AGFORWARD
Agroforestry for Europe

Lessons learnt: Alley cropping in Hungary

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Deliverable	Contribution to Deliverable 4.11 Lessons learnt from innovations within agroforestry for arable farmers
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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 field-, farm- and landscape scales, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to the second objective in that it contains results of the studied innovations from one of the systems being studied within work-package 4 which focuses on agroforestry for arable systems. Together with other reports, this document will contribute to Deliverable 4.11 on lessons learnt from agroforestry for arable farmers. Similar reports exist for agroforestry of high nature and cultural value, agroforestry with high value trees, and agroforestry for livestock farmers.

2 Background and objectives

Global climate change and its economic, environmental, and social effects are already tangible. In Southern Europe, and some parts of Central and Eastern Europe, it is evident in higher temperatures and more severe droughts in summer. This is causing reduced deterioration in the quality and yields of some crops. In affected areas, there is a strong need for rural development and the implementation of innovative and climate adaptive agricultural technologies that enable continued production and social-economical sustainability (Láng et al. 2007). For these reasons and in accordance with the practical needs described in the initial stakeholder report (Vityi 2014), our pilot project investigated the possibilities for climate-adaptive arable crop production using agroforestry.

The selected area is used by local stakeholders (e.g. co-operatives and local farmers) for feed production. A local reduction in the fodder production area has reduced the availability of feed for livestock, and adverse climate effects have also reduced feed quality. It is proposed that the effect of climate on feed quality can be minimised by integrating woody vegetation such as trees. During the AGFORWARD project, we examined whether the presence of recently established fast-growing trees had an effect on crop development. The selected tree species was *Paulownia tomentosa* var. Continental E. The research and development report (Vityi et al. 2015a) and the system description report ((Vityi et al. 2015b) provide background data on the examined system, the innovations tested and the applied research methods.

3 Objectives

The main objective of the trial which was to produce quantitative information about the change of crop production and its vulnerability as a non-irrigated system in an environmentally- and climate-sensitive area. Key questions included:

- How does the alley cropping system affect the local microclimate, system resilience, forage yields, tree yields, and soil water, nutrient and humus content,
- How to control weeds cost-effectively, to reduce the amount of labour and mechanical or chemical treatment in tree rows, and
- How to protect effectively trees from wild animals.

Alongside these questions, the following hypotheses were proposed:

- With fast growing tree species, the effect of trees on crop production and local microclimate can be detected in a non-irrigated system despite its young age.
- Savings will be made in terms of the cost of weed control and plant disease control (if using no or less mechanical treatment and/or chemicals), although these may be partly offset by the additional labour related costs associated with distribution of surface covering materials.

4 Methodology

A Paulownia tree plantation of 0.5 ha placed in similar site conditions, but without intercropping, was used as control plot. The measurements which have been taken in the agroforestry and the control plots are described Table 1.

4.1 Tree growth measurements

Diameter at breast height (DBH) and height measurements for trees in alley cropping plot were carried out on an annual basis.

4.2 Forage biomass

Forage biomass production for the alley cropping and the control plot was measured in each harvesting period to examine the effect of trees on the crop biomass yield.

4.3 Microclimatic parameters

Temperature and soil moisture values were measured during the four year experiment as described in Table 1. Further details of the measurements can be found in the Research and Development Report (Vityi et al. 2015).

4.4 Soil nutrient and humus content

The soil humus and nutrient content was measured using a sampling grid. A total of 19 sample points in the agroforestry system (50% in tree rows, 50% in the intercrop) and 9 sample points in the control, along the diagonals were applied, at three depths (0-10, 10-30, and 30-50 cm). The outermost 20-m areas on the edge of the plots were omitted from the sampling. The samples were repeated annually between 2014 and 2016. In 2016, additional samples were taken in different orthogonal distances from the tree rows, comprising 36 sampling points (32 in agroforestry and 4 in the control) and were analysed based on the common protocol.

In cooperation with the University of Extremadura (Spain), in the same 36 sampling points root samples were taken in 5 layers (0-15, 15-30, 30-45, 46-60, and 60-75 cm) in order to analyse root distribution and competition between the trees and the intercrop.

Table 1. List of measurements taken in the two treatments

Element	Parameter	Method	Measured
Trees	Height and diameter at breast height (DBH)	One measurement per year	October 2015, 2016, 2017
	Damage from wild animals and insects	Extent of damage has been recorded annually in alley cropping (AC) and control trees	2014-2017, continuously
Crop	Crop production	Crop yield of each plot (AC + control) measured at each harvest based on the total weight and moisture content of baled material and samples taken from 1 m^2 area, 4-4 samples from each plot as for control measurement in 2016.	2014 -2017, continuously
	Crop disease	Continuous monitoring; samples planned to be taken if effects of disease are noted (No diseases were noted in either plots)	2014-2017, continuously
Soil	Organic matter (OM) content	1. Soil samples taken in three depths (0-10 cm, 10-30 cm, 30-50 cm) and OM is analysed 2. Extension of soil measurements: Soil samples taken in each 15 cm until 75 cm depth (same protocol used by UEX, Spain). Root distribution and organic matter content planned to be analysed	Autumn 2014, 2015, 2016 Summer 2016
	Nutrient availability in soil N, P, K	Soil samples taken in three depth (0-10 cm, 10-30 cm, 30-50 cm) for nutrient content analysis	Summer 2016
Microclimatic parameters		An automatic agrometeorological station with one main station and two substations (sub 1 in the intercrop; sub 2 in tree rows) in the agroforestry plot and one substation in the control plot, established by the Cooperative, measured: • air temperature and humidity • precipitation • wind direction and speed • global radiation • leaf surface humidity (at two levels) • soil moisture (10, 20, 40, 60 cm depth) • soil temperature (10,20, 40, 60 cm depth) Data are registered on hourly basis by automatic sensors.	data are available from May 2014 to the end of 2017
Weed control		Alternative method of weed control (first-cut lucerne cover and use of aromatic shrubs) tested Labour time and costs spent on covering the surface for weed control recorded.	Summer 2015-2017

4.5 Testing innovations in weed control

Mechanical weed management might face obstacles in tree rows (e.g. because of the lack of space and presence of cultivated plants) and hence labour costs for weed control can be higher than in monocultures. It is also desirable to minimise the use of herbicides. Because of this, one of the objectives of the agroforestry experiment was to test alternative weed management methods. The following activities were implemented:

- An aromatic shrub treatment including lavender, lemongrass, mint, and oregano was planted in three tree rows in October and November 2015.
- The second treatment was the cutting of the herbaceous flora of the tree row and part of the first-cut alfalfa cover treatment which was applied as a mulch to three tree rows in early May 2016 and 2017. The weeds were cut using a motor-manual method, while alfalfa was harvested mechanically and was spread by hand in the tree rows.
- Trees rows with manual and chemical weed control were also established as controls.
- The effectiveness of the treatments measured by the relative extent of weed cover before and after. Tree row(s) without using alternative method were the control in these measures.
- Labour time and costs spent on covering the surface for weed control were recorded.
- Photographs of weed covering before and after application of the test method had been taken.

4.6 Tree protection methods against wild animals

Wild animals can harm the whole Paulownia plant in its first year or cause trunk damage in later years. The extent of damage – with and without using “wild alarm” substances – was recorded annually in categories according to the scale and location of damage. The effectiveness of tree protection was tested in three experiments (Table 2).

- Experiment 1: 120 trees in the fenced agroforestry plot
- Experiment 2: 24 trees planted on the external side of the fence around the agroforestry plot
- Experiment 3: 300 trees in a separate tree plantation of the same type of plants in similar site conditions, where different methods were tested for trees of different ages (1-3 years).

Across the three experiments, it was possible to test the methods in different stages of plant development - from installation to the age of 3-4 years (damage picture varies by tree age). In Experiment 2 and 3, the evaluation criteria were the environmental effects (e.g. suitability for organic farming), simplicity of application, effects on tree and crop production, longevity, and cost compared to physical protection with a tree guard.

