Guidelines for sustainable soil management
Digest: Agriculture

Caring for Soils
- Where Our Roots Grow

March 2020

Project:

Links4Soils (ASP399) www.alpine-space.eu/projects/links4soils

Funding:

EU Interreg III c Alpine Space programme www.alpine-space.eu

WP, Task and Deliverable:

Deliverable D.T.3.3.1 Management practices and guidelines for improved cross-sectoral management of tourism/agricultural areas

Task lead:

University of Torino, Department of Agricultural, Forest and Food Sciences

Editor

Dr Borut Vrščaj

Authors (alphabertical order)

Colombo N., D'Amico M., Freppaz M., Hudeck C.,Pintaldi E., Stanchi S., Viglietti D., Zecca O.

Acknowledgements:

We would like to aknowledge the Links4Soils Project partners for the cooperation and commitment during the project

How to cite

Links4Soils, 2020: Guidelines for sustainable soil management Digest: Agriculture. Links4Soils project publications. EU Interreg Alpine Space; Links4Soils project. ISBN 978-88-99108-19-9.

Version:

Final English version

Date:

March 2020

Summary for decision-makers

These guidelines collect the current state of knowledge about good management practices for sustainable soil management that could potentially be applied also in mountain agriculture.

The aim is to provide a synthetic, straightforward tool for practitioners, in order to mitigate the potential threats affecting mountain soils, and to promote sustainable soil management. This booklet describes some threats that are particularly relevant to mountain soils, and suggests selected mitigation measures taken from existing literature on agricultural soils, that we think could be transferred to mountain regions, maybe with some local adaptation.

Content

Figures

1 Introduction: what is the challenge in this sector?

Mountains soils, and among them mountain soils, provide food for a relevant number of people, including those living on lowlands (FAO, 2015). They required a long time to form and provide a wide range of ecosystem services (Figure 1) besides primary production, such as water filtration and purification, water retention, and surface runoff regulation. In addition, they actively contribute to nutrient cycling and act as a C sink, helping the mitigation of climate change. Besides the agricultural use, they host biodiversity and contribute to the landscape value. On the other hand, agricultural soils on mountain areas are subject to increasing threats, such as erosion, compaction, and sealing, that can lead to quick degradation of the soil properties and thus of the services provided. This is why the agricultural soils of mountain areas require a careful management, in order to preserve this important resource for future generations.

Figure 1: Hay meadows near Verrayes, a typical agricultural landscape in the Aosta Valley (Photo: S. Stanchi).

2 Guidelines for sustainable soil management in agricultural soils

2.1 Water erosion

Water erosion occurs when the precipitation intensity exceeds the soil infiltration capacity, with a consequent detachment and redistribution of fine soil particles along the slope.

The most erodible size classes are silt and very fine sand (Wischmeier and Mannering, 1969). In addition, poor soil structure, limited porosity, and limited organic matter content enhance the soil erodibility. The amount of mobilized particles mobilized depends on size and velocity of the raindrops, and the erosion rate is naturally high in mountain areas due to steep slopes and poorly aggregated soils. In this context, the soil erosion rate can exceed the rate of soil formation (FAO, 2015; Egli and Poulenard, 2016), thus making accelerated erosion irreversible. Estimated erosion rates in the Alps often exceed 50 t ha^{-1} y^{-1} (Panagos et al., 2015), and minimizing this hazard is one of the goals recommended by FAO in the Voluntary Guidelines for Sustainable Soil Management (2017). Water erosion depends not only on rainfall amount and distribution, topography and soil properties but can be influenced by soil management. For example, associating crops with permanent grass cover can significantly mitigate soil loss by water erosion on steep slopes (Halecki et al., 2018). Among the different agricultural uses, sloping vineyards are very susceptible to soil erosion, and this is particularly true when the grass cover is absent (Kosmas et al., 1997).

