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Agroecology and herbivore farming systems – principles and practices

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Abstract. To achieve the sustainability goals of future agriculture, agroecology was often mentioned and discussed in the last decade. Surprisingly, the very large majority of publications on agroecology are related to cropping systems and different issues of plant production, whereas only rare publications are related so far to livestock systems and animal production. In this paper we analyse this relation between agroecology and herbivore farming systems by defining six groups of principles and seven categories of agroecological practices. The principles we propose for agroecological herbivore farming systems can be classified into (i) knowledge, culture and socio-economics, (ii) biodiversity conservation and management, (iii) resource management, (iv) system management, (v) food and health, and (vi) social relations. The agroecological practices which could or should be implemented to establish sustainable herbivore farming systems can be grouped into (i) diversification of land use, land cover and productions, (ii) resource management in mixed crop-livestock systems, (iii) biodiversity conservation, (iv) grassland management, (v) livestock management, (vi) food and food system, (vii) diversification of income sources. These underlying groups of principles and categories of practices should be considered for the development of sustainable agricultural herbivore farming systems.

Keywords. Agroecological practices – Agroecological principles – Cattle management – Biodiversity conservation – Diversification – Grassland management – Ruminant livestock systems – Sustainable animal production.

Agroécologie et systèmes d'élevage de ruminants. Principes et pratiques

Résumé. *L'agroécologie est souvent mentionnée et analysée dans le cadre du développement et de la mise en œuvre de l'agriculture durable du futur. Etonnamment, la majorité des publications sur l'agroécologie sont en rapport avec des systèmes de culture et différents aspects de production végétale, tandis que peu de publications abordent jusqu'à présent les systèmes d'élevage et la production animale. Dans cet article, nous analysons cette relation entre l'agroécologie et les systèmes d'élevage d'herbivores en définissant six groupes de principes et sept catégories de pratiques agroécologiques. Les principes que nous proposons pour les systèmes d'élevage en agroécologie peuvent être classés dans les groupes suivantes : (i) connaissances, aspects culturels et socio-économiques, (ii) conservation et gestion de la biodiversité, (iii) gestion des ressources, (iv) gestion des systèmes, (v) alimentation et santé, et (vi) relations sociales. Les pratiques agroécologiques qui devraient ou pourraient être mises en œuvre pour établir des systèmes d'élevage durable peuvent être groupés dans les catégories suivants : (i) diversification de l'utilisation et la couverture du sol et des productions, (ii) gestion des ressources dans les systèmes mixtes bétail-culture, (iii) conservation et gestion de la biodiversité, (iv) gestion des prairies, (v) gestion du bétail, (vi) alimentation et système alimentaire, et (vii) diversification des sources de revenu. Ces groupes de principes et catégories de pratiques devraient être pris en compte pour le développement de systèmes agricoles durables comprenant des herbivores.*

Mots-clés. *Conservation de la biodiversité – Gestion des praires et pâturages – Gestion du bétail – Diversification – Pratiques agroécologiques – Principes agroécologiques – Production animale durable – Systèmes d'élevage de ruminants.*

I – Introduction

It is highly desirable that sustainable farming systems are established in all parts of the world. This type of agriculture should produce sufficient quality food, be economically beneficial for farmers, be socially fair, conserve (agro)biodiversity, and not harm the environment. Livestock is an important part to this puzzle, also because livestock is the largest land use sector on Earth (Herrero and Thornton, 2013). Moreover, livestock is a major player in global environmental issues (FAO 2006). To achieve the sustainability goals of future agriculture, agroecology was often mentioned and discussed in the last decade. Although different concepts and interpretations are present among the different stakeholders dealing with agroecology, the main interpretations of agroecology are that it is a scientific discipline, a practice, or a movement (Wezel *et al.,* 2009). Within agroecology as a science a major approach is to apply ecological concepts and principles to the design and management of sustainable farming systems, agroecosystems, and food systems (Altieri 1995, Gliessman 1997, Francis *et al.,* 2003, Gliessman 2007). The current scales of application for research are the plot/field scale, the farm/agroecosystem scale, and the food system scale (Wezel and Soldat, 2009). When dealing with agroecological practices the scale of application is mostly the plot/field scale, but for certain practices such as integration of landscape elements on farms or in landscapes the scale can be larger (Wezel *et al.,* 2014). The movement of agroecology appears more with the agroecosystem scale (for environmentalism and rural development movements in agroecology) and at the food system scale for different political and social movements within agroecology (Wezel *et al.,* 2009, Altieri and Toledo 2011, Rosset and Martínez-Torres 2012, Gonzalez de Molina 2013, Sevilla Guzmán and Woodgate 2013). Surprisingly, the very large majority of publications on agroecology are related to cropping systems and different issues of plant production, whereas only rare publications address so far to livestock systems and animal production.

