



DELIVERABLE N. 3.6

DYNAMIC SOD MULCHING AND USE OF RECYCLED
AMENDMENTS TO INCREASE BIODIVERSITY, RESILIENCE AND
SUSTAINABILITY OF INTENSIVE ORGANIC FRUIT ORCHARDS
AND VINEYARDS

YEARLY REPORTS OF BIODIVERSITY DATA
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Introduction

The challenge represented by weed management has been indicated as one of the mayor constraints in conversion into organic management (Bond & Grundy, 1998). Beside the limitation imposed in the use of chemical tool, the whole approach in organic weed management should be substantially different. Full weed eradication shouldn't be a goal (Blake, 1990), there are obviously conflicts between completely weed eradication and other aims of the organic system (Mattsson et al., 1990; Colquhoun & Bellinder, 1996). Despite the initial positive effect of a mechanic weed control due to organic soil matter mineralization, heavy negative outcomes will be detrimental for soil physical, chemical and biological fertility.

In the last decades a more holistic approach intended to increase the sustainability of the agronomic practices by increasing the biodiversity has characterized a rising part of the organic scenario (Mia et al, 2020a, b). Nowadays, a further challenge for the organic farmers should be to move from the goal of a “greater biodiversity” to the setting of a better diversity, finalized to the achievement of precise agroecosystem services.

Weed community composition in orchard agroecosystem depends on how the local biodiversity is selected and favorited by environmental, biotic, and especially management factors, that act as “environmental filters” (Gotzenberger et al., 2012; Borgy et al., 2016). Some of the practices, like tillage, act more than others as strong filters (Barberi et al., 1998). For these reasons, an integrated or ecological weed management requires precise knowledges on the effect of management practices on the weed population composition (Bastiaans et al., 2000).

An indiscriminate increase in biodiversity in the ground cover, as well as in the soil, due to the inclusion of naturally selected species, could induce competition and disequilibrium within the orchard, hardly tolerable in a productive layout. An innovative approach would manipulate biodiversity looking for an improvement of services and functions in the acro-ecosystem.

Diversification is recognized as a factor promoting system resilience, nevertheless a generical increase in biodiversity is not in itself a guaranty for the improvement of the economical sustainability of the organic practices (Barberi et al 2016).

The challenge evolves toward the identification of species combination able to provide services to the system and to maintain competition to a not detrimental level. It would be possible to intensify organic agriculture by developing strategies for targeted exploitation of biodiversity. Neri et al (2020) used a living wild strawberry mulch in vineyards to control the other weed competition without any detrimental effect on grape yield. Bender et al. (2016) proposed an interesting model on the contribution to input substitution by endogenous resources (Fig.1).

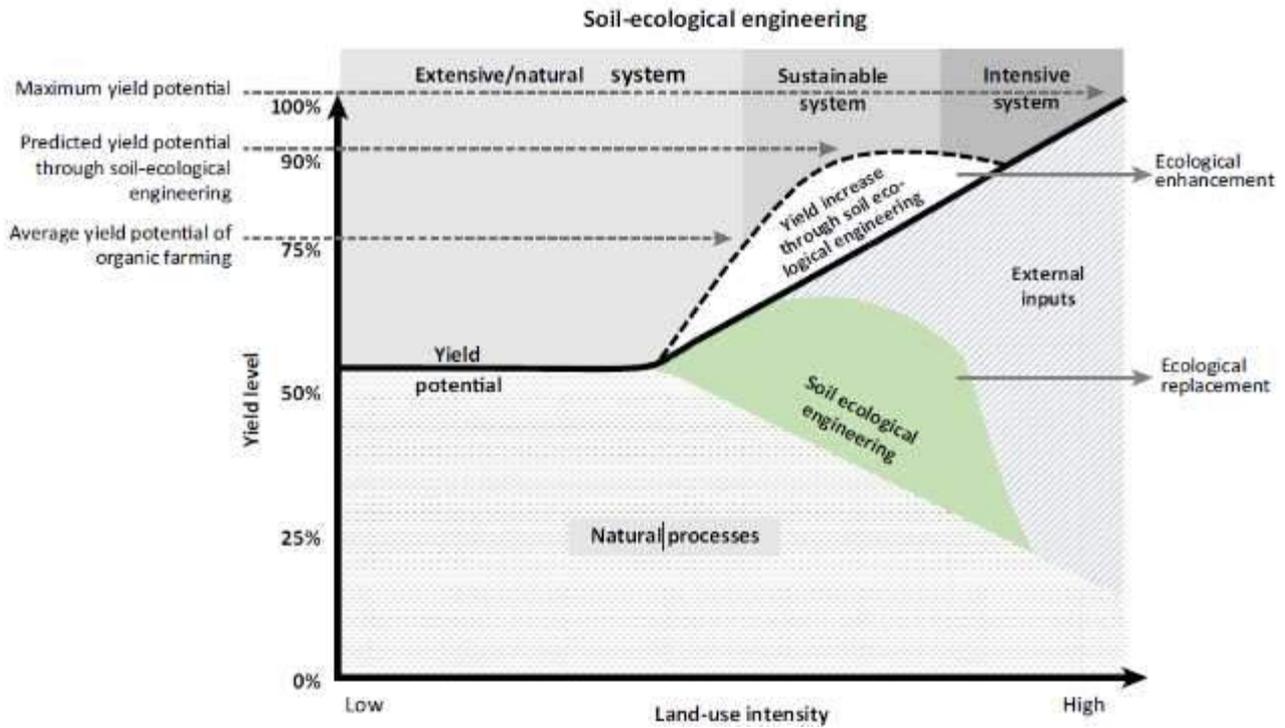


Figure 1: Conceptual model showing the contribution of external resource inputs and natural biological processes to an ecosystem function, in dependence of land-use intensity

At low land-use intensity, yield is low and sustained by natural biological processes. With increasing land-use intensity, dependence on external resource inputs increases and the contribution of natural biological processes decreases. Yield is highest under intensive management with a high level of external resource inputs. Soil ecological engineering (green) complements the contribution of natural biological processes and can partly replace external resource inputs, therefore either maintaining yields while reducing external inputs (ecological replacement) or enhancing yield without enhancing external inputs (ecological enhancement) (Bender et al. 2016).



DOMINO'S ACTIVITIES

All the research groups involved in the DOMINO project contributed in 2018-2020 to the definition of best practices, locally tested, for sustainable weed management. The goal was to reduce soil tillage, assure a permanent soil cover thus managing weed competition within a physiologically sustainable level. A further goal was to include species providing agroecological services and valorize for the same aim local biodiversity. In 2019-2020 some results were added to the studies of all the partners.

Living mulches: criteria for the selection of suitable species

Several local spontaneous or cultivated species have been tested for under-the-row ground management.

The choice for the species to be grown on the row has been done considering several aspects:

- a) the species is adapted to environmental and agronomic condition
- b) the species could provide an additional source of income
- c) the species could provide some agronomical services (e.g. phytosanitary activities)
- d) the species could provide a multifunctional activity

The selection of species issued from local biodiversity provides significant advantages in terms of plant resilience. Looking at local species behavior will also help in identify plants with the higher soil cover capability. When considering the additional source of income, **officinal plants** appeared as a potential target as well as horticultural species. A strong interest and market opportunity are recognized for organic officinal plants in several countries and at EU level. Discussions with producers of officinal plants have pointed out that the possibility of growing plants in a shadow environment, like that of a fruit tree row, is an added value for the market thus increasing product quality.

