AGFORWARD
Agroforestry for Europe

System Report: Silvopastoral Management for Quality Wood Production in Spain

Project name	AGFORWARD (613520)
Work-package	3: Agroforestry for High Value Tree Systems
Specific group	Silvopastoral management for quality wood productions in Spain
Deliverable	Contribution to Deliverable 3.7 (3.1): Detailed system description of a case study system
Date of report	23 September 2015
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Approved	Anastasia Pantera (11 April 2016); Paul Burgess (12 April 2016)

Contents

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1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to Objective 2, Deliverable 3.7: "Detailed system description of case study agroforestry systems". The detailed system description includes the key inputs, flows, and outputs of the key ecosystem services of the studied system. It covers the agroecology of the site (climate, soil), the components (tree species, crop system, livestock, management system) and key ecosystem services (provisioning, regulating and cultural) and the associated economic values. The data included in this report will also inform the modelling activities which help to address Objective 3.

2 Background

Europe has a shortage of quality wood and, therefore, there is a growing interest in the establishment of hardwood plantations. In Spain, hardwood species are commonly harvested after long rotations of up to 50 or 60 years. But with intensive management, the rotation length can be notably reduced by half (to 20-25 years). Fertilization and herbicide application are the most controversial management practices because of the high costs involved (Rigueiro-Rodríguez et al. 2009) and their impact on soil and water pollution. Silvopastoral management and implementation of legume pastures could allow reducing the economic costs of these plantations and optimize their environmental functions (Gselman and Kramberger 2008; López-Díaz et al. 2010; McCarteney and Fraser 2010).

This study will be carried out in an intensive plantation of walnut for the production of quality timber located in Extremadura owned by the company Bosques Naturales S.A.

3 Update on field measurements

Field measurements described in the research and development protocol began in October 2012, and continues to be conducted by the company.

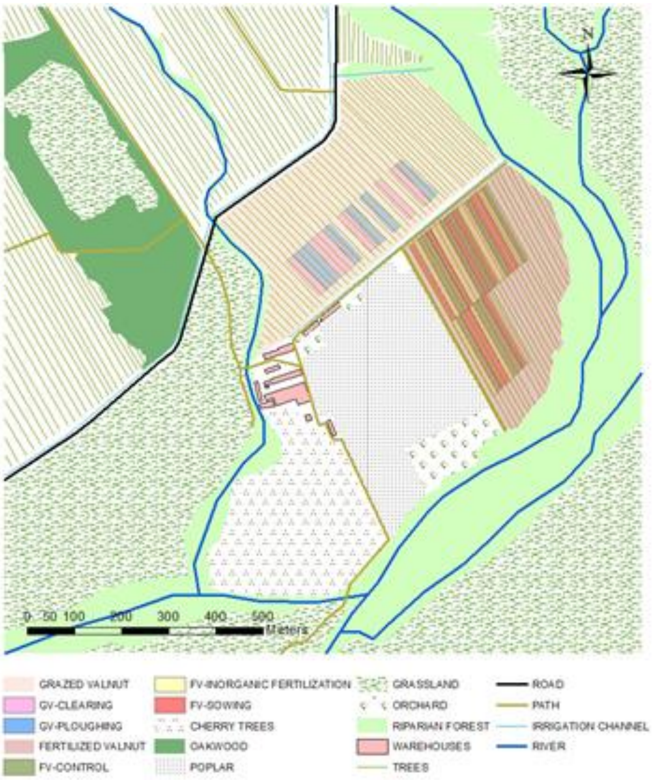
4 Description of system

Error! Reference source not found. provides a general description of the silvopastoral system for quality wood production. A description of a specific case study system is provided in Table 2.

Table 1. General description of the silvopastoral system for quality wood production

General description of system	
Name of group	Sivopastoral management for quality wood productions in Spain
Contact	Gerardo Moreno
Work-package	3: High value trees
Associated WP	WP2, WP5 (Use of livestock)
Geographical extent	Walnut timber production is located throughout Spain
Estimated area	2500 hectares in Spain. Bosques Naturales S.A. owns 1300 hectares of walnut with forestry certification of FSC.
Typical soil types	Cambisols
Description	Spain has a shortage of quality wood. In the last decade, hardwood plantations have substantially increased in many Spanish regions. In order to grow trees for high quality timber in short rotations, an intensive management, based on high levels of energy consumption and inputs, has been adopted, with high economic and environmental costs. The control of competing herbaceous vegetation and fertilization are two of the most controversial management practices.
Tree species	Hybrid walnut *(Juglans major x nigra mj 209xra)*
Tree products	High quality timber
Crop species	Herbaceous strata
Habitat services and biodiversity	Trees increase carbon storage. Trees in silvopastoral systems develop deeper root systems that reduce nitrate leaching.
Cultural services	This system will allow the exploration of new possibilities for sustainable development of farming and agricultural districts, seeking to combine livestock production, improved animal welfare, and medium-long term hardwood timber production.