Besides water erosion, also wind and tillage operations can induce erosion processes. Globally, FAO estimated a 0.9 mm average rate of soil loss by water, wind and tillage. In general, tillage has a strong negative impact on soil physical properties (e.g. Prosdocimi et al., 2016). Additionally, in tilled soils the pore system and thus the soil structure can be altered, reducing the infiltration rate with respect to no tillage systems, where the topsoil aggregates are generally more stable (Raclot et al., 2009).

In order to mitigate soil erosion, several techniques have been proposed and can be applied also in mountain regions.

- Limiting land use changes such as deforestation and improper conversion of pastures into arable land should be avoided, as they can cause a depletion of soil organic matter, which makes soils more prone to erosion processes. In addition, appropriate stocking rates and grazing intensities should be applied to avoid compaction and surface denudation by overgrazing (fig.2).
- No tillage is a cultivation technique that does not disturb the soil structure and no releases of the crop residues on the ground. This technique is therefore recommended for erosion control. Machines usually make a one-pass planting and eventually a second passage for fertilizing. No tillage has been defined by Busari *et al.* (2015) as the most environmental friendly agricultural management, resulting in higher aggregate stability and porosity in the topsoil. It can be associated with direct seeding together with mulching or use of cover crops, in order to improve soil conservation. However, no tillage technique means also a weaker mixing between organic and mineral fraction. This implies that the organic matter is not incorporated well in the mineral horizon, being therefore limited at the surface, thus causing a superficial plant roots development and consequently possible water stress during dry periods.

- Minimum tillage represents a compromise between conventional agriculture and no tillage system. Minimum tillage is the first step towards conservation agriculture, since it reduces the mechanical impacts on soil. The tillage depth is limited and the remixing of soil horizons should be avoided as much as possible; tillage occurrence is kept at the minimum and crop rotation/fallowing is encouraged. The instruments used in minimum tillage are commonly pulled by the tractors without the use of power take-off. Crop residues are released on soil surfaces (around 30% of the surface). This technique is usually applied for different objectives: stubble breaking (i.e. mixing crop residues with the topsoil), seedbed preparation, mechanical weed control and destruction of soil lumps after ploughing. Just like in no tillage systems, minimum tillage promotes soil aggregate stability and increases the resistance of soil aggregates to the splash effect of the raindrops. Jacobs et al. (2010) also observed that minimum tillage, compared to traditional cultivation techniques, improved aggregate stability as well as increased the concentrations of organic C and N within the topsoil aggregates. -Ridge tillage consists in planting crops on top of raised ridges or beds, which are prepared prior to the cropping season. Primary tillage is therefore confined to these ridges. Ridges are alternated with furrows protected by crop residues, with positive effects on moisture-holding capacity, soil fertility maintenance and biological activity and thus on water erosion and nutrient depletion by run-off. Despite there are evidences that ridge tillage can be an economically viable alternative to conventional tillage, with positive effects on soil conservation, this practice is still rarely applied. Similarly, hedges across long, steep slopes can reduce soil erosion as they intercept and slow down surface run-off water, preventing the formation of deep rills and gullies.
- Contour farming is the practice of tilling a slope along the contour lines. By increasing the soil surface roughness, contour ridging results in rainwater ponding in the furrow area, which reduces run-off velocity, increases infiltration, and thus reduces soil erosion. It is particularly useful also to prevent nutrients loss by run-off in irrigated plots.
- Intercropping is the growth of two or more crops in the same field during a growing season to promote the interaction between them. As in any biodiverse ecosystem, the interaction between complementary plants enhances the overall stability of the system, including a significant resilience against pests, diseases and weeds. This practice increases soil porosity and supports organic carbon and nitrogen cycles; there are indications of positive effects on soil biology and biodiversity, too.
- Buffer strips are areas of natural vegetation cover (grass, bushes or trees, and their combinations) at the margin of fields and arable land. Providing permanent soil cover, buffer strips offer optimal conditions for effective water infiltration and run-off reduction, i.e. they promote the natural retention of water. They can also significantly reduce the amount of suspended solids, nitrates and phosphates transported by water run-off.
- Man-made terraces have been widely used since ancient times in order to retain water and control erosion along severe slopes. They are normally constructed by cutting and filling to produce a series of flat or nearly flat surfaces, and reinforced by embankments made of soil or stonewalls. Bench terraces needs intensive labour and investment for construction and maintenance and, for this reason, they have often been abandoned in the last centuries (Stanchi et al., 2012).
- In order to control and direct water flows, a carefully designed system of drainage channels is essential. In addition, run-off amount and velocity can be successfully contained by cross slope barriers (e.g. grass strips and stone lines) and grassed waterways.

