soil management.	Widely used.
4	Effective weed control in crops and orchards.	Prevents the use of water by other plants than the crop. Should be address considering the full crop rotation. Reduces the number of host plants hosting pathogens (insects + fungi). Requires attentive management.	GMO crops resistant to herbicides (not approved in EU) combined with no till have lower costs.	If higher use of herbicides, higher environmental risks. GMO crops resistant to herbicides available but not approved in EU. Decreases the bio-diversity.	In general easy to manage. Timing of weed control critical Rotations can help break weed cycles Stale seedbeds can help control weeds. In America, GMO species (not approved in EU) facilitates weed control.	Efficient herbicides unavailable. Eventual weed resistances to herbicides. Integrated weed management is knowledge demanding.	Effective in some crops but problematic in others. Localised use of herbicides is widely used in orchard in Spain.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase water availability for crops and livestock?							
Options to reduce water losses							
5	Contour farming (crop sowing or trees establishment following contour lines).	Increases infiltration and reduces runoff. Water in excess may be stored in small-scale reservoirs. Not if steep slope (risk of accident). Less effective in irregular terrain. Excess water in very rainy periods. May difficult some operations.	Additional equipment may be required.	Reduces runoff and erosion (off-site transport of nutrients and pesticides).	Little extra cost (except if additional equipment required).	Requires good design. Plot size. Accidents risk. Further research needed.	Present in hilly land, and also in flat areas for increasing the uniform distribution of water (rain + irrigation). Widely used in USA and Brazil.
6	Plastic mulch.	Reduces soil evaporation. Increases soil temperature and favours early establishment (faster growth and higher root density). Black plastic makes weed control easier. Transparent plastic makes weed control harder.	High cost but may be cost effective in some conditions.	Pollution due to plastic disposal.	Extends crop growing season because of earlier planting dates (and may increase yield). Easy to install and manage. Does not require technical skills unless install with special equipment). Maybe cost effective.	Requires special machinery. High cost. Under plastic sheets root system is developed mostly in top soils. Biodegradability and controlled shelf live.	Widely in China. Used in east Spain. Intensive crops (fruit, salads, ornamentals) in the spring in North Europe.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase water availability for crops and livestock?							
Options to increase soil water holding capacity (i.e. increase soil organic matter or add water retaining products) and access to available water							
7	Soil ground covered by: a) Stubble/residues retention. b) External application of mulch (stubble of residues from external sources) or organic processed inputs (livestock manure, compost,…). c) Cover Crops. In annual crops or tree orchards; require to be in no-till systems to be most effective.	Increases SOM in superficial soil layers, improves water infiltration into soil. Reduces soil erosion. Cover crops reduce nutrient leaching and, when killed or flattened, reduce evaporation. Helps to suppress weeds. Chemical weed control limited to less persistent contact herbicides. Cover crops compete for water when they are growing unless high rainfall. May be killed by frost. Perennial weeds may find more favourable conditions. Large volume of external inputs required.	Cannot sell residues for cash. Reduces costs due to machinery and labour but may require more expensive herbicides. External:cost depends on transport (distance and volume).	Reduces soil erosion. Favours soil biodiversity and bird nesting. Increases natural enemies and reduce crop pests.External: depending on source, risk of toxicity, heavy metals and pathogens. Risk of N and P leaching.	Cover crops management known in olive orchards and vineyards, and also in organic horticultural cropping systems. Weed-suppress capacity. External: Attractive to organic producers. Build links between farmers and the organic matter producers.	b) Expensive depending on transport and nutrient richness and spreading method. c)Timing of cover crop killing; high risk because of water competition with crop; Needs water resources at the end of summer.Impact observed in the long term(3-7 years depending on environment.	b) close to animal farms and sources of organic wastes c) USA.Increasingly applied in annual cropping systems in Central and Northern EU, common in EU orchards and vineyards.
8	Ley pasture (under sown in the autumn).	Increases SOM. Less water demand in autumn-winter than in spring. Gives the baby plants in the ley a good start. Competition for water, species diversity, Competition on resources.	Additional seed costs.	More biodiversity.	Weed control.	Risk of poor ley establishment. Competition for water.	Australia. Farmers in northern Europe.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase water availability for crops and livestock?							
Options to increase soil water holding capacity (i.e. increase soil organic matter or add water retaining products) and access to available water							
9	Controlled traffic (wheels pass always over the same lines).	Space in between wheels not compacted, with higher soil porosity to fill in with water. Less compaction favours root growth to explore greater soil volume. Poor/no crop in wheeled lanes.	Expensive if wheels distance of machinery need to be adapted. Otherwise less cost. Reduces fuel use and increases yield.	Soil compaction is restricted. Erosion may occur in wheeled lanes.	Relatively low cost; higher yields.	Requires GPS guided tractor. Initial help required to optimise plot design. Machinery must have similar width between tyres.	In sugar cane in Australia. Extensively in UK by most progressive farmers. Few farmers in southern EU and the Netherlands (mainly organic).
10	Fallow (plot not cropped during one season).	Stores rainfall water and nutrients in the soil for the following season. Weed control. May produce less when compared to continuous cropping.	Less costs but no earnings in fallow year. Economic viability questioned.	Bare soil prone to wind and water erosion and detrimental to soil biodiversity.	Facilitates weed control . Promoted by CAP.	Its efficacy depends mostly on soil water holding capacity. Not effective in shallow soils.	Arid and semi-arid zones in southern EU.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase water availability for crops and livestock?							
Options to increase water supply for irrigation and livestock							
11	Use of alternative water sources (rainwater and drainage harvest) for livestock and crops.	Rainwater can be easily collected from roofs of buildings. Often needs to be upgraded so that they can be used as drinking water for livestock. Takes some land.	Capital cost. May be cost effective for glasshouse nurseries with large roof areas. May cost less than using public water but more than using ground water.	Sometimes specific local conditions (e.g. clay) can give some specific problems. Less leaching of nutrients from drainage systems into open water bodies.	Ample rainfall to collect in temperate countries. Can be cost effective in the long term if you have large areas of roof e.g. glasshouses, poultry houses.	Should follow legislation. Water must be treated in some countries. Too expensive.	Flanders. Used in UK in horticulture and intensive livestock production. Applied in Scandinavia and Baltic countries with aim to reduce eutrophication
12	Level controlled drainage: the drainage level can change to keep water in to the field.	Simple to introduce. Training of farmers needed to learn how to work with level controlled drainage.	Cheap.	Less pressure on more threatened water sources. Fear that will lead to more P-excess to surface water. Increases emission of NO_2.	Share water with other farmers.	Legislation. Research needed for local conditions. Voluntary local agreements possible but can lead to disputes. Lack of co-ordination between drainage authorities and farmers. Matters distance between drains, soil texture. Hardly possible to have in heavy soils.	Introduced in Flanders in 2013; some adaptation was necessary. Used in UK, Netherlands, and few places in Sweden and Finland.
13	On-farm pond(s).	They also can be filled in periods of drought. Simple to introduce. Requires soil movement.	Expensive, less when facilitated by landscape.	Less pressure on more threatened water sources. Must be monitored.	More stable access to water.	egislation; illegal in some countries. Farmers and the water management authorities must be trained. Uncontrolled water uptake.	Southern EU, Flanders. Common if livestock on farm. Licensing required in UK.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase water availability for crops and livestock?							
Options to increase water supply for irrigation and livestock							
14	Fog/mist harvesting.	Additional source of water Efficiency depends on the microclimate of the area.	High investment. Questioned in relation to benefits.		Low operational cost.	Site specific study is needed before the establishment. Highly dependent on micro-climate. Investments/benefits questioned.	Argentina, Chile, Southern Europe.
15	Renovation of the irrigation systems.	Effective if current system is in bad conditions. Increases the uniformity of water distribution and the irrigation efficiency.	Expensive.		Possibility to acquire more efficient and practical systems.	Expensive.	Wide use.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase the efficient use of water?							
Species/cultivars with intrinsic high water productivity							
16	Improved cultivars (annual crops): a. "stay-green" in sorghum; b. low discrimination against ^{13}C during photosynthesis in wheat grown on stored water; c. osmotic adjustment in wheat; d. short anthesis-to-silking interval in maize; e. adapted landraces.	Produces more biomass and yield under water stress. Cultivars may not profit from high rainfall years, may not be resistant to biotic stresses, may not have good quality product.	Often no additional cost. (e) low market appeal for old cultivars but may have niche and higher price.	(e) increase agrobiodiversity.	No extra cost; easy to adopt. (e) Recuperate traditional knowledge; increase agrobiodiversity.	(a, b, c, d) Limited/no seed availability; unknown cultivars. (e) may not be clear which old adapted cultivars perform better under drought.	(a, b, c, d) North America, Australia. (e) EU.
17	Cultivars / rootstocks of vigorous deep roots.	Vigorous, well-developed, deep root systems explore more soil. May have poor adaptation to different environments and resistance to biotic stresses. Scion/rootstocks interactions. May clog drainage systems.	No additional costs at planting time.	Less percolation and leaching of nutrients.	No extra cost; easy to adopt. In vegetable production it does represent extra cost but worth if combined with pathogen resistance.	Requires research: resistance to biotic diseases, productivity (yield and quality).	Fruit crops in southern Mediterranean regions, e.g. GF677 for peach, Farhold or MH for pear. Widely used in vegetable production.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase the efficient use of water?							
Understanding and closing yield gap: improvement in crop, pasture and grazing management and feeding, or in crop and animal health							
Options to use water more efficiently							
18	Tactical management (decide operations according to current season): a. calibrated crop models to local conditions (decision support systems); b. nutrient analysis / balances; c. check points (optimum values of plant; establishment, tillers/m2, etc, used as benchmarks) d. Integrated pest management.	Allows profiting from best years (e.g. sow a cultivar of shorter cycle or reduce fertiliser if the rainy season is delayed). Avoids using inputs unnecessarily. Allows correcting mismanagement. Reduces risk of failure. Higher yields/more efficient production. Requires training, guidelines and local calibration.	a, b) Cost depends on model and analyses. c,d) Cheap once guidelines are available. Expensive to keep seeds of different cultivars.	Reduce risks of contamination. More efficient use of inputs.	More knowledge for farmers and advisors. High production in the best years. Cheap.	Calibrated and validated models may not be available. Check points of local crops need calibration for local conditions. Requires training, guidelines and local calibration.	Applied by best (large) farmers. d) supported by policies in some crops.
19	Improved crop rotation / sequence.	Grain legumes or oilseeds crops may benefit the following cereal crop by fixing some N or reducing soil diseases. Increase the risk of failure with less familiar crops. Lack of marketable options.	Cheap. May be difficult to market products. Risk diversification.	Increases soil fertility and soil bio-diversity. Less use of pesticides.	Less production risks through crop diversification.	Limited availability of crops with attractive economic return. Limited seed availability.	Applied by best farmers.
20	Soil rehabilitation (e.g. liming to control acidity, gypsum application in sodic soil).	Favour wider and deeper rooting, better crop development and contributes to improved soil aggregation, and thus increase in soil water	Expensive. Cost varies with volume and transport.	Benefits biodiversity, soil and water resources.	Positive effects on productivity. Provide additional choices of crop establishment.	Site specific study is required prior to application.	Widely used.