Table 2. Description of the specific case study system

Specific description of site	
Area	9.72 ha. Nine replicates were used for each treatment of fertilization and control of herbaceous vegetation that resulted in 27 plots. Each plot (95 x 15 m) comprised two rows of 20 trees.
Co-ordinates	ETRS89 huse 20: X:298.303 Y:4.442326
Site contact	Gerardo Moreno
Site contact email	gmoreno@unex.es
Example photograph	 Figure 1. Sheep grazing with high value timber trees
Map of system	 Figure 2. Map of the experimental area

Experiments	
Comparison	Experiment I (hereafter **Fertilized walnut**). Three treatments are compared (with nine 12 x 50 m replicate plots): 1. Legume sowing 2. Mineral-fertilized native grasses 3. Unfertilized native grasses Experiment II (hereafter **Grazed Walnut**). Three treatments are compared (with nine 12 x 50 m replicate plots): 1. Grazing 2. Ploughing 3. Mowing
Climate characteristics	
Mean monthly temperature	14.1 °C
Mean annual precipitation	844 mm
Soil type	
Soil type	Fluvisols
Soil depth	>140 cm
Soil texture	Sandy loam
Additional soil characteristics	pH 5-6
Aspect	South-East
Tree characteristics	
Species and variety	Hybrid walnut (*Juglans major* x *nigra* mj 209xra)
Date of planting	2000
Intra-row spacing	5 m
Inter-row spacing	6 m
Tree protection	None
Typical increase in tree biomass	The annual increment of diameter at height breast was 0.5-0.7 cm. The values are low due to the high density (333 tree ha^{-1}).
Crop/understorey characteristics	
Species	Fertilized walnut: native grasses except in sown plots with legumes Grazed walnut: native grasses except in ploughed plots
Management	Fertilized walnut: grass managed by grazing in late Spring. Grazed walnut: grass managed by mowing, clearing and grazing depending on treatments.
Typical grassland yield	2 Mg dry biomass per ha.
Fertiliser, pesticide, machinery and labour management	
Fertiliser	*Inorganic fertilization:* application of 40 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1} only for mineral fertilizer and legume sown treatments of the experiment I.
Pesticides	-
Machinery	Grazed walnut: ploughing or clearing in treatments without grazing.
Manure handling	-
Labour	Sheep need to be checked daily (in terms of checking numbers, health and welfare).
Fencing	Fertilized walnut: fencing of mowing plots. Grazed walnut: all the area fenced to avoid grazing. Sheep are introduced only

	in late Spring.
Livestock management	
Species and breed	Sheep (Merina).
Description of livestock system	The ewes will conceive in the autumn ("tupping"), with lambing occuring in the spring. On average, each ewe will have about 1 lamb. During the weeks immediately before lambing the sheep are often kept indoors. After lambing, the ewe and the lambs will be moved to a field. The lambs will typically be separated from the ewe in late spring. The typical aim is to fatten the lambs as soon as possible ready for market, and to maintain the weight of the ewes until "tupping".
Period of grazing	Fertilized walnut: all year. Grazed walnut: late Spring.
Stocking density	1 sheep ha^{-1}
Animal health and welfare issues	Sheep need to be checked daily to ensure health and welfare.
Requirement for supplementary feed	Sheep may need access to mineral blocks and hay (in Summer)
Date of entry to site	Fertilized walnut: all year. Grazed walnut: late Spring.
Financial and economic characteristics	
Costs	-

5 Soil component

5.1 Nutrient availability

Ion exchange resins (50 cm^2) were installed at 15-20 cm depth for one month in May 2013 (both essays) and 2014 (Fertilized walnut). We used nine pairs of resins per treatment, each pair composed of one anion exchange resins (for nitrate and phosphate) and one cation exchange resins (for ammonium, calcium and potassium). Table 3 indicates that mowing increased P availability (4.8 µg P cm^{-2} $month^{-1}$) maybe due to the debris incorporation. Results were similar under grazing (3.61 µg P cm^{-2} $month^{-1}$). However, ploughing improved soil available Ca (64.4 µg Ca cm^{-2} $month^{-1}$) and N (190.3 µg N cm^{-2} $month^{-1}$), because of nutrient mineralization.

Table 3. Available nutrients (P, N, Ca, K; µg cm^{-2} $month^{-1}$) in soil in 2014 under different treatments of control of herbaceous vegetation (Grazed walnut). Mean value ± Standard error. Different letters indicate significant differences.

	Mowing	Ploughing	Grazing	Significance
P	4.8 ± 0.9 a	1.7 ± 0.5 b	3.6 ± 0.5 ab	**
N	11.3 ± 1.7 b	190.3 ± 41.8 a	25.3 ± 16.1 b	***
Ca	46.7 ± 1.9 b	64.4 ± 3.7 a	52.8 ± 2.4 b	***
K	39.8 ± 3.8	43.3 ± 3.3	39.7 ± 1.8	ns

With the fertilized walnut experiment, legume sowing resulted in the largest values of P, N and K (5.7 µg P cm^{-2} $month^{-1}$, 120.1 µg N m^{-2} $month^{-1}$ and 80.2 µg K cm^{-2} $month^{-1}$).

Table 4. Available nutrients (P, N, Ca, K; µg cm^{-2} $month^{-1}$) in soil in 2014 under different fertilization treatments (Fertilized walnut). Mean value ± Standard error. Different letters indicate significantly differences.