Gómez *et al.* (2013) found in their analysis of 115 original (empirical) agroecology papers including the word 'agroecological' in the title that only seven were related to livestock and livestock system. These publications deal with diseases and fertility of cattle, milk production, and productivity and management of pastures. Wezel and Soldat (2009) mention 28 out of 711 publications on agroecology that used the word 'livestock' in the title, with a broad variety of topics related to livestock and livestock systems.

Whereas agroecological practices for cropping systems have been described and defined in various publications (e.g. Arrignon 1987, Altieri 1995, 2002, Gliessman 1997, Wojtkowski 2006, Wezel *et al.,* 2014), this is only found in very few publications for the case for agroecological practices in livestock system, as well as for agroecological principles. Gliessman (2007) integrated a chapter about animals in agroecosystems in his book, but did not explicitly describe or define principles or practices for agroecological livestock systems. It is only recently that Dumont *et al.* (2013) defined five groups of agroecological principles, but they do not explicitly define agroecological practices. Bonaudo *et al.* (in press) analysed more specifically agroecological principles that can help farmers to redesign and improve integrated crop-livestock systems. They also defined agroecological practices for crops, crop-livestock integration, and livestock.

In this paper we explore the link between agroecology and herbivore farming systems with ruminants. We propose different groups of agroecological principles which in our opinion should be the basic rules to be followed for agroecological herbivore production systems. We will also describe agroecological practices in herbivore farming systems and group them in different categories. In our understanding, agroecological practices are agricultural practices aiming to produce significant amounts of food, which valorise in the best way ecological processes and ecosystem services in integrating them as fundamental elements in the development of the practices.

II – Agroecological principles

Although livestock systems over the world can considerably vary from extensive to intensive systems, from pasture-based to in-stable (factory farming) systems, from one breed to mixed breeds or multiple species systems, from specialised to mixed crop-livestock systems, they have the common primary objective to produce optimal quantities of meat, milk, or fibre in relation to resource inputs. Nevertheless, the underlying principles to attain this objective can be quite contrasting, e.g. feeding the animals with only grass fodder produced on the farm to almost complete concentrates feeding from imported maize, soybean or other resources. But what are or should be the principles of agroecological livestock systems?

In the following paragraphs, we list and discuss different principles of agroecological herbivore farming systems which we consider as relevant, also reflecting the basic principles of agroecology by having a system approach, considering simultaneously multiple scales, and having multi-stakeholder involvement when developing agroecological systems (Wezel and David 2012). Agroecology is inspired by the biomimicry principle (Benyus, 1997); it tries to adopt the principles of nature functioning such as diversity at all scales, nutrient cycling, permanent soil cover and self-regulation processes. In contrast with the Green Revolution and other strong commercial oriented input based systems, it does not rely on massive use of fossil fuel but it is ecosystem-based: it aims to restore ecosystems and to rely on ecosystem services provided by different types of biodiversity present in agroecosystems (Peeters *et al.,* 2013). The principles we propose for agroecological herbivore farming systems with ruminants can be classified into six groups: (i) knowledge, culture and socio-economics of farmers, (ii) biodiversity conservation and management, (iii) resource management, (iv) system management, (v) food and health, and (vi) social relations in the society (Fig. 1).

Principles of agroecological herbivore farming systems:

Knowledge, culture, socio-economics of farmers

- Systems should be economically viable for farmers (decent income) and 'liveable' (quality of life of farmer's family).
- Systems should be 'inheritable' (could be transferred to the next generation).
- Farmers' knowledge should be combined with the most up-to-date scientific knowledge and techniques.
- Systems should be locally and culturally adapted.

Biodiversity conservation and management

- Ensuring a central place to biodiversity as the driver of the agroecosystem: e.g. multi-breeds, multi-cultivars and multi-species ecosystems, and diversity of habitats.
- Conservation of all biodiversity types (agrobiodiversity, functional and heritage biodiversity).
- Conservation and development of semi-natural landscape elements on the farm or at landscape scale (e.g. semi-natural grasslands, hedges, thickets, herbaceous field margins, ditches, ponds).

Resource management

- Optimisation of nutrient cycling, favouring organic fertilisation with on-farm produced manure or slurry and nitrogen fixing legumes.
- Guaranteeing permanent soil cover for optimal nutrient cycling, carbon storage, and soil erosion protection.

- Minimum or ideally no use of inorganic nitrogen, other chemical fertilizers, pesticides and drugs.
- Minimum irrigation water.
- Optimisation of energy use.

