Agroforestry in Review

With Case Studies from:

Europe

China

New Zealand

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Literature Review

What is AF?

Agroforestry (AF) is a broad term for a series of agricultural practices that incorporates trees into farming systems with either livestock or vegetable crop production. Utilizing these multiple crop outputs on a given acre of land has great potential to increase farm profitability, marketability, and sustainability. The most widely accepted definition of AF from Lundgren and Raintree states:

> "AF is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In AF systems there are both ecological and economical interactions between the different components" (Gordon and Newman 1997).

AF today: multiple systems at work in the temperate world.

Agroforestry systems include: windbreak systems, silvopastoral, and intercropping/alley-cropping (Gordon 1997).

In a typical shelterbelt (windbreak) system, a series of trees are planted along the border of a field, perpendicular to the prevailing wind direction. The trees serve a vital ecological purpose. They slow and greatly reduce the wind speed, and its effect on the field, for up to 30 times their height (Gordon, et al. 1997). Brandle and Kort found Shelterbelts to reduce wind erosion supporting optimal crop yields (1991). Shelterbelts have also been shown to reduce airborne movements of pesticide, fertilizer, and unwanted animal smells, increase economic returns and field aesthetics, and increase the abundance of natural insect enemies (Batish 2008). Windbreaks can also reduce the energy required by cattle for foraging, improve animal health, and increase survivability (especially in young animals) from cold stress (Gordon 1997).

Silvopastoral systems are commonly used in modern, temperate AF systems. According to H.E. Garrett, silvopastoral systems use management practices for growing trees with forage and livestock under artificial agroecosystem conditions (1999). Trees are typically used in silvopastoral systems for shade in open pastures, and for cover in actively grazed wood lot settings. The trees also serve the benefit of being used for timber production in the future, as well as cattle fodder in the interim. P.K. Nair claims that soil conservation and erosion control is perhaps the single biggest reason for having tree cover on grazing lands (1989). In Galacia, Spain the combination of timber and animal production provides a positive economic benefit to landowners. It reduces the prevalence of fires in the temperate climate, and supplies a myriad of ecological advantages. Here, eucalyptus trees are planted on degraded farmland, with low fire risk grazing species adaptable to partial over story canopy closure. Studies in this area have proven that, given adequate spacing, consistent pasture production can be maintained over time (Batish 2008).

Chickens, pigs and, sheep are all commonly used in silvopastoral systems. Animals in these systems usually graze in specified areas for a given amount of time, and are moved to create the least residual damage to the trees. Animals in silvopastoral systems can also be used to provide prep work for actively managed timber stands. This reduces the amount of pesticide use for controlling competing vegetation, as well as machine soil scarification (the tilling of the soil to induce germination) (P.K.R. Nair 1987).

Intercropping, or alley cropping, is the planting of multiple crops in spaced rows during a given year, allowing the cultivation of crops between them (Batish et. al. 2008). Starting with the appearance of agriculture, and the gradual elimination of our hunter-gatherer past, human beings have practiced intercropping (Francis 1986). Perhaps one reason intercropping has been an attractive option is that it mimics the structure and diversity of natural systems. In temperate areas, common intercropped systems typically include a grain and a legume. The grain is used as a nurse crop to help establish the legume, which is later used in forage production. For example, in the temperate world oats are commonly grown with alfalfa and clover. The legume has also been shown to increase nitrogen production in the soil, helping with soil conservation (Francis 1986).

The examples proving intercropped areas cause less harm by insects, disease, weeds, and erosion are numerous. In the Netherlands, intercropped cabbage and spurry showed a drastic reduction in defoliating caterpillars as compared to traditional mono cropping. In Canada, intercropping of onion, garlic, leeks, and chives with carrots has been shown to reduce common pests to the carrot crops. California orchards have shown near elimination of a harmful cantaloupe eating fungus by planting wheat crops as a trap. The wheat crops were even shown to be more successful (and safe) than pesticide application. Careful selection of intercropped plant varieties can help suppress weed growth drastically, leading to a decrease in pesticide use. Intercropped areas can control erosion by providing a valuable winter cover crop. Erosion has been shown to increase soil loss at a rate of 2-3 times its replacement rate in mono cropping systems. (Innis 1997)

By using the trees as a cover crop, the vegetable crop planted between rows often requires less spraying for unintended weeds and pests, less irrigation, and decreased competition.

Benefits to farmers reported from one study of Ontario, Canada are: increased cash flow, diversified production, and improved growth and productivity of fruit trees. Intercropping is most commonly done with fruit and nut trees in the over story, and annual crops. Methods of intercropping in temperate systems allow for widely spaced rows of trees conducive to mechanized harvest (Gordon 1997).

AF History

AF has been practiced across the world for thousands of years. The roots of AF are based in the tropics primarily due to land constraints, burgeoning population explosion, and rapid plant growth rate. This led to the need for efficient utilization of the land. The tropics are defined as: the land area between the tropic of cancer and the tropic of capricorn. Imitating the natural diversity and structure of the tropical forest allowed farmers to plant a wide variety of species on a very small land area. This polyculture (the simultaneous cultivation or exploitation of several crops or kinds of animals) resisted insect and disease issues, while allowing farmers to plant more varied crops on a given unit of land. Common examples in the tropics typically include the production of a few dozen different species, on no more than a tenth of one acre. These species could consist of, for example: coconut or papaya in the over story with bananas or citrus mid story, followed by a shrub layer of coffee or cacao, annuals such as maize, and a ground layer of plants such as squash. The tropics are well suited for AF application due to their rapid growth rate, relatively small land base to work with, and imitation of the natural communities (P.K.R. Nair 1993).

As evidenced by the previous discussion, AF has applications throughout the world, and should not be confined to the relatively small land area that falls between the tropics. In

Europe, many landscapes were consistently managed for multiple uses throughout modern history. Using an AF approach, the settlers cleared land for cultivation, while preserving some of the high value trees. Oaks were kept for acorns, ashes were used for cattle fodder, beeches for mast, and fruit trees were scattered across open fields for human consumption (Gordon 1997). Trees in the fields serve the purpose of shade and protection for workers, a place for animals to take a break from the midday sun, and allowed farmers to grow trellises for grapevines. Some of these practices still exist in parts of Europe, but most have been replaced with a lean towards intensified, mechanized agriculture.

In the North and South America, early Native American's staple crops consisted of the "three sisters" varieties-corn, beans, & squash (Smith-Heavenrich 1992). While these may seem like three unrelated vegetables, they actually intermingled in the perfect nutritional balance for early settlers. What one crop lacked in nutrients, the other provided in abundance. Natives intercropped these three plants continuously rotating crops to ensure nutrient and water demands were met (Vivian 1998). There is a renewed interest in these not so ancient native farming techniques from scientists and farmers alike. These intercropped plantations were excellent at resisting insect and disease, controlling weeds, and reducing erosion. The genetics of seeds for replanting the following year were handpicked from the best specimens, and passed on through generations.

