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Handbook of soil restoration using vegetation



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1 Handbook of soil restoration using vegetation

1.1 Introduction

Soil degradation is widespread and a serious concern across Europe and China. This handbook draws on the work of the TUDI project funded by the European Union's Horizon 2020 Research and Innovation action. TUDI – Transforming Unsustainable management of soils in key agricultural management systems in EU and China – has carried detailed work into the how plants can influence soil health and be used to restore soils. Here we draw on this work to produce **a handbook to introduce growers, farmers and advisors to the potential for using vegetation to restore degraded soils.**

Our focus is on restoring soil function rather than restoring landscapes or wider habitats from either a hydrological or ecological perspective.

More detailed information on TUDI's work with vegetation and additional guides to soil and landscape restoration can found on the project's website, **TUDI-project.org**.

1.2 Soil restoration

Soil is multifunctional (*Figure 1*); it provides a substrate for plant growth and supplies plants with water and nutrients; stores, filters and transports water, supplying rivers and lakes; provides habitat for more species than any other ecosystem; supplies materials for fuel and construction; and is the largest active terrestrial carbon store. It is also of deep cultural significance for some communities.

Soil restoration is the process of improving the functioning of damaged or degraded soils to restore them back to their full potential and ensure they continue to perform these essential functions.

Soil restoration includes various techniques and management practices. You can find guides to a number of soil restoration approaches at TUDI-project.org. These guides include the use of organic amendments, cover crops, agroforestry and approaches to gully erosion control amongst others.

Here we focus on the **use of vegetation**, which is part of a suite of measures often referred to as **nature-based solutions**. These strategies use or replicate natural functions to improve soil health and restore ecosystems. As they are based on natural processes, the hope is that these solutions can be self-sustaining help restore degraded agricultural lands and support long-term productivity.

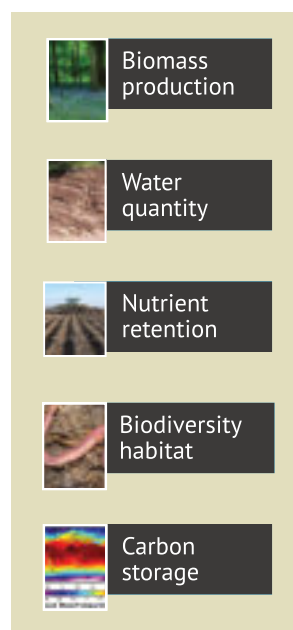


Figure 1. Key soil functions

There are two main types of restoration associated with the use of vegetation:

- **Active restoration:** Involves human intervention such as seeding or planting, mowing, or controlled grazing.
- **Passive restoration:** Involves letting nature recover on its own, often by discontinuing human interventions such as agricultural practices. This is sometimes described as rewilding.

1.3 Soil degradation processes

In the following section we restate the TUDI definitions of soil condition and degradation.

Soil erosion

Soil loss, usually loss of the topsoil horizon (*Figure 2*), results in declines in organic matter and nutrients, degradation of soil structure, and reduced water retention, which can increase the risk of flooding and landslides in surrounding areas. The movement and deposition of eroded soils can significantly disrupt nutrient and carbon cycles. These environmental impacts also come with high economic costs, particularly associated with reduced agricultural value of land, highlighting the urgent need for effective soil and water conservation measures.



Figure 2. Maize field in China suffering from soil erosion. Credit: J. Quinton

Soil structure

Soil structure refers to the shape, size, and spatial arrangement of individual soil particles and aggregates with varying stability. Water storage and flow in soils are largely influenced by soil structure, which plays a key role in shaping the soil's pore network. Structural stability, pore connectivity, and the soil's ability to transmit water determine its infiltration capacity and influence surface runoff. The interaction between soil structure and hydrophysical properties is complex, multifaceted, and not yet fully understood.

Surface crusting (*Figure 3*) is one form of structural degradation. Intense spring and summer rainfall, followed by prolonged dry periods, is a common cause of surface crusting in structurally degraded soils. Crusting impacts soil properties both directly and indirectly. Direct effects include the inhibition of seed emergence, as well as restricted root and plant growth. Crusting also reduces soil permeability, decreasing water infiltration and increasing both the risk of erosion and soil penetration resistance (hardness).



Figure 3. The development of soil crusts can decrease infiltration rates and prevent seedling emergence. Credit: J. Quinton

Soil compaction

Soil compaction (*Figure 4*) occurs when pressure on the soil surface breaks down aggregated structural units, realigns soil particles, and increases bulk density. This results in reduced porosity, lower water holding capacity, and decreased infiltration rates, all of which hinder plant development compared to non-compacted soils.

Healthy soils are more resilient to compaction, especially when managed using soil-conserving practices and trafficked under sufficiently dry soil conditions.



Figure 4. Soils compacted during maize harvest in Northern England, where harvest often takes place in unfavourable conditions. Credit: J. Quinton

Soil organic carbon

Soil organic carbon (SOC), a key component of soil organic matter (SOM) (Figure 5), is a vital indicator of soil fertility. It enhances soil aggregation, stabilizes structure, increases nutrient availability, and improves water holding capacity. SOC also supports soil biodiversity, immobilizes toxic organic pollutants, sequesters carbon, and underpins essential ecosystem functions such as carbon and nitrogen cycling, as well as the maintenance of freshwater and groundwater quality.

A general decline in SOM has been observed across European soils. Changes in land use and land cover are among the primary drivers of SOC and SOM loss in Europe.



Figure 5. The surface horizons of soil are often rich in soil carbon, particularly in wet and cool environments. Credit: J. Quinton

Loss of biology

Biological degradation of soil refers to the decline in the abundance and diversity of soil fauna and flora (*Figure 6*). This degradation is often associated with reduced vegetation cover and biomass, as well as shifts in vegetation diversity resulting from changes in habitat composition. The use of mineral fertilisers and chemicals for weed, pest, and disease control negatively impacts both micro- and macro-organisms in the soil. In addition, physical disturbances such as erosion, sealing, and compaction further diminish soil biodiversity. Alongside these factors, soil physical and chemical properties—along with water availability and temperature—play a critical role in influencing the abundance and functioning of soil biota.



Figure 6. Soil organisms help to break down plant remains, release plant nutrients and create soil organic matter. Credit: Andy Murray

Nutrient imbalance

Maintaining a good balance of nutrients in the soil is essential for sustaining plant growth and productivity. Nutrient imbalance occurs when one or more essential nutrients are either deficient or present in excess relative to plant needs. Deficiencies can lead to reduced yields and lower crop quality, while excessive nutrient levels can harm the environment through losses from the soil system. In recent decades, the intensification of fertilization aimed at maximizing yields has contributed to significant environmental issues affecting air, water, and soil. Phosphorus (P) and nitrogen (N) pollution from agriculture has become a major cause of water contamination in both Europe and China.

Soil salinity

This is when salts accumulate in the root zone at amounts that reduce crop yield. Salts often originate from saline high water tables or from salts in irrigation water. Salts prevent the plant from taking up sufficient water affecting their growth. Some salts contain ions that can be toxic to plants, such as sodium, chloride and boron, which can affect yields. Salinity can be a significant problem, particularly in irrigated agriculture in arid and semi-arid climates.

Degradation prevalence across the TUDI partners

TUDI brought together information from 33 sites across its project partners and asked each partner to identify the soil degradation issues present on each of the sites (*Figure 7*). It is clear that even in long-term experiments soil degradation is present. Physical and chemical sources of degradation were higher than biological aspects, however, soil biological monitoring is in its infancy and therefore the loss of soil biology may be underestimated. Partners were also not asked to consider soil structural degradation, and it is possible that some will have included this within the soil compaction category.

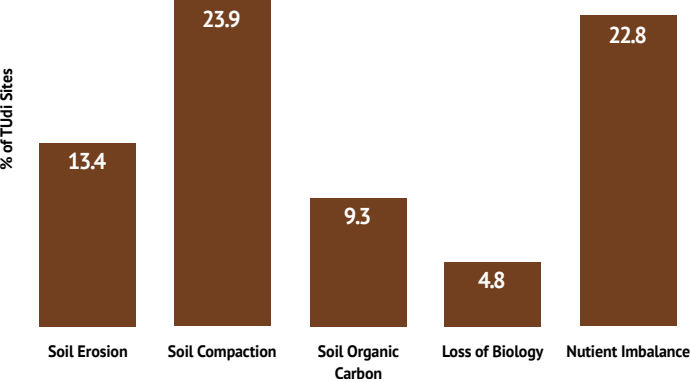


Figure 7. Proportion of the 33 sites from Austria (6), Bulgaria (3), China (1), Czech (5), Hungary (4), Italy (8), Spain (5), and UK (1) suffering from the six forms of soil degradation considered by the TUDI project (salinity was not present). Here we interpret nitrate leaching as reported in the original data as nutrient imbalance. Note that soil structure was not explicitly considered. Data from TUDI deliverable 3.1

1.4 The restorative effect of vegetation

Vegetation has long been part of the armoury for combatting soil degradation. Here we summarise the main restorative functions that can be provided by vegetation (*Figure 8*). They are grouped by plant characteristics or traits: these describe the morphological and physiological aspects of the plant and how they relate to the restorative functions provided by the plant. Plants have different rooting structures (*Figure 9*), canopy structures and grow at different rates. In terms of root structure, plants can be split into those with thick taproots and those with fibrous rooting systems. The distribution of plant roots is affected by the species and variety grown and the soil conditions. More detail on the restorative functions that plants can provide can be found in Dessureault-Rompré (2022).