Poland (INHORT): experiences from continental climate.

The experience of 2018

Among species that prefer such shadow environment is *Hierochloë australis* – the plant used to produce a unique kind of aromatized vodka typical of Poland: “zubrówka”. Furthermore, there are species which can be harvested very soon in the season (i.e. *Alium ursinum*), thus not causing competition with the fruit trees. Likely, there are species which are also quite well covering the ground, so highly reducing the competition from weeds (*Alchemilla vulgaris*, *Galium odoratum*, *Veronica officinalis*). Some of them, normally considered as “weeds”, can be valorized as officinal preparations.

Species able to provide agronomical services were also selected to sustain plant protection or plant nutrition. Soil-borne pests are quite difficult to control even in conventional orchards, and organic farming limitations in the use of pesticides needs to be overcome with new solutions. The availability of plants that produce specific **root exudates** containing compounds that can interfere with soil pests



is thus an opportunity that has been considered when selecting species to be grown on the row. Among them two have been considered, *Tagetes* sp. and *Taraxacum officinale*. The former is highly **repellent of parasitic nematodes**, while the second results to be preferred by white grubs (larvae of May beetle), thus reducing the risk of damaging tree roots. However, an unexpected positive effect of some officinal species on above ground pests was observed in preliminary trials established, during the project, to verify the feasibility of certain herbs to be grown on the row: a two-fold **increase of predatory mites** on the apple leaves was determined when growing nasturtium and mint. Dandelion is also requested for herbal preparations, thus making this plant a potential multifunctional species (phytosanitary and cash crop). We have also considered to test other species, which can be useful for weed control and production of raw materials for uses in phyto-cosmesis or food preparations, such as *Potentilla anserine*, *Melittis melissophyllum* and *Symphytum officinale*.

To improve plant nutrition, trials are established testing a modified “sandwich system”. Microclover has been planted along the tree row. This species has an initial slow development, but it is resistant to soil pounding by machines and do not compete much for water and nutrients due to its small size.

As a weak point, it should be stressed that not all species performed equally well in reducing weeds infestation. Nasturtium and mint, despite their promising characteristics did not succeed in competing with weeds so that their relative abundance progressively decreased, in the parcels.

In the interrow, a mixture of seeds has been sown. This is composed by a gramineous (for example *Festuca ovina*, which covers well the soil, but grows little and is highly resistant to pounding) and a leguminous, again to increase N supply. We are testing new leguminous species (Kura clover - *Trifolium ambiguum*, and *Galega orientalis*) that have proved to be interesting in Poland also for the production of feedstuff.

The experience of 2019

The species were selected on the basis of the results of the preliminary trials of 2018 at Inhort and of other partners. Only two of the previously tested species (mint and garden nasturtium) were further considered in this trial together with a third species tested in Germany and Italy (wild strawberry). In total 11 species were utilized and selected for their potential use as secondary crop, crop protection or soil phytoremediation properties. For the selection also the following characteristics were considered: the reduced competition with apple trees, the competition with weeds, the market need. Among them, 10 resulted to perform in a satisfactory way, with some interesting, unexpected, outcomes: the species *Viola odorosa* was able to maintain the row almost free from weeds probably due to an allelopathic mechanism. Data about soil and above-ground fauna were also collected showing also in this case very interesting results useful for the analysis planned under Task 6.1.

A trial for inter-row and row management (Task 3.2) using mixtures formed with *Festuca ovina* and one of four leguminous species (*Trifolium ambiguum*, *Galega orientalis*, *T. repens* normal type or micro type) was set up. The unusual dry season has initially jeopardized the establishment of the trial, but the cover crops have partly recovered during the last part of the season. Nevertheless, it is planned



to renovate the plots of the two new leguminous species in the next season. The soil analyses planned to follow the dynamic of nitrogen availability have been performed and are showing a quite interesting trend which will be assessed in combination with the data of soil biodiversity.

Three trials have been set in commercial orchards, testing some of the species selected for row management. The monitoring of the effects on major pests was performed.

Switzerland (FiBL, Frick)

At FiBL the demonstration trial with the living mulch in the tree row has been started in April 2019. Following six species were used as living mulch: *Fragaria vesca*, *Hieracium aurantiacum*, *Hieracium lactucella*, and *Potentilla reptans*, white clover, and micro clover. *Hieracium aurantiacum*, *Hieracium lactucella*, were sown in April, grown in the greenhouse, and later planted in May into the tree row, along with the strawberries (6 plants per meter). *Potentilla reptans* was already occurring naturally at the site and was transplanted into the tree row (also 6 plants per meter). White clover and micro clover were directly sown into the tree row in May (2 g/m²) but could not establish due to the drought. They were re-sown in September, but once again could not establish. Selective weeding was performed once a month from June until September (in total and on average around 20 min per square meter). End of June all living mulches covered between 25 and 40% of the tree strip, with *Potentilla reptans* being the most covering followed by *Fragaria vesca* and *Hieracium lactucella*, and *Hieracium aurantiacum*. End of July *Potentilla reptans* covered 90% of the surface, whereas the other living mulches covered only 50 to 60% of the surface. Mid November *Potentilla reptans* and *Hieracium lactucella* almost covered the whole tree strip, *Hieracium aurantiacum* covered around 75% of the tree strip, and *Fragaria vesca* around 65%. The plots with *Fragaria vesca* showed the most weeds compared to the other plots.



Figure 2: The naturally occurring *Potentilla reptans* as living cover in October 2019.



Figure 3: From top: *Fragaria vesca*, *Hieracium aurantiacum*, and *Hieracium lactucella* in May 2019 (left) and October 2019 (right).



The use of legumes

The trial with the legumes as living mulches in the inter- and intra-row has been started in April 2019. Peas as well as white clover and micro clover have been sown end of April in the intra-row for the peas respectively the inter-row for the clover. The peas developed well and were mulched in July. The clover however did not develop because of a drought and was sown again in September, but once again did not establish. Soil Nmin analyses were performed during the season from April until October.



Figure 4: The peas in the intra-row end of May 2019.



Germany (Stuttgart)

The demonstration trial to enhance biodiversity in the tree row in apple orchards was set up at the KOB in 2018 with wild strawberries and peppermint. The establishment of the strawberries was partly problematic, so some plants had to be replanted in July 2019. The ground cover was rated at three points in time for the strawberries and mint, as well as for the weeds. To reduce overgrowth of weeds, the plots were weeded by hand two times. The strawberries showed lower competitiveness against weeds than the mint. The mint grew to a height of 1 m and was cut back in August and October.

The use of legumes

The trial on leguminous mulches in the inter row as internal nitrogen source in apple orchards was delayed due to the insufficient establishment of the clover in autumn 2018 resulting from extremely dry weather conditions. Clover was therefore reseeded in spring 2019 and established in summer 2019 in the inter row. Measurements of biomass production and nutrient content of the clover as well as soil N_{min} are therefore postponed to 2020.

