EIP-AGRI Focus Group Water & agriculture: adaptive strategies at farm level

DRAFT DISCUSSION PAPER
Version 17 JUNE 2015

Helena Gomez-Macpherson, EIP-AGRI Service Point

Contents

funded by European Commission

1. Introduction

Water is an essential resource for crop and livestock production. Climate change is generating variation in rainfall forcing farmers to rethink how to produce their crops, breed their animals or manage their farms. To counter negative impacts of climate change on agriculture due to water scarcity, management strategies at the farm level need to be identified. It is also needed to establish channels and mechanisms to make this information available so that farmers can adapt their businesses in economically viable ways. Going beyond the "easy" solution of using more water for irrigation and livestock, this Focus Group will collect innovative approaches and adaptive strategies to counter water scarcity at farm/local level and discuss the related challenges and opportunities.

The aim of this Focus group is to discuss these issues in the specific context of the EIP-AGRI – a new policy instrument for 2014-2020 that aims to stimulate innovation and seek practical solutions to practical on-farm problems by bridging the gap between the practice and science of agriculture.

The specific objectives of the Focus group are:

- Make an inventory of competitive farming management practices and strategies which are currently available and/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?

- List promising alternative and cost effective, competitive (novel) crops and/or cropping/livestock/agricultural systems able to deal with water scarcity.· Assess the potential for soil and landscape management to improve water holding capacity.

- Identify the success (or the fail) factors (financial, environmental, societal…) concerning the transferability of adaptive strategies beyond the farm/local boundaries as well as to farms in different European regions.

- Identify needs from practice and possible gaps in knowledge on particular issues concerning adaptation(s) to water scarcity which may be solved by further research.

- Identify the main challenges farmers have to 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? What active role for extension services, training systems, information campaigns? Who shall initiate an "adaptation strategy"? What role for the (innovative) farmer? Can advisors play a role? How/when can they provide support?

- Proposing potential innovative actions to stimulate the knowledge and use of adaptation measures/strategies to water scarcity and to multiply positive effects within the agricultural sector.

- Proposing directions for future research work, and

- Proposing priorities for relevant innovative actions, including practical ideas for EIP-AGRI Operational Groups.

The Focus Group will start addressing the first five tasks, mostly around identifying and describing strategies or practices. The remaining tasks, mostly around improving adoption, will be addressed after the Rome meeting.

funded by European Commission

The purpose of this discussion paper is to:
- Establish a common understanding about the purpose of the Focus Group;
- Provide the background on water functions and paths at crop and farm level, particularly under water scarcity conditions;
- Provide an overview of current and potential adaptive strategies at farm level for reducing the impact of water scarcity on farm productivity, taking in consideration on-line contributions of Focus Group members;
- Identify key questions for discussion at the first Focus Group meeting.

2. Agriculture and water scarcity

Water shortage is a major abiotic factor limiting crop and livestock productions in Europe and its incidence is expected to increase with climate change, particularly negatively in southern Europe (Falloon and Betts, 2010). Areas in the Mediterranean are likely to suffer higher temperatures, more rainfall variability and greater frequency of extreme events (IPPC, 2007). The arid regions face the double burden of less and more erratic rainfall, and higher temperatures that surpass the threshold limits for major staple crops. By contrast, positive impacts are expected in northern Europe with climate change, particularly increased water supply and reduced water demand (Falloon and Betts, 2010). Apart from the geographical location, the impact of climate change on farm production will also depend on farm characteristics and on farmers' capacity to change management and adapt to new conditions (Reidsma et al. 2010).

Water sources for crop production at the farm are rainfall and irrigation (Figure 1). Rainfed crops grow mostly during the rainfall season, but can grow also from stored water in the soil during the dry season. Water is essential to extract nutrients from the soil and transport them to the rest of the plant where growth is taking place. Water is evaporated from the plant into the air through the stomata (**transpiration**) through which CO_2 is absorbed to store carbohydrates (photosynthesis) and grow. The hotter, drier and windier the air is (higher evaporative demand), the faster the water is lost through transpiration. Not all rainfall is 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.

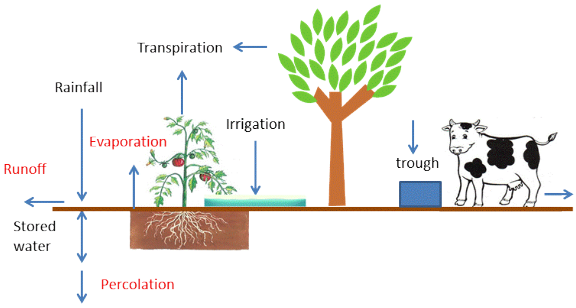

Figure 1. On-farm water components to be considered in adaptation strategies to water scarcity.

The damaging effect of a drought period will depend on its duration, on how much water is stored in the soil and the proportion that the crop can access, how fast it is used or lost, and the crop developmental stage at that time. Time scale of faced droughts of interest for farmers includes weeks to months, cropping season or years. Farmers can change the management of their systems to reduce drought impacts in the production e.g. adopting strategies to reduce runoff or percolation. However, fear of extreme events can lead to over conservative management that may reduce the opportunity to capitalize good years. Merging the on-farm experience with improved understanding of when crop grows and how much the weather impacts yield is the first step to reliable improvement in yield through adapted management.

funded by European Commission

Previous studies have identified venues for reducing 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 coincide with those propose 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 climate change scenarios in the future (Turral et al. 2011). Proposed actions go from molecular transformation of crops (e.g. transform rice plants into C4 plants) to the construction of new irrigation infrastructures (organizational solutions). **This paper focuses 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. Strategies at molecular to plant level are not discussed but some aspects are mentioned when referring to cultivar type chosen by farmers. Strategies dealing with irrigation at scales above the farm are not included either.