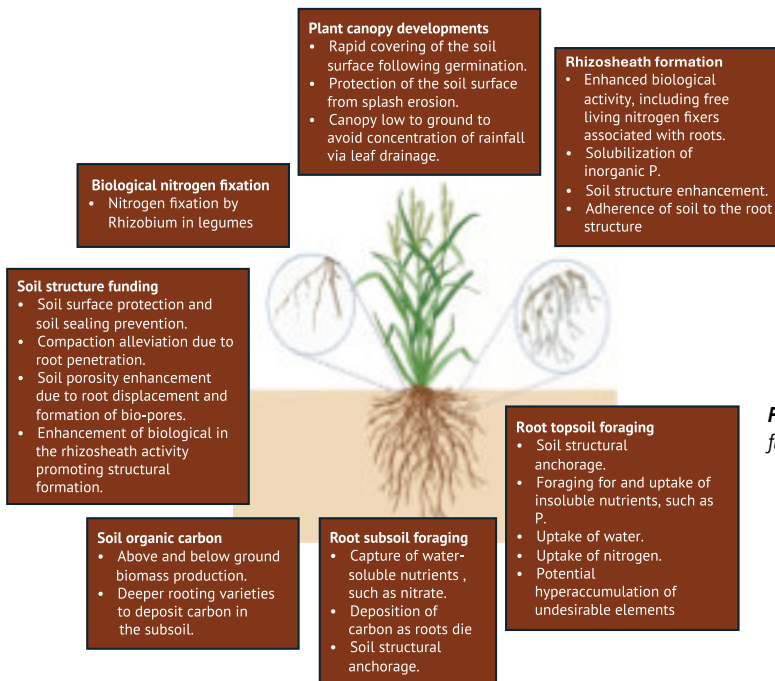


Figure 8. Restorative functions of vegetation

As well as climate, site-specific factors including topography and soil type will need to be considered when selecting vegetation species for restoration of a particular area. Therefore, to provide a useful tool for soil restoration across different environments, plants with a range of tolerances to different climatic, soil and topographic conditions are included in this handbook.

The methods used should be tailored to the specific soil type, environmental conditions, and land-use goals.

Tap Root



Fibrous Root



Figure 9. Taproots are found in dicotyledonous plants while fibrous or adventitious roots are found in monocotyledonous plants. Different rooting structures can have different impacts on the soil, with taproots being favoured for breaking up compaction and fibrous root systems being better at scavenging nutrients (figure developed using biorender.com)

1.5 Selection of vegetation species for soil health restoration

Set the soil restoration goal

Decide which soil functions do you want to restore? For example, an improve soil water holding capacity, alleviate compaction or increase nutrient levels.

Understand the site

Every soil restoration project is different, but successful ones start by understanding the sites abiotic constraints including its soil, climate (see Box 1), hydrology, landforms and land use. Without this understanding restoration attempts are likely to fail.

Address any abiotic barriers

Sometimes abiotic factors need addressing by means other than vegetation before vegetation can be established. Examples include large gullies, sites with severe compaction and areas with severe chemical contamination. Attempting to restore soil functioning without addressing the underlying abiotic constraints will increase the chance that the soil restoration scheme will fail. Guidance on addressing abiotic constraints can be found at **TUdi-project.com**.

Select species

Information on some of the most commonly used species for soil restoration can be found at the end of this handbook. However, the list is not comprehensive, and it is always important to take advice locally on the most appropriate species and species mixtures to use.

We recommend the following steps:

1. Make a shortlist of species that can address the soil function(s) that you wish to restore.
2. Take into consideration any soil constraints, for example knowing whether the soil is acid or alkali will affect the choice of species.
3. Consider the site's climate (see Box 1). This can be a major constraint on which species can be grown.
4. Prioritise native species where possible as these are more likely to thrive, being adapted to local conditions.
5. Using species mixtures (*Figure 10*) can be beneficial since different species can help to re-build different soil functions. Diverse mixes can also be more resilient and productive. For example, combining legumes with grasses and forbs can help to promote erosion control as well as increasing carbon capture.
6. Check that seed sources are available.
7. Consider trialling different species to check germination rates and that they provide the traits you require.
8. Monitor the success of the scheme. Tools such as the TUDI decision support tools available at **TUDI-project.com** can be very helpful in this regard.

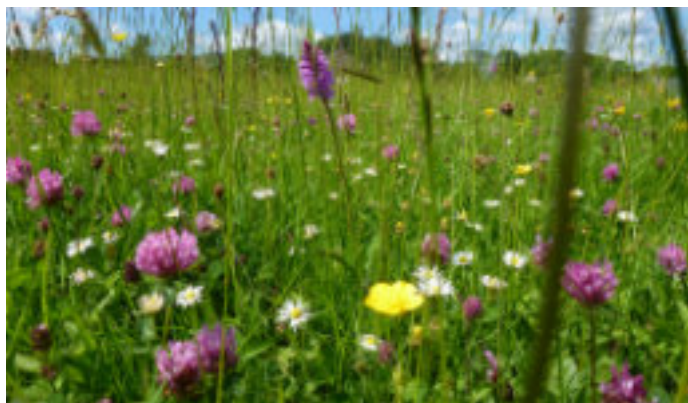


Figure 10. Species mixes can help to rebuild different soil functions. Credit: J. Quinton

Time frames

Restoration of soil functioning takes time. TUDI has estimated that restoration of croplands and grasslands can take between one and seven years to see improvements, and that for tree and vine-based systems the initial improvements may take in the order of ten years to come to fruition. The longer the intervention is maintained the stronger the restorative effect.

Follow up management

Poor follow-up management of vegetation can make or break a soil restoration scheme. In some schemes it will be essential to maintain the vegetation cover. This may mean cutting the vegetation periodically to promote growth or reseeding areas that have not established well.

Box 1: Climate

It is important the selected vegetation is adapted to the climatic conditions in the area it is to be grown in. Briefly the key elements of climate which influence the choice of species is as follows:

Temperature

Temperature influences seed germination, crop growth rates, flowering, and the timing of maturity. Extreme temperatures—either too high or too low—can stress plants, negatively impacting development and yields, and in severe cases, leading to crop failure or plant death.

Rainfall

Excessive rainfall can lead to waterlogged soils, which reduce oxygen availability to plant roots and promote the formation of toxic substances that hinder growth. Conversely, insufficient rainfall can cause drought stress, reduce plant productivity and potentially cause plant death in prolonged dry conditions.

Solar Radiation

As the primary energy source for photosynthesis, solar radiation is vital for plant growth. In northern latitudes, limited sunlight—especially if planting is delayed by poor weather—can prevent crops from completing their life cycles.

Humidity

Humidity affects the rate of plant transpiration and, therefore, water requirements. While it also influences the occurrence of pests and diseases, those topics fall outside the scope of this handbook.

Seasonality and Length of Growing Season

In northern regions, the growing season is significantly shorter than in southern Europe. This difference strongly influences which crops can be grown successfully in each region.

Extreme Weather Events

Extreme weather, such as heavy rainfall, drought, and storms, contributes to various forms of soil degradation—including erosion, crusting, and moisture stress. While research on the impact of extreme weather on soil biology is still limited, it is likely that prolonged or repeated events will have significant negative effects

1.6 Approaches to using vegetation for soil restoration

Here the focus is on soil, rather than landscape restoration. The report on TUDI deliverable 2.11 available at [TUDI-project.org](https://tudi-project.org) details other methods that use vegetation such as buffer strips, vegetative barriers, and hedges that can be important tools in restoration. In [TUDI-project.com](https://tudi-project.com) hosts a range of resources on these and other approaches.

Here we focus on species that may be used in cover cropping. Cover crops are, as the name suggests, used to cover the bare soil surface. This can occur after harvest or between the rows of a tree or vine crop. Typically cover crops include:

