JRC137742

European Commission

SCIENCE FOR POLICY BRIEF

Scientific evidence on farming practices improving sustainable water management in agriculture

HIGHLIGHTS

→ This brief reports the results of a systematic review on the effects of 34 farming practices on water management in agriculture (i.e. water use efficiency, water consumption, soil water retention, water quality, and nutrient leaching and run-off).

→ The analysis identifies 10 farming practices that are potentially beneficial for reducing water use quantity and 13 for improving water quality, with a total of 15 farming practices that can enhance water management in agriculture.

→ The following farming practices have at least two positive effects: crop residue management, mulching, cover and catch crops, buffer strips and small wetlands, soil amendment with biochar, water-saving irrigation practices in flooded and non-flooded lands, grassland management, and no tillage and reduced tillage.

INTRODUCTION

Context in Europe

The quantity and quality of water in the EU are facing major challenges. Agriculture is the largest net water user in the EU-27, accounting for up to 60 % at the EU level [1], while the countries most affected by drought have the largest share of irrigable areas [2]. Although total water abstraction in the EU decreased by 15 % from 2000 to 2019, agricultural consumption has not decreased, and neither has the area affected by water scarcity [3]. According to the water exploitation index plus, which compares water use with renewable water resources, approximately 29 % of the EU's territory was affected by water stress during at least one season in 2019 [3]. Water scarcity conditions happen in combination with increasing frequency and magnitude of extreme weather events, such as the droughts and floods experienced in Europe during summer 2023 [4] [5], and increased abstraction for irrigated agriculture, tourism and recreational activities, which happen mostly between July and September [6]. Southern Europe is the most affected region, with about 30 % of its population living in areas of permanent water stress and up to 70 % of its population living in areas of seasonal water stress during the summer. Moreover, water stress problems are also increasing in other parts of the continent [7].

In Europe, agricultural activities also degrade the quality of water through nutrient and pesticide losses into water [8] [9]. Currently, 22 % of European surface water bodies and 28 % of groundwater are significantly affected by diffuse pollution from agriculture [10], and water pollution from nutrients and pesticides is bound to remain an issue in the future, despite some improvements.

Climate change will further increase extreme weather events, entailing a rise in flood-related disasters and an increase in water scarcity and droughts [11] [12]. Hydrological projections of climate scenarios show a trend towards water scarcity, particularly (but not only) in southern and eastern Europe, which calls for mitigation actions.

Improved water management is expected in agriculture, in line with the overall objective of EU water policy to ensure that all Europeans, economic sectors and the environment have access to a sufficient quantity of water of good quality and to ensure the good status of all water bodies across Europe ([1]). This has to be done not only by reducing the use of water for irrigation and improving irrigation techniques but also by improving soil water retention through healthy soil and water quality. Improving water retention in agricultural soil can help reduce flooding, alleviate drought, reduce soil erosion and maintain or improve soil fertility. Identifying farming practices that fulfil these objectives is thus crucial to inform policymakers and underpin efficient policy implementation in agriculture.

Scope and methodology

Since 2020, through the integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (iMAP) project, the JRC has systematically reviewed the scientific literature of meta-analyses ([2]) on the effects of 34 farming practices on environment and climate. The effects on agricultural and animal production are also included, as they represent important trade-offs for farmers and society when applying measures to support the climate and the environment. In the context of this brief, an impact is defined as a category of metrics measuring specific aspects of the environment (e.g. biodiversity, soil erosion, water use), climate (e.g. greenhouse gas emissions) and production (e.g. crop yield). Overall, 570 meta-analyses have been reviewed, synthesising around 30 000 primary articles, and results have been assessed for 34 impacts. The results of this systematic review, including definitions of farming practices, are reported in factsheets available on the iMAP wiki [13] and compiled into the iMAP dataset [14]. The impacts reported in the iMAP dataset are those for which there is scientific evidence available in published meta-analyses, which does not preclude these farming practices from having other impacts on the environment and climate that are still not covered by primary studies or synthesis papers.