System management

- Design and establishment of ecosystem-based and not fossil fuel-based systems.
- Development of low commercial input systems (high commercial input systems only if not in contradiction with other agroecological principles).
- Development of diverse systems (e.g. over time, in space, land use and land cover types, plant traits, biodiversity types).
- Development of mixed crop-livestock systems if possible.
- Development of a maximum rate of self-sufficiency (protein, fodder) at farm, landscape, and regional scale.
- Creating conditions for best possible animal health.
- Priority to systems instead of individual techniques or breeds. Sustainable systems, adapted to local conditions, should be designed first and then techniques should be chosen and developed, cultivars and breeds should be adopted or bred in the perspective of these systems. Adoption of highly productive breeds often leads to modifications of the production systems that are unsustainable. Farming systems should thus not be adapted to techniques and breeds, it should be the opposite.

Food and health

- Reconciling supply and demand for food (food processing, short marketing chains).
- Production of healthy and tasty food.

Social relations in the society

- Founding human social relations on collaborations and the development of synergies instead on competition and antagonisms.

Figure 1 shows schematically that agroecological herbivore farming systems are driven by farmers and their families who take decisions on the basis of ecological, sociological and economic environments. In this process, they use their own knowledge with the support of technical and scientific information they got from advisers and diverse media. This knowledge is used for managing biodiversity as the key-component and driver of the system. Systems are designed and implemented. In advanced agroecological systems, they are managed in a way that optimize resource use and provide optimum quantity of quality food for consumers. In these systems, social relations seek to develop a new harmony in human societies.

Dumont *et al.* (2013) defined five groups of principles: (i) adopting management practices aiming to improve animal health, (ii) decreasing the inputs needed for production, (iii) decreasing pollution by optimizing the metabolic functioning of farming systems, (iv) enhancing diversity within animal production systems to strengthen their resilience and (v) preserving biological diversity in agroecosystems by adapting management practices. These groups of principles are not contradictory to ours, but they are much more specific and technical. They do not explicitly mention our three important principles that are related with the future and the role of agriculture in society: principle i) knowledge, culture, and socio-economics, principle v) food and health, and principle vi) social relations in human societies. With the food systems approach in agroecology (Francis

et al., 2003, Wezel and David 2012), these three groups of principles are also important to be considered. In contrast, Dumont *et al.* (2013) have defined one special group on animal health, which we consider under the principles of system management. Bonaudo *et al.* (in press) also deal with agroecological principles, but they focus specifically on integrated crop-livestock systems. They provide some principles which are more related to cropping systems within crop-livestock systems, but not explicitly defining the principles of the livestock system. Their major principles also are based on diversity, maximisation of ecological interactions, closing nutrient and energy cycles, optimising nutrient availability, and collective management at the landscape scale.

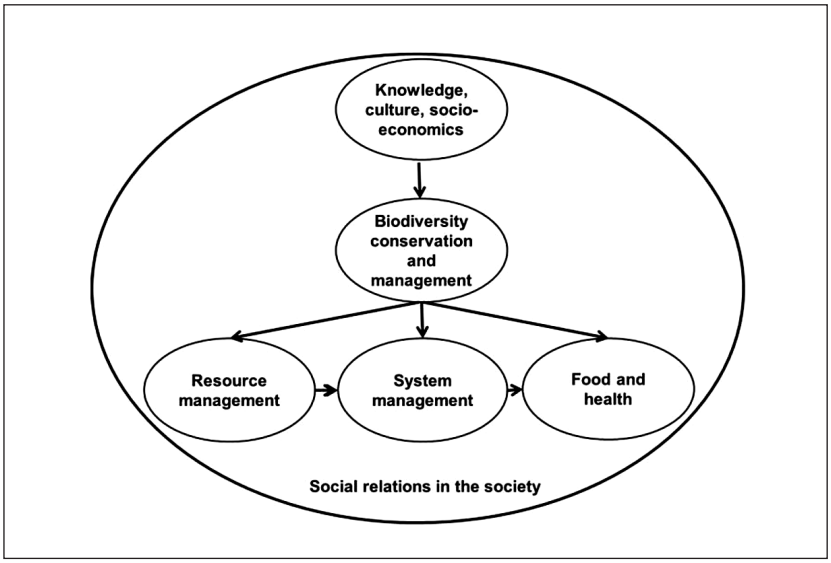

Fig. 1. The six groups of principles of agroecological herbivore farming systems.

III – Agroecological practices

If it is important to define a list of principles, the main concern for farmers is to translate them into concrete measures, practices and management. Therefore, we define here seven categories of agroecological practices which could or should be implemented to establish agroecological herbivore farming systems (Figure 2). Three categories of practices are related with land and resource management: (i) diversification of land use, land cover and productions, (ii) resource management in mixed crop-livestock systems, and (iii) biodiversity conservation. Two categories of practices are linked with technical aspects of (iv) grassland management, and (v) livestock management. The last two categories of practices (vi) food and food system and (vii) diversification of income sources are related with socio-economic aspects through the strong synergies and collaborations that exist in agroecological systems between different types of stakeholders and especially between farmers and consumers/citizens.