		availability.					
21	Fertirrigation.	Increased use efficiency of water and nutrients. Better control applying nutrients. Less compacting problems due to machineries. Clogging of the pipelines.	Reduce fertiliser losses.	Reduce fertiliser losses.	Reduce fertiliser losses (economic & env. benefits).	Need of farmers training.	Widely used with drip irrigation. In glasshouse crops and some outdoor crops.
22	Precision irrigation aided by remote sensing (RS) (satellite, planes, drones & sensors in machinery).	Profit from spatial variation. Identification and quantifications of field variability. Prescriptions for taking decisions and how to implement not clear. Data availability depends on weather conditions.	Getting images and their analysis (advisory service) is expensive.	Reduces leaching losses of nutrients and pesticides.	Reduced variability in production performances. Highly visual images.	Clear prescriptions for taking decisions required. Requires training and good consult. Research needed. Questioned practicability and profitability (contradicting results regarding the cost of application in response to the benefits).	Vineyards of large companies. Common in UK, e.g. potatoes, vegetables.
23	New growing technologies of livestock under controlled environment	Fully controlled growing environment around the year. Choosing best growing time when the feed is needed. Less arable land is needed.	Extra costs for establishment of greenhouses feed growing areas. Local grain can be used.	Water recycling.	Improved animal health due to improved nutritional value of feeds. Support for adaptation of innovations.	Expensive. Specific knowledge and maintenance is needed.	Asia. Some part of Europe.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase the efficient use of water?							
Understanding and closing yield gap: improvement in crop, pasture and grazing management and feeding, or in crop and animal health							
Growing when the evaporative demand is lower							
24	Matching the cropping and rainfall seasons: • growing the crop when most rain falls • Use crop models to define agro-ecological zones (which crops, climate, soils, others).	Improves water infiltration and reduces evaporation losses. Models give the possibility to analyse different agro-scenarios. Will contribute to crop diversification. Higher risk of early drought and harder weed control. Requires professionals. Knowledge and skills demanding.	Cheap.	Reduces erosion. Can evaluate the consequences of different system management on the environment.	More knowledge for farmers and advisors.	Lack of new varieties resistant to early droughts or low temperatures. Historical weather records required to characterise season. Harder to apply in more erratic weather patterns (climate change).	Applied by best farmers in Mediterranean countries. Where the extension services are effective.
25	East-west row orientation in trellised orchard/vineyards systems.	Reduces the canopy light interception and transpiration without compromising yield. Only applicable in sunny and warm environments. Not flexible.	Equally costly than north-south orientation.	Risk of erosion depending on slope orientation.	No extra cost. Easy to manage, it only requires planting the orchard and vineyard with east-west rows orientation.	Not applicable in established vineyards. Not useful in cloudy environments (mainly diffuse solar radiation). Might increase soil erosion.	Sunny and warm environments in vineyards, for fitting to plot shape.
26	Shading screens/nets in open fields and greenhouses.	Reduces temperature and evapotranspiration. Simple and easy to implement. Special covering materials prevent from hail damage and rains of high intensity. Reduces yield and quality in some species.	May be expensive although some farmers already install hail nets that can be used for shading.	Negative visual impact on landscape.	Depending on the net, cost may be reasonable e.g. when used in summer vegetable production.	Used in some crops but research needed for others. Only for cash crops.	Applied in selected systems. Used in UK for hardy ornamental nursery stock.
27	Use of kaolin (inert, white compound of aluminium silicate).	Reduces radiation interception, evaporation and leaf temperature. Barrier to	High cost. Prevents sunburn of fruit (better price).	Environmentally friendly (inert material for a wide range of pH).	More revenues if higher yield and if better price for	Might become phytotoxic if not applied properly.	Apple and pears in USA and Israel. Cash crops like

