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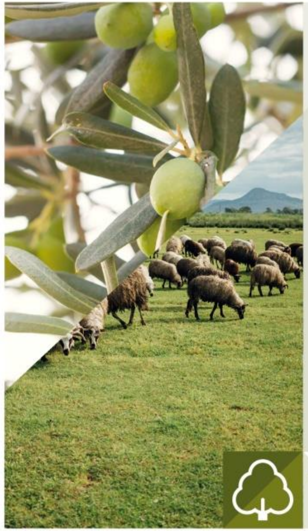

Module 1 – Agroforestry for Multifunctional Olive systems

Course 2 - Agroforestry Systems on Olive Orchards Soil Management

Chapter 1 - Cover crop and Green manure in olive orchards

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Cover crop definition

Cover cropping is a sustainable agriculture practice primarily aiming to reduce soil erosion and improve soil fertility and quality beside providing additional benefits. Cover crops also break weed cycles, help control pests and diseases, and can provide an additional production crop (Clark, 2007)

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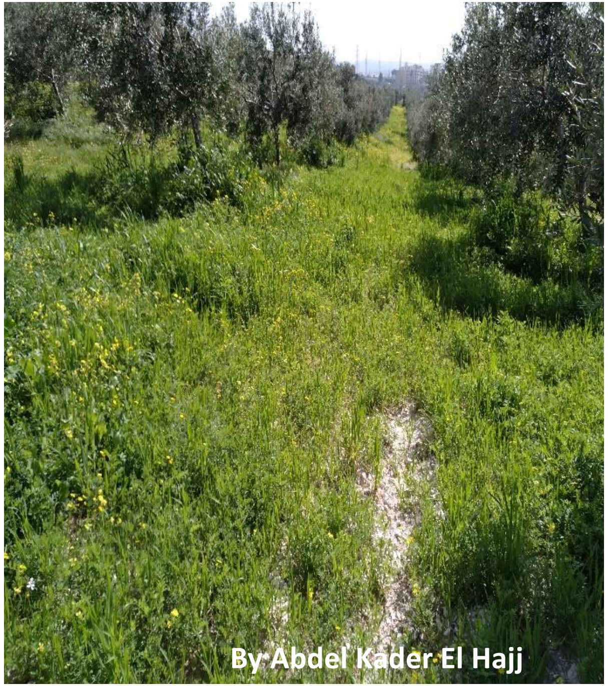
Green manure definition

- Green manures are crops sown with a specific purpose of being incorporated into the soil in an immature stage (Niemsdorff and Kristiansen, 2006)
- Green manure are crops grown withing the orchards in order to improve soil structure and increase soil fertility. They are typically ploughed into soil while green or shortly after flowering
- Incorporated young plants into the soil decompose fast and release minerals that would be readily available for the main crop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Role of cover crops

- The role of cover crop in agroforestry system is to manage:
  - Erosion
  - Soil fertility
  - Weeds
  - Pest and diseases
  - Biodiversity
- By managing these factors, cover crop can directly improve the sustainability of agroforestry system and indirectly the neiborighing ecosystem

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Benefits of cover crops

- Cover crops add more organic matter (OM) and more Nitrogen (N) to the soil
  - The decomposition of cover crop biomass contributes more OM to the soil
  - The obtained OM adds significant quantity of N to the soil
  - Cover crop supplies N and other nutrients for a neighboring crop (ex. Olive tree)
  - The addition of OM and N to the soil reduces the use of chemical fertilizers, as well as the cost of transportation, as this natural fertilizer is made directly in the soil
- Cover crops improve structure and physical properties of the soil
  - Humus, a final product of degraded cover crop biomass, acts as soil colloids which in turn improves soil structure and its physical properties such as water retention, gas exchange, soil infiltration, and cation exchange capacity (CEC)

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Benefits of cover crops

- Cover crops help in the suppression of weeds
  - The vegetative cover crop inhibits weed germination and development by limiting light and modifying the temperature and moisture at the soil surface
  - Tilling or incorporating the cover crop not only releases the accumulated minerals, but also eliminates weeds
  - The mulch formed on the soil surface after terminating the green manure can also suppress weeds
  - Also, some cover crops (such as sweet clover, hairy vetch, fall rye) are allelopathic, containing or secreting compounds that can inhibit the germination of other plants (eg. sweet clover green manure with high coumarin levels is allelopathic)
  - However, a competitive cover crop, such as sweet clover and hairy vetch, must be chosen
    - A vigorous, fast-growing cover crop competes strongly with weeds for space, light, nutrients, and moisture
    - Planting a grass in combination with a legume or other broadleaf crop is frequently more successful than growing either alone

Benefits of cover crops

- Cover crops reduce pest and disease problems
  - Cover crops provide habitat for pest predators
  - The amount of ready-to-use carbon in the form of organic amendments (fresh or dried plant material) added to the soil, stimulates the general microbial activity of the soil. Such improvements in soil microbial activity have been linked to a drop in the number of soil-borne pathogens, such as *Verticillium dahliae*
  - Cover crops of Brassica family (Canola, rapeseed, broccoli, cabbage, kale, arugula, cauliflower, Brussels sprouts, turnip, radish and mustards etc.) and other crops (sorghum, Sudan grass) have bio-fumigation potential, that refers to pathogen and disease suppression by the release of volatile toxic (isothiocyanates for brassica, hydrogen cyanide for sorghum) metabolic by-products
  - These crops are used to control nematodes (nematicide) and a variety of plant pathogens, such as Rhizoctonia, Verticillium, Sclerotinia, Phythophthora, Pythium, Aphanomyces and Macrophomina

Benefits of cover crops

- Cover crop reduces runoff and erosion as it provides ground cover to prevent damage to soil structure (in case of heavy rains)
- Cover crop enhances soil biology as it increases microbial biomass, microbial enzymathic activities, and the relative abundance of microbial taxa
- Cover crop enriches ecosystem biodiversity (habitat for beneficial organisms)
- Cover crop prevents leaching of soluble nutrients from the soil