A Master thesis was done on the current situation of the usage of the inter row and its potential as internal nutrient source to gain additional information. Farmers in the Lake Constance and the Freiburg region were interviewed, soil samples were taken, and throughout the season 2019 the biomass production in the inter row was measured as well as the nutrient content (C, N, P, K, Ca, Mg) of the cuts, transferred to the tree row. Differences in management strategies between farmers could be observed in terms of number of cuts and the establishment of flower strips. The nutrient content of the cuts fluctuated during the year. The thesis will be submitted in 2020, full data will be available then.

At the Competence Centre for Fruit Growing Bavendorf a demonstration trial has been started in October 2018 with wild strawberries (*Fragaria vesca*) and peppermint (*Mentha x piperita*) planted in the row under apple trees on M25 with a spacing of 3.6 m. The strawberries were planted with a density of 9.4 plants m⁻², the peppermint with a density of 4.4 plants m⁻², each on 10.8 meter length. The trees are planted in metal baskets to prevent damage by mice. During the vegetation period, the ground cover of the crops as well as the weeds will be measured two to three times and the results will be compared with the hoed and untreated control (Fig.5).



Wild strawberries in the row

Peppermint in the row



Figure 5: Demonstration trial in October 2018 and in spring 2019.



South Tyrol (Northern Italy)

Eight different species were pre-test at the Laimburg research Centre and their performance had been compared with grassed and tilled ground. Below the main traits considered for species selection and the full list of species selected for their interesting characteristics (table 1 and 2).

Table 1. Relevant features in living mulches species and relative scoring

Wanted features	*** or **	*	-	+* or +** (poor conditions improved up to **)
Height	< 45 cm	45 - 65 cm	> 65 cm	+ mulching
Light requirement	low	medium	high	
Reproduction potential	stolons/high seeds production	low or not mature seeds production	no seeds/stolons production	
Competitiveness against weeds	high	medium	low	+ stale seed bed
Competition with trees	low	medium	high	
Beneficial insects	predators or pollinator repellent or not	no data	attractiveness	
Pests	attractive	no data	attractiveness	
Drought resistance (orchard conditions)	high	medium	low	+ irrigation (only after sowing)
Nutrients requirement	low	medium	high	+ moderate fertilization



Table 2. Characteristics of the main species selected as living mulches

	Height	Light requirement	Competitiveness against weeds	Competition with trees	Beneficial insects
Living mulch					
<i>Portulaca oleracea</i>	***	***	***	?	
<i>Tropaeolum majus</i>	***	***	***	?	
<i>Potentilla reptans</i>	***	***	**	?	
<i>Galium mollugo</i>	***	***	***	?	
<i>Achillea millefolium</i>	***	***	*	?	**
<i>Trifolium repens</i>	***	***	**	***	
<i>Fragaria vesca</i>	***	***	*	?	
<i>Euphorbia helioscopia</i>	***	***	**	?	
<i>Sanguisorba minor</i>	**	**	***	?	
<i>Glechoma hederacea</i>	***	***	***	?	
<i>Salvia pratensis</i>	***	**	*	?	
<i>Trifolium resupinatum</i> <i>var. resupinatum</i>	***	**	**	***	
		Pests	Drought resistance	Nutrients required	Reproduction potential
Living mulch					
<i>Portulaca oleracea</i>		**	***	***	***
<i>Tropaeolum majus</i>		**	+*	**	Na
<i>Potentilla reptans</i>		**	**	***	***
<i>Galium mollugo</i>		**	**	***	**
<i>Achillea millefolium</i>		**	***	***	**
<i>Trifolium repens</i>		**	***	***	**
<i>Fragaria vesca</i>		**	-	***	***
<i>Euphorbia helioscopia</i>		**	***	***	**
<i>Sanguisorba minor</i>		**	**	***	Na
<i>Glechoma hederacea</i>		**	***	***	***
<i>Salvia pratensis</i>		**	***	***	*
<i>Trifolium resupinatum</i> <i>var.</i> <i>resupinatum</i>		**	**	***	***

In May 2018 LAIM performed a screening aiming to evaluate the potential of 16 species (single or in a mix) as cover crops in the orchard and 16 species (single or in a mix) in the vineyard. The selection of these species was done in function of the possible ecosystem services that the single species should provide (e.g., nitrogen fixation, high biomass production, control of the weed growth, attractivity for beneficial insects, etc.), besides the live mulching function. From the results obtained



in 2018 a further selection was done, to test the most promising species in a randomized block design with four repetitions per treatment. The species were selected in function of their light and water requirement, their competitiveness with fruit trees and with the other spontaneous species, their potential to grow and cover the soil, their physical characterize (e.g. height) and the results of the previous screening. During the 2019 trial only four species/mix showed satisfactory growth (i.e., *Trifolium repens*, *Gallium album*, *Trifolium resupinatum* and the mix *Trifolium repens*, *Gallium album*, and *Achillea millefolium*) but the trials of 2020 – 2021 will still proceed with the same species tested in 2019. All the other tested species, even if at the beginning of the season showed great potential (e.g., *Potentilla reptans*) they were not able to stop the development of *Echinochloa crus-galli*, one of the most aggressive weeds we found in our field.

Data about nutrients in the leaves, mineral nitrogen of the soil, fruit production and quality of the harvest were collected during the whole year and will be evaluated also in 2020. The results obtained in the vineyard are not satisfactory yet, as the plants growth was weak, and the selected species were not competitive enough against the weeds. Furthermore, many of the selected species (in particular *Achillea millefolium*, *Sanguisorba minor* and *Potentilla reptans*) were damaged by mole crickets.

No significant differences were found for the macronutrient content in the leaves of July, while Iron was significantly higher in the mix *Trifolium repens*, *Gallium album* and *Achillea millefolium* compared to the tilled soil. The mineral nitrogen was quite variable as influenced by the different soil management effectuated in the function of the sowing moment required by the different species, but as expected legumes increased or maintain constant the mineral nitrogen into the soil during the two sampling campaigns, while other species sharply decreases the amount of mineral nitrogen available in the tree line. Significant differences were also found during the harvest in the tree production, but further year assessments are required to establish if the live mulching could increase/decrease the fruit production.

The inter-row species selected for the green manure trial performed at Laimburg were tested in the orchard and in the vineyard. All the selected species used as single species or in a mix did not show satisfactory results in terms of biomass development and coverage of the ground. The weed pressure in the orchard was too high and the sowed species were not competitive enough. Moreover, the soil of the orchard was quite compact and did not allow the water to drain. The water excess was a second important limiting factor in our green manure field trial, which invalidates the experiment. The soil analyses planned to follow the dynamic of nitrogen availability were done only at the beginning of the experiment, as there was no necessity to monitor this unsuccessful trial.



Central Italy (UNIVPM)

Living mulches with horticulture species

Based on previous successful experiences, at UNIVPM, several species of strawberries have been tested in different agronomic condition in young rainfed apricot orchards in low hills close to Adriatic see (Ancona, Italy). While a wild strawberry species was established in rainfed vineyards in the internal high hillside (Castelraimondo, MC, Italy).