Diversification of land use, land cover and productions

- Increase diversity of livestock species and breeds to increase resilience of the system.
- Establish mixed livestock herds and flocks (e.g. cows, sheep, goats) whenever possible to improve resource use of different pastures and rangelands and control parasites.

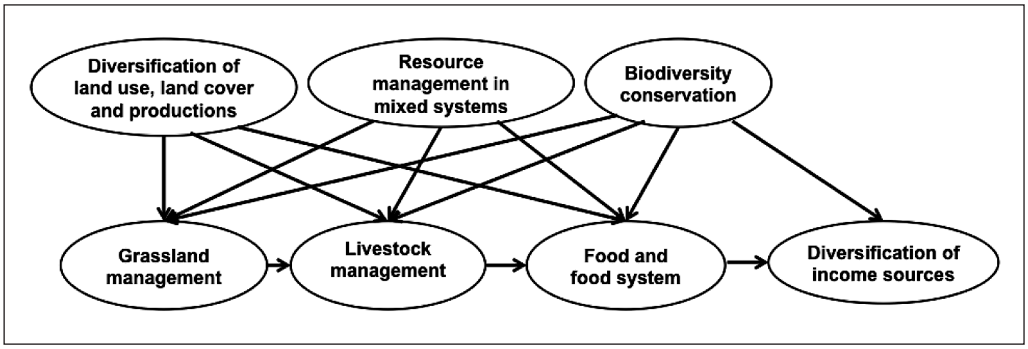

Fig. 2. The seven categories of agroecological practices related to herbivore farming systems. Arrows indicate which category of practices are strongly related to practices in other categories.

- Combination of the use of different grassland types for different types of animals: permanent/ temporary, mown, grazed, grazed/mown, intensive/extensive/semi-natural to improve resource use and decrease production costs.
- Use of semi-natural grasslands in combination with more intensive permanent and/or temporary grasslands to improve resource use in areas where semi-natural grasslands are available to maintain biodiversity and improve product quality.
- Favour high diversity of crops and long crop rotations including the integration of nitrogen-fixing legumes to improve fodder quality, reduce nutrient inputs, increase soil fertility, control weeds, disease and parasites in mixed crop-livestock systems.
- Integrate trees into the system for establishment of silvo-pastoral systems: e.g. fruit trees, trees for timber and fire wood, hedges e.g. to increase land productivity, diversify productions, provide shade to livestock, fix carbon.

Specific resource management in mixed crop-livestock systems

- Temporary grassland (ley) – crop combination for optimized weed, pest and disease control (to reduce pesticide use) and for fertility transfer from grasslands to crops.
- Large use of nitrogen fixing legumes in temporary grasslands and fodder crops (e.g. green cereal-legume mixtures) to reduce N inputs.
- Optimum management of organic matters and transfer between livestock and arable land (manure) and between arable land and livestock (litter, forage, by-products) to close the matter and nutrient cycling.
- Establish cooperation between arable farmers and livestock farmers for manure, crop residues, and forage (hay or silage) exchange to reduce energy for transport, to optimise nutrient, and matter cycling on local scales.
- Favour grass-based systems (in combination with local arable forage production) to reduce fodder imports (Figures 3 and 4).
- Orient towards self-sufficiency for fodder by using locally or regionally produced forage and feed to limit external fodder imports and reduce production costs.

Biodiversity conservation

- Use adapted stocking rates on semi-natural pastures and late or less frequent mowing on semi-natural meadows (to increase plant species richness, to improve product quality).
- Apply adapted grazing and re-use of marginal land (e.g. sheep and goat), for example in dry grasslands, open woodlands, and other types or rangelands (Figure 3 right) (to conserve biodiversity of these systems, to conserve specific species, to decrease production costs).
- Maintain or establish semi-natural landscape elements on the farm or in the landscape (Figure 3 left) (e.g. semi-natural grasslands, hedges, ponds) to increase species richness, ecosystem diversity and animal welfare.
- Conserve rare or less productive breeds to conserve genetic resources and to produce quality meat and dairy products.

Grassland management

- Large use of nitrogen fixing legumes in temporary and permanent grasslands to reduce N inputs.
- Choice of a multifunctional grazing method (e.g. rotational grazing to reduce parasites occurrence, to control weed and to increase forage quality).
- Adoption of optimum stocking rate according to seasons and grassland plot potential to maintain or improve sward quality, to avoid diseases, nitrate and phosphate pollutions and soil erosion.
- Favouring multiple species swards in grasslands for increasing yield, resilience and improving feeding quality.
- Apply reduced or no tillage techniques for temporary grasslands establishment to reduce soil erosion, to increase carbon storage, to limit nutrient leaching, to favour soil biodiversity, to promote biological activity, and to reduce energy inputs.
- Favouring tannin-rich forbs/legumes/woody species (e.g. *Taraxacum* spp., *Lotus* spp.) or essential oil-rich forbs for decreasing methane production and improving animal health (see below).