As a rule on severe slopes, keeping a permanent soil cover is also recommended in order to maximize erosion control.

Figure 2: Overgrazed area, with to intense surface erosion in the Lepontine Alps (Val Cavargna, Lombardy)

Figure 3: View of the Links4Soils experimental vineyard at the Institut Agricole Régional, in Aosta. Collection tanks are well visible at the end of each row (Photo: O. Zecca)

2.2 Organic matter and nutrients loss

The soil organic matter (SOM) is a major terrestrial pool for C, N, P, and S, and the cycling and availability of these elements is fundamental for soil functioning and quality conservation. In particular, soil organic matter plays a crucial role in climate change adaptation and mitigation, and the global storage of SOM into soils should be stabilized or increased.

Usually, decomposition rates in mountain areas are slow and the organic matter derived from vegetation residues tends to accumulate on the soil surface. Agriculture practices can strongly influence the stock of soil organic matter especially in the top horizons because tillage can influence the SOM turnover. In particular, tillage is used to mix and aerate the soil, and to incorporate cover crops, crop residues, manure, fertilizers and pesticides into the rooting zone. This technique has implication on microbial biomass, both in terms of stock and composition; because it can change substrate availability and pedoclimate (i.e. soil temperature and moisture). Additionally, tillage can expose organic carbon previously protected into aggregates with a consequent increase of microbial activity, thus boosting mineralization and turning the soil from sink into source of C. Fertilization is one of the most important factors influencing the amount of organic matter in soils. Since most of agricultural lands are N-limited, nitrogen fertilizers are largely used. Since the nitrogen application is subject to losses by volatilization, immobilization, denitrification and leaching, it may be necessary to compensate this by adjusting the fertilizer management.

Many measures can be proposed in order to minimize SOM and nutrients loss in mountain soils. Most of them also contribute to limit erosion and run-off, which transport soil particulate and nutrients.

- Pay attention to irrigation. Excess water can flush nutrients and organic matter in the soil to water bodies by run-off and sub-surface flow. It is desirable to use systems like drip irrigation or sub-irrigation that optimize the water-use efficiency and minimize nutrients leaching, besides limiting erosion.
- Preserve the areas with carbon-rich soils such as peatlands (Fig. 4) and forests.
- Increase organic matter content of agricultural land with appropriate fertilization management based on a calculated nutrient balance for different soil types, soil nutrient status and crop. It is useful to apply animal manure and/or compost to improve soil stability through SOM input. When possible, it is recommended to cover the manure in order to decrease nutrient losses (i.e. via ammonia volatilization) and dilution effect caused by rainwater. When possible, integrated systems should be adopted (e.g. crop-livestock systems or crop-livestock-forest-systems).
- Avoid or limit agricultural burning especially on steep or long slopes that have a high risk of erosion. Moreover, fire can reduce soil carbon and nitrogen concentrations thus releasing large amount of CO_2, CH_4 and NOx that contribute to the greenhouse effect.
- Adopt reduced- or no-tillage practices that limit the quick mineralization of SOM.