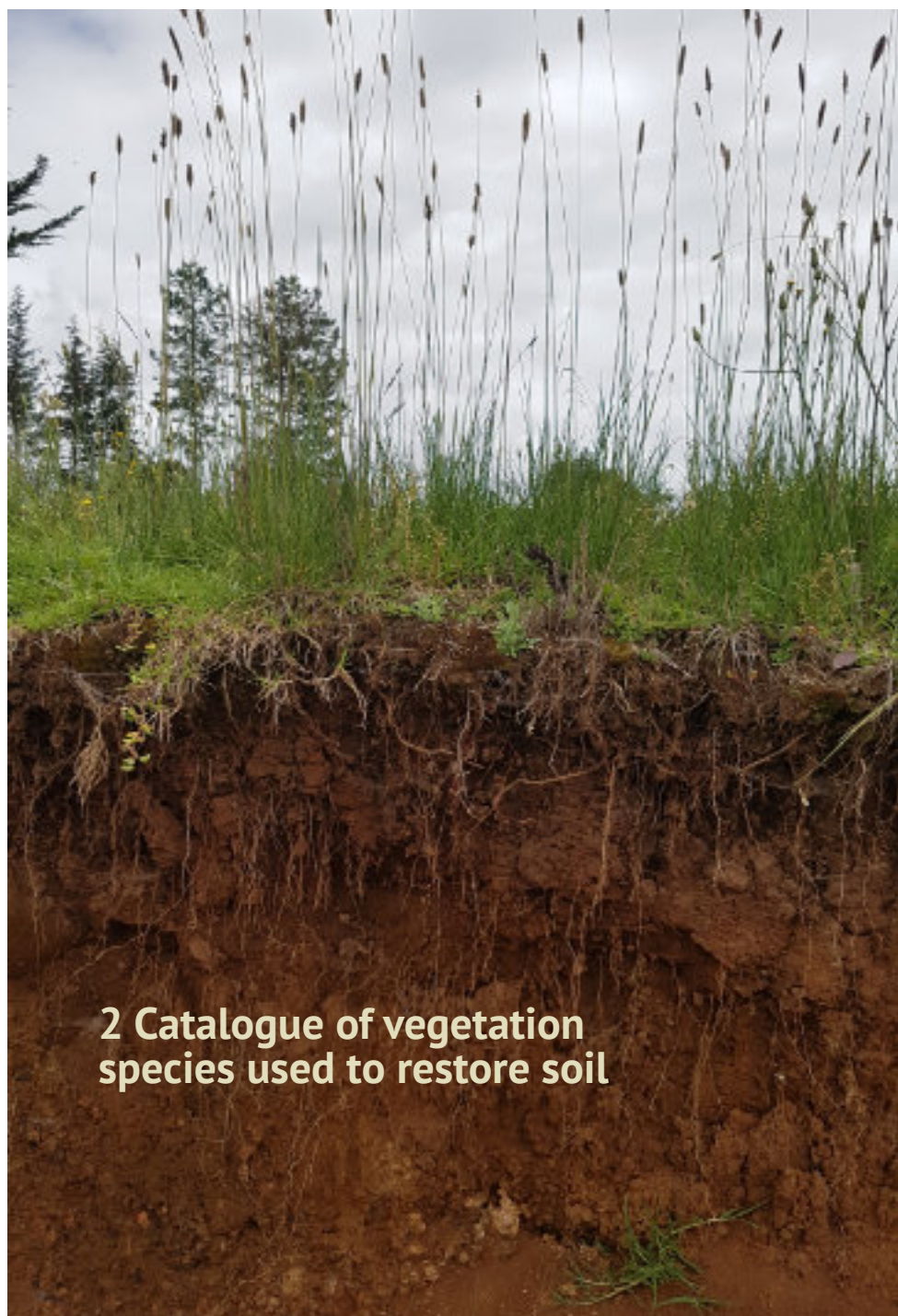
- Grasses (e.g. rye) that rapidly cover the soil surface thereby minimizing soil erosion.
- Legumes (e.g. clover) that have the potential to improve soil nutrient status by nodulation (N sparing).
- Tap-rooted species (e.g. oilseed radish) that can penetrate compacted soil layers.

In addition we include some species which have particular value in some circumstances (e.g. sea buckthorn).

Table 1 adapted from Hudek (2023) provides a summary of the soil restoration functions of common plants. More detail on each species can be found in section 2.

Table 1. Soil restoration functions provided by plants ■ High impact ● Moderate impact

Soil restoration functions provided by plants			Erosion Control	Increase SOM	Nutrient Uptake	Water Uptake	Topsoil Structure	Subsoil Structure	N Fixation
Name		Climate							
Grasses	Rye	Cool temperate	■	■	■	■	●		
	Black Oat	Cool temperate	■	●	●		●		
	Annual Ryegrass	Temperate and semi-arid	■	●	■	■	●		
	Tall Fescue	Temperate and semi-arid	■	●	●	●	■	●	
	Orchard Grass	Temperate and semi-arid	■		●	●	●		
	Millet	Temperate, tropical, semi-arid	●	■	●	●	●		
	Sorghum-Sudangrass	Warm temperate and tropical	■	■	■	■	●	●	
Brassicas	Mustard	Temperate	●	●	●	●	●		
	Canola	Temperate	●	●	●	●	●		
	Rapeseed	Temperate	●	●	●	●	●		
	Arugula	Mediterranean and semi-arid	●	●	●	●	●		
	Forage radish	Temperate to tropical	●	●	■	■	●	●	
	Forage turnip	Cooltemperate and semi-arid	●	●	■	■	●	●	
Legumes	Field Pea	Cool temperate	●	●	●	●	●		■
	Alsike Clover	Cool temperate	●	●	●	●	●	●	●
	Yellow Sweet Clover	Cool temperate	●	●	●	●	●	●	●
	Red Clover	Temperate	●	●	●	●	●	●	●
	Sainfoin	Temperate and semi-arid	●	●	●	●	●	●	●
	Alfalfa	Temperate and subtropical	●	■	●	●		■	■
	Hairy Vetch	Temperate to tropical	●	■	●	●	●	●	■
	Berseem Clover	Warm temperate to subtropical	●	●	●	●	●	●	●
	Cowpea	Tropical and Mediterranean	■	●	●	●	●	●	■
Herbs and Shrubs	Chicory	Cool temperate	●		●		■	■	
	Phacelia	Temperate	■		■		■		
	Common Yarrow	Temperate	■			●	■		
	Borage	Temperate and semi-arid	●	■			■	■	
	Sea Buckthorn	Cool temperate	■				■	■	●
	Buckwheat	Cool temperate	●	●	■	■	●		



2 Catalogue of vegetation species used to restore soil

Grasses

Grasses can provide a range of benefits for soil conservation and land restoration. Fast-growing annual grasses can be effective pioneer species, quickly colonising bare land and providing cover to reduce runoff and soil erosion. Perennial species can offer longer-lasting ground cover and stronger root systems, reducing erosion, improving soil structure, stabilising slopes, and enhancing water infiltration. Many grasses' high and fast biomass production can increase soil organic matter levels.



Picture credit: Mariana Rufino

Rye (*Secale cereale*)

Family: Poaceae (Grasses)

Role in Soil Restoration: Winter cover crop used to improve arable fields in cool temperate regions. Tolerant of a wide range of pH values and soil types. Winter hardy so provides good cover even in cold areas. A deep and extensive fibrous root system provides erosion control, improves topsoil structure and water infiltration, and captures nutrients, reducing leaching risk. Fast growth and high biomass production can boost soil organic matter. Has been shown to increase soil water storage capacity.



Picture credit: LSDSL (Wikimedia commons)

Character: Annual winter hardy cereal grain, grows up to 30 cm tall.

Environments: Cool temperate climates at altitudes of up to 4300 m. Prefers well-drained loamy soil at pH 5.0–7.0 but is tolerant of heavy clay or sandy soil and will grow in pH 4.5–8.0. Germinates at 5°C. Extremely frost tolerant (down to -34°C once established).

Propagation: Sow in late autumn at the first light frosts. Sow up to 5cm deep at a rate of 50–100 kg/ha. Fertilisation not needed if field previously fertilised as scavenges unused nutrients. Terminate growth before flowering (can be slow to decompose if it has flowered) in late winter/early spring by mowing to 15–30 cm tall and till into soil.

Uses: Overwinter cover crop for arable land, forage for livestock, overseeding for cash crops, rye grain can be used as a cash crop.

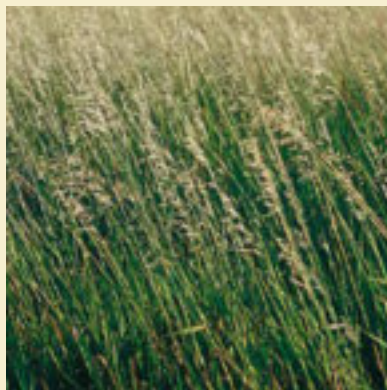
Sources / Further reading:

- Basche et al. (2016). Soil water improvements with the long-term use of a winter rye cover crop (<https://www.sciencedirect.com/science/article/pii/S0378377416301214>)
- Ecocrop Database (FAO) (<https://gaez.fao.org/pages/ecocrop-search>)
- Gardening know how (<https://www.gardeningknowhow.com/edible/grains/cover-crops/winter-rye-grass-growing.htm>)
- Cover crops guide (<https://covercropsguide.co.uk/selection/>)

Black Oat (*Avena strigosa*)

Family: Poaceae (Grasses)

Role in Soil Restoration: Cover crop and green manure. Extensive deep fibrous root system for erosion control and to scavenge nutrients from depth. Fast, high biomass production with a low C:N ratio meaning more nitrogen should be available to any following crops.



*Picture credit: Miquel Pujol Palol
(Wikimedia commons)*

Character: Upright annual grass growing 60–120 cm tall.

Environments: Cool temperate climates. Suited to moderate to low fertility soil and has some drought tolerance. Frost tolerance down to -8°C has been reported. Grows in a wide range of soil types preferring sandy or loamy soils, but can grow on heavy clay.

Propagation: Sow in August–October (May to September in the UK) at a rate of 50–75 kg/ha.

Uses: Generally grown as a winter cover and catch crop and for erosion control. Allelopathic properties of black oats can limit the growth of some weed species. It can also be used as animal forage.

Sources / Further reading:

- Ecocrop Database (FAO) (<https://fao.org/pages/ecocrop-search>)
- USDA (https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_avst2.pdf)
- Cover crops guide (<https://covercropsguide.co.uk/selection/>)
- Plants for a Future (<https://pfaf.org/user/Plant.aspx?LatinName=Avena+strigosa>)

Annual Ryegrass (*Lolium multiflorum*)

Family: Poaceae (Grasses)

Role in Soil Restoration: Low cost winter cover crop for temperate areas. Tolerant of poor, rocky or wet soils and can tolerate some flooding when established. Winter hardy. Has a dense shallow root system providing erosion control and increasing water infiltration rates and water holding capacity in the topsoil. Efficient nutrient capture, reducing leaching risk. Fast growth and high biomass production can boost soil organic matter following termination.



Picture credit: Matt Lavin (Flickr)

Character: Annual grass, winter hardy although can be killed by prolonged cold temperatures. Careful management needed to avoid establishment as a weed.

Environments: Temperate/semi-arid climates. Prefers fertile well-drained loam/sandy-loam soil at pH 5.0–7.5 but is tolerant of clay or poorly drained soil and tolerates pH 4.5–8.2. Can grow at altitudes from sea level to 2440 m.

