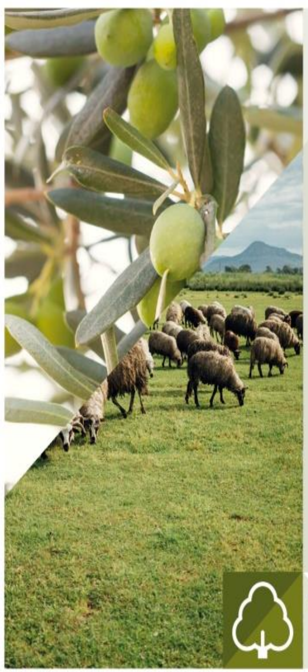

Module 1 – Agroforestry for Oliviculture
Course 4 – Success Stories

Chapter 1 –Examples of the successful use of agroforestry in olive orchards

By Nidale El Hachem, Eng. & Michel Frem, PhD
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Success Stories: Examples of the successful use of agroforestry in olive orchards

Photo credit: Dr. Peter Moubarak

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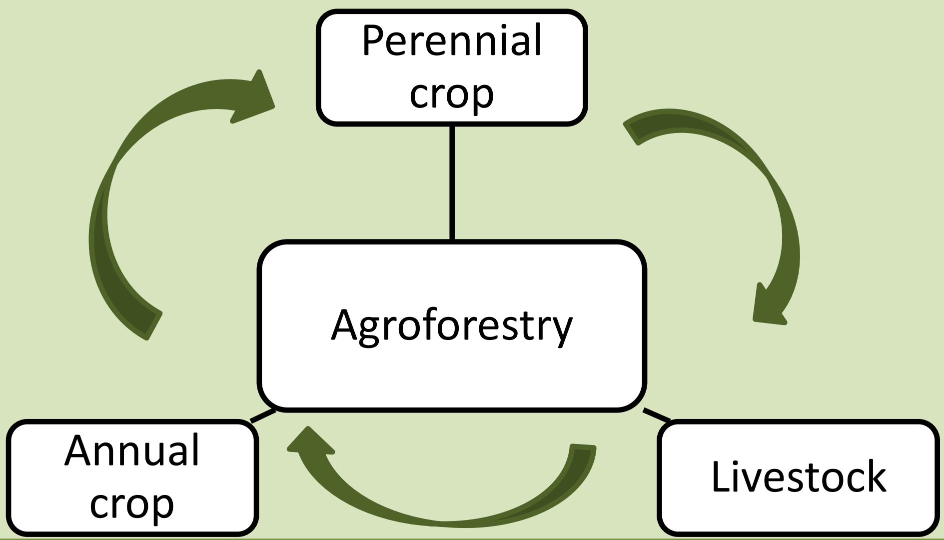
What is agroforestry?

Traditional and natural innovation



Agroforestry Benefits

- Biodiversity preservation
- Carbon sequestration
- Moderation of the effects of climate change
- Product diversification
- Land profitability
- Livestock integration
- Erosion control

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Agroforestry Extent

EU 27 15.4 m ha (LIVINGAGRO,2020)

Worldwide 1,023 m ha (FAO,2000)

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Outline
Olive-based agroforestry success stories

1- Optimal distance between olive trees and annual crops in a rainfed intercropping system in northern Morocco

2- Feasibility of growing arable crops in olive groves

3- Productivity of agroforestry systems for sustainable production of food products

4- Leguminous cover crops improve the profitability and the sustainability of rainfed olive (*Olea europaea* L.) orchards: from soil biology to physiology of yield determination

Greece | EURAFeuropeanagroforestry.eu

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Outline
Olive-based agroforestry success stories

5- Grass intake and meat oxidative status of geese reared in three different agroforestry systems

6- Life Cycle Assessment of olive cultivation in Italy: comparison of three management systems

7- Assessing the sustainability of different poultry production systems: a multicriteria approach

Greece | EURAFeuropeanagroforestry.eu

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Case Study 1: Optimal distance between olive trees and annual crops in a rainfed intercropping system in northern Morocco

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Structure of olive agroforestry systems

System	Temporal arrangenent	Tree spacing	Tree density	Tree height & diameter	Tree age
Intercropping in olive orchard	Intercropping in fall –spring with fababean	10x10	100 trees/ha	7 m 4 m	Over 30 years
Intercropping in olive orchard	Intercropping in spring with coriander	10x10	100 trees/ha	7 m 4 m	Over 30 years

Table 1

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Experimental Plan

Distance	Annual crop		
	Wheat	Faba bean	Coriander
	(T1)	(T1)	(T1)
	(T2)	(T2)	(T2)
Time of sowing	November	November	February
Time of harvesting	Mid June	End March	Mid April