3. What are we searching for at farm level?

Water scarcity occurs when there is an excess of water demand over available supply. In this document, water scarcity at farm level refers to excess of water demand over availability supply to produce agriculture outputs. Under these conditions of scarcity, **farmers' common objective is using available water most productively and profitably without damaging the environment**. Farmers have to comply with water resources and environmental regulations.

Relevant farm outputs are crop yield, biomass, oil protein or calories and can be expressed as mass (kg/ha), energy (MJ/ha) or economic units (€/ha). **Water productivity** is defined as the ratio of output and unit of used water (kg or MJ or €/m^3; kg or MJ or €/ha/mm); and **irrigation efficiency** as the ratio of output and unit of supplied water. **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. Both plot water productivity and irrigation efficiency contributes to farm water productivity.

Attention: Water productivity estimates on its own may not provide enough information for understanding the impact at farm level (Wichelns 2014; Hall et al. 2014). For example, high values of water productivity as a result of low water used in transpiration can result in small plants, yield penalty and low economic returns (Blum 2005). The efficiency at one scale (leaf) may disappear at another scale (crop). Similarly, high irrigation efficiency in one farm may not be effective at scheme scale (Berbel and Mateos 2014).

Attention: Studies on water productivity in farmers fields have shown that often yield is affected by other factors than water in both rainfed and irrigated conditions (Angus and van Herwaarden, 2001; Grassini et al. 2011; Grassini et al. 2015). Figure 2 shows that reported yields in districts are well below the expected yield if water was the sole limitation. Understanding the causes of this yield gap is necessary before designing any strategy. Poor crop management, e.g. poor weed control, results in less available water and nutrients for the crop. On the other hand, part of this yield gap may be due to farmers' strategies to minimize risks as discussed in Section 2.

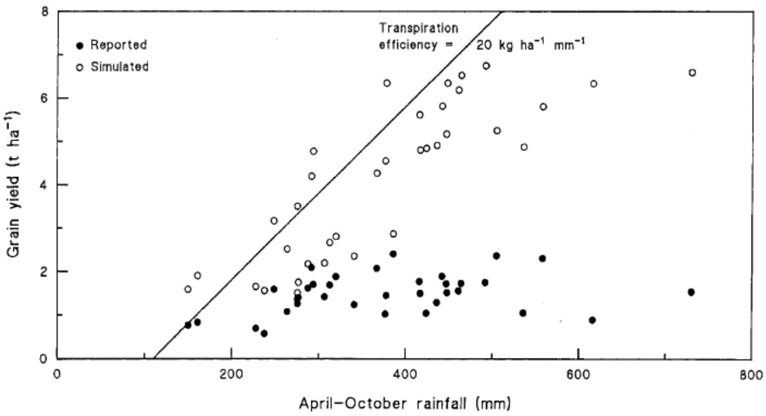

Figure 2. Reported wheat yield in relation to growing season rainfall and simulated yield with crop model in Wagga Wagga, Australia (Angus and van Herwaarden, 2001).

funded by European Commission

Because of the close link between water used and biomass produced by the crop, the most effective adaptation strategies aim at **maximizing water availability**. Other strategies focus on **using the water more efficiently** or on **increasing farm resilience under water scarcity.** The first two approaches focus on plot scale while the third profits from farm characteristics. Improving management and **closing the yield gap** is transversal to the three. Rainfall provides an important part of the water consumed by irrigated crops and most strategies increasing water availability and efficient use of water will probably applicable in irrigated conditions. There are, however, some strategies only applicable to irrigation systems.

Attention: The adaptive strategies will differ in effectiveness, viability, associated risks (including environmental risks), associated benefits (e.g. ecological services) and economic efficiency according to local conditions. At the farm, any change in management has to consider effects on water quality and the trade-offs with other system components (e.g. fertilization) and with related energy and cost savings. Furthermore, in rainfed agriculture, rainfall variability is the main cause for the annual farm income variability and farmers are reluctant to make changes unless benefits are clearly observed.

4. Existing strategies at farm level

4.1 Which strategies at farm level increase water availability for crops considering rainfall as the sole source of water?

In general, strategies intended at increasing water availability in rainfed conditions will benefit also productivity in irrigated systems as rainfall provides part of the water consumed by irrigated crops. To increase availability, strategies will either aim at reducing water losses by reducing runoff, drainage and/or soil evaporation, or at increasing the capacity to store the water that may be used by the crop.

a) How to reduce water losses?

Any management strategy that increases soil water infiltration (and therefore reduces runoff), or that reduces soil evaporation, will increase water stored in the soil, provided it is not lost by percolation or drainage. These strategies include:

- Conservation agriculture (defined as a combination of minimum soil disturbance, maintaining of residues on the ground and crop rotation) results, on one hand, in the increase of water infiltration into the soil, and on the other, in a reduction of soil evaporation thanks to the residues cover. No-tillage by itself may have the opposite effect (soil sealing/compaction and higher runoff) and should be accompanied by stubble retention (Brouder and Gómez-Macpherson, 2014). Many farmers, however, sell the residues for extra cash. Crop establishment in undisturbed soil and through residues is a major challenge and specific drills are required. (*See Practice 1 in Annex 1*).
- Stubble retention / mulching by itself reduces soil evaporation (Hatfield et al. 2001). Stubble may be retained until just before sowing when it will be incorporate into the soil during seed bed preparation. Stubble is quite effective retaining snow. Mulching within tree rows can be practiced in orchards also.
- Early ground cover after the break of the rainy season reduces soil evaporation in similar way than mulching. Early ground cover can be obtained by sowing early, dry sowing, seed priming (pre-soaking seeds to enhance germination), sowing cultivars with early vigor or optimizing plant density-plant arrangements through crop, cultivar, establishment and fertilization management (Passioura and Angus 2010; Fletcher et al. 2015). On the other hand, lower plant density results in more water per plant and is tactic option often observed in the field.
- Deep tillage may be required to increase water infiltration if a hard pan is present in the field (Chamen et al. 2015). In these cases, deep tillage will also favor root growth into deeper layers.
- Crops or cultivars with deep root systems will reduce the risk of losing water by drainage (*See Practice 8 in Annex 1*). Agroforestry may combine annual crops with permanent species of deeper root system.