China, being one of the most ancient civilizations on earth, naturally has practiced AF for many centuries (Gordon 1997). During the infamous Han Dynasty, officials recommended to farmers that forests be used for livestock husbandry and crops. The Chinese also considered planting crops that would complement each other, such as hemp and paper mulberry. Hemp served a purpose in preventing the paper mulberry from freezing in the later part of the cold (winter) season. Most astonishing about the Chinese, is they were years ahead of their time, as they were intercropping chestnut and soybean in 1640. Chestnut was planted along with soybean to help the soybean grow upright. Also using intercropping, the Chinese used staples such as wheat or sesame planted between rows of high value fir trees (Gordon 1997).

In other systems, historic cultures used AF techniques to keep their livestock happy and healthy. One ancient AF system is the Deheasa system of southwestern Spain and Portugal. The Dehesa System is characterized by a random scattering of oaks, which are interplanted with cereals and fodder crops. This complicated arrangement of cereal crops, used to control weed growth in pastures and grazing, was shown to be highly effective. Early Renaissance paintings (1400-1600's) provided visual evidence of AF being practiced by feeding livestock acorns or chestnuts from standing trees left in the pastures (Gordon 1997). The Dehasa system is still used today in parts of the Mediterranean, but is considered endangered as mechanized, mass produced crops have become the norm (Gordon 1997).

Around this same time in England, Japan, and India, natural forests were commonly used for grazing pigs and other livestock. This type of agriculture in productive forest lands continued until timber production became the main objective of forest management within the last few centuries (P.K. Nair 1993). Before this paradigm shift, the main function of forests was for hunting, extraction of wood for fuel and construction, and grazing of livestock.

Present day agricultural shortfalls: a renewed interest in AF.

In the 1970s, the president of the World Bank, Robert McNamara, issued a sobering report about world development policies and approaches. In it, he said we need to think about the basic needs of the poorest, especially the rural poor, which he quantified at 1.3 billion members in farm families. Many of these people live on less than $100 per year, and are ravished by hunger and malnutrition, among other modern day preventable maladies. McNamara went on to state:

> "The miracle of the Green Revolution may have arrived, but, for the most part, the poor farmer has not been able to participate in it. He cannot afford to pay for the irrigation, the pesticide, the fertilizer, or perhaps for the land itself, on which his title may be vulnerable and his tenancy uncertain. (P.K.R. Nair, McNamara 1993)"

According to Noble and Dirzo (1997), AF is an age-old practice revived in the recent past with a renewed scientific interest to maintain the sustainability of agroecosystems. AF is needed today, more than ever, to meet the exponential demands of an increasing population, compensate forests in the wake of an ever increasing rate of deforestation and solid degradation, and to conserve biodiversity. The United Nations has set a list of Millennium Development Goals (MDG) aimed at: eradicating poverty and hunger, bettering health, nutrition, and education to people, gender equality, and environmental sustainability, particularly in the developing world. According to Daizy Batish ("Ecological interactions in AF: An overview"), et al. (2008), AF is substantially assisting the UN in meeting these goals.

AF systems have many benefits over traditional agriculture systems designed under the Green Revolution. AF systems have been shown to improve soil fertility and microclimate. Soil degradation and decreasing fertility are a serious threat to agricultural productivity. Tree litter can improve soil nutrient availability, increase the level of organic matter, and improve soil structure (P.K.R. Nair 1987).

AF can also help maintain water quality, and has been shown to reduce the levels of pollution and soil erosion (Buck 1998). AF does this primarily in riparian buffer zones by reducing runoff to rivers and streams. Having an adequate tree cover over soil has also been shown to increase the soil water holding capacity, reduce evaporation, and increase water infiltration (Nair 1987).

Perhaps the greatest benefit of AF systems (especially in the developing world) is their use in weed and pest management. Weeds and pests interfere with primary crop productivity, and can have huge impacts on harvest levels. Use of pesticides and herbicides in the west to control weeds has led to many unintended effects on non-target organisms, environmental degradation, and reduced sustainability of crop land. Pesticides are also relatively affordable in the west, but prohibitively expensive in much of the developing world. Although there have been contrasting studies on both sides of the issue, the general consensus is that AF crops reduce weed population due to shading. They also decrease insect attacks by providing a physical barrier to airborne pests and pathogens (Batish, et al. 2008).

The loss of biodiversity is the single greatest pitfall of modern, industrialized agriculture. AF plots can help to preserve biodiversity by providing a protective tree cover within, or alongside fields. Numerous studies have shown higher biodiversity levels in AF plots than in traditional sole cropping agriculture (Buck 1998). AF provides a number of biodiversity conservation benefits by providing secondary habitat for species, reducing rate of conversion of primary habitats, and by creating an acceptable transition zone between primary habitats (Batish 2008).

The benefits of AF in the temperate world are numerous. AF can help low income farmers increase their income by providing a valuable marketable product. Farmers are provided with the food they need to feed their families, while also having a source for a much needed export of timber, wood fiber, fuel, medicine, and more.

Economic Basis for AF Systems and Governmental Policy:

According to Chris Doyle and Tony Waterhouse, "...the results of studies on the potential profitability of AF in temperate regions during the last 10-15 years have been inconclusive (qtd. In Batish 2008)." Studies have been conducted in Europe comparing silvopastoral systems in AF applications, to those in traditional grazing applications. One potential downfall of studies is that they are comparing the short term profit of cattle farming, with the long term profit of timber production. Selecting the proper discount rate was also a deciding factor in AF profitability. Doyle and Waterhouse found that in Europe, a higher discount rate of 10 percent, instead of the traditional 5 percent, was used rendering AF economically worthless over the long term (Batish 2008).

A small number of studies have proven that AF can have positive economic benefits, when coupled with ideal land management practices. AF is unique in the fact that by combining multiple crops, with unique harvest intervals, economic analysis is usually over a number of years, not the usual single year analysis. Silvopasture systems in the SE U.S. have shown positive, long term economic gains. Ludgren found that silvopasture systems here could realize an a 4.5 percent positive rate of economic return when used with a southern pine over story in Florida (1983). Additionally, Clason found in Louisiana silvopasture systems have a greater economic benefit than either pasture alone or pure timber stands (1995).