T1: Below the canopy close to trunk; T2: From the limit of the olive canopy

Table 2

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Measurements of olive trees

- Annual shoot elongation
- Leaf area
- Yield level

Photo credit: Dr. Peter Moubarak

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Measurements of annual crops

- Plant height
- Biomass
- Yield

Photo credit: Faten Dandachi

Performed below the olive tree canopy and at different distances from the canopy edge: 0 m, 1.5 m and 3 m

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The effects of annual crops on olive trees

	Olive associated with wheat	Olive associated with Faba bean	Olive associated with coriander
Olive shoot length growth	Reduced by 40% in T1 and 20% in T2	Improved by 30% in T1 and 12% in T2	Neither depressive Nor positive effects
Leaf area	Reduced by 20% in T1 and T2	Improved leaf area by 22% especially in T1	
Olive yield	Reduced by 30% especially in T1	Improved by 40% in T1 and 12% in T2	

Table 3

Biomass and yield of annual crops

- The annual crops' biomass was reduced beneath the olive tree canopy in response to the shading effect.
- Below the tree canopy, the crops were practically unproductive. Crops started to produce around the edge of the tree canopy.
- Their yield level became normal and interesting at the distances indicated in Table 4.

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Table 4 shows **the optimal location where annual crops should be planted** to produce a satisfactory biomass (amount of crops) in an intercropping system with olive trees, depending on the olive grove's exposure to the sun (Razouk *et al.*, 2016)

Olive orchard exposure	Distances at which disappears the shading effect on annual crop biomass
North/ south	2.1 m from the tree canopy edge on the east side From the edge of the tree canopy on the west side
East/ west	2.1 m from the tree canopy edge on the north side From the edge of the tree canopy on the south side
North-east/ South- west	from the tree canopy edge on both sides of the tree rows
North- west/ south-east	3 m from the tree canopy edge on both sides of the tree rows

Table 4

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Wheat yield according to distance from olive trees

- At the edge of the olive tree canopy, shading induced a 70% reduction in wheat yield and a 10% decrease in grain weight.
- 1,5 m from the olive tree canopy edge, the wheat yield was considerable, but significantly lower than the yield observed **2.1 m or more from the olive tree canopy, the distance where the effect of shading on crop biomass disappeared.**

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Recap

- Since faba beans and coriander were sown and harvested during olive trees' dormant period, the reduction observed in their growth and yield in the area around the tree canopy is related to the shading effect.
- The reduction in wheat growth and yield is also explained by its competition with olive trees for nutrients and water, since its growth cycle overlapped with that of the trees.

Conclusions

- **Efficient management of an olive agroforestry system requires judicious decisions about the distance between trees and crops, which will vary depending on the intercropped species, the exposure of the tree rows, and the trees' vigor.**
- **For sowing faba beans and coriander, the optimal distance starts at the point where the shading effect becomes insignicant**, which varies according to tree height.
- In the shaded areas around trees, faba beans and coriander do not affect the growth and yield of olive trees, but their yields are low, with small products whose use may be limited to animal feed.

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Conclusions

- **For sowing wheat, the optimal distance relates to not only the trees' shade, but also the competition for soil moisture and nutrients.**
- The distance at which the interactions between wheat and olive trees becomes insignificant depends mainly on the areas explored by olive roots, which is often related to tree height.
- When olive trees are 7 m tall, this distance is 2.1 m outside the tree canopy. Sowing wheat at a smaller distance from the olive tree canopy induces considerable reduction in growth and yield for both crops.

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Case Study 2: The feasibility of growing arable crops in olive groves

The olive orchard is located at the INRA DIASCOPE station in Mauguio, France

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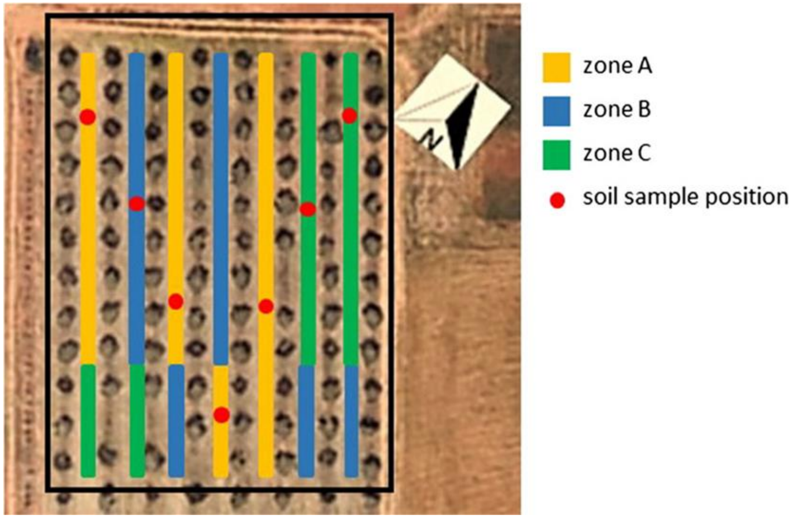
Experimental layout