- Effective weed control prevents the use of water by the competitive plants and also results in more soil explored by crop roots. There are GMO roundup-ready species (not approved in Europe) that facilitates weed control.

b) How to increase soil stored capacity of water and how to improve access to that water?

The stored available water content depends greatly on the soil texture and structure. The texture is fixed but the structure can be improved by increasing soil organic matter or by reducing soil compaction. Additionally, there are products in the market that can absorb more water than the soil. Strategies that improve the rooting system will improve access to the stored water. These strategies include:

- Soil tillage promotes soil organic matter degradation; thus, conservation agriculture, as defined above, has been shown to increase soil organic matter. Crop residues, together with roots, are the main source of carbon and nutrients for the microorganisms.
- Water retaining hydrogel will increase soil capacity to retain water. There are commercial products available in the market (*See Practice 6 in Annex 1*).
- Controlled traffic will restrict soil compaction to the zones where wheels pass leaving the space in between wheels with higher soil porosity to fill in with water (Chamen et al. 2015). Additionally, less compaction favors root growth to colonize the soil.
- Crops differ in rooting ability to colonize the soil and reach water in deeper zones. This applies also to rootstocks of perennial crops (*See Practice 8 in Annex 1*). The thicker the root zone, the more water available to the plant.
- A plot may not be cropped during one season (fallow) to store water rainfall of that season in the soil (Cantero et al. 1995). Part of this water will be available the following season. Its efficacy depends mostly on soil water holding capacity and has an added benefit of some more nitrogen available. Nowadays, fallows are common only in the driest environments. Whenever possible, fallows were substituted by cropping with improved systems.

4.2 Which strategies at farm level increase the efficient use of water when rainfall is considered the sole source of water?

These strategies aim at increasing crop production given the available water and, as for the strategies presented in 4.1, they may apply to rainfed and irrigated systems. For a given season, farmer's first decision is which crop and cultivar to grow. Then, several management decisions will follow aiming at a good crop establishment, growth and harvest with less costs and lower risks as possible.

a) Are there crops or cultivars with intrinsic higher water productivity?

For the last decades, there have been strong research programs for identifying and incorporating traits that confer drought resistance into cultivars. Few traits, however, have shown an impact at crop level. A major critic is that most studies are done in pots that do not reflect field conditions.

- Nevertheless, some traits 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 (photosynthesis is maintained as senescence is delayed at the end of the crop cycle); low discrimination against Carbon 13 during photosynthesis (closely link to CO_2 assimilated per unit water transpired) in wheat grown on stored water; osmotic adjustment (solutes accumulate in cells under drought stress) in wheat can maintain plant growth and increase yield; short anthesis-to-silking interval (ASI) in maize.
- The metabolic pathway of photosynthesis makes C4 plants (e.g. maize or sorghum) have higher water productivity than C3 crops (e.g. wheat, rice or beans). However, C4 plants are mostly tropical and have a higher optimum growth temperature than temperate crops. Thus, they are commonly cultivated in summer and require irrigation.

funded by European Commission

- The conversion efficiency of sugar into grain ranks in this order: cereals > pulses > oilseeds. This reflects the differences in energy content of the seed and differences in water productivity when grain yield is considered the output of the system. For example, it explains in part why grain yield of faba beans is lower than wheat yield in the same environment.
- Less sensitive-to-drought cultivars, crops and livestock are better adapted to drier environments. Barley, olives and goats may dominate drier environments while fruit orchards, maize, vegetables and cows may dominate wetter environments.

b) Which management options will help to use water more efficiently?

Management options can aim at improving system productivity, at adapting to the season (tactical decisions), at growing the crop when the water is "cheaper" or at modifying the crop environment to use less water.

- Any improvement in crop, pasture and grazing management and feeding, or in crop and animal health, that increases system output will increase water productivity:
    - Improved crop sequences that result in an overall increase in production also improves water productivity (*See Practice 13 in Annex 1*). The inclusion of grain legumes or oilseeds crops will benefit the following cereal crop in certain conditions by fixing some nitrogen or reducing soil diseases;
    - Tactical management to adapt to the season and profit from best years (higher rainfall than average). Depending on the development of the season and the potential yield, farmer can decide on applying nitrogen or other treatments. Calibrated crop models to local conditions help to take these decisions. Mating time or mating populations can be programmed based on seasonal conditions and forescast.
    - If the break of the rainfall season is delayed, farmer can sow a cultivar of shorter cycle.
- Farmer may increase water productivity by choosing the specie/cultivar or by improving crop management, however, there is an interaction between cultivar and management so that some combinations potentiate the results. For example, a good performing cultivar shows its potential when fertilizers are applied properly and pests, diseases and weeds are controlled.
- 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 yield per unit of water used (*See Practice 14 in Annex 1*). Furthermore, matching the cropping season to the rainfall season reduces the water losses via evaporation, runoff and deep percolation. Matching the crop and the rainfall season requires first the characterization of the rainfall and temperature pattern and soil capacity to stored water: break of the season (first significant rainfall), length of growing period, and risks of early, medium and late droughts and intensities. This will help to understand the likely limitations to specific crops in degree and time. Direct seeding allows more timely and flexible sowing as no time is required for soil preparation. *How to characterize the prevailing environment and droughts and how to match the crop?*
- Shading nets or east-west orientation of orchards and vineyard rows (*See Practice 15 in Annex 1*) to intercept less radiation, but above light saturation, will improve transpiration efficiency.

4.3 Which strategies at farm level increase water availability for irrigation / animal drink or which strategies increase irrigation water efficiency?

