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Agroecological concepts and alternatives to the problems of contemporary agriculture: Monoculture and chemical fertilization in the context of climate change

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Abstract: The modernization of agriculture has transformed natural agrarian systems into other new conventional ones, making it possible to exponentially increase agricultural production. This leads to the destruction of ecological functions, and services, and has negative impacts on human health. This critical situation has given rise to a new model of agriculture called agroecology, which has emerged as a systemic approach that can understand the practices of traditional agricultural systems, as a scientific discipline that defines, classifies, and studies agrosystems from an ecological and socio-economic point of view. This paper explores the major problems of agriculture, including climate change, monoculture, and chemical fertilization at the local, regional and global scale. Equally, we defined the different concepts that bring together the agroecological approach. We based on agroecology as a scientific discipline, as a practice by defining the different agroecological practices and their scale of application, as well as the politico-economic aspect of this concept. Further, we have proposed the agroecological alternatives that can remedy the three problems recorded in the first section, based on several recent studies and research that can examine whether agroecological practices have positive results on monoculture, chemical fertilization, and climate changes. However, more advanced studies, using rigorous research design, such as case controls, longitudinal studies, and surveys in regions where agriculture is their main source of income, such as Morocco, are still needed. These investigations are suggested to fill the gap of data on such areas and fields of research.

Keywords: Agriculture, agroecology, agroecosystem, chemical fertilization, climate change, monoculture.

Introduction

The revolution of the agricultural sector dated from 1950 to 1980 and created an intensive agriculture, called green revolution that was based on increasing fieldwork and yields, which were mainly based on aggressive mechanization and intensive use of chemical inputs, namely fertilizers and pesticides (Fathallah, 2010; Griffin, 1979; Gupta, 1998; Harwood, 2019; Kumar, 2016; Prashar & Shah, 2016; Shattuck, 2021). This has led to a depletion of fossil resources causing impacts on the entire compartment of the environment. Fertilizers lead to the pollution of groundwater and eutrophication of surface waters by chemical substances, such as nitrates and phosphates (Bijay-Singh & Craswell, 2021; El Mountassir et al., 2022; Khan et al., 2018; L. Liu et al., 2021). Pesticides affect the fauna diversity and the accumulation of pesticide residues at the plant level and reduction of pollinating activity, as well as the resulting reduction in the floral and faunal diversity of the soil (Abebe et al., 2022; Domergue, 2017; Pahalvi et al., 2021; Prashar & Shah, 2016).

The modernization of agriculture has transformed natural agrarian systems into other new conventional ones, making it possible to exponentially increase agricultural production (Harwood, 2019; Rockström et al., 2017; Shattuck, 2021). This intensification aims to ensure food security, which has been proportional to the demographic increase in the world's population and has warded off shortages and famines, to the detriment of biodiversity (Douxchamps et al., 2016; Harwood, 2019; Shattuck, 2021). The agricultural revolution has been the subject of several controversies since the last half of 20th century (Cornu, 2021; Shattuck, 2021; Yadav & Anand, 2022). The agricultural activities have changed, in particular the installation of monoculture, deep plowing, and genetically modified crops GMCs (Jacobsen et al., 2013; Wu et al., 2021). Despite the massive reliance on pesticides, the resilience of monoculture systems against pest infestations remains limited, because the reliance on a single crop makes these systems vulnerable to widespread damage from pest attacks and diseases, as they can easily adapt and exploit the lack of genetic diversity among the cultivated plants (Altieri, 2009; Cook, 2006; Sarker et al., 2007; Sekine et al., 2021; Ziaie-Juybari et al., 2021). Monocultures rely on chemical fertilizers primarily due to the specific nutritional requirements of the single crop being cultivated over large areas (Altieri, 2009; Clapp, 2023; Fitzgerald, 1990; Kloppenburg, 2005). When a single crop dominates the landscape, it depletes the soil of particular nutrients essential for its growth, resulting in nutrient imbalances and reduced soil fertility over time (Bhattacharya, 2019; Bitew et al., 2019; Rosset & Altieri, 2017). To maintain high yields and meet the nutritional needs of the crop, farmers turn to chemical fertilizers to supplement the missing nutrients (Clapp, 2023; Fitzgerald, 1990; Kloppenburg, 2005). This leads to the destruction of ecological functions, services, and negative impacts on human health (Altieri, 2009, 2018; Cornu, 2021; Rosset & Altieri, 1997; Shukla et al., 2019).

In Morocco, the conditions for agricultural production have become increasingly difficult, particularly with the disastrous impact of the Covid-19 pandemic (Vodounou & Doubogan, 2016). Equally, the accentuation of climate change phenomenon has led to increasing temperatures and low water availability, which are very crucial for the agriculture (Abdelmajid et al., 2021; Abedin et al., 2019; Ferioun et al., 2023; Hssaisoune et al., 2020). It is predicted that there will be 43 megacities like Wuhan and Paris that will exceeding 11 million inhabitants in 2050, and more than two-thirds of the world's population able to live in urban areas (Laborde et al., 2020; Maja & Ayano, 2021). Climate change, resulting from anthropogenic activities, presents an unprecedented challenge for agriculture. Rising temperatures, altered precipitation patterns, and extreme weather events have disrupted traditional growing seasons and heightened the incidence of crop failures (Abdelmajid et al., 2021; Bezner Kerr et al., 2019; Ferioun et al., 2023; Mukhopadhyay et al., 2021; Mutengwa et al., 2023). Moreover, changing climate conditions have facilitated the spread of pests and diseases (Adams et al., 1998; Elad & Pertot, 2014; Shrestha, 2019), further jeopardizing global food security (Altieri et al., 2015; Mukhopadhyay et al., 2021; Mutengwa et al., 2023). As agriculture is both a contributor to and a victim of climate change, a comprehensive and sustainable response is urgently needed.

In the face of these interconnected challenges, this critical situation has given rise to a new model of agriculture more resilient and sustainable called agroecology, which has emerged as a promising and holistic approach to mitigate the risks posed to the environment, soil, ecosystem services and the health of both human and animal species (Debray et al., 2019; Francis et al., 2003; Gliessman, 2018; López-García et al., 2021). Agroecology is an interdisciplinary approach that comprises three strands: a scientific discipline integrating multiple fields, agricultural practices utilizing natural processes for sustainable productivity, and a social movement empowering farmers and promoting inclusive food production (Altieri, 2018; Migliorini & Wezel, 2017; Shiming & Gliessman, 2017; Wezel, 2017; Wezel et al., 2009, 2014). It reconciles agriculture with biodiversity conservation, emphasizes context-specific methods, and advocates for farmer empowerment and participation in the food system (Bezner Kerr et al., 2021; Jeanneret et al., 2021; López-García et al., 2021).

Given this context, the purpose of this review paper is first to discuss the three major problems of agriculture, including climate change and its impact on agriculture, chemical fertilization, monoculturing and environmental health, at the local, regional and global scale. In the second part, we defined the different concepts that bring together the agroecological approach: (i) agroecology as a scientific discipline, (ii) as a practice by defining the different agroecological practices and their scale of application, and (iii) the politico-economic aspect of agroecology. In the third part, we have proposed the agroecological alternatives that can remedy the three problems presented in the first section, while basing ourselves on several recent studies and research that can examine whether agroecological practices have had positive results on monoculture, chemical fertilization, and climate changes.