Variety	Tree spacing	Tree height	Tree age
(cv. Picholine)	6m x 6m	3.4 m	12 yrs

SC durum wheat

Fig. 9a: Zones A and B: agroforestry treatment (AF) (see fig.10. Red points indicate the position of the soil samples for nutrient analysis. Zone C = Olive control (natural grass cover)

Panozzo *et al.,* 2019

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Experimental layout 2014-2017

Orchard zones	Management of the inter-row			Treatment
	2014-2015	2015-2016	2016-2017	
Zone A	Durum Wheat	Legumes	Durum wheat	Agroforestry
Zone B	Legumes*	Durum Wheat	Legumes	Agroforestry
Zone C	Natural grass cover	Natural grass cover	Natural grass cover	Olive control

Details of rotation management in the three inter-row zones of the orchard during the 3 growing seasons of the experiment (2014–2017) (Panozzzo *et al.,* 2019)

*Chickpea, faba bean and forage mixtures which varied from one year to another

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Measurements Taken

- ❑ Soil:
- ✓ The nitrogen available in the orchard's soil, measured over the period 2015–2017

- ❑ Olive tree:
- ✓ Weight of all the olives
- ✓ Weight of 100 counted olives

- ❑ Durum wheat:
- ✓ Gross weight of grains
- ✓ Moisture of grains
- ✓ Net weight of grains

Photo credit: Dr. Peter Moubarak

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Results: Olive weight as an indication of orchard productivity

Table 5: Average yield per olive tree (in kg) and average weight of 100 olives (in grams) for the period 2014–2017 for agroforestry (AF, intercropping) and the control

Treatment	Olive weight/tree (kg)	100 olives weight (g)
AF	7.6 a	405.8 a
Olive control	5.8 b	409.3 a

Panozzo *et al.*, 2019

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Results: Impact of associated crop

- ✓ **A significantly higher olive fruit production was obtained using the agroforestry treatments** (7.6 kg/tree).

- ✓ **The type of crop used for intercropping makes a difference.** In 2015 and 2016, the trees bordering the legumes reached a yield 36% and 40% higher than the trees bordering the wheat.

Panozzo *et al.,* 2019

Results: Yield & LER

Table 6: Yield of durum wheat and of olive (in tons/hectare) in the sole part (Yw and Yo respectively) and in the intercropped (Ywo and Yow) part of the design, and partial and total LER data

	Durum wheat (t/ha)			Olive (t/ha)			LER
	Yw	Ywo	Ywo/Yw	Yo	Yow	Yow/Yo	(Ywo/Yw)+ (Yow/Yo)
2015	1.1	1.2	1.09	0.5	0.8	1.43	2.42
2016	1.6	0.9	0.56	1	0.8	0.82	1.38
2017	2.3	1	0.43	2.9	4.1	1.42	1.85
Mean	1.7	1	0.62	1.5	1.9	1.29	1.81

The mean values for the 3 years of experiment and the partial LER (Ywo/Yw and Yow/Yo) for each year are highlighted in bold

Panozzo et al.,2019

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Results: Economic impact of agroforestry for farmers

- ✓ Results of the experiment showed that olive production increased by more than 25% (29%) with the agroforestry treatment.
- ✓ It can therefore be assumed that the agroforestry system would lead to an additional olive yield of 1 to 2.5 t/ha (i.e. 25% more), thus significantly increasing farmers' income, judging by the olives alone.
- ✓ An additional crop (such as wheat or legumes) can increase farmers' income even more, either through money saved on animal feed or via sale of the harvested crop.