In irrigated agriculture, water scarcity concerns water availability and reliability and its sustainable use. Strategies specifically related to irrigation and dealing with water scarcity includes increasing water supply and reliability, choosing the irrigation system, maintenance of current irrigation system, improving uniformity of water distribution and of application efficiency (Pereira et al. 2002; Playan and Mateos 2006). Some of these options apply to water resources for animal drink.

funded by European Commission

a) Which strategies could result in increased water supply?

- Development of new sources of water (*See Practices 17 and 18 in Annex 1*): treated water, drainage water or harvested water. Treatment of waste water is necessary to avoid health hazards (there are international standards) and have an economic cost. The quality of drainage water may not be good enough to be reused in cropping or drinking.
- Access to underground water by constructing wells under the supervision of water authorities. Dynamic private wells are available in Flanders region. (*See Practice 20 in Annex 1*).
- Reduce water losses in irrigation systems and animal drink systems through maintenance and renovation (*See Practice 21 in Annex 1*).
- Reduce water losses by runoff and percolations. In sprinkler irrigation, distribution uniformity and water depth should be appropriate to cover crop water demand within irrigations but avoiding runoff and percolation. Similarly, in flood irrigation, distribution uniformity and water depth should be establish to minimize deep percolation. Aerobic rice (grown without continues flooding) requires less applied water than continuously flooded rice.
- In subsurface irrigation, soil water evaporation is avoided while uniformity is very high.
- Plastic mulching to establish spring crops reduces water evaporation and increases soil temperature and plant growth when temperatures are still low.

b) Which management options increase irrigation efficiency?

Irrigation efficiency may increase by improving distribution uniformity and/or application efficiency. In the last decades, modernization of irrigated systems at farm and scheme levels has increased irrigation efficiency significantly (minimizing losses and improving uniformity) but, rather than resulting in more reliable annual allocation (the general objective), the saved water had resulted in an expansion of the irrigated area (Berbel and Mateos, 2014).

- Irrigation systems differ in distribution uniformity and application efficiency (*See Practices 22 to 26 in Annex 1*). In general, flood irrigation has the least uniformity and the higher drainage losses. Furrow irrigation improves the distribution uniformity (even more with intermediate dikes) but often below those obtained with sprinkler or drip systems. On the other hand, furrow irrigation consumes less energy. Distribution uniformity can be measured on farm, and causes for low values, corrected.
- Laser levelling is the best approach to improve distribution uniformity in flood and furrow irrigation systems. Sprinkler and drip irrigation systems can be used in sloppy land.
- Less water than that required for maximum production with full irrigation can be applied:
    - Supplemental irrigation is applied in rainfed systems during a drought period. The production target corresponds to that produced in an average rainfall year.
    - In deficit irrigation, less water is applied during the less drought-sensitive phenological phases of the crop (Fereres and Soriano 2007). The system has maximum production as target. It is used in irrigated orchards. (*See Practice 31 in Annex 1*)
    - Alternate furrow irrigation improves water productivity in crop rows.
- Irrigation scheduling must match crop requirements during the growing season (for yield and quality) while minimizing 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: soil sensors, water balance, models, setting the crop load. (*See Practices 27 to 29 in Annex 1*)
    - In sprinkler systems (rain-guns, central pivots, lateral move system and set of sprinkler systems), irrigation uniformity depends largely on system's characteristics.
- Intensive optimized vegetable production under protected structures (*See Practice 30 in Annex 1*): high farm income / high quality products where a market is assured.

funded by European Commission

4.4 Which strategies at farm level increase farm resilience under water scarcity?

In this section, strategies profit from within farm spatial differences and current yield gaps. Large farms have more scope for zone diversification. Large farms can afford also their own equipment and timely operations.

- Agroforestry and landscape elements can be designed to reduce and capture runoff. When water is in excess, water may be stored in small-scale reservoirs (*See Practices 36 in Annex 1*). These strategies require complying with water resources regulation.
- Strategies may aim at reducing risks of failure:
    - Crop diversification within the farm reduces the impact of failing with one crop. Similarly, crop diversification within the plot (intercropping) reduces the risk of failure when climate is too erratic.
    - When water irrigation allocation (the amount of water that a farmer can use that year for irrigation) is not reliable, part of the farm can be dedicated to rainfed crops (or crops requiring supplemental irrigation) so farmer can assure optimum irrigation of higher income crops.
    - The best soils within the farm can be allocated to most productive crops while the poorer areas can act as buffers.
    - Early-warning systems regarding weather hazards help farmers to plan according. For example, to decide allocation of crops within the farm or to decide of treatments applications.
    - Insurances are generalized in most European countries.
- Identifying reasons for yield gap due to lack of technical knowledge or limited access to information. These causes are different to poor management (fertilization, pest control, un-adapted genetic material, etc) as a result of poor farmer performance or of risk aversion decissions. Farmers can obtain useful technical, environmental and economic information and training from Water Users Associations to close this knowledge gap. Public or private advise services (in situ, on-line servives, cell phone services …) can also fill this gap.

5 Questions to the currently existing strategies

There are no systematic on-farm evaluations of current practices for their "effectiveness" increasing water productivity. The impact of some strategies can be assessed through the application of hydrologic principles, water balances or other models if they are calibrated for local conditions. Nevertheless, the evaluation of the effectiveness will often require understanding the impact at higher scales (irrigation scheme and watershed).

There are limits to the improvement of water productivity on farm, not necessarily associated to water scarcity. There is a need to know these limits in order to avoid useless efforts. Benchmarks for water productivity are realistic references that can be considered as objective for farmers. For example, local benchmarks could be values of water productivity or irrigation efficiency obtained by the best local farmers.

Economic and environmental risks associated to any strategy must be well understood and evaluated for resulting viable options. These risks may vary between socio-economic and environmental conditions. Ideally, strategies should not result a burden for farmers in term of labor or large capital investments nor should they damage the environment.