Highly vegetative species selected for their stoloniferous aptitude maintained a soil cover exceeding the 40% during the first summer and produced an interesting number of stolons and new plantlets. In late winter soil cover for those species exceeded the 50% (figure 6).



Figure 6: white strawberries soil cover in February 2019



Figure 7: potentilla soil cover in February 2019

The same excellent performance was recorded for the living mulches with *Potentilla ssp.* A 60% of soil cover has been reached in this case, with several soil spots showing a 100% of covering by the mulches (figure 7).

Wild species of strawberries, rather adapted to shadow condition, suffered instead some summer drought stress in calcareous soil in low hill, in the absence of complementary irrigation. After an initial soil cover percentage ranging at around 30%, one month after transplanting, the soil cover decreased during summer and a relevant percent of plantlet failed. A remaining 10% of soil covered by mulching was recorded during autumn and winter. The recovery of those species was hard during the following spring, due to a large population of weed development in the parcel.

Mulches performances strongly differed due to soil and climatic characteristics as well as due to soil management practices. In fresh, acid soils in the internal high hills, in the presence of abundant rains during spring and a mild summer wild strawberries doubled the percentage of soil covered in 4 months



moving from an average 30% to a 70%. In those condition the ideal number of plantlet to be installed under the main crop was one for each side of the grapevine. Variant with a double number of plantlets did not differed accordingly in performances thus indicating that, in the presence of favourable conditions to runners production, a low initial investment would assure the success and the efficacy of the mulching. A labor investment of about 30 hours/ha was estimated for mulching installation in favourable condition. An initial investment of 0,10 cent/plantlet will be required, thus meaning a cost of about 1.000€ for a pilot surface of 1 ha. It has to be highlighted that the high production of runners will allow to self-produce, within one year, the material for any further transplant. The harvest and transplant of the plantlets can be managed by using internal labor in rainy days thus allowing a great compatibility with the other activities scheduled. Mulches resulted particularly helpful especially in the management of the area surrounding the trunk harder to manage otherwise (Neri et al. 2020) (figure 8) .

No further extra costs were required other than the management routinely required by the vineyard. A production of 1000 Kg/ha was estimated for the second year after installation, thus fully covering the installation cost. The added value of the mulching as to be considered also in terms of social and commercial perception of the agronomical practices by the consumers (figure 9).



Figure 8: Soil fully covered under the vineyard can. No further soil management will be needed after strawberry full set.



Figure 9: Strawberries adopted as living mulches, in the home page of the farm as commercial claim on the sustainability of the agronomic practices.

The experience of 2019

The Colle Stefano winery (Castelraimondo, MC, Italy) in high internal hillside of Marche region, hosted the trial managed with UNIPM about the wild strawberry of Sibillini's mountains as living mulching in the row. Three years after strawberry planting, the soil covering by strawberries and



weeds was measured. The treatments were 0, 2 and 4 strawberry plants per vine. All treatments were tilled with a horizontal blade that cuts the soil to a depth from 5 to 15 cm in order to cut the roots of the weeds that spread in depth with taproot.

The results collected so far are very encouraging, indeed the coverage of the strawberry in April 2020 was about 90% for both the treatments. The blade and strawberry combination is a winning strategy in this environment, in fact there is a decrease of weeds for treatments with strawberry (figure 11-12).

In the other trial carried out at the low hillside at the experimental university farm in Ancona-AN trial on the tree row of apricot orchard white strawberry and potentilla showed a good establishment compared to other strawberry cultivars and wild species. This result can be explained by the provenience area of the wild strawberry (Sibillini Mountains where there are more summer rains) and the less competition of the cultivated strawberries (figure 11).

The same orchard in Ancona hosted the inter-row cover crops trial, where, in Autumn 2017 it was sown a mix of *Festuca rubra* (70%), *Trifolium* spp (20%) and *Sinapis alba* (10%). In September 2018, we carried out a syntaxonomic classification that shown a maturity index of 5% higher in the seeded row than in the control row.



Figure 10: Living mulch along the grapevine row by wild strawberry during the winter.

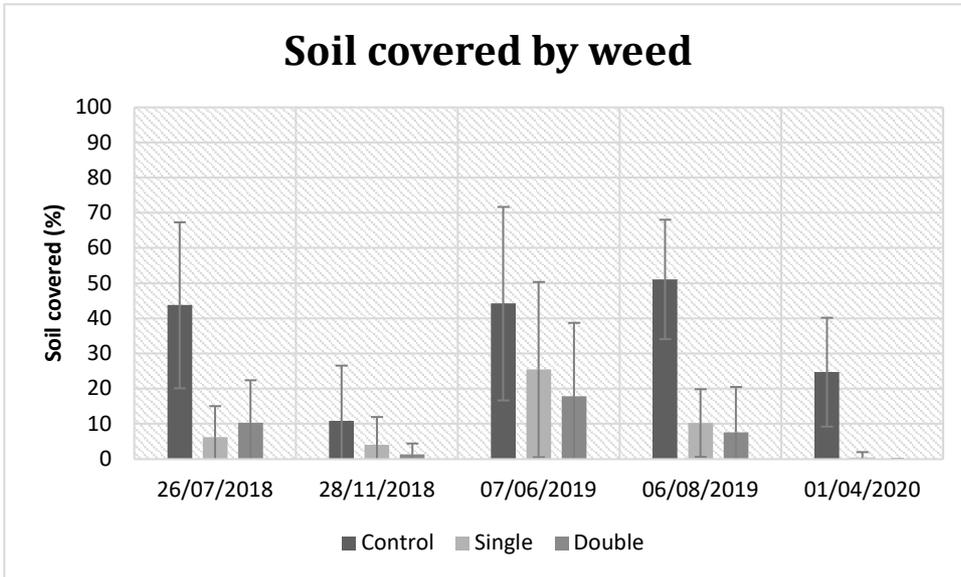


Figure 11: percentage of the soil covered by weed according to single (2 strawberry plants per grapevine) and double (4 strawberry plants per grapevine) mulching density (mean±st. dev.).