	Control	Fertilization	Legume sowing	Significance
P	1.3 ± 0.1 b	2.6 ± 0.8 b	5.7 ± 1.3 a	**
N	81.8 ± 2.7 b	88.2 ± 4.8 b	120.1 ± 6.9 a	***
Ca	60.1 ± 2.9 a	52.9 ± 1.6 b	49.7 ± 1.9 b	**
K	28.1 ± 2 b	44.2 ± 2.8 b	80.2 ± 14.3 a	***

5.2 Soil moisture

In March 2012, 54 access tubes were installed to measure monthly the soil moisture with a portable soil moisture probe (model Diviner 2000; Sentek technology, Australia) (n = 9 tubes per treatment). Measurements are taken each 10 cm until 1 m each month (Figure 3). The soil moisture profile was similar in all treatments showing slightly higher moisture contents at depth. The mean soil moisture content in each treatment is shown in Figure 3 and 4.

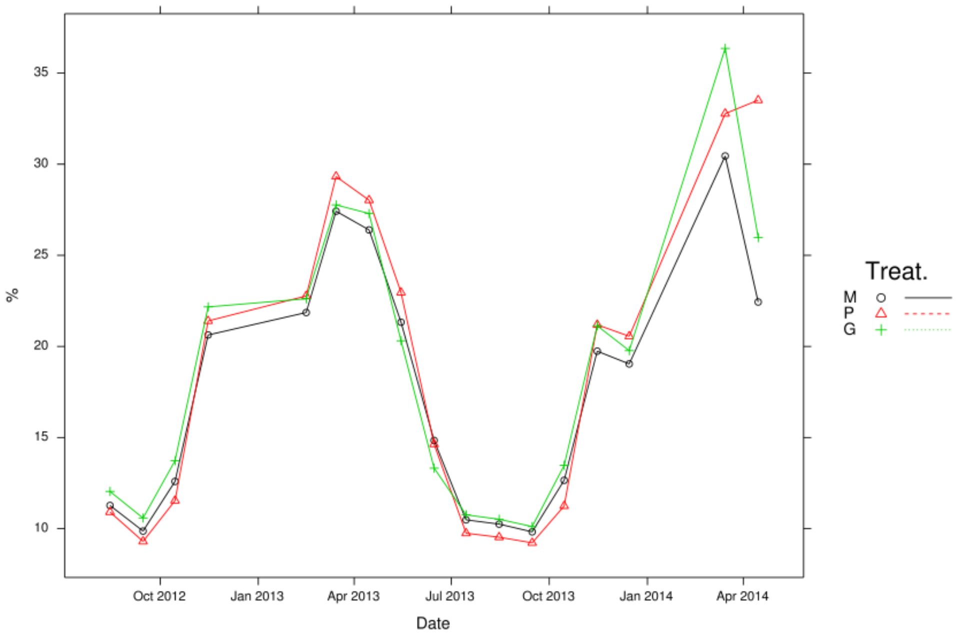


Figure 3. Soil moisture (%) under different treatments of control of herbaceous vegetation (Grazed walnut). M: mowing; P: ploughing; G: grazing.

In the grazed walnut, in April, May and June 2013, when most pasture growth is produced, the largest soil moisture readings were detected under the ploughing treatment (14.6-23.0%), followed by the mowing (14.8-21.3%) and grazing (13.3-20.3%) treatments. During the summer and autumn of 2013, the highest soil moisture content (10.6-13.7%) was found in the grazing treatment and the lowest values were observed in the ploughing treatments (9.3-11.2%).

In the fertilized walnut experiment (Figure 4), in the winter and spring of 2013, the soil moisture was greater in the sowing (30.8-32.2%) treatment, maybe due to the ploughing before the sowing, with similar values in the fertilization (29.4-31.2%) and control (29.3-30.6%) treatments. In the summer-autumn of 2013, the control maintained higher levels of soil moisture (13.8-15.1%) than the fertilization (13.1-13.7%) and sowing (11.1-11.9%) treatments. The lowest tree and pasture growth was observed under the control treatment and it appears that this is not due to water competition.

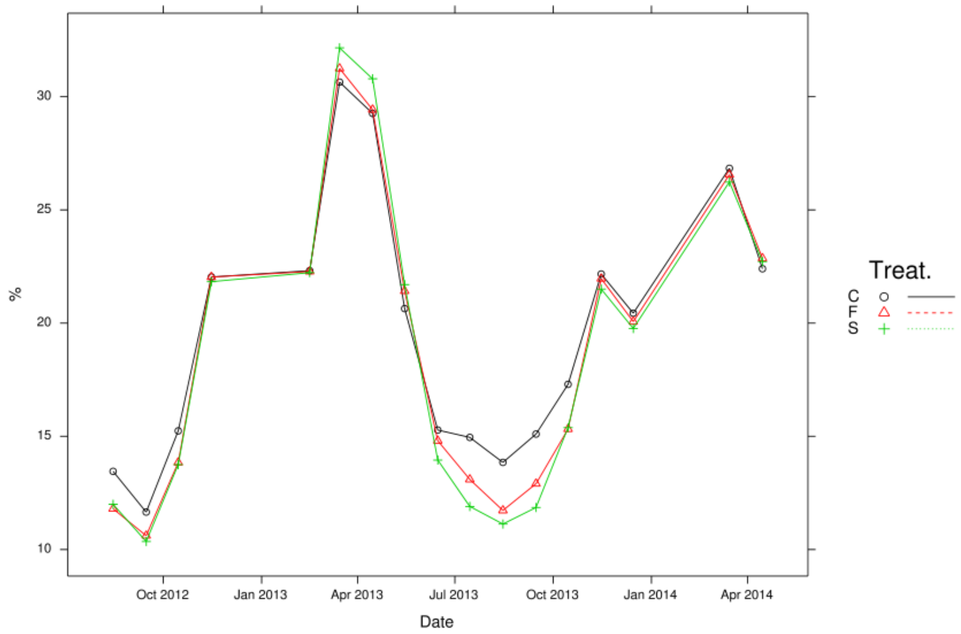


Figure 4. Soil moisture (%) under different fertilization treatments (Fertilized walnut). C: control; F: inorganic fertilization; S: legume sowing.