The aim of this policy brief is to identify farming practices that help to reduce water use and improve water quality while maintaining the same crop type, by conducting a cross-analysis of the scientific evidence collected in the iMAP dataset. Sustainable practices are compared with conventional practices. In this brief, a conservative approach was applied by reporting only those farming practices that have a majority of positive effects on water quantity and quality impacts. This fast-track method proved to be robust in identifying the effects of different farming practices [15]. The impacts considered in this brief are:

- water use efficiency (WUE);
- water consumed by the crop;
- soil water retention;
- water quality.

In addition, indirect impacts on water quality such as nutrient leaching and run-off were considered; where relevant, it was examined whether selected practices also affect crop yield. In the conclusions, the absence of irrigation (i.e. rainfed systems) is discussed in comparison with water-saving irrigation practices. In the 'Results by impact' section, some quantitative values of the effect of the assessed farming practices are given as examples, without claiming to be representative of the whole European context.

RESULTS

Overview

By synthesising the effects of 120 meta-analyses, each including between 4 and 522 individual studies, on the selected impacts, scientific evidence was found that 15 of the 34 farming practices reviewed can reduce the quantity of water consumed by the crops or reduce water pollution (see Table 1). The 54 meta-analyses cited in the 'Results by impact' section are reported in the Annex.

Out of 15 farming practices, 10 can reduce the amount of water consumed by crops by increasing the WUE, reducing the amount of water either supplied for irrigation or consumed by the crop, and increasing soil water retention. These farming practices are agroforestry, cover crops, crop residue management, organic amendments in grasslands, terraces, mulching, no tillage and reduced tillage, and soil amendment with biochar. These farming practices not only include water-saving irrigation practices but also encompass systems or practices that improve the soil chemical-physical and biological qualities related to soil water management.

Furthermore, 13 out of the 15 farming practices can help reduce water pollution and therefore improve water quality. These farming practices act as a filtering system and/or reduce leaching and run-off of

([1]) European Water Regulators, 'The EU water acquis' (https://www.wareg.org/european-water-acquis/).

([2]) A meta-analysis is the systematic statistical synthesis of the results of many independent individual experiments.

nutrients. They are cover crops, crop residue management, the use of enhanced-efficiency fertilisers (EEF) in grassland, landscape features (buffer strips and small wetlands), mulching, soil amendment with biochar, wetland creation or restoration, and water-saving irrigation practices in flooded and non-flooded land.

Table 1. Farming practices with a positive effect on water quantity and water quality (marked in blue), based on the systematic review of meta-analyses

Farming practice	Water quantity			Water quality	
	Water use efficiency	Water consumption	Soil water retention	Water quality	Nutrient leaching and run-off
Agroforestry systems			■		
Cover and catch crops	■		■		■
Crop residue management	■	■	■		■
Enhanced-efficiency fertilisers					■
Grassland management			■		■
Landscape features (buffer strips and small wetlands)			■	■	■
Low-ammonia-emission techniques for mineral fertilisers					■
Mulching	■	■	■		■
No tillage and reduced tillage		■	■		
Organic farming systems					■
Organic fertilisation					■
Soil amendment with biochar	■		■		■
Wetland conservation and restoration				■	
Water-saving irrigation practices in flooded lands	■	■			■
Water-saving irrigation practices in non-flooded lands	■	■			■

RESULTS BY IMPACT

Which farming practices can increase crop water use efficiency?

Box 1. Water use efficiency

WUE is a measure of the amount of biomass produced per unit of water used by a crop [16]. A higher value of WUE indicates higher efficiency, with a higher quantity of biomass harvested per unit of water used by the crop. Several factors influence WUE, such as crop type, irrigation amount, method and timing, soil type and climate.