The principles of cover crop/ green maure practice

- Must be well adapted to climate and soil conditions
- The seeds must be inexpensive and readily available
- The cover crops must be easily established and with high biomass production
- The cover crops must have rapid germination and growth
- The cover crops must require minimal management during growth
- The cover crops must have competitiveness with weeds
- The cover crops must have the ability to grow in nutrient-poor soil
- The cover crops must use water efficiently
- The cover crops must be ease of incorporation

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The choice of crops for cover crop / green manure

- The choice of a cover crop as a green manure depends mainly on prevailing weather conditions. Fall/winter planting is the most appropriate for the semi-arid Mediterranean basin particularly in the rain-fed olive orchards
- Legumes (clover, alfafa, vetch, beans, lentil, peas)
  - Legumes have developed a mechanism to fix atmospheric N with the help of microorganisms living in their roots. The legumes will be incorporated into soil when reach a specific growth stage. The tree will benefit from the N and other minerals such as P released during the mineralization of debris of the legume crops
  - Clover is the most widely grown crop for fertility enhancement
  - Lucerne or alfalfa is a long-lived perennial plant with a deep taproot ideally suited to dry climate. Lucerne is particularly susceptible to *Verticillium wilt* and can suffer from clover rot and crown wart disease
  - Trefoil is an annual or biennial legume that gives good yields and grows well on shallow calcareous soils
  - Lupin is a traditional green manure of temperate climates and well adapted to sandy soils. Wild lupin contains toxic alkaloids in their foliage and seeds
  - Common vetch: a winter and spring varieties of vetch are available. They are mixed well with cereals. Vetch can release large amounts of available N to a following crop

The choice of crops for cover crop / green manure

- Non-legumes (barley, oat, wheat, turnip, mustard)
  - Non-legumes do not fix N, but can provide useful amounts of OM and retain nutrients that might otherwise be leached
  - Several annual plants, such as grass and cruciferous species, have also been tested as cover crops with diverse objectives
  - Some non-legume species especially Brassicaceous crops have a biofumigation potential. Biofumigation is the suppression of soil borne pests and pathogens resulting from biocidal compounds released from cover crops
  - The use of *Sinapis alba* as green manure was particularly effective in reducing the incidence of *Verticillium dahliae* in olive (*Olea europaea* L.) Alcántara et al. (2017)

The choice of crops for cover crop / green manure

- Non-legumes (barley, oat, wheat, turnip, mustard)
  - Rye (*Secale cereale*) is the most vigorously growing overwinter green manure
  - Oats (*Avena sativa*) or barley (*Hordeum vulgare*) may be grown as alternatives to rye
  - Cocksfoot (*Dactylis glomerata*) produces a large amount of root mass which is beneficial for soil OM content and soil structure.
  - Mustard (Sinapis alba) grows large very quickly. It is very shallow rooted. It survives in cold winters
  - High glucosinilate content that under the right conditions can have biocidal properties against pests, weeds and diseases
  - Stubble turnips (*Brassica rapa*), oil seed rape (*Brassica napus*), fodder radish (*Raphanus sativus*). These crops are planted for winter grazing (usually for sheep) and green manuring purposes
  - Buckwheat (*Fagopyrum esculentum*) is a short growing cycle (2-3 months) with broad leaved annual crop. It performs badly on heavy soils. It is believed to be effective at scavenging the soil for phosphorus. This crop may be grown as an attractant for beneficial insects

The choice of crops for cover crop / green manure

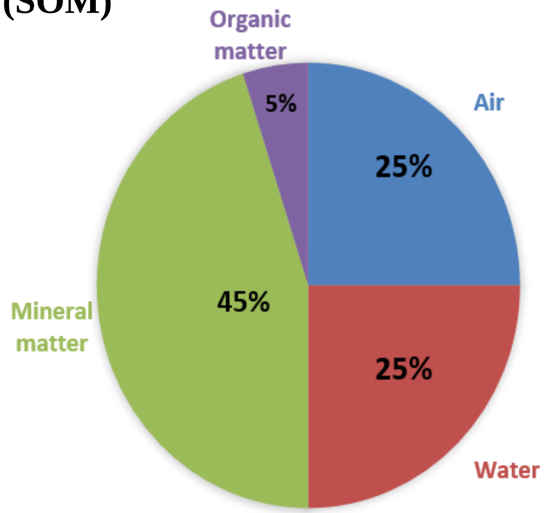
- Mixture
  - Sowing a mixture of legume and non-legume species is often desirable as to combine the benefits of each:
    - Legumes are high in N while non-legumes have sufficient content of carbohydrates
    - Legume plant will benefit from physical support of non-legume
    - The fixed N from legume might benefit the non-legume
    - The N depletion will be reduced if different plant species with various decaying rates are mixed. Instead of utilizing the soil N reserves, the decomposing bacteria will use the N and carbohydrates released from leguminous and non-leguminous species for their growth and reproduction
  - Examples of used mixtures
    - Red clover/ryegrass
    - Oats/peas/vetch
    - Barley/vetch

Limitations of cover crop / green manure adoption

- Farmers prefer to exploit the space in the orchards with cash crops rather than to grow cover crops as a green manure
- The adoption of green manure is complicated by the fact that this application is a long term system. It takes several seasons to see the results especially on very poor soils
- The requirement of soil tillage for sowing, which can coincide with a period of high risk of soil erosion, and a second tillage for the incorporation of plant debris into the soil, which can also damage the root system

Soil organic matter (SOM)

- SOM is any material produced originally by living organisms (plant or animal) that is returned to the soil and goes through the decomposition process (Alexandra Bot and José Benites, 2005)
- OM in the soil is composed of plant or animal residues in various stages of decaying
- The OM for most agricultural soils constitutes about 3 to 6 percent
- SOM is usually composed of 50% carbon, 5% nitrogen, 0.5% phosphorus, 0.5% sulfur, 39% oxygen, and 5% hydrogen, but these values can vary from soil to soil