Discussion questions:

- How common are the above mentioned strategies found in European farms? In other continents?
- Which is the best method to measure and compare the effectiveness of proposed strategies for water conservation? Is the impact diluted at irrigation scheme or watershed scales?
- How to ensure that higher water productivity strategies are attractive to the farmer? that economic and environmental risks are not increased?

funded by European Commission

- Which are practical benchmarks and how to obtain them? How to ensure selected benchmarks are relevant to local conditions?

6 Existing but not adopted strategies on farm level

Some of these techniques may not be really effective increasing water productivity on farm, may require some fine-tuning for adaptation to local conditions, may not be economically viable or may have some environmental problems.

Conservation Agriculture is promoted worldwide for control erosion, and under certain condition, to increase water availability. It is widely adopted in America (North and South) but very little in Europe or Africa in spite of extensive research and promotion. There are technical problems at farm scale not appreciated in experiments on-station (difficulties managing crop residues, poor weed control or specialized machinery not locally adapted), lack of knowledge and inadequate extension actors (Soane et al. 2012). There are agronomic and environmental problems but also socioeconomic barriers to adoption (Lahmar 2010). In America, round-up ready cultivars of maize and soybean facilitates enormously weed control in these crops. Additionally, machine companies have developed direct drills adapted to local conditions.

Precision irrigation is available in the market but not adopted by farmers yet. The complicated technique (spatial soil maps, ruling decisions) does not represent clear advantages and profit to farmers. Similarly, hydrogel and other products that increase water holding capacity of soils may be too expensive for the marginal production gain.

Discussion questions:

- Which are the main limitations for adoption?
- Is further research needed?
- Should research projects use a participatory / multiactors approach?

7 Potential new strategies

- Micro basins can capture runoff and concentrate it in cultivated points with trees or shrubs, or even annual crops as in the Sahel (Blum, 2015).
- Runoff water may be stored in a wetland for fodder availability later in the season (*See Practice 2 in Annex 2*).
- Conservation Agriculture requires addressing the following topics (*See Practices 3 to 5 in Annex 2*):
    - Breeding for better adapted cultivars to direct seeding (more vigorous cultivars during crop establishment);
    - Direct drills and strip till drills able to deal with high amount of residues and adapted to heavy clay soils;
    - Adapted crops (other than cereals) to conservation agriculture systems;
    - Cover crops.
- Tactical management
    - Calibrated check points (crop benchmarks) 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 proposed target value, possible problems like presence of crust, deep sowing, bad seed, etc., should be explored. Check points are available for rice production in Australia (Ricechecks) and wheat in northern Africa (Gómez-Macpherson et al. 2010).
- New drought resistant cultivars (*See Practices 6 to 7 in Annex 2*):
    - Lately there has been much effort for understanding variations in root systems and search of traits that confer drought resistance. Strong and deep roots are required if there is a hardpan

    - or in deep soils with moisture in deeper horizons. Shallow and fast renewal roots are preferred for environments with common light rains.
    - Development of less sensitive-to-low-temperature cultivars of spring-summer crops (maize, sunflower, etc) for advancing sowing and, therefore, cropping earlier in the season, when evaporative demand is lower.
    - C4 transformed rice (still decades to change required CO_2 paths and anatomy).
    - Drought-resistant transformed hybrid maize cultivars (DroughtGard, AQUAmax,Agrisure Artisan) are available in USA since few years. However, they have shown modest protection against moderate drought periods and they do not appear really competitive compared to best conventional bred hybrids.
- More effective irrigation systems (*See Practice 12 in Annex 2*):
    - Oxygenation of water in subsurface irrigation.
- New techniques for improving irrigation scheduling (*See Practices 15 to 16 in Annex 2*):
    - Precision irrigation (site-specific variable rate irrigation) considers spatial variability to irrigate less where more moisture is stored. Clear decision protocols are needed.
    - nano-sensors, sap-flow and eddy-covariance;
    - new models;
    - monitoring of fruits.

Discussion questions:

- Are these strategies ready to be adopted? Do they require first some fine-tuning research? Do they require extensive research?
- Are these strategies widely applicable or are they more indicated for specific conditions?
- How to facilitate success of new potential strategies?
- Is there any bottleneck not being addressed currently?

REFERENCES

Angus, J.F. & van Herwaarden, A.F. (2001). Increasing water use and water use efficiency in dryland wheat. Agronomy Journal, 93, 290–298.

Berbel, J. & Mateos, L. (2014). Does investment in irrigation technology necessarily generate rebound effects? A simulation analysis based on an agro-economic model. Agricultural Systems, 128, 25-34.

Blum, A. (2009). Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Research, 112, 119–123.

Blum, A. (2015). PlantStress on-line platform (http://www.plantstress.com/).

Brouder, S. & Gómez-Macpherson, H. (2014). The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. Agriculture, Ecosystems and Environment, 187, 11-32. Review article.

Cantero-Martínez, C., O'Leary, G. J., & Connor, D. J. (1995). Stubble retention and nitrogen fertilisation in a fallow-wheat rainfed cropping system. 1. soil water and nitrogen conservation, crop growth and yield. Soil and Tillage Research, 34, 79-94.

Chamen, W. T., Moxey, A. P., Towers, W., Balana, B., & Hallett, P. D. (2015). Mitigating arable soil compaction: A review and analysis of available cost and benefit data. Soil and Tillage Research, 146, 10-25.

Falloon, P., & Betts, R. (2010). Climate impacts on European agriculture and water management in the context of adaptation and mitigation—the importance of an integrated approach. Science of the Total Environment 408, 5667-5687.

Fereres, E., & Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany, 58, 147-159.