- **Cover crops**, mainly legumes, can increase the WUE of the subsequent cash crop by 5.0 % compared with no cover crop (fallow) [M1] ([3]).
- **Incorporation of crop residue** into the soil or retention of crop residue on the soil increases WUE in rainfed cereals [M2], but also in irrigated maize [M3]. The same result is reported for many other crops on a global scale [M4].
- In general, **mulching** significantly increases WUE. In particular, mulching with plastic/biodegradable film and straw is very effective, as demonstrated globally and including data from Europe, with increases in WUE ranging from 20 % to 60 % [M5] [M6] [M7] [M8]. Mulching is often used in combination with water-saving irrigation practices, including drip irrigation systems, to further increase WUE. In China, mulching is also reported to be used in rainfed agriculture (32–64 % increase in WUE) [M9]. However, mulching with plastic film is also responsible for plastic residue in the soil [M10], which can be avoided using biodegradable film.
- **Soil amendment with biochar** (from < 20 t ha^{-1} to > 30 t ha^{-1}) significantly increases WUE, with values ranging from 19 % to 27 % [M11] [M12], compared with no amendment.
- **Water-saving irrigation practices in flooded** rice cultivation include intermittent irrigation and alternating wet and dry periods, which significantly increase WUE compared with continuous flooding [M13]. None of the reviewed synthesis papers, however, includes studies conducted in Europe.

([3]) This code refers to the meta-analyses listed in the Annex.

- **Water-saving irrigation practices in non-flooded lands** include **aerated irrigation**, **deficit irrigation**, **partial root zone drying** and **optimised irrigation period**. These practices generally increase WUE compared with non-water-saving irrigation practices (full irrigation). Deficit irrigation is by far the most commonly reported technique with positive effects in annual crops (e.g. maize, wheat, legumes, vegetables) and perennial crops (e.g. fruit trees). Increases in WUE range from 5 % to 9 % [M14] [M15].

Which farming practices can reduce the quantity of water consumed by crops?

Box 2. Water consumption

A farming practice reducing the quantity of water consumed by the crop decreases the water volume required from irrigation, rainfall and soil storage. Several factors influence water consumed by the crop, such as crop type, soil type and climate.

- **Incorporating crop residue, in this case straw, into soil** significantly reduces water consumption and increases the yield of irrigated maize compared with residue removal, as reported for China [M3].
- Overall, **plastic film mulching** reduces water consumption. Indeed, plastic mulching significantly improves WUE by markedly increasing yield while reducing water consumption [M3]. However, as reported above, this involves the use of plastic and the risk of increasing plastic residue in the soil [M10].
- In rice systems, **reduced tillage** and **no tillage**, combined with direct seeding in dry conditions, have lower water use than conventional intensive wet tillage (puddling) and manual transplanting [M16].
- **Water-saving irrigation practices in paddy rice**, including intermittent irrigation, alternating wet and dry periods, and limited flooding, reduce the volume of irrigation water compared with continuous flooding [M13]. The reviewed synthesis papers include only studies conducted in China.
- **Water-saving irrigation practices in non-flooded lands**, including **drip and intermittent irrigation**, significantly reduce irrigation volumes compared with conventional irrigation management in maize in China [M3]. **Optimised irrigation rates** reduce the volume of irrigation water without causing yield losses compared with conventional irrigation rates in wheat in China [M17].

Which farming practices can increase soil water retention?

Box 3. Soil water retention

A farming practice increasing soil water retention enhances the capacity of the soil to retain or store water. Several factors influence soil water retention, mainly the degree of porosity/compaction of the soil, the organic matter content and the soil type.

- **Agroforestry practices** significantly improve soil water retention (12 %) compared with crop monocultures [M18].
- **Retention of crop residue** such as straw increases soil water retention from 10 % to 14 % compared with crop residue removal [M4] [M19] [M20].
- **Organic amendments in grasslands** increase soil water retention by 11 % in arid, semi-arid and Mediterranean climates compared with no organic amendments [M21].
- **Terraces** improve soil water retention in grassland (28 %) and cropland (14 %) compared with slopes without terraces in China [M22].
- There is strong evidence that **mulching** (with plastic film or straw) increases soil water retention, both before sowing (fallow) and during the growing season in arable crops, compared with no mulching [M8] [M23] [M24]. This is particularly relevant in rainfed agriculture, as plastic mulching results in increased precipitation storage in the deep soil layer during the non-growing season, which appears to fully offset the additional water loss due to increased evapotranspiration as a result of higher soil moisture and soil temperature [M9].