Sources of OM

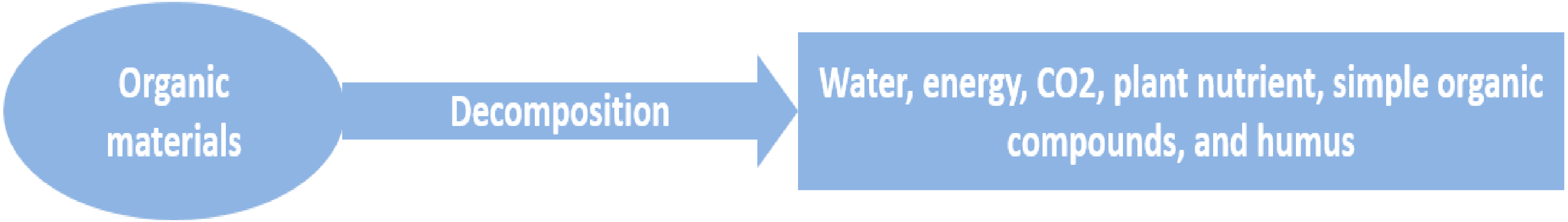
- Crop residues
- Animal manure
- Compost
- Deceased micro-organisms, insects and earthworms
- Old plant roots

Sources of OM

- These sources contain the following organic molecules that decompose at varying rates:
  - Non-humic substances. Easily attacked by microorganisms and degrades at varying rates:
    - Sugars, starch and proteins have rapid decomposition
    - Cellulose, fats, waxes, and resins have slow decomposition
    - Lignin have very slow decomposition
  - Humic substances. They are relatively resistant to microbial attack:
    - Fulvic acid, light in color, is soluble in both acid and alkali, and most susceptible to microbial attack (15–50 years)
    - Humic acid is soluble in alkali but insoluble in acid, and intermediate in susceptibility to degradation by microbes (100+ years)
    - Humin, dark in color, is insoluble in both acid and alkali, and most resistant to microbial attack

The process of decomposition

- “Decomposition is a biological process that includes the physical breakdown and biochemical transformation of complex organic molecules of dead material into simpler organic and inorganic molecules” (Juma, 1998)



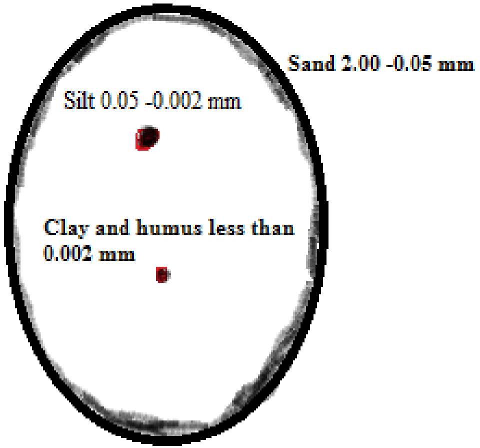
The process of decomposition

- Soil microbes decompose raw organic matter into mineral compounds via the mineralization process
    - This process contributes to soil fertility through releasing nutrients such as nitrogen, phosphorus, and potassium
- Some organic material is not mineralized, instead, they decompose into stable OM (humus)
    - Humus has less influence on soil fertility. However, it serves as a soil colloid that enhances soil structure (aggregate stability), exchangeable cation capacity ECC, water retention and soil microbial biodiversity
    - Humus makes up about 60–80% of SOM and it is derived mainly from plants (flora), with a significant portion coming from the roots, and a very small fraction comes from soil animals (fauna)

Functions of SOM

- Nutritional function
  - Large surface area of humus colloids stores water and nutrients
    - Humus as a stable OM fraction contains most of the soil's supply of N, boron and molybdenum, P and S.
    - Humus adsorbs and holds nutrients in a form available to plants
  - OM enhances sandy soils properties by increasing their water and nutrient holding capacity
    - OM absorbs water like a sponge with the ability to absorb and hold up to 90 percent of its weight in water
    - A significant amount of water held on clay particles is not readily available to plants, whereas the majority of water absorbed by OM is readily available to plants

Relative sizes of soil particles



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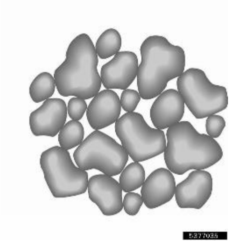
Functions of SOM

- Nutritional functions
  - OM acts as a major reservoir of soil nutrients that are released during the mineralization process. Indeed, when the rate of addition of crop and tree residues is higher than the rate of decomposition of existing OM, SOM increases
  - OM is required as an energy source for N-fixing bacteria
- Nutrition availability
  - OM not only stores nutrients but also makes several nutrient more available for plant use. In fact, as OM decays it releases mild organic acids which dissolve soil minerals freeing them for plant use
  - Soil P tends to form compounds that do not dissolve in water. However, released organic acids act on these compounds making P more available for plant use
  - Some metallic nutrients such as zinc and iron usually form insoluble compounds. However, humus molecules form a ring around the metal atom in a process called chelation. These chelates protect metal atom from being locked in the soil, and thus make it available for plant use
  - Copper is tightly bound to humus particles, for this reason it is least available in high OM soils

Functions of SOM

- Physical function
  - Humus contributes significantly to the improvement of soil physical properties by forming soil aggregates. In fact, OM together with microorganisms (fungi) cause the soil to clump and form soil aggregates:
    - Gummy substances produced by soil organisms bind to soil clumps
    - Humus particles that coat mineral particles also bind those particles together



  - Aggregation is important for good soil structure, aeration, water infiltration and resistance to erosion and crusting
  - Water infiltrates in soils high in OM more quickly during rain storms leading to less water run off that can move soil from the field
  - Better aggregation improves soil permeability and tilth and makes soil resists compaction