5.3 Nitrate leaching

Two porous cup tension lysimeters were installed in each plot at 30, 60 and 90 cm to assess the soil nitrate profile, indicator of the nitrate leaching. Soil water was sampled periodically from October to May when soil was enough wet. In the grazed walnut experiment, the nitrate concentration in soil water (Figure 5) was greatest in the ploughing treatment, presumably because of nitrogen mineralized from the herbaceous vegetation. However, the differences were only significant in the uppermost layer (30 cm depth). Nitrate concentration decreased sharply with depth, indicating the low risk of nitrate leaching and groundwater pollution with any of the three treatments. The low risk of nitrate leaching could be explained by the deep root system of walnut trees (see Figure 12).

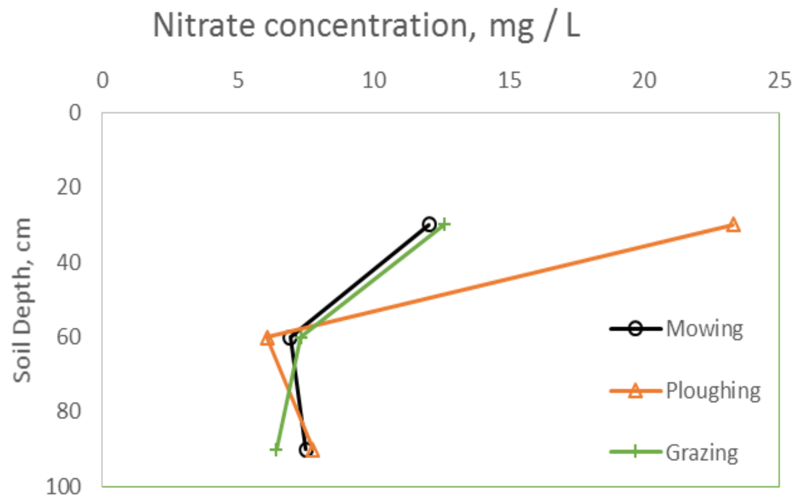


Figure 5. Nitrate leaching (mg N-NO_3^- l^{-1}) under different treatments of control of herbaceous vegetation (grazed walnut)

Figure 6 shows the soil nitrate profile under different fertilization treatments of the fertilised walnut treatments. In the uppermost layer the concentration of soil nitrate levels was highest for the fertilization and legume sowing treatments. Although the nitrate concentration decreased with depth in all cases, values at 90 cm were highest with the legume sowing treatment, probably due to the increased production of N-rich and easily mineralizable biomass including fine root turnover. The mineral fertilized plot showed the lowest nitrate concentration at 90 cm depth. This may be because the higher grass production led to increased uptake of mineral N from the soil. These results suggest that nitrate leaching may occur from legume rich pastures even in the presence of the deep roots of walnut trees.

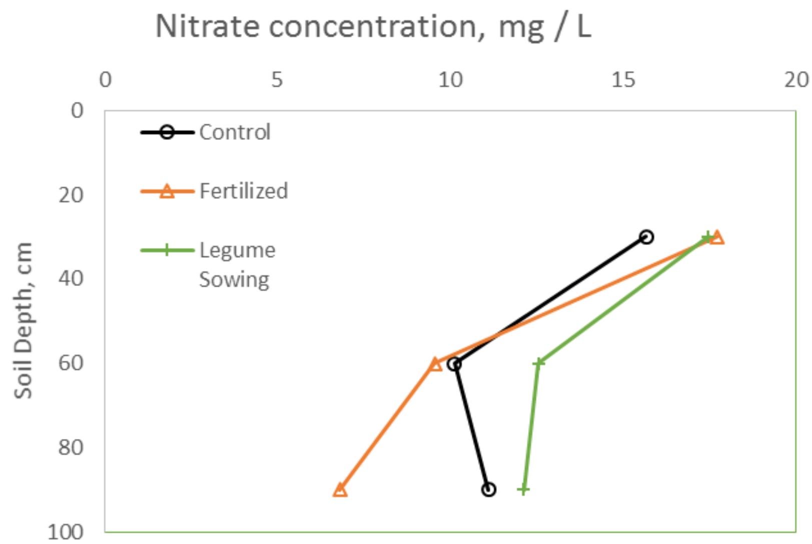


Figure 6. Nitrate leaching (mg N-NO_3^- l^{-1}) under different treatments of control of herbaceous vegetation (fertilised walnut)

6 Tree component

6.1 Leaf nutrients

In 2012 and 2014, tree leaf nitrogen in the grazing and ploughing treatments (Figure 7) was similar and higher than mowing treatment, although such changes were not observed in soil. In 2013, the high spring rainfall led to increased pasture production which was in excess of that removed by the chosen stocking rate. Consequently, in 2013 trees with grazing showed the lowest N leaf contents.