Figure 4: A peat-bog in Slovenia. Peatbogs act as carbon sinks and contribute to climate change mitigation (Photo: S. Stanchi)

2.3 Soil compaction

Soil compaction derives from a reduction of soil porosity that determines an increase of soil bulk density and formation of platy aggregates. In healthy soils, 50% to 60% of the soil is made of voids, while porosity in compacted soils can be reduced from 30% to 40%, thus impeding root development. Soil texture is one of the most important factors that influence the susceptibility to compaction. Finer textures are the most susceptible to compaction. Soil compaction determines a significant reduction of soil functionality (e.g. affecting infiltration rate of water and nutrients, limiting biodiversity etc.) and biomass production (e.g. impeding root penetration). Unsuitable agriculture practices can increase compaction: a plough pan is characterized by a hard layer due to excessive vehicle passage and heavy mechanization; it is often observed in arable soil. On steep slopes, the plough pan and the subsequent impeded infiltration can drastically increase the risk of landslide or topsoil instability. The negative effects of mechanization are maximum when the soil is moist, and compaction can affect also the subsoil with permanent consequences. Not only agriculture practices, but also timber harvesting can reduce soil porosity, with negative effects which may persist for years. All the practices that promote SOM incorporation and structure formation are effective in preserving an optimal soil porosity.

No tillage determines a significant reduction of tractor passage thus limiting the risk of compaction. Simplified cultivations are to be preferred to preserve the vertical orientation of soil pores and aggregate stability and consequently to avoid the severe packing.

- Stop field works, harvesting and mechanization when soils are too wet (Fig. 5). If the surface layers are moist and soft, while the subsoil is dry, the topsoil may be strongly compressed. The best condition to work is restricted to when soil moisture is below the field capacity.
- Preserve soil organic matter, promoting the formation of good soil structure and decreasing the soil bulk density. It can be helpful to increase the soil organic matter content with animal manure, green manure and/or leaving crop residues in field.

- Disrupt hard pan mechanically for example, as suggested by using narrow tines, winged tines or vertical disks to obtain a relatively undisturbed but fissured surface layer.
- Prefer cropping systems and agroforestry including crops plants with the strong root system that can break up compacted soils.
- In pasture, ensure a sufficient vegetation cover of growing in order to limit trampling, compaction and erosion; keep grazing intensity and timing sustainable.

Figure 5: A compacted forest soil affected by severe compaction and, consequently, waterlogging (Photo: S. Stanchi)

2.4 Soil contamination

Contaminants are substances that can determine an environmental damage, irreversible or reversible. The contamination status is usually reached when the concentration of physical, chemical or biological agents exceeds the thresholds for health, safety or welfare.

Soil contaminants in agriculture are often related to the use of pesticides containing pharmaceuticals, PCBs, PAHs. Moreover, heavy metal input in agriculture is caused by anthropogenic activities like fertilization and amendment practices, which are commonly used to increase soil productivity (for example phosphate fertilisers usually contains cadmium).

The use of pesticides increased the food production over the last few decades (Oerke, 2006).

Large use of pesticides, herbicides and fertilizes can determine soil contamination. A contaminated soil has exceeded its capacity for natural attenuation for one or more substances, and consequently passes from acting as a protector to cause adverse effects to the water system, the atmosphere, and organisms.

Effects of pollutants strongly depend on their bioavailability, which in turn depends on environmental conditions (pH, moisture content, adsorption complex), and detoxification pathways in organisms.

For example, copper is traditionally used in fungicide treatments for several crops, like grapevine, olive, and tree fruits, including organic productions.

To avoid soil contamination, it is recommended to adopt a rational use of pesticides, herbicides and fertilizers, in association with accurate monitoring of the field conditions (e.g. soil moisture) and meteorological forecasts (for example avoid the treatments before rainfalls). Pesticide fate in the environment depends on the rate, timing, and method of application, as well as a variety of dynamic and interrelated physical, chemical, and biological processes. Careful consideration of these processes and their interactions is necessary to evaluate the risk to groundwater and surface water.