Brownlow and others did an interesting study evaluating the profitability of pigs in a silvopastoral setting in Britain (UK). Much of the small livestock in the UK was traditionally run in agroforestry settings, until recently when indoor intensive feed operations became the norm. However, demand is shifting back, and currently as much as 20 percent of the entire herd is under a silvopastoral system. Brownlow developed a model entitled the “Modeled Assessment of Swine and Trees” (MAST), which allowed him to asses the cost benefit ratio of swine in silvopasture to swine in a traditional factory farm setting. Using the model, over a course of 20 years, Brownlow determined that the average profit margin increased almost 9 percent per pig, assuming a worst case scenario and 25 percent per pig under ideal (study) conditions (251-263).

For example, Nitrogen application can be used to increase timber species growth rate (Batish 2008). The general consensus is AF applications can have a higher return than systems that are relying only on grazing livestock. By combining these multiple “crops” in a given area, a farmer is creating a more diverse product. A diversified creation could have more marketability given an economic slump in one area or another.

In most cases, government policy needs to be favorable in order to encourage widespread adoption of AF systems. However, governments are cautious about investing in an AF future, as it is hard to grasp the initial economic returns. According to Doyle and Waterhouse, governments will start to support AF positively if environmental goods are provided that the public values, or if it has a wider income and employment benefits (qtd. in Batish 2008). Doyle conducted an interesting study in the Scottish highlands which proved the real economic and social benefits of AF to the community. In it he showed the measurable job creation of AF systems in Scotland, as well as the economic benefits to the community. The study proved that for every US dollar of farm income, $1.7 is produced in an AF application, and 1-2 additional jobs are created per 100 Ha (Battish 2008).

Some possible downfalls of a modern AF system:

It may seem from the preceding discussion that AF is an answer to the world's agricultural problems. AF has shown some real promise in sustainable agricultural systems throughout modern history, even though its use has subsided due to monoculture and mechanization. It has been practiced for thousands of years, and is promising in developing countries lacking capital for mechanized harvesting equipment. However, AF is not without its downfalls, which include: shade, competition, allelopathy, harboring of harmful pests, and threat form invasive potential of trees (Batish 2008).

Although a number of factors are responsible in determining productivity, shading is generally looked at as decreasing output. Productivity is dependent on soil type, climate, crop or tree species, and specific management practices in use on the specific site. Some studies have shown little to no, or even a positive effect due to shading (Batish 2008), while others have shown that shading can drastically reduce yield. Important factors in silvopasture settings are to keep tree spacing optimal for overstory species, and to select ideal understory grazing species that are compatible with a reduced sunlight intensity. Batish found the greatest reductions in forage yeild under conifer plantations, but little effect was observed with decidous overstories. Ideally, the study recommended densities of trees to be kept under 600 trees per hectare with conifers, and 2000 trees per hectare in broadleaves (Batish 2008). Van SamBeek et. al. (1997) came up with a comprehensive list rating understory species for tolerance in an AF setting from the University of Missouri test plot. They found that cool season forages typically do better in AF systems than warm season forages (Sambeek, et. al. 1997). These results were duplicated in a study of understory species suitable in temperate silvopasture settings by C.H. Lin et. al (1999).

Also of concern in AF systems are resource competition and allelopathy. Resource competition can have some severe negative affects crops, if species selection is not carefully managed. Poor tree selection in intercropped AF plantings can cause trees to compete with target crops for light, resources, shade, and water. If this occurred crop yields could be greatly devastated. Careful selection of both tree and crop species, and studies of rooting depth between interspersed crops can reduce these problems. Allelopathy (the release of chemicals by one plant into the surrounding environment) is a relatively uncommon negative interaction with AF trees. It often retards or suppresses the growth of other plants (Batish 2008). As in the previous example, careful consideration needs to be made when selecting tree and crop species, being mindful of potential interactions.

Black walnut is considered the most allopathic of all trees, and therefore makes an excellent example for tree/crop interaction considerations (Rietveld 1983). Somewhat contradictory, it is also planted the most among trees in AF settings due to its astronomical timber value. The chemical juglone, which black walnut exudes through the root system, has been shown in several studies to have detrimental growth affects herbaceous and woody plants alike (Jose 1998). Jose found that juglone concentrations from individual trees were evident in the soil up to 4.24 m from individual trees (1998).

On the flip side, beneficial effects can be achieved from allelopathy. For example, it may help reduce the number of competing weeds in a crop. In southeastern Mexico, farmers interplant squash with corn and beans in polycultures to aid in weed control (Chacon and Gliesman 1982). The ingenious farmers used the natural shading of the squash leaves as a consistent cover over the soil to deter weeds. Squash is also known to emit phytotoxins, decreasing the prevalence of weeds (Francis 1986). Farmers said they were happy if they recieved a few fruits from the squash as well.

Case Studies

The case studies presented here are of three main regions where AF is practiced in the temperate world: Europe, China, and New Zealand. While these three countries are very different on the surface, they all have instituted a form of AF, which have been mentioned earlier, and are on the path to sustainable agricultural development into the future. All three countries have been actively implementing and researching long term demonstration plots, assessing the multitude of factors that go into a modern AF system. They all have a slightly different approach to AF and are not meant to serve as a direct comparison of each other, but as an example of a sustainable agricultural process in the world today.

Temperate Agroforestry: European Style

The European landscape has gone through drastic changes over the last few hundred years. People have occupied and manipulated the landscape in Europe for centuries. In this period people had the opportunity to settle the land, convert to agriculture (often utilizing AF), and switch back to a modern monoculture, and revert yet again to AF.

Much of Europe's original AF land is now gone, and has been replaced with some of the more cutting edge AF projects in the world today. Some of the prominent AF areas that are still under heavy use occur in the Mediterranean area. The ancient practice of intercropping olive plantations with vineyards, and the use of silvopasture systems in both forests and fruit orchards is still carried out in the Mediterranean (Lelle and Gold 1994). However, some systems have gone the way of the dodo, such as using scattered deciduous trees for fodder in cultivated fields (Dupraz and Newman 1997).

One exception to fading AF systems in Europe is the Dehasa system of the Iberian peninsula in Spain, which has been practiced for many centuries. The Dehasa system can be labeled a “silvoarable AF system.” It is characterized by a savannah like landscape setting with sparsely populated oaks (20- 50/Ha), allowing grazing of ruminants to take place. The carefully selected trees serve as fodder for animal consumption (including humans), while the spaced area between is planted with cereal crops such as barley or wheat (Joffre 1998). The trees are regularly planted, managed, and pruned. The trees serve an ecological purpose for soil stabilization, soil water retention, and ecosystem level precipitation influence. The forest is the largest AF system in place in Europe, and still covers an area of roughly 2 million hectares Dupraz and Newman 1997).