Propagation: Sow at 22.5 kg/ha on top of freshly cultivated soil or at up to 1 cm depth. If using over winter, seed 40 days before first frost to reduce risk of winter kill. Germinates best at 10–18°C but has been reported to germinate at 4°C. Produces seed in late spring which can pose a weed problem; negate this by termination mechanically or with herbicides. To maximise nutrient release, delay seeding following crop for several weeks after termination.

Uses: As an arable winter cover crop, either alone or in mixtures with legumes. Ground cover in vineyards and orchards, however if not intensely mowed may compete with trees/vines for moisture and nutrients.

Sources / Further reading:

- Ecocrop Database (FAO) (<https://fao.org/pages/ecocrop-search>)
- (SARE) (<https://sare.org/publications/managing-cover-crops-profitably>)
- Johnny's Seeds (<https://johnnyseeds.com/growers-library/farm-seed-cover-crops/grasses-milletts-and-sorghums>)
- Penn State College of Agricultural Sciences (<https://northeastcovercrops.com/wp-content/uploads/2021/03/Ryegrass.pdf>)

Tall Fescue (*Festuca arundinacea*)

Family: Poaceae (Grasses)

Role in Soil Restoration: Stress tolerant plant so useful ground cover in many environments either alone or as part of a mixed grassland sward. Useful for soil stabilisation and erosion control due to its well-developed root system.



Picture credit: Bajra (Pixabay).

Character: Frost tolerant perennial grass growing to 80–160 cm tall.

Environments: Cool and warm temperate and semi-arid climates. Altitudes of up to 1600 m. Tolerant to many stresses (drought, excess moisture, cold, low fertility, pH range 4–9.5) so suited to a wide range of environments. Optimal annual daytime temperatures are 15–22°C, but can grow at 5–30°C. Frost tolerance down to -8°C has been reported. Tolerant of low fertility soil and a wide range of soil types. Wide pH tolerance, preferring pH 5.5–8 but tolerating 4–9.5.

Propagation: Sow in late spring to late summer (May to September in the UK) at a rate of 25 kg/ha (pure stand) or 1.25–5 kg/ha in a mixture.

Uses: Generally grown in mixed swards for animal forage or erosion control. There have been reports that the endophyte associated with the resilience of this plant may reduce the performance of grazing animals.

Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- USDA (https://plants.usda.gov/DocumentLibrary/factsheet/pdf/fs_loar10.pdf)
- Cotswold Seeds (<https://www.cotswoldseeds.com/species/65/tall-fescue>).

Orchard grass/cocksfoot (*Dactylis glomerata*)

Family: Poaceae (Grasses)

Role in Soil Restoration: Used as ground cover, as part of grassland swards, or to combat soil erosion in a wide range of environments and climates. Complex deep root structure provides soil stabilisation, reduces risk of erosion, improves soil structure and water infiltration.



Picture credit: Harry Rose (Flickr).

Character: Perennial grass that can grow to 20 to 120 cm and create tussocks if not grazed or cut.

Environments: Grows in a wide range of soil types and environments from sea level to 4000 m. Frost, drought and flood tolerant, able to survive hot summers, cold winters and a variety of moisture levels from waterlogged to semi-arid. Prefers annual daytime temperature of 12–26°C and pH 6–6.5 but can tolerate temperatures of 5–31°C and pH 4.5–7.5. When dormant it can survive to -25°C. Can grow in poor fertility soil.

Propagation: Sow in spring or autumn at 20 kg/ha (pure stand) or 5 kg/ha (in mixtures) at a depth of 1 cm. Frequent grazing/cutting advised to prevent the plant forming tussocks.

Uses: Pasture and hay production. Used as ground cover in agroforestry and in mixes with legumes and grasses to reduce erosion after fire.

Sources / Further reading:

- Cotswold Seeds (<https://temperate.theferns.info/viewtropical.php?id=Dactylis+glomerata>).
- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Useful Temperate Plants (<https://temperate.theferns.info/viewtropical.php?id=Dactylis+glomerata>).

Pearl millet (*Pennisetum glaucum*)

Family: Poaceae (Grasses)

Role in Soil Restoration: Summer cover crop used to improve arable fields. Dense fibrous root system provides erosion control, improves topsoil structure and water infiltration, and enables nutrient capture. Fast growth and high biomass production can boost soil organic matter.



Picture credit: Bajra (Pixabay).

Character: Annual drought tolerant grass, growing up to 3 m tall.

Environments: Warm temperate, tropical and semi-arid climates at altitudes of up to 1800 m. Annual daytime temperatures of 25–35°C are optimal for growth, but will tolerate 12–40°C. Prefers well-drained soil at pH 5.0–6.5 and is very drought resistant but is tolerant of medium textured soils and pH 4.5–8.3. Not frost tolerant.

Propagation: Sow in May – June, or mid-summer, if used as cover after an early season cash crop at depth of 1 cm. Sow at 6–12 kg/ha (pure stand) or proportional to the amount of millet seed in mixtures. Seed needs a temperature of 21°C for germination. Maturity reached in 100–110 days for seed harvest.

Uses: Plants and grains used as food for livestock. Grains can be cooked or made into flour for human consumption. Used as a warm season cover crop mainly in mixes e.g., with Sorghum-Sudangrass, cowpea or buckwheat.

Sources / Further reading:

- Growing Millets for Grain, Forage or Cover Crop Use-University of Missouri (<https://extension.missouri.edu/publications/g4164>)
- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Useful Temperate Plants (<https://temperate.theferns.info/viewtropical.php?id=Pennisetum+glaucum>).
- Pearl Millet for Grain- University of Georgia (<https://extension.uga.edu/publications/detail.html?number=B1216>).

Sorghum-Sudangrass (*Sorghum bicolor* x *Sorghum bicolor* var. *sudanese*)

Family: Poaceae (Grasses)

Role in Soil Restoration: Summer cover crop for improvement of arable fields in warm regions. Tolerant of a large range of pH values. Drought tolerant when established so good summer cover in dry areas. If managed correctly can form a deep root system, providing erosion control, improving topsoil structure by alleviating compaction and improving water infiltration. Also effective at capturing nutrients, reducing leaching risk. Fast growth and high biomass production can boost soil organic matter.



Picture credit: Harry Rose (Flickr).

Character: Heat-loving summer annual grass, grows 1.5–3.5 m tall if unmown.

Environments: Warm temperate, tropical and semi-arid climates. Prefers fertile soils and near neutral pH but can tolerate low fertility and pH from 5.0–9.0.

Propagation: Not frost tolerant, so should be planted after the soil warms up to 18°C in spring or summer, but at least two months before the first frost. Sow in moist soil up to 5cm deep at 40–55 kg/ha. Once established it withstands drought by going nearly dormant. Grazing or mowing to 15 cm when around 1 m tall encourages tillering and deeper rooting and keeps regrowth less fibrous. Delayed planting (within 2 months of frost) makes mowing unnecessary. Terminate by frost killing (or herbicide) then chop for faster incorporation.

Uses: Summer cover crop for arable land, provides forage for livestock. Important: do not graze until over 0.6 m tall or after drought stress / frost killed as plants may produce prussic acid poisonous to livestock.

Sources / Further reading:

- US Department of Agriculture (USDA) (<https://www.nrcs.usda.gov/plantmaterials/mtpmcsr13973.pdf>).
- Sustainable Agriculture Research and Education (SARE) (Clark et al., 2007) (<https://www.sare.org/publications/managing-cover-crops-profitably/nonlegume-cover-crops/sorghum-sudangrass/>).

Brassicas

A family of annual, biennial or perennial herbaceous plants including mustards, radishes and cruciferous vegetables, with a diverse range of growth habits and characteristics. A range of Brassica species are used as winter cover, within arable crop rotations, or as fodder for grazing livestock. Many are deep rooting and provide good ground cover. Some have biofumigant properties, contributing to soil pest and pathogen control.



Picture credit: Bajra (Pixabay).

Brown mustard (*Brassica juncea*)

Family: Brassicaceae

Role in Soil Restoration: Spring or summer cover crop. Develops a long tap root (60–80 cm) which can help to alleviate soil compaction and aid water infiltration. Fast and high biomass production boosting soil organic matter. Can be used as a winter killed mulch.



Picture credit:
Balaji-Coimbatore
(Wikimedia commons)

Character: Annual or biennial brassica growing up to 1.6 m high. Many cultivars exist with differing characteristics.

Environments: Temperate regions. Not frost hardy, winterkilling at -4°C and dislikes very hot weather. Can grow up to altitudes of 2000m. Prefers well drained, medium textured moist soil with high fertility and pH 5.5–6.5 but can tolerate moderate heat, pH 5.0–8.0 and light to heavy soils with moderate fertility.

Propagation: Sow seeds April–September up to 1 cm deep at 5–7.5 kg/ha.

Uses: Cover crop with the capacity to help alleviate soil compaction. Also used as a winterkilled mulch to boost soil organic matter. Seed is used as a mustard flavouring. Some biofumigation capacity against pest species. Additionally, can be used for phytoremediation, reducing soil heavy metal pollution, including cadmium, lead and zinc by incorporation into plant tissues and subsequent harvesting of the plants.

Sources / Further reading:

- Useful temperate plants (<https://temperate.theferns.info/viewtropical.php?id=Brassica+juncea>)
- SARE (<https://www.sare.org/resources/managing-cover-crops-profitably-3rd-edition/>)
- Cover crops guide (<https://covercropsguide.co.uk/selection/>).
- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Antonio dos Santos et al. (2021) Biofumigation with species of the Brassicaceae family: a review. *Ciência Rural*. 51. DOI 10.1590/0103-8478cr2020040. (https://www.researchgate.net/publication/346955360_Biofumigation_with_species_of_the_Brassicaceae_family_a_review).