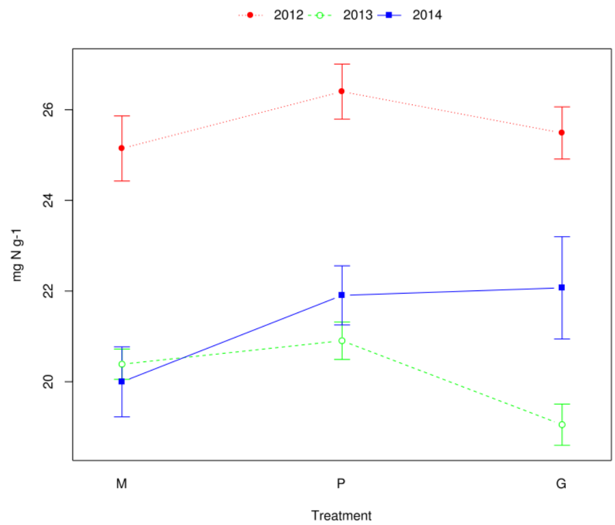


Figure 7. Leaf N (mg N (g leaf)$^{-1}$) under different treatments of control of herbaceous vegetation (Grazed walnut) in 2012, 2013 and 2014. M: mowing; P: ploughing; G: grazing.

In the fertilized walnut experiment, legume sowing (18.7 and 23.3 mg N g^{-1} in 2013 and 2014, respectively) (Figure 8) was as effective as inorganic fertilization (18.5-22.6 mg N g^{-1}) for providing N to trees. There were no significant differences between treatments for other nutrients (P, K and Ca).

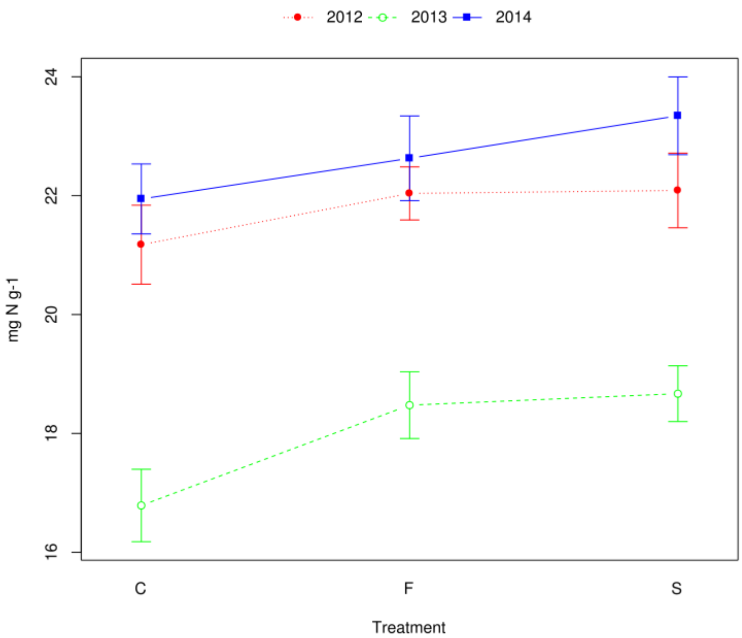


Figure 8. Leaf N (mg N (g leaf)$^{-1}$) under different fertilization treatments (Fertilized walnut) in 2012, 2013 and 2014. C: control; F: inorganic fertilization; S: legume sowing.

6.2 Tree diameter increment

Diameter at breast height (dbh) was measured from January 2012 to January 2015. In general, the growth was low due to the relatively high tree density (333 trees ha^{-1}). Figure 9 shows that in the grazed walnut experiment, the greatest diameters were achieved under ploughing (16.1 mm), as soil and leaf nutrients showed, whose effect was increased with time, followed by grazing (14.4 mm). Respect to grazing, it seems that its effect is improving at long time, due to the livestock contribution of nitrogen and organic matter.

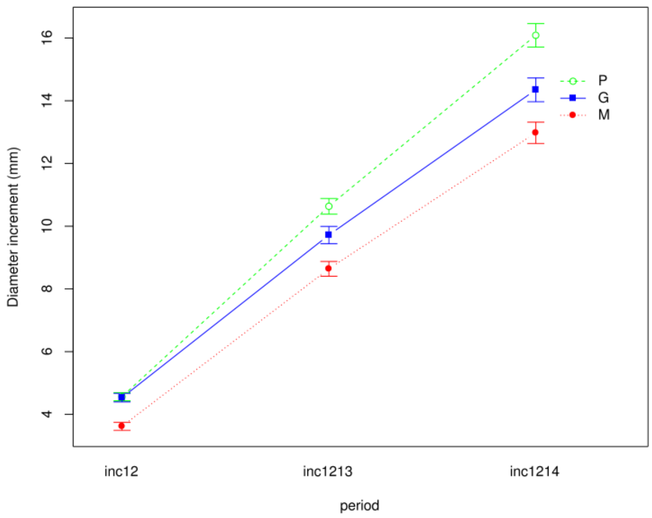


Figure 9. Accumulated tree diameter increment (mm) since 2012 (beginning of the experiment) under different treatments of control of herbaceous vegetation (Grazed walnut). M: mowing; P: ploughing; G: grazing.