Much of the AF that currently takes place elsewhere in Europe uses some form of a silvopastoral system. In the 1980s, agricultural commodities were being overproduced in Europe, forcing managers to search for an alternative crop that could be planted on the same cropland, while guaranteeing long term economic profits. The Dehasa system had many proponents, as well as other AF systems in place in the UK. The Dehasa system has high species diversity, and more productivity than monocultures. An added benefit was the reduction of pesticide or fertilizer use in these AF plantations. Farmers are just beginning to adapt to new AF techniques, but it looks like they have the push from the conservation groups and the public alike (Dupraz and Newman 1997).

Forest grazing is one such silvopasture-like technique showing real use in Europe. Traditionally, it is done with forest grown oak trees spaced further than 20 m apart in irregular arrangements, with sheep grazing underneath. The sheep (or in some cases cattle) help control the competing regeneration reducing wildfire risk drastically, as well as improving multi-use pursuits of the forest (recreation). This system is most commonly done in the Mediterranean regions of Europe: Italy, France, and Spain (Dupraz and Newman 1997).

Newer silvopastoral systems in place in Europe can be attributed to a number of studies from the 1980s proving the profitability of growing timber in such systems. Dupraz and Neman also compiled a list of reasons for conversion to silvopastoral systems in their paper entitled, "Temperate Agroforestry: The European Way." The reasons for conversion include:

1. to maintain a fodder resource on areas where landowners would have otherwise planted forests...
2. to diversify farm incomes through long-term high quality wood production, by creating new stands of multiple-use trees...
3. to provide shade and shelter to animals in windy or exposed locations
4. to shift grass production towards summer in the shade of trees in dry-prone climates.

Converting an existing woodland to a silvopastoral system can be relatively easy, especially if one has large, mature trees already present. If this is the case, a farmer just needs to do some selective thinning to ensure the understory receives enough light, and remove any brush that may be a problem for cattle grazing. In this scenario there are no barriers to regeneration. The trees are tall enough to be out of reach of hungry cattle's mouths, and they are likely to live longer.

However, many of the systems that are currently proposed are being done so on open grazed grassland, which presents a single, albeit massive problem: establishment. Grazing animals will stampede or browse young trees until they are dead, especially if they find them particularly palatable. Farmers in Europe have found a few unique ways around this. Those with enough land to do so, have fenced off areas entirely which they are converting to AF use, allowing the trees to grow for 5-20 years before letting the cattle loose to graze. This system can work by keeping the hungry cattle away from the trees, but it also gives the understory time to catch up. Many times it does just that, and is invaded by undesirable shrubs and weeds (Dupras and Newman 1997).

A more attractive option, using some relatively modern technology, is using tree shelters to allow the tree to get past the reach of cattle before being browsed. Tree shelters are a tall plastic tube 1.5-2.5 m tall (dependent on slope and cattle type), which afford the tree some physical protection until they are out of reach of cattle. Early tree shelters used in Europe were found to be a little too protective, enclosing too much of the tree and reducing growth by shading out the sun and constricting diameter growth. However, thanks to advancements in plastics technology, new twin walled and extruded polypropylene tree shelters have proven both useful and cost effective (Potter 1999).

Tree shelters are placed with a seedling inside in the field of choice, and then driven in with a stake. By the time the tree grows out of the shelter it will be out of reach of animals. Sometimes trees in shelters develop some irregular forking or different branching patterns, but this can easily be corrected with some corrective pruning. The shelter remains around the base of the tree until the diameter growth of the tree forces the shelter to "unzip" along a perforated line manufactured into the shelter. The average time a shelter is on is dependent upon diameter growth of a tree, but typically in the 5-15 yr. range (Dupraz and Newman 1997).

In one case study evaluating tree shelters, a group of research was undertaken simultaneously at several experimental agriculture sites throughout the central range of France, UK, Greece, and the Mediterranean. At each site researchers evaluated the growth rate of trees in a controlled setting, as well as in an AF setting. Sites had either sheep, cattle, poultry, or goats, while one site had cattle and poultry. Many sites had recent tree establishment, and were using tree shelters to get the AF plot started. Interestingly enough, all research plots reported positive results for tree growth rate, shelter protection, survivability of trees after shelter removal, and fodder production (Dupraz and Newman 1997).

Another very old AF technique in Europe is orchard intercropping, which dates back to the first century. Historically, wheat was typically planted with olive trees, or other fruit orchards to help improve the fruit growth for the following year (Dupraz and Newman 1997). These practices were abandoned with much of the mechanization of modern agriculture, but like the above techniques has developed a renewed interest. However, it was not until the 1970's when people begin to realize the high productivity that was achievable with AF systems. Common crops now used for orchard intercropping in Europe, primarily planted in the Mediterranean, are walnut, almond, peach, apricot, and olive trees, with the intercrops being vegetables, cereals and vineyards (Dupraz and Newman 1997). The intercropped area serves multiple benefits with heavy fall rains including preventing soil erosion, allowing machinery traffic on soggy fields, and improved fruit quality by competition for water resources (Baldy).

Much of the intercropping that currently takes place in Europe has been designed, established, and implemented by the farmers. Little research has been conducted on their efficacy. Common intercrops include corn, sorghum, winter wheats, soybean, canola, sunflowers, and tobacco, as well as fodder crops such as alfalfa, aromatic crops such as lavender, small fruits, and fruit trees. The French are particularly fond of intercropping, with as much of 20 percent are walnut orchards, and 80 percent of all other orchards intercropped. Another interesting kind of intercropping utilized involves corn, and either black walnut or poplar (Dupraz and Newman 1997).

While these intercropping systems work with animals, or some form of vegetable crop, the real economic powerhouse of temperate European, AF comes with high quality hardwoods. Europeans wanted to reduce their imports of high quality tropical hardwoods, while helping to realize their full potential of timber production. France even went as far as instituting a target of 30,000 Ha/yr. for conversion into AF systems. However, much research needs to be done on the issue to find fast growing timber species suitable for AF in Europe. In places where systems like this have worked, such as New Zealand and China, crop improvement programs have been in place for years. This allows only the best tree planting stock. Most of these programs are using either pinus radiata (monterey pine) or paulownia spp., both of which have had clonal genetic improvement of planting stock for decades. Some propagation for genetic improvement has been started in France and Italy with poplar trees, but most other high quality hardwoods such as ash, maple, and walnut, are still lacking genetic improvement programs resulting in a major barrier for widespread institution (Dupraz and Newman 1997).

Agroforestry in Europe has had a long history. Europe has a wide variety of AF practices: from the first landscape level manipulation in the Dehasa system, to modern silvopastoral systems, to orchard or vegetable intercropping. While many of the former systems have been abandoned in favor of mechanization and specialization in agriculture, a resurged interest is forming from a community level, all the way up to the farmers growing the crops. With increased interest in decreased pesticide and fertilizer use and a quality product, AF can help pave the way to a new European agricultural landscape.