Canola/Rapeseed (*Brassica napus*)

Family: Brassicaceae

Role in Soil Restoration: Winter hardy cover crop. Shallow rooting to aid surface erosion control and topsoil water infiltration. Fast and high biomass production for nutrient capture and to boost soil organic matter.



*Picture credit:
Contri (Wikimedia commons)*

Character: Annual or biennial erect herb growing up to 2 m tall. Many cultivars exist with differing characteristics.

Environments: Generally temperate regions but can be grown in the tropics. Frost hardy, can survive down to -15°C with young growth surviving -6°C. Can grow up to altitudes of 2000 m. Prefers well drained, medium-light textured soil with high fertility and pH 6.5–7.6 but can tolerate up to 41°C, pH 5.5–8.0 and light to heavy soils with moderate fertility. Does not tolerate waterlogging.

Propagation: Sow seeds April–September up to 1cm deep at 5–7.5 kg/ha.

Uses: Cover crop with the capacity to help alleviate soil compaction. Also used as a winterkilled mulch to boost soil organic matter. Seed is used as a mustard flavouring. Some biofumigation capacity against pest species. Additionally, can be used for phytoremediation, reducing soil heavy metal pollution, including cadmium, lead and zinc by incorporation into plant tissues and subsequent harvesting of the plants.

Sources / Further reading:

- Useful temperate plants (<https://temperate.theferns.info/viewtropical.php?id=Brassica+juncea>)
- SARE (<https://www.sare.org/resources/managing-cover-crops-profitably-3rd-edition/>)
- Cover crops guide (<https://covercropsguide.co.uk/selection/>).
- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Antonio dos Santos et al. (2021) Biofumigation with species of the Brassicaceae family: a review. *Ciência Rural*. 51. DOI 10.1590/0103-8478cr2020040. (https://www.researchgate.net/publication/346955360_Biofumigation_with_species_of_the_Brassicaceae_family_a_review).

Arugula (*Eruca sativa*)

Family: Brassicaceae

Role in Soil Restoration: Fast biomass production boosting soil organic matter. Develops a short, branched tap root which aids soil structure and water infiltration and helps mitigate surface erosion.



Picture credit: Harry Rose (Flickr).

Character: Erect annual herb growing up to 80cm high.

Environments: Temperate regions, originally from the Mediterranean. Optimal annual daytime temperature of 15–25°C is preferred, but tolerant of temperatures below freezing for short periods when established. Prefers well drained, medium to light textured moist soil with moderate fertility and pH 7.0–8.0 but can tolerate pH 6.0–8.5 and low fertility soil and has some drought tolerance when established. Not tolerant of waterlogging.

Propagation: Sow seeds early spring, or late summer for an autumn harvest up to 1 cm deep. Seeds take 7–10 days to germinate. Plants will bolt in hot weather.

Uses: Cover crop with the capacity to help alleviate soil surface erosion. Leaves used as a salad crop. Some biofumigation capacity against pest species. Additionally, can be used for phytoremediation, reducing soil heavy metal pollution, by incorporation into plant tissues and subsequent harvesting of the plants.

Sources / Further reading:

- Useful temperate plants (<https://temperate.theferns.info/viewtropical.php?id=Eruca+sativa>).
- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Seedsavers (https://seedsavers.org/wp-content/uploads/2023/07/PDF-Grow-_-Save-Arugula-1.pdf).
- Antonio dos Santos et al. (2021) Biofumigation with species of the Brassicaceae family: a review. *Ciência Rural*. 51. DOI10.1590/0103-8478cr2020040. (https://www.researchgate.net/publication/346955360_Biofumigation_with_species_of_the_Brassicaceae_family_a_review).

Forage Radish aka Daikon Tillage Radish (*Raphanus sativus*)

Family: Brassicaceae

Role in Soil Restoration: Used as a cover crop or for intercropping. Has a large and long tap root. This can create vertical fissures in soil (biodrilling) helping to combat compaction in both topsoil and subsoil layers. Effective nutrient scavengers, reducing leaching risk. High biomass production can boost soil organic matter. Has also been found to increase soil carbon, microbial populations, soil moisture and porosity. If harvesting the root the discarded tops are a good winter mulch.



Picture credit: Moushomi B.C. (Wikimedia commons)

Character: Erect annual brassica with a long tap root.

Environments: Temperate-tropical regions with consistent precipitation. Daikon radish is not drought tolerant. Prefers fertile soils of pH 6.0–7.0 but can tolerate pH 4.3–8.3.

Propagation: Minimum germination temp is 7°C. In cool temperate regions, sow April to October at 1cm deep at a rate of 10 – 15 kg/ha. Frost tolerance reports vary so not suited to regions with prolonged cold winters.

Uses: Cover crop or intercrop for improvement of soil structure particularly alleviation of compaction in both topsoil and subsoil layers.

Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- US Department of Agriculture (USDA) (https://www.nrcs.usda.gov/sites/default/files/2024-04/Radish%20Cover%20Crop%20Fact%20Sheet_0.pdf)
- Cover crops guide (<https://covercropsguide.co.uk/selecion/>).
- Ahmadnia, F. et al- (2024) Impact of Oat (*Avena sativa* L.) and Daikon Radish (*Raphanus Sativus* var. Longipinnatus) Cover Crops on Some Soil Properties. (https://www.researchgate.net/publication/384241192_Impact_of_Oat_Avena_sativa_L_and_Daikon_Radish_Raphanus_Sativus_var_Longipinnatus_Cover_Crops_on_Some_Soil_Properties)

Forage turnip (*Brassica rapa*)

Family: Brassicaceae

Role in Soil Restoration: Cover crop useful in very cold areas. Develops a large and long tap root which can help to alleviate soil compaction. High rates of nutrient capture can reduce leaching risk. High biomass production boosting soil organic matter. Has been shown to reduce wind erosion of soil.



Picture credit:
Matt Lavin (Wikimedia commons)

Character: Frost tolerant annual or biennial brassica. Can grow up to 1.5m high. Many cultivars exist with differing characteristics and climatic tolerances.

Environments: Cool temperate/semi-arid regions. Can grow at high altitude (up to 2000m). Prefers well drained, moist soil with pH 7.0–7.5 but can tolerate mild drought, moderate heat, pH 4.8–8.5 and sandy to clay soils with low fertility. Frost hardy down to -15°C with some cultivars surviving significantly lower temperatures.

Propagation: Sow seeds summer or autumn, at least 4 weeks before the first hard frost, up to 2 cm deep at 2–10 kg/ha. Soil temp for planting should be above 7°C. Winterkill may occur in very low temperatures depending on the cultivar tolerance. If not winterkilled terminate at the early flowering stage to avoid seed set and growth in cash crops, terminate by mowing or flail mowing and incorporate the plant material into the soil.

Uses: Cover crop with the capacity to reduce erosion and nutrient leaching and alleviate compaction. Also used to boost soil organic matter. Other uses include animal forage (care needed as sulphurous compounds may cause illness in some livestock), as a vegetable crop for human consumption and for oil production.

Sources / Further reading:

- Royal Horticultural Society (<https://www.rhs.org.uk/plants/106082/brassica-rapa/details>)
- USDA Plant Guide (https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_brrar.pdf)
- Ma et al. (2019) Ecological and economic benefits of planting winter rapeseed (*Brassica rapa* L.) in the wind erosion area of northern China. (<https://www.nature.com/articles/s41598-019-56678-3>)

Legumes

The roots of legumes have nodules containing symbiotic rhizobia bacteria. These bacteria convert atmospheric nitrogen into a plant available form (ammonium) via a process known as biological nitrogen fixation. Seeds of some legumes may need to be inoculated with the correct strain of rhizobia to maximise nitrogen fixation and plant growth.



Picture credit: Harry Rose (Flickr).

Field Pea (*Pisum sativum* var. *arvense*)

Family: Fabaceae (legume)

Role in Soil Restoration: Cover crop, green manure, or forage crop for improvement of soil nutrient status and livestock feed. Often intercropped with cereals to boost yields and resilience of both crops. A leguminous crop with the ability to fix atmospheric nitrogen, increasing soil nitrogen levels when the plant tissues decompose. Can reduce need for mineral fertilisers and improve yields of following crop. Provides livestock feed and useful as a disease break crop for cereals and oilseeds. Beneficial to pollinators.



Picture credit: Jamain (Wikimedia commons)

Character: Annual plant with vining (climbing) habit, grows to 2.5 m. A leafless variety has been bred to improve sunlight infiltration to pods.

Environments: Cool temperate climates. Grows in a range of soil types but sensitive to compaction and not tolerant to drought or waterlogging. Optimum pH for N fixation is 6.5 but tolerates pH 5.0 – 8.0. Requires plenty of sunlight to yield well.

Propagation: Sow in autumn or spring, when soils are at least 10°C and ideally dry (to reduce risk of compaction) to a depth of at least 3 cm. Early drilling can improve yields and pest avoidance. Requires vertical support, which can be provided by companion cereal crop e.g., barley. Relatively high P and sulphur (S) requirements.

Uses: Green manure, cover or forage crop for soil improvement, livestock forage and disease suppression. Works well as part of a cereal rotation and of particular benefit to organic or low-input farms, providing nitrogen for following crops.

Sources / Further reading:

- BASF Agricultural Solutions UK (https://www.agricentre.basf.co.uk/Documents/BASF_PEA_GROWTH_GUIDE_FINAL.pdf?1744121104010).
- USDA (<https://www.nrcs.usda.gov/sites/default/files/2022-12/FieldPeasForForage.pdf>)
- SARE (<https://www.sare.org/publications/managing-cover-crops-profitably/legume-cover-crops/field-peas/>)

Alsike clover (*Trifolium hybridum*)

Family: Fabaceae (legume)

Role in Soil Restoration: Winter hardy cover crop used to improve arable land in cool temperate regions. As other legumes, can increase soil nitrogen levels through its nitrogen fixing capability. Can also boost soil organic matter. Tolerant of flooding so can be useful in wet areas to reduce soil erosion risk.

