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RESEARCH ARTICLE

Silvopastoral systems as a strategy for drought resilience: A short international review

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Abstract

Agroforestry is the combination of wooden plants (trees and shrubs) with agriculture or pasture from the same area. Silvopastoral systems combine natural resources such as planted trees and livestock in the land management unit. This combination would provide environmental and financial benefits. Some of the environmental benefits include aesthetics, water quality, improvement, soil conservation, carbon sequestration, biodiversity and fuel reduction. Using online search about 20 relevant research reports were found and reviewed to present the main research outcomes and experiences on silvopastoral systems around the globe. The results indicated that silvopastoral systems could be beneficial to the landowners and farmers which could improve drought resilience by increasing air humidity and reducing weather temperature impact which eventually contributed to mitigation fire risks in farms. From a financial perspective, silvopastoral systems proved to be an attractive financial practice especially when silvicultural treatments were implemented in year zero to increase timber production. The negative aspects were long payback periods and high risk to consider in native forest management.

Keywords

Silvopastoral System, Drought, Resilience, Farm, Forest

Introduction

Agroforestry is the combination of wooden plants (trees and shrubs) with agriculture or pasture from the same area. Agroforestry is a traditional form of land management with a long history. Central Europe has had large areas of combined wooden plants and farms a long time (Markut et al., 2022). According to Timber Queensland (2021) and the Department of Agriculture, Water and the Environment (2022), silvopastoral systems combine natural resources such as planted trees and livestock in the land management unit. This combination would provide environmental and financial benefits. Some of the environmental benefits include aesthetics, water quality improvement, soil conservation, carbon sequestration, biodiversity and fuel reduction (Sales-Baptista, Ferraz-de-Oliveira, 2021). Financial benefits may include income diversification, increasing the resilience of a farm to the impact of climate change and complementing annual cash flows from livestock with longer term timber harvesting income (Timber Queensland, 2021; Stephens, 2023).

A research project on silvopastoral systems (SPS) was initiated to include pasture, timber and beef production at Caribbean pine plantation managed by HQP in Cardwell, Queensland in 2021. Three scenarios (treatments) were considered including commercial pine plantation at full tree stocking (approximately 1000 stems per hectare), SPS in pine plantation with timber and livestock production with 30% tree thinning and SPS in pine plantation with timber and livestock production with 50% tree thinning. There is still need to improve knowledge on SPS in Australia and globally thus this research was taken to review the key literatures on SPS to provide a comprehensive overview of these farm/forestry management methods for the academic and industry users.

Literature review

To find the required literature for this short review, the following keywords in English were used: Silvopastoral Systems, Drought, Resilience. The electronic search Google Scholar was used which generated 3,270 cases. Through screening and filtering, a total of 19 reports were chosen to prepare the literature review (note only one German report was selected to be used in the introduction).

North and South America

Brazil

Sarabia et al. (2020) mentioned that the farms are usually monoculture systems planted with major native grasses or African grasses. As animals graze and gain further weight they produce more methane (CH_4) and nitrous oxide (N_20) which needs to be managed. In Latin America, one of the effective management ways is the application of SPS. These systems can establish high dense shrub legumes and forage grasses to increase livestock economic returns. This will lead to 100% increase in forage quality compared with monocultural systems which will reduce the costs associated with buying cereal grains and nitrogen fertilisers. Sarabia et al. (2020) suggested a combination of legume species with grasses and *Leucaena* (*Leucaena leucocephala* L.) which could improve soil fertility and animal productivity. These scholars indicated that SPS are widely and successfully applied in different regions of the world. Scientific data proves that higher production, higher carbon sequestration and improved N cycling on farms used for livestock production can be achieved by SPS. Assad et al. (2022) conducted an integrative review on the adaptation and resilience of agricultural systems to climate change and extreme events. They found that two policies in Brazil, including a low carbon agriculture plan and a national plan on recovery of native vegetation, may contribute to adaptation and resilience of agricultural systems. Adding an arboreal component to agricultural production systems could provide following advantages including increased resilience to the drought, higher air humidity, decreased temperature impact and diminished fire risk.