Temperate AF - How the Chinese do it

China covers an extremely large area of about 9.6 million square kilometers, roughly equivalent to the size of the United States. According to Yungying and Zhaohua, Mountainous regions comprise 33 percent plateaus 26 percent basins 19 percent, plains 12 percent, and hilly lands 10 percent. China has over 60 percent of its land in temperate regions, with 26 percent falling into tropical and subtropical regions. 70-80 percent of the rain that falls in the temperate zone falls in the monsoon season of July-September.

The history of AF in China is much longer than that of Europe. The Han dynasty in China was one of the originators of modern AF methods, advocating development of forests to accommodate livestock husbandry and crops according to local conditions. The Chinese also practiced intercropping as early as the sixth century, planting Chinese scholar tree with hemp. The idea was that the trees helped the nutrient poor hemp while the hemp helped keep the trees in proper form. Hemp was also intercropped with paper mulberry, to help prevent it from freezing in the cold winter season. The Chinese also used a complicated intercropping system during the Ming Dynasty (1300-1600) preparing Chinese fir plantations with sesame seed for weed control, and then intercropping the fir with wheat or millet (Yungying and Zhaohua).

Today AF is more important than ever in China with a burgeoning population explosion, environmental degradation, and resource depletion. China has nearly 20 percent of the worlds population, and a high demand for an increased standard of living (Bongarts 1997). Also, land can be severely limited in China, with the average farmer receiving only 0.1 ha. This can be a positive thing, as people hold a much higher revere for their land. Due to these limiting factors, China is faced with a need to meet the basic food requirements of people, while still supplying an adequate level of timber production.

China has some favorable land development policies in place advocating the provision of shelter, intercropping of trees and agricultural crops and the control of soil erosion (Yungying and Zhaohua). Much of their current interest in AF came in the 1970s when they were faced with problems in feeding their population. China has made great strides in the development of AF systems to help stabilize soil, institute shelter belts, and add intercropping systems. China has "one of the most extensive systems of tree-crop admixtures in the world..." (Gold and Hanover 1987). No doubt, they have some help from their socialistic government, which helped institute programs on a large scale in the late 1970s through the 1980s.

One plant with a promising future in China is Paulownia. Paulownia is a native deciduous tree to China, highly adaptable, very fast growing, and has a wide variety of uses. As of the 1990s, Paulownia was planted on roughly 2 million ha throughout the country. Typical rotation age of Paulownia is a remarkable 10 years, and it is usually intercropped with winter wheat. The wheat is planted in the fall, and harvested mid summer of the following year, reducing competition of light from the trees. Paulownia does not directly compete with intercrops such as wheat, as it has been shown to have a rooting system well below the plough layer, where the cereal crops are using soil water and nutrients (Lin, et al. 1999). Other common intercrops planted with Paulownia include oilseed rape, garlic, cotton, soybean, millet, peanuts, sweet potato, vegetables, melons, medicinal herbs, and others (Yungying and Zhaohua).

Paulownia was first developed in the Henana province of China (Wu), but it is cultivated throughout the country today. In the Dafan Village, roughly 2600 people live, tending 167 ha of farmland of mixed Paulownia intercrops. The village has actively planted Paulownia trees with a current inventory of almost 33,000 trees and 15,000 cubic meters of standing timber. 5400 cubic meters have been harvested to date, with a current US value of about $400 thousand (based on current currency conversion of 2.7 million Yuan). The annual growth rate of trees in the AF crops is 6000 cubic meters a year, and the village harvests roughly 1/5 or this yearly. 50 percent of the lumber is exported, and the rest is used locally for construction uses. In all, the income from Paulownia in the village accounts for 37 percent of the total agricultural income, a large chunk of their total economic output (Yungying and Zhaohua).

Hedgerow intercropping is another popular AF system that has been heavily instituted in China since the 1990s. A more applicable term to the hilly regions where it is used in China is hedgerow intercropping, which is the use of a double border of nitrogen (N) fixing plants, planted along contour lines of a hillside (Tang 2000). Hedgerows are considered intercropping, as the space between them is used for domestic cash crops. Hedgerows are reported to have excellent soil erosion control on steep slopes, fertility improvement, and water conservation benefits (Tang 2000).

In the mountainous areas of China, more than 80 percent of the arable lands are considered sloping, and an astonishing half of these slopes are greater than 25 degrees. The Contour hedgerow system was first tested in the Three Gorges region of China, and sponsored by the International Center of Integrated Mountain Development (ICIMOD). Many other studies have been done since and the myriad of benefits from hedgerows has been proven. Hedgerows were shown to reduce soil loss by 26-60 percent and runoff by 18 percent. N fixing hedgerows were also shown to improve soil fertility, increasing nutrient level and soil organic matter (Sun 2008).

The economics of hedgerow systems have been studied, and results look very promising. Most studies cite the number one initial effect of hedgerow systems being an increase in productivity from the start. This is achieved through a stabilized moisture regime, and the increased soil fertility has benefits alluded to previously. One study showed yields of maize increasing up to 22 percent without fertilizer addition, and up to 70 percent increase with fertilizer use (Sun 2008). Wang reported that the average annual yield increase of hedgerows is about 15 percent (2000). Hedgerows also provide a cash crop benefit, which has also been shown to increase in yield, thanks to soil fertility improvements. Finally, hedgerows themselves can provide fodder to farmers livestock, helping nourish them through tough economic times. Fodder can be used to support a variety of animals including pigs, cows, sheep, goats, and others.

China has a long tradition of growing agricultural crops in the rural landscape that dominates it. The Chinese have been very inventive throughout the years, using early AF systems before the myriad of benefits were even known. Today, with a little push from modern development, and population expansion issues, China faces a crossroads in agricultural development. The government has shown that they will back the AF systems that have promised so much in this rapidly developing country. The Chinese citizens themselves are now faced with the enormous task of instituting these modern day agricultural advances to help feed their families, and provide much needed economic support.

New Zealand-a temperate AF model.

Like the other regions mentioned before, AF has had a recent surge in popularity in New Zealand (NZ). However, unlike the other areas, AF has no real history here. According to Fenton and Sutton, who published a research paper analyzing the economics, AF was first considered in NZ in 1969 with the planting of monterey or radiata pine in actively grazed areas.

Grazing was achieved primarily with cattle and sheep to control the undergrowth, while trees were maintained on a roughly 200-350 stems per ha basis (Hawke and Knowles 1997).

The total plantation area of NZ's current forested land is roughly 1.6 million ha, or about 7 percent of the total land base. Radiata pine plays a huge role in this forested land as it is planted in about 90 percent of this area. Radiata pine has excellent marketability on a global scale, it grows well on a wide range of sites and can achieve heights of nearly 30 m in 20 years. Typically, radiata pine is managed on a 25-30 year rotation, and has been shown to have good economic returns. Due to the very favorable economic climate, in 1996 alone, 80,000 ha of previous open grazing land has been converted for use in silvopasture systems using a radiata pine over story. Also, in NZ, excellent genetic improvement programs exist, with good dispersal of varieties to farmers in need (Hawke and Knowles 1997).