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Functions of SOM

- Biological functions
  - OM serves as an energy source for the living organisms in the soil. Thus, OM enhances soil microbial biodiversity and activity which can help in the suppression of diseases and pests
    - The incidence of pathogenic organisms in soil are directly or indirectly influenced by OM
    - OM may favor the growth of saprophytic organisms relative to parasitic ones
    - Antibiotics and some phenolic acids may enhance the ability of some plants to resist attack by pathogens
  - OM enhances pore space through the actions of soil microorganisms. This helps to increase infiltration and reduce runoff
- Undesirable effect
  - N is tied up in the bodies of microbes during the decay process and is not available for plant use
  - Some plant residues are toxic to other plants (allelopathy) because they exude chemicals into their rhizosphere that inhibit the growth of other plants

Factors affecting the accumulation of SOM

- Vegetation - grasses and trees
  - Cover crop vegetation protects soil from erosion and facilitates rainwater capture and infiltration, lowering the rate of OM loss
  - The extensive root systems of grasses and trees generate a large amount of underground OM
  - Trees generate a continuous organic materials for the activity of macro and microorganisms decomposers
  - Leguminous applied as green manure which usually have low C/N ratio undergo fast decomposition and increase of N pool while graminaceae species favour nutrient immobilization, OM accumulation and humus formation, with increased potential for improved soil structure development
- Climate - temperature and moisture
  - Temperature and rainfall are the key factors that affect the OM
  - More rainfall and optimal temperature promote more vegetation therefore more biomass and more OM
  - OM decays more rapidly at higher temperature, therefore soil in warmer climates tend to contain less OM than those in cooler climates
  - OM is generated faster than decay when soil temperatures are below 25 degree Celsius and decay stops when temperature is below 5 degree Celsius

Factors affecting the accumulation of SOM

- Soil texture
  - Fine-textured soils tend to have more OM than coarse soils
  - Better aeration of coarse soils facilitates the rapid decay of OM
  - Heavy clay soils with poor drainage reduce the movement of oxygen in their pores. Therefore, they accumulate more OM.
- Tillage reduces OM
  - Tillage encourages rapid OM decomposition by stirring the oxygen into the soil and raises its average temperature
  - Tillage tends to break down soil aggregates which contain OM protected from decaying organisms
  - Tillage is a form of fertilization since it promotes humus consumption
  - Tillage creates condition for biological activity that promotes the consumption of some humus liberating N for plant growth

Management of SOM

- There are two general approaches for increasing soil organic matter:
  - Slow down decomposition rates (for example, by reducing tillage intensity)
  - Enhance carbon inputs from organic materials (cover crops or compost amendments)

- Ways to increase soil organic matter:
  - Agroforestry cover crop/green manure
  - Crop rotation within agroforestry system
  - Compost adding
  - Zero or minimum tillage

Management of SOM

- Practicing soil conservation technique in the agroforestry system is best achieved through the rotation of cover crops
  - It is important to start crop rotation in the first years with grasses and cereals that add a lot of biomass which decompose slowly (high C/N ratio) and improve soil characteristics with their abundant root system. Grasses and cereals are rotated with legumes in the following years
  - Applying a mixture of fast (vetch) and slow (oat, wheat) decomposing crops in agroforestry system will significantly improve soil fertility status. The tree will benefit from the released nutrient from fast decomposing crops, while slow decomposing crops will improve soil structure
- Minimizing soil tillage
  - Tillage exposes the OM to air and will result in the lowering of stable OM
  - Minimum tillage lowers the incidence of soil compaction and waterlogging
- Establishment of cover crops as a green manure in agroforestry system will enhance OM accumulation
  - Cover crop reduces the adverse effects erosion and runoff

Management of SOM

- Cover crop adds plant material to the soil for OM renewal
- Cover crop provides habitat for beneficial insects and other organisms
- Cover crop moderates soil temperatures and therefore protects soil organisms

Nitrogen fixation (NF)

- “NF, any natural or industrial process that causes free nitrogen (N_2), which is a relatively inert gas plentiful in air, to combine chemically with other elements to form more-reactive nitrogen compounds such as ammonia, nitrate, or nitrites”
- It is worth to note here that, N_2 gas, which is present in the atmosphere, is unavailable to plants

Types of NF

- Atmospheric nitrogen is converted into available forms to plants through different kinds of fixation:
  - N can be fixed through the industrial process that creates fertilizer (ammonium nitrate NH_4NO_3)
  - Lightning allows oxygen to react with atmospheric N to form NO and NO_2. These forms of N then enter soils through rain or snow

N2 + O2 = 2NO

2NO + O2 = 2NO2

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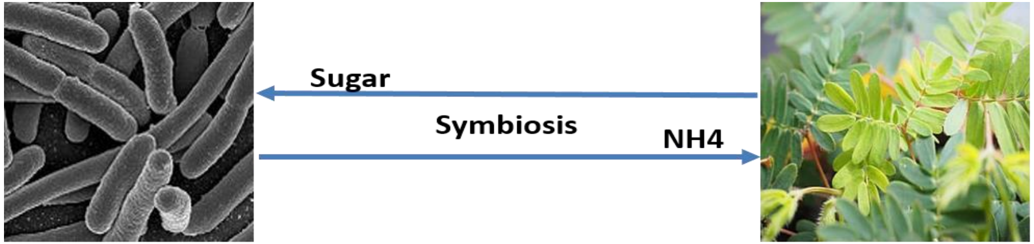
NF

- Atmospheric nitrogen is converted into available forms to plants through different kinds of fixation:
  - Biological NF accounts for significant amounts of N that are fixed as ammonia, nitrites, and nitrates by soil microorganisms
    - Symbiotic fixation: Legume-bacteria (*Rhizobium*) fix atmospheric N via an enzymatic mechanism and convert it to an available form (ammonium NH_4) for the host plant. The plant then provides the bacteria with carbon and other energy compounds produced during photosynthesis



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    - Nonsymbiotic fixation: free living bacteria (cyanobacteria, *Anabaena* and *Nostoc* and genera such as *Azotobacter*, *Beijerinckia*, and *Clostridium)* in soils can fix nitrogen without symbiotic relationship

