AN AGROPASTORAL SYSTEM AS A PRACTICE TO ENHANCE ORGANIC MATTER IN LEBANESE INLAND MOUNTAINOUS SOILS

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ABSTRACT

Organic matter (OM) is an essential soil component that results from the decomposition and decay of plant and animal materials. Decomposition processes are influenced by several biotic and abiotic factors. The Lebanese inland regions are characterized by low rain and elevated temperature. Soil formation and evolution occur under dry conditions and rare vegetation cover. Due to the absence or insufficiency of plant residues and frequent cultivation, the soils of the eastern mountain chain are characterized by low OM content. Given the importance granted to carbon sequestration in view of climate change and the importance of OM in soil fertility and resilience to erosion, the aim of this work is to assess the soil organic matter (SOM) levels by following an agropastoral system consisting of growing feed crops between the fruit trees as winter cover crops.

A two-year study between 2009 and 2010 was conducted in Jurd Aarsal, Anti-Lebanon, to assess the biomass production from cover crop in orchards and to estimate the potential increase of SOM content in plots planted with legume species (Vicia sp., Lathyrus sp.) and barley (Hordeum vulgare). Soil and plant samples were taken from 7 orchards ranging in altitude between 2016m and 2 236m. SOM was analyzed in composite samples before and after the experiment. Plant samples were collected throughout the season to assess the dry matter production. Result showed that the sites were supplemented with OM varying between 140 and 250 kg $ha^{-1}season^{-1}$ resulting from the decomposition of plant root residues. The above-ground plants provided the orchards with 95-665.7 kg $ha^{-1}season^{-1}$ of OM. It is suggested to follow the practice of winter cover leguminous fodder crop between fruit trees, in dry Lebanese regions, in order to provide additional biomass for small ruminants, enrich the soils with OM and fixed nitrogen and better use of surface soil moisture.

Keywords: soil organic carbon, Jurd Aarsal, marginal lands, intercropping system, carbon sequestration, cover crop

INTRODUCTION

Global warming is a major environmental problem facing the world and caused by greenhouse gases emission, especially carbon dioxide (Gerard & Wilson, 2009). Carbon sequestration is one of the proposed solutions to reduce carbon emissions into the atmosphere by applying good agriculture practices. Some forms of conventional agriculture have caused a massive decline in soil organic matter (SOM), due to its decomposition by incorrect tillage practices (Gaiser *et al*., 2009) and topsoil loss through wind and water erosion. Following the loss of SOM content, a decline in soil aggregate cohesion and stability is recorded (Chenu, 2000). Increasing soil carbon sequestration can reduce by 25% Australia's greenhouse gases created by agriculture and assist in alleviating the impact of climate change (Ugalde, 2007). Consequently, every ton of carbon lost from soil adds 3.67 tons of carbon dioxide gas (CO_2) to the atmosphere. Conversely every ton increase in soil organic carbon represents 3.67 tons of CO_2 sequestered from the atmosphere and removed from the greenhouse gas equation (Jones, 2006). Therefore, maintaining or increasing SOM by the regeneration or return of plant material and residues to the soil, can significantly improve water capture and storage in the soil for later use by the plants.

Management practices, such as conservation tillage and legume-based cropping sequences, have the potential to enhance total soil carbon (SC) content and improve soil aggregation that in turn can reduce soil erosion (Bhattacharyya *et al*., 2009). These are seldom observed in Lebanese mountains where climatic conditions, deforestation and recurrent forest fires (Masri *et al.*, 2006) as well as improper conventional agricultural practices lead to soils poor in organic matter, with concentrations ranging between 0.7% and 3.0% (Darwish *et al*., 2009). OM loss from the soil is also due to burning plant residues or their removal with harvest, overgrazing, and wide application of bare fallow.