Columbia

Cuartas et al. (2014) reported that intensive silvopastoral systems (ISS) are seen as useful options in Columbia as they can contribute to the seasonality of plants and animal production. The main effect of ISS is mitigation emissions, and it is anticipated that application of ISS can remove up to 26.6 tons of CO_2 eq/Ha/yr from the atmosphere. Profitability of animal production would increase using ISS. Research findings showed that ISS resulted in higher protein content of meat (14.3 *vs*. 10.0%) and lower content of neutral detergent fiber (58.4 *vs*. 66.8%) compared to traditional grazing diets. Nicolls, Altieri (2012) published a report on agro-ecological approaches to enhance resilience. They indicated that a five story ISS composed of a layer of grasses, *Leucaena* shrubs, medium-sized trees and a canopy of large trees has been established in a farm located in Cauca, Colombia. This case of ISS has been used over 18 years and it has increased the stocking rates to 4.3 dairy cows/ha and its milk production by 130%. Using ISS in that farm removed the need for chemical fertilization as a positive environmental impact.

Costa Rica

Olivero Lora (2011) conducted her thesis on the functional trait approach to assess the ecological process of drought and water use efficiency in SPS. She studied 20 traits and found that species such as *Guazuma ulmifolia* and *Crescentia alata* were useful to improve ecosystem services of drought resistance and pasture production in Rivas areas. In dry seasons, these species could prevent significant amounts of evapotranspiration under their canopies while providing sufficient light transmission to reach the understory to support pasture growth.

Mexico

Solorio et al. (2017) indicated that pastures have deteriorated due to some causes such as low soil fertility and irregular pattern of rainfall distribution in Mexico. To deal with climate change impact, agricultural systems can benefit from linking adoption with mitigation. Thus, SPS were introduced that could result in higher productivity, lower costs, and lower environmental impact (including improved carbon sequestration and system resilience). Sanchez-Romero (2021) applied an integral analysis to find management strategies, SPS practices and socioecological drivers in traditional livestock systems in tropical dry forests located in western Mexico with average rainfall of 800 mm. The Mexican scholars conducted interviews with 32 cattle farmers in the region. Considering the limited resources, the adaptive management of livestock and forests provided an opportunity for forest conservation and SPS practices using local species. The SPS practices included forest browsing (100% of interviewees), allowing trees amongst grasslands (100%), live fences (47%), planted multi-purpose trees (22%) and selective forest clearance (16%). Most cattle farmers (91%) rotated cattle between plots. Main woody forage species in the area were Cascalote (*Caesalpinia coriaria*), Huizache (*Acacia* sp.), Habillo (*Hura polyandra*), Guajillo (*Leucaena lanceolata)* and Ebano (*Caesalpinia sclerocarpa*). Other frequently mentioned species (72% of interviewees) with forage and other uses (fencing, fuelwood, shade), were Barcino (*Cordia eleagnoides*), Coral or Acatizpa (*Caesalpinia platyloba*) and Cacahuanance (*Gliricidia sepium*).

USA

According to Cubbage et al. (2012) SPS is used in the Southeast USA. They reviewed SPS and its prospects in eight regions of the world. In the USA, the system combination includes pine trees with warm-season and cool-season grasses and cattle. Trees are mainly native *Pinus spp.* Natural hardwood stands might also be used in some areas. Two or three rows of trees are usually planted by leaving an alley of 12 m between the rows to allow greater light penetration for pasture growth. The typical size of SPS is about 16 ha in the southeast USA. Research results in North Carolina showed that during extreme drought most of the crops failed; however, planted trees survived and grew well. Species included loblolly pine (*Pinus taeda*), longleaf pine (*Pinus palustris*), and cherrybark oak (*Quercus pagoda*) (Glenn et al., 2011). Shade provided by trees can improve livestock growth especially in climate conditions such as high temperature and humidity conditions. Shade results in various benefits such as improved animal condition, milk production, breeding efficiency, feed intake, and weight gain. Walter (2011) reported that the impact of shade depends on animal selection, high heat-humidity indexes, types of grass and rotational grazing. In southern states such as Alabama, Arkansas, Georgia, Louisiana and Mississippi , silvopastoral systems combine cattle grazing under hardwoods, nut orchards and Pecan plantations (*Carya illinoinensis*). In southern states timber production is not an objective in land management (Ares et al., 2006). However, in commercial plantations, growing livestock would provide extra fertilisation, weeding and extra income (Jose, Dollinger, 2019).