Fletcher, A. L., Robertson, M. J., Abrecht, D. G., Sharma, D. L., & Holzworth, D. P. (2015). Dry sowing increases farm level wheat yields but not production risks in a Mediterranean environment. Agricultural Systems, 136, 114-124.

funded by European Commission

Gómez-Macpherson, H., van Herwaarden A. F. & Rawson H. M. (2010). Constraints to cereal-based rainfed cropping in North Africa. In: Explore On-farm: the case of North Africa. ICARDA, Aleppo, Syria, 21-36 pp.
Grassini, P., Torrion, J. A., Yang, H. S., Rees, J., Andersen, D., Cassman, K. G., & Specht, J. E. (2015). Soybean yield gaps and water productivity in the western US Corn Belt. Field Crops Research. 179, 150-163.
Grassini, P., Yang, H., Irmak, S., Thorburn, J., Burr, C., & Cassman, K. G. (2011). High-yield irrigated maize in the Western US Corn Belt: II. Irrigation management and crop water productivity. Field Crops Research, 120, 133-141.
Hall, A., Bullok, A. & Adolph, B. (2014). Forward-looking review of the CGIAR Challenge Program on Water for Food 2013-2014. CGIAR Challenge Program on Water for Food.
Hatfield, J. L., Sauer, T. J., & Prueger, J. H. (2001). Managing soils to achieve greater water use efficiency. Agronomy Journal, 93, 271-280.
Iglesias, A., & Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. Agricultural Water Management, 155, 113-124.
Lahmar, R. (2010). Adoption of conservation agriculture in Europe. Lessons of the KASSA project. Land Use Policy, 27, 4-10.
OECD (2014). Climate Change, Water and Agriculture: Towards Resilient Systems, OECD Studies on Water, OECD Publishing, Paris, 100 pp.
Olesen, J. E., Trnka, M., Kersebaum, K. C., Skjelvåg, A. O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J., & Micale, F. (2011). Impacts and adaptation of European crop production systems to climate change. European Journal of Agronomy, 34, 96-112.
Parry, M. A. J., Flexas, J., & Medrano, H. (2005). Prospects for crop production under drought: research priorities and future directions. Annals of Applied Biology, 147, 211-226.
Passioura J. B. (2006). Increasing crop productivity when water is scarce—from breeding to field management. Agricultural Water Management 80, 176-196.
Passioura, J. B. & Angus, J. F. (2010). Improving productivity of crops in water-limited environments. Advances in Agronomy, 106, 37-75
Playán, E. & Mateos, L. (2006). Modernization and optimization of irrigation systems to increase water productivity. Agricultural Water Management, 80, 100-116.
Reidsma et al (2010). Adaptation to climate change and climate variability in European agriculture: the importance of farm level responses. European Journal of Agronomy 32, 91-102.
Richards, R. A., Watt, M., & Rebetzke, G. J. (2007). Physiological traits and cereal germplasm for sustainable agricultural systems. Euphytica, 154, 409-425.
Sadras, V. O., Grassini, P., & Steduto, P. (2012). Status of water use efficiency of main crops. Rome: Food and Agriculture Organization of the United Nations.
Santos Pereira, L., Oweis, T., Zairi A., 2002. Irrigation management under water scarcity. Agricultural Water Management 57, 175–206.
Soane, B.B., Ball, B.C., Arvidsson, J., Basch, G., Moreno, F. & Roger-Estrade, J. (2012). No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. Soil Tillage Research, 118, 66–87.
Turner et al. (2014). Strategies to increase the yield and yield stability of crops under drought – are we making progress? Functional Plant Biology 41, 1199-1206.

ANNEX 1 Current strategies

Code	Name of practice/strategy	Advantages	Disadvantages	Economic aspects	Environmental aspects	Bottlenecks that limit use	Applied in:
	Which strategies at farm level increase water availability for crops considering rainfall as the sole source of water?						
	Options to reduce water losses in rainfed conditions (applicable to irrigated conditions also)						
1	Conservation Agriculture (combination of minimum soil disturbance, residues retention and crop rotation)	Improves water infiltration (slow runoff) and reduces evaporation losses. Increase SOM in superficial soil layers	Requires specific machinery. High risk of poor establishment in heavy soils. Hard weed control.	Cannot sell residues for cash. Reduces costs due to machinery and labors but increases herbicides.	Reduces soil erosion. In some conditions may sequester carbon.	Complex, requires adjusting many elements (machinery, rotation, residues management,…).	North and South America and Australia. Little practice in Europe, except in olive orchards in Spain.
2	Early ground cover: sowing early, dry sowing, seed priming (pre-soaking seeds to enhance germination), sowing cultivars with early vigor or optimizing plant density/arrangement	Improves water infiltration (slow runoff) and reduces evaporation losses.	Hard weed control. Higher risk of early drought. Requires longer cycle cultivar.		Reduces soil erosion	Higher risk of early drought.	Mediterranean environments.
3	Deep tillage if a hard pan is present	Increase water infiltration (and will also favor root growth into deeper layers)					Widely used.
4	Effective weed control	Prevents the use of water by other plants than the crop.			There are GMO roundup-ready species (not approved in Europe) that facilitates weed control.	Efficient herbicides unavailable.	Effective in cereals but problematic in other crops.

	Options to increase soil water holding capacity and access to it						
5	Stubble (residues) retention or cover crops in no-tilled systems (annual crops or tree orchards)	Increases SOM in superficial soil layers, improves water infiltration into soil. Cover crops, when dead, reduces evaporation.	Cover crops compete for water when they are growing. May be killed by frost. Long term observable positive impact.	Cannot sell residues for cash. Reduces costs due to machinery and labors but increases herbicides	Reduces soil erosion. Favours fauna: fungus, bacteria, insects and birds	Cover crops: timing of cover crop killing; high risk because of water competition with crop; Needs water resources at the end of summer	USA, some farms in Sweden. Cover crops are common in olive orchards.
6	Water retaining hydrogel	Increases soil capacity to retain water		Commercial products available			UK.
7	Controlled traffic (wheels pass always over same lines)	Space in between wheels not compacted, with higher soil porosity to fill in with water. Less compaction favors root growth to colonize the soil	Requires GPS guided tractor.		Soil compaction is restricted.		Australia, few farmers in southern Spain.
8	High cultivar/rootstocks ability to colonize the soil	Reach water in deeper zones.					Italy.
9	Fallow (plot not cropped during one season)	Stores water rainfall and nitrogen in the soil for the following season.				Its efficacy depends mostly on soil water holding capacity	Arid zones in Mediterranean conditions.
	Which strategies at farm level increase the efficient use of water when rainfall is considered the sole source of water?						
	Species/cultivars with intrinsic high water productivity						
10	Improved cultivars: "stay-green" in sorghum; low discrimination against ^{13}C during photosynthesis in wheat grown on stored water; osmotic adjustment in wheat; short anthesis-to-silking interval in maize		Cultivars may not profit from high rainfall years, may not be resistant to biotic stresses, may not have good quality product.			Limited seed availability. Unknown cultivars.	