		pests and avoids sunburn. Rain washes the kaolin application.			higher fruit quality and less pests.	Might be expensive if repeated applications are needed.	fruit trees.
28	Wind break.	Reduces wind speed and evapotranspiration. Reduces eolic soil erosion. Not applicable in large plots in some conditions.	High cost.	Increases biodiversity. Reduces eolic erosion.	If formed by olive trees, these may be harvested. Requires time for establishment and being effective.	Unproductive land (unless harvestable fruit trees). Requires well design.	Windy areas, e.g. in southern Italy, in the Fens in the UK for vegetable and salad crops.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase the efficient use of water?							
Which management options will increase irrigation efficiency?							
Irrigation system							
29	Drip irrigation.	Higher irrigation uniformity. Simple management. May help farmers to control salinity problems. Can be used with fertilisers / aeration. Weed control. Requires water on demand; requires energy for low water pressure. Maintenance. Root system develops only in humid bulb.	Expensive the installation but less labour intensive afterwards. Worthwhile if water price is high.	Less water consumed. Successfully used in saline soil with good quality water.	Automation; Scheduling possible; Less water requirements and more energy than flood but lower energy than sprinkler.	Requires water on demand (in permanence) and energy; expensive. Maintenance. Clogging.	Mainly vegetable production, vines, fruit orchards, hilly lands, and protected agriculture.
30	Subsurface drip irrigation (system buried under the cultivated row for underground water distribution).	Reduces evaporative water losses, while increasing the distribution efficiency. Less weeds present. In association with drainage system, prevent soil anoxia in case of excessive irrigation/rain. Requires water on demand; requires energy. Maintenance (roots intrusion).	Higher initial investments compared to traditional drip irrigation. Reduced management work with respect to other.	Low soil evaporation and highest use efficiency of irrigation water.	Less water required than the rest. Easier farm operations. Low energy consumption.	Logistical/technical problems in maintaining the correct functioning (failure detection). Requires water on demand. Very expensive. Root intrusion within the emitters. Extensive equipment damages by rodents.	Orchards and vegetables, both in open fields and greenhouses. Coupled with conservation agriculture practices.
31	Oxygen or air injection applied to the subsurface drip irrigation system.	Increases root respiration in heavy or compacted and/or saline soils, simple to apply, machinery available. Maintenance & monitoring requirements.	Cheap or expensive, depends on applied technology.	Positive effect on soil quality and biodiversity. Requires low energy input.	Increases production.	Research and demonstration needed.	USA, Australia. Experimental system in Italy.
32	Sprinkler irrigation.	Higher irrigation uniformity. Easy to install.	Expensive.	Must avoid wind. Evaporation may be	Scheduling possible; Less water	Requires water on demand and high	Wide use.