- **No tillage** increases soil water retention in cropping systems by 6 % to 16 % compared with conventional tillage [M25] [M26]. Greater soil water retention in no-tillage systems is associated with better soil physical properties, such as increased soil aggregate size and stability.
- **Soil amendment with biochar** significantly increases soil water retention, compared with no amendment. The increase in soil water retention is directly related to the improvement in soil biophysical properties [M27] [M28]. The effect of biochar on soil water content may depend on soil type, with greater effect on coarse-textured soil [M29].

Which farming practices can reduce water pollution and improve water quality?

Box 4. Water pollution from agricultural activities

Water pollution can be reduced/avoided by farming practices that prevent or reduce the amount of agricultural chemicals, including nitrogen, phosphorus, heavy metals and pesticides, entering the water bodies. Several factors influence the reduction of water pollution such as crop type, soil type, fertilisation rate and timing, cover crop species, buffer strip width, annual rainfall, slope gradient and water management.

- Non-leguminous **cover crops** significantly reduce nutrient leaching and run-off compared with no cover crops, for both arable [M30] [M31] [M32] and perennial crops [M33].
- Non-leguminous cover crops can reduce nitrogen leaching by around 50 %, while leguminous cover crops have no effect [M32] [M34] [M35].
- **Crop residue retention** reduces nitrogen leaching and run-off in arable crops, including paddy rice, by 8–39 % [M4] [M36]. However, crop residue retention in paddy rice has a negative effect on methane emissions.
- The use of **EEF** reduces the leaching of nitrates from controlled-release fertilisers (– 42 %) and fertilisers amended with nitrification inhibitors (– 45 %) in arable crops and grasslands [M37].
- The use of EEF, including nitrification inhibitors and urease inhibitors, in **grassland management** leads to a significant reduction in nitrate leaching, ranging from 13 % to 58 % reduction, depending on the type of inhibitor [M38].
- Several **landscape features**, such as buffer strips, ditches and ponds, field margins, hedgerows and small wetlands, can reduce nutrient leaching and run-off and thus, indirectly, improve water quality. **Buffer strips** can reduce nitrogen and phosphorus leaching and run-off compared with cropland or grassland without buffer strips [M39] [M40]. Nitrogen and phosphorus interception by **field margins** and **hedgerows** is more than 70 % [M41]. **Ditches and ponds** effectively reduce total nitrogen losses, with an overall removal rate of about 40 % and higher values for vegetated water bodies and non-concrete ditches [M42]. **Small wetlands**, including constructed wetlands, significantly reduce annual nitrate loads by an average of 41 % and phosphorus loads by 33 % [M43]. **Buffer strips** and **small wetlands** are effective risk mitigation techniques for reducing pesticide exposure in downstream surface water [M40] [M44]. However, their performance varies depending on their physical and hydrological characteristics and on the properties of the pesticides entering these systems.
- Among the **low-ammonia-emission techniques** for mineral fertilisers, deep versus superficial placement and split versus single application can reduce nitrogen run-off by 15 % and 36 %, respectively, in cereals in China [M45].
- **Mulching** reduces nitrogen losses through run-off by 39 % in permanent (tree) crops [M34].
- All types of **organic farming systems** (arable and mixed) can reduce nitrogen losses compared with conventional systems, but they have no effect on phosphorus losses [M46].
- Replacing mineral fertiliser with **organic fertiliser** reduces nitrogen leaching and run-off by 27 % in maize systems on a global scale [M47].
- **Soil amendment with biochar** reduces nitrogen leaching by 13–26 %, depending on the feedstock source (woody or grassy) of biochar and the dose applied [M48] [M49].