Panozzo et al.,2019

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Results: NH4 + & NO3-

Table 7: Evolution of NH4 + and NO3- concentrations in soil mg/Kg TS, where TS = total solids) in the agroforestry treatment and in the olive control, over the period 2015–2017. The values of the three sub-samples collected at three depths in the soil (0–30; 30–60; 60–90 cm) for each sample point position were averaged

	NH4+			NO3-		
	2015	2016	2017	2015	2016	2017
Agroforestry	1.3 (a)	0.6 (a)	1.3 (a)	2.7 (a)	2.4 (a)	2.6 (a)
Olive control	1.2 (a)	0.6 (a)	1.3 (a)	2.5 (a)	1.5 (b)	1.6 (b)

For each year, means with different letters, highlighted in bold, are significantly different according to Tukey's HSD

Panozzo et al.,2019

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Results: Soil nitrogen analyses

- ✓ The highest nitrogen content was found in the first 30 centimetres. A higher concentration of nitrate (NO3-) than ammonium (NH4+) was also measured at all depths and for all 3 years
- ✓ No significant difference was observed for NH4+ between the agroforestry system and the control.
- ✓ But for NO3-, a difference was observed in 2017 (Table 7), with higher values in AF treatments, significant considering the intermediate soil horizon investigated (Hor 2: 30–60 cm depth).
- ✓ This can be due to the biological activity of the soil (not measured) and to a greater amount of soil organic matter (crop residues and tree branches were incorporated into the soil each year)

Panozzo et al.,2019

Forestas
SardegnaForeste
CIHEAM MAI CHANIA
ATM CONSULTING sas

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Results: Economic equivalent ratio

Table 8: Economic equivalent ratio arising from the olive tree additional production and from the durum wheat produced in the agroforestry system

	Durum Wheat			Olive			LER
	Wheat mono	Wheat asso	Wasso/Wmono (wo/w)	Olive mono	Olive asso	Oasso/Omono (ow/o)	(wo/w)+ (ow/o)
Yield (t/ha)	1.7	1.0	**0.6**	1.5	1.9	1.29	**1.8**
Selling price (E/ha)	663	390		750	950		
Production cost (E/ha)	260	260		544	544		
Direct profit (E/ha)	403	130	**0.3**	206	416	2.0	**2.3**

Panozzo et al.,2019

''mono'' = control treatment: open field for wheat and natural grass cover for olive; ''asso'' = AF treatment: wheat and olive intercropping
Selling price: wheat: 390 €/t (revenuagricole.fr-average 2014–2017), olive: 5 €/liter
Production cost: wheat: 260 €/ha for seeds and mechanical operations (Arvalis 2013), olive: 544 €/ha (Roblin and Le verge 2014)
Partial (wo/w and ow/o) and total economic equivalent ratios are highlighted in bold

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Conclusions

- ✓ Thanks to minimum soil tillage in the part of the orchard where agroforestry (AF) was introduced, or because of the higher fertility of the soil (higher nitrate content), **intercropping significantly increased olive production**.
- ✓ Over the 3 years of monitoring, **the olive yield in AF increased by 29%** compared to the control, leading to an **additional income ranging from 630 to 1380 €/hectare**.
- ✓ **When pruned each year, olive trees gradually increase their productivity**, and the associated **durum wheat is an additional source of income**.
- ✓ If durum wheat varieties adapted for agroforestry were provided, they could achieve higher yields when combined with olives and thus further increase the sustainability of the orchard.
- ✓ The yield reduction may vary from 8 to 80%, depending on the durum wheat variety (Desclaux 2017).

Panozzo *et al.*, 2019

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Case study 3: Productivity of Agroforestry Systems for Sustainable Production of Food Products

Location

- A silvopastoral agroforestry system in Orvieto, Italy (42°75' N, 12°17' E), in the region of Umbria.
- The area is characterized by a moderate slope about 385 m above sea level, and the soil is sandy clay loam (22% clay, 23% silt, 54% sand).
- The average temperature is 12°C, and annual precipitation is about 660 mm.

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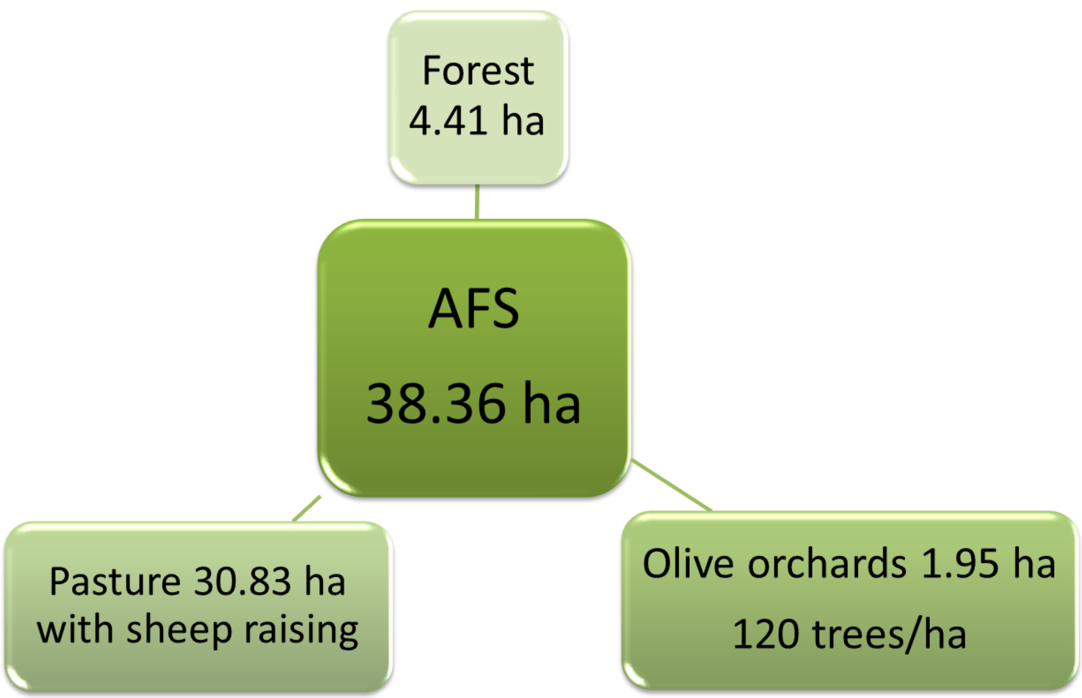
Agronomic structure of the silvopastoral system