		Requires energy for water pressure.Poor irrigation uniformity in hilly or windy areas. Higher risk of fungi attacks.		significant. Soil erosion in hilly land.	requirements than flood. Mobile systems.	energy; expensive. Maintenance Not recommended for hilly land.	
33	Flood irrigation.	Wash salts in saline soils. Hard to schedule irrigations as water generally available on turns. Requires levelling. Nutrients leaching; water percolation.		Risk of contamination. Low energy use.Runoff is used downstream.	Low energy use.	Requires more water and levelling. Leaching.	Common in flat land in traditional irrigated areas.
34	Laser levelling in flood irrigation.	Higher irrigation uniformity reducing percolation losses. Risk of nutrients leaching and water percolation.	Expensive.	Risk of contamination. Low energy use.	Improves significantly flood irrigation.	Expensive.	Common in flat land and in rice crops.
35	Mist irrigation.	Land extensive. Low intensity. Frost protection. Reduces vapour pressure deficit. Relatively small areas. Used to increase humidity of environment.		High evaporation in open field.	Preferred system when high environmental humidity required.	Depends on wind in open field. Not for irrigation of crops.	Mainly controlled environment (greenhouses). To propagate cuttings and young plants.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase the efficient use of water?							
Operative solutions for irrigation scheduling (when, where, how much irrigate)							
36	Use of soil sensors (capacitive or resistive probes installed into the soil and remotely connected).	Software elaborates the information and it gives back the trend of water in the soil layer explored by the root system. Possibility to monitor soil water content at any time scale and at the same place. It has no destructive character on soil. Minimal sets of measurements per field plot depends on soil spatial variability. Requires water supply on demand. Farmers should be trained and assisted.	Cost often too high respect to the farmer's revenues.	Percolation and groundwater pollution can be avoided.	Improved irrigation needs assessment. Increase efficient use of water. The information obtained can be easily interpreted. Depending on sensors, can be easy to use (via mobile phone) and also an affordable service.	Heterogeneous soils are not indicated for hosting the probes for monitoring the soil water content. Farmers should be trained and assisted directly in their fields. Lack of assistance and extension services. Water supply at demand not available. Cost. Number of sensors depends on the soil. Security. Maintenance.	Wide use. Strawberry, mandarins, orange trees in southern Europe. Private companies. Field vegetables and glasshouse crops.
37	Crop water balance calculated daily at field scale and adapted to the crop characteristic, simulated or inputted by the farmer (e.g. IRRIFRAME, Italy).	Users are provided with optimal irrigation volume and interval, via web or mobile phone text message. Requires water supply on demand; meteorological and soil data and crop parameters.	Free of charge (depending on programme can be taxes for daily data).	Percolation and groundwater pollution can be avoided.	Friendly interface, adapt to new smartphones. Can be applied to large areas without the need of additional on-farm sensor data. Efficient scheduling. Application of the most effective crop tailored irrigation strategy.	Requires calibration to be used in other environments. Research needed for further improvement. Much data is needed. Farmers have to be educated or consulting needed.	Wide use.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase the efficient use of water?							
Operative solutions for irrigation scheduling (when, where, how much irrigate)							
38	Crop load adjustment based on the actual water availability (setting up the correct crop load at the beginning of the season based on the water usually available in the cultivation site /area)	Late adjustment of crop load, i.e. removal of fruits if extreme conditions of water scarcity occur, in order to reduce the tree water requirements. Requires water supply on demand.	No further investments needed		Easy to manage	Training required or advisor	Israel, Spain
39	Supplemental irrigation: water applied only during droughts periods, particularly if coinciding with critical crop phases	Option for areas with limited or unreliable availability of water for irrigation. Target yield is not maximum yield under irrigation but lower yield.	Economic cost must be evaluated. Quality may be assured.		Less water used. Similar yield assured every season. Lower costs	May not economically viable	Wide. Recommended when limited water for irrigation.
40	Regulated deficit irrigation (RDI): applied water is assured when plant yield and quality are most sensitive to water stress, otherwise it is reduced.	Can also help to control excessive vegetative growth or to improve quality (higher dry matter content, soluble solids content, storability) Requires water supply on demand. Need for advanced technical support as high risk of negative effects on yields if not well managed.	No additional costs for using this approach.	Percolation and groundwater pollution can be avoided	Improved quality. Improved yield and water productivity	RDI protocols still under improvement/research. Need for advanced technical support to farmers and high risk to have negative effects on production	Orchards in Spain and Italy where water scarcity is already a problem. In UK fruit production in glasshouse and tunnels.
41	Tied ridges: micro-basins along the irrigated furrows or between row crops.	Increase infiltration rate; requires less irrigation depth. Capture of runoff; reduction of soil erosion. Time and energy consuming	Extra machinery needed.	Reduction of run-off.	Extra water supply tothe plants.	Requires specific machinery. Requires development for EU conditions.	Common in central pivot and furrow irrigation in USA and Asia.