Picture credit:
BerndH (Wikimedia commons)



Character: Winter hardy, semi-erect, short crowned perennial legume with tolerance to flooding and acidic soils. Not drought or shade tolerant.

Environments: Cool temperate climates up to 2000 m. Prefers medium to heavy soil (silty clay loams), pH 5.5–6.5 but can tolerate pH 4.5–8. Grows well in medium to high fertility soil. Prefers daytime temperatures of 12–20°C but can tolerate 4–27°C and down to -10°C when dormant.

Propagation: For pasture, sow as a grass-legume mix at a proportion of 25%. Sow in spring or autumn when the soil is moist and at least 6 weeks of growing season remains to allow establishment before frost. Seed should be inoculated with the correct rhizobium bacteria and sown 1 cm deep at 2 kg/ha. In mixtures can be overseeded after grass to limit competition. As cover crop sow at 5 kg/ha and plough in to increase soil nitrogen and organic matter on decomposition.

Uses: Generally used in mixtures with grasses for pasture in areas where conditions are not favourable for other legumes. Undersowing in apple orchards is thought to improve taste and storage time of the fruit. Used as animal forage but there is a risk of bloat so livestock must be introduced gradually. Used as a cover crop in rotation with cereal grains or corn.

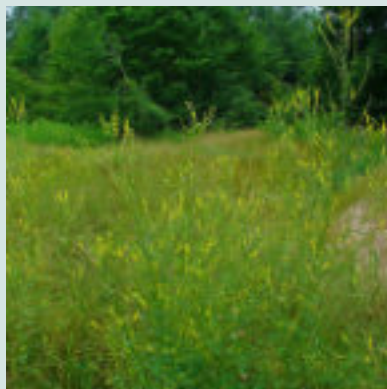
Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- USDA Plant Guide (https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_trhy.pdf).
- Trowbridge & Holl (1991) Effects of alsike clover/Rhizobium on lodgepole pine seedlings and soil N in west central British Columbia. (<https://open.library.ubc.ca/soa/cIRcle/collections/59367/items/1.0042201>).
- Useful temperate plants (<https://temperate.theferns.info/viewtropical.php?id=Trifolium+hybridum>)

Yellow Sweet Clover (*Melilotus officinalis*)

Family: Fabaceae (legume)

Role in Soil Restoration: Fast growing, easily established plant used for soil and water conservation and revegetation of degraded / marginal sites such as mine spoil and verges. Widely branched and deep taproots aid soil stabilisation and water infiltration. Can capture nutrients from deep soil horizons. As a legume, fixes nitrogen, so can be used as green manure for soil nutrient improvement. Fast biomass production boosts soil organic matter. Good source of nectar for pollinators.



Picture credit: H. Zell (Wikimedia commons)

Character: Annual or biennial erect branched legume, 30 cm to 2.5 m tall.

Environments: Cool temperate climates to 4000 m. Optimal growing temperatures of 12–24°C but will tolerate 5–28°C. Some frost tolerance but may be killed at -5°C. Tolerates low fertility soil and a range of soil types. Prefers a pH of 6–7 but tolerates 5–8.5. Seedlings will tolerate short duration spring floods. Established plants show some drought tolerance.

Propagation: For a pure stand (not recommended unless used as a green manure) sow at 4.5 kg/ha. Within a mix, use at a proportion of up to 10%. In irrigated fields sow at least 6 weeks before hard frosts. If not irrigated plant just before spring/summer rains (moisture required for germination). Plant rarely sets seed in the first year of growth. If left to seed, seeds can remain dormant in the seedbed for years so if used as green manure prior to crops, terminate before seed set to avoid weed problem. Concentrated grazing in the late summer/autumn can weaken roots and increase chance of frost kill to help reduce regrowth.

Uses: Green manure, cover crop or in grassland swards. Can be used as animal forage, however plant tissues contain the chemical coumarin which breaks down to the anticoagulant dicoumarin if the plant is damaged / mouldy, therefore do not use as animal feed in degraded state.

Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- USDA Plant Guide (<https://plants.usda.gov/plant-profile/MEOF>)
- Useful Temperate Plants (<https://temperate.theferns.info/viewtropical.php?id=Melilotus+officinalis>).

Red clover (*Trifolium pratense*)

Family: Fabaceae (legume)

Role in Soil Restoration: Within grassland swards, temporary grass leys, for silage, as an arable cover / break crop or undersown into grain crops to improve soil nutrient status. As other legume species, increases soil nitrogen levels via nitrogen fixation. Improves soil structure via a large and extensively branched tap root. high biomass and root production can boost soil organic matter levels. Can also provide weed suppression benefits.



Picture credit: Matt Lavin (Flickr)

Character: Biennial or short lived perennial. Upright form, with stems of up to 70 cm long growing from a central crown.

Environments: Cool to warm temperate regions. Winter hardy and frost tolerant but growth over winter is limited. Moderately drought tolerant. Tolerant of shade allowing undersowing beneath cereal or maize crops. Prefers well-drained medium and fine textured loamy soils but will tolerate less well-drained soils. Optimum pH is >6.0 but will grow in moderately acidic soils. Relatively high P, K and S requirements.

Propagation: Drill or broadcast in spring or summer into a fine seed bed at a depth of 0.5–1 cm. Best used in a mix with grasses at a proportion of around 50%, but can be sown as a monoculture for silage at a rate of 12–14 kg/ha. Seeds should be inoculated before sowing. Rolling helps to ensure sufficient contact with the soil. Can also be oversown into pasture or undersown into arable crops. Cut 3–4 times a year before flowering, to no shorter than 7–8 cm to protect the crown from which new stems grow. Has a lifespan of 2–3 years.

Uses: Livestock grazing, silage production and to improve soil fertility. Due to high N content avoid grazing in damp conditions and wilt for 48 hours after cutting to avoid livestock bloat. Avoid grazing ewes on red clover for six weeks before mating.

Sources / Further reading:

- Teagasc (Ireland Agriculture and Food Development Authority) (<https://www.teagasc.ie/media/website/rural-economy/organics/Red-Clover-leaflet-update.pdf>).
- USDA (https://plants.usda.gov/DocumentLibrary/factsheet/pdf/fs_trpr2.pdf).

Sainfoin (*Onobrychis viciifolia*)

Family: Fabaceae (legume)

Role in Soil Restoration: Cover or forage crop for grassland in a range of climatic zones. Sainfoin can fix atmospheric nitrogen and therefore provide nitrogen to soil when the plant decomposes. The root structure consists of a sturdy long main tap root to combat soil compaction and aid water infiltration in both top and subsoil. Some drought tolerance and able to grow in poor fertility soil so useful in semi-arid areas. Also used in land previously used for coal mining.



Picture credit: Eric Steinert (Wikimedia commons)

Character: Upright perennial growing to 40 – 80 cm.

Environments: Temperate and semi-arid climates with pronounced seasons (e.g., Mediterranean) up to 3000 m. Winter hardy; once established can tolerate down to -4°C and up to 34°C. Prefers soil pH of 6.5–7.5 (chalk/limestone soils) but tolerates pH 4.9–8.2. Semi drought tolerant but does not tolerate waterlogging. Can grow in low fertility soils. Can also tolerate high amounts of lead and copper.

Propagation: Sow up to 2cm deep in spring or autumn at 13–38 kg/ha. Do not plant with aggressive grass species. Do not graze for the first 2 years and let seed naturally every 2–3 years to maintain the crop. With irrigation, stands should last 3–6 years and longer if rot is controlled.

Uses: High protein animal forage for sheep and cattle. High nectar content for pollinators. For soil restoration of degraded grasslands.

Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Soil Association (<https://www.soilassociation.org/farmers-growers/low-input-farming-advice/herbal-leys/benefits-of-holy-hay-sainfoin/>).
- USDA Plant Guide (https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fplants.usda.gov%2FDocumentLibrary%2Fplantguide%2Fdoc%2Fpg_onvi.docx&wdOrigin=BROWSELINK).
- Sakhraoui et al. (2024) Sainfoin: a legume with great ecological and agronomical potential under climate change. *Journal of Agricultural Science*.
- Cover crops guide (<https://covercropsguide.co.uk/selection/>).

Alfalfa (*Medicago sativa*)

Family: Fabaceae (legume)

Role in Soil Restoration: Cover crop in cool temperate to tropical regions. Very deep rooted (up to 6m), improving soil structure and water infiltration, and enabling scavenging of nutrients from the subsoil. These long roots can fix large amounts of atmospheric nitrogen in the presence of the correct rhizobium bacteria, increasing the nutrient status of the soil. Has been shown to increase soil organic carbon levels.



Picture credit: Kurt Stüber (Wikimedia commons)

Character: Perennial herbaceous legume growing to 30 – 100 cm. Relatively slow to establish but vigorous above ground growth in the second year.

Environments: Cool temperate to sub-tropical regions up to elevations of 4000 m. Optimal annual daytime temperatures of 21–27°C, but can tolerate 5–45°C. Once established can survive temperatures down to -25°C via dormancy, but young growth can be damaged below 0°C. Tolerant of drought but not waterlogging. Grows best in pH 6.5–7.5 but can tolerate 4.3–8.7. Can tolerate low fertility soils providing they are well drained.

Propagation: Sow at 6 – 10 kg/ha at a depth of 0.5–1 cm. Sow in spring or summer when the soil is moist. Growth can be slow in the first year and competition from grasses should be avoided. Produces vigorous growth thereafter which can be cut 2–3 times during the growing season.