Major problems of contemporary agriculture

Impacts of climate changes on agriculture

The continued accumulation of greenhouse gases GHGs in the globe atmosphere is projected to worsen in the upcoming future i.e increasing the average global temperature, changing the amount and distribution of precipitation, and increasing the frequency and severity of extreme weather events, which results in climate change, characterized by low rainfall, severe drought, strong winds, or floods that can destroy crops and cause post-harvest losses (Alexandridis et al., 2023; Mballo et al., 2019; Mutengwa et al., 2023).These phenomena pose serious threats to agriculture and therefore to households that potentially live of natural resources (Chien et al., 2023; Kabore et al., 2019), such as air, water, solar radiation, soil, and other products that are used to produce energy like wind power, hydropower, solar power, biomass, and biofuel (Hanif et al., 2019). In fact, (Chien et al., 2023) attested that NR (Natural Resources) are being depleted by the integration of technologies of food, water, and energy (Al-Ansari et al., 2017). Lieberei & Gheewal (2017) affirmed the mitigation of NR used for electricity generation and consumption of energy, increasing the emissions of GHGs. Loss of trees, decreased fishing, use of fossil fuels, and water usage are all linked to the depletion of NR (Chien et al., 2023). Climate change affects differently humans, natural ecosystems, and infrastructures depending on the environmental changes and geographical location (Cramer et al., 2018). The population of the Middle East and North African countries multiplied from 1960 to 2015, and during this same period, the rate of urbanization doubled from 35 to 64% (Elgendy & Abaza, 2020). Farmland management is intensifying, in particular, through better irrigation, as many agricultural soils in the East and South seem to have the potential to increase yields. Agricultural organisation is therefore likely to change with the different influences on water resources, biodiversity, and the functioning of the natural landscapes (Clergue et al., 2005). Climate change has a variety of effects on the ecosystem, including the intensification and acceleration of soil salinity problems, especially in arid and semi-arid regions and coastal agricultural areas, with significant implications for global food security. It may also result in higher CH4 and N2O emissions (Corwin, 2021; Mukhopadhyay et al., 2021). Soil microbiome plays a crucial role in ecosystem health through biogeochemical cycling, bioremediation, plant growth, and primary productivity (Cavicchioli et al., 2019). Climate change perturbs microbial profiles and their functions through changes in carbon/nitrogen cycling (Naylor et al., 2020), resulting in positive effects such as GHGs emissions or negative effects like carbon immobilization into microbial and plant biomass, soil warming, and elevated CO2 levels (Sulman et al., 2014). Furthermore, it induces genetic changes and the extinction of some species (Idris et al., 2022). Variations in air temperature, rainfall, and the intensity and frequency of extreme weather events can have direct or indirect effects on climate change, which can lead to negative consequences (Lacetera, 2019). Climate change has been forecast to cause more droughts in the near future across the majority of the world's regions, with an increase in the area impacted by drought from 15.4 to 44% by the year 2100 (Idris et al., 2022). The region considered to be most vulnerable is Africa. According to Cavicchioli et al. (2019), increasing temperatures and drought are having major impacts on crop growth. Major crops yield in drought-affected areas were predicted to drop by more than 50% by 2050 and by nearly 90% by 2100 (Li et al., 2009). Heat stress can negatively impact animal health directly by causing oxidative stress, metabolic changes, immune suppression, and mortality. Climate change indirectly impacts microbial abundance, disease spread (Lacetera, 2019), and food and water scarcity (Abdelmajid et al., 2021; Chien et al., 2023; Hssaisoune et al., 2020; Idris et al., 2022; Matthan, 2022; Mutengwa et al., 2023). Temperature and precipitation changes lead to increased pesticide use (Idris et al., 2022; Kaka et al., 2021), toxicity, decreased bioavailability, altered earthworm growth patterns, and increased acidification and eutrophication potential (Leal Filho et al., 2023; Matthan, 2022; Mutengwa et al., 2023; Parmesan et al., 2022; Pimbert, 2015). Insects face declining populations and shifting distributions due to climate change affecting agriculture (Sánchez-Guillén et al., 2016; Shrestha, 2019). One of the most significant main elements determining the severity of soil erosion in the future is the spatiotemporal variation in precipitation intensity and duration leading to floods, that is predicted for the coming decades (Corwin, 2021; Cramer et al., 2018; Eekhout & De Vente, 2019; Leal Filho et al., 2023; Leippert et al., 2020), as a result of climate change (Pal & Chakrabortty, 2019). Erosion depletes topsoil depth, soil organic carbon, and nutrient status (Mandal et al., 2023), impacting soil texture and structure, available water holding capacity, water retention, and transport properties (Pimentel & Burgess, 2013). It strongly exacerbates the depletion of N, P, and K (Lal, 2001; Lobo et al., 2005) which impacts crop yield (Mandal et al., 2023), reduces the CEC (Lal, 1988; Mandal et al., 2021) and increases soil bulk density (Frye et al., 1982; González-Rosado et al., 2021). One of the most regular and virulent extreme weather events worldwide is flooding (Balgah et al., 2023). Floods directly affect food insecurity (Ahmad & Afzal, 2021; Ashraf et al., 2013), through the loss of households and agrarian assets (Ashraf et al., 2013), such as livestock and stored crops (Buchenrieder et al., 2021), but also indirectly through mortality, forced migration, or labor loss due to soil destruction and land degradation (Ashraf et al., 2013). Wind erosion poses a particular threat to soils, blowing away their surface layers and carrying them over long distances. This is facilitated by traditional cultivation practices that destroy soil structure, lack of perennial grasses and cover crops, inadequate field plantations, and forestry, and lack of water. Sandstorms cause great damage, especially in grasslands. Wind erosion ranges from 6 to 7 million hectares in normal years, but can cover up to 20 million hectares of agricultural land in sandstorm years (Moldavan et al., 2023). In terms of water, the consequences of climate change have two dimensions like the availability of water and its quality that intimately related to human health risks (Abedin et al., 2019; Anik et al., 2023; Lobo et al., 2005). With rapidly growing urbanization, transport and other factors, air and water pollution are only increasing despite local improvements in wastewater treatment processes. Political conflicts also apply considerable force on the environment, and migratory pressure continues while impacting resource-poor economies, finding it difficult to adapt to environmental changes (Cramer et al., 2018).

Climatic conditions affect directly agriculture, which is one of the sectors most vulnerable to the risks of global climate change (Aguilera et al., 2020; Singh Malhi et al., 2021), due to its enormous size and sensitivity to weather conditions with significant economic effects (Mendelsohn & Mendelsohn, 2009). The production of crops is substantially impacted by variations in climatic events (Ahmad & Afzal, 2021; Chien et al., 2023; Faye & Braun, 2022; Idris et al., 2022; Kew et al., 2021; Matthan, 2022; Singh Malhi et al., 2021). Fluctuations of climatic conditions, in particular the drop in rainfall coupled with thermal warming and human activities, cause the imbalance of ecosystems which leads to impacts on farming practices that affect the lives of populations and more specifically that of farmers (Matthan, 2022; Mballo et al., 2019), in particular small and marginal farmers that are less able to adapt to climate change, which increases their vulnerability to losses, due to a lack of awareness (Baul & McDonald, 2015) and a lack of management strategies and financial impacts, especially for African countries (Biber-Freudenberger et al., 2016). Farmers' net income has been observed to drop dramatically as temperatures rise or precipitation falls (Matthan, 2022; Mballo et al., 2019; Singh Malhi et al., 2021). Further, the negative impacts of climate change on agriculture can be increased tenfold by two mechanisms: (i) the non-proportional interactions between the different components of the climate system and (ii) the interactions with the depletion of natural resources and other components of climate change, including those of the Earth system, freshwater use, nutrient cycles and the entire biosphere (Steffen et al., 2015). Tropical regions are more affected by climate change overall because tropical crops are still closer to their high-temperature optimums and are therefore more susceptible to high-temperature stress during elevated levels of temperature (Singh Malhi et al., 2021). According to his study, Idris et al. (2022) showed that climate change will have an effect on places with temperatures higher than 30 °C, soil moisture below 20%, little rainfall, and lower than average vegetative photosynthetic activity. In general, the impact of changing precipitation patterns, rising temperatures, and CO2 fertilization differs depending on the crop, the area, and the degree of change in the parameters. The yield is found to decrease when temperature rises, but the influence of the rising precipitation is probably countered or lessened (Adams et al., 1998; Altieri et al., 2015; Singh Malhi et al., 2021). These worrying worldwide changes highlight the need for new standards and strategies that can provide more advanced food production systems that are resilient to climate change and resource depletion (Cramer et al., 2018; Leal Filho et al., 2023; Malek et al., 2018; Mutengwa et al., 2023; Parmesan et al., 2022; Saj et al., 2017). These new approaches are suggested to guarantee food sovereignty, especially in regions of high risks, such as Mediterranean areas impacted by climate change (Cramer et al., 2018; Malek et al., 2018).

Agricultural management changes

Monoculturing and environmental health

Monoculture is the annual production of the same plant species on a farm, for one or more years (Andres et al., 2016; Utomo et al., 2016). It is a commercial mode of production that has been predominant in recent decades and has largely integrated food market systems, as it is mass-produced (Woźniak, 2020). Monoculture has been adopted by farmers around the world, however, researchers have shown that monoculture can lead to several frequent declines in soil quality (Manici et al., 2013; Xiong, Zhao, et al., 2015). For example, Zhao et al. (2018) have currently showed that coffee monoculture, in the long term, decreased soil pH and organic matter content, while it increased soil salinity, which severely inhibited the growth of coffee plants and therefore affected its yield. The richness of soil bacteria and of fungal communities also declined with continued coffee cultivation (Zhao et al., 2018). Similarly, Xiong et al. (2015) have demonstrated that continuous and long-term cultivation of black pepper resulted in a significant decrease in organic matter content, soil pH, and enzyme activities. These led to a decline in the abundance of soil bacteria, hence 454 pyrosequencing analyzes of 16S rRNA genes revealed that acidobacteria and proteobacteria were the major phyla that dominated 73% of the soil around black pepper plants. Similarly, the relative abundance of the Bacteroides and firmicutes phyla was depleted with continuous cultivation, and at the genus level, the abundance of Pseudomonas decreased significantly after 21 years of monoculture (Xiong, Li, et al., 2015). Further, Liu et al. (2014) also confirmed this finding and have revealed that soil bacterial communities formed by potato monoculture have increased soil incidence of Fusarium wilt disease which impacted the performance of this crop. When a crop is grown as a monoculture, the microbial community is instantly exposed to the roots of that plant, selecting certain groups of microorganisms, namely soil pathogens, which are responsible for debilitating the yield of that crop (Cook, 2006). Several studies on the monoculture of soybeans (Bai et al., 2015), melon (Soriano-Martín et al., 2006), bananas (Chen et al., 2013), and apples (Mazzola & Manici, 2012). With regard to yield and plant biomass, it turned out that the latter dropped significantly, in monoculture. This was supported by the study conducted by Zhao et al. (2018), which showed that shoots and dry weight of coffee decreased significantly with increasing years of monoculture. Similarly, Strom et al. (2020) found that soybean did not have a high yield after planting it directly after five years of continuous maize cultivation. Further, continuous cultivation of black pepper severely inhibits its growth (Xiong et al., 2015). Continuous cultivation or monoculture can lead to an unhealthy and unsustainable environment, easily developing diseases and draining the soil from its nutrients, which is responsible for debilitating yields (Salaheen & Biswas, 2019). The crops grown in the genetically homogeneous monocultures that characterize industrial farming are neither able to feed the world's expanding population nor resilient to the more frequent and destructive climate extremes (Altieri et al., 2015; Reza & Sabau, 2022). For instance, Wright et al. (2017) found that crop species grown in plots with higher biodiversity were, on average, less adversely affected by flooding, and the plants with higher system leaf area and higher root system performed better. Furthermore, plots with mixed crops had higher soil porosity, which positively impacted plant performance. The negative impact of flooding on the performance of monocrops is primarily due to limited gas exchange due to slower gas diffusion in water compared to air, and low light intensity in turbid floodwaters, thereby causing an energy and carbohydrate deficit (Sasidharan & Voesenek, 2015), inhibiting plant growth, and eventually its survival (Mommer & Visser, 2005; Nguyen et al., 2018; Zhou et al., 2020). According to the survey carried out by Reza & Sabau (2022), it has been shown that monocropping has a negative impact on soil depletion and contributed to a decrease in soil nutrient diversity. Although this cropping system is commercially efficient and profitable, it provides an unbuffered niche for parasitic species, increasing the crop's vulnerability to opportunistic insects, plants, and microorganisms (Blary et al., 2021; Dolezal et al., 2019; Suarez et al., 2023). Because a single crop is more vulnerable to a particular pathogen or pest, it accelerates the spread of diseases and pest outbreaks (Biber-Freudenberger et al., 2016; Cui et al., 2023; Kaur et al., 2021), increasing farmers' intensive reliance on pesticides and fertilizers, which affects water quality, human health, and wildlife population (Rahman, 2023). Increased use of chemical fertilizers and synthetic pesticides will ultimately increase emissions of greenhouse gases such as N2O (Reza & Sabau, 2022). Compared to monocultures, intercropping contains more water, biomass, root system, and litter and can supply habitat for more organisms and contribute to flood mitigation, soil conservation, habitat quality, and carbon storage (Li et al., 2020; Ma et al., 2022; Sun et al., 2021). Climate change will increase the likelihood and severity of droughts into the future in many worldwide locations