		operation.					
42	Alternate furrow irrigation (AFI) or Partial root drying (PRD).	Little infrastructure required. Balanced vegetative and reproductive growths. Requires levelling. Nutrients leaching; water percolation.	Cheap.	Risk of contamination. Low energy use.Runoff is used downstream.	Cheap; easy to apply. Less water required. PRD can be successfully applied with drip and subsurface irrigation.	Requires adapting to local conditions. Not all species have been tested. Needs further research and documentation of benefits.	AFI in cereals in Asia. PRD in vines and trees in southern Europe.
43	Irrigation at night.	For sprinkler irrigation, less evaporation and less wind. Requires autonomy and remote control of irrigation.	Lower cost if energy at night costs less.	If system breaks, farmer is not present.	Possible lower costs if tiered tariff implemented.	Practical issues to move irrigation systems at night.	Where tiered tariff, cheaper energy at night.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase the efficient use of water?							
Cropping system							
44	Intensive high-tech vegetable production (productive seeds, soil amendment, localised and high frequency irrigation according to crop needs, mulching and, in some cases, the use of greenhouse).	High input use and high-related risk.	Requires high investment.		Improved crop quality and yield for high value horticultural crops. Interesting when pressure of water limitation has made it worthwhile in the medium term.	Expensive. Strategy needs to be adapted to each crop and each productive system. High skill demand.	Spanish and UK protected horticulture. In other regions, in orchard production, but less common.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase farm resilience under water scarcity?							
45	Natural water retention measures (NWRM): buffer strips, grasslands, terracing (may be combined with Agroforestry).	Increases infiltration and reduces runoff. Water in excess may be stored in small-scale reservoirs. Requires proper viability and environmental studies and high investment. Best measures are site and/or catchment scale specific.	Land not used for cropping. Very expensive when soil moved. May start with natural regeneration of species on boundaries, etc.	Reduce erosion. Requires complying with water resources regulation. Aquifer recharge.	Recommended in EU**http://www.nwrm.eu/**.	Cost; land not used for cropping. Culture. Expensive. Resistance to change. Relevance of income.	In Europe. Some trial work and small scale application in UK.
46	Desalinated water.	High potential applications along the coast. Requires more external nutrients application.	Very expensive, particularly if desalinisation is associated to traditional energy sources.	High energy/carbon costs.		Very expensive. High energy and more fertilisation costs (during desalination nutrients are also removed). Questionable at farm level.	Where access to saline water on-farm and to renewable energy. Only with highest value crops.
Diversification within farm to reduce risks							
47	Crop diversification within farm and within plot: • Agroforestry, association of woody perennials (trees, shrubs, etc.) with crops and/or livestock on the same land unit. • different annual crop species or cultivars.	Profit from spatial variation. Reduces the risk of failure when climate is too erratic. Complex management. Agroforestry requires farming systems approaches. Problems harvesting intercrops.	Expensive. Increased operational costs. High initial investment when planting trees.	Enhanced soil biota and improved soil structure. Can reduce yields of target crops.		Knowledge intensive. Hard to mechanise, also to harvest co-existing crops/cultivars at different time. Resistance to change. Relevance of income.	France. Dehesa well establish in Spain. Tree crop-pasture in Greece.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase farm resilience under water scarcity?							
Diversification within farm to reduce risks							
Others							
48	Involvement in networks, including water users associations	Access to knowledge and other benefits provided by network. Reduce yield gap or costs. Expensive to create and maintain networks. Difficult to promote.	Expensive unless network created already.		Support by network. Access to diverse knowledge and various benefits (e.g. low input price, higher product price).	Assistance. National legislation. Sometimes too heterogeneous.	Traditional irrigated areas. Schemes with active water users associations.
49	Involvement in training, skills development and awareness raising.	Simple and easy to adopt. Promotion of alternative techniques at operational level. More efficient use of irrigation equipment or improved crop management, etc. Time consuming.	Expensive or cheap. Strategic infrastructure may be needed. May increase economic outcome.	More efficient use of resources.	Multiple short and long term benefits. Water awareness and practical management can be included in "New Entrant Farmers" training.	Overcome inertia of current practices. Limited funding mechanisms, programmes, demonstration sites. Benefits may occur when training at catchment scale rather than at farm scale.	Wide. Some on line actions.
50	Insurance Contract.	Stablished in most countries. Requires understanding.	Cost depending on covered risks.		Needs high number of users. Partly co-funded.	Cost. Resistance to change Relevance of income	EU support.
51	Access to early warning systems (weather forecasting).	Medium and long range weather forecasting to help plan irrigation operations Limited reliability of most forecasts.	Purchase of locally accurate forecast. Variable, can be economic.		Needs a high number of users to make it cost effective.	Uncertainty. Risk of failure. Resistance to change. Relevance of income.	JRC-EDO.
52	Follow certification standards for efficient water use at the farm (water	Requested by many retailers, and standardised e.g. by Globalgap. Standards set can be difficult	Associated to costs. Added value to certificated products.	Reduced waste.	Consumer demand for sustainable production. High control of the	Certificates have different origins, but usually linked to industry.	Pepsico & UK farmers aim to reduce their water use by 50%

	efficiency, respect to freshwater biodiversity).	to attain.			production processes at the farm scale.		in 5 yr as part of their supply contract.
53	Payment of water according to volume used (multi-user electronic hydrants).	Simplify water distribution and water billing. Responsible water use by farmers. Logistics demanding.		Reduce farm water demand.	Supply water to authorised users. Canimplement tiered water tariff.	System established at scheme level. Out-farm regulation.	In many irrigation schemes in southern EU.

Annex 4: List of documented potential strategies

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase water availability for crops and livestock?							
P1	Capture runoff: a) Micro-basins: concentrate runoff in small areas (c.a. 1m^2) where a tree is planted or few plants are sown. b) Tied ridges. (Maintenance of residues recommended)	Capture rain and runoff. Inputs applied only in micro-basins. Time consuming to establish. Machine required for soil movement. Space between basins clean (erosion risk).	Expensive to make micro-basins; maintenance has low cost.	Avoids runoff. Less inputs. Initial SOM losses but accumulates afterwards if residues retained.	In arid and semiarid conditions assures water availability in growing points (micro-basins). Less inputs (only micro-basins cultivated).	Expensive. Time consuming. Not applicable to larger commercial farming unless machinery developed.	a) Semiarid zones: trees, annual crops. Sahel, Middle East, southern EU.b) Partly obliged from 2016 in Flanders.
P2	Conservation Agriculture: a) No-till direct drills and strip till drills able to deal with high amount of residues and adapted to heavy clay soils. b) Adapted annual crops (other than cereals) to conservation agriculture systems. c) Selection of more vigorous cultivars during crop establishment.	Improves water infiltration (slow runoff) and reduces evaporation losses. Increases SOM in superficial soil layers. Will contribute to crop diversification and viable rotations in Conservation Agriculture. Early ground cover protects the soil from erosion and reduces evaporation. Expensive. Knowledge and skills demanding. Requires extensive agronomic studies to fine-tune management. c) May use water too fast increasing risk of late drought.	a) Requires collaboration with machinery industry b) New crops normally with less economic return. Economic diversification of production. Requires seed companies interested.	Protects the soil. Risk of soil compaction of heavy soils Improves biodiversity. Rotations facilitate pests and diseases control. New crops must be examined for any weed and invasive behaviour.	Less energy (at the end of the balance) ↓ energy, ↓ costs Economic diversification of production. No tillage cost.	Very expensive (machinery). Weed control limited to contact herbicides. Long term results (time demanding). Needs extensive research and field trials. b) May result less productive.	USA, Australia. Some experiments in EU. New opportunities with “greening”. Except for cereals, few current major crops are adapted to CA
P3	Addition to soil of water retaining	Increases soil capacity to retain water and reduces	Zeolite: Low cost. Hydrogel: costly.	Zeolites improve soil structure and functioning.	In green houses or in pots.	Has to be mixed with top soil layer plus	Zeolite: USA Russia, EU.