Agronomic productivity

- The Land Equivalent Ratio (LER) is used to assess agronomic productivity.
- LER is the relative area of land required in monocrops to produce the same yield as in an intercrop or agroforestry system.
- Monoculture / LER=1, while LER >1 indicates higher productivity.

$$\text{LER} = \left(\frac{\text{crop yield in agroforestry}}{\text{crop yield in monoculture}}\right) + \frac{\text{tree yield in agroforestry}}{\text{tree yield in monoculture}}$$

Lehmann *et al.,* (2020)

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Agronomic Productivity

Table 9: Overview of partial and combined LER

Country	Year	AFS	Crop species	Tree species	Crop LER	Tree LER	Combined LER
IT	2016	Traditional silvopastoral system	Pasture for sheep production	Olive orchard	0.75	0.75	1.50

Higher agronomic productivity in AFS

- Results show enhanced yields in agroforestry systems (AFS).
- The higher productivity noted in AFS is explained by more efficient use of solar radiation, nutrients and water for enhanced land productivity compared to monoculture systems.
- AFS further provide a suite of ecosystem services which are not marketable, such as carbon sequestration, erosion prevention, shelterbelt effects, pollination, control of pests and diseases, soil formation and aesthetic value. While these services do not have a precise monetary value, they can be quite valuable in terms of maintaining the productivity of land and mitigating the adverse impact of climate change.

Case study 4: Leguminous cover crops improve the profitability and the sustainability of rainfed olive (*Olea europaea* L.) orchards: from soil biology to physiology of yield determination

The study was carried out over 4 years in a commercial orchard (cv. Cobrançosa) in Northeast Portugal.

Google.com/map

Treatments

1) Ordinary tillage techniques (OT) used by local growers (two tillage trips per year);
2) Cover crop with self-reseeding annual legume species (AL);
3) Natural vegetation fertilized (NVF) with 60 kg N hm-2 (as in OT);
4) Natural vegetation (NV) left unfertilized.

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Agronomic Productivity

- **The cover crop with self-reseeding annual legume species (AL) is the best option**, producing 37%, 53% and 95% higher cumulative yield than NVF, OT and NV, respectively, partly due to greater physiological performance during the summer. This is mainly evident in lower oxidative damage and favorable changes in water status and net photosynthetic rate.
- Moreover, the annual-legume covered soil presented considerable microbial diversity and enzymatic activities, which may **help promote and conserve soil quality and health, as well the stability of ecosystems**.
- Thus, **leguminous cover crops improve the profitability and sustainability of rainfed olive orchards**.

Case study 5: Grass intake and meat oxidative status of geese reared in three different agroforestry systems

- Location: Perugia, Italy
- Objective:

Evaluate the grass intake and the oxidative status of the meat of geese reared in three different agroforestry systems--apple orchard (AO), olive trees (OT) and vineyard (V)--in comparison to a control group of geese reared indoors (C).