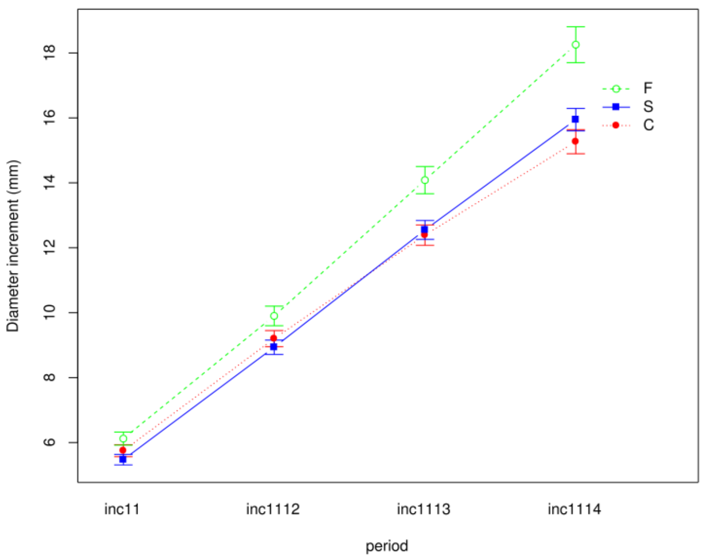


Figure 10. Accumulated tree diameter increment (mm) since 2012 (beginning of the experiment) under different fertilization treatments (fertilized walnut). C: control; F: inorganic fertilization; S: legume sowing.

In the fertilized walnut experiment, tree diameter growth (18.3 mm after three years) was higher with fertilization than with legume sowing (15.9 mm) and control (15.3 mm). During the third year, the increase in diameter was also greater in the inorganic fertilization (4.2 mm) than the legume sowing treatment (3.4 mm) and the control (2.9 mm). It can be proposed that high levels of pasture production need not lead to poor tree growth.

7 Pasture production

Forage legume species (*Trifolium michelanium* and *Ornithopus compressus*; 15 kg ha^{-1} per species) were sown the two first years, as the installation in the first year was deficient. The main difficulty was to find a mixture that could survive under tree shade and hence the plots were sown with legumes each year. In the fertilised walnut experiment, measurements of pasture production were taken during the spring of 2011, 2012 and 2013, because this is the main period of pasture growth in the Mediterranean climate. The grass production for the rest of the year was negligible. Pasture production (Figure 11) was improved by inorganic fertilization (3.62-5.92 t ha^{-1}) and legume sowing (3.56-6.44 t ha^{-1}) compared to the control (1.92-3.47 t ha^{-1}). In 2012, legume pasture production was low because there was a problem with the herd management: sheep were introduced in fenced plots too early. High precipitation and warm spring temperatures resulted in higher pasture production in 2013 than in other years.

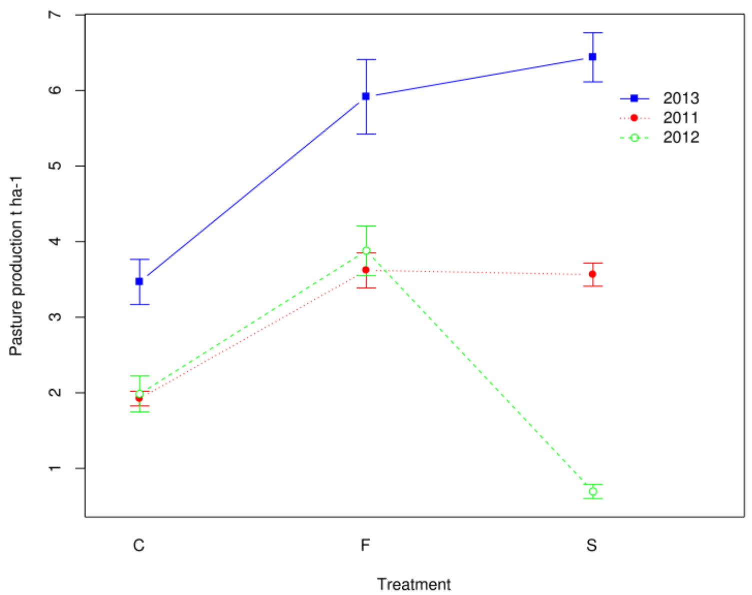


Figure 11. Pasture annual production (t ha^{-1}) in 2011-13 under different fertilization treatments (Fertilized walnut). C: control; F: inorganic fertilization; S: legume sowing.

8 Root length

In each plot, soil cylinders (n = 9) were taken each 10 cm until 1 m depth and roots were separated in tree and pasture (Figure 12). Samples were weighted and analyzed with Winrrhizo program for determining length, which is related to the ability to absorb nutrients and water.

