Syntropic farming systems for reconciling productivity, ecosystem functions, and restoration

Johanna Jacobi, Christian Andres, Farhah F Assaad, Stéphane Bellon, Xavier Coquil, Sebastian Doetterl, Dayana Naimid Esnarriaga, Diana Ortiz-Vallejo, Cyrille Rigolot, Johanna Rüegg, Sylvain Takerkart, Martin Trouillard, Boris Vilter, Janina Dierks

Inspired by the succession and vertical stratification found in nature, syntropic farming systems (SFS) incorporate annual and perennial plants in diversified farming systems. Numerous practice examples show the potential of SFS to enhance agroecosystems via optimised design and active management. Yet, scientific knowledge on SFS remains scarce, especially in the temperate zone. We compiled findings on the outcomes and enablers of SFS from 67 studies comprising diverse SFS designs—mainly from tropical countries—that have the potential to be implemented in temperate agricultural landscapes. Most studies highlight the high agrobiodiversity, nutritional diversity, and yield quality of SFS. Comparing the productivity of SFS with other farming systems shows mixed results. Carbon storage, soil fertility, water cycling, climate resilience, and plant health appear favourable in SFS across widely varying cropping systems and environments. SFS can also provide meaningful and dignified work. Nevertheless, remaining obstacles include high labour demand, intensive knowledge requirements, availability of tools and machines for SFS, and a lack of enabling policies. Efforts should focus on harnessing SFS to address the escalating socioecological crises in agri-food systems worldwide, including those of intensively managed cropland systems in the temperate zone where SFS systems could help to redesign agricultural landscapes.

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Federal Institute of Technology (ETH Zürich), Zürich, Switzerland (Prof J Jacobi PhD, C Andres PhD, Prof S Doetterl PhD, D N Esnarriaga PhD); **TUM School of Life Sciences, Technical University of Munich, Munich, Germany** (Prof F F Assaad PhD); **National Research Institute for Agriculture, Food and the Environment (INRAe), Villeneuve-d'Ascq, France** (S Bellon MSc, X Coquil PhD, D Ortiz-Vallejo PhD, C Rigolot PhD, B Vilter BSc); **Research Institute of Organic Agriculture (FiBL), Frick, Switzerland** (J Rüegg MSc); **Vers des Vergers Ouverts, Urbains, Méditerranéens (VVOUM), Marseille, France** (S Takerkart PhD); **Research Institute for Organic Agriculture (FiBL France), Eurre, France** (M Trouillard PhD); **Institute of Crop Science & Resource Conservation, University of Bonn, Bonn, Germany** (Prof J Dierks PhD)

Correspondence to: Prof Johanna Jacobi, Institute of Agricultural Sciences (ETH Zürich), 8082 Zürich, Switzerland **johanna.jacobi@usys.ethz.ch**

Introduction

To address sustainability issues concerning food production, a transformative redesign of our agricultural systems is necessary.[1] Syntropic farming systems (SFS) are a unique form of agroforestry inspired by the functioning of natural forests in space and time.[2] Core principles of SFS design and management are: (1) ecological species succession; (2) stratification emphasising high plant diversity and density within each stratum; and (3) apical and lateral pruning and mulching, including weeding in a selective and targeted manner to stimulate successional processes and dynamic system development.[3] Plant consortia include specific perennial herbs, shrubs, and trees[3] that contribute to in situ production of plant residues that cover the soil continuously and build up soil organic matter.[4] SFS are established to optimise the use of available resources—especially light,[5] water,[6,7] and nutrients[8,9]—across vertical strata and time (figure 1) and to minimise the use of external inputs.[10] As a result, a multifunctional agroecosystem can be achieved that produces goods from under 1 month (eg, young leaves and medicinal herbs) to decades (eg, fruits, berries, nuts, mushrooms, timber, etc).[11,12] A growing community of practice now commonly uses the term syntropic to refer to the accumulation and organisation of energy via optimised photosynthesis and biomass management, enabling greater differentiation and system complexity.[2] Other terms used are successional or dynamic agroforestry. The method promotes ecological principles, including facilitation and niche differentiation. SFS have been inspired by indigenous agroecosystems in tropical and subtropical climates,[13,14] encompassing successional cropping systems—eg, in Mexico,[15–18] East Africa,[19] Madagascar,[20] Indonesia,[21] Micronesia,[22] and India.[23]

By fostering biodiversity and promoting soil regeneration, SFS are increasingly recognised for their resilience to biotic and abiotic perturbations and their potential contribution to sustainable agriculture. Moreover, SFS have been successfully established on degraded and marginal lands, enabling regeneration as an effective tool for ecological restoration[24,25] and contributing to a biodiverse matrix outside of protected natural areas.[26–28] SFS remain more common in tropical and subtropical regions, but are gaining increasing attention in temperate regions.

Syntropic farming thus represents a transformative approach with potential benefits in agronomic (eg, high quality, diverse yields, and sustainability), ecological (eg, soil and plant health, carbon storage, and water cycling), economic (eg, diverse products without technological dependency), and social (eg, farmers' wellbeing and autonomy)[2,29] domains. Previous reviews on SFS[27,28] found that designing agroecosystems to resemble natural forest structures can improve soil fertility and reduce soil erosion and pest and disease pressure. However, the absence of in-depth knowledge on biological processes and socioeconomic conditions has been identified as a major obstacle to large-scale adoption of SFS.[27,28]

In this Personal View, we asked the following question: what does the available scientific evidence show regarding the biophysical and socioeconomic outcomes of SFS, in particular with a view to assessing the economic viability, labour requirements, (possible) market links, and implementation of SFS in intensive, mechanised agricultural landscapes of temperate climate regions? One key knowledge gap concerns the potential of SFS to productively restore intensive agricultural landscapes in temperate zones such as those in Europe. Therefore, we systematically reviewed existing empirical