Deforestation hit badly the region of Aarsal in the Anti-Lebanon where the forests disappeared due to cutting and overgrazing. Despite the expanding quarries (463 ha), the Jurd region of Aarsal is still dominated by grassland (25 000 ha) followed by orchards that reach 4 878 ha (Darwish & Faour, 2008). Fruit trees, especially cherries, expand there at the expense of grassland (Darwish & Zurayk, 2001). Rainfed fruit trees were planted in hilly areas, without neither terracing, nor effective water harvesting techniques. Almost half of the farmers in Aarsal are at the same time herders. Consequently, pasture, rare forest, rangelands and orchards in Aarsal are all subject to overgrazing (Darwish & Faour, 2008). Overgrazing of marginal land can accelerate land degradation in dry areas.

A general practice in Aarsal consists of keeping the soil of orchards bare during winter, followed by shallow cultivation in spring. The agropastoral system consisting of planting fodder crops between largely spaced fruit trees is not widely practiced in Lebanon. The reason raised being to save soil moisture by avoiding the competition between trees and cover crops. Shallow rooted leguminous fodder crops can serve as food for the animals. Residues left in the soil provide biomass that enhances SOM content, with associated yields improvement and soil protection from water erosion. In addition, leguminous cover crops improve soil fertility from residual N fixation (Becker *et al*., 1995; Toomsan *et al*., 2000).

Soils at high altitudes, managed by farmers-herders, contain higher amounts of OM due to continuous manure application and improved water regime. Herders in Aarsal may benefit from including cover crops as additional sources of fodder crop. This study was designed to promote the development of an agropastoral system and to evaluate the effects of legume cover crops on soil carbon accumulation in the soils of low and high Aarsal Jurd along the eastern Mediterranean chain. The first objective was to compare between the performance of vetch *(Vicia sativa* L.) alone and vetch mixed with barley (*Hordeum vulgare* L.) under rainfed conditions as winter cover crops in orchards. Another trial studied the seed increase of ervil (*Vicia ervilia* L.), vetch and red pea (*Lathyrus cicera* L.), all needed to provide seeds for the winter cover crops.

MATERIALS AND METHODS

Study area

The study was conducted in Aarsal (360 km^2), caza of Hermel, which is located on the Anti-Lebanon mountain chain. Aarsal is distinguished by its arid climate with a rainfall ranging between 350 mm in low Jurds and 600 mm in middle and high Jurds, low temperature (T) during the short winter (December-March) and very high temperature in the long dry season (April-November). At high altitude, snow covers the area for two-three months between December and March, the melting of which can secure additional water.

Aarsal region is typical for its hilly topography, complex macro relief and homogeneous hard limestone (C_4) geology. Hills are separated by small basins and depressions (Darwish & Zurayk, 2001). In general Aarsal Mountains are dominated by grassland and bare rocky land. Uncultivated soil is characterized by low OM content ranging between 0.2% in Xeric Torripsamments and 3.4% in Lithic Leptosols (Darwish & Zurayk, 2001).

During the 2009-2010 season, a comparison was made in seven orchards between the performance of vetch alone (sites 1-3) and a mixture of vetch and barley (sites 4-7) under rainfed conditions (Figure 1a). Continuous supply of seeds was provided by the cultivation of lowland areas equipped with irrigation facilities. There, a comparison between the performance of certified seeds of *Vicia ervilia* (Kersanneh in arabic) cultivar (cv) *Amara, Vicia sativa*, (Bakia in arabic) and *Lathyrus cicera* (Jelbaneh in Arabic) cv Jabbouleh was undertaken (Figure 1b). For the importance of *Lathyrus sativus* and *Lathyrus ciceria* in feed production in East Africa and West Asia, a hybridization program was initiated to incorporate the character of low neurotoxin 3-(N-Oxalyl)-L-2, 3-diaminopropanoic acid (B-ODAP content from ICARDA's low neurotoxin seed fund into locally adapted land races (Abd El-Moneim *et al*., 2000). Selection in F3 onwards resulted in low neurotoxin (<0.15%) and high yielding lines which were kindly provided by ICARDA station in Terbol and used in this experiment. Planting density varied between 50 kg seeds ha^{-1} in the orchards and 100 kg ha^{-1} in the seed increase sites. As winter cover crop, the time of sowing was November.