Although the physical protection was effective, it was costly and hence if applied commercially it would reduce the profitability of the system. In the fenced agroforestry area, the trees were exposed to only small animals (e.g. voles and rabbits) while trees outside the plot and in the control plot are exposed to larger mammals as well. In Experiment 2 and 3 the tested methods (Table 2) were:

- spread of WAM Extra paste on trunks and buds. WAM stands for Wild Abwehr Mittel, German for Wild Repellents (Witasek 2018).
- spraying Forester EW (Emulsion in Water) liquid repellent substance on trees. Forester EW is a contact insecticide which can also be used to control bark beetles on felled logs (Fargo 2018).
- a trunk protector net and trees with no protection as controls.

Table 2. Tree protection methods tested between 2014 and 2017

No. of exp.	Location of trees and date of experiment	No. of trees	Tested method	Picture of experiment
1	tree rows in alley cropping plot (2014-2017)	120	Trunk protector net (removed in the 2nd year) Wildlife fence (from the 2nd year)	 2014  2017
2	Tree row alongside the fence outside of the agroforestry plot (2015-2016)	24	Chemical game repellents: • Forester EW • WAM extra	 2016
3	Tree plantation of the same genetic material placed in similar site conditions as the agroforestry plot, (no irrigation) (2015-2016)	300	Chemical game repellents: • Forester EW • WAM extra Different methods were tested for trees of different ages (1-3 years)	  2014 2017

In Experiment 3, the tree protection methods were tested in four plots (Table 3). The tree protection methods were:

- WAM paste in strips of 3 year old *Paulownia tomentosa* var. Continental E. (4 m x 4 m) (Lines 1, 2, 4 and 6) with untreated intermediate lines (rows 2 and 3) (green in Figure 1)
- Trunk protection nets in 3 year old *Paulownia* variety 1 (4 m x 4 m) which showed substantial tillering (blue in Figure 1).
- Tree guard and WAM paste in 1-year old *Paulownia* variety 2 (3 m x 3 m) which showed substantial tillering. The paste was used to protect the thin shoots (pink in Figure 1)
- use of Forester EW in 3 year old *Paulownia tomentosa* var. Continental E. (3 m x 3 m); one third of trees in two strips were treated and 22 were left as untreated controls (yellow in Figure 1).

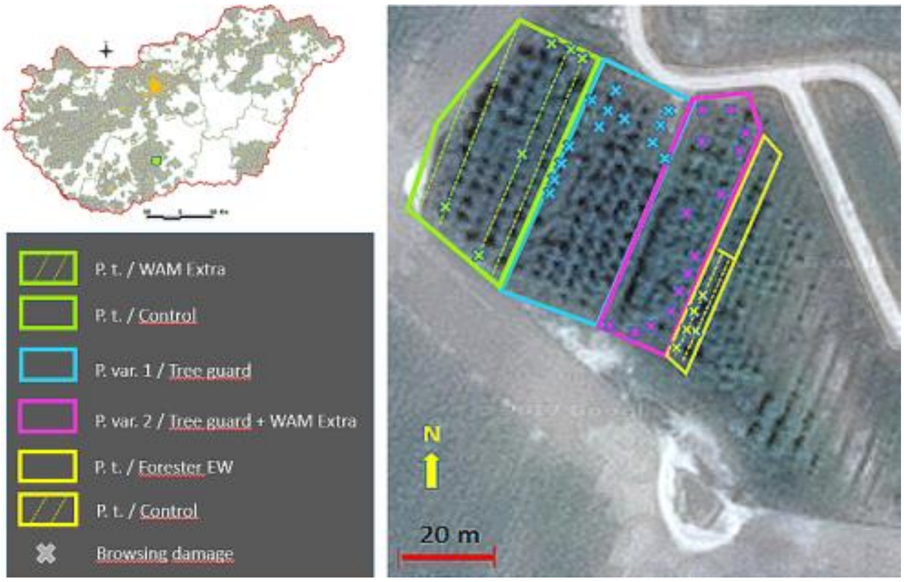


Figure 1. Map of Experiment 3

Table 3. Description of Experiment 3 for testing chemical repellents against tree guards

Specific description of site	
Area	~ 0,5 ha
Place	Fajsz, Hungary
Site contact	Andrea Vityi (vityi.andrea@uni-sopron.hu)
Climate characteristics	
Mean monthly temperature	12.5 °C (11.0°C)*
Mean annual precipitation	429 mm (534 mm)*
Details of weather station (and data)	Short-term (5 years) data from the Hungarian Weather Network from weather station at Kalocsa-Öregcsertő[1], accessed from website http://www.flaiszg.hu/wxtempsummary.php Long-term data (110 years) from the Hungarian Meteorological Service, climate data series http://www.met.hu/eghajlat/magyarorszag_eghajlata/eghajlati_adatsorok/Szeged/adatok/eves_adatok/

[1] located at 11 km far from the experimental plot

	**selected data series of Szeged city which is located in the same average temperature and precipitation zone as Kalocsa*
Soil type	
Soil type	WRB classification: Phaenozem
Soil depth	>140 cm
Soil texture	Loam
Aspect	North-East/South West
Comment	Sandier soils and lower groundwater levels in the Northern part of the system, higher soil moisture level and periodically covered by inland excess water in the southern part of the system
Tree characteristics	
Species and variety	Paulownia varieties
Date of planting	2012
Intra-row spacing	Varies by tree varieties (3 m / 4 m)
Inter-row spacing	Varies by tree varieties (3 m / 4 m)
Understorey characteristics	
Species	Different weed species (no crop sown)
Management	Mechanical weed control
Fertiliser, pesticide, machinery and labour management	
Fertiliser, pesticide	No fertilisers are used. Pesticides were used occasionally, when necessary, to control insects. There are only a few pests of Paulownia.
Labour	The plot was ploughed before planting the trees. Labour was then used for weed management (2-3 times a year) with farm machinery Management of young trees: pruning every year Tree protection: fixing trunk protectors, spraying with Forester EW and daubing with WAM Extra
Tested methods	1. Chemical treatment (once, with environmentally friendly products) • WAM Extra Recommended for use against peeling of deer and mouflon and against deer, goat, and hare browsing damage. The paste is rough granular and has odour, taste and optical properties It was used at the recommended volume of 2 kg/1000 plants, and spread undiluted on buds, before the start of the winter, above 0°C. • Forester EW spray Usable for keeping the deer liable to cause great damage to tree plantations. A liquid emulsion form of game repellent spraying agent with long lasting effect, contains natural substances. Physical treatment (as for control) 2. Flexguard' Tree Guard Width 32 cm, Length 110 cm UV stabilised and flexible woven plastic fabric for protection against browsing by animals.
Duration of experiment	
Duration	20 December 2015 – 20 August 2017

5 Results

5.1 Yield assessment

5.1.1 Tree growth

During the four years, differences in height and DBH could be identified. The average value of DBH in the alley cropping system was 21% lower than in the sole tree plantation. The reverse trend was found for height measurements where, on average, trees in the agroforestry plot were 13% higher than the ones in the control plot.

5.1.2 Intercrop yields

Yields per unit area in the agroforestry parcel were consistently 15-25% above the annual average yield of the control area (Figure 2). This is partly due to the higher density of alfalfa plants in the agroforestry plot; the control area contained a significant amount of weed which also partly contributed to the yield.

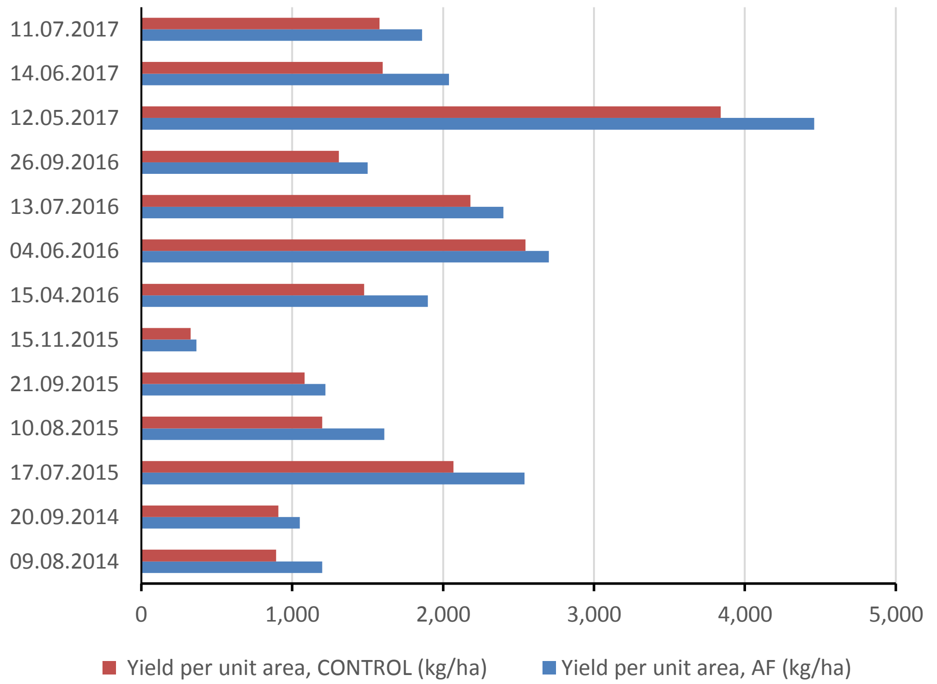


Figure 2. The yield of the intercrop in the agroforestry (AF) and control areas between 2014 and 2017, excluding harvests when material was left because of unfavourable weather conditions