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Biological NF by legumes

- Nodule formation initiates when NF bacteria invades the root in response to the chemical signals (flavonoids) released by the host legume plant
- The indication of the start of NF and bacterial activity is when the inside nodules color turns from white or gray to pink or red
- Dead, inactive nodules are usually greyish green or brown inside
- The pink or red color is caused by leghemoglobin (similar to hemoglobin in blood) that controls oxygen flow to the bacteria

Leghemoglobin (also leghaemoglobin or legoglobin) is an oxygen-carrying phytoglobin found in the nitrogen-fixing root nodules of leguminous plants

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Biological NF by legumes

- The shape of nodules can differ from one plant species to another
  - Large round nodules are usually found in annual legumes such as beans, peanuts, soybean and are renewed during the growing season
  - Small elongated nodules present in perennial legumes that fix N throughout the growing season
- The rate of N fixation is highest during the flowering stage. Nodules lose their ability to fix nitrogen during the pod filling process
- In the middle of the growing season, pink or red nodules should predominate on roots. If white, grey, or green nodules predominate, this indicates that NF is relatively low due to an inefficient rhizobia strain, poor plant nutrition, pod filling, or other plant stress
- Nodules become senescent and begin to decay as the plant matures
- After cutting the aboveground biomass, the roots of the perennial legumes left in the soil initiate a new nodulation process in the spring

Factors affecting NF

- Bacteria inside nodules require energy from the host plant; thus, any factor affecting photosynthesis, such as water stress, temperature, and nutrient deficiency, will reduce biological NF
- NF depends on the presence of specific bacteria strain in the soil that will partner with a specific legume crop. However, if the bacteria strain is not present in the soil, inoculation of seed with the appropriate bacteria is required before planting
- Soil physico-chemical properties such as OM, pH, temperature and moisture content affect the abundance of fixing bacteria
  - Low pH inhibits NF and nitrification processes. The optimum pH is 7.0, but ranges between 5.0 and 9.0 are tolerable
  - Low water availability and high temperatures cause a drop in the biological NF. 40 ºC at 5 cm depth, imposes limitations on the NF and nodule viability in the soil. Therefore, cover crop will reduce the soil temperature
- The efficacy of NF depends on the species of legumes:
  - Peanuts, cowpeas, soybeans, and fava beans, are good nitrogen fixers whereas beans are poor fixers
  - Perennial and forage legumes, such as alfalfa, sweet clover, true clovers, and vetches, may fix 300–560 kg of N per ha

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The fate of N fixed through NF process

- The N fixed during biological fixation is accumulated in different plant tissues and will be released to the soil upon the decomposition of plant residues. However, some of the N is released in the soil for neighboring non-legume plants

- Legumes such as beans, lentils, lupine, peas, and peanuts when grown for their grain contribute little to soil nutrition as most of the N is removed from the field along with the grain

- Perennial or forage legumes add significant N for the following crop if the entire biomass (stems, leaves, roots) is incorporated into the soil

Management of NF

- N is the most limiting nutrient especially in rain fed traditional olive orchards
- Adopting a natural N source is required to mitigate the disadvantages of the high cost of synthetic N fertilizers and associated environmental issues and also to ensure proper tree growth and optimal yield
- In this regard, integrating legumes as a cover crop or green manure into olive orchards can improve infertile soils and thus proper tree growth and yield
- Fall cultivation of legumes in an olive orchard located at low and medium elevations will benefit from autumn and winter rainfall for better growth and accumulation of more biomass
  - In spring, the crop will be either cut or incorporated into the soil
  - Olive tree will benefit from the nutrients released upon the decomposition of legume residue

Nutrient leaching

- **Definition:** Nutrient leaching is the downward movement of dissolved nutrients in the soil profile with percolating water

- Nutrient leaching:
  - Reduces the availability of nutrients to crops and trees
  - Is a major cause of groundwater contamination
  - Is problematic in soils with high infiltration rates and low nutrient retention, such as sandy soils.
  - Poses environmental and economical problems

Nutrient leaching / Causes of nutrient leaching

- Inappropriate agricultural practices in intensive agriculture can greatly increase leaching losses
- Water leaching happens when water input by irrigation or rainfall exceeds evapotranspiration
- Nutrient leaching is high in humid region than in arid
- Soils with high infiltration rates and low nutrient retention or well aggregated soils with low OM content are usually prune to nutrient leaching
- Macro-pores induced by cracking clay soil or by biological or root growth activity increase the flow of water with dissolved nutrients especially under heavy rains or excessive irrigation leading to nutrient leaching

Nutrient leaching / Causes of nutrient leaching

Macronutrients		Ionic forms
Nitrogen	N	NH^{4+} and NO_3
Phosphorus	P	H_2PO^{4-} , HPO_4^{2-}
Potassium	K	K^+
Calcium	Ca	Ca^{2+}
Magnesium	Mg	Mg^{2+}
Sulfur	S	$(SO_4)^{2-}$

Micronutrients		Ionic form
Boron	B	$(BO_3)^{3-}$
Chlorine	Cl	Cl^-
Copper	Cu	Cu^{2+}
Iron	Fe	Fe^{2+} , Fe^{3+}
Manganese	Mn	Mn^{2+}
Molybdenum	Mo	$(MoO_4)^{2-}$
Zinc	Zn	Zn^{2+}

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Nutrient leaching / mineral elements

- Seventeen nutrients are essential for plant growth
  - Non-mineral nutrients: Carbon (C), hydrogen (H) and oxygen (O), account for approximately 96% of dry plant weight, mostly in the form of carbohydrates. The sources of C, H, and O in plant materials are carbon dioxide (CO_2) in the air and water (H_2O)
  - Mineral nutrients: the macronutrients (N, P, K, Ca, S and Mg) account for approximately 3.5% of dry plant weight. However, micronutrients (Fe, B, Cl, Mn, Zn, Cu, Mo and Ni), account for about 0.04% of dry plant weight
  - Both macro and micro- nutrients are usually obtained from the soil
- N is typically the first limiting nutrient, followed by P, K, and S