Soil sampling and analyses

Soil samples were taken from 0-30 cm depth on the 5th and 27th of May 2009 from the orchards and on the 15th of May 2009 from the seed reproduction plots. The samples were homogenized, stored in plastic bags and transported in a cool box to the laboratory for analysis. Soil samples were air-dried then separated into fine, medium gravel, coarse gravel and stones fractions. The volumes of gravel and stone were measured by dropping them into a graduated container filled with water and their density was measured by the ratio of gravel over occupied water volume.

Soil samples were grinded and sieved to pass 2 mm fraction. For the OM analysis the representative soil sample was finely ground and sieved at 200 µm. Then a soil sample of 0.15 to 0.5 g was treated with a mixture of concentrated sulfuric acid and potassium dichromate (Ryan *et al*., 1996).

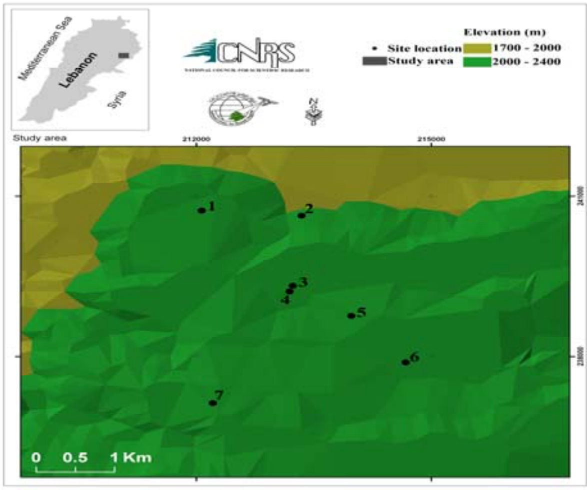

Figure 1a. Distribution of orchards planted with vetch (sites 1-3) or with vetch mixed with barley (sites 4-7) (source: CNRS).

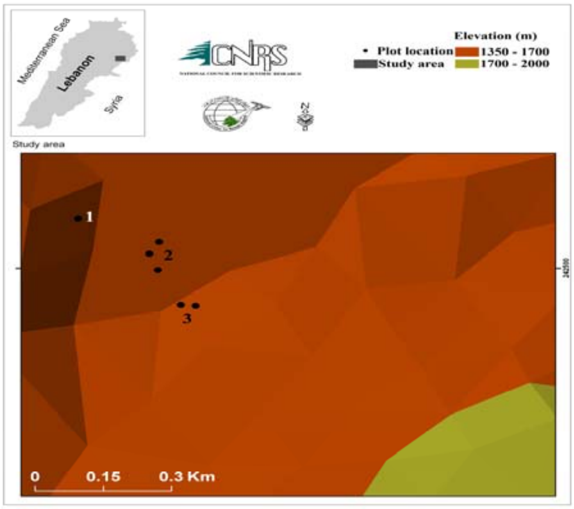

Figure 1b. Distribution of irrigated plots planted with ervil, vetch and red pea for the purpose of seed increase (source: CNRS).

Plant sampling and analysis

In the orchards, the fresh biomass of the mixture of barley + vetch or vetch alone was sampled on the 27th of May 2009. The plants were in the early flowering stage. In the seed reproduction sites, the roots dry matter production of Kersanneh, Bakia and Jelbaneh were also collected. Fresh plant samples were taken on the 15th of May and weighted. The plants in the seed reproduction sites were in the advanced podding stage. In each plot, 3 replicates of above and below ground biomass were taken at random from a quadrate (60 x 60 cm). The remaining vetch and barley was left above ground to be ploughed in. After cutting into small pieces, plant material was sub-sampled by the quartering method. Dry matter was then obtained after oven-drying at 75°C for 48 hrs. Dried plant material was ground for further analysis.