- Several **water-saving irrigation practices** are reported to reduce nitrogen run-off and leaching **in flooded land** compared with continuous flooding, contributing towards an optimal water–nitrogen management mode in rice fields. Alternating wet and dry irrigation reduces nitrogen run-off and leaching losses from paddy fields by 33 % and 14 % [M50]. Nitrogen leaching losses from paddy fields are also reduced by 49 % under controlled irrigation. Moist irrigation and thin and wet irrigation reduce nitrogen run-off losses by 66 % and 35 %, respectively [M50].
- Many **water-saving irrigation practices** have been reported to be effective in reducing nitrate leaching and run-off in **non-flooded** land (20–30 %), such as reduced water management in vegetable cultivation in both open-field and greenhouse conditions in China [M31]. All improved water management practices, such as **improved irrigation scheduling or techniques** and **deficit irrigation**, can reduce nitrate leaching compared with irrigation in line with crop needs in cereals and vegetables, according to a meta-analysis on a global scale, including data from Europe [M51].
- **Restoring or creating wetlands**, including small wetlands (considered here as landscape features), reduces nutrient leaching and run-off compared with degraded or non-existent wetlands, respectively [M43] [M52].

CONCLUSIONS

There is robust scientific evidence that some farming practices (10 assessed here) can **reduce the quantity of water** used by crops by increasing WUE or reducing water consumption and by increasing soil water retention. There are also farming practices (13 assessed here) that can help reduce water pollution, particularly from nutrient losses, and therefore may **improve water quality**.

Out of a total of 15 farming practices, 2 – namely crop residue management and mulching, preferably with biodegradable film to avoid plastic pollution of soil and water – are outlined to have positive effects on 4 out of the 5 impacts considered in this brief. Additionally, 5 farming practices – cover crops, landscape features (buffer strips and small wetlands), soil amendment with biochar, and several of the water-saving practices for flooded and non-flooded land – have positive effects on 3 out of the 5 impacts.

Grassland management and reduced tillage / no tillage have positive effects on 2 out of 5 considered impacts, while EEF, low-ammonia-emission techniques, organic fertilisation and organic farming systems have positive effects on 1 impact, that is, nutrient leaching and run-off. Wetland conservation/restoration has 1 positive effect on water quality.

No irrigation leads to an obvious direct reduction of water use, but this technique cannot be recommended on its own without other adaptation strategies, such as switching to more drought-resilient or less water-demanding crops, because it may lead to a significant decrease in crop yield [M53] [M54].

The scientific evidence supporting these findings comes from experiments carried out in different parts of the world, not always including the EU. In particular, the results of water-saving practices in flooded rice fields and mulching come mainly from China. These results have been included because similar conditions to those in Europe (e.g. arid areas) may occur there.

REFERENCES

[1] European Environment Agency, *Water and Agriculture: Towards sustainable solutions*, EEA Report No 17/2020, Publications Office of the European Union, Luxembourg, 2021, doi:10.2800/73735 (https://www.eea.europa.eu/publications/water-and-agriculture-towards-sustainable-solutions).

[2] Eurostat, 'Agri-environmental indicator – Irrigation', 2019 (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_irrigation).

[3] European Environment Agency, 'Water scarcity conditions in Europe (water exploitation index plus)', 2023 (https://www.eea.europa.eu/ims/use-of-freshwater-resources-in-europe-1).

[4] Ben Aoun, W., Biavetti, I., Bratu, M., et al., *JRC MARS Bulletin – Crop monitoring in Europe*, Vol. 31, No 7, 2023, doi:10.2760/086166.

[5] Biavetti, I., Bratu, M., Bussay, A., et al., *JRC MARS Bulletin – Crop monitoring in Europe*, Vol. 31, No 8, 2023, doi:10.2760/922863.

[6] Rossi, L., Wens, M., De Moel, H., et al., *European Drought Risk Atlas*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/608737.