11	Cultivars / rootstocks of vigorous deep roots	Vigorous, well-developed, deep root systems explore more soil.	Some rootstocks have poor adaptation to different environments and resistance to biotic stresses. Scion/rootstocks interactions	No additional costs at planting time.	Less percolation.	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
	Options to use water more efficiently							
	Understanding and closing yield gap: improvement in crop, pasture and grazing management and feeding, or in crop and animal health							
12	Tactical management (adapt to current season): may use calibrated crop models to local conditions or check points	Profit from best years	Requires training, guidelines and local calibration	Cheap			Applied by best farmers
13	Improved crop sequences	Grain legumes or oilseeds crops may benefit the following cereal crop by fixing some N or reducing soil diseases	Increase the risk of failure. Lack of marketable options.	Cheap. May be difficult to market products.		Limited availability of crops with attractive economic return. Limited seed availability.	Applied by best farmers
	Growing when the evaporative demand is lower							
14	Matching the cropping season to the rainfall season: early sowing	Improves water infiltration (slow runoff) and reduces evaporation losses.	Hard weed control. Higher risk of early drought.	Cheap	Reduces erosion		Applied by best farmers
15	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	Equally costly than north-south orientation		Not applicable in established vineyards. Not useful in cloudy environments (mainly diffuse solar radiation)	Sunny and warm environments in vineyards, for fitting to plot shape

16	Shading nets	Reduces temperature and evapo-transpiration. Simple and easy to implement.	Reduces yield and quality in some species	May be expensive although some farmers already install hail nets that can be used for shading.		Used in some crops but research needed for others	Applied in selected systems
	Which strategies at farm level increase water availability for irrigation / animal drink or which strategies increase irrigation water efficiency?						
	Options to increase water supply for irrigation and livestock						
17	Use of waste water (water affected by a combination of domestic, industrial and commercial activities)	If appropriately processed, it may reduce needs of mineral fertilization inputs		Advanced facilities for water purification are needed. Can be quite expensive if a water distribution system from source is needed.	Strict regulations on quality thresholds. Control activity on the territory, landscape conservation. Maintains a certain level of toxic elements and microorganisms.	Strict regulations; infrastructural absence of local depuration facilities; distance between water source (city, industry) and cultivated areas	Horticulture, olive and citrus orchards (e.g. in Matera, Italy).
18	New water sources (rainwater and drainage harvest) for livestock		Often needs to be upgraded so that they can be used as drinking water for livestock.	May cost less than using public water but costs a lot more than using ground water	Sometimes specific local conditions (e.g. clay) can give some specific problems	Should follow legislation. Water must be treated. Too expensive.	Flanders

19	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.	Legislation. Research needed for local conditions.	Introduced in Flanders in 2013. Some adaptation was necessary.
20	Dynamic private open wells	They also can be filled in periods of drought. Simple to introduce.		Cheap	Less pressure on more threatened water sources. Must be monitored.	Legislation. Farmers and the water management authorities must be trained.	Flanders
21	Renovation of the irrigation systems						Irrigation systems damaged during the Balkan War in Zadar
	Which management options will increase irrigation efficiency?						
	Irrigation system						
22	Drip irrigation	Higher irrigation uniformity. Simple management.	Requires water on demand; requires energy. Maintenance	Expensive	Successfully used in saline soil with good quality water	Requires water on demand and energy; expensive.	Mainly olives, grapes, fruit orchards. In sloppy land.
23	Flood irrigation	Wash salts in saline soils; requires little energy; water on turns	Requires levelling. Nutrients leaching; water percolation.		Risk of contamination. Low energy use.		Common in flat land
24	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.		Common in flat land
25	Sprinkler irrigation	Higher irrigation uniformity	Requires water on demand; requires energy	Expensive		Requires water on demand and energy; expensive.	Wide use

26	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 oclusion)	Higher initial investments compared to traditional drip irrigation	Low soil evaporation.	Logistical/technical problems in maintaining the correct functioning. Requires water on demand	Orchards and vegetables, both in open fields and greenhouses.
	Operative solutions for irrigation scheduling (when, where, how much irrigate)						
27	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.	Minimal sets of measurements per field plot unknown (depends on soil spatial variability). Requires water supply on demand. Farmers should be trained and assisted directly in their fields.	Cost too high respect to the farmer's revenues.	Percolation and groundwater pollution can be avoided	Heterogeneous soils are not indicated for hosting the probes for monitoring the soil water content. Lack of assistance and extension services. Water supply at demand not available.	Strawberry, mandarins, orange trees in southern Spain. Private companies.
28	IRRIFRAME: crop water balance calculated at daily step and at field scale and adapted to the crop characteristic, simulated or inputted by the farmer.	Users are provided with optimal irrigation volume and interval, via web or mobile phone text message.	Requires water supply on demand. Requires meteorological and soil data and crop parameters, including application of the most effective crop tailored irrigation strategy.	Free of charge	Percolation and groundwater pollution can be avoided	Requires calibration to be used in other environments. Research needed for further improvement.	Italy

29	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			Israel, Spain
30	Supplemental irrigation: water applied during droughts only						Mediterranean environ.
31	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 and quality if not well managed	No additional costs for using this approach.	Percolation and groundwater pollution can be avoided	RDI protocols still under improvement/research. Need for advanced technical support to farmers and high risk to have negative effects on production	Peach, kiwi, orange. In Spain and central Italy. When water scarcity is already a problem and/or with higher water costs
32	Alternate furrow irrigation	Little infrastructure required					
	Cropping system						
33	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 an investment that can only be afforded 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.	Spanish protected horticulture. In other regions, in orchard production, but less common.