Buffer strips next to arable land are very effective to reduce the volume of suspended solids, nitrates and phosphates transported by run-off to water bodies. Although buffer strips reduce the agricultural surface, they are very effective in limiting the yield of suspended solids, P and N (Bradbury and Kirby, 2006). Morschel et al. (2004), for example, demonstrated that grass strips significantly reduce pollution in water bodies and soil, also preserving natural biodiversity.

2.5 Biodiversity loss

Soil biodiversity (Orgiazzi et al., 2016) can be described in many ways including:

- ecosystem diversity which encompasses the variety of habitats in the soil.
- Species diversity is the variety and abundance of different types of organisms which inhabit a soil. This is similar to the concept of taxonomic diversity.
- Genetic diversity is the combination of different genes found within a population of a single species, and the pattern of variation observed within different populations of the same species. This can also be assessed across the whole community of organisms.
- Phenotypic diversity is based on any and/or all of the morphological, biochemical or physiological aspects of the organism in the soil and is a result of genes and environmental factors.

• Functional diversity is the variety of functions performed by the soil biota such as nitrification and litter degradation.

Soil biodiversity decline can be interlinked with erosion, organic matter depletion, contamination and compaction. In fact, the increased use of fertilizers, pesticides and herbicides has significantly reduced biodiversity. Moreover, monoculture, removal of crop residues, soil erosion and soil compaction can threaten biodiversity.

The decline in soil biodiversity is defined as a reduction of living organisms in the soil (both in term of quantity and variety) and of related functions: these reductions have a negative effect on resistance to change and resilience (i.e. the ability to recover after perturbations). It is widely recognised that soil biodiversity adaptation to a change in land use requires decades to reach a new equilibrium.

In order to preserve biodiversity in mountain soils, many strategies can be adopted, such as:

- maintain or enhance the soil organic matter content with sufficient vegetative cover, well-balanced nutrient additions and limited soil disturbance.
- seed nitrogen fixing leguminous species in order to increase soil nutrients available for microbial biomass and vegetation.
- promote crop rotation, inter-cropping, and preservation of field margins, hedges and encourage biodiversity refuges. Consider the habitat and feeding needs for local endangered species, such as birds and pollinators. For example, while pollinators take advantage of permanent grassing, some bird species (i.e., hoopoes) or nest (i.e., bee-eaters) in bare soil and therefore need a minimum surface cleared from vegetation.

3 Conclusions

Mountain agriculture faces several challenges due to harsh site conditions such as steepness and climate. In addition, it is often based on family farming. The conservation of healthy soils in mountain areas is fundamental both for the ecosystem and for human well-being. Sustainable soil management is a fundamental step in order to keep alive agricultural soils and their functioning and to cope with the main soil threats affecting soil quality and fertility.

Did you know?

Mountain soils perform vital ecosystem services and contribute to ensure food security and nutrition to 900 million mountain people around the world. In addition, they benefit billions more living downstream (FAO, 2015).

According to FAO (2015) they host 25% of the terrestrial biodiversity including agro-biodiversity, gene pools for locally adapted crops and livestock.

References

Bradbury RB, Kirby WB 2006. Farmland birds and resource protection in the UK: Cross-cutting solutions for multi-functional farming? https://doi.org/10.1016/j.biocon.2005.11.020

Busari MA, Kukal SS, Kaur A et al., 2015. Conservation tillage impacts on soil, crop and the environment. https://doi.org/10.1016/j.iswcr.2015.05.002

Egli M, Poulenard J, 2016. Soils of Mountainous Landscapeshttps://doi.org/10.1002/9781118786352.wbieg0197

FAO. 2015. Understanding Mountain Soils: A contribution from mountain areas to the International Year of Soils 2015, by Romeo, R., Vita, A., Manuelli, S., Zanini, E., Freppaz, M. & Stanchi, S. Rome, Italy.

FAO 2017. Voluntary Guidelines for Sustainable Soil Management. Food and Agriculture Organization of the United Nations Rome, Italy.