(Abdelmajid et al., 2021; Altieri et al., 2015; Chien et al., 2023; Leal Filho et al., 2023; Moldavan et al., 2023; Mutengwa et al., 2023; Shukla et al., 2019). Natarajan & Willey (1986) studied the effect of drought on improved yields with multicropping by manipulating water stress on intercrops of sorghum and peanut, millet and peanut, and sorghum and millet. All the intercrops overyielded consistently at five levels of moisture availability, ranging from 297 to 584 mm of water applied over the growing season. Finn et al. (2018) found that grassland monocrop with experimental drought, decreased strongly the yield by 66%, in contrast, mixtures increased yield by 33% compared to the average of monocultures. Altieri et al. (2015) attested that multicropping has been shown to have higher yield stability and less productivity loss during drought than monocropping. The effects of drought on yield depend on environmental conditions, including agricultural intensity (Sun et al., 2021; Vogel et al., 2012; Zwicke et al., 2013), as well as pre-drought conditions and soil type, in particular, soil moisture retention properties (Hofer et al., 2016). Extreme weather events last longer, droughts become longer, moisture deficits during plant development during vegetation increase, soil moisture declines, and new pests and plant diseases appear (Cui et al., 2023; Moldavan et al., 2023) that agroecological farms are better able to counteract through the use of genetically diverse varieties of cultivated plants (Chien et al., 2023; Cui et al., 2023; Ma et al., 2022; Moldavan et al., 2023). Pathogen development and survival are most likely to be impacted by projected climate changes (Elad & Pertot, 2014). It is projected that a crop will become more vulnerable to numerous pests, diseases, and weeds as a result of changes in an area's climate or weather pattern. While yields are predicted to decline at lower latitudes, they are forecast to increase in countries with high and middle latitudes (Rosenzweig et al., 2001). However, estimates indicate that a one-degree increase in temperature will result in a 10–25% increase in losses from insect pest infestation (Deutsch et al., 2018; Shrestha, 2019).

Fertilizer practice changes

Fertilization is the application of mineral and organic fertilizers to increase the productivity of soil, which is a common and pioneering practice in agriculture (Verma et al., 2005). It serves to improve the availability of nutrients for crops, and therefore their yields (KOTAIX et al., 2019). However, the intensive use of chemical fertilizers can also affect soil properties and those of microbial communities and their functions (Pahalvi et al., 2021; van der Bom et al., 2018). Excessive use of nitrogen fertilizers can leach nitrates into water bodies, causing eutrophication and affecting aquatic life and drinking water quality (Khan et al., 2018). Phosphate is adsorbed on soil particles and transported to water bodies by soil erosion. Long-term excessive fertilizer use causes soil acidification, with long-term effects on soil productivity and soil protection (Mandal et al., 2020). In recent decades, the use of fertilizers and pesticides has increased the exposure of farmers, farm workers and the general population to these chemicals (Gupta, 2008). Dhankhar & Kumar (2023) attested that when fertilizers are applied to croplands, they are either directly or indirectly distributed into grains and vegetables, harming human health and lowering the nutrient density of the dominant plants. For instance, the nitrates and nitrites in fertilizers have been linked to cancer, birth defects, and other health issues like intoxications (Guo et al., 2020; Savci, 2012). Furthermore, lead and cadmium-based fertilizers can be hazardous to both humans and animals, resulting in health difficulties such organ damage, neurological abnormalities, and developmental problems (Dhankhar & Kumar, (2023). Furthermore, Sharma (2017) reported that according to the U.S Environmental Protection Agency EPA’s Office of Pesticide Programs, most of the pesticides contain ingredients that are cancerogenic to humans.

The continued use of fertilizers hardens the soil, and can even modify its pH by increasing its acidification. For example, Pan et al. (2021) found that P addition slowed the process of nitrification in urea-treated soils, where a high N:P ratio appeared to be a major barrier. Ammonia-oxidizing bacteria's (AOB) response, which was more responsive to P addition than ammonia-oxidizing archaea's (AOA's) response, further corroborated this. The findings of this study indicated that the nitrification process in soil amended with urea was slowed by the application of P fertilizer, indicating that a synergistic feature of N and P nutrient management should be further investigated to slow N losses from agricultural systems. Furthermore, the most frequently form of nitrogen or sulfur fertilizer in soil is nitrates or sulfate (S) (Brito et al., 2007; Vandenberghe et al., 2012), which is likely to exacerbate secondary salinization in the soil layer (Lu et al., 2019; Shen et al., 2016). Increased secondary salinization may lead to a reduction in soil fertilizer availability, which would reduce the productivity of crops, like cotton (Osanai et al., 2017; Tian et al., 2018), sunflower (Aziz et al., 2019), and maize (Lu et al., 2019; Rajeshwar & Khan, 2010). These will contribute to a drop in the content of organic matter in the soil, humus and the useful microbial load, relating to the decrease in quality of agricultural land, stunted plant growth, which is responsible for greenhouse gas emissions (Pahalvi et al., 2021). On the other hand, the excessive and long-term application of the chemical inputs is confirmed to contaminate the soil by heavy metals, including arsenic, mercury, and cadmium which are present either in the raw materials of the fertilizers (Atafar et al., 2010; Pogrzeba et al., 2018). Some Heavy Metals are required for plant development, such as, Fe, Cu, Mn, Mo and Zn, although they can be toxic to plants when present in excess. In addition, there are other Heavy Metals (Cd, Hg, Pb) that are irrelevant to plant development and can damage plants (Pogrzeba et al., 2018). The infiltration of these constituents, during the production processes, cannot be fully absorbed by the crops, and penetrates into the groundwater which causes their contamination (Chen et al., 2021). Nitrogen (N), phosphorus (P) and potassium (K) are the main macronutrients frequently required by crops to maximize their productivity (Gautam et al., 2020; Maathuis, 2009). Global nitrogen use, which is the single most important determinant of crop yield, is expected to increase by 1.6% per year until 2018, while phosphate use is expected to increase by 2.2% and potash 2.6%. In comparison, supplies of these three essentials are expected to grow by 3.7%, 2.7% and 4.2% per year, respectively (Nations, 2015). In North Africa, Morocco and Egypt account for the majority of nitrogen consumption. The share of the latter in the world consumption of nitrogen is 1.7%, 1.4% for phosphate, and 0.5% for potassium, according to the report of the FAO (Nations, 2015). Skorupka et al. (2021) revealed that agriculture was found to be responsible for 80-95% of total ammonia emissions into the atmosphere, but at the same time, it has great potential to reduce them. Mineral nitrogen fertilization (particularly urea) accounts for 19.0-20.3% of total ammonia emissions from agriculture. Ammonia emissions have a negative impact on the environment and human health. Therefore, it is important to minimize ammonia volatilization and increase fertilizer use efficiency. In addition, due to their high dissolution characteristics, only 50–60% of synthetic nitrogen fertilizers given to soil are typically absorbed by crops (Sommer et al., 2009), while the remainder flows off into water bodies (surface or groundwater) (Bijay-Singh & Craswell, 2021). For plants and animals, phosphorus is likewise a necessary and indispensable nutrient, but unlike atmospheric nitrogen, which has virtually limitless global stores, phosphate rock has limited supplies and there are serious concerns about the future availability and price of phosphate rock (Dawson & Hilton, 2011). Depending on the type of fertilizer used, phosphorus availability to plants following chemical fertilization might vary, and even in the optimal circumstances, only about 25% of applied P is absorbed by plants during the first cropping season (van de Wiel et al., 2016). P can then precipitate (at high pH owing to the presence of calcium and magnesium and at low pH due to an iron and aluminum presence) (Bhattacharya, 2019), or can be immobilized in soil (Bindraban et al., 2020), depending on the pH and moisture of the soil. When P is applied as fertilizer and flows off into surface waters, eutrophication results (Bindraban et al., 2020; Pahalvi et al., 2021; Pogrzeba et al., 2018). The intensive use of nitrogen fertilizers causes emissions of ammonia and nitrogen oxide into the atmosphere and therefore has the effect of harming the ozone layer, its overuse can lead to an accumulation of nitrates in soils, leading to their acidification and salinization (Chen et al., 2021). In addition, the phenomenon of acidification accelerates the leaching process of calcium and magnesium, this can contribute to the reduction of the saturation of soils in nutrients and possibly their fertility (Chen et al., 2021; Pahalvi et al., 2021). These are suggested to influence the biodiversity and sustainability of soil. Consequently, it has become essential to protect and maintain soil productivity in the long term without resorting to destructive and unbalanced practices, in particular the irrational application of chemical inputs which leads to a degradation of soil quality and water (Abebe et al., 2022; Gautam et al., 2020; NING et al., 2017; Wu et al., 2021).

Agroecology: Concepts and Approach

Different concepts of agroecology

According to (Altieri, 1992), one of the greatest pioneers of the agroecology concept, this discipline joins agriculture with ecology. Agroecology invites farmers to adopt the natural regulations of the agroecosystem to ensure their production rather than the use of chemical inputs, without drawing on natural resources, especially those that are not renewable (Gallardo-López et al., 2018). It is an integrative approach, which addresses agri-environmental impacts, which is important to address the multidimensional challenges of agriculture, including climate change (Lal, 2004). Agroecological systems are able to maintain productivity with minimal and efficient use of chemical inputs and based on internal ecological processes (Ameur et al., 2020; Bezner Kerr et al., 2019, 2023; Bhattacharya, 2019; Dale, 2020; Ewert et al., 2023; Isaac et al., 2018). It is based on the recycling of organic matter, agro-silvo-pastoral integration, and the promotion of diversification in functional crops (Aguilera et al., 2020). As a result, there is a big difference between industrial systems in energy metabolic patterns and agroecological systems that show a high rate of energy that remains stored in internal loops (Aguilera et al., 2020). This makes agricultural landscapes mosaics of heterogeneous land cover patterns, providing ecosystem services like biodiversity conservation (Marull et al., 2019). Further, Sirami et al. (2019) demonstrated that the mosaic of agroecology enhances multi-trophic diversity more than semi-natural landscape cover.