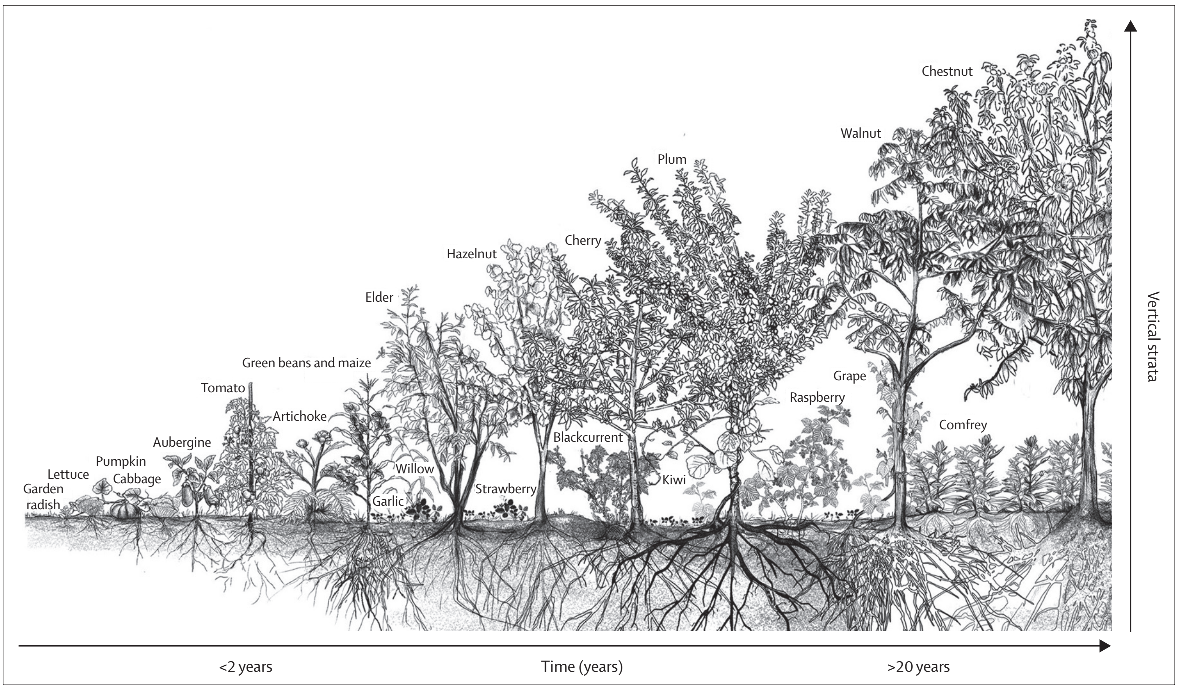

Figure 1: **Illustration of the dynamics of a vertically stratified multifunctional plant species assemblage adapted for syntropic farming systems that are suited to temperate European climate conditions**

Syntropic farming systems (SFS) are designed to cover all stages of ecological succession—including pioneer species (eg, short-lived annual crops), intermediate species (eg, stone fruits), and climax forest species—with all components usually sown and planted at the start. In addition to diverse edible, ornamental, medicinal, and otherwise usable plants, so-called service plants for biomass are an integral part of SFS plant consortia.

studies on the benefits and challenges of SFS and made a first attempt at illustrating the potential of SFS in European contexts.

Methods

See Online for appendix

We applied a PRISMA review flow diagram[30] (appendix p 3) to identify scientific studies on SFS. After applying our search criteria, 56 studies were retained. We then screened 41 additional studies from our own libraries and the literature lists of others. Of these, 11 were retained, resulting in a total of 67 studies included in our review. Notably, we might have overlooked studies that do not explicitly mention the management principles we focused on and studies in languages not found in Web of Science or our literature databases. When evaluating the studies, we specifically emphasised potential regional and climatic biases and grouped ecological and socioeconomic variables of SFS management into outcomes (ie, productivity, agrobiodiversity, carbon storage, soil fertility, water cycling and climate resilience, plant health, income and production costs, labour, product diversity, and nutritional diversity) and enablers (ie, motivation, obstacles, policies, and knowledge) according to the direction of impact (figure 2; appendix p 4). For exemplary designs of potential SFS in Europe (figures 1, 3, and 4), we visited syntropic farms in different pedoclimatic zones[31] (ie, continental and Alpine South).

Results and discussion

Of the 67 empirical studies included, most were conducted in Latin America, particularly 32 (47·8%) in Brazil and 18 (26·9%) in Bolivia, where SFS were initially developed and studied in long-term field trials, projects, and research centres. The remaining studies were conducted with four (6·0%) in Mexico, two (3·0%) in Costa Rica, one (1·5%) in Colombia, and one (1·5%) in Ecuador; three studies were conducted in Europe, including two (3·0%) in Portugal, and one (1·5%) in Germany; and five in Africa, specifically two (3·0%) in Ghana, two (3·0%) in Côte d'Ivoire, and one (1·5%) in Tanzania. One (1·5%) study came from Yunnan, China.

The scale ranged from very small and repeated test plots[32] to a 2300 hectare farm featuring 36 hectares of SFS.[33] SFS were mostly compared with other cropping systems in 48 (71·6%) studies and with natural regeneration forests in 25 (37·3%) studies. The results according to the reference system are shown in figure 5. However, 14 (20·9%) studies—emphasising products, nutritional diversity, and more—did not include a reference system. The variety of reference systems and SFS designs in our sample restricted our ability to derive strict conclusions. Nevertheless, by systematically reviewing the literature, we uncovered potential benefits and challenges of SFS. Most studies pointed to positive effects in SFS (62 [92·5%] of 67 studies), particularly with respect to ecological outcomes (54 [96·4%] of 56 studies reporting ecological outcomes), socioeconomic outcomes (29 [90·6%] of 32 studies reporting socioeconomic outcomes), and enablers across a broad range of cropping systems and environments. 29 (43·3%) of all 67 studies also showed no effects or negative effects for specific categories. SFS rarely performed worse than the reference cropping systems. Even compared with natural regeneration, SFS often performed (equally) well. Measurements were frequently made on young SFS; as a result, specific SFS benefits might have been underestimated, such as in the case of slow-growing timber trees.[34] Furthermore, most studies were from the tropics and subtropics; for many parts of the world, we found no studies on SFS, which might limit the relevance of SFS findings for other regions of the world. However, this might also result in underestimating the potential of SFS to improve the sustainability and resilience of temperate agroecosystems, and their ability to restore degraded land.