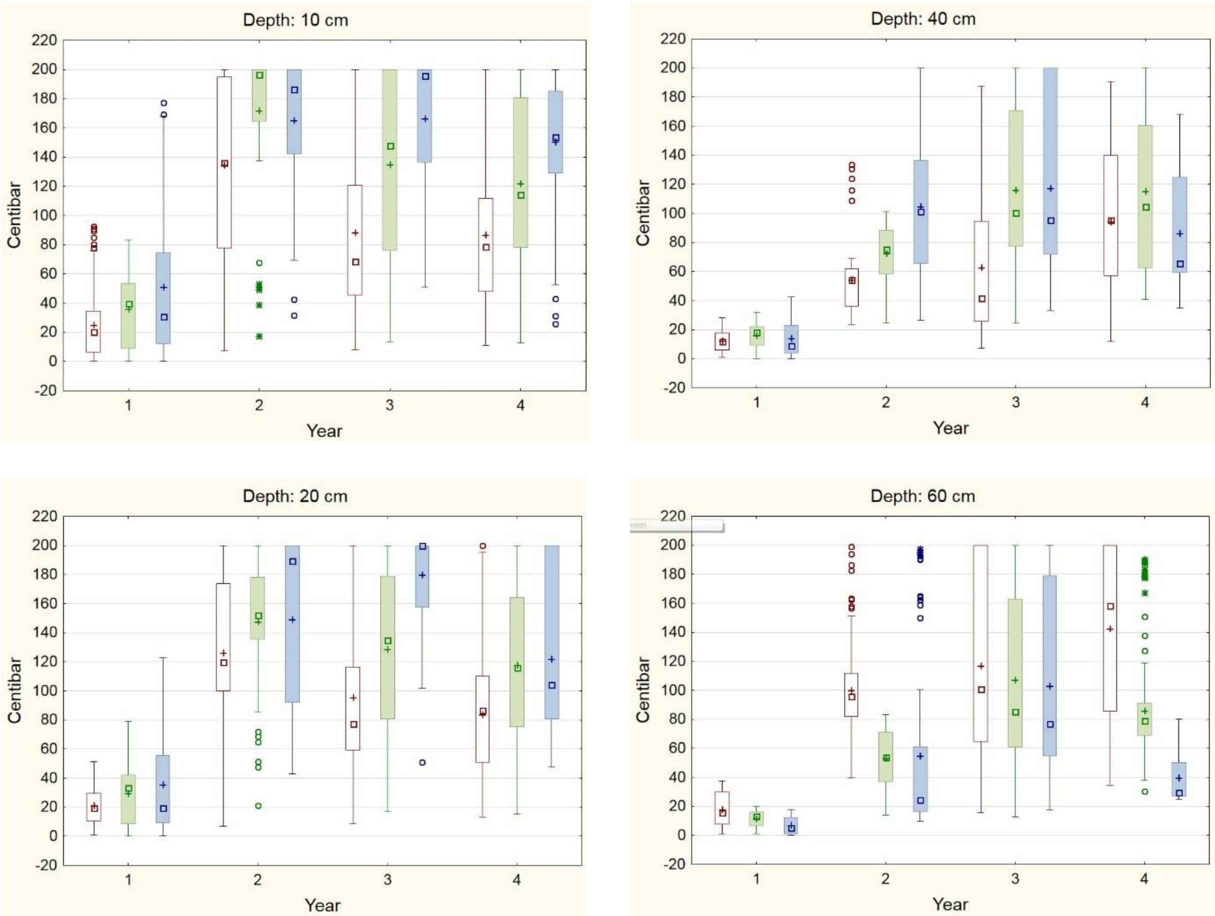
5.2 Microclimatic results

5.2.1 Soil water tension during 2014-2017

There was a general tendency for the soil water tension (negative soil water potential) to increase from year 1 to year 4 (Figure 3). There were significant differences ($p < 0.05$) in soil water tension between the agroforestry and control areas in the third year (Figure 3).

The greatest treatment differences in soil water tension occurred in the upper 10 cm of soil. In the last two years, the tension at 10 cm was lower in the alley cropping than in the control area.

Soil water tension
Median: □; Mean: +; Box: 25%-75%; Whisker: Non-Outlier Range



Legend: □ Tree alley; ■ Intercrop; ■ Control

Figure 3. Soil water tensions (negative water potential) at 10, 20, 40, and 60 cm depth in each of four years. Higher soil water potential values indicate a higher level of soil drought.

In years 3 and 4, the soil water tension at 20 cm in the agroforestry area was also lower than in the control area. During these two years, the soil tension at 20 cm in the two agroforestry measurement points was typically lower than 200 cm, while in the control plot it was often at 200 cm or above (Figure 5).

In the deeper layers, the differences in soil tension between the control and agroforestry area were less pronounced. There is an impermeable clayey layer at a depth of 30-50 cm. At 60 cm, perhaps the greatest tensions occurred in the tree alley areas, perhaps due to the combined suction effect of alfalfa and tree roots. It is possible that although the trees help to preserve soil moisture in the top 20-30 cm layer of soil, they caused a decrease in soil moisture in deeper layers.

5.2.2 Soil temperature between 2014 and 2017

The standard deviation of the temperature in the control area - in all the examined soil layers (0-10, 10-20, 20-40, 40-60 cm) - was greater than that in the agroforestry area. This difference is most pronounced in the upper 10 cm and shows a slight increase each year (Figure 3). In the last two years the interquartile range (middle 50%) of measured data was also larger in the control area than the alley cropping samples. The reduced variation in the agroforestry area could be a result of the trees reducing extreme changes in soil temperature during drought periods.