Europe

Bulgaria

According to Kachova et al. (2018), Bulgaria's agroforestry includes various activities such as protective forest belts, agricultural farming (agricultural usage of forest areas) and SPS. The application of these systems could help diversify the production from farmlands and forest areas in addition to several ecological and social benefits. Forest areas could yield products such as leaf fodders, fruits, and other natural products while grass and feed crops are produced in grass areas. Hinkov et al. (2019) focused on Old Oak Forests in Krumovgrad State Forestry Unit, Eastern Rhodopes Mountains. Their study examined the impacts of long-term grazing and subsequent abandonment on these forests, highlighting soil exhaustion, erosion, and reduced regeneration. Despite these challenges, the study also identified valuable genetic diversity and regeneration potential, noting improvements in forest health since grazing reduction. It suggested protecting some areas as old-growth forests under Natura 2000 or Forest Stewardship Certification to safeguard their ecological value. Bencheva and Petkova (2023) published a guide on agroforestry practices applicable for Bulgaria where they pointed out that SPS is applied in some regions of Europe with temperate climate such as Croatia and Montenegro. To apply SPS, selected trees should be high-quality, resilient to environmental challenges. Fodder can be a mix of annual and perennial species, productive in shade and drought, and resilient to grazing. Livestock, like cattle, sheep, goats, pigs, birds, etc. should align biologically with trees and fodder, meeting ecological and legal land use standards (Bencheva, Petkova, 2023).

Greece

Jucker Riva et al. (2017) studied the impact of various land management on the resilience of Mediterranean forests and rangelands on eight study sites in five countries including Cyprus, Greece, Italy, Portugal, and Spain. SPS was practiced in some of the study areas in Greece which provided various services including production (animal and plant productivity, land available for production), ecology (reduced erosion, above ground biodiversity) and socio-culture (maintaining traditional landscape). Grazing lands were afforested by carob trees (SPS) which provided higher resilience to drought compared with the extensive grazing systems in Greece. Jucker Riva et al. (2017) also noted that there are some incompatibilities among land management objectives such as increasing resilience of ecosystems to the drought might reduce the resilience to fire.

Portugal

Acacio and Holmgren (2014) reported that the extensive usage of ever green cork oak (*Quercus suber*) has resulted in soil erosion and deforestation. Degraded lands have been covered by pioneer heathland rockrose (*Cistus* spp.) shrubs in the Iberian Peninsula. Currently 70% of total cork oak forests are under SPS management. Planting density varies from 40 to 80 trees per ha in flat terrains of cork oak area. Cork is the main use of planted trees. Understory is used for pasture and/or crop production including wheat, barley, and oat. Soil fertility will dictate the intensity of grazing and crop production. Portuguese researchers indicated that grazing can be an expensive land use option especially when farms are small with low fertility.

To improve the restoration of cork oak stands, Acacio, Holmgren (2014) suggested some actions including removal of Cistus shrubs, planting or seeding acorns, and planting nurse shrubs to increase oak seed germination, seedling survival (Gómez-Aparicio et al., 2004) and perch the trees to attract long-distance dispersers such as jays (Walker, Del Moral 2009). Drought is a threat to seedling survival in Mediterranean-climate regions therefore the artificial planting techniques should be modified to work better in dry conditions to combat the climate change impacts or as post-fire restoration techniques (Vallejo et al., 2006). Sales-Baptista, Ferraz-de-Oliveira (2021) reported an international literature review which pointed out that there are two types of SPS including ancient and intensive systems. The ancient systems were mostly based on cultural grounds and focus on conservation issues regarding the soil and plants. Intensive systems are mostly production-oriented ones which consider climate change mitigation programs as well. The intensive silvopastoral systems were introduced to land use management due to technological changes in grazing livestock models. Both ancient and intensive SPS has been widely applied internationally under various grazing methods and animal species. Both systems can be applied in a wide range of available combinations in the integrated and sustainable land use management.