Outcomes

Productivity

Of the 19 studies that investigated the productivity of SFS, 11 (57·9%) reported positive results compared with other production systems. These results mainly referred to the total system yield of edible crops[11,16,19,27,29,33,35–37] in SFS, but also their yield of key cash crops including cassava, tomato, papaya, citrus fruits,[11] cocoa,[38,39] oranges,[40] and castor beans.[41] Notably, yields of castor oil in SFS almost doubled compared with monocropping and the total system yield of SFS was 4·2 times greater in Brazil.[41] In Côte d'Ivoire,[27] SFS were found to produce significantly higher pod counts and cocoa dry bean yields. In the Bolivian lowlands, cocoa productivity in SFS was similar to monoculture and SFS simultaneously produced a multitude of different products.[29] On-field trials showed lower cocoa yields in SFS,[27] but total system yield for marketable goods (eg, cocoa, bananas, fruits, and tubers) were 43%[37] to 200%[35] higher than in other production systems. Although SFS produced fewer cocoa pods, yield per pod was higher than that of monocultures.[42] With respect to maize and okra[43] and cocoa,[44] SFS yields were 41% and 65% lower compared with other production systems, respectively. Possible reasons for these findings were poor seed quality[43] or reduced flowering success from shading or lack of pollination.[37,44] Beyond increasing total system yields, SFS tend to regenerate degraded land and provide construction material and firewood.[41]

Agrobiodiversity

We understand agrobiodiversity as encompassing the wide variety of species that are directly or indirectly integrated in farming systems, including microorganisms, predators, and pollinators that support agroecosystems.[45] Agrobiodiversity is intrinsically linked to the structural and temporal complexity of SFS.[9] A total of 26 (89·7%) of 29 studies reported high agrobiodiversity for SFS.[11,12,19,29,34–37,41,43,46–56] Of particular note with regards to ecosystem functioning, endangered tree species[29] and native trees and shrubs[47] are often purposefully included and maintained in SFS. These species provide important habitats for birds and pollinators[12,49,57] and can be used for their essential oils for pest control or aromatic purposes.[49] Vertical stratification, overall high functional diversity, and subsequent broad niche occupation enable native and slow-growing species to thrive—in contrast to the generalist species that dominate in conventional systems—including glyphosate-resistant species such as *Amaranthus viridis*.[49] In this way, SFS actively maintain aboveground biodiversity and contribute to conservation. Overall, the relative effects of SFS on belowground biodiversity and natural regeneration remain understudied and should be emphasised in future research. Still, for some taxa, there is evidence that soil-biodiversity richness in SFS is comparable to natural regeneration (eg, for arbuscular mycorrhizal fungi[58] or epiedaphic fauna)[59] or higher (eg, for earthworms),[53] and is also higher than in other cropping systems (eg, for fungi in general).[60]

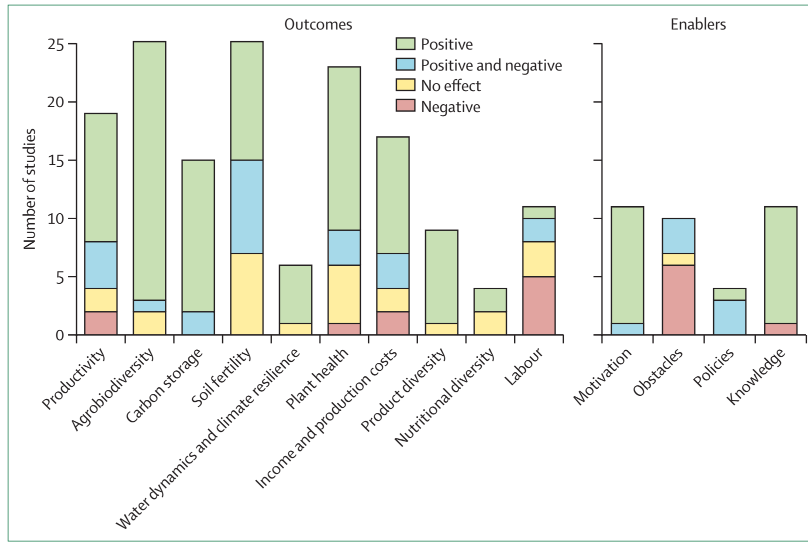

Figure 2: **Biophysical and socioeconomic outcomes and enabling factors from 67 studies on syntropic farming systems based on direction of effect, including both quantitative and qualitative results**
The reference systems are specified in the respective results section of this article and in figure 5. "Income and production costs" refers to results on economic aspects, such as higher incomes or lower production costs as a positive outcome. "Motivation" refers to the rationales behind starting and managing syntropic farming systems (SFS) in a positive case or stopping it in a negative case. For "Labour", positive results refer to lower labour intensities. "Obstacles" are difficulties and context factors that impede starting and managing SFS. Obstacles are mostly negative to SFS, but sometimes actively overcome. Studies that did not consider specific outcomes are not shown here.

Carbon storage

According to the International 4 per 1000 Initiative: Soils for Food Security and Climate, increasing carbon in the top 30–40 cm of soil by just 0·4% (on average 0·6 Mg/hectare) annually could mitigate the annual atmospheric rise of carbon dioxide.[61] Given the importance of carbon sequestration, it is promising that