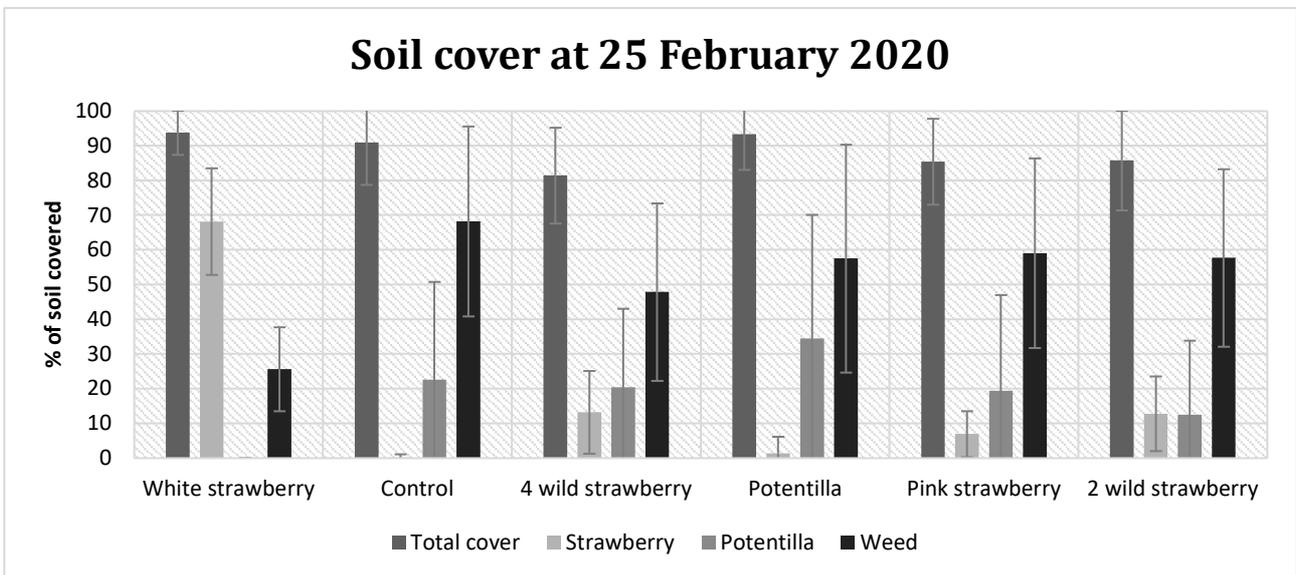


Figure 12: percentage of the soil covered by weed, strawberry, potentilla and total for each treatment (mean±st. dev.).

Selective weeding: engineering local biodiversity

The valorization of local biodiversity in soil cover management was the goal of a selective manual weeding applied in an apricot orchard in the low hillside at University experimental farm in Ancona. 2 months after installation the spontaneous weed population was manually selected in order to



eliminate by uprooting just competitive, tap root and taller species. 8 months after manual intervention the average and maximum weed height were 50% lower in weeded parcels (Fig.13) thus reducing competition and inducing significant advantages in the main crop development resulting in a 20% higher trunk caliper relative growth rate. A significantly reduced incidence of highly competitive species was still appreciable after 10 months.



Figure 13: Weed height in control (left) and selectively weeded (right) parcels



France (CTFIL)

Perennial plants, dwarf lawn and green manures for the French organic apple orchard

In southwestern France, at the Ctifl Center in Lanxade, the choice was made to proceed in two stages. A large panel of ground covers selected for their expected ecosystem services are first experimented in an open field trial, with the purpose to begin to verify the effectiveness of these services, to establish the ability of these ground covers to adapt to local soil conditions, to examine their compatibility with the apple tree growing calendar, and finally to begin to establish the way of managing these covers. It is only in a second step that a small choice of these covers will be selected (some for implantation on the row and others for interrow) and then implanted in an organic apple orchard of the Story® variety, to continue to study them over time.

The "ground covers assessment trial" was established in October 2018, first with 15 species or mixtures of ground cover species, chosen for their herbistatic properties (allelopathic species; short-growth tapering species), for their positive action in pest protection (repellent species; beneficial insects and mites host plants), for their improving action on the functioning of the soil and their nutritional potential for the tree, and/or for their ability to generate an additional income for the farmer (with here, aromatic herbs – Thymus, Mentha, Melissa – and fruiting species – *Fragaria vesca* and *Fragaria moschata*). The trial was completed in spring 2019 with 11 other species or combination of species, for a total of 26 treatments, implemented at the rate of 3 replicates of 25 m² each, over a total surface area of 3,371 m². The list of these treatments is given in table 3; among these, 13 are intended for implantation on the row and 13 for interrow (12 legume-based green manures and a flowery mixture).

A variety of observations have been made since the trial was implemented. They concern: (i) biodiversity measurements (percentage coverage by planted or sown ground covers and spontaneous flora (weeds), earthworm counts by mustard test, abundance measurements of soil beneficial fauna by using Barber traps; (ii) soil status measurements (nitrogen balance at 30 cm below the surface, soil moisture, infiltration capacity), (iii) cover growth measurements (height and biomass), (iv) work times and input costs recording.

Ground covers springtime development

After a winter period when the cover did not change much, spring started with clean soil in most of the trial plots, but spring weeds, which appeared timidly at the seedling stage in January, began to gain ground in March and became largely established in April. This spontaneous flora (which here was next to a maize crop) consists mainly of *Stellaria media*, *Veronica persica*, *Matricaria sp.*, *Senecio vulgaris*, *Sonchus arvensis*, *Rumex acetosa*, *Vicia sp.*, *Cardamina hirsuta*, *Plantago lanceolata*. Weeds have invaded the established covers unevenly, with the "space occupancy" factor



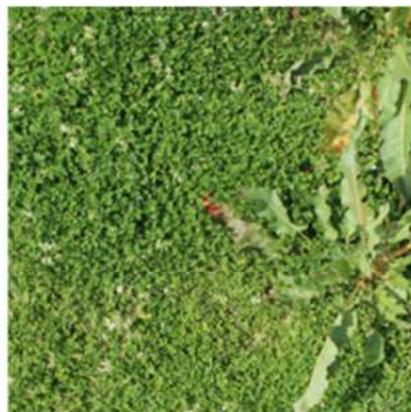
appearing to be predominant: the faster the cover occupies the space, the cleaner the plot remains in early spring, and then, the stronger its growth, the cleaner it remains over time.

Thus:

- Dwarf lawn (white micro-dwarf clover and dwarf alfalfa) kept a very nice appearance until mid-April, and then allowed some fast-growing weeds to escape, such as rumex or groundsel.
- Green manures (sown at high density) remained clean beyond their flowering stage, with very good biomass production, varying according to the potential of the mixed species.
- Perennials planted for their allelopathic properties, planted at a rate of 6 plants per m², didn't show at this stage any ability to hinder the germination of spontaneous flora or its spread. Most of these perennials were chosen for their stolon propagation mode, but during this first springtime, only a very small extension of these plants was observed, which nevertheless remain very much alive even if covered by a layer of well-developed weeds.



Association Lupin / Forage peas / Vetch very well developed and weed-free



White micro-clover with a good coverage "polluted" by a rumex



Flowering potentilla, little developed since fall 2018 and invaded by the Persian speedwell

Figure 14: Fouling by weeds according to the ability of the ground cover to quickly occupy the space



Table 3: Ground covers tested in the pre-screening field trial in Périgord, France.
The chosen species are tested alone or in combination