RESULTS AND DISCUSSION

Soil characteristics

The soils of the area are represented by Leptosols and Regosols. The studied orchards occupy low lands with sediment input and belong, after rehabilitation, to the Cumulic and Profondic Luvisols, Calcaric and Eutric Anthrosols. They are stony on the soil surface and have mainly silty clay and clay loam texture and typical physico-chemical properties for the dry mountainous areas (Table 1). The soils are slightly calcareous with pH value ranging between 7.5 and 8.2. The orchard soils at high altitudes were characterized by relatively high organic matter content, ranging between 2.9% and 4.0%. In the seed reproduction sites, the clay soil was dominated by a pH of 7.9 and 21% of total calcium carbonate while it showed lower OM content ranging between 1.7% and 2.1% with a mean value of 1.9% (Table 1).

TABLE 1

Physical and Chemical Properties of the Orchard Soils (Sites 1 to 7) and the Site Used for Seed Increase in Aarsal

Plots	Altitude (m)	Particle size (%)			Soil texture	Total $CaCO_3$ (%)	pH	OM (%)
		Clay	Sand	Silt				
1	2 016	40	21	39	Silt Clay	12	8.1	3.01
2	2 070	38	32	30	Clay loam	23	8.1	3.45
3	2 086	45	23	32	Clay	29	7.5	2.94
4	2 113	40	21	38	Silt Clay	8	8.2	3.62
5	2 134	50	16	34	Clay	9	8.0	2.94
6	2 160	44	15	40	Silt Clay	4	7.9	3.73
7	2 236	44	24	32	Clay	24	8.0	4.02
Seed increase	1 470	36	37	27	loam	21	7.9	1.90

Plant production in the seed increase site

In the seed increase site, vetch (*Vicia sativa)* and red pea (*Lathyrus cicera)* gave the best seed production (400 kg and 700 kg respectively). The remaining legumes gave no more than 200 kg of seeds with a dominance of green biomass production. Dry weight production of above-ground was similar for *Vicia ervilia* and *Vicia sativa*. But *Lathyrus cicera* had a significantly higher above-ground production, especially the over irrigated subplot located near the irrigation canal (Table 2). In these plots, the above-ground part is eventually cut few centimeters above the ground and removed, while the remaining material serves as fodder. For this, the low OM content in the seed reproduction area is not surprising. Farmers who rent this land are not interested in enhancing the soil fertility for the next years. On the contrary, the relatively higher OM content in some soils under orchards owned by herders-farmers is due to the systematic application of composted manure, which is available in the own sheep farm (Table 1).

The below-ground biomass is usually left within the soil to supply root residues and N fixed in the tubers. Despite the difference found in shoot production in the four seed reproduction sites, there was no significant difference in the dry matter production of the below-ground root residues. Plots, except the excessively irrigated one produced comparable below-ground biomass (Table 2) supplying the soil with additional amount of sequestered carbon. During the decomposition process, microorganisms convert the carbon structures of fresh residues in the soil into transformed carbon products; roots left in the soil undergo decomposition. Humus is the result of successive steps of OM decomposition. Some 35% of the dry matter may be humified one year after application (Singh & Rattan, 2005).

TABLE 2

Biomass Production in the Certified Seed Increase Plots and the Expected Organic Matter Supply in 10 Years

Species (plot)	Seed production (kg ha^{-1})	Biomass production (kg ha^{-1})		Mass remaining after 10 years (kg ha^{-1})	
		Shoots	Roots	Shoots	Roots
Vicia ervilia (1)	2000^{c}	4177.6^{c}	493.9^{x}	630	70
Vicia sativa (3)	4000^{b}	4367.1^{c}	519.1^{x}	660	80
Lathyrus cicera (4)	7000^{a}	5986.7^{b}	403.2^{x}	900	60
*Lathyrus cicera** (5)	5750^{a}	12178.1^{a}	700.6^{x}	-	-

Mean values followed by a common subscript are not significant at 0.05 levels.
* Mismanaged by over irrigation, thus it was omitted from further analysis.