	(hydrophilic) products, e.g. hydrogel, zeolite, biochar.	nutrient leaching. Synchronisation of plant nutrients requirements and soil nutrient availability.		More efficient use of nutrients. Can reduce soil erosion.	Biochar is a residue of an energy production process. Easy to apply.	hydrogel expensive. Applicable to high value crops. Research and demonstration needed.	Hydrogel: commercial products available in EU.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase the efficient use of water?							
P4	Drought resistant/tolerant cultivars: • Improved root system in selected crops.	Larger soil horizon explored by roots. Must meet commercial quality standards. Higher risk of late frosts.	High cost of breeding programme. Requires seed companies' and farmers' interest.	Improves biodiversity.	Effective once cultivar is obtained. Easy to understand and be adopted. No need to change the farmer behaviour.	Decades of effort/ investment on drought resistant cultivars with very limited success. Expensive breeding programme. Long termresearch/ solution.	
P5	Cultivars of spring-summer crops less sensitive to low temperatures (maize, sugar beet, sunflower, etc) toadvance sowing (earlier than spring or summer).	Cropping earlier in the season when evaporative demand is lower. Must meet commercial quality standards.	High cost of breeding programme.	Improves biodiversity.	Effective once cultivar is obtained. Easy to be adopted. No need to change farmer's behaviour.	Expensive breeding programme. Long term research/ solution. Requires seed companies' and farmers' interest.	
P6	Closing yield gap: • Identify poor management and how to tackle it using check points or benchmarks. https://rirdc.infoservices.com.au/downloads/08-005	More efficient use of resources. Requires training, guidelines and local calibration.	Cheap once guidelines are prepared.	Increases understanding on environmental impact of farming practices.	Easy to understand and be adopted. Increases knowledge on interaction between management and crop performance.	On-farm studies needed to fine-tune check points of rice and wheat to EU conditions and to identify check points of other crops.	Rice production in Australia (Ricechecks) and wheat in Asia &Africa.
P7	Use of TiO_2 to increase reflectance.	Increases radiation reflection and reduces leaf temperature and heat stress. Also for the photocatalytic treatment and reuse of water. Overdose may have adverse effects on transpiration.		Listed under WHMIS class D2A carcinogen.	Natural products (mineral origin),requires treatment.	Under development.	Japan.

Code	Name of practice/strategy	Agronomic aspects	Economic aspects	Environmental aspects	Success factors	Fail factors	Applied in:
Which strategies at farm level increase irrigation efficiency?							
P8	Irrigation scheduling: a) based on indices focused on the organ of economic interest; b) use of nanosensors; c) use of sap-flow; d) eddy-covariance, bowen ratio or surface renewal.	Allows more accurate and efficient application of water and other inputs. Possibility for automatic system. Difficult to define thresholds for water stress (can change with stem diameter, phenological stage, canopy development).	Depends on the parameter to be measured and on the sensor available.	More efficient use of resource inputs.	Global benefits for yield and quality of products. Demonstrations that they work. Increases understanding of crop water needs.	Questioned applicability and profitability. Difficult to manage. Research + training + good consult needed. Requires local models and thresholds to interpret data. Costly (price of sensor). Requires more user friendly sensors.	Widely used in research. High value crops. Sap-flow: potential use in tree orchards and vineyards.
P9	Precision irrigation: • Site-specific variable rate irrigation (VRI= considers spatial variability to irrigate less where more moisture is stored).	Profit from spatial variation. Identification and quantifications of field variability. Clear prescriptions for taking decisions required.	VRI: expensive irrigation system able to apply different rates over a given area.	Reduces leaching losses of nutrients and pesticides.	Reduced variability in production performances.	Research needed to define prescriptions for taking decisions. Requires training and good advisors. Questioned practicability and profitability.	VRI central pivots used in research in USA. Hard to use with drip irrigation unless designed specifically.
P10	Improved irrigation water managementthrough benchmarks in crop productivity and irrigation performance.	Provides local references for potential productivity and irrigation performance. Increases productivity. Requires good methodology to determine comparable benchmarks.	Benchmarking costs.	More efficient use of resources.	Increase farmers' and advisors' knowledge. Aid target policies.	Research needed. Requires tools to identify reasons for producing below benchmarks.	Some research in Southern Europe.
P11	Optimisation of the time of irrigation (during the day).	Water provided when hourly water stress most damaging, particularly in sandy soil limited capacity to store water.	No additional costs.		Results will highly depend on the crop and soil.	Research needed to determine the actual best time for irrigation according to crop physiology	Most interest for sandy soil. Drip and subsurface irrigation.

		Requires autonomy / remote control of irrigation.				(not necessarily at night).	
Which strategies at farm level increase farm resilience under water scarcity?							
P12	Construct wetlands on-farm as multifunctional ecosystems e.g. water storage during wet periods and pasture lands during dry periods.	Stored water for different uses. Increase pasture yield in dry periods. Point and non-point source pollution control, water reuse potential. Takes land out of production. Lower total yield per hectare. Quality of pastures may be reduced.	Expensiveunless favoured by landscape. Requires good design and hydrological study.	Increases biodiversity. Increases emission of NO2, may decrease soil quality. Aquifer recharge.	Biodiversity, ecosystem services Valorisation if in marginal land. May provide secondary benefits as training/recreation areas.	Quality of pastures. It takes land out of the production. Pests and weeds control.	Initial tests in Italy by kiwi growers. Pilot cases for water treatment and reuse on-farm in Greece.
P13	Innovative use of plant residues for water treatment on-farm (decontaminate water effluents polluted with inorganic/organic contaminants).	Use of crop by-products. Seasonality due to fruit peels availability (only for de-pollution of inorganic contaminants).	Cheap/Low cost.	Positive effect on water quality. Possibility to reuse water for agricultural purposes.	Environmental friendly. Easy to adopt. Circular economy and waste reduction. No training and special machinery is needed.	Research needed to optimise the two-step process.	Effluents from fish and animal farms and farm waste water.
P14	Creation of new innovative solutions / technologies based on research for improving: a) On-farm water recycling systems; b) Use of saline water.	New solutions. If appropriately processed, it may reduce needs of mineral fertilisation inputs. Unknown solutions. Time consuming. Water quality needs to be closely monitored.	High investments to develop prototypes/ technology. A water distribution system is needed.	Depends on possible solutions Need for energy. Strict regulations on quality thresholds.	Develop prototypes. More water available. Stable source of water.	Searching for new unknown solutions. Expected result can be negative. Long-term, high investment. Strict regulations; environmental legislation. Consumers fears. Risk of pollution.	Potential for high value crops.
P15	(Reduce) fruit (quality) standards to reduce irrigation water consumption.	Higher fruit dry matter content, major storability. Simple to be adopted by growers. Lower fruit diameter, less	No additional costs. Requires consumers' acceptance.	Poor soils may limit the applicability of the strategy.	Not driven by farmers. Easier if production for industrial purposes. Reduce waste.	Appropriate irrigation protocols still to be developed for different species/environment	Locally limited.