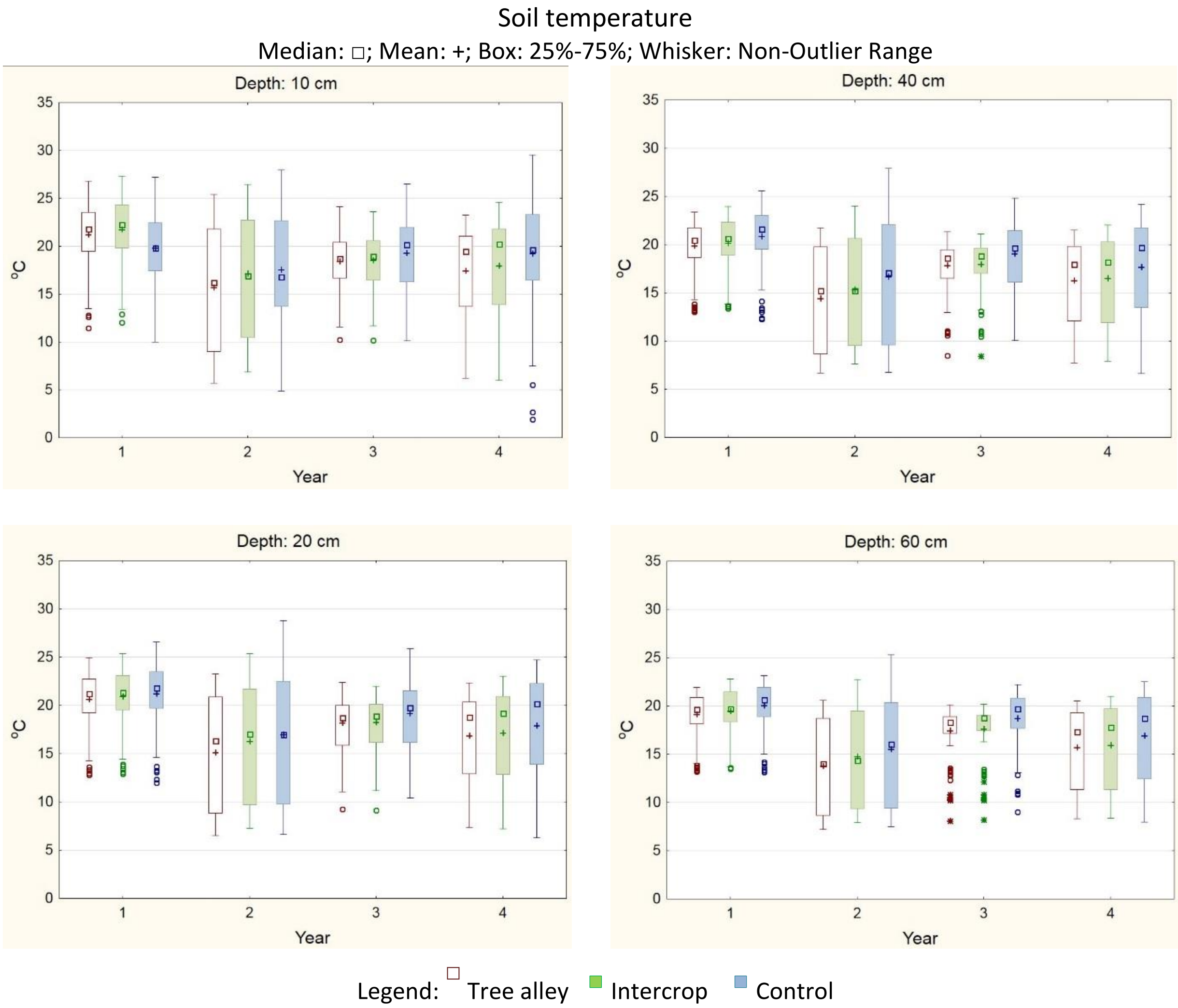


Figure 4. Results of statistical analysis of yearly soil temperature data series from 10, 20, 40, and 60 cm depth

5.2.3 Soil temperature and moisture during drought periods

The mitigation effect of the agroforestry system on extreme weather conditions was examined for two hot and dry summer periods over one month in 2016 and 2017. For both periods, the upper 30 cm soil layer dried more slowly in the alley cropping area, and hence the period when the tension was greater than 200 cm was reduced relative to the control (For an example see Figure 5; for all depths together with rain, temperature and wind data of the same periods see Figure 14 and 15 in Appendix A).

Soil water tension
16 August 2016 - 30 September 2016

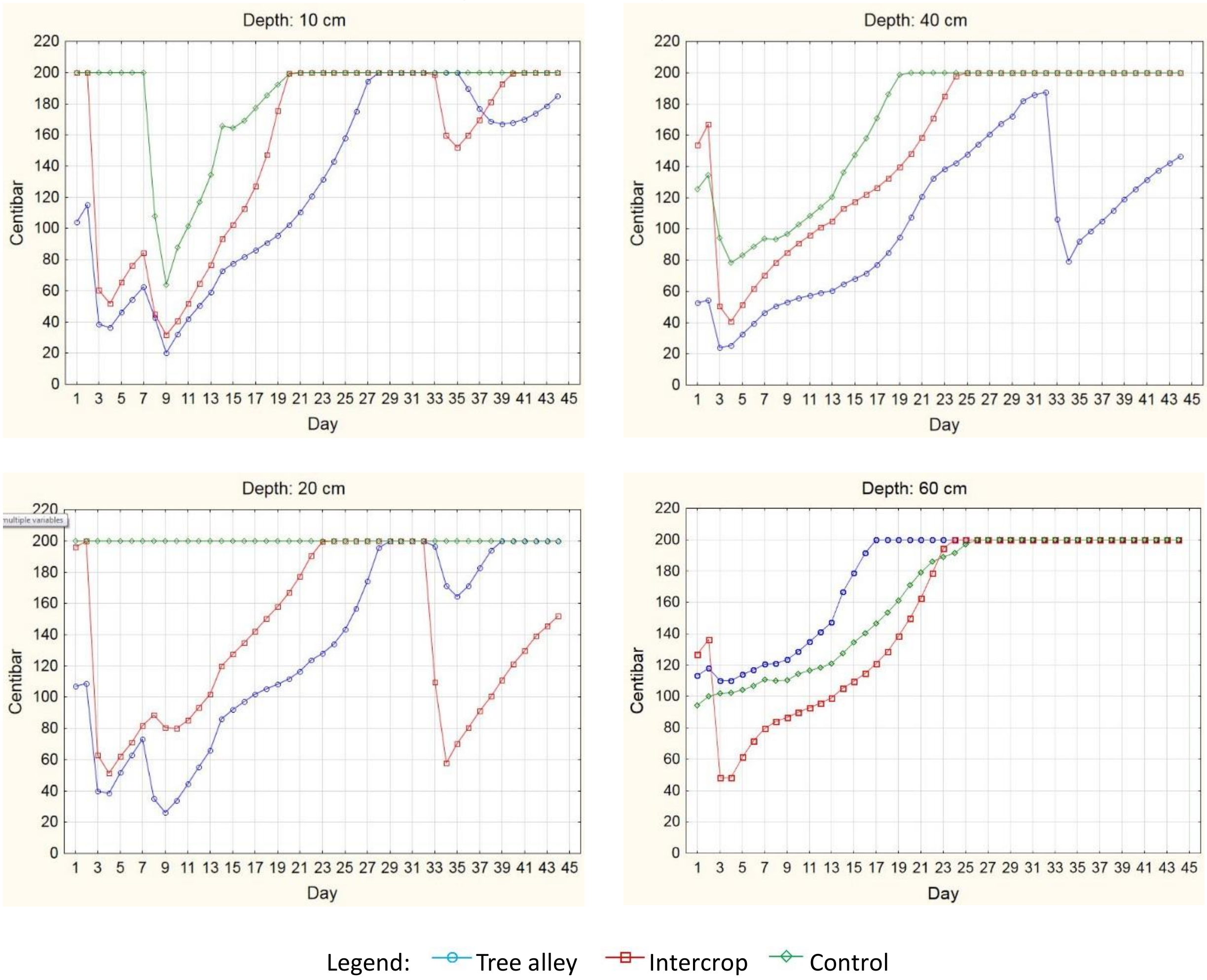


Figure 5. Change of soil water tension at depths of 10, 20, 40 and 60 cm in a dry period of the 2016 growing season. A high tension indicates a low moisture content. Although it depends on the soil type, a tension of about 170 cm can represent 50% depletion of the plant available water.

In the upper 10 cm, the soil temperature changes over the same periods were greater in the control area (following the fluctuations in air temperature), whilst the changes in the agro-forestry system were moderated (Figure 6 and Figure 14 in Appendix A). In the layers of 20-60 cm, the difference between the two treatments was minimal. Hence the trees not only moderate the extremely high temperatures, but also equalize the heat fluctuation in the upper 10 cm of soil during drought periods.

Soil temperature
16.08.2016-30.09.2016

Legend: Tree alley Intercrop Control

Figure 6. Soil temperature at depth of 10, 20, 40 and 60 cm in a drought period of growing season 2016.

Soil moisture curves in Appendix A show that during drought periods, the upper soil layers in the tree rows dry out more slowly than in the control area. In the latter case, precipitation of a small amount cannot be utilized, while soil dryness decreases as a result of even a slight precipitation in the alley cropping areas. Presumably, the better soil moisture conservation capacity of the agro-forestry areas in the upper layers could be explained by the reduced drying effect of wind.

5.3 Soil nutrient and humus content results

Soil nutrient and humus contents were compared between the control area with solely alfalfa and the strips of alfalfa intercrop and the tree rows in the agroforestry area.

5.3.1 Initial soil nutrient characteristics

The soil is a medium-calcareous, alkaline-like clay or clayey loam. Since the site used to be a solid manure storage site, the soil humus, nitrogen content, and nitrite/nitrate-nitrogen content is high. Similarly phosphorus and potassium contents are very high. Other meso- and micro-elements appear sufficient although there is a lower level of manganese in the top 30 cm. No significant differences were found in the “null position” parameters of the agroforestry and the control plot.