After a time span of 5 to 10 years, only 15 % of the root dry matter may remain in the soil (Eldor, 2007). Projected results of the root biomass left in the seed reproduction sites in Aarsal, cultivated with legumes for one season, showed modest amounts of OM formation in the soil ranging between 140 and 250 kg ha^{-1} and between 60 and 110 kg ha^{-1} one year and five to ten years later respectively (Table 2). Referring to the rate of mineralization of 1.5% of OM reported for the soils of the area (Kechli, 1999), this corresponds to a relative increase in soil OM content between 0.007-0.012% and 0.003-0.005% respectively. The continuous cultivation of legumes to secure seed fund would result in a cumulative increase of plant and root residues that leads in the long run to a significant increase of SOM.

When above-ground plant residues are returned to the soil, organic compounds undergo a biological process called decomposition. Decomposition includes the physical breakdown and biochemical transformation of complex organic molecules of dead material into simpler organic and inorganic molecules (Juma, 1998). Above-ground parts are an excellent source of amendment (green manure) because of the higher amount of OM increase in the soil. The continuous addition of decaying above-ground plant residues to the soil will increase soil organic matter almost tenfold more than the left root residues (Table 2).

Organic matter content in the seed increase plots

At the end of the experiment, the SOM content varied mainly between 2.44 and 2.98 %, except one sample (number 5), which showed a lower percentage of SOM content. However, the stocks of soil organic matter, based on the amount of fine soil per unit areas, were highly comparable (Table 3). This approach is justified as coarse fragments decrease the volume occupied by the soil and they relatively reduce soil OM content, because OM compounds are held by the soil fine fractions. In fact, most of these sites (3 of them) contained more than 45% of coarse fragments, on a volume basis.

Production of fodder crops grown in orchards

Observations done during early May 2009 showed that some vetch plants were burned under the effect of the frost registered at high altitudes even in the dry Lebanese mountain area (Figure 2). Surviving plants (50-60% of originally sown seeds) were in post emergence stage with 2 to 3 cm height (Figure 3) with empty space between plants at flowering stage (Figure 5). Whereas barley was more developed than vetch, thus confirming that barley is not only more tolerant to drought but it is also more resilient to cold weather (Figure 4).

At the end of May 2009, as temperatures became warmer the surviving cover plants entered the full flowering stage. In the second year (2009-2010), stakeholders decided to postpone the sowing process in late fall 2009 to delay the seedlings formation until after snow melting to avoid yield loss by frost. However, the winter of 2009 was mild with little snow, and the late planted rainfed cover crop did not adequately develop in spring 2010 due to a shortage in soil moisture. This is a new evidence of agriculture being subject to the effect of climatic variability and difficulty of weather predictions that can complicate the life of farmers and herders.

In 2009, orchard number 2 planted with vetch had higher plant dry matter production compared to orchards 1, 4, 6 and 7 (Figure 6). Orchards 1, 2 and 3 were located at the same altitude range and OM content was lower in orchard 2 compared to orchard 1. Orchard 2 was exposed westward, thus received more direct sunlight and was better protected under cherry trees from chilly weather. Field observation showed that legume plants in orchard 2 were denser and smaller in size than surviving plants in orchards 1 and 3 (Table 4). Cover crop there gave higher plant dry matter production due possibly to higher survival rate during winter. The analysis of biomass production from the cover crop under fruit trees showed no significant difference between the below-ground plant production, except for the orchard 6 that presented high SOM content (126.8 t ha^{-1}).