Livestock management

- Apply integrated disease and parasite control:
  - systematic use of prevention methods (e.g. rotational grazing, balanced feeding, adapted housing, hygiene, rustic breeds, mixed grazing of different livestock species).
  - when necessary disease treatment with plant extracts or essential oils (phytotherapy) to replace chemical disease treatments when possible.
  - use of tannin-rich forage species for parasite control).
- Giving priority to feed (e.g. fresh grass, hay, silage) (Figures 3 and 4) compared to food (e.g. cereal, pulses).
- Use of locally adapted breeds for maximum use of grasslands to reduce concentrate feed including commercial feed.
- Use of modern types of double-goal breeds to have both meat and milk production to limit hyper-specialization of high yielding animals while conserving good income. Hyper-specialization induces health and fertility problems, reduces animal welfare and lifetime expectation, and limits the possibilities to use green forage in animal feeding which induces its replacement by concentrates (e.g. food like cereals and soy).

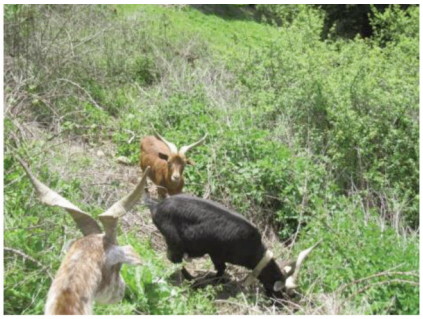

Fig. 3. Pasture-based system in mountainous areas (left), and grazing of shrub rangelands (right) in south-eastern France.

Fig. 4. Livestock systems based on alternating and combined use of pastures and meadows for fodder and feed production in southern Germany.

Food and food system

- High quality of products (nutrition, taste):
  - Adopt grass-based productions to decrease total and saturated fats, to increase omega3/omega6 fatty acid ratio and conjugated linoleic acids (CLA), in dairy and meat products.
  - Favour species-rich vegetation to improve milk quality, polyphenol content, and livestock and human health.
- Local dairy and meat product processing to reduce transport energy, and to provide local employment.
- Adoption or development of quality labels (e.g. geographical indications) and trade marks to increase selling price and income.
- Short and medium marketing chains to reduce transport costs and energy, to link to consumers and increase selling price and income.
- Cooperation, collaboration and development of synergies between farmers, between consumers/citizens and farmers (e.g. by signed agreements like those of Community-Supported Agriculture), and between consumers/citizens (e.g. urban agriculture) for increasing and stabilizing farmer's income, for improving access to quality food and decreasing food prices for consumers, for increasing contacts between cities and rural land, for improving contacts of citizens with nature and farming.

Diversification of income sources

- Product diversification to increase economic resilience of farmers, and to reduce dependence on global and national market prices, including 'minor' (niche) productions instead of large-scale productions integrated in global value chains.
- Diversification of activities (e.g. agri-tourism).

Dumont *et al.* (2013) presented and discussed also agroecological livestock practices, and provide valuable details for some practices. They also included practices of non-ruminant systems with pigs, poultry, and rabbits, or of aquaculture systems. A specific agroecological practice related to nutrient cycling, fertilisation of grasslands with vermicompost, is described by Boval *et al.* (2013). Different agroecological practices for crops, crop-livestock integration, and livestock are stated in Bonaudo *et al.* (in press). For agroecological livestock practices they mention calving periods, animal batches, the ratio permanent grassland/main fodder area, herd mixity, learning, pythosanitary practices, share of grazing in the feed, and choice of species and breeds. These practices are mainly referring to our practices categories 'grassland management', 'livestock management', and 'diversification of land use, land cover and productions'. The practices for crop-livestock integration stated by Bonaudo *et al.* (in press) are feed production, recycling by-products for feed and litter, organic fertilisation, effluent management, and gazing pressure. These practices are naturally in strong accordance with our category 'resource management in mixed crop-livestock systems', but also with our category 'grassland management'.