Radiata pine is usually planted as a small seedling, only 20-30 cm high, and reaches a heigh of between 50-150 cm in the first growing season. During this critical period, it is important to slow the grazing, so that no damage is done to young seedlings. Damaging effects from cattle include browse, debarking, and trampling. To help manage for these potential threats to early tree death, managers have to limit the amount of cattle on the pasture early in the trees life, or just use smaller animals such as sheep, which have less interest in the young trees. However, to ensure high survival, the most common practice is to eliminate cattle grazing for the first two years of tree establishment (Hawke and Knowles 1997).

Radiata pine in NZ need to be actively pruned throughout their life to obtain the best market value. The best way to take care of larger lower limbs (below 6 m), which are in the way of grazing animals, was mechanical pruning (Sutton 1972). Pruning, along with timing can also help increase the pasture yields. Pruning waste is generally recommended just to stay on the site as it can help provide some needed shelter for young lambs (Hawke and Knowles 1997).

Although radiata pine stands have been proven to be economically viable, they are not always beneficial to the livestock. Hawke and others performed a series of studies to assess live weights of sheep under different AF systems using radiata pine. They found an inverse relationship between tree stocking percentage and age, and animal weight. A control of a traditional bare pasture was instituted, and indeed did have the highest animal weights. However, the weights of sheep in the open woodland were not far behind. Cows have more adaptability, as they are better utilizers of the grazing material. Pilot studies have been done with red or Sitka deer, as well as goats, with moderate debarking problems (Hawke and Knowles 1997).

Another important use of radiata pine, outside of silvopasture settings, is its use as a shelter belt in the lowland areas of NZ, where it has been used for over 100 years. Little research was conducted on the efficacy of the plantings until the 1980s, when the National Shelter Working Party began conducting research (Hawke and Knowles 1997). They found that the sheltered area was half as windy, sheltered warmer soils for summertime growing, and yielded a 60 percent improvement in pasture production. Studies also found increases in soil and herbage nutrient production near shelter belts. Timber production can be achieved in new shelter belt plantations in as little as 20 years, with growth rates similar to pines under silvopasture (Hawke and Knowles 1997).

Another, perhaps more traditional form of AF in NZ is forest grazing. Forest grazing has the advantage of having the forest already in place. Many of the plantation forests that are in NZ have been actively grazed over much of the last quarter century. While cattle grazing in forests started as a supplement to their diets, it is now used as a silvicultural tool to control competing weeds. According to a 1986 survey, there was roughly 60,000 ha of forest land currently under some form of grazing (Hammond). Remarkably, control of some weeds by grazing has proven more effective, and more economical than herbicides (Hawke and Knowles 1997).

Interplanting in the understory of forest grazed stands is sometimes done to help provide cattle with a complete diet. Some forest grazing stands with low nutrient levels, due to weeds in the understory, are supplemented with Maku lotus. Maku lotus is a small understory plant that can be used in AF settings. Like most good AF species, Maku is very adaptable to a wide range of site and climatic conditions, and doesn't compete with native tree species. Maku also has the added benefit of being able to grow up through slash. Maku is very nutritious for the cattle that eat it, showing substantial weight gains, and it has not been shown to cause any kind of bloating (Jones 1970). Furthermore, Maku has been shown to have very high forage yields, and is nitrogen fixing. The nitrogen fixation of the Maku has been shown in studies to have basal area responses from 12 percent-30 percent over a 5 year period (West and Van Rossen).

AF is used in a variety of ways in New Zealand, besides for radiata pine and maku lotus interplanting. One of the older uses of AF involves a tree we are all familiar with: poplar. Poplar has been promoted for a hundred years in NZ to help farmers stabilize erosion prone hillsides. One recent interesting study compared the pasture production of two sites: one in a traditional open setting, and the other in a silvopasture setting with poplar. The authors of the study found decreased soil temperatures in the poplar AF, and no significant correlation with soil water capacity. However, the main function of the poplars, in protecting eroded hillsides was fully served, and no further erosion was exhibited (Guevera et. al 1997).

Poplar has recently been shown to be an attractive option, and more research is underway determining its compatibility in pastured settings. One study by G.B. Douglas, and others et al. (1999), specifically addressed this measuring the growth rate of understory grasses and forbs in a silvopasture setting with poplar species. Gueveara-escobar et al. (1997)and others found in their own study, that pasture growth reductions under poplar can be staggering, reaching as high as 70 percent, with nearly a 20 percent decrease in protein levels (1997). G.B. Douglas found indisputable evidence that the trees in the pasture reduced the growth and nutrient quality, and increased litter level in the pastures. Overall, they found that natural pasture production under the poplars was decreased by 23 percent, compared to open environments (1997).

NZ has an excellent climate for AF development. The radiata pine plantations have been helping farmers realize their full economic potential for decades now. Not only are they useful in silvopastoral settings, but also as shelter belts, and in natural forest grazing areas. Promising research has also shown supplementing the herb (grazing) layer with other species such as the Maku lotus to achieve higher nutrient levels. Finally, poplar, although one of the older options in place in NZ, is not the least. Although poplar does cause some reductions in forage productivity, it serves the purpose of soil stabilization, and water retention of soils, while also providing shade and cover for cattle throughout the year. NZ's wide range of sites, mild climate, and adaptability of common AF species put it in the perfect spot to benefit from AF plantations.

Critique of successes/failures of systems

The Europeans have the advantage of using AF lessons taught form generations past, to help develop current technologies. The Dehasa system that has been in place for hundreds of years has shown real promise in nourishing cattle, while providing a source of marketable timber for the future. One problem with the Dehasa system, is that it needs continuous upkeep to maintain its present open grown savannah condition. A fluctuation occurred in the market in the 70s and 80s, which caused much of the Dehasa to be abandoned, due to low market prices. When this happened, competing regeneration took hold, and much of the abandoned farmland well kept under the Dehasa for hundreds of years was quickly invaded by weeds and shrubs. The cattle are an integral part of the AF system functioning, as are the people who guide them to graze. Without the cattle on the landscape, weeds quickly invade the fields, followed by other species of little to no commercial value. Although there is plenty of interest now in systems like this in the Mediterranean regions of Europe, the Dehasa system is currently considered endangered due to a few short decades of disregard.