TABLE 3

Concentrations and Amounts of Organic Matter in the Upper Soil (0-30 cm) before and after the 2009-2010 Season in the Seed Reproduction Site

Before planting		After planting		
Organic matter (%)	Stock of organic matter (ton ha^{-1})	Plot	Organic matter (%)	Stock of organic matter (ton ha^{-1})
1.70	48.3	1	2.44	53.3
2.10	38.3	3	2.98	45.2
-	-	4	2.51	48.5
-	-	5	1.86	43.0

This high content of organic matter is due to the variable supply of manure from one orchard to another depending on the number of flock and owned area. It seems that the presence of manure protected seeds from pre-emergence frost injuries and supplied young seedlings with nutrients needed for better development. Dry matter (DM) production of the above-ground part, after the exclusion of the two extreme orchards (number 3 and 6 giving the lowest and highest dry matter production respectively) presented no significant difference between the remaining orchards (numbers 1, 2, 4, 5 and 7).

A low seed density (50 kg ha^{-1}) was observed in the all studied orchards and was justified by the farmers-herders' fear from restricted soil moisture content and competition with the fruit trees. Still, the recommendation is to increase the sowing density. Depending on available soil moisture, higher plant density (Figure 7) will probably result in higher biomass production and higher soil supplement with organic matter.

OM improvement in the cherry orchards

Orchards were planted with *vetch or* a mixture of barley and *vetch* as winter cover crop. The objective was to reduce soil erosion and supply the soil with additional OM and nitrogen. The stakeholders participating in this study are owners of orchards in Jurd Aarsal, with ownership area varying between 2.0 and 4.0 ha. Farmers are at the same time herders with more or less large flocks ranging between 500 and 3500 heads. Continuous (yearly) manure addition, which was available at no cost and the awareness of the positive role of OM in improving soil productivity and the quality of the cherry fruits, can explain the relatively higher soil OM content found in the soils (Table 5). This high OM content was found despite the presence of the coarse fraction representing between 31 and 44 % of the soil volume for all orchards, except number 7. This fact can create favorable conditions for SOM decomposition and flush nitrification leading to intensive leaching under seasonal torrential rain. Enriching the soil with OM would increase its water retention and nitrate holding capacity.

Figure 2. Burned vetch plant due to freezing.

Figure 3. First stage of vetch growth.

Figure 4. Barley early growth stage.

Figure 5. Vetch at pre-flowering stage.

Figure 6. Vetch low density cover crop in orchards.

Figure 7. High density irrigated seed crops in the seed increase site.

Following plowing, plant cover will undergo decomposition (Table 4) and will add a supplement of organic matter between 0.004 and 0.029 % to the initial soil organic matter content. Previous research done in the Bekaa Valley in Lebanon with similar dry summer conditions and milder winter indicated a rate of mineralization of 1.5% of OM in the soil (Kechli, 1999). The modest increase on the SOM from single cultivation of legumes can be significantly enhanced when good agricultural practices consisting of growing legumes on a yearly basis, both under fruit trees and in rotation with annual crops. A similar practice was successfully introduced also by GIZ and the MoA as part of conservation agriculture under olive, apple and cherry trees in Lebanon (Jouni, 2011). When left on the soil surface in no till practice, vetch seeds can regenerate next year after first rain and keep the soil surface green and protected from water erosion.

TABLE 4

Cover Crop Dry Matter Production in the Mountainous Orchards of Aarsal and Expected Soil Supplement with Organic Matter Following One Cover Crop