Trial Description

- Trial carried out from April to August 2019
- The farms in this trial were organic
- Geese reared: Romagnola geese of both sexes
- Pasture area: 1 ha of each agroforestry system
- Geese were kept in a poultry house until 20 days of age with a temperature ranging from 20 to 32°C, relative humidity from 65 to 75% and indoor density of 5 geese/m2

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Trial Description

- ✓ At 21 days of age: access to pasture
- ✓ Feed: organic diet
- ✓ At 150 days: all geese are slaughtered
- ✓ Feed was withdrawn 12 hours before slaughtering

Photo credit: Dr. Peter Moubarak

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Measurements

- ✓ Grass intake estimation
- ✓ Fatty acid profile
- ✓ Antioxidant content
- ✓ Oxidative status

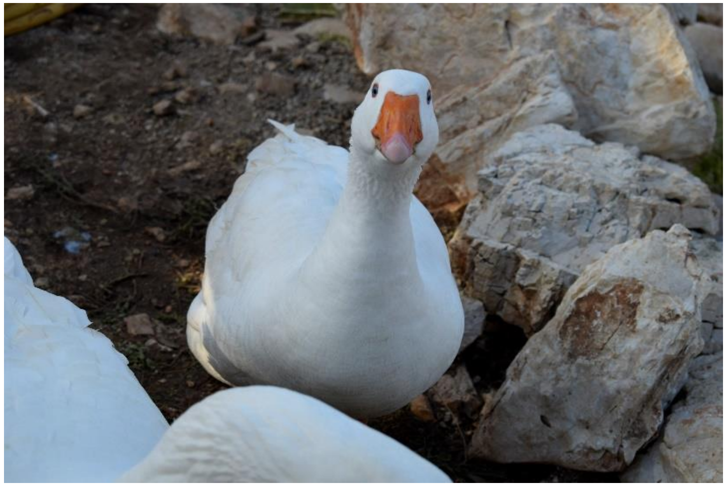

Photo credit: Dr. Peter Moubarak

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Grass intake

Grass intake was estimated by applying the modified method of Lantinga *et al.* (2004), using the following equation:

$$\text{Grass intake} = (GMs - GMe) + \{[1 - (GMe/GMs)]/ - \ln[GMe/GMs]\} \times (Gmu - GMs),$$

where GMs is the herbage mass present when the birds entered each pen; GMe is the forage that remained at the end of the trial; and Gmu is the undisturbed forage mass from the exclusion. The geese belonging to the control group (C) were always reared indoors.

Mancinelli *et al.,* 2020

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Results: Grass Intake

The estimation of grass intake showed that the geese in the apple and olive orchards ingested a higher quantity of grass than the group in the vineyard.

Photo credit: Dr. Peter Moubarak

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Discussion

- The geese in the vineyard group (V) had a lower grass intake than the other agroforestry groups; accordingly, they showed a lower concentration of n-3 PUFA, tocopherols and antioxidants compared to geese bred in the apple and olive orchards (AO and OT groups).

- This could be explained by the lower presence of grass in the vineyard and the presence of trees in the orchards that make animals feel protected from predators and provide more shade in the hottest hours of the day.

- With this environmental enrichment, animals are more stimulated to explore pasture and consequently to ingest grass.

Conclusions

- This study showed that geese, with their high grazing aptitude and limited environmental needs, are suitable for rearing in agroforestry systems.
- The presence of pasture increased the n-3 PUFA (table 10), tocopherols and antioxidant content in the meat of geese, especially in those reared in agroforestry systems with trees.
- In particular, the n-6/n-3 ratio (table 10) was more balanced and very close to the recommendation for the human diet.

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Conclusions

- Further studies are needed regarding the oxidative status of meat in order to better understand how to counteract the oxidative mechanisms triggered by the locomotory activity connected with the grazing activity.

- It would probably be necessary to supplement the diet of grazing animals with further complex antioxidants such as vitamin E, vitamin C, and polyphenols.

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Case study 6: Life Cycle Assessment of olive cultivation in Italy: comparison of three management systems

- Location:

Orvieto, in the Umbria region in central Italy

- Objective:

Evaluate the potential environmental life-cycle impacts of olives produced in three management systems of olive trees integrated with natural grassland

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Traits of the three farms involved in the study

	Silvopastoral (+sheep)	Organic	Traditional
Area (ha)	1	4.5	8.5
Age	60	40	36
Density (trees/ha)	135	200	529
Yield (t)	3.64	2.2	7.05
Fertilization	Fresh & dry sheep manure	4 tons of cow manure/ha	Pruning remains & olive pomace
Irrigation	no	no	yes

Table 12

Borzęcka *et al.,* 2018

Estimated on-field emissions caused by fertilization and irrigation

Agricultural practice	On field emissions	methodology	Unit/ha/yr	silvopastoral	organic	traditional
Fertilization	Dinitrogen monoxideN_2O	EEA/EMEP (2013)	kg	0	0.0005	0.00031
	Carbon dioxide CO_2	WFLDB-Guidelines	kg	0	0	0.03118
	Ammonia NH_3	EEA/EMEP (2013)	kg	0.00892	0	0.00103
	Nitric oxide	EEA/EMEP (2013)	kg	0.01235	0.0342	0.00024
Irrigation	water	WFLDB-Guidelines	m^3	0	0	0.14