Agroecology has existed for several decades, it has initiated in 1928 by the Russian agronomist Basil Bensin (1881-1973) who defines agroecology as an interdisciplinary approach combining the ecology of cultivated plants, agricultural technology and knowledge of the natural and socio-economic environment (Gallardo-López et al., 2018). Between 1930-1960, agroecology was developed from the plot or field level to a scale of the agroecosystem, and to finally reach the food system approach (1970-2000) (Wezel & Jauneau, 2011), to ensure food sovereignty (Levidow et al., 2014). The use of the concept of agroecology as a social movement has been strongly influenced by the various environmental movements against industrial and/or conventional agriculture (Gallardo-López et al., 2018; Levidow et al., 2014; López-García et al., 2021; Rosset & Altieri, 2017; Silici, 2014) (Figure 1).

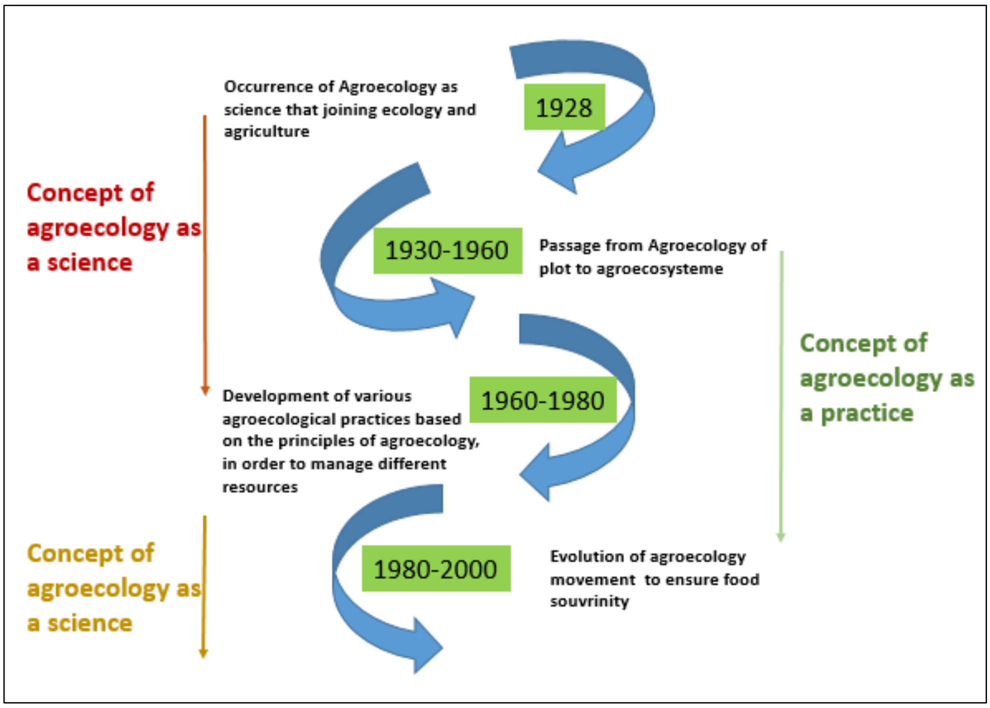

Figure 1 - Historical evolution of agroecology from the scale of the field, then the farm, towards the agroecosystem.

Concept of agroecology as a science

In terms of science, (Francis et al., 2003) have defined the agroecology as the application of methods and principles of ecology, economic, and social dimensions for the management of sustainable food systems. Recently, Gliessman (2018) defined agroecology as the integration of research, education, actions, and behavioural changes that can lead to sustainability in the ecological, economic and social domains of the agri-food system (Barrios et al., 2020). The concept of agroecology, which presents itself as a scientific discipline, studies the interactions between the ecosystem and human activities without resorting to judging the results obtained according to their sustainability (Silici, 2014). The fundamental goal of this science is to better understand agroecosystems (Lacey & Lefèvre, 2015).

Agroecosystem is a unique area of cultivation, specific to a particular region, managed by man, in order to satisfy his food needs and all that is useful to him (Thiesen et al., 2022).

Agroecosystems are presented as ecological entities, and provide several ecosystem functions and services (Raj et al., 2021). Further, Lacey & Lefèvre (2015) have defines the agroecosystem as a historical unit, which is sustainable, evolves over time and can be transformed while retaining a visible identity over time. It involves several components, including: i) Microorganisms, mineral elements, genetic, anatomical and physiological structures of plants, and diseases affecting plants and animals; ii) Farmers' well-being, aspirations, knowledge-producing practices, values and cultures; iii) Objects used for experiments, such as seeds, land, agricultural mechanization and equipment, division of agricultural fields, water sources, animals, plants, microorganisms and humans; vi) Farms, communities and natural ecosystems. Its functioning depends mainly on the edaphic, climatic and atmospheric conditions, and on the relations with the social, cultural and political whole in which it is designed. Agroecology has proposed the convergence of several disciplines, such as agronomy, ecology, sociology, economics and philosophy so that it stands out as a transdisciplinary field (Gallardo-López et al., 2018). The FAO (2016) has attested that agroecological innovations apply ecological principles, including: (i) recycling of biomass; (ii) efficient use of natural resources (solar radiation, air, nutrients and water sources); (iii) reducing external inputs; (iv) increasing biodiversity and (v) maintaining soils and synergies to implement resilient agricultural systems that promote interactions between plants, animals, humans and the environment, for food security and nutrition. However, this definition has been readjusted by that of Altieri (1992) who defines agroecology as a science that applies ecological concepts and principles, for the management of sustainable food systems. The report HLPE (2019) defined agroecology as a transdisciplinary science, which combines different disciplines, in order to overcome the challenges facing agriculture today. It is in partnership with several stakeholders, analysing their local knowledge and cultural values. All these in a reflexive and iterative way, allowing mutual learning between researchers and practitioners, as well as the horizontal dissemination of knowledge from farmers to others, and any relevant actor along the food chain.

The definitions, interpretations, and methods have changed since it was originally used in the early 20th century. Agroecology definitions have multiplied recently as many organizations and nations define it according to their concerns and goals. These definitions acknowledge the interdisciplinary nature of an agroecological approach, which includes science, a set of practices, and a social movement (Isaac et al., 2018; Méndez et al., 2013; Wezel et al., 2009) they also acknowledge the concept's application to entire agri-food systems, from food production to consumption and everything that occurs in between (Francis et al., 2003; Wezel et al., 2020).

Concept of agroecology as a set of practices

The ultimate goal of agroecology is the transformation of the conventional agricultural system in sustainable agriculture (Altieri et al., 2017; Gliessman, 2018). The transformation of agriculture based on high amount of input of fertilizers and pesticides which are moreover dangerous for the health of humans, animals and the environment to rural development by promoting agricultural practices as an alternative to conventional and/or industrial agriculture (Altieri et al., 2017; Gliessman, 2018; Kremen et al., 2012). A set of agroecological practices is implemented to ensure a transition to more environmentally friendly and sustainable agricultural systems, while optimizing the use of biological processes and ecosystem functions (Deguine et al., 2017; Duru et al., 2015; FAO, 2016; Pimbert, 2015; Rosset & Altieri, 1997; Wezel et al., 2014; Wibbelmann et al., 2013).

According to Wezel et al. (2014), agroecological practices can be considered as agrarian applies aimed to produce considerable quantities of food while valuing ecological processes and ecosystem services by integrating them as fundamental elements in the development of said practices. Agroecological practices are in contrast to a simple dependence on external inputs, such as the application of chemical fertilizers and toxic pesticides, or on technological solutions, including genetically modified organisms (Valenzuela, 2016). This assumes that biological processes are able to replace chemical or physical inputs, or more simply to interact favorably with them while limiting external costs, in particular, environmental costs (Wezel & Silva, 2017). As an applied science, agroecology uses ecological principles, as mentioned above, for the management of diverse agroecosystems in which chemical inputs are replaced by biological processes such as: natural soil fertility, allelopathic effects, and biological control. Each practice is linked to one or more principles, thus enabling its participation in the functioning of agroecosystems (Wezel & Silva, 2017).

In the previous review, Wezel et al. (2014), presented agroecological practices by classifying them according to the method of (Hill & MacRae, 1996). For Shiming & Gliessman (2017), agroecological practices are ecologically sound methods that can balance and improve all the services that agroecosystems provide, such as nutrient recycling, biological fixation of nitrogenous (N), natural regulation of pests, soil, conservation of water and biodiversity, as well as carbon sequestration (Wezel et al., 2014). Therefore, agroecological practices can greatly contribute to the sustainable development of agriculture. During their analysis of agroecology as a practice, Gallardo-López et al. (2018) mentioned three important elements in this concept counting (1) crop production, (2) animal production and (3) landscape diversity.

Agroecology as a practice for plant production

This research focuses on the transition from conventional to sustainable agriculture, which is reputed to be safer. According to Phocas et al. (2016), agroecology uses ecosystem services, ecological processes and local/natural resources instead of chemical inputs to design productive and resilient livestock and crop production systems.

This was also supported by Rusch et al. (2017), who reported that the intensification of ecological practices across landscape heterogeneity affects positively the biological control of vineyard pests. The monitoring of these practices by farmers is an original approach aimed at identifying and analyzing alternative systems and ensuring their development. Similarly, Alaphilippe et al. (2013) studied the environmental impacts of nine apple orchard systems using life cycle analysis, and showed that low input systems planted with cultivars with low disease susceptibility, reduced environmental impacts by 6-99%. Equally, potential toxicity was reduced by 2-40% for humans, 71-82% for aquatic life, and 97-99% for terrestrial life by using mechanical control rather than toxic pesticides against weeds and diseases.

Agroecology as a practice for animal production

In this side, the aspect of agroecology focuses on agroecological practices for the management of sheep, cattle, and pigs, attested that farmers depend on a range of resources to feed their animals and how they combine these resources to play an important role from an agroecological point of view (Aubron et al., 2016).

For example, in the case of cattle breeding, this activity is judged as one of the main contributors to environmental deterioration, use of unsustainable technologies and the emission of greenhouse gases into the atmosphere (Cisneros-Saguilán et al., 2015; Herrero et al., 2013). However, Sommer et al. (2009) reversed this trend by demonstrating that changes in management manure, such as separation and incineration of the solid fraction, can induce changes in CH4 and N2O emissions, and in carbon sequestration. Further, the introduction of environmental alternatives can vary significantly depending on farming practices and climatic conditions.