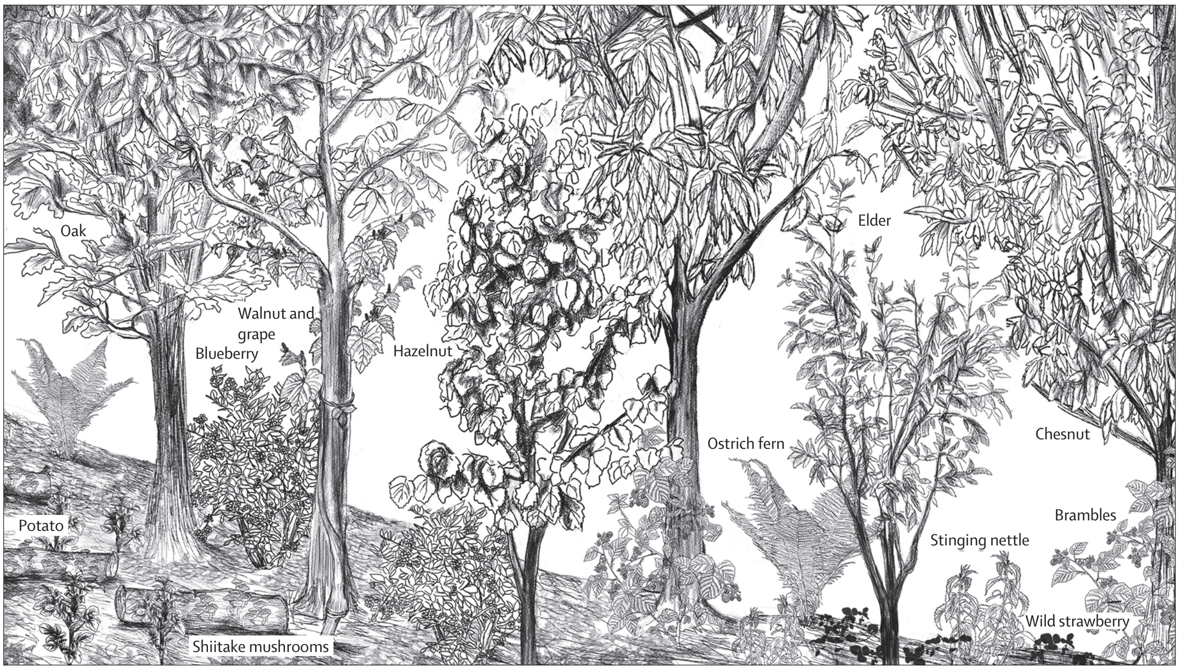

Figure 3: **Fruit–nut–berry–mushroom production system with elements of syntropic farming**
Based on the example of a chestnut grove in Ticino, Switzerland (Alpine-South climate), which draws on traditional knowledge, this illustration shows what a syntropic farming system can look like after approximately 20 years. Acorns and hazelnuts are used for speciality food products (eg, vegan cheese) while chestnuts, walnuts, blueberries, and shiitake mushrooms are sold to established value chains.

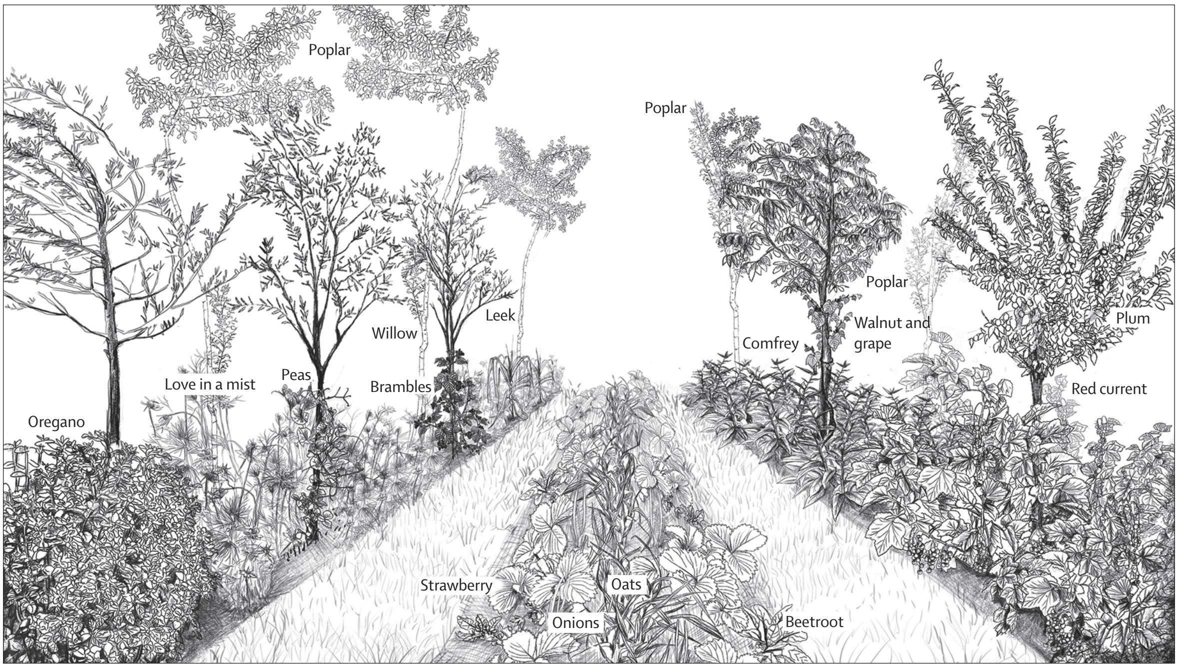

Figure 4: **Example agroecosystem design with elements of syntropic farming from a European, continental climate, including areas with trees and shrubs of varying sizes and areas with alternating vegetables and cereals**
Areas in between perennial elements might be kept wide enough to allow for the use of machinery and could simultaneously be used to produce biomass (eg, with grass).

13 (86·7%) of the 15 studies that measured biomass[10,35,62,63] and aboveground and belowground carbon stocks[8,12,46,64,65] in SFS obtained positive results—ie, organic carbon either increased over time or was higher than the reference systems—while two (13·3%) studies had mixed results.[35,46] In SFS in Bolivia[46] and Brazil,[12] aboveground