Oceania

Australia

Timber Queensland (2021) and the Department of Agriculture, Water and the Environment (2022) commenced some trials on silvopastoral systems in Queensland's forests and farms. Lewis et al. (2022) suggested private forest in southeast Queensland could have the potential for SPS in regrowth forests. They pointed out that appropriate pasture and tree species, suitable planting configurations and spacing (e.g. double row planting with spacing of 10-20 m between paired rows) should be selected to ensure success. Another study by Francis et al. (2022) compared traditional forest management practices in southeast Queensland against silvopastoral system alternatives over a period of 20 years. Their results confirmed that SPS was an attractive financial practice especially when silvicultural treatments were implemented in year zero to increase timber production. The negative aspects for SPS were long payback periods and sovereign risk to consider in native forest management. A recent thesis was completed by Bell (2023) in Queensland. His study showed that the application of SPS in subtropical forests can impact carbon sequestration. Tree growth can be enhanced by managing native forest through thinning treatments. From a carbon perspective, although the application of SPS improved the pasture growth by sowing forage species post-thinning, it, however, accelerated carbon posture loss. Table 1 provides a summary of key literature review findings on the application of SPS in different regions of the world covered in this article.

Table 1. Summary of key literature review results on silvopastoral systems

Region	Key findings
America	- Enhance drought resistance and pasture production - Reduce fire risk and improve carbon sequestration. - Increase animal production including milk, breeding efficiency and weight gain.
Europe	- Improve drought resilience by application of artificial planting. - Improve animal production, high ecological benefits (reduced erosion, above ground biodiversity) and socio-culture (maintaining traditional landscape).
Oceania	-Increase timber production and pasture production through silvicultural treatments in native forests. - Long payback period and high risk for native forests as negative aspects.

Conclusions

From a South American perspective, the ISS could be beneficial to the landowners and farmers which could improve drought resilience by increasing air humidity and reducing weather temperature impact. This would eventually contribute to fire risk mitigation in farms (Table 1). The North American experience with SPS indicated similar benefits. In the Southern USA, timber production from SPS was not a primary interest to the farmers; however, positive impacts on increased animal production (milk, breeding efficiency and weight gain) were mostly reported. European SPS trials have strongly shown positive effects on sustainable land management (Table 1). It is notable that the main objective of modern silvopastoral systems is based on production rather than conservation goals dominated in old European silvopastoral systems.

From a biological perspective, international knowledge emphasized on a proper selection of species that can cope better with water stress and factors such as leaf area index, canopy density and phenology, could be used to predict drought responses. Future research is required to investigate ecological processes that link functional diversity with an ecosystem service to support SPS management and design (Olivero Lora, 2011). There is still much to learn about the interactions between different tree species, forage plants, and livestock under drought conditions. More research is needed to identify optimal species combinations and management practices that maximize resilience to prolonged dry periods while maintaining productivity and ecosystem services. Climate change is altering rainfall patterns and increasing the frequency and intensity of droughts in many regions, including areas where silvopastoral systems are implemented (Table 1). There is a need for research that examines how changing climatic conditions will affect the performance and sustainability of silvopastoral systems over the long term. This includes studying the resilience of different tree and forage species to future climate scenarios, as well as exploring adaptive management strategies to mitigate the impacts of climate change on silvopastoral productivity and ecosystem functioning. Addressing these knowledge gaps will be essential for advancing the development and adoption of silvopastoral systems as a sustainable land use practice, particularly in regions prone to drought and other climate-related challenges.

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