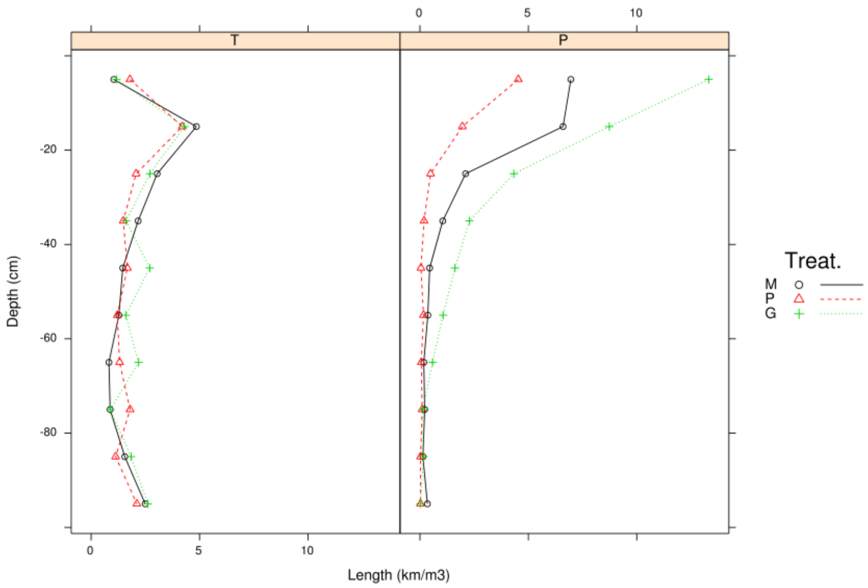


Figure 12. Tree (T) and pasture (P) root length (km m^{-3}) at different depth under different treatments of control of grass understory (grazed walnut). M: mowing; P: ploughing; G: grazing.

Figure 13 shows that the high development of pasture roots in depth under grazing, allowing more efficient use of nutrients and water. A similar tendency was observed below the tree. Similar improvement in length was detected for both vegetation strata with inorganic fertilization and legume sowing respect to control, mostly at 40-70 cm depth.

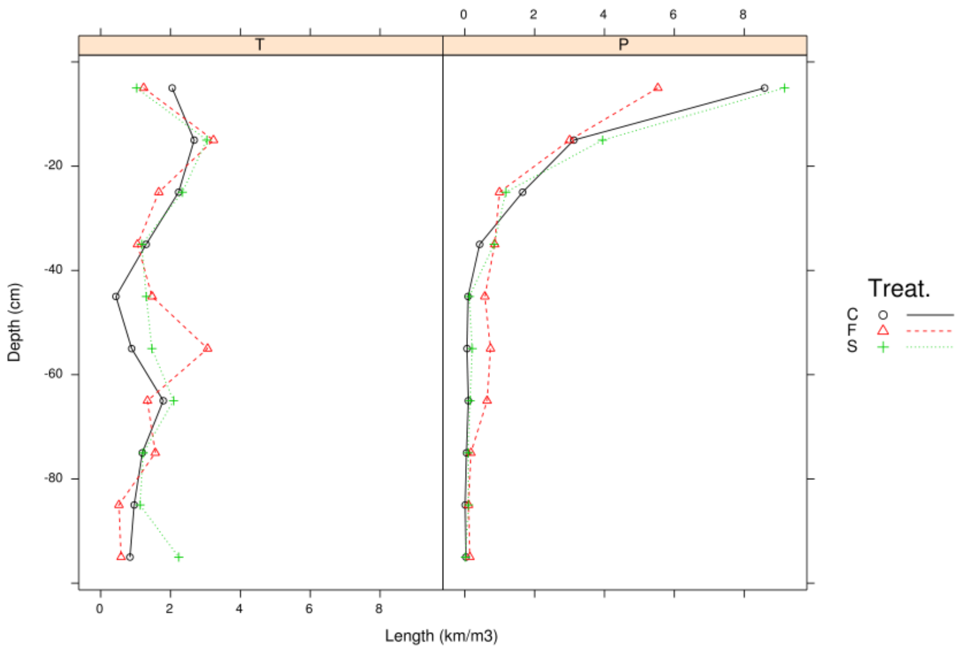


Figure 13. Tree (T) and pasture (P) root length (km m^{-3}) at different depth under different fertilization treatments (fertilized walnut). C: control; F: inorganic fertilization; S: legume sown.

9 Potential of carbon storage

Variations in carbon sequestration were calculated based on the soil organic matter (SOM) and biomass in tree trunk and herbaceous (fine roots) and tree roots (thick and fine roots) based on data collected in 2014, three years after the beginning of the experiments. The fine roots of trees and grasses were termed "fine roots" (Figures 14 and 15). For determining SOM, soil samples (n = 9) were taken each 10 cm depth from the same cylinders used to measure roots. Tree biomass was calculated according to Montero (2005) formulas for obtaining tree trunk and tree root (thick roots). Sequestered carbon by vegetation was calculated by multiplying the aerial and root biomass by 0.5. The results indicated that the largest reservoir of carbon was soil (73-84% of sequestrated carbon), followed by the tree. In the tree, 60% of the carbon was sequestered in the aerial part and 40% in the roots. In the experiment, the percentage of carbon stored in the fine roots was between 0.6 and 0.8% of the total C.

In the control of herbaceous vegetation experiment (Figure 14), mowing produced the greatest contribution of carbon to the system (180.0 Mg C ha^{-1}), due to the incorporated debris, that produced the highest SOM (141.0 Mg C ha^{-1}). The tree biomass, as tree trunk was 23.7 Mg C ha^{-1} and thick tree roots was 14.6 Mg C ha^{-1}, and fine roots of both strata was 0.7 Mg C ha^{-1}. Mowing was followed by grazing (158.9 Mg C ha^{-1}) and the lowest value (146.9 Mg C ha^{-1}) was achieved with ploughing. The grazing treatment had a higher SOM (121.1 Mg C ha^{-1}) and fine roots (0.7 Mg C ha^{-1}) than ploughing (0.7 Mg C ha^{-1}), but lower tree growth (23.0 Mg C ha^{-1}) compared to 23.7 Mg C ha^{-1} with ploughing.