In a survey carried out by on organic cattle farming systems, Vaarst & Alrøe (2012) demonstrated that organic conceptions of animal welfare, linked to the principles of organic farming, can very well explain to cattle breeders their natural behaviours and needs, such as feeding ruminants that are polygastric, like ruminants and not like monogastric organisms. The introduction of livestock can potentially contribute to the management of shrub invasion, by designing a multitude of appropriate livestock management and feeding practices and soil conservation as found by Girard et al. (2008).

Agroecology as a practice for biodiversity and the landscape

Landscape ecology contributes greatly to the development of agroecology (Jeanneret et al., 2021). Agroforestry, for example, is now increasingly discussed as an alternative to conventional agriculture, since it is a practice that enhances biodiversity and provides additional ecosystem services (Jose, 2012; Moreno et al., 2018; Pantera et al., 2018). It combines the use of trees with annual crops or fodder plants and possibly with livestock on the same plot (Somarriba, 1992). The components interact with each other and create synergies, if well-chosen and well arranged, which maintains long-term productivity and leads to great resilience (Rosati et al., 2018). The promotion of biological pest control is a major pillar of agroecology, as it supports natural ecosystem processes reducing the use of pesticides by complexifying ecological networks at all scales (Bohan et al., 2013). Its purpose is to improve pest management by supporting existing natural enemy populations in the agroecosystem and promoting their effectiveness in reducing pest populations. Many studies have thus focused on the impact of landscape heterogeneity on the abundance of pests and their suppression by natural enemies with the aim of promoting biological control (Begg et al., 2017; Petit et al., 2020a). The abundance and species diversity of natural enemies should together improve natural pest control (Dainese et al., 2019).

Recently, Petit et al. (2020) have explored the potential of the spatial expansion of landscape-scale agroecology to improve pest management. One of the goals of agroecology is to promote multiple biological communities that take into consideration the important role of soil biodiversity for their operations (Coudrain et al., 2016). Similarly, it is proposed that agroecological systems rely as much as possible on the services provided by agroecosystems according to their principles and characteristics, for example, introducing organic matter (humus) into the soil and implementation of ecological infrastructures, is a condition that makes it possible to maintain and enhance ecosystem services and therefore to recapitalize ecosystems (Peeters et al., 2013). The approach of agroecology to positively impact biodiversity and the agricultural landscape, is a fundamental characteristic of agroecology that has allowed it to be considered one of the epistemological currents of sustainability, with a greater contribution to the design, management and evaluation of agroecosystems (Cisneros-Saguilán et al., 2015).

Concept of agroecology as a social movement

The politico-cultural proposals of agroecology took particular importance with the emergence of the food sovereignty paradigm in the early 1990s (Giménez & Shattuck, 2011; Pérez, 2016; Rosset & Altieri, 1997). The concept of food sovereignty was first introduced in Rome in 1996, by an international peasant movement "la Via Campesina" (HLPE, 2019). Further, Sélingué (2007) has defined food sovereignty as the right of people to healthy and culturally appropriate food, produced by ecologically sound and sustainable methods, and to have the right to define their own food and agricultural systems. Moreover, Saghai (2021) has currently proposed the following definition: "Food sovereignty is the right to direct and participatory democratic control over small-scale, largely autonomous and relocated agrifood systems based on (i) sustainability (agroecology or agriculture organic), (ii) social justice, (iii) gender equity, and (vi) respect for cultural diversity, nature, the value of food and the peasant way of life. It is also the process that leads to the full realization of this right and this vision for the future".

Generally, agroecology is seen as a bottom-up path to food sovereignty, based on traditional knowledge systems, supported rather than science-led, where small-scale producers, their communities, and organizations play the primary role, rather than agri-food companies (Altieri & Nicholls, 2012; Anderson et al., 2019). Agroecological approaches aim to build sustainable and resilient local food systems, strongly linked to their territories and their ecosystems (Anderson et al., 2015; Nyéléni, 2015; Varghese & Hansen-Kuhn, 2013). The rights to healthy food, access to agrarian land, the preservation of agricultural ecosystems, and the depopulation of rural areas have been debated issues at the heart of the agroecological movement as asserted by Montesinos & Pérez (2015). In addition, small-scale agricultural production or smallholdings are part of market-oriented reforms, and ownership of agricultural, peasant, and transnational movements (Narotzky, 2016). Based on statistical estimates, these small farms (often defined as < 2 ha) are suggested to represent 80% of all farms worldwide (Samberg et al., 2016). In 2017, it was shown that small and medium farms provide significant amounts of various food groups (vegetables, fruits, legumes) around the world, thus contributing to human nutrition (Herrero et al., 2017). In contrast, smallholder farming households represent a high proportion of the world's population suffering from chronic food insecurity (Bosc et al., 2013).

Gallardo-López et al. (2018) have studied the relationship between the concept of agroecology as a social movement, scales, and analytical factors. These authors have found that this concept was linked to the regional scale, that of the agroecosystem, and that of the agri-food system. Regarding the factors, it was related to social, cultural, economic, and political factors, therefore agroecology as a social movement is greatly influenced by the environmental movements of regional agroecosystems and agrifood systems (Massicotte & Kelly-Bisson, 2019). In this sense, the objective of agroecology is to achieve food security and sovereignty, since this has been the most important part of a movement that can meet the demand for the production and consumption of enough healthy food (Altieri & Nicholls, 2012; Montagnini & Metzel, 2017).

Agroecology: Solutions and alternatives for the major problems of agriculture

Agroecology as a systems approach to climate change

Agroecological models have the potential to contribute to both the fight against climate change and the desertion of the dominant food system (Altieri et al., 2015; Dale, 2020). Agroecology is defined as a holistic approach to agrifood systems, it takes into consideration the social sciences and the politico-economic aspects of agriculture (Méndez et al., 2013). Equally, on local and indigenous knowledge, and uses ecological concepts to build a sustainable and equitable food system. Agroecological practices play a crucial role in mitigating the risk of climate change in agriculture. These practices promote carbon sequestration in soils and vegetation, reduce greenhouse gas emissions, and enhance soil health (Altieri et al., 2015; Bezner Kerr et al., 2019; Dale, 2020; Kaye & Quemada, 2017; Shukla et al., 2019). Agroecological systems are more resilient to extreme weather events and prioritize biodiversity conservation, contributing to climate change adaptation (Dai et al., 2018; Debray et al., 2019; Moldavan et al., 2023; Singh Malhi et al., 2021). By emphasizing water management and local adaptation, agroecology helps farmers respond to changing climate conditions (Abedin et al., 2019; Córdoba Vargas et al., 2020; Kabore et al., 2019; Mutengwa et al., 2023). Harvey et al. (2014) proposed alternatives relate to climate change adaptation strategies, such as climate-smart agriculture and/or agroecological practices. These elements are suggested to reduce costs, enhance soil health and improve community resilience to climate change, environmental and economic challenges (Lin, 2011; Snapp et al., 2010). These practices include agroforestry, crop diversification, ground cover, integration of legumes into farming systems, and organic production methods (Bezner Kerr et al., 2021; Mbow et al., 2014).

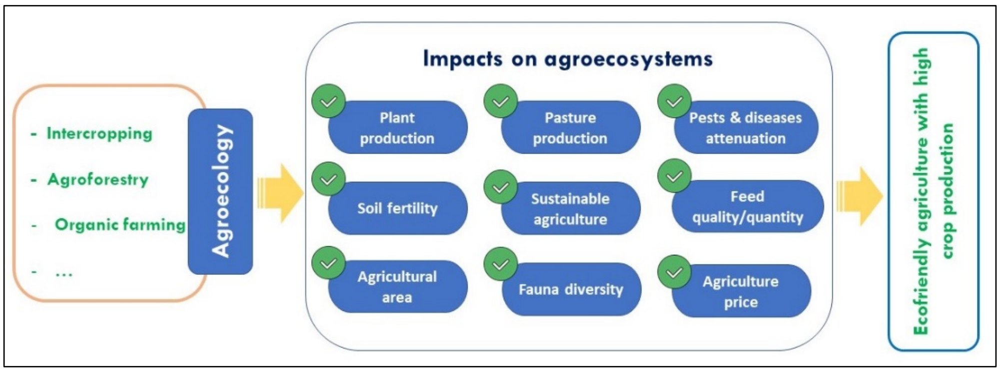

Figure 2 - Beneficial effect of agroecological practices on agroecosystems.

Agroforestry has been shown to have multiple benefits for adaptation to climate change (Nguyen et al., 2013). Trees colonize the soil and therefore contribute to the fight against its erosion (Torralba et al. 2016; Kay et al. 2019). Equally, agroforestry systems contain a high content of soil organic carbon and thus improve soil fertility, nutrient cycling, and content (Sharma et al., 2016; Torralba et al., 2016). This practice improves soil fertility, rehabilitates degraded cropland, increases vegetative cover, and decreases the risk of crop loss during the season's temporary drought, it improves water retention and infiltration (Debray et al., 2019). Similarly, Lin et al. (2018) have shown that local management of vegetation and ground cover can reduce average and maximum temperatures in gardens, which influences plant behaviour, and gardeners with regard to irrigation, via reduction of the quantity of water used. In its climate change report, IPCC (2014) summarized that practices like agroforestry improve cropland and livestock management, and increase soil organic carbon content which can significantly reduce greenhouse gas emissions (Figure 2).

Crop rotations have been identified as one of the effective strategies to adapt to climate change (Bonciarelli et al., 2016; Borrelli et al., 2014). They prevent soil from erosion, contribute to soil management, and increase water use efficiency (Rosa-Schleich et al., 2019). Similarly, crop rotations could help maintain a high carbon balance in soils and induce negative CO2 efflux (Shahzad et al., 2022). The evaluation of the different agroecological practices that promote adaptation to climate change, was carried out by Debray et al. (2019) who showed that farmers have traditionally adapted their rainfed systems (culture in "Bour") by implementing a few practices adapted to rainfall variability and soil fertility (Abdelmajid et al., 2021; Yu et al., 2022), such as: (i) The selection of shorter season cultivars to adapt to rainfall variability, (ii) crop rotations with a selection of crops adapted to limited rainfall conditions and including a fallow period of 2 to 3 years, (iii) intercropping species with different growth cycles and maintenance of forests for local climate regulation (cooling) (Figure 2).