Site	Plants	Height (cm)	Biomass ($kg\ ha^{-1}$)			Expected increase in soil organic matter ($kg\ ha^{-1}$)	
			Shoots	Roots	Total	after 1 year	after 5 years
1	Vetch	18 - 20	384.5^{bc}	62.9^{x}	448.3	156.9	67.2
2		7 - 10	633.4^{b}	103.5^{x}	736.6	257.8	110.5
3		10 - 18	223.1^{c}	48.1^{x}	271.3	95.0	40.7
4	Vetch; barley	9 - 10 30 - 40	661.3^{b}	98.7^{x}	760.0	266.0	114.0
5	Vetch; barley	9 - 15 28 - 42	652.6^{b}	208.1^{x}	860.7	301.2	129.1
6	Vetch; barley	8 - 12 22 - 30	1480.7^{a}	421.1^{z}	1901.9	665.7	285.3
7	Vetch; barley	6 - 10 17 - 28	571.2^{bc}	80.4^{x}	651.6	228.1	97.7

Mean values followed by a common superscript are not significant at 0.05 levels

In this experiment, the herders-farmers learned new practices on how to secure continuous flow of seeds and water harvesting for supplemental irrigation of fodder crops. Therefore, an agropastoral system has been implemented also as spring crop on supplemental irrigated lands of Qaa-Hermel area. Results received from the farmers-herders indicate the possibility to improve the yield of fodder crops with a sowing density of 100-125 $kg\ ha^{-1}$. On-site grazing remains a possibility that reduces the energy spent on harvest and transport. Such a practice in the orchards located in the north-east Bekaa plain, on the road of flocks and herders to summer grazing on the tops of western mountain chain allows for direct onsite "life manure system". Grazing density depends on irrigation facilities and yields of fodder crops which varied between 4 and 6 tons/ha. This practice leaves between 8 and 15 $ton\ ha^{-1}$ of animal manure which supplement OM to the soil, in addition to the plant residues rich in nitrogen and residues.

TABLE 5

Soil Organic Matter Content (upper 30 cm) and Stocks in the Orchard Soils at the End of 2009-2010 Season

	Fine soil		Organic Matter	
Site	Volume (%)	Mass ($ton\ ha^{-1}$)	Concentration (%)	Stock ($ton\ ha^{-1}$)
1	56.26	1947.8	4.21	81.3
2	59.11	1980.9	3.30	65.8
3	63.64	2240.6	3.13	70.7
4	59.02	1868.8	5.89	109.8
5	67.07	2445.6	3.36	82.0
6	65.42	2290.5	5.51	126.8
7	89.80	2876.4	4.02	115.7

CONCLUSION

This two year study was conducted in the Middle Jurds of Aarsal to evaluate the importance of winter cover crop between the fruit trees as a means to protect the soil against possible sheet erosion and to improve the soil physical and chemical properties by supplementing the soil with organic matter. The farmers-herders were approached on their fields with the aim to show them the advantage of the agropastoral system and to enhance their independence in term of seeds increase so they could maintain the sustainability of the system.

In the certified seed increase trial, the irrigated *Lathyrus cicera* and *Vicia sativa* gave the highest seed yield and dry matter biomass production. After decomposition, the left roots of vetch added to the soil may increase the SOM between 0.007 and 0.012 %. After the collection of seeds, the above-ground part of vegetation could add between 0.066 and 0.184 % of OM to the soil. An alternative use of this biomass can be as direct fodder supplement to animals which will be returned indirectly to the soil as animal manure besides the advantages in meat and milk production.

No clear cut results were reached due to the short duration of the study (2 years) and to the climatic differences between the seasons. The 2008-2009 winter season was cold with acceptable distribution of precipitation along the winter period, while the 2009-2010 winter season was mild with heavy short seasonal rain and long dry spring period. Nevertheless, despite the low planting density and injuries caused by chilly cold temperatures, the incorporation of plant material in the orchards will contribute to the soil OM after its decomposition between 0.004 and 0.029%. For this reason certain technical assets can be proposed concerning the cover crop practices in the Aarsal. Thus, farmers should increase the plant density and try mixing *Vicia sativa* with barley to ensure better canopy development in the orchard and should supplement the soil with organic manure in order to protect the seed from freezing injuries. Such a practice has double benefits as income generating activity for the farmers as well as a conservative measure that can reduce soil erosion and protect land’s environmental functions.

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