5.3.2 Humus content

In 2014, there was a significant difference between the humus content in the agroforestry and the control plots at depths below 10 cm. In 2016, the significant difference was limited to the lowest layer (Figure 7). The humus content in the upper two soil layers increased during the three years, and this was associated with increases in plant productivity. Whereas the increase in values continues in the layer below 30 cm in the areas covered with alfalfa, we found lower values in the lowest level of the tree rows, compared to the upper layers. At 0-10 cm the greatest increase in humus content occurred in the control area whereas at 10-30 cm, the greatest increase in humus content occurred in the alleys.

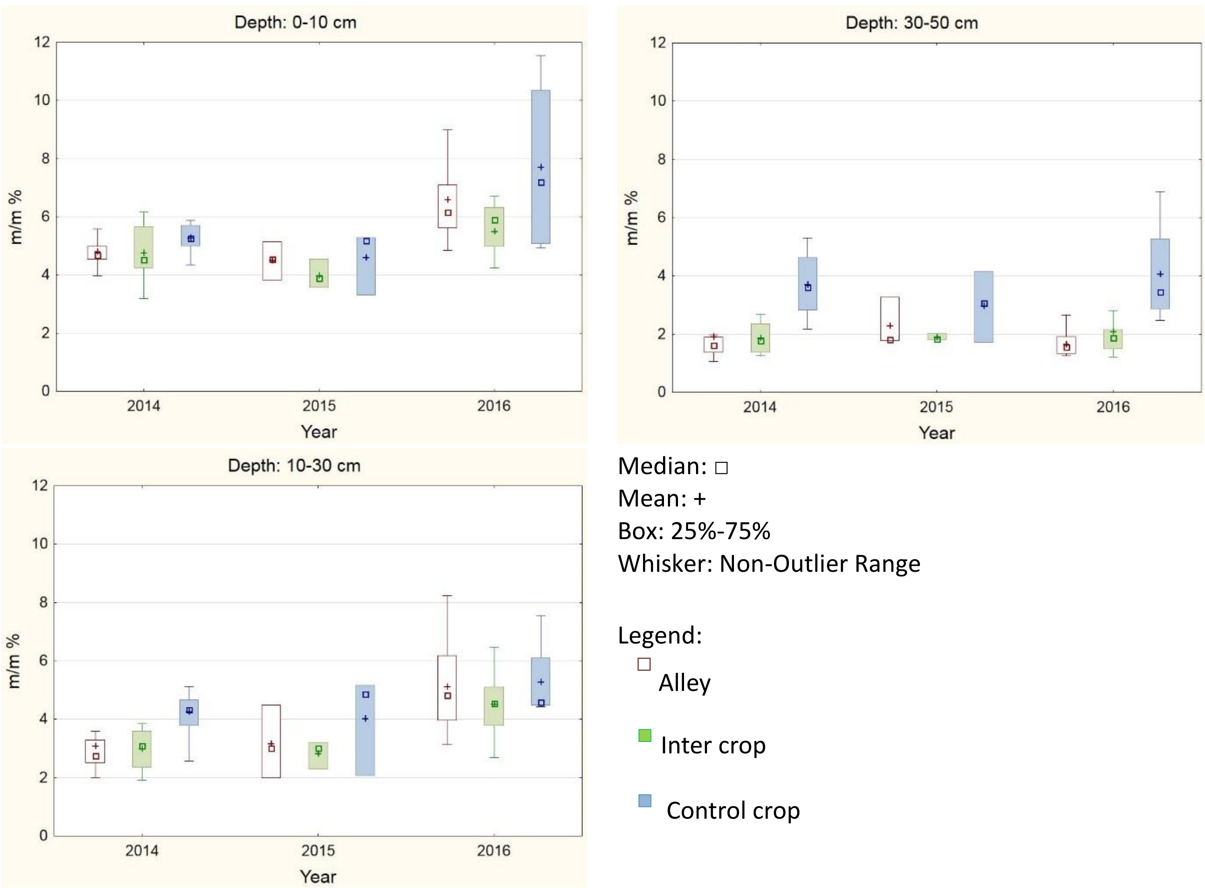


Figure 7. Humus content in the agroforestry (alleys and intercrop strips) and control experimental plots between 2014 and 2016

5.3.3 Phosphorus and potassium content

In all three treatments, the phosphorus (Figure 8) and potassium content (Figure 9) in the upper 10 cm declined from 2014 to 2016. This could be due to the uptake of nutrients by the plants. In the deeper layers, there was an increase in the phosphorus content in the agroforestry system, which was not evident in the control plot. In the upper 10 cm, the phosphorus in the alleys declined between 2014 and 2015 before increasing again to the 2014 level. By contrast, in the control area, the phosphorus content for the third year was well below the value of the first year. For the third year, the average phosphorus content in the 10-30 cm layer of alleys was well above the value of the first year, and an increase in phosphorus was also observed at 30-50 cm.

In summary, the initial differences in the soil phosphorus content between the agroforestry area and the control area in the upper 30 cm decreased considerably over the three years for the benefit of the alley cropping production system.

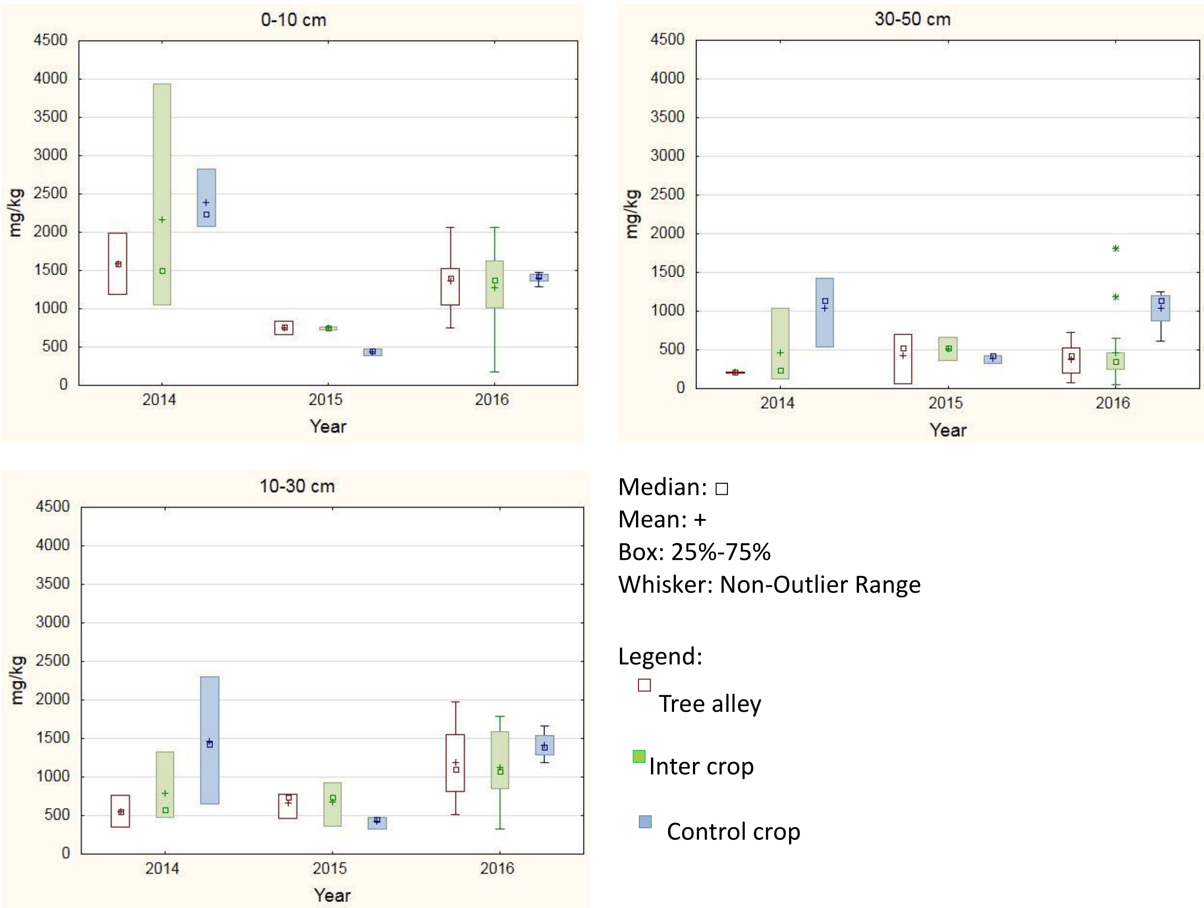


Figure 8. Phosphorus content in the agroforestry (alleys and intercrop strips) and control experimental plots between 2014 and 2016

Similar findings can be made regarding changes in the potassium content of the soil (Figure 9). In 2014, the highest potassium content was found in the control in all three depths, followed by the intercrop. The 2017 results show the opposite in the upper 30 cm with the highest potassium content found in the tree alley. In the 30-50 cm layer, the differences observed in 2014 were removed by 2016.