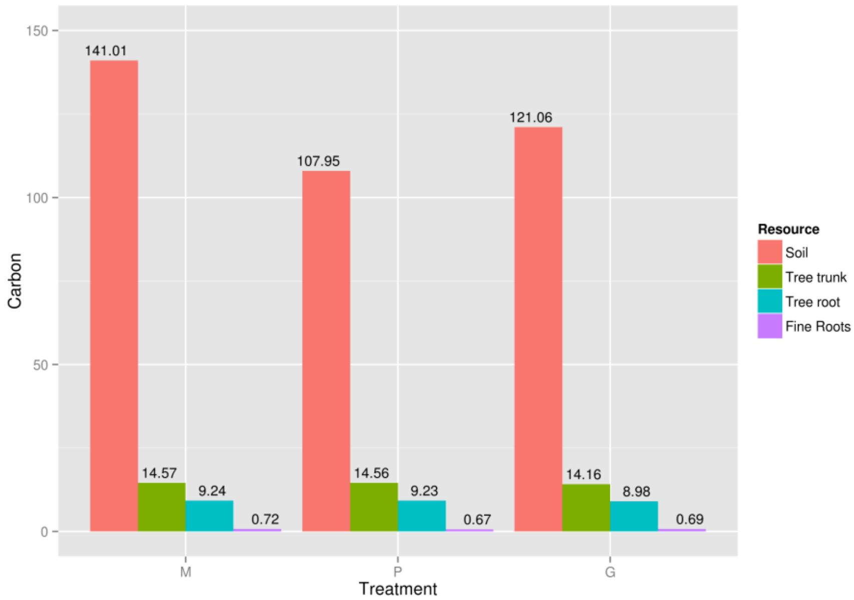


Figure 14. Carbon sequestration (Mg C ha^{-1}) in soil, aerial biomass (tree trunk), and tree thick roots (tree root) and fine roots (tree and pasture) (Fine roots) under different treatments of control of herbaceous vegetation (Grazed walnut). M: mowing; P: ploughing; G: grazing.

In the other experiment (Figure 15), inorganic fertilization produced the highest carbon sequestration values (168.1 Mg C ha^{-1}), followed by legume sowing (164.2 Mg C ha^{-1}) and, at last, by control (159.7 Mg C ha^{-1}). The SOM reduction after sowing can be explained by the mineralization after ploughing. However, it can be expected that these results will improve over time. Carbon sequestrated in tree trunk with legume treatment is slightly lower than under control, due to the higher initial diameter of the control plots. However, the last year the tree sizes of both treatments are similar, as a result of higher growth under legumes (Figure 9). Therefore, it is expected that the improvement of carbon sequestration with legumes will be increased.

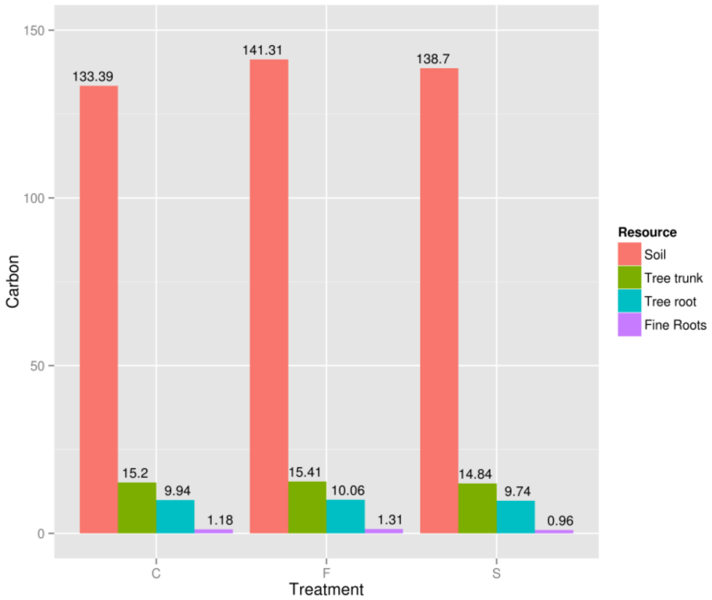


Figure 15. Carbon sequestration (Mg C ha^{-1}) in soil, aerial biomass (tree trunk), and tree coarse roots (tree root) and fine roots (tree and pasture) (fine roots) under different fertilization treatments (Fertilized Walnut). F: inorganic fertilization; S: legume sowing.

10 Acknowledgements

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11 References

Gselman A, Kramberger B (2008). Benefits of winter legume cover crops require early sowing. Australian Journal of Agricultural Research 59: 1156-1163.

López-Díaz ML, Rolo V, Moreno G (2011). Tree's role in nitrogen leaching after organic, mineral fertilization: a greenhouse experiment. Journal of Environmental Quality 40: 1-7.

McCartney D, Fraser J (2010). The potential role of annual forage legumes in Canada: A review. Canadian Journal of Plant Science 90: 403-420.

Montero G, Ruíz-Peinago R, Muñoz M (2005). Producción de biomasa y fijación de CO_2 por los bosques españoles. Monografías INIA: Serie Forestal, nº 13

Rigueiro-Rodríguez A, Fernández-Núñez E, González-Hernández P, McAdam J, Mosquera-Losada MR (2009). Agroforestry Systems in Europe: Productive, Ecological and Social Perspectives. In:

Agroforestry in Europe. Rigueiro-Rodríguez A, McAdam J, Mosquera-Losada MR (eds.). Advances in Agroforestry 6: 43-65. Springer