However, other silvopasture systems are in place throughout other parts of Europe, and the biggest advantage to them is the public consent. Consumers in Europe are increasingly demanding a higher quality product, and with this comes more knowledge from the origins of these products. The wide diversity of landscapes in Europe is another such advantage that allows them to have so many outputs.   Not only can they use cattle or sheep in silvopastoral settings like the Dehasa, but they have the options of using their abundant forest resources to graze them in a natural woodland setting for part of the year to help supplement diets. High quality hardwoods have economic potential for Europe in years to come, as long as the nursery business continues to work with genetic improvement programs tailored to the regions they are grown in.

China is a real powerhouse in the modern agricultural world, with their abundant natural resources over an immense land base. China is has some very diverse climates as well, amenable to growing a wide variety of crops, from the mountainous arid regions, to the temperate lowlands, to tropical and subtropical regions in the South. One of their biggest cultural advantages is their long history of agriculture dating back to 100 B.C. Practices that were in place in the very early years of China have somehow held on, and knowledge has been passed down generations, in order to ensure that only the best planting practices are taken into the future.

Of the three countries, China seems to be in the most dire need for some modern AF advancements. They are faced with a population boom unlike that of the other regions, and will be forced to feed millions more on a decreasing agricultural land base. A desire for those in rural areas to move to the city and find a better way of life will decrease the number of rural farm families in China as well. However, this will likely not create a problem as most farm families in China currently own an average of only 0.1 ha, so an increase in land area may be beneficial. With an increase in overall farm size families should be able to produce more food in a more consistent manner.

China also has the advantage of having government backing on AF programs, which help farmers convert their land in a relatively short amount of time. The institution of Paulownia intercropping has proved to be an economic boon for many small villages throughout China, while still allowing them to grow the cash crops that they are dependent upon for basic nutrition. Hedgerow intercropping is also showing some real promise on degraded lands in some of the more mountainous regions of China. By helping to stabilize the hillsides, these systems are reducing overland runoff, decreasing nutrient loss, and reducing stream sedimentation.

New Zealand is the odd duck between the economic world powerhouse that is China and the quiet, developed region of Europe. NZ’s settlement history is relatively young, and many of the agricultural practices that have taken place there have been experiments in design. The oldest system in place in NZ is not thousands of years old, but maybe a hundred. The poplar trees in New Zealand, have been shown to help stabilize erosion prone hillsides, and increase nutrient retention in silvopasture settings. However, they have also been shown to decrease the forage availability to cattle. This could be a really big issue on an island that is generally considered constrained due to land ownership issues.

While NZ lacks in overall land base, they make up for it with their excellent growing season climate. The growth rate of radiata pine there is excellent, and an added bonus is the cattle production that they receive in companion with such silvopasture systems. With their relatively small population, they are in the perfect spot to meet their domestic timber needs, while providing a valuable export to countries around the world.

The grazing production under their radiata pine stands has been shown to be reduced slightly, but economic gains have been proven in the long run, with the management of pine on 20-30 year rotations. In areas of NZ that are already under forest cover, grazing can be supplemented underneath the radiata pine over story while selectively removing trees for profit. While the systems here do not seem quite as intricate, and developed as those of China or Europe, NZ sits in a unique location with a favorable growing environment, and a willing population of farmers.

Executive Summary

AF incorporates trees into farming systems with livestock and/or vegetable crop production. Using an AF system, farmers can increase their profitability, marketability, and most importantly, sustainability. Many different AF systems are in use throughout the world, including windbreak, silvopastoral, and intercropping. Each of these systems has enormous potential in their respective applications. Windbreaks are best used in arid areas to help reduce soil loss, silvopastoral systems are used where grazing of animals is needed along with timber production, while intercropping combines timber or fruit tree production with common sustenance crops such as wheat or corn.

AF systems have been used as long as humans have been practicing agriculture. Primary reasons for use of an AF system are land constraints, population growth, and rapid plant growth rate. Farmers in the tropics have used AF as a way to mimic the natural structure and diversity of the rainforest. In tropical regions, farmers are able to plant a few dozen different species, on no more than a tenth of an acre. Western Europeans have used AF techniques by leaving high value trees in pastured areas, to harvest at a later date. The Chinese have also used AF systems dating back hundreds of years. Early records show them using intercropping techniques with staple crops such as wheat and soybeans and higher value trees like chestnuts.

AF systems have a better environmental record than most traditional large scale monoculture based farming. Silvopastoral systems are known to have fewer weeds, reducing the amount of pesticides a farmer has to use for control. Intercropping has similar benefits, reducing the pesticide use, as well as improving the soil through nitrogen fixing varieties interspersed with another crop. The diversity of intercropped AF systems helps them reduce attacks from insects and disease, while providing a farmer with a number of valuable exports. AF is showing increased interest as citizens become more concerned about the environment they live in, and the negative affects of industrialized farming techniques.

The European Dehasa system is one of the oldest known AF systems in the region. The area of Spain farmed in the Dehasa is considered so unique, that conservationists are promoting preservation of the silvopasture techniques. Here, the savannah like landscape is sparsely populated with oak trees, while spaces between are planted with cereal crops such as barley or wheat. The trees help stabilize the soil, retain the soil water content, and influence precipitation on an ecosystem level. Although some areas have been abandoned under the Dehasa system, more than 2 million hectares are still being managed under this unique system.

The temperate areas of Europe are also well suited to forest grazing systems. These systems use sheep or cattle to graze the understory while high value timber species are grown above. The cattle help reduce the competition of invasive weeds, and help prevent the risk of a catastrophic wildfire. Forest grazing systems give farmers a much needed boost in income, especially when used with high value hardwoods suitable for growing in the region.

China has a variety of unique AF systems due to their diverse landscape. One of the most promising AF crops in China is the paulownia tree, which can be intercropped with cereal crops and provides a much needed secondary source of income. Paulownia is very fast growing, and farmers can intercrop it with many common sustenance crops, allowing them to feed their families, while producing a valuable timber export. In mountainous areas of China, hedgerow intercropping is a popular system. Hedgerows provide a variety of benefits including reducing soil loss, increasing soil fertility, and increasing soil organic matter. Hedgerow crops have been shown to increase productivity on farms, helping farmers to increase their net profit.

The temperate climate of New Zealand is well suited to AF farming techniques. Radiata pine is most frequently planted in AF systems here, as it has incredible growth rates, and provides a valuable timber exports. It is commonly used with silvopasture grazing cattle or sheep underneath, which provide farmers with a continuous secondary source of income. Forest grazing is also done in New Zealand with benefits similar to those of techniques used elsewhere. Forest grazed stands have shown less use of pesticides to control competing weeds, along with a diversified income for the forest landowner. In steeper regions of New Zealand, poplar is commonly planted in pastured areas to help stabilize erosion prone hillsides.