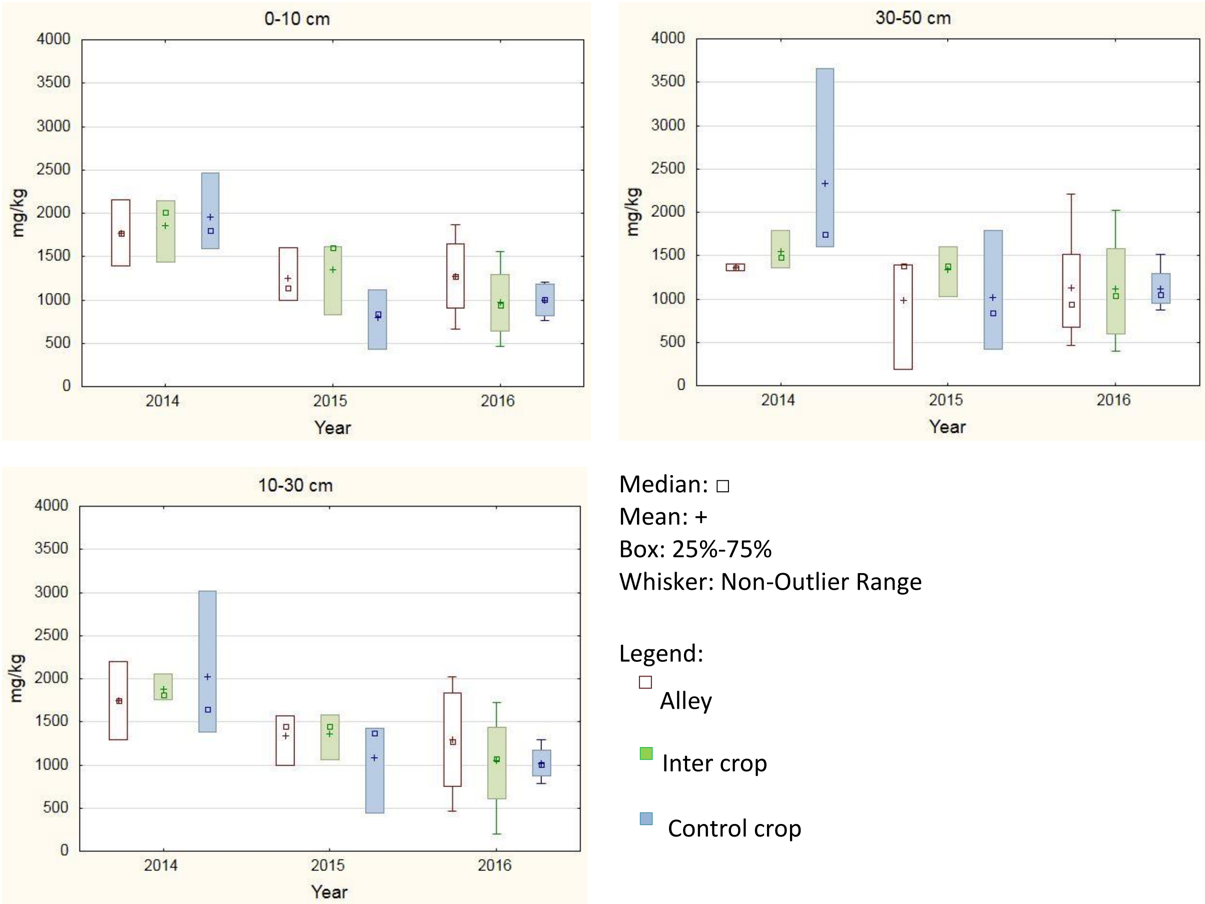


Figure 9. Potassium content in the agroforestry (alleys and intercrop strips) and control experimental plots, between 2014 and 2016

5.3.4 Nitrogen content

Because of the difference between the common protocol applied in 2016 (all N determinations) and the method of examinations carried out in previous years (determination of soluble N-compounds), the results were not comparable and therefore they are not reported.

5.3.5 Root distribution

It was not possible to determine root distribution using the visual imaging method applied at the University of Extremadura because it was very difficult – or impossible - to distinguish the roots of alfalfa and the trees.

5.4 Alternative tree protection methods

Most of the trees located along the fence of the agroforestry plot in Experiment 2 were lost, because of unsuccessful rooting or mechanical damage caused by machines. However surviving trees treated with Forester EW and WAM paste showed no further damage despite the lack of physical protection. The poor survival could also be related to the freshly planted two-year old propagation material being hollow and thin branches and shrivelled up during the winter. Hence it was useful to have a separate experiment (Experiment 3) to determine the effect of tree protection.

When the Paulownia is in leaf, although the leaves and shoots could have been eaten by deer, no such damage was observed in Experiments 2 and 3. By contrast, breakage of trees caused by big game were observed in two previous years (Table 4). Damage caused by hares, during period when the Paulownia was not in leaf, was also observed during the four years (Table 5). In 2016, 38 incidents of hare damage were recorded (Figure 9).

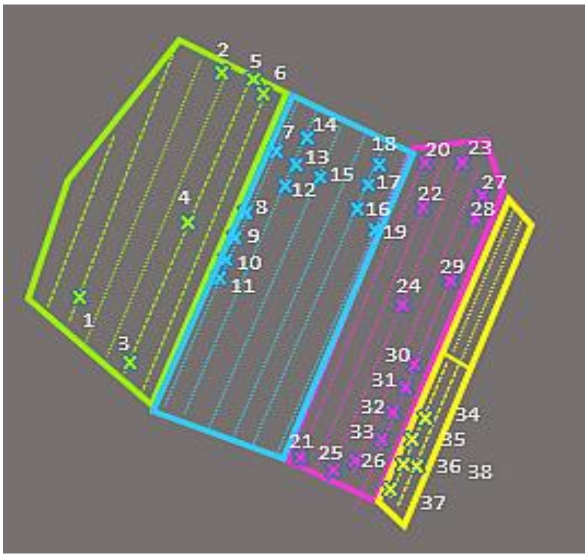


Figure 10. Map of damage caused by wild animals in Experimental plot 3

Table 4. Assessed damage caused by wild animals per year (2013 – 2015)

Year	Proportion damaged	Winter weather	Comment
2012/2013	16.2% (P.t. 4x4) 8.3% (P.t. 3x3) 16.3% (P.t. var.1. 4x4)	Average winter temperature, precipitation well above average from December to April	High damage ratio of young seedlings, both trunk and canopy affected
2013/2014	No browsing damage but breakage caused by big game was observed in each parcel	Relatively mild winter (low average temperatures) and dry weather except for December	Breakage of 2-3 individuals of each varieties in the southern end of the rows
2014/2015	No browsing damage but breakage caused by big game was observed in each parcel	Even milder winter, but more precipitation than in 2014	Breakage of plants at similar rate as in the previous year
2015/2016	8.3% (P.t. 4x4) 17.9% (P.t. 3x3) 15.5% (P.t. var.1. 4x4) 11.2% (P.t. var.2. 3x3)	December and January colder than average, much higher than average rainfall in January and February	High damage ratio, dominantly tillage damage caused by hares (see the details in Table 5)

Table 5. Damage caused by wild animals in Experiment Plot 3 between December 2015 and October 2016