For a long time, ground covers have been known for their ability to reduce erosion, to fix atmospheric nitrogen, to reduce the leaching of nitrogen and improve soil health (Debray et al., 2019; Kaye & Quemada, 2017; Ruiz-Colmenero et al., 2013). In addition, the presence of a vegetation cover improves the biological and chemical properties of the soil and allows an accumulation of soil organic matter (Vicente-Vicente et al., 2016). According to Guardia et al. (2016), vegetative covers, under Mediterranean conditions, can be applied either as a substitute for fallow in winter crop rotations or as winter covers in summer crop rotations, or as living mulch between row crops (Canali et al., 2017). Pantera et al. (2018) also showed that ground covers are of particular interest in Mediterranean woody crops, which provide several physicochemical, biological, and economic services. Moreover, their management aims to find a balance between the ecosystem services they provide, and the competition for soil resources with the main crops (Garcia et al., 2018). This agroecological practice can improve the resilience of crop and livestock systems by providing fodder in times of resource scarcity (Debray et al., 2019). Carpio et al. (2017) has noticed an increase in wild animal species associated with the presence of vegetation covers.

Agroecosystems can be resilient by improving biodiversity and biological soil management (Córdoba Vargas et al., 2020). Further, Debray et al. (2019) brought together agroecological practices aimed at improving soil quality. This category is for farmers located in sub-humid and semi-arid areas of Africa who use different types of organic amendments, such as compost, green manure, crop residues, and mulch. Therefore, they valorise unused organic material, such as compost liquid or biogas sludge which improves soil fertility. Enriching the soil with organic matter helps retain water (Wheeler et al., 2015), especially in hot and dry environments (Liu et al., 2017), which can increase carbon sequestration (Francaviglia et al., 2019). On the other hand, appropriate management of soil with organic matter improves soil quality and increases plant productivity. At the same time, the gain in biomass productivity allows the incorporation of a higher rate of biomass into the soil which increases the soil organic matter and productivity (Aguilera et al., 2020; Liu et al., 2017).

Farmers would potentially have to avoid industrial agricultural systems that emit greenhouse gases in order to adapt to the vagaries of climate change (Rosa-Schleich et al., 2019). Reducing tillage is a practice that can save fuel, lubricants, and increased mechanization, which can lead to limiting the resulting environmental impacts (Lovarelli & Bacenetti, 2017) in particular greenhouse gas emissions (Dachraoui & Sombrero, 2020; Lee et al., 2019; Litskas et al., 2017; Lovarelli & Bacenetti, 2017). In agroecological systems, tillage is reduced or shallow and without inversion (Cooper et al., 2016), allowing the beneficial role of carbon sequestration (Aguilera et al., 2013). It has been shown that high levels of soil organic matter in organic systems reduce the mechanical energy required for traction (Peltre et al., 2015). In addition, the use of non-synthetic inputs in organic agricultural systems has three benefits; i) it reduces dependence on external energy inputs, ii) it allows efficiency, and iii) the rational use of fossil energy (Smith et al., 2015). These confer resilience to agricultural systems and adaptation to climate change (Kuzucu, 2017). According to Aguilera et al. (2020), the reduction of fossil fuels in sustainable agricultural systems is also concerned with water management and attests that irrigation can be obtained from solar or renewable wind energies.

Mixing crops as a systems approach to monoculture

According to the various scientific articles and bibliographical reviews analysed in this work, we have assumed that almost of the researchers were based themselves on a comparison between the conventional practice of "monoculture" and the agroecological practice of "association of crops" in order to show the positive results of the latter one.

Agroecological intercropping offers a solution to mitigate the risks associated with monoculture in agriculture. Intercropping disrupts pest and disease buildup (Gao et al., 2014; Hei et al., 2022; Kaur et al., 2021; Peeters et al., 2013), improves nutrient efficiency, enhances soil health (Cuartero et al., 2022; He et al., 2021; Wezel, 2017; Wezel et al., 2014), and promotes biodiversity (Bybee-Finley & Ryan, 2018; Jeanneret et al., 2021; Petit et al., 2020; Thiesen et al., 2022). Intercropping also provides economic benefits and climate resilience, resulting in a more sustainable and resilient agricultural system. It helps reduce the negative impacts of monoculture while promoting a diverse and balanced agroecosystem (Altieri, 1995; Duchene et al., 2017a; Elouattassi et al., 2023; Esnarriaga et al., 2020; Iqbal et al., 2019; Wojtkowski, 2019).

Intercropping is the simultaneous cultivation of one or more species, in the same plot and for at least one growing season, interacting with each other and with the agroecosystem (Esnarriaga et al., 2020; Kaur et al., 2021). This is a key strategy in agroecology since it supports the hypothesis that the complementarity of nutrient acquisition between associated species allows efficient exploitation of environmental resources (Wezel et al., 2014). Intercropping has been dubbed “the new green revolution” because it is able to improve land use by harnessing the phenomenon of complementarity between species, thus providing a means to achieve sustainable agricultural intensification (Xu et al., 2020).

In his review, Blessing et al. (2022) discussed the 4 models of intercropping, which are:

- Relay intercropping: This involves planting one or more crops within an already established or existing crop, so that the initial growth stage of the second crop matches the maturity stage of the first crop, but is not yet ready for harvest.
- Row intercropping: this involves growing of two or more crops in the same field, simultaneously with one or more crops grown in a separate row.
- Strip intercropping: this refers to the cultivation of two or more crops, grouped together in strips, and wide enough to facilitate the work of modern agricultural

machinery. Also, contiguous enough to allow interaction and synergy between the different associated species. According to Iqbal et al. (2019), this type of intercropping is considered excellent for mechanical cultivation, and crop harvesting, and also contributes to appropriate competitiveness between intercropped species.

- Mixed intercropping: In this model, the cultures are totally mixed in the available space without a defined line arrangement. this type of intercropping increases income, improves ecosystem diversity and functions, modifies soil biota and improves its quality, and responds to forage preferences and/or cultural requests (Bi et al., 2019; Duchene et al., 2017b).

Compared to monoculture systems, intercropping systems have clear advantages in ecosystem services that cultivation alone cannot provide counting soil fertility, increase in yield, and diseases, pests and weeds.

The positive impacts that can result from the intercropping systems are the complementarity between the associated crops as compared to the monoculture systems (Li et al., 2018). The selection of species grown in intercropping systems must be based on differences in vegetative architecture, in particular root depth, the aerial parts, and the phenological stages, in order to increase the distribution of available resources in the soil, and therefore, to reduce competition between species (Bybee-Finley & Ryan, 2018; Litrico & Violle, 2015). The introduction of legumes in intercropping systems contributes to improving the constraint of nitrogen limitation through biological fixation, of atmospheric nitrogen as demonstrated by (Bedoussac et al., 2015).

Microbial communities are key factors in all biogeochemical cycles, they obtain mineral nutrients from the soil (Delgado-Baquerizo et al., 2017; Jacoby et al., 2017), they maintain soil fertility by breaking down organic matter, and support sustainable plant growth and productivity (Itelima et al., 2018). Further, Zhang et al. (2021) demonstrated that the intercropping systems modify the number of microorganisms and the enzymatic activities of the soil, which in turn regulate the genes involved in the cycles of N and P and the renewal of organic matter. Equally, Zhang et al. (2021) found that intercropping of sugarcane/peanut significantly increased N and P available, and regulated pH and acid phosphatase activity, which are very important in the use of soil P in intercropping systems (Li et al., 2004), compared to groundnut monoculture. Similarly, Zhang et al. (2021) demonstrated that sugarcane/peanut intercropping improves physicochemical properties by altering N and P cycling and soil organic matter turnover of the root zone. Zhou et al. (2018) also confirmed that lily/maize intercropping can increase the relative abundance of beneficial bacteria and affect the diversity and structure of the microbial community in the lily rhizosphere. Generally, this agroecological practice has a strong effect on soil pH, nutrients, and enzymes (Liu et al., 2021).

One of the main reasons for adopting intercropping is to produce a higher yield than monoculture, in the same area and in a given period (Renwick et al., 2020). Willey (1990) considered this practice to be an economical method because of its high production and minimal use of chemical inputs. The higher production of intercropping results from increased growth rate, biomass production, and efficient use of nutrients and space (Zhang & Li, 2003). According to Bedoussac et al. (2015), there are three phenomena of plant-plant interactions: (i) competition: when one species negatively alters the environment of the other species, such as competition for a resource; (ii) complementarity: when intercropped species do not compete for a resource (i.e. light, water, nutrient) over time and/or space, leading to a set of benefits, such as yield, dry weight, and species (seed) quality, especially when interspecific competition is weaker than the intraspecific competition; and (iii) facilitation: it occurs when environmental modification is beneficial for a species, such as allelopathy, or the barrier effect against the disease, weed infestation, or by the transfer of a nutrient element (N and/or P), from one species to another. According to Willey & Rao (1980), intercropping improves the use of environmental resources by 10 to 50% compared to monoculture, in the same area, by calculating the LER index (Land Equivalent ratio). It is defined as the relative area needed in pure crops to have the same production as the combination of crops (Willey, 1990). The competitive relationship between the crop components, the efficient use of space, and the overall productivity of the intercropping system can be accurately assessed using the LER (Willey & Rao, 1980). When the LER is greater than 1, the yield and growth of associated species are favoured by intercropping, on the other hand, when it is less than 1, intercropping negatively affects their growth and yield (Willey & Rao, 1980).

Several abiotic and biotic factors, such as low soil fertility, weed infestation, diseases, and pests are among the main causes of yield reduction as mentioned in Table 1. According to Maitra (2019), the beneficial insect population that develops in intercrops keeps the pest population under control and reduces the need for chemical inputs. Intercropping two or more species alters the environmental state of the host plant, which affects the ability of the pest to recognize and/or identify it (Lulie, 2017). In a study conducted on intercropping cowpea/cotton, Chikte et al. (2008) showed that the cotton gave the best result in suppressing trips and whiteflies, and recorded a high yield. Furthermore, it was detected that when soybeans were grown in close proximity to maize (i.e. 5cm), the severity of the disease counting red collar rot of soybeans, was significantly reduced (Gao et al., 2014). Similarly, Schoeny et al. (2010) noted that the severity of ascochyta blight (Mycosphaerella pinodes) on pea was lower in the pea-cereal intercropping system than in the weight monoculture, due to the modification of the microclimate inside the canopy of intercropping combinations. Nawaz & Farooq (2016) also reported that intercropping is a natural way to control weed growth. According to Girjesh & Patil (1991) and Mousavi & Eskandari (2011), intercropping is known to be more effective in suppressing weed infestation than monoculture. Intercropping has been observed as an effective tool for disease management. In intercropping systems, intercropping provides functional diversity that limits the spread of pathogens through differential adaptation due to the presence of diverse pathotypes (Finckh et al., 2000). Its effectiveness lies either in its ability to invade weed resources or to block their development by allelopathy.