Grassland management is central for agroecological herbivore farming systems. Grasslands are the basis of livestock feeding systems. They ensure a high rate of forage and protein self-sufficiency, and reduce production costs compared to systems based on the use of commercial concentrates. They can contribute a lot to animal welfare and health. They play an important role in soil fertility building on the whole farm. This role is direct in the case of temporary grasslands that take part in crop rotation and increase organic and nitrogen contents of arable soils. Fertility accumulated during the temporary grassland episode is largely available for the following crops of the rotation. Green forages harvested on temporary and permanent grasslands are fed to livestock and a large part of their nutrients are found in effluents. This organic manure can then be spread on crops or grasslands which closes the cycle and increases nutrient availability for plants and yield. Perennial legumes of grasslands have a much higher biological nitrogen fixing ability than annual legumes cropped for grain such as pea or faba bean. Lucerne and red clover for instance can fix up to 300 to 400 kg N/ha annually while temperate pulses (e.g. pea and bean) fix usually less than 100 kg N/ha annually. The incorporation of forage legumes in agroecological herbivore farms is thus essential for the productivity of their production system. Grassland-based products are healthier than grain-based products for human health. Compared with grain-fed beef or milk, grass-fed beef or milk are for example lower in total fat, lower in saturated fatty acids, linked with coronary heart diseases, higher in total omega-3 and higher in conjugated linolenic acid that is anti-cancer (Dhiman *et al.,* 1999, Couvreur *et al.,* 2006, Duckett *et al.,* 2009). In addition, the principle of biodiversity conservation and management is important in agroecology. Therefore two crucial questions are how to manage grasslands in (i) assuring biodiversity conservation and (ii) using biodiversity as an asset for ruminant production systems? Metera *et al.* (2010) and Gaujour *et al.* (2012) provide in their reviews significant insights in showing that different management options exist. Gaujour *et al.* (2012) also state that it is necessary to go beyond simply looking at management practices such as grazing, fertilisation, and mowing, implemented at the field scale, but considering also the landscape scale as this can influence significantly species pools and species richness on grasslands. This multiple scale approach is specifically important when dealing with agroecology (Wezel and David, 2012).

Agroecological cropping practices are specifically important for mixed crop-livestock systems in order to have the complete system oriented towards sustainable production. These practices were

defined and described in Altieri and Rosset (1995), Maljean and Peeters (2003), and Wezel *et al.* (2014), but will not be presented in detail here. Among them are practices related to crop choice, crop rotation management, cover crops, fertilisation, irrigation, weed, pest, and disease management, tillage management, and management of landscape elements. These practices do not exclude other ones that have a lower general scope such as production of biogas from manures and use of residues on fields or grasslands to optimize nutrient cycling and produce energy.

IV – Application of practices to selected farming systems

The application of principles of agroecological herbivore farming systems into real practices can vary significantly according to farming system types in diverse locations with variable climate, soil, natural vegetation, and relief. Some examples of practices which are or could be applied to mountain or Mediterranean farming systems in Europe are presented in Table 1.

V – Livestock systems and food value chain

Food value chains are can be quite different from on livestock production system to another. In general, food value chains tend to be shorter in agroecology than in industrial farming (Figure 5), also for systems with livestock. Industrial farming such as 'Intensive conventional agriculture', 'Green Revolution' (Gaud 1968), 'Doubly Green Revolution' (Conway 1997) and 'Sound Farming' ('Agriculture raisonnée' in French) (Paillotin 2000) are fossil fuel-based. The value chain starts from fossil fuel pits and finish in the plate of consumers. Upstream and downstream industries are important parts of the system. Farmers devote a large part of their revenue for buying inputs and paying loans to banks. Farmers' margins are limited because of low prices paid by strong dealers. A large part of total profit is captured by food processors and retailers. In agroecology, shorter value chains are favoured. They are ecosystem-based. Biodiversity fulfil several functions that drive the system such as biological nitrogen fixation by legumes, pollination, parasite and disease control by natural enemies. A proportion of the food produced is processed in farms and sold in short marketing chains to consumers. Production costs are thus reduced and a large proportion of increased profit is kept in farms. Since producers (farmers) and consumers are in close contacts, the food chain is more transparent than in long industrial value chains. This induces higher consumer trust in product quality. Although short value chains are often favoured in agroecology, also midscale value chains may provide many positive aspects to farmers (Lev and Stevenson 2011, Stevenson *et al.,* 2011). These midscale food value chains are often based on strategic alliances among small and midsized sized farms and other agri-food enterprises that operate at regional levels.

A well-known example is the Comté cheese production in France where both a short value chain and a midscale food value chain can be found, but also a more conventional long value chain (Torre and Chia 2001, Ricard 2009, Jeanneaux *et al.,* 2011). The Comté cheese is recognized by a PDO (Protected Designation of Origin) label which certifies a geographical indication with the territory where it is produced as well as that production is in agreement with defined production rules, e.g. to only use pastures and meadows with a certain minimum of plant species diversity for the production of the milk. The cheese is either produced directly on farms and sold on farm, or in local shops (short value chain), produced in dairies in the production area and sold regionally and nationally (mid-scale value chain), or produced in dairies in the production, but sold nation-wide and on the European market by retailers (long value chain). In general, the Comté cheese can be sold with higher prices on the market because of his geographical indication, and his reputation as a high quality product.