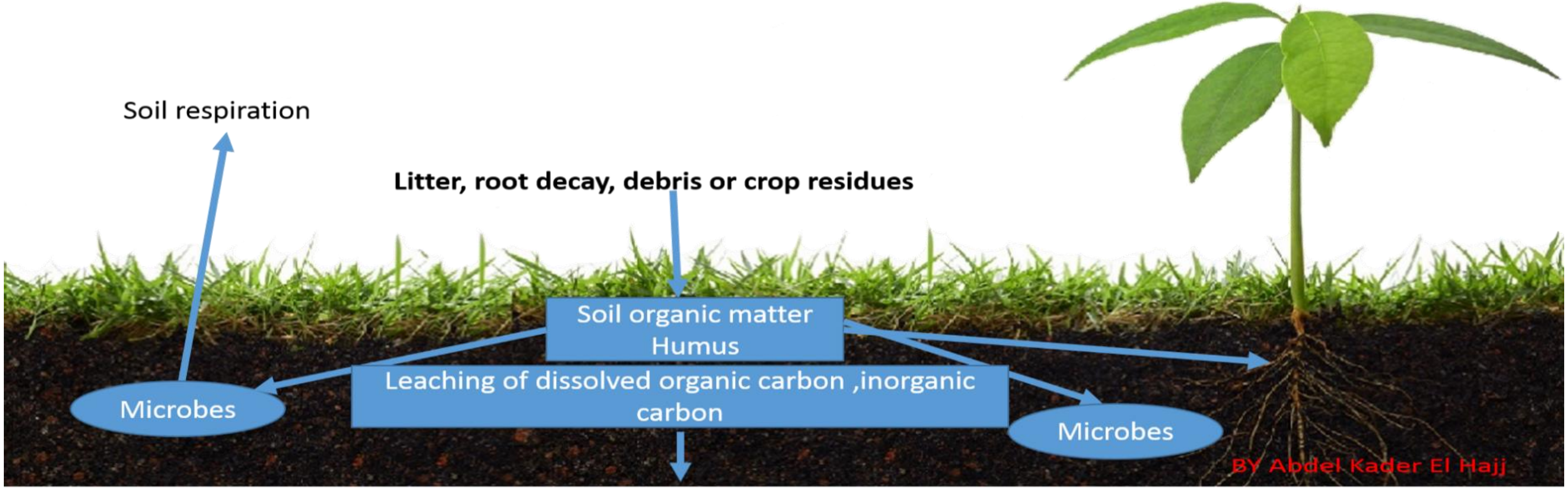
Nutrient leaching / Nutrient uptake

- Plants absorb essential nutrients from the soil in soluble, inorganic forms
- Ions are absorbed by plant roots by three main mechanisms
  - Root interception. Nutrient uptake happens, when roots come in contact with ions during their movement through the soil profile. This process is related to root system volume
    - Mycorrhizal fungi increase plant root volume via the production of their own root-like structures called hyphae, which act as extensions of the plant's root system. Thus, mycorrhizal fungi increase nutrient uptake
  - Mass flow. Dissolved nutrients move with water towards root surfaces where they are absorbed
  - Diffusion. Movement of nutrients from high concentration to areas of low concentration. Diffusion is an important process in crop uptake of P and K.

Nutrient leaching / Carbon cycle

- Agroforestry plays an important role in global carbon cycle as it provides two sinks of carbon (woody parts and humus in the soil)
  - Atmospheric carbon dioxide used by the process of photosynthesis is accumulated as organic carbon in all agroforestry components (tree/crop)
  - Considerable fraction of the accumulated organic carbon is stored in woody parts of the tree for a long time
  - Organic carbon accumulated in the other parts of the plant (roots, litter, debris, or residues) is released into the soil through the decaying process
  - In the soil, a fraction of the carbon becomes part of SOM (humus) which stores carbon for a long period and the other fraction will be respired via decomposer organisms back to the atmosphere
  - Some dissolved organic carbon (DOC) and inorganic carbon (HCO_3) may leach to groundwater and surface water

Nutrient leaching / Carbon cycle



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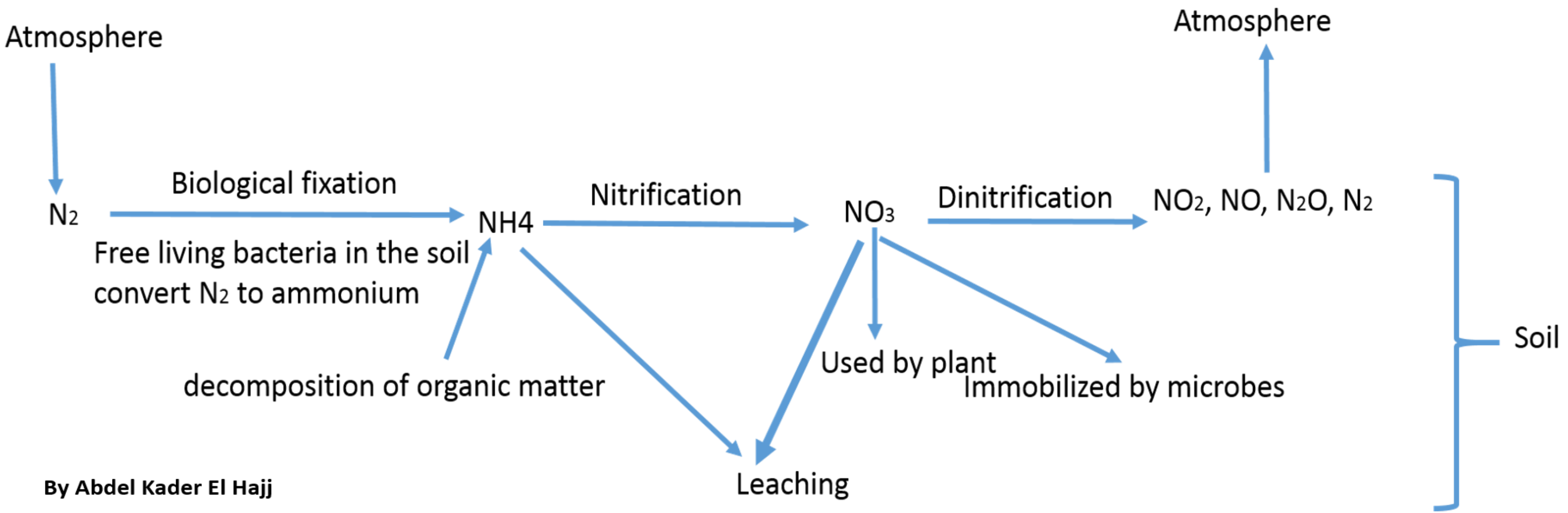
Nutrient leaching / N cycle