		Implementation method (TP : transplant plugs ; S : seedling)	HERBISTATIC EFFECT		SOIL IMPROVEMENT		PESTS & DISEASE CONTROL			ADDITIONAL INCOME	
			Short tapering ground cover	Allelopathic properties	Beneficial effect on nutrition	Beneficial effect on soil structure	Repellent effect on pests	Nematicide action	Pest antagonist host species	Edible crop	Aromatic plants
<i>Mentha spicata</i>	🟢 □	TP		✗			✗				✗
<i>Sagina subulata</i>	🟢 □	TP	✗								
<i>Hieracium pilosella</i>	🟢 □	TP		✗							
<i>Melissa officinalis</i>	🟢 □	TP									✗
<i>Thymus hirsutus</i>	🟢 □	TP	✗	✗							✗
<i>Potentilla verna</i>	🟢 □	TP		✗							
<i>Soleirolia soleirolii</i>	🟢 □	TP	✗								
<i>Scleranthus biflorus</i>	🟢 □	TP	✗								
<i>Fragaria vesca</i>	🟢 □	TP		✗						✗	
<i>Fragaria moschata</i>	🟢 □	TP		✗						✗	
<i>Tagetes species</i>	🟢 □	TP		✗				✗			
White micro-dwarf clover ⁽¹⁾	🟢 □	S	✗		✗						
Dwarf alfalfa ⁽¹⁾	🟢 □	S	✗		✗						
<i>Trifolium fragiferum</i> ⁽¹⁾	🟢 ❖	S	✗		✗	✗					
Oats / Vetch / Berseem clover ⁽²⁾	🟢 ❖	S			✗	✗					
Dwarf and intermediate white clover, trefoil, alfalfa lupulin, incarnate clover ⁽³⁾	🟢 ❖	S			✗	✗					
Oats / Fababeans	🟢 ❖	S			✗	✗					
Lupin / Forage peas / Vetch	🟢 ❖	S			✗						
English Ray Grass / Tall fescue ⁽⁴⁾ REF	🟢 ❖	S				✗					



Phacelia / Vetch / Triticale	🌱❖	S				x	x					
Mustard / Vetch / Triticale	🌱❖	S				x	x					
Vetch / Faba bean / Mustard / Triticale	🌱❖	S				x	x					
Incarinate clover	🌱❖	S				x	x					
Soybean	🌱❖	S				x	x					
Inoculated soybean	🌱❖	S				x	x					
Mixture of 25 field flowers ⁽⁵⁾	🌱❖	S								x		

Establishment period: 🌱 autumn 2018 🌱 spring 2019 - **Destination:** □ row ❖ interrow

(1) BARENBRUG's cultivars; (2) « Green Spirit Proteo 2 »-BARENBRUG; (3) « Multiflore LD »-BARENBRUG

(4) « Enherbement verger N°3 »-BARENBRUG; (5) « Coccinelle »- BARENBRUG

Providers : BARENBRUG - Pépinières LEPAGE - Pépinières FILIPPI - Atelier du Végétal – Pépinière Ribanjou

Ground covers management

- ▶ The green manure mixtures were cut at the beginning of May, 2 weeks after flowering, and then mulched on adjacent strips of bare soil to assess their nitrogen release. Of these mixtures, those consisting of annual species were managed on a rotational basis with other green manures, in order to be able to supply the fertilizer needs of apple trees during their most active demand period, from spring to the end of August. Thus, a sowing of soybeans followed the mixtures Oats + Fababeans, Lupin + Forage peas + Vetch and Oats + Vetch + Berseem clover; soybean was chosen for its ability to produce a high level of biomass, and therefore, we hoped so, to release large amounts of nitrogen.

On its side, the perennial mixture « MULTIFLORE LD » (White clover + Trefoil + Alfalfa lupulina + Incarnate clover) was cut and mulched on the side, but was not followed by another sowing, in order to determine its capacity to maintain itself and restore enough nitrogen by successive cuts.

- ▶ The so-called allelopathic species did not show any capacity to prevent the emergence of weeds as quickly as one might have hoped, and the many examples we can see in our gardens show that this potential may be acquired as the plant sets up, perhaps even 3 to 4 years after introduction. It was therefore decided, for the new set of perennial plants introduced in spring 2019, to associate them from the outset with a dwarf clover seedling, to assess whether this combination could be able to fill the space quickly enough to contain weed growth, thus giving time for the perennial plants to settle and expand, and then to become dominant after several vegetation cycles.



Ground covers summertime development

12 new treatments were installed on mid-May 2019:

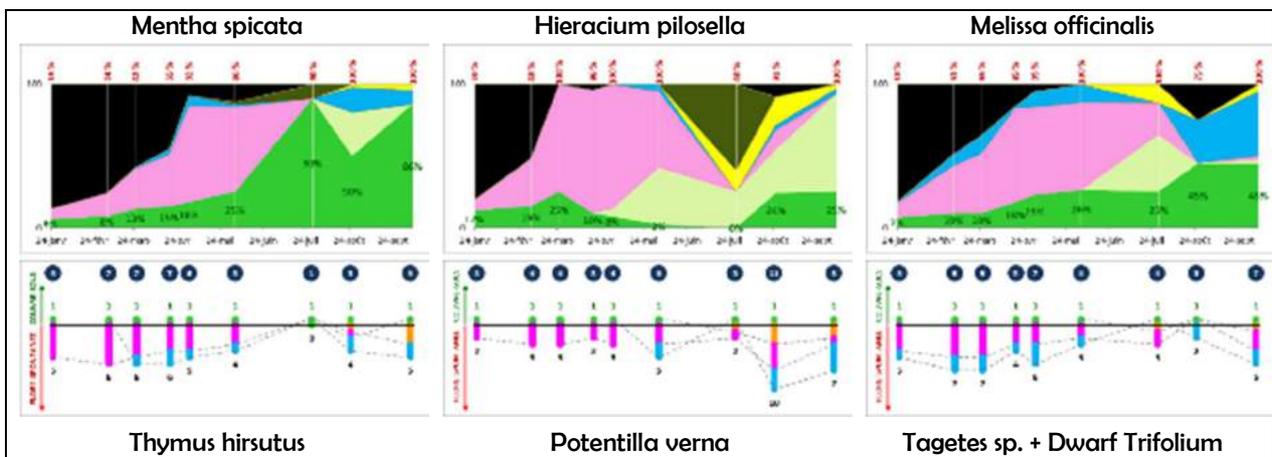
- 5 perennial plants species, chosen for their potential interest as alternatives to lawn grass (*Soleirolia soleioli*, *Scleranthus biflorus*), for their fruit production potential (*Fragaria vesca*, *Fragaria moschata*) or for their nematicide interest (*Tagetes sp.*). These species were planted as transplant plugs, in association with a micro-dwarf white clover seedling (20 kg/ha).

These 5 new treatments were planted on trial plots whose soil had been tilled in the autumn and then left bare, under the protection of an obscuring plastic sheeting. Just before planting in May, the soil was tilled again to obtain a fine seeding bed.

- 6 green manure mixes, whose composition was chosen to provide rapid nitrogen supply, but also stable humus to improve the soil structure and the natural drainage of the field plots (combination of the following species: phacelia, vetch, triticale, mustard, fababean, incarnate clover or soybean). These species were settled following a green manure independent of the trial, after its destruction and soil tillage.

- Soybean was sown at a 90 kg/ha density, on the spring "non-perennial green manure" trial plots, after mowing and soil tillage.

▶ None of the species planted or sown in May succeeded in growing, all of them being quickly invaded by 3 summer grass species (*Echinochloa crus-galli*, *Setaria*, *Digitaria*). A series of mowings were performed several times to try to control these weeds, so as to give the ground covers a chance to emerge, and then, simply to avoid them invading the entire trial with their seeds. This measure has not proven to be effective (figure 15).