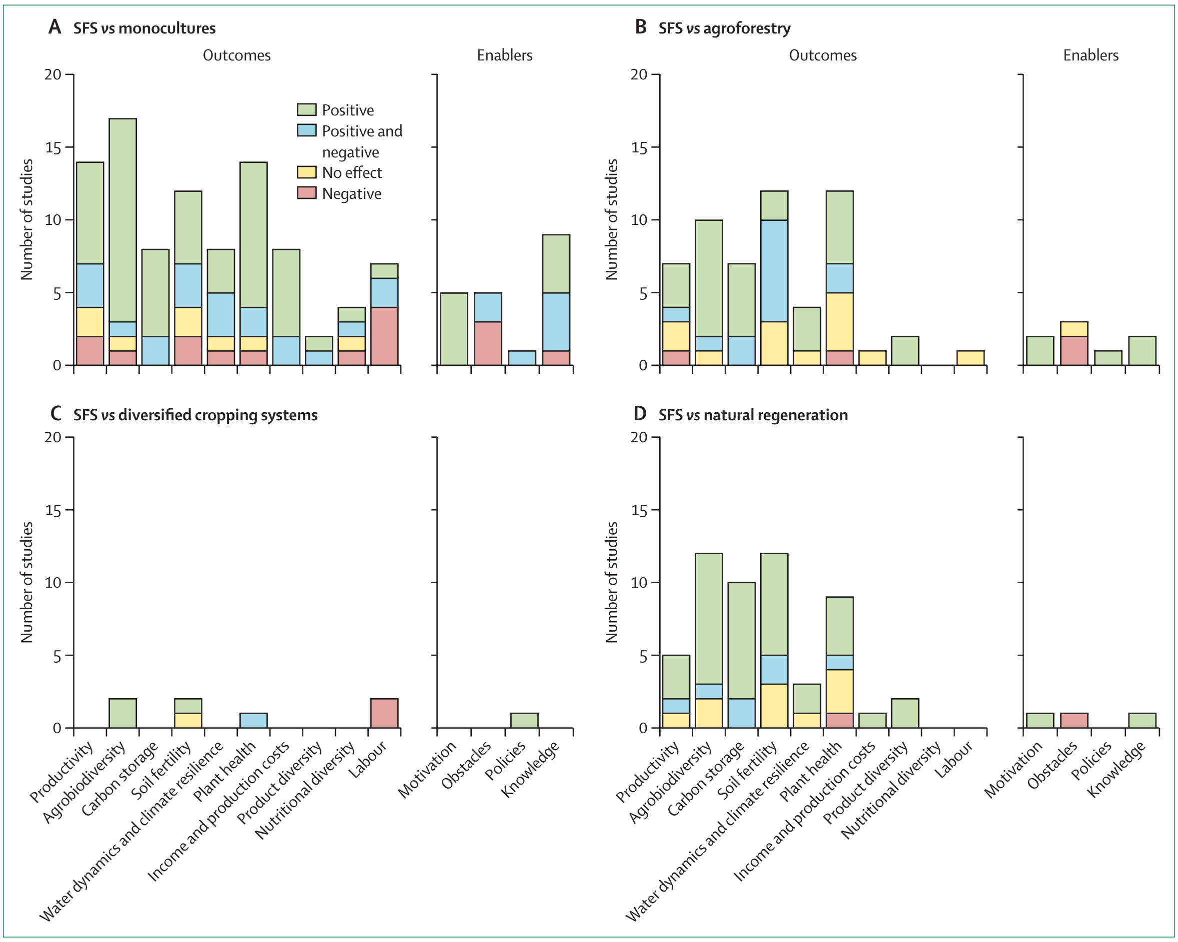

Figure 5: **Outcomes and enabling factors from studies on syntropic farming systems in comparison with different reference systems**
Biophysical and socioeconomic outcomes and enabling factors from studies comparing SFS with at least one of the following reference systems: monocultures (A), diversified cropping systems (B), simple agroforestry (C), and natural regeneration or primary forest (D). SFS=syntropic farming systems.

and belowground carbon stocks were greater than in other production systems and natural regeneration, which might be linked to the structural complexity of SFS. Specific plant traits seem to drive the quality and quantity of biomass, presenting an easy intervention point for management.[66,67] Total aboveground biomass was four times higher in cocoa-based SFS compared with cocoa monocultures,[35] but lower compared with natural regeneration and mature rainforests.[48] The quantity of litter input in SFS was the same[10] as or up to 50% greater than in natural regeneration,[62,63] suggesting a positive contribution to soil carbon and nutrient storage and dynamics. This finding might be due to the high share of twigs versus leaves in SFS, compared with natural regeneration, as a result of intensive pruning.[62] Twigs contain more recalcitrant components than leaves, especially lignins and other polyphenols, which form precursors for the build-up of soil organic matter.[68] Twig (but not leaf) litter input was positively correlated with soil organic matter content in the topsoil,[68] which could explain why soils in SFS can contain greater amounts of soil organic matter than in natural regeneration[47] and greater quantities of humus than in monocultures.[40,46] In SFS in Brazil, an annual biomass input of 28·6 Mg/hectare in a 7-year-old SFS[64] was reported, and an increase in soil organic carbon stocks from 56 Mg carbon/hectare in a 6-year-old SFS to 79·6 Mg carbon/hectare in a 12-year-old SFS from 0–100 cm soil depth,[10] which corresponds to an average annual increase of 3·9 Mg carbon/hectare. Although this number might be exceptional due to local site and management conditions, it illustrates the potential of SFS to contribute considerably more to improving soil carbon storage than conventional agriculture. It is to note that soil organic carbon content in SFS might be the same or lower than in other cropping systems or in natural regeneration, depending on the land use history, the degree of soil degradation,[10,46] and the age of the SFS.[10]

Soil fertility

In SFS, high inputs of plant residues improve soil fertility. For example, leaf litter input contributed

100 kg nitrogen/hectare, 5 kg phosphorous/hectare, and 10 kg potassium/hectare to the soil in a Brazilian SFS.[62] The content of soil macronutrients is typically high around trees,[17] increases over time,[64,65] and is often higher in SFS than other production systems,[29,40] including agroforestry[9] and natural regeneration.[48,53,68] By affecting soil nutrient content, plant residues alter the soil fauna,[63] microbial activity,[9] and decomposition and nutrient cycling.[9,63] Soil microbial biomass carbon and microbial biomass nitrogen in the top 20 cm were lower in SFS than in natural regeneration, but higher than in cocoa monocultures.[69] Soil microbial activity, specifically soil respiration and nitrogen mineralisation, was greater in SFS than in monocropping,[60] but lower than natural regeneration[10,59]—although it increased with time.[10] Similarly, decomposition, measured as cellulase activity, was enhanced in SFS compared with monocropping.[69] In this way, SFS can stimulate nutrient cycling, but seven (25·9%) of 27 studies found no differences and eight (29·6%) had mixed results regarding soil fertility—keeping in mind that this depends on many factors such as soil history, as mentioned earlier.