Agroecological alternatives to chemical fertilization

The management of the cycles of mineral elements, in relation to that of carbon, is at the heart of the concerns of agroecology, because they are both available to the growth of plant and animal species (Lal, 2004). However, these mineral elements have the potential to contaminate the environment. Agroecology relies on internal cycles to exploit soil resources more efficiently than monocultures, and agroecological practices offer farmers alternatives to limited resources to ensure sustainable agrosystems (Dubey et al., 2020). Agroecological practices offer effective ways to reduce the reliance on chemical fertilization in agriculture. By adopting techniques such as crop rotation, cover crops, split fertilization, organic amendments, biofertilizers, agroforestry and intercropping, farmers can improve soil fertility, nutrient cycling, and water retention (Demirdogen et al., 2023; Rodríguez et al., 2020; Wezel et al., 2014; Yu et al., 2022). These practices enhance the overall health and resilience of the agricultural system while reducing the need for synthetic fertilizers (Abebe et al., 2022; Aguilera et al., 2020; Elouattassi et al., 2023; Irhza et al., 2023; Leippert et al., 2020; Rhioui et al., 2023; A. Sharma, 2017). Agroecology promotes a more sustainable and ecologically balanced approach to farming, mitigating the environmental impacts associated with chemical fertilization. Currently, Rafaela et al. (2022) have reported that populations in Mozambique use maize-legume intercrops and maize rotations with a staple crop. Intercropping has the potential to increase soil organic C and plant performance, allowing farmers to take advantage of resources with limited access (Rusinamhodzi et al., 2016). In crop rotation, the biological activity of soil is enhanced, and in the case of legumes, N supply is assured for the next crop (Birkhofer et al., 2008; Steenwerth & Belina, 2008). Legumes are an important source of easily absorbable N, due to their ability to fix atmospheric N (Fustec et al., 2010) and release large amounts of labile carbon compounds, promoting microbial growth, and improving soil structure (Shepherd et al., 2006). Crop rotations and intercropping have been shown to be two agroecological practices that improve production (Rafaela et al., 2022). Vegetation covers are widely applied in agroecology to limit the use of chemical fertilizers, reduce the risk of water contamination by leaching, and reduce soil and wind erosion (Wezel et al., 2014). Agroforestry is widely considered the most holistic practice that can improve soil fertility, reduce erosion and improve water quality (Meragiaw, 2017). Many farmers grow different trees and herbaceous plants, which regularly replenish soil fertility, microclimatic conditions of their farms, and productivity through a continuous supply of organic matter and protection against erosion and leaching (Mebrate et al., 2022). According to Wezel et al. (2014), the application of fertilizers by splitting, over time, is a better match between supply and demand and can improve the efficiency of the practice and limit the contamination of ground and surface water by fertilizers. Nakhro & Dkhar (2010) compared the use of inorganic and organic fertilizers, and found that soils treated with the organic one had the highest number of microorganisms and a higher microbial biomass. Continued use of chemical nitrogen (N) fertilizers resulted in decreased phosphorus (P) availability, suppression of a community phoD bacterial genes, considered valuable for soil and plants (Chen et al., 2019). In contrast, the addition of manure in large quantities and over the long term positively influences the fate and dynamics of carbon (C) and nitrogen (N), as well as the structure microbial communities, compared to chemical fertilizer treatments and control (control) treatments (Gautam et al., 2020). Further, Lupwayi et al. (2019) confirmed this result by demonstrating that long-term manure spreading increased enzymatic activities and that the latter was found in the soil, after 29 years of its application (Figure 3).

Xu et al. (2018) supported these results by showing that recurrent application of manure accumulates organic matter and increases the carbon stored in the soil, which acts as a substrate to improve microbial activity and biomass. Using compost from peanut shells is an effective alternative to chemical fertilizers, to improve yield without affecting soil fertility and the environment (Nalluri & Rama Karri, 2018). Pathak et al. (2021) reported that spent mushroom compost can reduce the introduction of agrochemical inputs and remediate degraded soil. These authors also mentioned that this type of compost has enzymes secreted by the mycelium in the compost, which helps the plant to develop systematic resistance, as well as it has derivatives of organic acids allowing the microbiomes to develop. Elouattassi et al., 2023) found that organic fertilization with compost provided almost similar results to mineral fertilization. Further, there are other types of organic fertilizers, which are also derived from plant or animal matter, or other organic constituents, which are either a by-product or an end product of natural origin, containing both essential nutrients and micronutrients for plant growth, such as vermicompost, biochar, biosolids, biosurfactants (Dincă et al., 2022). The application of biofertilizers is another strategy that can reduce the use of synthetic fertilizers and therefore reduce environmental pollution (Mahanty et al., 2017). Biofertilizers are either bacteria, fungi, algae or biological compounds, including plant growth promoting bacteria, which when applied either at the seed level or on the plant surface or soil, they ensure the availability of primary nutrients to the host plant (Gouda et al., 2018; Riaz et al., 2020; Singh et al., 2021).

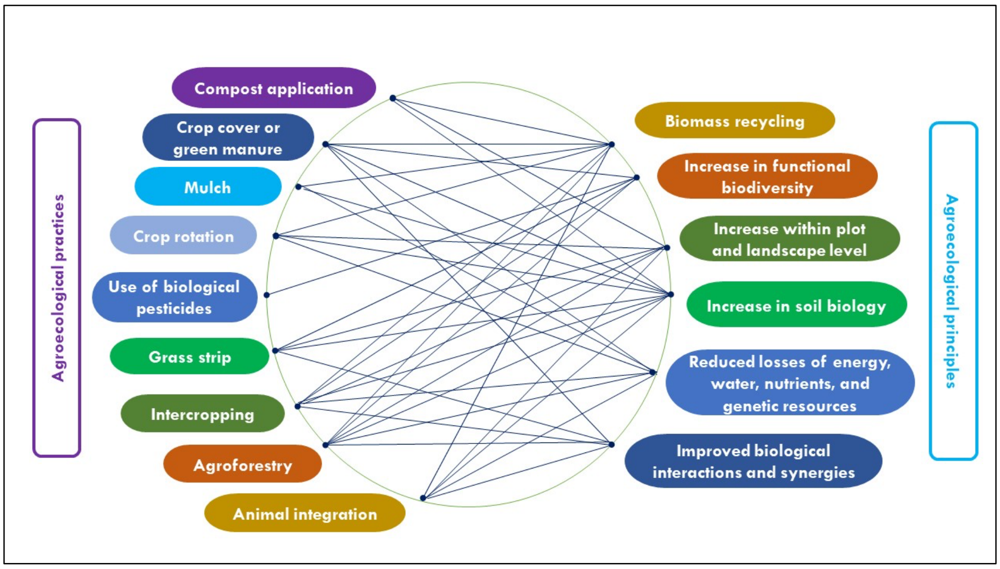

Figure 3: The relationship between agroecological practices and agroecological principals.

Conclusions

Through this review paper we discussed the alternatives and/or solutions to the problems of current agriculture, in particular climate change, monoculture, and chemical fertilization through the use of agroecological practices. We concluded that the vast majority of the studies analyzed found solutions to these problems by using agroecological practices, by comparing their conventional trials to agroecological trials deemed to be healthy, while reporting high yields of the different crops used. Further, we deduced that agroecology provides multiple benefits to society and the environment by restoring ecosystem services and biodiversity. We also demonstrated that agroforestry, intercropping and plant covers were the most recurrent agroecological practices, and the most commonly used in research, given their positive effects on the three problems mentioned above. Although the present study provides a clear indication of the potentially positive results of agroecological practices on monoculture, chemical fertilization and climate change, other studies, using rigorous research design, such as case controls, longitudinal studies and surveys in regions where agriculture is their main source of income, such as Morocco, are still needed.

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Conflict of interest

The authors declare that they have no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article are original and any liability for claims relating to the content of this article will be borne by them.

References

Abdelmajid, S., Mukhtar, A., Baig, M. B., & Reed, M. R. (2021). Climate Change, Agricultural Policy and Food Security in Morocco. In Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa (pp. 171–196). Springer International Publishing. https://doi.org/10.1007/978-3-030-72987-5_7

Abebe, T. G., Tamtam, M. R., Abebe, A. A., Abtemariam, K. A., Shigut, T. G., Dejen, Y. A., & Haile, E. G. (2022). Growing Use and Impacts of Chemical Fertilizers and Assessing Alternative Organic Fertilizer Sources in Ethiopia. *Applied and Environmental Soil Science*. https://doi.org/10.1155/2022/4738416

Abedin, M. A., Collins, A. E., Habiba, U., & Shaw, R. (2019). Climate Change, Water Scarcity, and Health Adaptation in Southwestern Coastal Bangladesh. *International Journal of Disaster Risk Science*, 10(1), 28–42. https://doi.org/10.1007/S13753-018-0211-8/TABLES/3

Adams, R. M., Hurd, B. H., Lenhart, S., & Leary, N. (1998). Effects of global climate change on agriculture: an interpretative review. *Climate Research*, 11(1), 19–30. https://doi.org/10.3354/CR011019

Adetunji, A. T., Ncube, B., Meyer, A. H., Olatunji, O. S., Mulidzi, R., & Lewu, F. B. (2021). Soil pH, nitrogen, phosphatase and urease activities in response to cover crop species, termination stage and termination method. *Heliyon*, 7(1). https://doi.org/10.1016/j.heliyon.2021.e05980

Aguilera, E., Díaz-Gaona, C., García-Laureano, R., Reyes-Palomo, C., Guzmán, G. I., Ortolani, L., Sánchez-Rodríguez, M., & Rodríguez-Estévez, V. (2020). Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. *Agricultural Systems*, 181, 102809. https://doi.org/10.1016/j.agsy.2020.102809

Aguilera, E., Lassaletta, L., Gattinger, A., & Gimeno, B. S. (2013). Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis. *Agriculture, Ecosystems & Environment*, 168, 25–36. https://doi.org/10.1016/j.agee.2013.02.003

Ahmad, D., & Afzal, M. (2021). Flood hazards, human displacement and food insecurity in rural riverine areas of Punjab, Pakistan: policy implications. *Environmental Science and Pollution Research*, 28(8), 10125–10139. https://doi.org/10.1007/S11356-020-11430-7/METRICS