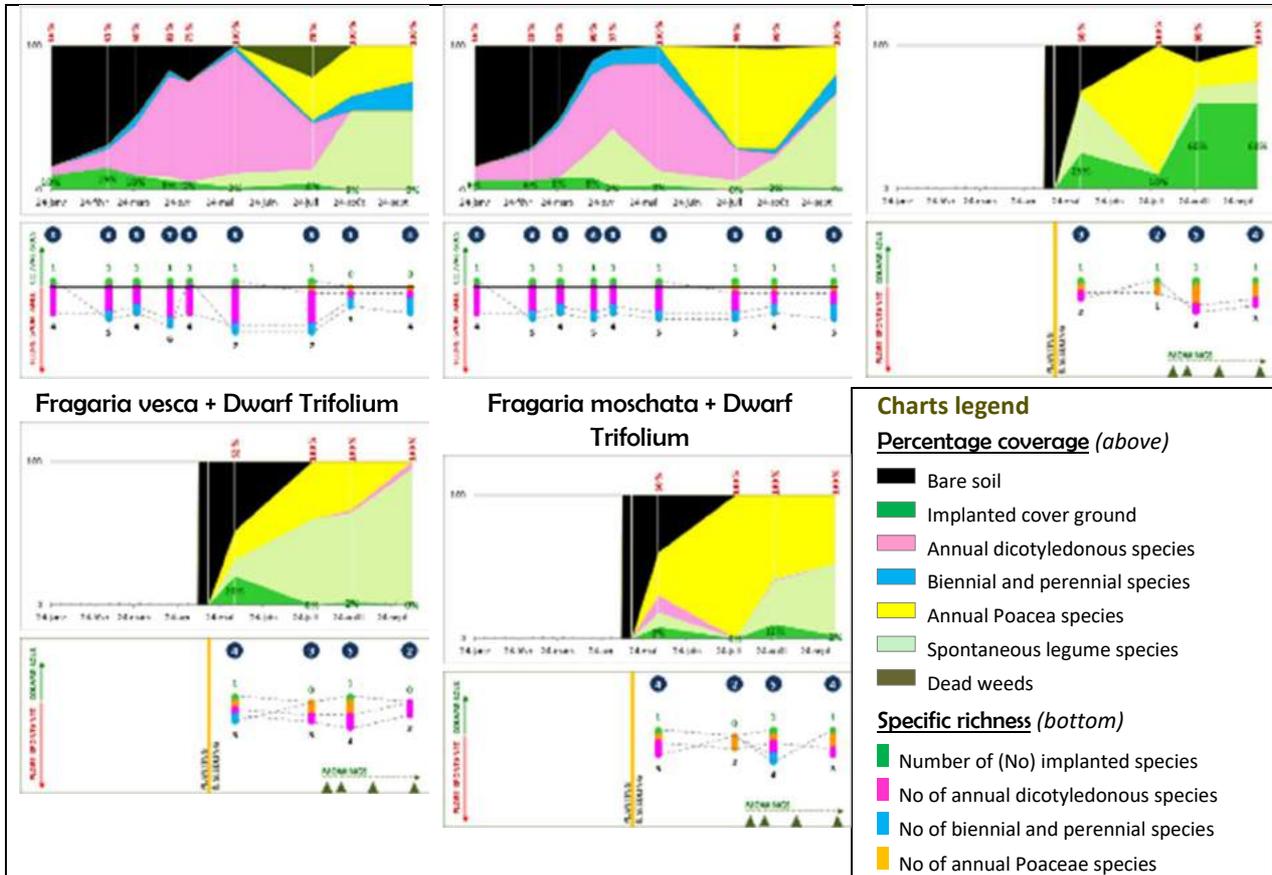


Figure 15. Allelopathic species planted as transplant plugs: floristic evolution during year 2019

- ▶ Among the species sown in the fall, micro-dwarf white clover and the « MULTIFLORE LD » mixture maintained a maximum percentage coverage throughout the season, *Trifolium fragiferum* (perennial) disappeared temporarily in mid-summer and reached a maximum percentage coverage by late August, while dwarf alfalfa (annual) completed its cycle in early June, to reappear later in early October, probably from its seeds (figure 16).

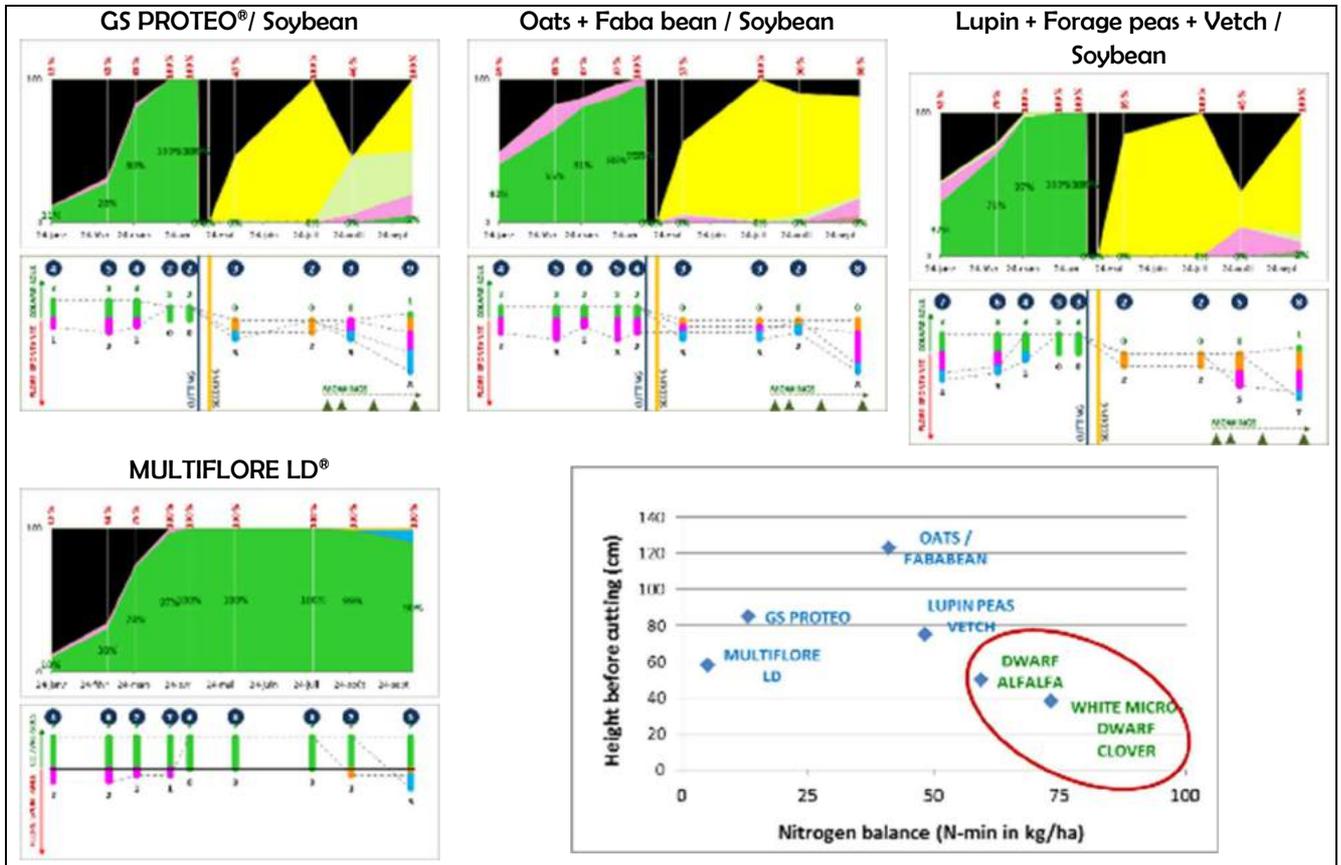


Figure 16: Green manures: floristic evolution during year 2019 and nitrogen balance in early June