Uses: Used as cover crops and green manure. Harvested as hay or used in manufacture of animal feed. Grazing of alfalfa can cause bloat in livestock so caution should be taken.

Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Useful temperate plants (<https://temperate.theferns.info/viewtropical.php?id=Medicago+sativa>)
- USDA (https://plants.usda.gov/DocumentLibrary/factsheet/pdf/fs_mesa.pdf)
- Plants for a Future (<https://pfaf.org/user/plant.aspx?LatinName=Medicago+sativa>).

Hairy vetch (*Vicia villosa*)

Family: Fabaceae (legume)

Role in Soil Restoration: Winter hardy nitrogen-fixing cover crop. Rapid growth and capture of nutrients (N, P and K), reducing leaching risk. These nutrients are released into the soil when the plant decomposes. Develops a long tap root which can help to alleviate compaction and improve water infiltration in both topsoil and sub-soil horizons. Its low creeping nature provides good ground cover, reducing risk of soil erosion by wind and water and stabilising slopes.



Picture credit: Kristian Peters (Wikimedia commons)

Character: Annual or biennial herbaceous legume. Vine-like plant with creeping up to 1.8 m long. The most winter hardy vetch is not drought tolerant.

Environments: Temperate, sub-tropical and tropical regions to 3000 m. Tolerates pH of 5.7–7.5 but prefers 6.0 – 7.0. Prefers well drained loamy or sandy soils. High P and K requirements and needs some S. Not drought tolerant.

Propagation: Sow at 25 kg/ha up to 2 cm deep, either 30–45 days before first frost for use as winter cover or in mid/late summer to be used as a winterkilled mulch. Optimum germination temperature of 15–23°C. Requires moist soil to germinate, but those sown to overwinter will not require significant moisture after germination. Terminate by roller crimping when starting to produce pods. Close mow at peak flowering to avoid reappearance as a weed in subsequent years.

Uses: Cover crop for weed and erosion control. Green manure to capture nutrients and provide to subsequent crops. Cover crop on non-agricultural sloping land such as verges to prevent erosion. Pollinator food if allowed to flower. Can be used as forage before seed set (seeds can be poisonous to livestock).

Sources / Further reading:

- Sustainable Agriculture Research and Education (<https://www.sare.org/wp-content/uploads/Managing-Cover-Crops-Profitably.pdf>).
- Penn State Extension (<https://extension.psu.edu/hairy-vetch-as-a-crop-cover>).
- University of Wisconsin Extension (<https://www.hort.purdue.edu/newcrop/afcm/vetch.html>)
- USDA (https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_VIVI.pdf).
- Feedipedia (<https://www.feedipedia.org/node/238>)
- Anugroho et al. (2010) Potential growth of hairy vetch as a winter cover crop in subtropical soil. (<https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1747-0765.2010.00445.x>)

Egyptian/Berseem clover (*Trifolium alexandrinum*)

Family: Fabaceae (legume)

Role in Soil Restoration: As a legume, Berseem clover can fix atmospheric nitrogen enabling increases in soil nitrogen levels. Taproot and side shoots help to build soil structure improving water infiltration and soil stability. The extensive root system also enables effective capture of nutrients.



*Picture credit: Emmanuel Bouchard
(Creative Commons licence, Plantnet.org)*

Character: Erect or semi-erect, annual legume, stems 40–90cm long.

Environments: Grows well in warm temperate climates, in the Mediterranean to sub-tropical zone. Lower water requirement than other clover species. Prefers heavy loam soil with moderate fertility with pH 6.5–7.0 but can tolerate pH 4.9–7.5. Not frost tolerant. Prefers temperatures of 16–27°C but can tolerate 4–27°C with minimum temperature tolerance of -8°C when dormant.

Propagation: Sow 1 cm deep at a seed rate of 9–15 kg/ha in spring or autumn depending on climate (minimum germination soil temperature is 6°C). For best nitrogen fixing performance seed should be inoculated with the correct *Rhizobium* prior to sowing. As a cover crop, can be used as part of a mixture. Can be terminated by winterkill or mechanical means (tilling), although this may not fully kill a densely grown stand.

Uses: Used as a cover crop or green manure. It can be used as forage for livestock and does not cause bloat.

Sources / Further reading:

- USDA (https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_TRAL6.pdf;
[https://www.nrcs.usda.gov/sites/default/files/2024-07/Berseem Clover Crop Fact Sheet.pdf](https://www.nrcs.usda.gov/sites/default/files/2024-07/Berseem%20Clover%20Crop%20Fact%20Sheet.pdf))
- Useful Temperate Plants (<https://temperate.theferns.info/plant/Trifolium+alexandrinum>)

Cowpea (*Vigna unguiculata*)

Family: Fabaceae (legume)

Role in Soil Restoration: Summer cover crop for warm regions. A leguminous crop with the ability to fix atmospheric nitrogen therefore helping to increase nutrients in the soil when the plant decomposes. Has a root structure with a main tap root which may help to alleviate soil compaction. Can also improve water infiltration in both topsoil and subsoil horizons, reducing risk of soil erosion. A fast-growing plant with high biomass production which may boost soil organic matter.



Picture credit: IITA (Flickr)

Character: Fast growing annual tropical and subtropical legume that grows erect, tendrilous, semi-tendrulous, or bushy.

Environments: Tropical, sub-tropical or warm Mediterranean climates (not frost tolerant). Tolerant to drought and high temperatures: optimum range 13–28°C. Does not tolerate waterlogging so requires well drained soil. Tolerates pH 5–8.

Propagation: Sow seeds early summer, up to 5cm deep at 60kg/ha. Soil temp for planting should be above 18°C. Terminate at the early flowering stage to avoid seed set and growth in subsequent crops, terminate by mowing and light tilling and incorporate the green plant material into the soil for maximum nitrogen gain.

Uses: Seed is a commercial crop (black-eyed peas). Animal forage. Summer cover crop grown during fallow periods in crop rotation. Some evidence of outcompeting of weeds during growth phase, and allelopathic effects after termination causing weed suppression (Zannopoulos, S. et al (2024) but could cause suppression of subsequent crops so caution needed. Has been used for ground cover in orchards. (USDA NRCS Cowpea Plant guide).

Sources / Further reading:

- US Department of Agriculture (https://plant.usda.gov/DocumentLibrary/plantguide/pdf/pg_vlun.pdf; <https://www.nrcs.usda.gov/sites/default/files/2024-04/Cowpea%20Crop%20Fact%20Sheet.pdf>).
- Sustainable Agriculture Research and Education (<https://www.sare.org/wp-content/uploads/Managing-Cover-Crops-Profitably.pdf>).
- Zannopoulos et al. (2024). The Potential of Three Summer Legume Cover Crops to Suppress Weeds and Provide Ecosystem Services—A Review. *Agronomy journal*.

Herbs and Shrubs

Herbaceous broadleaf plants (non-grasses), other than legumes, are often referred to as herbs. Buckwheat, phacelia, chicory and linseed are examples of herbs commonly used in agriculture, often as cover crops or break crops between cash crops. Shrubs (woody perennials) are less commonly used in agriculture, but can be useful for soil rehabilitation, particularly stabilisation of slopes and eroding land due to their long-lasting and strong root systems.



Picture credit: Gilles San Martin (Wikimedia commons)

Chicory (*Cichorium intybus*)

Family: Asteraceae

Role in Soil Restoration: Used as green manure as part of seed mixes. Long taproot can improve soil structure, particularly alleviating compaction and improving water infiltration. Deep roots can also enable capture of nutrients from deeper soil horizons, benefitting soil nutrient status.



Picture credit: Christian Fischer (Wikimedia)

Character: Frost tolerant perennial herb, growing to 1 – 2 m when flowering.

Environments: Cool temperate climates from sea level to 2000 m. Optimum annual daytime temperatures are 10–30°C, but can tolerate 6–35°C. Frost tolerance to -5°C. Requires moderately fertile, well drained, moisture retaining soil. pH of 6–7.5 is preferred, but tolerates 4.5–8.3.

Propagation: Sow in May or early summer (useful temperate plants) at 1 cm deep.

Uses: Generally grown in mixed swards for animal grazing/forage or for green manure. The roots can be harvested for a coffee substitute and the tops for salad.

Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- USDA Plant Guide (<https://plants.usda.gov/plant-profile/MEOF>)
- Useful Temperate Plants (<https://temperate.theferns.info/viewtropical.php?id=Cichorium+intybus>).
- Plants for a Future (<https://pfaf.org/user/plant.aspx?LatinName=Cichorium+intybus>)

Phacelia (*Phacelia tanacetifolia*)

Family: Boraginaceae

Role in Soil Restoration: Cover crop or catch crop in temperate regions. The shallow taproot and side shoots aid good topsoil structure, improving water infiltration and soil stability, reducing soil erosion risk. Efficient at capturing nitrogen, reducing leaching risk and releasing back into the soil when plant tissues decompose, benefitting the following crop. Shown to decrease sugar beet nematode populations. Food source for pollinators.



Picture credit: Andreas Eichler (Wikimedia commons)

Character: Annual erect forb growing to 30 – 90 cm high. Drought tolerant and prefers well drained soils.

Environments: Grows well in warm temperate climates but also sold as a winter annual in the UK. Drought tolerant, grows at a wide range of altitudes, from sea level to 2500 m. Tolerates pH values of 6.4–8.5.

Propagation: Germinates at temperatures of 5–18°C. For soil improvement sow in autumn 1 cm deep at a rate 5 kg/ha. Germination is inhibited by light. Can be terminated by winterkill or mechanical means. Terminate before seed sets to reduce the likelihood of selfseeding. Semi winter hardy; killed at -6°C.