		production.			Simple to adopt.	s. Introduce new quality standards. Requires consumer acceptance.	
P16	Farmer's reactions to: a) Water governance (measures that benefit farmers that have reduced water consumption; incentives to invest in water scarcity). b) Water footprint. c) Water pricing flexibility to encourage peak flow capture.	a) Legislation that builds farmer confidence to invest in changes. Fostering awareness and cooperativism. b) Marketing link (Ethical water). Could be associated to the certification. Can support decision making at farm level and policy planning. Logistics demanding.	a) High cost. b) Cheap to calculate. May effectively contribute to water pricing decisions (WFD) c) Peak flow water is lower cost to encourage its capture and storage, but high capital cost of storage.	a) May be combined with environmental protection. Water Framework Directive (WFD). b) Increasing consumer and political recognition of sustainability issues.	Voluntary collaboration may be more effective than regulation. Opportunities for multi-sector approach to water stewardship at catchment scale. Public pressure. b) Greater recognition of water use in the whole food supply chain. Food supply chain has to support.	a) Individualism. Complicated if rights to water amongst competing users are poorly defined. b) Complicated calculation. Research needed. c) Pricing system can be complicated. Must compile with catchment regulations.	Being developed in the UK. b) Used in UK by Pepsico.

Annex 5: List of research needs from practice

For most strategies, their effectiveness conserving water at farm level and their economic return are unknown.

Nº	Improvement of	Strategies	Research needed
1	water availability	Conservation Agriculture (minimum soil disturbed + residues maintained + crops rotated)	For local conditions, evaluate for water conservation and water productivity, in the short and long terms. Participatory field testing and research on A) no-till & strip till drills adapted to high amount of residues and heavy clay soils; B) adapted annual crops (other than cereals) to CA; C) selection of better adapted cultivars to CA; D) long term experiments to evaluate evolution of soil quality.
2	water availability	Ground covered and increased soil organic matter (water holding capacity) by: A) residues retention; B) external application of mulch; C) cover crops; D) crop rotation; E) good tillage practices.	Field testing, short and long-term research (the last for increasing soil organic matter and improved crop rotation). Evaluating practices for water conservation and cost-benefit in different cropping systems and environments. Identifying appropriate machinery.
3	water availability	Increasing soil water holding capacity by adding water retaining products	Finding locally available sources of materials and evaluating performance of products and cost-benefit.
4	water availability	Improved root system in cultivars & rootstocks	Changing the focus to find tolerant varieties (crops and trees). Characterise rooting ability and evaluate benefits for local conditions.
5	water availability	Deep soil loosening / reduce soil compaction	Identify best tillage practices and management. Evaluating impact on soil quality and long term effects. Evaluating cost-benefit.
6	efficient use of water	Benchmarking of efficient use of water to identify the most and least efficient strategies for specific conditions.	Focus of the research on the analysis of the biological, environmental and socioeconomic conditions that lead to high or low values. Set benchmarks for local conditions
7	efficient use of water	Matching the crop and the rain: A) cultivar cycle; B) crop modelling to define agro-ecological zones	To extend online tools (existing for climate + extend with soil, different crops + integrate in the tool)
8	efficient use of water	When non-limiting light irradiance, use of shading nets to reduce radiation, temperature and water use	Evaluation in different cropping systems and define the optimal shading level. Evaluation for water conservation and cost-benefit.
9	efficient use of water	Hydroponic green fodder production	Fine-tuning vertical closed cycle hydroponic green fodder systems. Evaluation for water conservation and cost-benefit.
10	irrigation efficiency	Use of indices or plant-based sensors (nanosensors; sap-flow; dendrometers; fruit gauges) and decision support systems for irrigation scheduling	Physiological understanding and modelling of the various parameters monitored. Improving sensor robustness and friendly use; and reducing cost. Evaluating cost-benefit. Developing decision support systems (plant based / orchard). Calibration for different species and conditions.

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11	irrigation efficiency	Irrigation protocols aimed at minimising the impact of the stress, while maintaining yields or improving crop quality: A) regulated deficit irrigation protocols; B) diurnal modulation of water supply. This can be accompanied by online expert systems.	Their range of use needs to be widened and adapted to different crops based on the physiological behaviour and irrigation needs of each species. Defining clear prescriptions for taking decisions. Testing in different pedo-climatic conditions. Evaluation for water conservation and cost-benefit.
12	irrigation efficiency	Precision agriculture and site-specific variable rate irrigation (VRI). This can be accompanied by remote sensing.	Defining clear prescriptions for taking decisions. Development/improvement of irrigated systems that allow applying water differently in space. Need for more accurate remote sensors and improved; New sensors, drones, data elaboration and connection with the irrigation system. Evaluation for water conservation and cost-benefit.
13	farm resilience	Construct wetlands on-farm as multifunctional ecosystems	Short term research – small scale wetlands – socio economic research.
14	farm resilience / water availability	Use of alternative water sources	Field testing and long-term research to study the effect on soil quality, crop productivity and quality, feed conversion, macrobiological consequences, food safety (microbiological), impact on fresh water resources. Evaluation cost-benefit.
15	farm resilience	Use of poor quality water and new innovative solutions for improving it or managing: A) water recycling systems; B) use of saline water	Applied research. Determination of detrimental effects of salinity stress on woody plants productivity.
16	farm resilience	Crop diversification within farm and within plot. New crops/cultivars, including aromatic and medical plants.	Evaluation of agronomic suitability of new crops/cultivars and their impact on farm water conservation. If irrigated, identification of the necessary irrigation water in response to species, phenological stage, soil quality and climate. Socio economic research.