- ▶ Among the « allelopathic » perennial species, only *Mentha spicata* was able to invade all the space during the first growing season after establishment (90% coverage reached in mid-July). *Melissa officinalis* grew more slowly, with a 45 % coverage reached at the end of August, which maintained until the end of the season (figure 16). *Hieracium pilosella* was not able to prevent weed development during this first year, but it remained alive on a bottom stratus, hidden by



weeds. This species remains interesting because it develops as ground-plated rosettes. It began to form very promising rosette carpets in the following mid-winter.



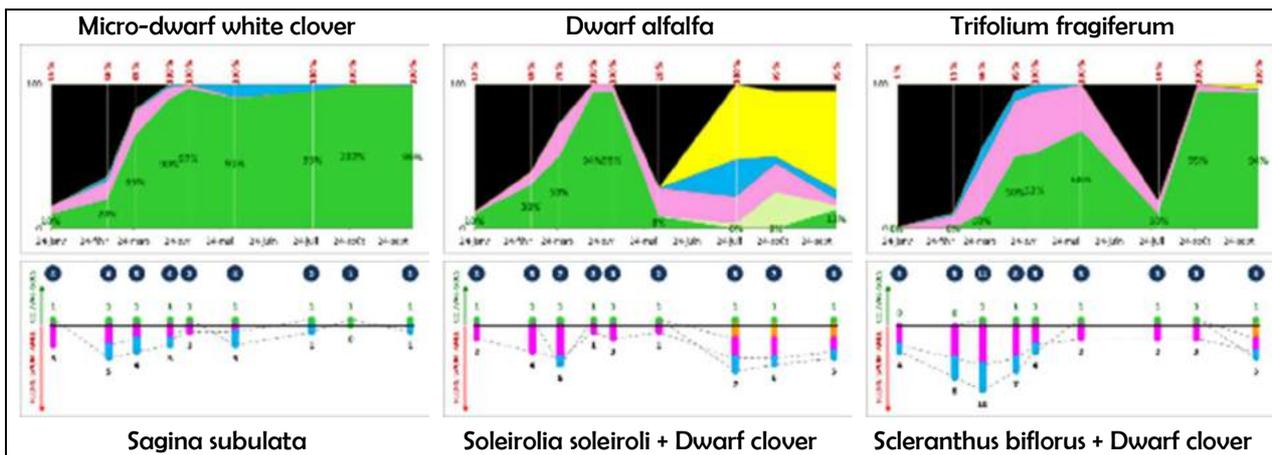
Hieracium pilosella planted in fall 2018 begins to form rosette carpets during winter 2019/2020



Perennial "MULTIFLORELD" green manure remains very well developed over the winter

Figure 17: Coverage by two promising ground covers: views during winter after a first growing season.

- ▶ Finally, the 3 species suggested as "alternatives to lawn grass" (*Sagina subulata*, *Soleirola soleirolii*, *Scleranthus biflorus*) rapidly died after their planting (whether they were planted in autumn or spring), probably because of their shade requirements (figure 18).



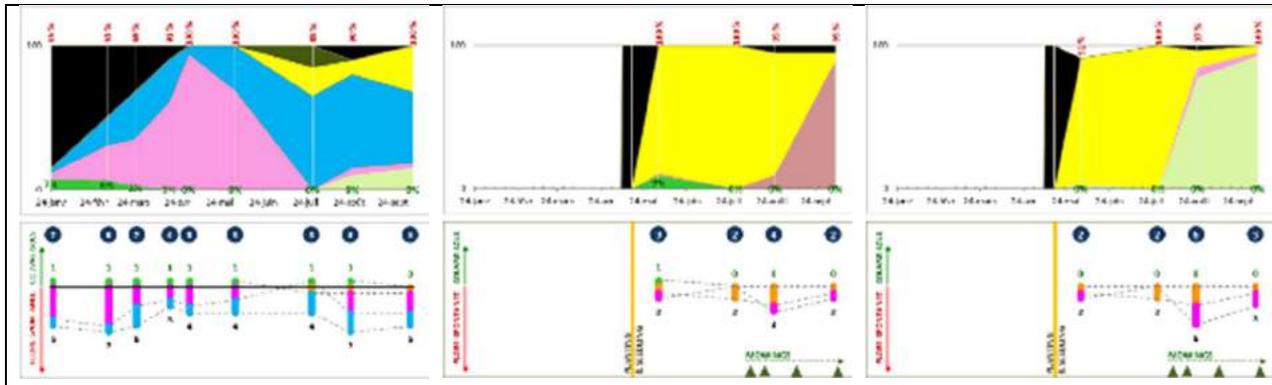


Figure 18: Dwarf lawn species and “alternatives to lawn grass” species: floristic evolution during year 2019

- ▶ Spontaneous clover development was observed from late spring or summer on many experimental plots, with no relation with the planted species.

Observed ecosystem services

- ▶ During this first year, with an open field experiment, no difference was observed between treatments concerning the ground covers impact on antagonistic fauna (*Carabidae*, *Staphylinidae*, *Araneidae*), which was present on all the plots in varying degrees.
- ▶ On soil samples taken one month after mowing the green manures and mulching them on the soil, without incorporation, nitrogen balance quantification gave supply amounts ranging from 5 to 73 kg N/ha, with a maximum efficiency (nitrogen supply in relation to the biomass produced) for micro-dwarf white clover and dwarf alfalfa.

With a lower nitrogen supply, the « MULTIFLORE LD » mixture is also very interesting, due to its perennial growth, which will avoid the need for successive sowings, often difficult to perform in an orchard (Figure 17).

- ▶ The use of ground covers as a source of additional income does not seem appropriate in the French context, due to their incompatibility with the pesticide calendar applied in apple orchards, even in organic systems: a toxicological risk remains for the consumer, both for aromatic or medicinal plants and for wild strawberry production. Only the herbistatic potential will therefore be researched for the plants to be settled on the tree rows.

With this purpose, *Mentha spicata*, *Melissa officinalis*, micro-dwarf white clover, *Trifolium fragiferum* and, to a lesser extent, dwarf alfalfa and *Hieracium pilosella*, seem to be interesting options, suitable for our pedoclimatic context.



Green manure in full bloom of the incarnate clover: in addition to providing nitrogen, our living mulches attracts honey-gathering insects and make the landscape beautiful



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