Table 1. Some examples of agroecological practices in mountain or Mediterranean herbivore farming systems in Europe

Practices	Example of practices	
	Mountain areas	**Mediterranean areas**
Diversification of land use, land cover and productions		
• Diversity of livestock species and breeds	Conservation of rare or less productive cattle breeds (e.g. Villard de Lans, Vercors area in the French Alps)	Conservation of rare or less productive cattle breeds (e.g. Avileña – Negra Ibérica in Spain)
• Mixed livestock herds and flocks	Mixed grazing with cattle, sheep and goats	
• Combination of the use of different grassland types	Complementarity between permanent/temporary meadows of the valleys and natural and semi-natural pastures at high altitudes	Complementarity between (irrigated) lucerne, grazed dry areas, grazed fallows and grazed annual medics or clovers on arable land
• Use of semi-natural grasslands in combination with more intensive grasslands	Vertical transhumance between plains or mountain valleys and summer grazing on alpine pastures	Transhumance between winter and summer pastures
• High diversity of crops and long crop rotations.	Use of temporary grasslands (grass/clover mixtures) in crop rotations to improve fodder quality, reduce nutrient inputs, increase soil fertility, control weeds, disease and parasites in mixed crop-livestock systems	In the Dehesa, use of annual legumes during several years in alternation with cereals
• Integrate trees into silvo-pastoral systems	Integration of trees into silvo-pastoral systems: Park grasslands of Jura grazed by cattle	Integration of trees into silvo-pastoral systems: - Dehesa and Montado grazed and browsed by cattle, sheep and pigs and harvest of cork, fire wood, timber and acorn; - Matorral grazed by goats
Specific resource management in mixed crop-livestock systems		
• Temporary grassland (ley) – crop combination	Integration of temporary grasslands (grass-clover mixtures) in crop rotation including potato and cereals	Integration of irrigated lucerne in crop rotation with maize
• Optimum resource management	Adapted fertilisation of meadows and pastures with on-farm produced manure	Guaranteeing permanent soil cover with low stocking rates in sensitive areas
• Large use of nitrogen fixing legumes	Use of cereal-pea mixtures	
• Orient towards self-sufficiency for fodder	Low purchase of concentrates	
Biodiversity conservation		
• Adapted stocking rates	Plant diversity conservation in pastures and meadows in the Comté cheese production area (Jura region, France)	
• Adapted grazing and re-use of marginal land		Support of goat shepherds in woodlands and matorral for shrub and fire control
• Maintain or establish semi-natural landscape elements		Tree and hedge plantations for animal shelter (e.g. sun)
• Conserve rare or less productive	Sheep breeds: Vicenza,	Sheep breeds: Serrai,

	breeds	Cadore and Friuli in Italy; Cattle breed: Ferrandaise in Puy de Dôme, France	Katafigion, Chalkidiki, Roumloukion, Thraki, Argos and Chios in Greece; Cattle breed: Alistana-Sanabresa in Spain
Grassland management			
•	Large use of nitrogen fixing legumes		Use of annual medics and clovers for establishing productive pastures
•	Adoption of optimum stocking rate	Low stocking rate adapted to grassland growth and inducing efficient lung and livestock internal parasite control	
•	Favouring multiple species swards in grasslands	Grazing of species-rich swards in high mountain areas	Grazing of species-rich plant communities
•	Use of tannin-rich forbs/legumes/woody species		Use of tannin-rich plants by browsing trees and shrubs improving animal health
Livestock management			
•	Integrated disease and parasite control	See above	
•	Priority to feed compared to food	Low use of complements (e.g. cereals)	
•	Use of locally adapted breeds	Example of cattle breed: Montbéliard in Jura (France)	Example of cattle breed: Avileña – Negra Ibérica in Spain
•	Use of modern types of double-goal breeds	Example of cattle breed: Brown Swiss	
Food and food system			
•	High quality of products (nutrition, taste)	Very large adoption of grass-based productions Production of high quality cow cheese on farms or in local dairies for short or mid-scale supply chains Examples: - Beaufort cheese in Savoie (France) - Fontina cheese in the Alps of Italy	Very large adoption of grass- and shrub-based productions Production of high quality sheep and goat cheese on farms or in local dairies for short or mid-scale supply chains. Examples: - Roquefort cheese in Savoie (France) - Ragusano in Sicily
•	Local dairy and meat product processing	Local dairies and cooperatives for milk collection and processing	
•	Adoption or development of quality labels	Large development of quality and geographical origin labels	
•	Cooperation, collaboration and development of synergies between farmers, between consumers/citizens and farmers, and between consumers/citizens	Multi-stakeholder cooperation for herbivore farming systems in mountain areas and conservation of cultural landscape for tourism activities	Good cooperation between transhumant herders, municipalities and biodiversity conservation institutions such as parks, forest departments for best management of rangelands (and communal pastures)
Diversification of income sources			
•	Product diversification	Combination of cheese making, honey, cooked and/or dried meats, …	
•	Diversification of activities	Agri-tourism (e.g. ski, hike)	Agri-tourism (e.g. hunting)