Water cycling and climate resilience

Depending on SFS design and management—in particular, the timing and intensity of pruning, which in turn affects water and light availability—the microclimate can be altered in a targeted manner for specific crops.[70,71] For example, the establishment of cupuaçu (*Theobroma grandiflorum*) trees can be improved under the shade of banana plants.[71] SFS can maintain a more favourable and relatively homogenised microclimate throughout the season compared with monocultures.[70] Changes in relative humidity and evapotranspiration during the dry season were lower in SFS than other cropping systems.[70] In addition, relative humidity and air temperature were lower in SFS than in other cropping systems, particularly during the day.[70] Accordingly, soil temperature in SFS might be 1–2°C lower than in monocultures.[6,72] Soil water content appears to be higher in SFS than in monocultures[6,41,72] compared with natural regeneration; however, the results are mixed.[6,48]

Climate resilience—here understood as the capacity of a system to buffer, self-organise, and adapt to change[73]—was investigated by four (6·0%) of 67 studies, all of which indicated positive results for SFS.[9,29,39,41] For example, cocoa SFS were more resilient to climatic shocks than cocoa monocultures.[39] Overall, the climate resilience of SFS is mostly achieved by means of continuous soil cover and build-up of soil organic matter, tightening resource cycling, and most importantly, high system diversity minimising the risk of complete harvest loss from extreme events.[29,39,41]

We found no studies examining the effect of SFS on water cycling or climate resilience in temperate regions. Given that temperate regions are characterised by periods of cold (including frost) in winter and short daily photoperiods that restrict vegetative growth, but also (increasingly) extreme soil temperatures in summer, the design of SFS should be adjusted in terms of strata, species diversity, density, and management.

Plant health

14 (60·9%) of the 23 studies on plant health aspects found positive effects of SFS. For instance, tree survival was 90–100% in SFS versus 70% in commercial agroforestry in Pará, Brazil.[71] Good SFS management can help enhance resilience to biotic stress factors, such as disease and herbivory,[29,27,38–40,42,47,74] also by means of companion plants that repel pests.[19] Differences were sometimes high; for example, disease incidence in cocoa at 30·4% in SFS compared with 96·4% in monocultures[29] or more than double the damage of fruit flies on oranges in monocultures.[40] Shading by banana plants in SFS diminished insect damage in young mahogany trees.[71] Leafcutter ants cut only 0·03% of total leaf area in SFS compared with 0·3% in cassava monocultures.[74] Eight (88·9%) of nine SFS required no interventions for pest management.[47] However, on cocoa, damage from small mammals and birds was greater in SFS than in monocultures, possibly due to the enhanced biodiversity.[42] Structural complexity and pruning, characteristic of SFS, also showed positive effects on plant growth[37,75]—eg, among timber trees.[75] Positive outcomes in vegetative growth were also reported in SFS.[3,35,47,71,75–78] For example, SFS with fruit-producing plants promoted better vegetative growth of arugula, lettuce, and okra.[76] However, mixed results for vegetative growth were also reported—eg, slower growth of conilon coffee[76] and cocoa trees[35,37] in SFS compared with monoculture. A high-value timber species *Khaya ivorensis* showed slower growth but a similar annual increment in stemwood volume to that of monocultures.[75] Fine root-to-shoot ratio, root volume, and root biomass were greater in SFS compared with cocoa monocultures[35] and root density was almost double in cocoa-based SFS compared with monocultures in Bolivia.[46] In summary, evidence suggests that SFS positively affect plant growth, survival, and resistance to disease and herbivory; however, plant physiological measurements are lacking and should be included in future studies.

Income and production costs

Ten (58·8%) of 17 studies that investigated the costs and benefits of SFS showed clear positive results, three (17·6%) had mixed results, two (11·8%) found no effect, and two (11·8%) showed negative results. SFS achieve the same total productivity and income as conventional soybean, maize, and milk production on only 10% of the land[36] while achieving profits already in the first months[11,36,79]—eg, from selling vegetables and aromatic herbs.[52] SFS farmers pursued different strategies to sell their products, including offering vegetable boxes, supplying local restaurants, or hosting on-farm tourists.[47,80] In one SFS, local food processing led to a notable increase in income due to direct marketing of organic products in Recife, Brazil.[41] Furthermore, SFS not only provided direct income, but also reduced production costs and costs for external inputs.[62,81] Land-equivalent ratios comparing SFS with cocoa, pineapple, rice, plantain, papaya, beans, coffee, or carambola with cocoa monocultures in Bolivia were between 2·8 and 4·1, while SFS incomes were 33–200% higher compared with other cropping systems.[29] Timber-based SFS in China provided considerable income from wood (about ten times the value of similar cropping systems without timber) and food security for local families.[82] Five (29·4%) of 17 studies showed less favourable results. For example, one (5·9%) study in Bahia, Brazil, estimated that SFS were only profitable after 10 years.[83] Reasons for compromised SFS profitability included 30% higher labour costs[27] and inputs such as seedlings[43] in the first years of production or reduced yields of the main cash crop in SFS when compared with monocultures (eg, for citrus).[33] However, in SFS, labour costs and input requirements tend to decrease over time[27,29,81] and can be compensated by selling higher quality (by)products (eg, strawberry, tubers, and timber).[33,43,82] Timber is also expected to compensate for potential yield gaps of cash crops in SFS compared with monocultures.[36]

Labour

Labour requirements are often thought to be high in SFS—especially in the first few years—eg, for planting, selective weeding, frequent harvesting, and pruning. However, findings are mixed. Five (45·5%) of 11 studies identified higher labour costs for cocoa in SFS than in other cropping systems.[8,27,33,78,81] However, in Bolivia, the labour requirements of cocoa monocultures were 55% higher than in SFS, especially for younger systems, mainly due to weeding.[29] Indeed, two (18·2%) studies pointed to understory weed suppression in SFS,[5,29] which reduced labour requirements. Furthermore, the working conditions in SFS are often better than in other cropping systems. For example, women's participation in SFS activities was higher than in citrus or cocoa monocropping for two reasons: (1) the system-inherent food production and (2), the shaded and comfortable climate generated on SFS farms, which enabled women to work with their children by their side.[29] In Ghana, farmers cited hard physical work in young SFS, but felt "more excited to work".[78]