AF has a variety of uses throughout the developed and developing world alike. Farmers practicing AF techniques do not need a range of expensive machinery, but instead a simple understanding of the land that they are working with and the knowledge to implement the system while maintaining a profit. AF systems provide a number of benefits including a secondary source of income, improved soil moisture content, improved organic matter, less pesticide use, stabilized soil, and higher nutrient contents. AF has been practiced throughout the world for hundreds of years, and is still used today in many areas in the world. AF systems are varied to suit a variety of landscapes throughout the temperate world. AF systems are well suited to help a growing population meet their consumer demands with the simultaneous production of food and timber.

Works Cited

Batish, Daizy Ray., et al. Ecological Basis of Agroforestry. New York. CRC. 2008

Baldy, C., Dupraz, C. and Schilizzi, S. "New of Agroforestry and Climate Moderation in the Mediterranean." Book of Agricultures 2, 375-380

Bongaarts, John. Future Population Growth and Policy Options. Publication. New York: Population Council, 1997.

Brownlow M.J.C., Doward P.T., and Carruthers S.P. "Integrating Natural Woodland With Pig Production in the United Kingdom: An Investigation of Potential Performance and Interactions." Agroforestry Systems. 64: (2005): 251-263

Brandle, J.R. and J. Kot. "A windbreak evaluation model." Ontario, Ridgeway,. Canada. Ridgetown College. 1991.

Buck, Louise E., James P. Lassoie, Erick C.M. Fernandes. Agroforestry in Sustainable Agricultural Systems. New York. CRC. 1998.

Clason T.R. "Economic implications of silvopasture on southern pine plantations." 1995. Agroforestry Systems: (29) 227-232

Chacon, J.C. and Gliessman, S.R. " Use of the "non weed" concevpt in traditional tropical agroecosystems of south-eastern Mexico." Agro-ecosystems. 8 (1982) 1-11.

Dupraz, C., and S.M. Newman. Temperate agroforestry: the European way. In Temperate Agroforestry systems, ed. A.M. Gordon and S.M. Newman, 181-236. Wallingford, UK: CAB International. 1997.

Fangdong, Li. "Light Distribution, Photosynthetic Rate and Yield in a Paulownia-wheat Intercropping System in China." Agroforestry Systems 74 (2008): 163-72.

Fenton, R. and Sutton, W.R.J. "Silvicultural proposals for radiata pine on high quality sites. New Zealand Journal of Forestry. 13 (1968) 220-228

Francis, Chares A, ed. Multiple Cropping Systems. Macmillan Publishing Company: New York. 1986.

Guevera, Auerelio., et. al. "Pasture production and compoistion under poplar in hill environment in New Zealand." 2007. Agroforestry Systems. 69:199-213.

Guevera-Escobar A., et. al. "Case study of mature Populus deltoides-pasture system in a hill environment." 1997. NZ Grassland Association. 59:179-185

Gold, M.A. and Hanover, J.W. "Agroforestry for the temperate zone." 1987. Agroforestry Systems. 5: 109-115.

Gordon, Andrew M., Steven M. Newman. Temperate Agroforestry Systems. New York. CAB International. 1997

Hammond, D. "Survey of agroforestry in New Zealand." In: macLaren, P. (ed.) Agricultural Symposium Proceedings. New Zealand Ministry of Forestry. Forest Research Institute, Bulletin 139 pp. 14-16

Hawke, M.F. and Knowles, R.L. 1997. Temperate Agroforestry in New Zealand. In Temperate Agroforestry (Ed. Gordon A. and Newman S.) CAB International, UK.. 267 pp.

Innis, Donald Q. Intercropping and the Scientific Basis of Traditional Agriculture. London. Intermediate Technology Publications Ltd. 1997

Joffre, R., et. al. "The dehasa: an agrosilvopastoral system of the Mediterranean region with special reference to the Sierra Morena area of Spain." Agroforestry Systems. 6 (1988) 71.

Jones, W.T., Lyttleton, J.W., and Clarke, R.T.J. "Bloat in Cattle: The soluble protiens of legume forages in New Zealand and their relationship to bloat. New Zealand Journal of Agricultural Research. 13 (1970) 149-156

Jose, Shibu. Gillespie, Andrew R. "Allelopathy in black walnut alley cropping. Plant and Soil. 203 (1998) 191-197

Lelle, M.A. and Gold, M.A. "Agroforestry systems for temperate climates: lessons from Roman Italy." Forest and Conservation History. 38 (1994) 118-120

Lin, C.H. et. al. "Shade Effects on Forage Crops With Potential in Temperate Agroforesetry Practices." Agroforestry Systems. 44 (1999) 109-119

Lundgren G.K., Conner J.R., and Pearson H.A. "An economic analysis of forest grazing on four timber managment situations. 1983. South J Appl For: (7) 119-124

McNamara, Robert. One hundred countries, two billion people; the dimensions of development. Praeger Publishers Inc. 1973

Nair, P.K.R., ed. Agroforestry Systems in the Tropics. Massachusetts. Kluwer Academic Publishers. 1989.

Nair, P.K.R. An Introduction to Agroforestry. Massachusetts Kluwer Academic Publishers. 1993.

Nair, P.K.R. . Soil productivity under agroforestry. The Hague, the Netherlands. Martinus Nijhoff Publishers. 1987

Potter, M.J. “Treeshelters” Forestry Commission Handbook. 1999. No. 7, HMSO, London, pp. 48

Rietveld, W.J. “Allelopathic effects of juglone on germination and growth of several herbaceous and woody species.” Hournal of Chemistry and Ecology. 9 (1983): 295-297

Sun, Hui., Tang, Ya., Xie, Jiasui. “Contour hedgerow intercropping in the mountains of China: a review.” Agroforestry Systems. 73 (2008) 65-76

Sutton, W.R.J. 1972. “Mechanisation of pruning-a summary. Proceedings of the 15th IUFRO Confress, IFURO Division No. 2, Publication NO. 1. (NZ FRI Reprint 562).

Tang, Y. “Manual on contour hedgerow intercropping technology. ICIMOD. Katmandu, Nepal. 31 p.

Van Sambeek, J.W. “Ranking the Shade Tolerance of Forty-five Canidate Groundcovers for Agroforestry Plantings. 15 (2007):

US Forest Service Center for Agroforestry. University of Missouri. “Hardwood silvopasture management.” Columbia, MS. 2010.

Vivian, John. “The Three Sisters-The Nutritional Balancing Act of the Americas.” Mother Earth News. Feb./Mar. 2001. 50+

West, G.G., and Van Rossen, R. “Cutover oversowing for weed control and improved tree growth. In: Zabkiewicz, J. (ed.) Proceedings, Workshop on Forestry Weed Control. NZ Forest Research Institute Bulletin No. 183

Wu, Y.Y. “Paulownia-crop intercropping to promote sustainable development of rural economics.” Forestry and Society. 1992.