34	Certification standards for efficient water use at the farm (water efficiency, respect to freshwater biodiversity)	Requested by many retailers, and standardised e.g. by Globalgap		Associated to costs		Certificates have different origins, but usually linked to industry	
	Which strategies at farm level increase farm resilience under water scarcity?						
35	Landscape reshape to reduce and capture runoff	Increases infiltration and reduces runoff. Water in excess may be stored in small-scale reservoirs.	Requires proper viability and environmental studies and high investment.	Expensive	Reduce erosion. Requires complying with water resources regulation		Present in hilly land. Widely used in USA and Brazil.
	Diversification within farm to reduce risks						
36	Agroforestry: association of woody perennials (trees, shrubs, lianas etc.) with crops and/or livestock on the same land unit	Risk diversification.	Complex management. Knowledge intensive. Expensive.	Expensive	Enhanced soil biota and improved soil structure		Dehesa well establish in Spain. France.
37	Crop diversification within farm / within plot (intercropping).	Profit from spatial variation. Reduces the risk of failure when climate is too erratic.	Problems for harvesting intercropped plots.		Enhanced soil biota.		
	Link to other scales						
38	Link to networks, including water users associations	Reduce yield gap due to lack of technical knowledge					
39	National irrigation needs assessment						

ANNEX 2 Potential strategies

Code	Name of practice/strategy	Advantages	Disadvantages	Economic aspects	Environmental aspects	Bottlenecks that limit use	Apply in
	Which strategies at farm level increase water availability for crops considering rainfall as the sole source of water?						
1	Micro basins: capture runoff and concentrate it in small cultivated areas (around 1 m2).	Capture runoff	Time consuming.	Effective.			Trees, shrubs or annual crops. Sahel, Middle East
2	Construct wetlands for reducing the amount of nutrients (during wet periods) and provide pasture land (during dry periods)	Reduce the amount of nutrients in wet periods and increase pasture yield in dry periods. Simple and easy to implement		Expensive	Increases biodiversity. Increases emission of NO2, may decrease soil quality.		Some initial tests in Italy by Kiwi growers
3	Conservation Agriculture: Breeding for better adapted cultivars to direct seeding (more vigorous cultivars during crop establishment)	Will contribute to Conservation Agriculture development					
4	Conservation Agriculture: direct drills and strip till drills able to deal with high amount of residues and adapted to heavy clay soils	Will contribute to Conservation Agriculture development					
5	Adapted crops (other than cereals) to conservation agriculture systems	Will contribute to Conservation Agriculture development					Except for cereals, few crops are adapted to CA
	Which strategies at farm level increase the efficient use of water when rainfall is considered the sole source of water?						
6	Drought resistant/tolerant cultivars: improved root system in selected crops		Must meet commercial quality standards.	High investment needed		Long term research.	Decades of effort with limited success.

7	Drought tolerant cultivars: less sensitive to low temperatures cultivars of spring-summer crops (maize, sunflower, etc) to advance sowing	Cropping earlier in the season when evaporative demand is lower	Must meet commercial quality standards.	High investment needed		Long term research.	
8	Matching crop and environment: Use crop models to define agroecological zones for crop sustainability					Required guidance of agricultural agencies to farmers. Research needed. Farmers assume risks when changing crops.	
9	Under sown ley in the autumn	Less water demand in autumn-winter than in spring. Gives the baby plants in the ley a good start.				Risk of poor ley establishment.	Few farmers
10	Tactical management to adapt to current season (e.g. Sow a cultivar of shorter cycle if the rainy season is delayed) and profit from best years						
11	Closing yield gap: identify poor management and possible improvement (can use check points or benchmarks)	More efficient use of resources	Requires training, guidelines and local calibration	Cheap	Increase understanding on environmental risks		Rice production in Australia (Ricechecks) and wheat in northern Africa
	Which strategies at farm level increase water availability for irrigation / animal drink or which strategies increase irrigation water efficiency?						
12	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		Cheap	Positive effect on soil quality and biodiversity. Requires low energy input.	Research needed	
13	Use of caolin in sprinkler systems and zeolite in subsurface systems to reduce required irrigation water	Simple and easy to adopt. Machinery available		Cheap		Requires training.	
14	Schedule irrigation based on plant water indices (including the fruit)		Difficult to define thresholds for	Low cost.		Difficult to manage, requires training. Some are unfriendly.	

			water stress as parameters can change with plant age, stem diameter, canopy development.				
15	Use of nanosensors, sap-flow or eddy-covariance to determine water requirement and automate application of water	Easy to adopt		Final cost of the technology critical factor for the farmer		Requires training. Research needed	
16	Precision irrigation: site-specific variable rate irrigation (considers spatial variability to irrigate less where more moisture is stored)		Expensive. Clear protocols for taking decisions required			Research and training needed	Available in USA
17	Improved irrigation water management through water footprint assessment and benchmarks in crop production					Research needed	
18	Reduce fruit quality standards to reduce water consumption.	Higher fruit dry matter content, major storability, and increased content in nutraceutical components. Simple to be adopted by the grower	Lower fruit diameter	No additional costs.	Poor soils may limit the applicability of the strategy	Appropriate irrigation protocols still to be developed for different species/environments	
	Which strategies at farm level increase farm resilience under water scarcity?						
19	Farmers training and awareness raising	Simple and easy to adopt		Cheap		Overcome inertia of current practices: some farmers associate the use of water with increased crop production.	