Product diversity

Eight (88·9%) of nine studies investigating SFS product diversity showed positive results. In Chiapas, Mexico, 37 different non-timber products were documented,[16] including crops, medicinal plants, and wild animals. In 22 SFS fields in Portugal, numerous trees, shrubs, and herbaceous plants planted in small areas were recorded,[47] including perennials arranged in rows 3–4 m apart and the high annual production of vegetables between the rows. In Brazil, soils were restored by SFS while simultaneously producing fruits, nuts, firewood, stakes, rubber, corn, grain, and roots, providing income and household goods.[82] In Bolivia, cocoa SFS support economic resilience by means of product diversity, buffering against price declines for specific products;[29] furthermore, from an ecological perspective, SFS product diversity enabled improved responsiveness to challenges ranging from drought to pests—challenges that greatly affect monocultures.[33] Lastly, SFS home gardens in Tanzania supply about half the fuelwood requirements of families,[19] highlighting the potential of SFS to alleviate pressure on forests, which was also shown in a study from Yunnan, China.[82] Regarding product quality, syntropic coffee plots achieved the highest sensory quality compared with simple agroforestry and coffee planted in old-growth forest.[84]

Nutritional diversity

Only four (6·0%) of 67 studies reported nutritional diversity. In Bolivia, SFS farmers produced six different crops for family consumption within the first year (ie, rice, cassava, various legumes, and different vegetables) and the following year, the SFS also produced fruits (eg, pineapple and banana), together meeting most of the nutritional needs of families.[29] Food security among SFS cocoa farmers in Ghana was higher than among cocoa monoculture farmers.[78] However, they did not make use of all the diversity of food they produced (especially legumes), pointing to a need for better integration with food traditions and nutritional education efforts. In successional milpas in Chiapas, daily values were exceeded by 530% for all nutrients, except for saturated fats, cholesterol, sodium, calcium, and iodine.[16] Harvests consistently provided enough nutrients to ensure food security for Lacandon farmers and their families over 3 years of study. Based on their findings on soil nutrients and productivity, the authors calculated that Maya milpas can cover most of the nutritional needs of a family of five on 2·33 hectares; however, they estimated that 28 hectares would be required per family to enable the traditional 60-year fallow cycle and 5-year milpas. This estimate suggests a need for improved perennial SFS management that combines traditional knowledge and new knowledge.

Enablers

Motivation

To provide successful SFS implementation support, it is crucial to understand people's rationales. Relevant research included a study estimating 5000 farmers who adopted SFS in Brazil[2] and a study identifying 22 SFS farms in Portugal.[52] On these farms, people were motivated by a desire for ecological sustainability while maintaining profitability, although most had no organic certification.[52] Indeed, organic certification can have a considerable effect; for example, with respect to shade tree diversity in cocoa plots.[46] People's motivations across SFS studies touch on many different aspects; for example, feeling a deep personal relationship to plants can play an important role[27] together with the related knowledge. Other motivations identified include goals of biodiversity, resource conservation, and water quality and availability; aims of hosting wildlife; the desire to produce healthy food year-round; and people's links to projects, organisations, and other SFS farmers. Other motivations included people's desires for diversified products, soil restoration, and crops that would be less susceptible to pests and diseases.[46] Similarly, goals of restoring degraded farmland (ie, pasture)[9] or minimising (unavoidable) restoration costs[83] were identified as motivational factors for implementation of SFS. Importantly, indigenous worldviews can also play a role in motivating people to adopt SFS management; for instance, the Maya cosmology was interwoven with milpa management, viewed as nothing less than a spiritual act or sacred duty.[16] In Portugal, all study participants were very satisfied with SFS and all but one planned to add more SFS plots.[47]

Obstacles

The main obstacles to SFS identified in the literature include labour requirements and people's lack of corresponding knowledge and extension services.[29,47] Ten (14·9%) of 67 studies identified obstacles for SFS implementation and maintenance—particularly demanding management requirements.[29,16,47] In cocoa SFS in Bolivia, farmers cited difficulties with managing the high diversity of different crops[46] and a lack of tools and machines.[29] Another limitation identified was a lack of SFS knowledge among hired labourers, who could accidentally damage and eliminate valuable species.[29,46] Periods of water stress causing seedling mortality during SFS establishment was also identified as an obstacle hindering the adoption of SFS by farmers.[71] To overcome challenges during SFS establishment, especially on degraded land, alternative means of income (eg, honey production) and support from local non-government organisations might be needed.[41] Legislation was misaligned with the reality of SFS by separating conservation and production (or the use of secondary forest vegetation) while not curbing the negative effects of conventional agriculture.[85]

Policies that hinder or enhance SFS

Only four (6·0%) of 67 studies dealt with policies that support SFS. One (1·5%) study stressed the importance of communication and framing, highlighting the need to promote milpas as a valuable, livelihood-supporting land-use system, not a backward technology to be looked down upon.[16] Another study emphasised the importance of financial support for SFS, showing how participation of around 1500 farmer families in five communities was facilitated via monthly payments of the equivalent of around US$20 for the first 4 years.[41] This initial financial support was considered crucial by the SFS farmers. Training and material support (eg, plants and seeds) were also considered key to implementation.[34] Lastly, policies are needed that recognise and enable productive restoration, including the use of native species; joint handling of agriculture, forestry, and conservation; and engaging and supporting social actors interested in SFS.[85]