Uses: Rotational cover crop or short period catch crop to capture nutrients and release slowly, improving soil nutrient status and benefitting following crop.

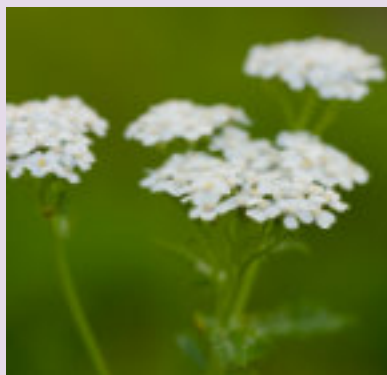
Sources / Further reading:

- USDA (https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_phta.pdf and <https://www.nrcs.usda.gov/plantmaterials/mtpmctn12938.pdf>).
- Useful Temperate Plants (<https://temperate.theferns.info/plant/Phacelia+tanacetifolia>).
- Cotswold Seeds (<https://www.cotswoldseeds.com/species/44/phacelia>)

Common Yarrow (*Achillea millefolium*)

Family: Asteraceae

Role in Soil Restoration: Used as part of diverse grassland swards. The deep and spreading root system helps to improve soil structure and water infiltration and reduce risk of erosion. Very frost and drought tolerant, when established can tolerate down to -25°C and stays green when grasses have gone brown during droughts. Not suitable as an arable cover crop as can be invasive.



Picture credit: Peter Stenzel (Flickr)

Character: Low growing, perennial herb spreading via rhizomes with approx. 1 m tall flower stems. Can be invasive.

Environments: Cool temperate and cool semi-arid climates due to frost and drought tolerance. Tolerant of low fertility soil however can be invasive so not good for use in arable systems.

Propagation: Sow no more than 0.5 cm deep as light required for germination. Requires warm temperatures (18–24°C) to germinate. Grows best in neutral to slightly alkaline soil, of low fertility and well drained.

Uses: Used as part of a diverse grazing sward. Also grown as ground cover in orchards.

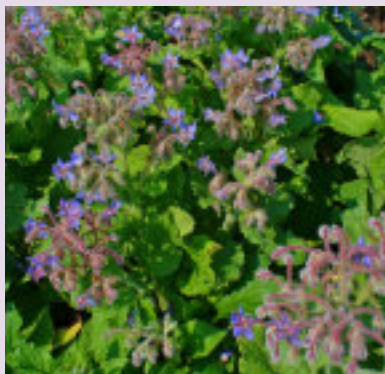
Sources / Further reading:

- USDA (https://plants.usda.gov/DocumentLibrary/plantguide/pdf/cs_acmi2.pdf).
- Useful Temperate Plants (<https://temperate.theferns.info/viewtropical.php?id=Achillea+millefolium>).
- Cotswold Seeds (<https://www.cotswoldseeds.com/species/147/yarrow>)

Borage (*Borago officinalis*)

Family: Boraginaceae

Role in Soil Restoration: Useful as a summer cover crop being easily established in a range of soil types, or as green manure to increase soil organic matter. Large tap root and high root volume provides good soil stabilisation and increases water infiltration. Also beneficial as a nectar source for pollinators.



Picture credit: H. Zell (Wikimedia commons)

Character: Annual or biennial erect herb growing to 20–100 cm.

Environments: Suitable for temperate and semi-arid climates. Tolerant of drought when established, and some waterlogging. Tolerant of light to heavy soils with moderate to low fertility and pH of 6.0–8.3, although 6.5–7.5 preferred. Optimum annual daytime temperatures of 15–22°C, but can tolerate 4–26°C. Frost tolerant to -5°C but may not survive consecutive frosts..

Propagation: Sow in warm soils at 1.5 cm deep. For a pure stand sow at 20 kg/ha. Flowers May to September (UK). Will selfseed the following year if left until maturity.

Uses: Summer cover crop, or companion crop to attract pollinators. Green manure. Leaves used in small quantities in cooking.

Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Useful Temperate Plants (<https://temperate.theferns.info/viewtropical.php?id=Borago+officinalis>).
- Cotswold Seeds (<https://www.cotswoldseeds.com/species/170/borage>)

Sea Buckthorn (*Hippophae rhamnoides*)

Family: Elaeagnaceae

Role in Soil Restoration: Sea buckthorn's strong root system, concentrated within the topsoil horizon, makes it useful for reclamation of sloping land affected by degradation and soil erosion, via slope stabilisation and improved soil structure. Atmospheric nitrogen fixation can occur in root nodules through symbiosis with *Frankia* bacteria, increasing soil nitrogen levels.



Picture credit: Sander van der Molen
(Wikimedia commons)

Character: Deciduous shrub with orange-yellow berries growing to 2–4 m. Can be invasive in North America.

Environments: Cold temperate regions of Europe, northern Asia and China, from sea level to 4500 m. Can grow in waterlogged soils and tolerant of high salt concentrations.

Propagation: Can be planted as seedlings or suckers at a rate of 6,000–10,000 seedlings per hectare. Fast natural vegetative propagation by sprouting, suckering and layering.

Uses: Used for restoration of areas affected by erosion and landslips, often in combination with trees, particularly in Eastern Europe and the Himalayan region (Sharma et al. 2019). Has also been used to combat desertification.

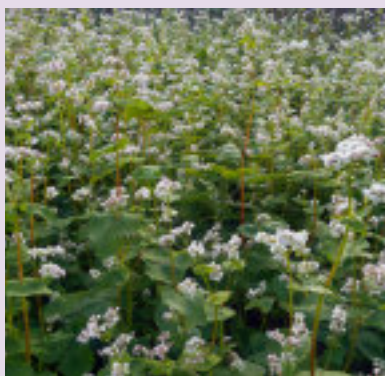
Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Useful Temperate Plants (<https://temperate.theferns.info/viewtropical.php?id=Hippophae+rhamnoides>).
- Constandache et al. (2016) The usage of Sea Buckthorn for improving Romania's degraded lands (https://ibn.idsi.md/sites/default/files/j_nr_file/2_2016.pdf#page=51).
- Sharma et al. (2019) Sea buckthorn-a new approach in ecological restoration of Himalayan Ecosystem: A review. International Journal of Chemical STUdies. (<https://www.chemijournal.com/archives/2019/vol7issue1/PartU/7-1-132-535.pdf>)

Common Buckwheat (*Fagopyrum esculentum*)

Family: Polygonaceae

Role in Soil Restoration: Extremely fast-growing species (flowers 3–7 weeks after planting) so useful as a summer cover crop. Shallow taproot and side shoots aid topsoil structure and erosion control. Tolerant of low fertility soil. Efficient at scavenging phosphorous from the soil and mineralising rock phosphate, benefitting soil nutrient status.



Picture credit: Maria Weronika Kmoch
(Wikimedia commons)

Character: Annual erect broadleaved herb with multiple stems, growing 60–90 cm.

Environments: Suitable for temperate/sub-tropical climates. Not tolerant of frost, waterlogging, compacted soils or drought. Requires light to medium texture, well-drained soils with moderate to low fertility and pH of 5.0–6.5, although 4.4–7.5 tolerated. Optimum annual daytime temperatures of 17–27°C preferred, but can tolerate 7–40°C.

Propagation: Sow in warm soils at 1.5–2 cm deep at 50 kg/ha. Flowers 3–7 weeks after planting. Will selfseed the following year if left until maturity. If seeding is not required mow less than 10 days after flowering begins. Easily killed by mowing or frost, and residue breaks down quickly.

Uses: Summer cover crop, or companion crop to attract pollinators. Green manure. Can be grown as a commercial crop, the dehusked grain is processed for flour and other products. May cause skin disorders and photosensitivity in livestock if used as forage.

Sources / Further reading:

- Ecocrop (FAO) (<https://gaez.fao.org/pages/ecocrop-find-plant>).
- Useful Temperate Plants (<https://temperate.theferns.info/plant/Fagopyrum+esculentum>).
- USDA plant guide (https://plants.usda.gov/DocumentLibrary/plantguide/pdf/pg_faes2.pdf).
- SARE (<https://www.sare.org/resources/managing-cover-crops-profitably-3rd-edition/>)
- Cover crops guide (<https://covercropsguide.co.uk/selection/>).
- Vieites-Álvarez et al. (2024)-A decade of advances in the study of buckwheat for or-ganic farming and agroecology (2013-2023). Frontiers in Plant Science.

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2.5 Further reading and resources

Papers and reports

Dessureault-Rompré J (2022) Restoring Soil Functions and Agroecosystem Services Through Phytotechnologies. *Frontiers in Soil Science* 2:927148. DOI: 10.3389/fsoil.2022.927148.

Griffiths M, et al (2022). Optimization of root traits to provide enhanced ecosystem services in agricultural systems: a focus on cover crops. *Plant, Cell & Environment*, 45, 751– 770.
<https://doi.org/10.1111/pce.14247>

Hudek, C et al. (2024) Report on metaanalysis on the impact of different soil restoration strategies across different soil degradation gradients in EU and China. TUDI deliverable D3.1. Available from [TUDI-project.org](https://tudi-project.org)

Hudek, C et al. (2024). First version of report on information for guiding material for phytotechnological soil restoration strategies across different soil degradation gradients in EU and China. TUDI deliverable D3.5. Available from [TUDI-project.org](https://tudi-project.org)

Websites

FAO Global Crop Profile and
crop statistics. GAEZ portal

<https://gaez.fao.org/pages/crop-summary>

Plants for the future

<https://pfaf.org>

USDA Plant Guides

<https://plants.usda.gov/plant-profile>

Useful temperate plants

<https://temperate.theferns.info>

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