[7] European Environment Agency, *Water Resources across Europe – Confronting water stress: An updated assessment*,

EEA Report No 12/2021, Publications Office of the European Union, Luxembourg, 2021, doi:10.2800/320975.

[8] Vigiak, O., Udías, A., Grizzetti, et al., 'Recent regional changes in nutrient fluxes of European surface waters', *Science of the Total Environment*, Vol. 858, 2023, 160063, doi:10.1016/j.scitotenv.2022.160063.

[9] Pistocchi, A., Dorati, C., Galimberti, F., et al., 'A screening study of the spatial distribution and cumulative toxicity of agricultural pesticides in the European Union's waters', *Frontiers in Environmental Science*, Vol. 11, 2023, doi:10.3389/fenvs.2023.1101316.

[10] European Environment Agency, *Drivers of and pressures arising from selected key water management challenges – A European overview*, EEA Report No 09/2021, Publications Office of the European Union, Luxembourg, 2021, doi:10.2800/059069.

[11] European Commission, Joint Research Centre, Bisselink, B., Bernhard, J., Gelati, E., Adamovic, M., Guenther, S., Mentaschi, L., Feyen, L. and de Roo, A., *Climate Change and Europe's Water Resources*, Publications Office of the European Union, Luxembourg, 2020, doi:10.2760/15553.

[12] European Commission, Joint Research Centre, De Roo, A., Bisselink, B. and Trichakis, I., *Water-energy-food-ecosystems pathways towards reducing water scarcity in Europe – Analysis using the water exploitation index plus*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/478498 (https://data.europa.eu/doi/10.2760/478498).

[13] European Commission, 'Impacts of farming practices on environment and climate', iMAP wiki (https://wikis.ec.europa.eu/display/IMAP/Impacts+of+farming+practices+on+environment+and+climate).

[14] Schievano, A., Perez-Soba Aguilar, M., Bosco, S., et al., *iMAP FP Dataset – An evidence library of the effects of farming practices on the environment and the climate*, European Commission, Ispra, 2023, doi:10.2905/4e3c371a-be72-4ea0-aa0b-45f8cdda2064 (https://publications.jrc.ec.europa.eu/repository/handle/JRC135820).

[15] Makowski, D., Catarino, R., Chen, M., et al., 'Synthesising results of meta-analyses to inform policy: A comparison of fast-track methods', *Environmental Evidence*, Vol. 12, 2023, 16, doi:10.1186/s13750-023-00309-y.

[16] Hatfield, J. L. and Dold, C., 'Water-use efficiency: Advances and challenges in a changing climate', *Frontiers in Plant Science*, Vol. 10, 2019, 103, doi:10.3389/fpls.2019.00103.

ANNEX

List of the meta-analyses supporting the results of the policy brief:

[M1] Wang, J. et al., 2021, doi:10.1016/j.agwat.2021.107085.
[M2] Liu, B. Y. et al., 2022, doi:10.1007/s13593-022-00766-8.
[M3] Zheng, H. et al., 2020, doi:10.1016/j.agwat.2020.106119.
[M4] Xia, L. et al., 2018, doi:10.1111/gcb.14466.
[M5] Qin, W. and Onema, O., 2015, doi:10.1038/srep16210.
[M6] He, G. et al., 2021, doi:10.1016/j.fcr.2020.108026.
[M7] Zhang, W. et al., 2022, doi:10.1016/j.still.2022.105392.
[M8] Adil, M. et al., 2022, doi:10.3389/fpls.2022.825309.
[M9] Ren, A. T. et al., 2021, doi:10.1016/j.agee.2021.107354.
[M10] He, G. et al., 2018, doi:10.1016/j.jclepro.2017.10.269.
[M11] Gao, Y. et al., 2020, doi:10.1016/j.fcr.2020.107763.
[M12] He, Y. H. et al., 2020, doi:10.1111/gcbb.12720.
[M13] He, G. et al., 2020, doi:10.1016/j.jclepro.2019.118928.
[M14] Tong, X. Y. et al., 2022, doi:10.1016/j.agwat.2021.107321.
[M15] Allakonon, M. G. B. et al., 2022, doi:10.1016/j.agwat.2022.107746.
[M16] Chakraborty, D. et al., 2017, doi:10.1038/s41598-017-09742-9.
[M17] He, G. et al., 2017, doi:10.1016/j.jclepro.2017.06.085.
[M18] Kuyah, S. et al., 2019, doi:10.1007/s13593-019-0589-8.
[M19] Li, Y. et al., 2019, doi:10.1016/j.still.2019.06.009.
[M20] Zhao, X. et al., 2020, doi:10.1002/ldr.3492.
[M21] Gravuer, K. et al., 2019, doi:10.1111/gcb.14535.
[M22] Chen, D. et al., 2020, doi:10.1016/j.agwat.2019.105849.
[M23] Lee, H. et al., 2019, doi:10.1007/s10113-018-1447-y.
[M24] Li, Y. et al., 2022, doi:10.1016/j.geoderma.2022.115851.
[M25] Li, Y. et al., 2020, doi:10.1016/j.geoderma.2019.114099.
[M26] Mondal, S. et al., 2020, doi:10.1002/ldr.3470.
[M27] Edeh, I. G. et al., 2020, doi:10.1016/j.scitotenv.2020.136857.
[M28] Omondi, M. O. et al., 2016, doi:10.1016/j.geoderma.2016.03.029.
[M29] Razzaghi, F. et al., 2020, doi:10.1016/j.geoderma.2019.114055.
[M30] Jian, J. et al., 2020, doi:10.1016/j.still.2020.104575.
[M31] Bai, X. L. et al., 2020, doi:10.1007/s11356-20-08322-1.
[M32] Shackelford, G. E. et al., 2019, doi:10.1016/j.landusepol.2019.104204.
[M33] Liu, R. et al., 2021, doi:10.1016/j.catena.2020.105085.
[M34] Thapa, R. et al., 2018, doi:10.2134/jeq2018.03.0107.
[M35] Valkama, E. et al., 2015, doi:10.1016/j.agee.2015.01.023.
[M36] Li, Z. J. et al., 2021, doi:10.1007/s13593-021-00715-x.
[M37] Li, T. et al., 2017, doi:10.1111/gcb.13918.
[M38] Cai, Y. J. et al., 2017, doi:10.1080/00380768.2017.1367627.
[M39] Valkama, E. et al., 2019, doi:10.2134/jeq2018.03.0120.
[M40] Zhang, X. Y. et al., 2010, doi:10.2134/jeq2008.0496.
[M41] Van Vooren, L. et al., 2017, doi:10.1016/j.agee.2017.04.015.
[M42] Shen, W. et al., 2021, doi:10.1016/j.agee.2021.107409.
[M43] Carstensen, M. V. et al., 2020, doi:10.1007/s13280-020-01345-5.
[M44] Stehle, S. et al., 2011, doi:10.2134/jeq2010.0510.
[M45] Xia, L. et al., 2017, doi:10.1111/gcb.13455.
[M46] Mondelaers, K. et al., 2009, doi:10.1108/00070700910992925.
[M47] Wei, Z. B. et al., 2020, doi:10.3390/agronomy10081149.
[M48] Borchard, N. et al., 2019, doi:10.1016/j.scitotenv.2018.10.060.
[M49] Liu, Q. et al., 2018, doi:10.1007/s11104-018-3619-4.
[M50] Qiu, H. N. et al., 2022, doi:10.3390/plants11131690.
[M51] Quemada, M. et al., 2013, doi:10.1016/j.agee.2013.04.018.
[M52] Land, M. et al., 2016, doi:10.1186/s13750-016-0060-0.
[M53] Zhang, G. X. et al., 2023, doi:10.1016/j.fcr.2022.108787.
[M54] Daryanto, S. et al., 2017, doi:10.1016/j.agwat.2017.05.005.