Knowledge

Deep knowledge of local flora and fauna is required for successful SFS management.[3] Older members of rural communities and small traditional farmers are often familiar with the native species of their respective regions. In many places, there are still remnants of valuable indigenous knowledge about the uses of plants for food, medicine, and construction, and regarding the interactions between different plants. Studies detail the Lacandon Mayan traditional ecological knowledge (TEK),[16,17] which enables conservation of surrounding forests while simultaneously obtaining food and other goods and services. TEK is important to the cultural integrity of Mayan communities and the ecological integrity of Mexican tropical lowland ecosystems. In this way, TEK can inform species selection for restoration.[17] Milpas, for their part, provide a habitat for diverse biological communities; pollination and soil fertility; and cultural aspects, such as a sense of place and education.[16] As another example, the Chagga people of Tanzania possess intimate knowledge of diverse local crops and plants and their ecological requirements.[19] The management techniques currently applied by the Chagga—eg, opening up the canopy to ensure better coffee fruiting, spacing out banana stools, and manuring—have been continuously refined, tested, and conserved for generations. The Chagga also maintain plant species that repel pests and know the best fodder trees and shrubs and how to use them. In this way, an important challenge and opportunity is that of identifying and connecting remaining TEK with new knowledge in the context of co-creation approaches. For instance, cocoa farmers in Ghana reported the production and use of 65 medicinal plant species in their SFS.[78] In Brazil, SFS farmers were provided with more capacity building than organic, traditional, and conventional farmers, highlighting the value of SFS courses.[86] Knowledge sharing is promoted by cooperatives and other local farmers' organisations, in particular when they share a decisive common goal regarding social and ecological principles.[39,78]

Significance for central Europe and general research gaps

Many farms in the Mediterranean, Atlantic, and Continental climate zones of central Europe already apply syntropic methods. Nevertheless, we only found three studies in the temperate zone that covered the elements of syntropy,[47,52,55] and the SFS were still young (<7 years). In Portugal, syntropic methods were documented on 26 farms, 11 of which were exclusive SFS.[47] Although short-term economic outcomes were generally lower than expected, all the syntropic growers anticipated higher incomes longer term.[47] Perceived SFS advantages included minimal input requirements and product and nutritional diversity. Negative results concerned the yields of individual cash crops—although the total system yield was typically greater in polycultures such as SFS compared with monocultures[29,37,87]—and socioeconomic factors, such as labour costs and availability, initial financing, access to knowledge, and technical assistance. One key limiting factor was the absence of suitable machines capable of speeding up routine SFS processes and reducing labour requirements and costs. Knowledge is also lacking about the feasibility of SFS in temperate agroecosystems with lower organic matter recycle rates than in the tropics. External obstacles were also mentioned in the studies, including water stress during system establishment and the lack of labour, knowledge, and interim financial support.[47]

Intensive farming in central Europe has been linked to a massive loss of insects,[88] soil erosion,[89] pollution (eg, pesticides or fertilisers),[90,91] and climate risks.[1,92] Nowadays, the question of how to design more resilient intensively managed farming systems has acquired particular urgency given increasing climatic stress and frequency of extreme weather events.[93] By improving biodiversity and regenerating and maintaining soil fertility with the build-up of soil organic matter, SFS have the potential to build resilience. Additionally, SFS might provide important social benefits ranging from diversified diets to innovative jobs, such as tree caretakers or pomologists. Against this background, SFS demands serious consideration in science and policy.

Old and new knowledge in central European agri-food systems

Agroforestry was once widespread in Europe.[94,95] Fruit trees were traditionally almost always cultivated alongside other crops (eg, vegetables, annual crops, and vines) or were integrated into hedgerows.[96] Pollarding techniques were frequently used to manage the canopies of interparcellar or intraparcellar trees, with the resulting biomass either fed to domestic animals, used as firewood, or left on the ground to decompose.

Some of this ancestral knowledge has been conserved, adapted, enhanced, and mixed with modern cultivation techniques to enable production of high-quality specialty goods. For example, chestnut groves in the Swiss Alps, diversified by application of syntropic principles, produce a plethora of high-value products, including shiitake mushrooms, walnuts, hazelnuts, and blueberries (figure 3). Other SFS designs include establishment of alternating rows of trees and shrubs, grass, and vegetables and cereals (figure 4). These SFS are partly mechanised and could further benefit from technological advances. The design of SFS varies greatly depending on local conditions and although this presents challenges, especially in the initial transition phase, it also presents opportunities to adapt to rapid changes while building and maintaining resilience across ecological, economic, and social dimensions.

Productive restoration: conclusion and future directions

Although existing evidence on SFS has mainly been derived from the tropics and is still scarce for agricultural landscapes in the temperate zone, the findings highlight an important avenue for investigation and experimentation with SFS for a transformative redesign of intensive agricultural landscapes in temperate regions. Larger-scale adoption of SFS will not work overnight due to the high diversity of settings and appropriate systems, and the longer periods needed for specific perennial plants to develop fully, which preclude one size fits all recommendations for SFS design and management. However, given that SFS can be established on small and degraded farm areas, they provide a pathway for gradual transitioning towards more sustainable agroecosystems and restoration at various scales. Furthermore, advances in technology (eg, related to remote sensing or specialised machines for syntropic management) could and should increasingly ease the management of such complex farming systems. For a syntropic redesign of European agricultural landscapes, the knowledge gaps should be filled and policies need to be co-created to overcome existing barriers and support the conversion of monocultures and degraded soils into productive, biodiversity-rich, and climate-resilient agroecosystems. This Personal View provides a first broad overview of existing studies. More systematic meta-analyses on specific aspects of SFS are needed. Future studies should help provide knowledge for SFS establishment and management. Existing SFS in Europe offer a valuable basis for conducting research and obtaining systematic

Search strategy and selection criteria

A Web of Science search was last performed on Jan 5, 2025 using the keywords “Agroforest*” AND “Agricultur*” AND “Syntrop*” OR “Sintrop*” OR “Dynamic” OR “Dinamic*” OR “Succession*” OR “Multistrat*” OR “Multiestrat*” OR “Multistor*” and provided 920 studies in English, Portuguese, and Spanish, which we screened for syntropic management and empirical content. Inclusion criteria were: (1) referring to syntropic, dynamic, successional, or multi-strata agroforestry or agriculture; (2) showing empirical data; and (3) corresponding to the syntropic farming systems core principles.

knowledge to overcome barriers to implementing SFS and help encourage its wider adoption.

Contributors

JJ and JD conceptualised the study and took the lead in writing. JJ, JD, SB, DNE, JR, and MT reviewed the studies. CA, FFA, XC, SD, DO-V, ST, MT, and BV contributed to the concept and writing. All authors had full access to all the data in this study and had final responsibility for the decision to submit for publication.

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