Annex 6: Suggestions for Operational Groups

Nº	Improvement of	Strategies	Operational Groups
1	water availability	Conservation Agriculture (minimum soil disturbed + residues maintained + crops rotated)	Adapt methods to local conditions and cropping system; Survey impact on soil quality; Analyse long term experiences on CA in different areas and cropping systems in order to demonstrate to farmers the importance of well-founded agronomic practices on soil fertility and yield stability over years.
2	water availability	Increase soil organic matter (water holding capacity) by maintaining soil ground covered: A) residues retention; B) external application of mulch; C) cover crops; D) crop rotation; E) good tillage practices.	Develop special machinery; Production of compost on farm from either farm or other sources; Study agroecological services of cover crops (explore possibility of taking advantage of local agrobiodiversity); Reviewing on farm practices which enhance natural soil processes such as porosity or humus formation; Test these technologies in a range of field situations (soil, climate, crop rotation, residues, fertiliser use,...) to develop local protocols. Testing techniques on 5 to 10 farms and monitor evolution and impact, including economic effects.
3	water availability	Soil amendments	Study the economics of soil amendments with farmers to identify those that produce the best returns. Test these technologies in a range of field situations to develop protocols.
4	water availability	Reduce soil compaction	Developing innovative methods to reduce soil compaction in intensively managed soils (crops and livestock farming).
5	water availability	Improved root system in cultivars and rootstocks	Improving rooting conditions.
6	water availability	Controlled drainage systems Groundwater as alternative water resource	Assess the effect of controlled drainage (increased groundwater level) on water availability and soil water holding capacity during dry periods. Find the most effective controlling /regulating periods and distant mechanisms required by farmers.
7	efficient use of water	Improved *Brassicaceae* cultivars	Evaluation of *Brassicaceae* cultivars for resistance/tolerance to biotic and abiotic stresses (water and salinity).
8	efficient use of water	Crop suitability index and improved crop rotation	Crop suitability indexing utilising agricultural statistical data, climate data and crop models. Improved yield and reduced irrigation by improving crop rotation (farmers).
9	efficient use of water	Early sowing of spring-summer crops less sensitive to low temperatures	Test cultivars resistant to low temperatures during crop establishment; evaluate if the resistance is independent of photoperiod. Operate directly in the farm, following good agricultural practices, in collaboration with researchers. Include seed companies.
10	efficient use of water	Closing yield gap: Identify poor management and how to tackle it using check points or benchmarks	Social innovation project.
11	irrigation efficiency	Improved irrigation management through benchmarks for crop productivity and irrigation performance	Assessing tools for irrigation and crop management; developing irrigation protocols with consultancy help.

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12	irrigation efficiency	Optimisation of irrigation with crop water balance and soil sensors, supplemental irrigation or adopt regulated deficit irrigation (RDI) to maintain/increase yield or quality	Integration of sensors with other tools for better representativeness; Cost /benefit analysis; Fine-tuning, long-term field testing and demonstration. Determine RDI protocols to increase fruit dry matter concentration in kiwifruit with acceptable size; requires high level of technical expertise from the grower; a decision support tool providing irrigation advices based on monitoring fruit growth and environmental conditions, would represent a key added value.
13	irrigation efficiency	Precision irrigation accompanied by remote sensing.	Tomato and maize with high quality reducing water consumption (farmers, researcher, advisors). Test innovative sensors, transportable by drones, for mapping the physiological state of the crops. An IT platform can be developed for data processing to obtain a variable-rate irrigation advice ("map of irrigation"). Develop a control system.
14	irrigation efficiency	Site-specific variable rate irrigation (VRI)	Prescription of the practicability and profitability
15	irrigation efficiency	Knowledge and technology transfer of best irrigation practices to the end users	Calibrate and test user friendly DSSs for local condition to provide irrigation recommendations, based on current systems. In this sense, an operational group with different irrigation actors should be developed including scientist, knowledge and technology transfer specialists, end-users and private companies related with the consulting and irrigation technology sector
16	farm resilience / water availability	Use of alternative water sources	Match water treatment (water quality, quantity) to the cropping system. Technical and economical optimisation of the management of wastewater treatment systems.
17	farm resilience	Use of poor quality water and new innovative solutions for improving it or managing: A) water recycling systems; B) use of saline water	Define the best options considering the tolerance of crops at different growth stages. Water quality: How to avoid/minimise contamination problems (ground and surface water).
18	farm resilience	Crop diversification within farm and within plot. New crops/cultivars, including aromatic and medical plants and wild cornel.	Demo projects to show benefits. Dissemination. Optimisation of irrigation and crop management of new crops. Mapping autochthonous populations of wild cornel (*Cornus mas*), evaluation of ecological and physiological characteristics and product quality, identification of suitable areas for competitive cultivation, socioeconomic evaluation.
19	farm resilience	Farmer's reactions to: A) Water governance; B) Water footprint; C) Water pricing flexibility.	When cross-borders groups are permitted (H2020)

Annex 7: List of Case Studies

Available on **https://ec.europa.eu/eip/agriculture/en/content/collaborative-area-focus-group-water-agriculture-adaptive-strategies-farm-level-0**

"*Misión Posible*" (=field visit)	Guido Schmidt
Using alternative water sources for livestock	Dominique Huits
An irrigation strategy for East of England	Paul Hammett
Hydroponic green fodder production technology	Laima Taparauskiene
Wastewater reuse for quality crop production	Paolo Mantovi
UE Agritech Water Cluster	Martin Collison
Taxation and financial incentives/supply chain	Martin Collison
Water conservation through traditional land use practices of the Mediterranean	Dimos Anastasiou
Soil/water variable mapping & distribution in an app format	Dimos Anastasiou

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eip-agri
AGRICULTURE & INNOVATION

The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as through the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

More details on EIP-AGRI Focus Group aims and process are given in its charter on:
http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf
More information: EIP-AGRI brochure on Focus Groups

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