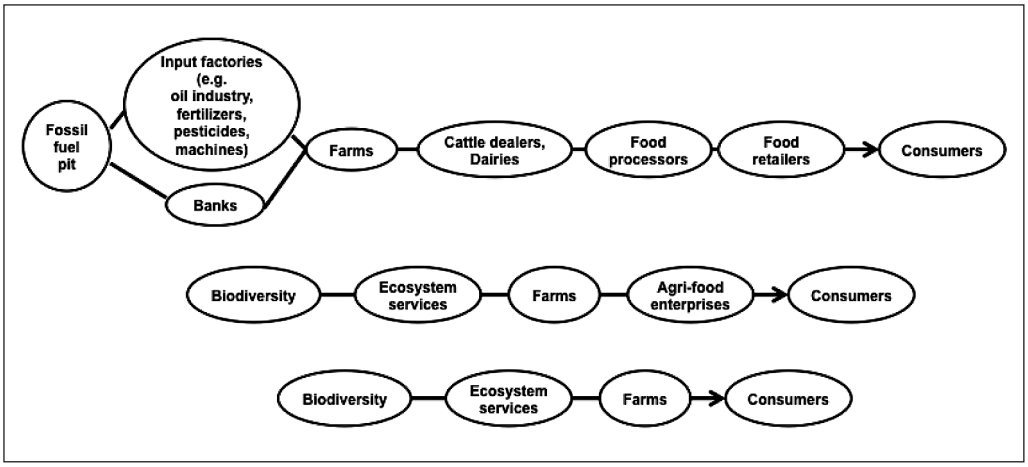

Fig. 5. Industrial (above) and agroecological mid-scale (middle), and short (below) food chains.

VI – Conclusions

The development of sustainable agricultural systems is needed to feed the world but in assuring simultaneously limited negative environmental impacts, and providing economic and social benefits for farmers and other stakeholders. The underlying principles necessary for agroecological herbivore farming systems can be classified into six groups: (i) knowledge, culture and socio-economics, (ii) biodiversity conservation and management, (iii) systems management, (iv) resource management, (v) food and health, and (vi) social relations. The agroecological practices which could or should be implemented to establish sustainable herbivore farming systems and which are based on the above mentioned principles can be grouped into seven categories: (i) diversification of land use, land cover and productions, (ii) resource management in mixed crop-livestock systems, (iii) biodiversity conservation, (iv) grassland management, (v) livestock management, (vi) food and food system, (vii) diversification of income sources. Taking into consideration these principles and the practices which derive from them, the development of agroecological herbivore farming systems can be implemented.

A fast transition from conventional to agroecological systems would require a strong political will, corresponding budgets and a strong involvement of many types of stakeholders: farmers at the first place, and also scientists, teachers of technical schools, farmer's advisers, traders of the food sector. It will require in priority (Peeters *et al.,* 2013):

- new agricultural policies;
- a reform of the training of future farmers, technicians and farmer's advisers in technical schools;
- a reform of the specialization training (master) of agricultural scientists in higher education institutions;
- a restructuration of agricultural research that will define new priorities. The dominance of reductionist research should be inverted at the benefit of holistic and participatory research. In the short term, groups of pilot farmers should be created and associate different types of stakeholders (ex.: holistic researchers, reductionist researchers, farmers' advisers, technical and higher education schools, consumers, nature conservationists).
- a technological revolution for designing and developing agroecological methods and systems, adapting them locally, disseminating them, supporting farmers in their transition period;

- the design of a biodiversity friendly agriculture: the integration of heritage biodiversity enhancement in methods and practices;
- giving priority to agroecological products in school and administration cafeterias (canteens).

Besides changes in policy, budget allocation, and involvement of diverse stakeholders in the development of agroecological herbivore farming systems, also research has an important role to play. Major implications for research would be:

- to have a more systemic approach in taking into account the whole livestock farming system and its location in a socio-technical network of stakeholders and policy frame;
- to reinforce research on use of pastures and rangelands and their integration into herbivore farming systems;
- to broaden research for systematic use of prevention methods for integrated disease and parasite control;
- to take into account biodiversity conservation when developing new practices and adapting farming systems.

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