FURTHER READING

- European Commission, iMAP wiki (https://wikis.ec.europa.eu/display/IMAP/IMAP+Home+page).
- Water scarcity:
  - European Commission, 'Water scarcity and droughts' (https://environment.ec.europa.eu/topics/water/water-scarcity-and-droughts_en).
  - European Commission, Joint Research Centre, De Roo, A., Bisselink, B. and Trichakis, I., *Water-energy-food-ecosystems pathways towards reducing water scarcity in Europe – Analysis using the water exploitation index plus*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/478498 (https://data.europa.eu/doi/10.2760/478498).
- Water and climate:
  - European Commission, Joint Research Centre, Bisselink, B., Bernhard, J., Gelati, E., et al.., *Climate Change and Europe's Water Resources*, Publications Office of the European Union, Luxembourg, 2020, doi:10.2760/15553 (https://joint-research-centre.ec.europa.eu/system/files/2020-05/pesetaiv_task_10_water_final_report.pdf).
  - European Environment Agency, European Climate Risk Assessment, EEA Report No 01/2024, Publications Office of the European Union, Luxembourg, 2024, doi:10.2800/204249 (https://www.eea.europa.eu/publications/european-climate-risk-assessment).

FARMING PRACTICE DEFINITIONS

- **Biochar** is charcoal that is produced by the thermal decomposition of biomass at elevated temperatures in the absence of oxygen. It is used to store carbon while improving soil functions.
- **Cover crops** are grown to provide vegetative cover between rows of main crops in orchards and vineyards, or in the period between two main arable crops, to prevent erosion and minimise the risk of surface run-off by improving the infiltration. They may also function as **catch crops**, which scavenge the remaining nitrogen after the main crop is harvested, thereby reducing nutrient losses from leaching.
- **Landscape features** are small fragments of natural or semi-natural vegetation in an agricultural landscape that provide ecosystem services and support for biodiversity, such as hedgerows, ponds, ditches, small wetlands, trees in rows, in groups or isolated, field margins, buffer strips, terraces, dry stone or earth walls, individual monumental trees, water streams, springs or historic canal networks. A buffer strip is an area of land maintained in permanent vegetation at the margin of a field, arable land or a watercourse. Small wetlands are small, transiently flooded surface depressions covered with wetland vegetation and embedded in an agricultural landscape. This class includes the remnants of historic wetlands or freshwater ecosystems and constructed wetlands.
- **Mulching** is defined as the application of various cover materials to the soil surface, primarily to minimise moisture loss and weed growth and to increase crop yield. The most common mulching materials used in commercial agricultural systems are plastic film, biodegradable film and straw. Living mulch is not included here.
- **Deficit irrigation** is an optimisation strategy in which irrigation is applied during the drought-sensitive growth stages of a crop.
- **Nitrification inhibitors** are substances that, in combination with fertilisers, delay the bacterial oxidation of ammonium to nitrite for a certain period by suppressing the microbial activity. In this way, mineral nitrogen is retained as ammonium, which is less prone to leaching than nitrate, and which cannot be lost to the atmosphere by denitrification.
- **Urease inhibitors** are substances that can be added to nitrogen fertilisers (both organic and mineral, excluding nitrate-containing mineral fertilisers) to delay the hydrolysis of urea into ammonium by blocking the urease-binding sites.

Suggested citation

Bosco, S., Perez-Soba, M., Chen, M., Montero-Castaño, A., Schievano, A., Tamburini, G., Catarino, R., Guerrero, I., Bielza, M., Assouline, M., Angileri, V., Dentener, F., Makowski, D. and Terres, J.M., *Scientific evidence on farming practices improving sustainable water management in agriculture*, European Commission, Italy, 2024, JRC137742.

Contact information

Jean-Michel.TERRES@ec.europa.eu, Simona.Bosco@ec.europa.eu

EU Science Hub
joint-research-centre.ec.europa.eu