Row (no. of individuals)	Serial number of trunk damage in the drawing	Serial number of tiller damage in the drawing	No. of damaged individuals per row	Share of damaged individuals per row (%)
P.t. 4 x 4 m				
I.(1-14)	6		1	7.1
II.(15-28)	5	3,4	3	21.4
III.(29-42)	2		1	7.1
IV.(43-56)			0	0
V.(57-66)		1	1	7.1
VI.(67-72)			0	0
Sub-total	**3**	**3**	**6**	**8.3**
P. var.1 4 x 4 m				
VII.(1-14)	19		1	7.1
VIII.(15-28)	17	16,18	3	21.4
IX.(29-42)			0	0
X.(43-56)		15	1	7.1
XI.(57-70)	13	12,14	3	21.4
XII.(71-84)		7,8,9,10,11	5	35.7
Sub-total	**3**	**10**	**13**	**15.5**
P. var.2 3 x 3 m				
XIII.(1-20)		27,28,29,30,31,32,33	7	35
XIV.(21-44)		26	1	4.2
XV.(45-68)	23,25		2	8.3
XVI.(69-92)		22	1	4.2
XVII.(93-116)		20,21	2	8.3
Sub-total	**2**	**11**	**13**	**11.2**
P.t. 3 x 3 m				
XVIII.(1-14)	38		1	7.1
XIX.(15-28)		34,35,36,37	4	28.6
Sub-total	**1**	**4**	**5**	**17.9**

For non-protected individuals, the damage to the trunk was typically caused by rabbits that usually chewed the south side of the trunk. Where tree guards were used, there were only two cases of damage to the trunk, when the growth of the trunk led to part of the trunk becoming exposed. In all other cases, when using the tree guard, subsequent shoots were destroyed. This explains the relatively high injury rate (11.2% and 15.5%) was observed in Paulownia varieties 1 and 2 in 2016.

The high incidence of damage in Paulownia varieties 1 and 2 may be a result of trunk damage in previous years and the strong tillering habit of the varieties. Lower than average temperatures in the winter and very high higher precipitation may also have contributed. On the damaged trunks, the subsequent shoots usually grew to a height of 1-2 m. The lower shoots (located at 1-1.5 m high) were affected by game, and destroyed in the upper third.

The map of damages showed that the wildlife has primarily affected trees along the northern and southern edges of the area, where due to the differences in local soil and groundwater conditions (see Table 3 "Soil type / Comment") and because of the events of the previous year's damages, trees were less developed than in the middle lane of the area. There was no damage in the Forester-EW treated area, compared to the untreated control area beside it (yellow-lined in Figure 1), where the proportion of trees damaged was particularly high.

The low proportion of trees which suffered trunk damage, when treated with repellent paste, suggests that the treatment was effective. The rare signs of chewing might be due to the incompletely dyed paste. The high proportion of chewed shoots could be due to the extensive tillering after the 2015 treatment when the trees were left unprotected. The results suggest that Forester EW was the most effective treatment, since neither the trunk nor subsequent shoots were damaged by game. The results from Experiment 3 (Tables 4 and 5) also suggest that the trunk of older trees (with a minimum of 5-10 cm in diameter) may also be affected during cold winter with continuous snow cover when the animals cannot find any other food.

5.5 Alternative methods of weed control

5.5.1 Bio-mulching and weed cover in tree rows

The mulch showed good weed control:

- the bio-mulch suppressed weeds for about 60 days and reduced the need for two weed-cuts during the growing season;
- the percentage of weed cover in treated rows was 25% less than the non-covered rows by the end of the second month
- the number of weed species and their density decreased significantly

The thickness of bio-mulch layer is crucial. It is recommended that it is minimum 10 cm and that using material harvested close to tree rows is the most cost-effective approach.

Figure 11. Change of weed pattern in tree rows in relation to time (1-2-3) and control rows without bio-mulching (4).

5.5.2 Bio-mulching and tree development

There was a significant difference in tree diameter growth for rows covered with bio-mulch (alfalfa and weed), compared to non-covered rows (Figure 12). The bio-mulch provided effective weed control with one treatment per year, applied at the beginning of the off-season. This is probably explained by the mulch having a beneficial effect on soil water balance and nutrient status.

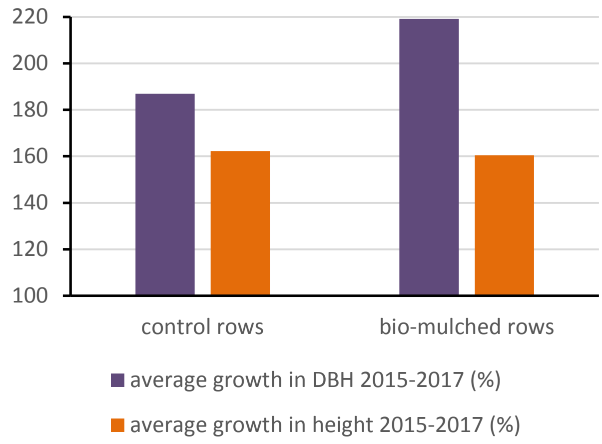


Figure 12. Bio-mulching resulted in differences in tree growth rate

5.5.3 Economic impact

The overall balance between costs and savings of the two methods (chemical treatment & mechanical treatment vs bio-mulching) was similar (Figure 13). However the bio-mulch is likely to have a more positive environment impact because of the improved microclimate and soil fertility; better tree development; reduced chemical stress and soil erosion, and the lower external costs of chemical or mechanical treatment.

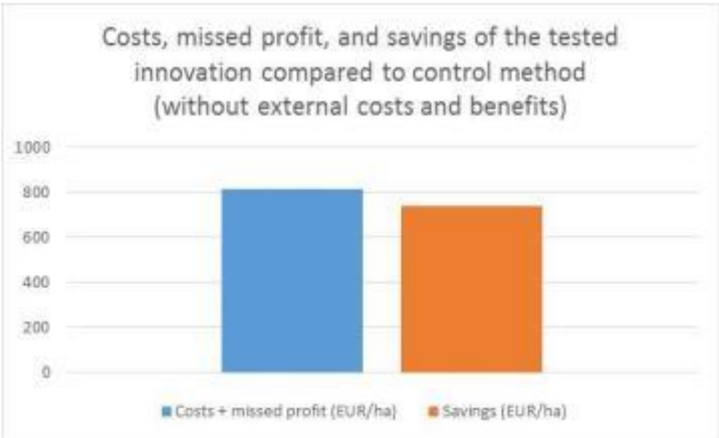


Figure 13. Additional costs and savings of bio-mulching compared to the control method

5.5.4 Early stage results of the use of herbaceous plants to reduce weed cover in tree rows

Due to the high fertility of tree rows with weeds, the planted aromatic shrubs were underperforming, providing no weed suppression effect in their first two years (2016 and 2017). However, the mortality rate was low in both years (5%), and assuming the same rate of development and the same tree row management, aromatic plants might provide a more or less continuous cover within the next two years. Though the labour time and cost was high in the first years, it is expected that they would reduce near to zero after the closure of aromatic shrub vegetation.

6 Main lessons learnt

The principal lessons learnt from the measurements and observations in the alley cropping system:

- Greater tree heights in the agroforestry plot, compared to the tree plantation, might suggest that the intercrop (whose height exceeded tree heights in the first year) has a positive effect on tree development in early stage of the plantation.
- Higher crop yields in the agroforestry plot, compared to the control area, suggests that the higher soil moisture in the agroforestry area had a positive effect on the yield of alfalfa.
- From an age of two years, the trees affected the soil moisture and temperature regime. They reduced the mean soil temperature, the variation in temperature, and the frequency of temperature extremes. They also helped to preserve soil moisture in the upper 20-30 cm layer whilst causing a decrease in the layers below 30 cm.
- During hot and dry periods, surface soil water conditions were more favourable for plant growth in the agroforestry system. The results of the measurements showed that the presence of trees reduced significantly soil temperature variability in the upper 10 cm layer.
- The above results suggest that the use of trees in alley cropping can improve soil moisture for shallow-rooted crops (e.g. cereals and vegetables) and also reduce the extreme changes in soil temperature during periods of drought, associated with high temperatures or in extreme cold weather conditions.
- Integration of trees resulted in higher soil phosphorus and potassium contents compared to the control plot
- Using herbaceous biomass for weed control was technically successful and economically viable. Furthermore, improved water use efficiency may be possible due to reduced soil evaporation within the tree rows. Mulching is suitable for both organic and conventional systems.
- A two-year experiment on alternative tree protection suggest that the methods tested are effectively applicable for protecting the woods that are not protected with a fence and tree guards. The tested methods were also suitable for organic systems.