Table 13

Borzęcka *et al.,* 2018

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Environmental impact of different olive cultivation systems

Impact category	Unit	silvopastoral	organic	traditional	average Italian system
Global warming (GWP100a)	kg CO_2 eq	0.1664	0.2658	0.6546	0.3882
Acidification	kg SO_2 eq	0.0215	0.0178	0.0070	0.0076
Eutrophication	kg PO_4 eq	0.0050	0.0048	0.0023	0.0041

Table 14

Borzęcka *et al.,* 2018

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Conclusions

- This study used life cycle assessment methodology to compare three small farms with different farming systems (silvopastoral, organic and traditional).
- The impact categories most closely related to agriculture were assessed: global warming potential, acidification and eutrophication.
- All the farms used a small amount of fertilizers and chemicals, and no pesticides.
- Fertilization had the highest environmental impact, followed by machinery use.
- The silvopastoral system appears to be the most promising one due to the minimal organic fertilizer application.

Case study 7: Assessing the sustainability of different poultry production systems: a multicriteria approach

Objective:

Compare the global impact of intensive, free-range, and free-range combined (with an olive orchard) systems, according to a sustainability approach which includes environmental, economic and social criteria

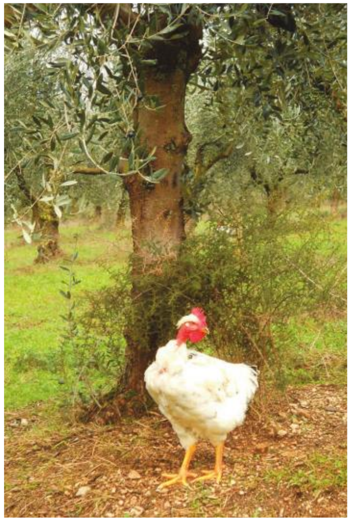

Photo credit: Rosati

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Systems' traits

Characteristics	Intensive	Free-range	Combined
Genetic strain used	Fast-growing	Slow- growing	Slow- growing
Total birds per cycle (N)	1000	1000	1000
Cycles of production (n/year)	6.4	3.0	3.0
Building area(m^2)	80	-	-
Density (birds/m^2)	12.69	0.1	0.1
Pasture area (ha)	-	1	1
Feed conversion*	1.9	3.3	3.3
Final live weight (kg)	2.6	2.8	2.8
Meat produced (t/year)	16.6	8.4	8.4

Table 15: Characteristics of the poultry systems analyzed

Rocchi *et al.,* (2018)

Methodology

i) Analysis and data collection for three different poultry systems (intensive, free-range and free-range combined with an olive orchard)

ii) Selection of relevant environmental, social and economic criteria needed to compare the level of sustainability of the three systems

iii) Application of a multicriteria method to achieve a final ranking, including a standardization and weighing procedure, in relation to three different panels of stakeholders: farmers, consumers and scientists

iv) Use of the Life Cycle Assessment (LCA) approach and a biodiversity index to address environmental criteria

Rocchi *et al.,* (2018)

Definition of the goal and scope of the Life Cycle Assessment study

- The Life Cycle Assessment (LCA) method enables the environmental implications of a product, process, or service to be analyzed throughout the stages in its life cycle, via the quantification of the use of the resources (energy, raw materials, water) and of the emissions into the environment (emissions into the air, water and soil, plus waste) and co-products associated with the system under evaluation.

Rocchi *et al.,* (2018)

Phases analyzed in the Life Cycle Assessment study

The main phases analyzed in the LCA studies went from the production of the initial necessary inputs (cultivation of the main feed ingredients) to the rearing phase (production of poultry), including the intermediate feed manufacturing and transport processes, and omitting the final product distribution, which was the same for all three systems, as shown in the next slide.

Rocchi *et al.,* (2018)

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Impact assessment phase

- In order to choose the categories with the greatest environmental impact, an LCA normalization procedure was applied.

- This LCA normalization process identifies the relative significance of each category (Kim *et al.,* 2012). Climate change, respiratory inorganics, acidification/eutrophication, land use, and fossil fuels were identified as the most important categories (Table 16, next slide).