- Nearly 80% of N is found in the atmosphere as N_2 . Sedimentary rocks contain roughly the remaining 20%
- Free living bacteria in the soil convert atmospheric N into ammonium $(NH_4)^+$. $(NH_4)^+$ also comes from the decomposition of OM. $(NH_4)^+$ formed from these two sources is then converted to nitrates (NO_3^-) through a nitrification process
- Part of NO_3^- is assimilated by plants and bacteria, part is leached through soil profile and the other part is converted to N gas and released back to the atmosphere through a denitrification process

Nutrient leaching / N cycle



By Abdel Kader El Hajj

Nutrient leaching / N cycle

- Routs of N loss in the soil
  - Leaching of NO_3^- , NH_4^+ and dissolved organic N
    - Due to its high mobility NO_3^- anion is leached easily through the soil profile as it shows negligible interaction with the negatively charged matrix of the soil. NO_3^- leaching is favored by high rainfall and irrigation especially on soils with coarse texture
    - However, tree-crop (mainly winter cover crop – grasses and legumes) interaction in agroforestry system is effective in capturing and recycling of nutrient from deeper soil layers
  - Soil erosion
    - Surface runoff carry dissolved nutrients or sediments. However, cover crops reduce negative effect of erosion
- In natural ecosystems these N losses are compensated through biological N2 fixation (BNF) by leguminous plants living in symbiosis with Rhizobium and other N2 fixing bacteria, or free-living bacteria

Nutrient leaching/ P cycle

- The first source of P is from weathering parent materials. The release of P from this source is extremely slow
- The second source is the soil solution: inorganic P dissolved in water/soil solution is readily available for plant uptake
- The third source is comprised of inorganic phosphorus attached to clay surfaces, iron (Fe), aluminum (Al) in acidic soils, and calcium (Ca) oxides in alkaline soils. P is released slowly for plant uptake
- P is removed from the soil by:
  - Erosion and runoff (runoff is the more important route of P loss)
  - Tree / crop uptake
  - Leaching (is minimal compared to surface runoff removal)

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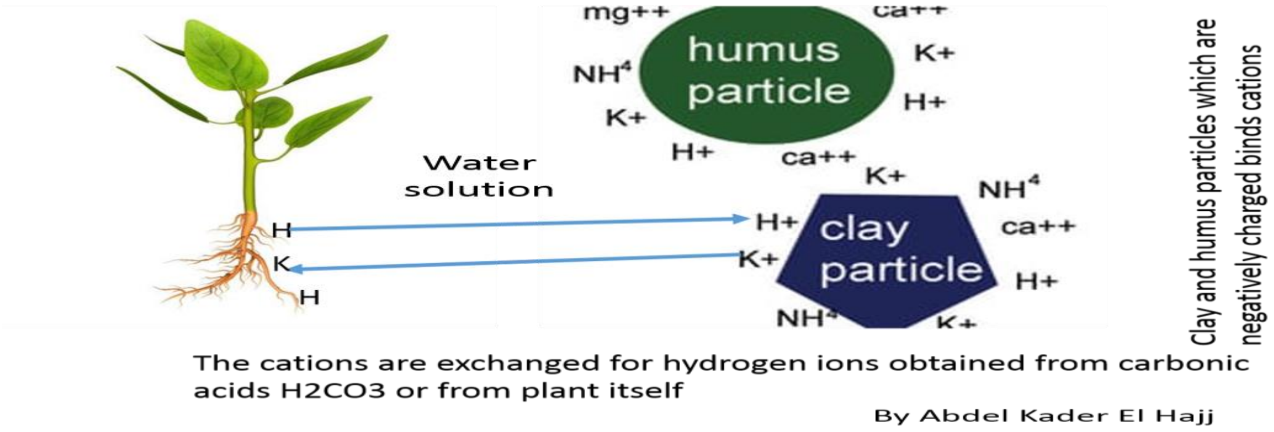
Nutrient leaching / P cycle

- P availability is influenced by the following factors:
  - OM. Increasing of OM will increase P availability through the mineralization process and competition of organic molecules with phosphate (PO_4^{3-}) adsorbed to soil surfaces that will reduce P retention
  - Clay Content. Soils with higher clay content have high P retention capacity
  - Soil pH. In acidic soils, PO_4^{3-} forms bond very strongly with aluminum and iron. At high pH, when calcium is the dominant cation, PO_4^{3-} tends to precipitate with calcium
  - Environmental factors. In warm and humid areas, the decomposition of organic material is faster that in cool and dry climates

Nutrient leaching / K cycle

- In soil, K occurs in four pools: soil solution; exchangeable site; fixed and parent minerals
- The soil solution and exchangeable site of K are in equilibrium with each other: plants absorb K exclusively as the K^+ ion, which is the only form that exists in soil solution. Exchangeable K refers to ions adsorbed to exchange sites on soil particles
- K fixation is the entrapment of the K^+ ion in the structure of clay minerals. The fixed pool is not able to release K at rates sufficient to meet the demands of growing crops. However, a portion of this pool will become available as the exchangeable and soil solution K supplies are depleted
- There are two ways K can be lost from the system:
  - Leaching and erosion. K leaching can occur on coarse textured soils that receive above average precipitation. Erosion is a more important route of K loss