7 Acknowledgements

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Appendix A: Soil moisture and temperature

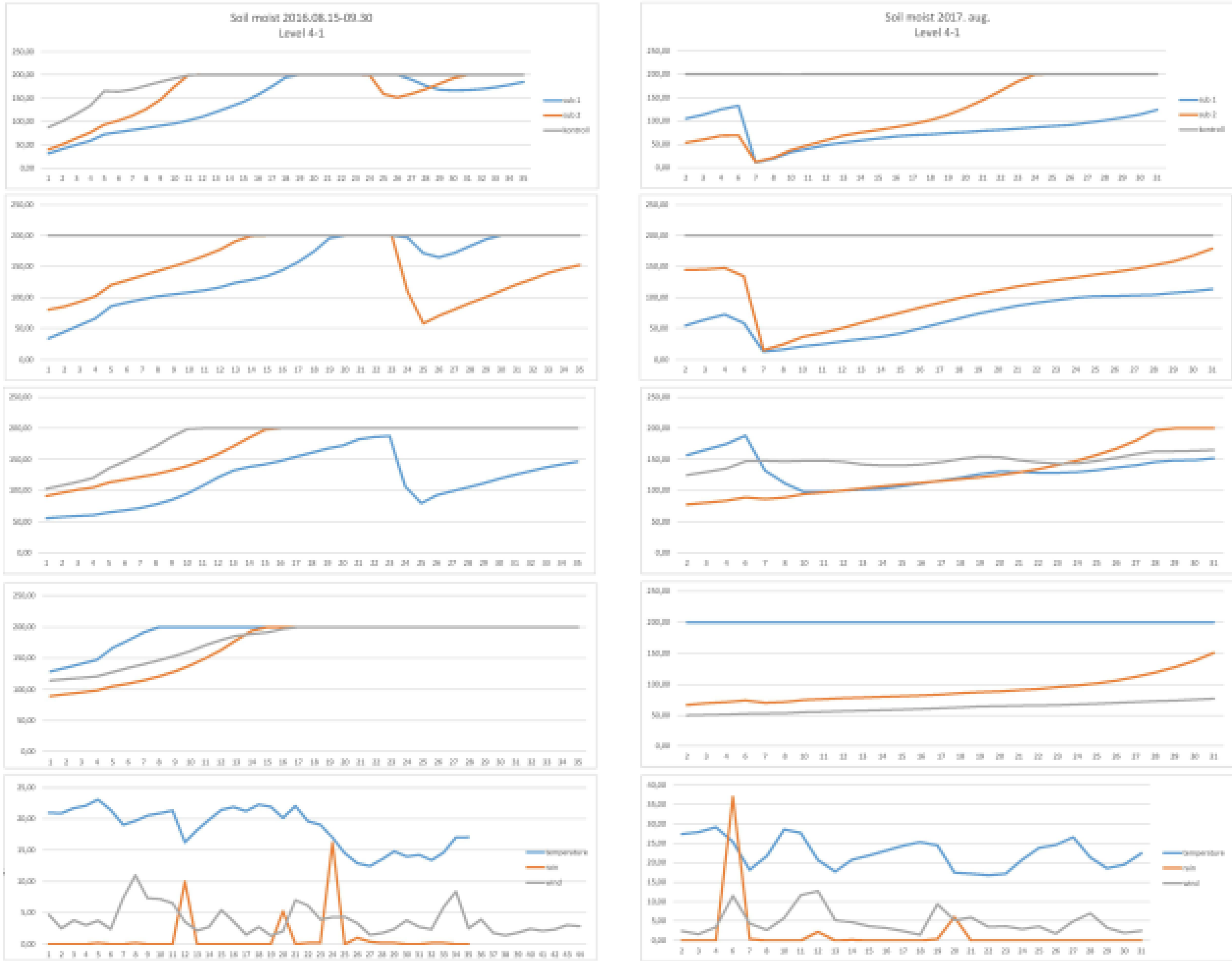

Figure 14. Soil moisture during dry periods of the 2016 and 2017 growing seasons (top to bottom: at 10, 20, 40 and 60 cm depth)

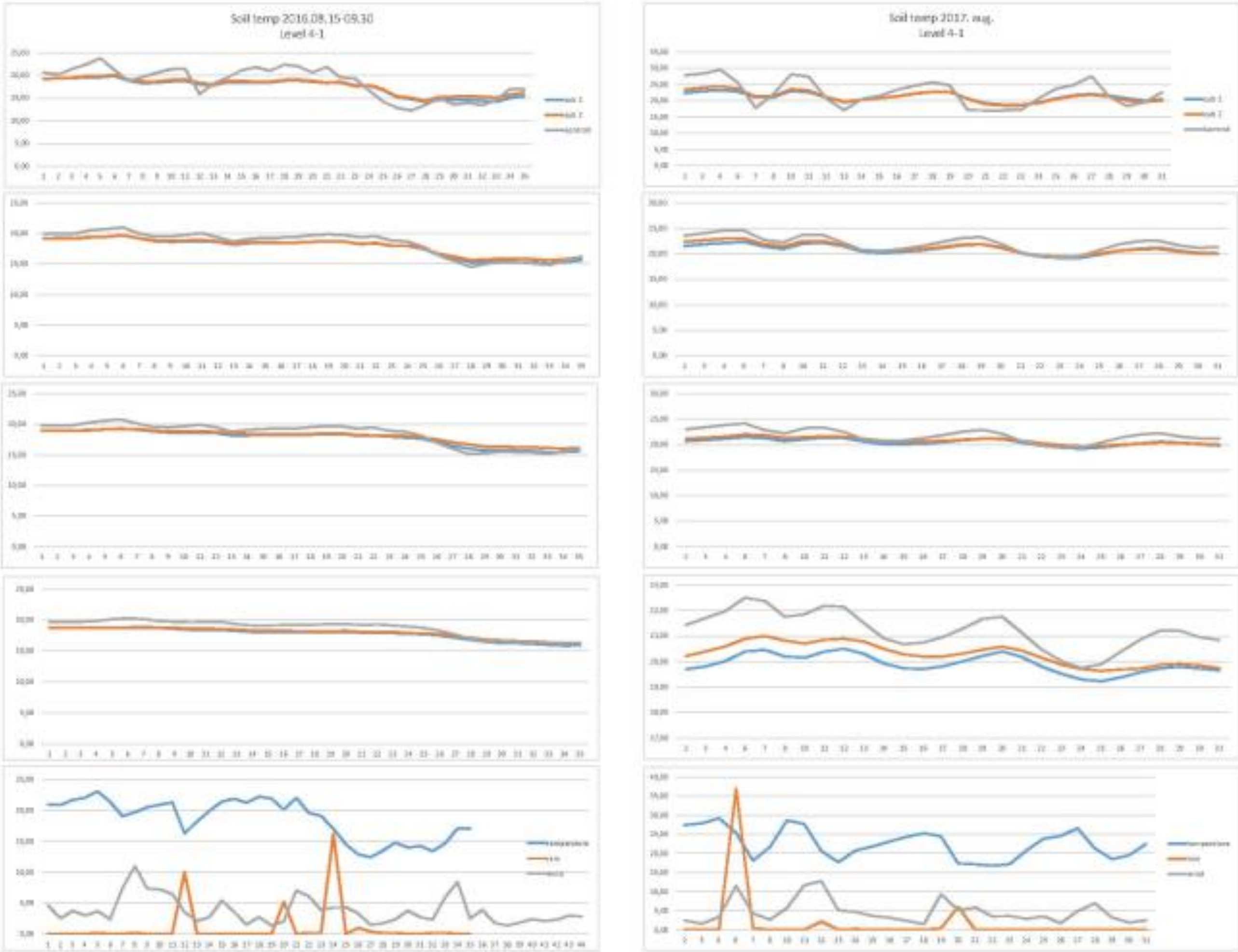

Figure 15. Changes in soil temperature in the drought periods of growing seasons of 2016 and 2017 (top to bottom: at 10, 20, 40 and 60 cm depth)