Halecki W, Kruk E, Ryczek M, 2018. Evaluation of water erosion at a mountain catchment in Poland using

the G2 model. https://doi.org/10.1016/j.catena.2018.01.014

Jakobs A, Helfrich M, Hanisch S et al., 2010. ffect of conventional and minimum tillage on physical and biochemical stabilization of soil organic matter. https://doi.org/10.1007/s00374-010-0472-x

Kosmas C, Danalatos N, Cammeraat LH, 1997. The effect of land use on runoff and soil erosion rates under Mediterranean conditions. https://doi.org/10.1016/S0341-8162(96)00062-8

Morschel J, Fox DM, Bruno JF, 2004. Limiting sediment deposition on roadways: topographic controls on vulnerable roads and cost analysis of planting grass buffer strips. https://doi.org/10.1016/j.envsci.2003.10.003

Oerke EC, 2006. Crop losses to pests. doi: https://doi.org/10.1017/S0021859605005708

Orgiazzi, A., R.D. Bardgett, E. Barrios, V. Behan-Pelletier, M. J. I. Briones, J. L. Chotte, G. B. De Deyn, P. Eggleton, N. Fierer, T. Fraser, K. Hedlund, S. Jeffrey, N. C. Johnson, A. Jones, E. Kandeler, N. Kaneko, P. Lavelle, P. Lemanceau, L. Miko, L. Montanarella, F. M. de Souza Moreira, K. S. Ramirez, S. Scheu, B. K. Singh, J. Six, W. H. van der Putten, and D. H. Wall. 2016. Global Soil Biodiversity Atlas. European Commission, Publications Office of the European Union, Luxembourg

Panagos P, Borrelli P et al. 2015. The new assessment of soil loss by water erosion in Europe. https://doi.org/10.1016/j.envsci.2015.08.012

Prosdocimi M, Cerdà A, Tarolli P 2016. Soil water erosion on Mediterranean vineyards: A review. doi:10.1016/j.catena.2016.02.010

Raclot D, Le Bissonnais Y, Louchart X et al., 2009. Soil tillage and scale effects on erosion from fields to catchment in a Mediterranean vineyard area. http://doi.org/10.1016/j.agee.2009.06.019

Stanchi S, Frepppaz M, Agnelli A et al., 2012. Properties, best management practices and conservation of terraced soils in Southern Europe (from Mediterranean areas to the Alps): A review. doi: 10.1016/j.quaint.2011.09.015

Wischmeier WH, Mannering JW, 1969. Relation of Soil Properties to its Erodibility. doi:10.2136/sssaj1969.03615995003300010035x

Imprint

About this report

These guidelines collect the current state of knowledge about good management practices for sustainable soil management, that could be potentially be applied also in mountain agriculture.

About the Links4Soils project

The Links4Soils project focuses on awareness raising on soils in Alpine region, review of the existing regional and national soil data, transfer of knowledge and best management practices to policymakers and other stakeholders, and the promotion of efficient soil protection strategies. Links4Soils aims to overcome soil awareness, information, knowledge and networking gaps and to contribute to better implementation of the Alpine Convention Soil Protection Protocol.

Links4Soils project partners

Agricultural Institute of Slovenia, SI (project leader) ● Office of the Tyrolean Provincial Government, AT ● Autonomous Region of Aosta Valley, IT ● Municipality of Kaufering, Department of Environment and Nature, DE ● National Research Institute of Science and Technology for the Environment and Agriculture, Grenoble Regional Centre, Mountain Ecosystem Research Unit, FR ● Slovenian Forest Service, SI ● Institute of Geography, University of Innsbruck, AT ● Climate Alliance Tirol, AT ● University of Torino, Department of Agricultural, Forest and Food Sciences, IT

Acknowledgements

This project is co-financed by the European Regional Development Fund through the Interreg Alpine Space programme.

WEB links

Links4Soils Internet IIIC Alpine Space: www.alpine-space.eu/projects/links4soils

Alpine Soils: www.alpinesoils.eu

Additional information and contacts

info@alpinesoils.eu