Nutrient leaching / K cycle



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Nutrient leaching

- The role of agroforestry in reducing nutrient leaching
  - Agroforestry which provides additional cover between trees improves nutrient retention by increasing litter, mulch, and root production, all of which boost SOM and cation exchange capacity
  - Active absorption of nutrient by tree and cover crop may reduce nutrient concentrations in the percolating soil solution
  - Humus increases exchangeable site, thus nutrient retention
  - Water uptake by trees may reduce water infiltration and, therefore, nutrient leaching
  - Crop cover, tree canopy, and litter reduce the erosive effect of runoff, resulting in less nutrient loss
  - Trees reduce nutrient leaching by absorbing nutrients that were leached beyond the shallow root system of the crop

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Soil conservation – Definition and Goal

- Definition. Soil conservation is the prevention of loss of the top most layer of the soil from erosion or prevention of reduced fertility caused by over usage, acidification, salinization or other chemical soil contamination
- Goal. The primary goal of soil conservation is to control erosion and thus maintain soil fertility through practices and management strategies such as zero tillage combined with cover crop and crop rotation
    - Erosion lowers soil fertility, through removal of OM and nutrients in eroded sediment
    - Soil fertility decline is the inability of a soil to sustain plant growth by providing the essential nutrients and maintaining its physical, chemical, and biological characteristics for better plant growth
- The soil conservation practices (no tillage, no fertilizers, no pesticides) play a major role in increasing abundance, biomass, and diversity of earthworms

Soil conservation – The role of agroforestry

- Agroforestry plays a major role in conservation of soil fertility
  - Residues produced by tree and crop roots and associated mycorrhizae can increase SOM, soil porosity, and aggregate stability. It can as well enhance water holding capacity, hydraulic conductivity, and biological soil processes (more root biomass, more microbial association, more biological activity)
- In agroforestry system, both cover crop and tree control soil erosion in rainy season by forming a network of roots that hold soil together. This network of roots enhance the soil permeability
- Tree canopies and crop cover conserve the soil from the erosive impact of raindrops
- The leaf litter and humus control the flow of water and allow them to percolate into the soil, store a large amount of rainfall, reduce evaporation of soil moisture and decrease nutrient loss through the reduction of run-off

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Soil conservation

- The trees with their extended root system deep into soil layers, capture the leached nutrients, and decrease pollution entering into aquatic ecosystems
- Density, distribution and thickness of cover crop roots play an important role in controlling erosion
  - Cover crops with fine-branched roots are most effective in preventing erosion
  - Cover crops with thick roots (e.g. white mustard and fodder radish) are less effective than cover crops with fine-branched roots (ryegrass and rye) in preventing soil losses by erosion
  - Olive orchards that include mixed cultivation of legumes and grasses (e.g. vetch and barley that have different root system make up) are proved to control erosion

Soil conservation

- Soil conservation practices that have a positive influence on soil biochemical characteristics and soil microbial genetic diversity in olive orchards include:
  - Cover crop
  - Incorporation of cover crops (green manure)
  - Conservation tillage (minimum or zero tillage). Zero-tillage with cover crop residue gradually increases soil OM and suppresses weeds, as well as reduces costs of machinery, fuel and time associated with tilling
  - Compost amendments
  - Incorporation of pruning residues into the soil after their chopping

Water conservation – Goals and cycle

- The goals of water conservation strategies are to store more rain water, increase infiltration, decrease runoff and percolation and minimize evaporation. Water conservation is important, especially in areas where water is limited or not enough for crop production
- Most of soil functions depend directly or indirectly on soil water retention and transmission
- Water cycle
  - The main source of water in the soil is from rainfall. Part of the rainfall is lost through runoff the second part infiltrate into soil
  - Water in the soil is used by plants, some water in the soil percolates into the ground water. However, the water retained in the soil evapotransperates from soil and plant cover

Water conservation

- Factors determining soil capacity of retaining and releasing water:
  - Soil texture. Clay particles have the capacity to retain more water and nutrient than sandy particles
  - Soil depth:
    - Shallow soils have the tendency to waterlog in heavy rains, and fall below the permanent wilting percentage under drought conditions
    - Deeper soils, in addition to provide better mechanical support to the trees, also can provide more water and nutrients to plants than more shallow soils
  - Soil porosity. The pore space affects the movement of water and air; the transport and the reaction of chemicals; and, the residence of roots and other biota
  - Biological activity. The contribution of the microorganisms to hydraulic properties of the soil is through creating OM

Water conservation

- OM content:
  - Organic molecules create soil aggregates by sticking clay particles together
  - Large pores between aggregates let water moves through soil profile; small pores within aggregates hold water which will be available to the plants
  - OM colloids (humus) act as a sponge that retain more water

Water conservation

- Most of the practices that increase soil moisture content are often related to OM:
  - Water infiltration:
    - Litter, tree canopy, and crop cover effectively manage the infiltration rate and the runoff of water from the soil surface
    - OM accumulated in the soil within agroforestry system enhances water retention and infiltration rate
  - Soil evaporation. Natural organic mulches developed by agroforestry practices effectively manage soil evaporation
  - Soil moisture storage capacities. Improving soil moisture storage capacity can be achieved by adding more organic materials (green manure, cover crop, litter, and tree and crop residue)

Water conservation

- Practices aiming on improving soil water content include:
  - Mulching. Leaf litters and crop residues (slow and fast nutrient release) are good mulching materials
  - Agroforestry – Cover crop:
    - Minimize runoff and improve infiltration and soil water storage capacity
    - Minimum tillage reduce the disturbance of soil attributes (aggregate stability, soil biological activity, etc.)
    - Decrease evaporative losses through a mulching effect
  - OM amendments. Include compost, animal manure, green manure and other organic fertilizers
  - Terracing. Very important on steep lands

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