Rocchi et al., (2018)

Impact assessment phase

Impact categories	Meaning
1. Respiratory inorganics	Emissions to air, mainly of SO2 and NO, causing respiratory effects
2. Climate change	Emissions to air of hydrocarbons, carbon dioxide, methane, etc., causing global warming
3. Acidification/Eutrophication	Emissions to air and water (mainly nitrogen, ammonia, phosphorus) causing change in pH and nutrient availability
4. Land use	Occupation and transformation of land, causing effects on vascular plant species
5. Fossil fuels	Consumption of non-renewable resources

Table 16 : The meaning of five impact categories

Source: our elaboration, from Goedkoop and Spriensma (2001)

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Results: Economic Analysis

	INTENSIVE €/kg	FREE-RANGE €/kg	COMBINED €/kg
Chicks	0.17	0.13	0.13
Feed	0.59	0.86	0.86
Labor	0.07	0.03	0.03
Energy	0.04	0.02	0.02
Veterinary drugs	0.02	0.05	0.05
Other costs	0.04	0.06	0.06
Chicken capture	0.02	0.04	0.04
DIRECT COST	0.95	1.19	1.19
Depreciation	0.03	0.05	0.05
Interests	0.01	0.01	0.01
TOTAL COST	0.99	1.25	1.25
Price	1.20	1.56	1.56
Avoided costs in the orchard	0	0	0.07
NET INCOME PER KILO	0.21	0.31	0.38

Table 18 : Economic analysis of three poultry systems

Rocchi *et al.,* (2018)

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Results : Environmental Criteria

			ALTERNATIVES		
			INTENSIVE	COMBINED	FREE-RANGE
Environmental criteria					
Respiratory inorganics	Daily	min	1.71E-03	1.38E-03	1.49E-03
Climate change	Daily	min	1.95E-04	1.51E-04	1.92E-04
Acidification/ Eutrophication	PAF*m2yr	min	2.14E+02	1.07E+02	1.11E+02
Land use	PAF*m2yr	min	1.43E+03	2.84E+03	3.45E+03
Fossil fuel	MJ surplus	min	1.03E+03	1.40E+03	1.64E+03
Biodiversity index	Index	max	3	9	8

Table 18: Environmental effects of the three systems

Rocchi *et al.*, (2018)

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Results: Environmental Criteria

Regarding environmental criteria, **the combined system was best**, considering climate change impact, acidification, respiration inorganics and the biodiversity index, thanks to the avoided impact of mowing and fertilization in the olive orchard.

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Results: Social Criteria

			ALTERNATIVES		
			INTENSIVE	COMBINED	FREE-RANGE
Social criteria					
Labour safety index	INDEX	Max	0	1	1
Moving index	%	max	15	35	30
Stocking density	Kg/m^2	min	33	0.28	0.28
Time spent outdoor	%	max	0	70	30
Breast blister	%	min	10	0	0
Severe foot pad lesions	%	min	38	5	8
Landscape	INDEX	max	0	1	0.7

Table 19: Performance of the three systems regarding social criteria

Rocchi *et al.,* (2018)

Results: Social Criteria

From a social point of view, **the intensive system was the worst**, while **the combined system had the best performance**, followed closely by the free-range system.

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Results: Economic Criteria

			ALTERNATIVES		
			INTENSIVE	COMBINED	FREE-RANGE
ECONOMIC CRITERIA					
Net income per kilo	€	Max	0.21	0.38	0.31
Feed conversion	kg feed/kg	mix	1.9	3.3	3.3
Mortality rate	%	min	4	7	7
Tenderness	kg/kg breast	max	1.1	1.9	1.9
Fat content	f.m. (%)	min	1	0.5	0.5
n-3 fatty acids	n-3 % total f.a.	max	1.5	3.1	2.8

Table 20: Performance of the three systems in terms of economic criteria

Rocchi *et al.,* (2018)

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Results: Economic performance

From an economic perspective, the intensive system performed best in terms of feed conversion and mortality rate, while the combined and free-range systems were equally good for tenderness and fat content. The combined system performed best in terms of n-3 fatty acids and net income.

Conclusions

- Combining chickens and olive orchards appeared to bring about **reductions in the environmental impact** of both systems.
- More specifically, using the orchard for grazing reduced the land use relative to the free-range chickens, while **the birds fertilized and weeded the orchard**, thus reducing the orchard's impact to almost nothing, except for the land use.
- Other benefits included the possible **contribution of grazing to the chickens' diet** (thus reducing consumption of purchased feed) and the **positive effect of trees on animal welfare** and grazing activity, and therefore on meat quality and yield.

Conclusions

- Further studies with a **broader approach to sustainability** might contribute to a better assessment of these effects.
- These results were obtained with a focus on the particular case of olives and chickens, but they can easily be extended to **other tree-animal combinations**.
- In fact, when using more strictly herbivorous species (e.g. sheep), **grazing can actually contribute even more** to the animals' feed requirements, allowing for even greater environmental benefits.

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Thanks for your attention.

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