Al-Ansari, T., Korre, A., Nie, Z., & Shah, N. (2017). Integration of greenhouse gas control technologies within the energy, water and food nexus to enhance the environmental performance of food production systems. *Journal of Cleaner Production*, 162, 1592-1606. https://doi.org/10.1016/j.jclepro.2017.06.097

Alaphilippe, A., Simon, S., Brun, L., Hayer, F., & Gaillard, G. (2013). Life cycle analysis reveals higher agroecological benefits of organic and low-input apple production. *Agronomy for Sustainable Development*, 33(3), 581–592. https://doi.org/10.1007/s13593-012-0124-7

Alexandridis, N., Feit, B., Kihara, J., Luttermoser, T., May, W., Midega, C., Ingrid¨oborn, I. I., Poveda, K., Sileshi, G. W., Zewdie, B., Clough, Y., & Jonsson, M. (2023). Climate change and ecological intensification of agriculture in sub-Saharan Africa-A systems approach to predict maize yield under push-pull technology. *Agriculture, Ecosystems & Environment*, 352, 108511. https://doi.org/10.1016/j.agee.2023.108511

Altieri, M. A. (1992). Agroecological foundations of alternative agriculture in California. *Agriculture, Ecosystems & Environment*, 39(1–2), 23–53. https://doi.org/10.1016/0167-8809(92)90203-N

Altieri, M. A. (1995). Agroecology: the science of sustainable agriculture. Intermediate Technology Publications Ltd (ITP). https://repository.graduateinstitute.ch/record/82348/

Altieri, M. A. (2009). Green deserts: Monocultures and their impacts on biodiversity. First published in December 2009, 67.

Altieri, M. A. (2018). Agroecology: the science of sustainable agriculture. CRC Press.

Altieri, M. A., & Nicholls, C. I. (2012). Agroecology Scaling Up for Food Sovereignty and Resiliency (pp. 1–29). https://doi.org/10.1007/978-94-007-5449-2_1

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. In Agronomy for Sustainable Development (Vol. 35, Issue 3, pp. 869–890). Springer-Verlag France. https://doi.org/10.1007/s13593-015-0285-2

Altieri, M. A., Nicholls, C. I., & Montalba, R. (2017). Technological approaches to sustainable agriculture at a crossroads: An agroecological perspective. *Sustainability*, 9(3). https://doi.org/10.3390/su9030349

Ameur, F., Amichi, H., & Leauthaud, C. (2020). Agroecology in North African irrigated plains? Mapping promising practices and characterizing farmers' underlying logics. *Regional Environmental Change*, 20(4). https://doi.org/10.1007/s10113-020-01719-1

Anderson, C., Pimbert, M., & Kiss, C. (2015). Building, Defending and Strengthening Agroecology. A Global Struggle for Food Sovereignty. https://www.agroecologynow.com/wp-content/uploads/2015/05/Farming-Matters-Agroecology-EN.pdf

Anderson, C. R., Maughan, C., & Pimbert, M. P. (2019). Transformative agroecology learning in Europe: building consciousness, skills and collective capacity for food sovereignty. *Agriculture and Human Values*, 36(3), 531–547. https://doi.org/10.1007/s10460-018-9894-0

Andres, C., Comoé, H., Beerli, A., Schneider, M., Rist, S., & Jacobi, J. (2016). Cocoa in Monoculture and Dynamic Agroforestry (pp. 121–153). https://doi.org/10.1007/978-3-319-26777-7_3

Anik, A. H., Sultan, M. B., Alam, M., Parvin, F., Ali, M. M., & Tareq, S. M. (2023). The impact of climate change on water resources and associated health risks in Bangladesh: A review. *Water Security*, 18, 100133. https://doi.org/10.1016/J.WASEC.2023.100133

Ashraf, S., Iftikhar, M., Shahbaz, B., Khan, G. A., & Luqman, M. (2013). Impacts of flood on livelihoods and food security of rural communities: a case study of southern Punjab, Pakistan. *Pakistan Journal of Agricultural Sciences*, 50(4), 751–758.

Atafar, Z., Mesdaghinia, A., Nouri, J., Homaee, M., Yunesian, M., Ahmadimoghaddam, M., & Mahvi, A. H. (2010). Effect of fertilizer application on soil heavy metal concentration. *Environmental Monitoring and Assessment*, 160(1–4), 83–89. https://doi.org/10.1007/s10661-008-0659-x

Aubron, C., Noël, L., & Lasseur, J. (2016). Labor as a driver of changes in herd feeding patterns: Evidence from a diachronic approach in Mediterranean France and lessons for agroecology. *Ecological Economics*, 127, 68–79. https://doi.org/10.1016/j.ecolecon.2016.02.013

Aziz, A., Ashraf, M., Sikandar, S., Asif, M., … N. A.-S., & Babar, B. H. (2019). Optimizing sulfur for improving salt tolerance of sunflower (Helianthus annuus L.). *Soil Environ*, 38, 222-233. https://doi.org/10.25252/SE/19/71647

Bai, L., Cui, J., Jie, W., & Cai, B. (2015). Analysis of the community compositions of rhizosphere fungi in soybeans continuous cropping fields. *Microbiological Research*, 180, 49–56. https://doi.org/10.1016/J.MICRES.2015.07.007

Balgah, R. A. ;, Ngwa, K. A. ;, Buchenrieder, G. R. ;, Kimengsi, J. N., Balgah, R. A., Azibo Ngwa, K., Buchenrieder, G. R., & Kimengsi, J. N. (2023). Impacts of Floods on Agriculture-Dependent Livelihoods in Sub-Saharan Africa: An Assessment from Multiple Impacts of Floods on Agriculture-Dependent Livelihoods in Sub-Saharan Africa: An Assessment from Multiple Geo-Ecological Zones. *Land*, 12(334). https://doi.org/10.3390/land12020334

Barrios, E., Gemmill-Herren, B., Bicksler, A., Siliprandi, E., Brathwaite, R., Moller, S., Batello, C., & Tittonell, P. (2020). The 10 Elements of Agroecology: enabling transitions towards sustainable agriculture and food systems through visual narratives. *Ecosystems and People*, 16, 1. https://doi.org/10.1080/26395916.2020.1808705

Baul, T. K., & McDonald, M. (2015). Integration of Indigenous knowledge in addressing climate change. IJTK Vol.01(1) [January 2015], 1(1), 20–27. http://nopr.niscpr.res.in/handle/123456789/32021

Bedoussac, L., Journet, E. P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E. S., Prieur, L., & Justes, E. (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. In Agronomy for Sustainable Development (Vol. 35, Issue 3, pp. 911–935). Springer-Verlag. https://doi.org/10.1007/s13593-014-0277-7

Begg, G. S., Cook, S. M., Dye, R., Ferrante, M., Franck, P., Lavigne, C., Lövei, G. L., Mansion-Vaquie, A., Pell, J. K., Petit, S., Quesada, N., Ricci, B., Wratten, S. D., & Birch, A. N. E. (2017). A functional overview of conservation biological control. *Crop Protection*, 97, 145–158. https://doi.org/10.1016/j.cropro.2016.11.008

Berdjour, A., Dugje, I. Y., Dzomeku, I. K., & Rahman, N. A. (2020). Maize–soybean intercropping effect on yield productivity, weed control and diversity in northern Ghana. *Weed Biology and Management*, 20(2), 69–81. https://doi.org/10.1111/wbm.12198

Bezner Kerr, R., Madsen, S., Stüber, M., Liebert, J., Enloe, S., Borghino, N., Parros, P., Mutyambai, D. M., Prudhon, M., & Wezel, A. (2021). Can agroecology improve food security and nutrition? A review. In Global Food Security (Vol. 29). Elsevier B.V. https://doi.org/10.1016/j.gfs.2021.100540

Bezner Kerr, R., Postigo, J. C., Smith, P., Cowie, A., Singh, P. K., Rivera-Ferre, M., Tirado-von der Pahlen, M. C., Campbell, D., & Neufeldt, H. (2023). Agroecology as a transformative approach to tackle climatic, food, and ecosystemic crises. *Current Opinion in Environmental Sustainability*, 62, 101275. https://doi.org/10.1016/J.COSUST.2023.101275

Bezner Kerr, R., Young, S. L., Young, C., Santoso, M. V., Magalasi, M., Entz, M., Lupafya, E., Dakishoni, L., Morrone, V., Wolfe, D., & Snapp, S. S. (2019). Farming for change: developing a participatory curriculum on agroecology, nutrition, climate change and social equity in Malawi and Tanzania. *Agriculture and Human Values*, 36(3), 549–566. https://doi.org/10.1007/s10460-018-09906-x

Bhattacharya, A. (2019). Changing environmental condition and phosphorus-use efficiency in plants. *Changing Climate and Resource Use Efficiency in Plants*, 241–305.

Bi, Y., Zhou, P., Li, S., Wei, Y., Xiong, X., Shi, Y., Liu, N., & Zhang, Y. (2019). Interspecific interactions contribute to higher forage yield and are affected by phosphorus application in a fully-mixed perennial legume and grass

intercropping system. *Field Crops Research*, 244. https://doi.org/10.1016/j.fcr.2019.107636
Biber-Freudenberger, L., Ziemacki, J., Tonnang, H. E. Z., & Borgemeister, C. (2016). Future Risks of Pest Species under Changing Climatic Conditions. *PLOS ONE*, 11(4), e0153237. https://doi.org/10.1371/JOURNAL.PONE.0153237
Bijay-Singh, & Craswell, E. (2021). Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. *SN Applied Sciences*, 3(4). https://doi.org/10.1007/S42452-021-04521-8
Bindraban, P. S., Dimkpa, C. O., & Pandey, R. (2020). Exploring phosphorus fertilizers and fertilization strategies for improved human and environmental health. *Biology and Fertility of Soils*, 56(3), 299–317. https://doi.org/10.1007/S00374-019-01430-2
Birkhofer, K., Bezemer, T. M., Bloem, J., Bonkowski, M., Christensen, S., Dubois, D., Ekelund, F., Fließbach, A., Gunst, L., & Hedlund, K. (2008). Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. *Soil Biology and Biochemistry*, 40(9), 2297–2308. https://doi.org/https://doi.org/10.1016/j.soilbio.2008.05.007
Bitew, Y., Alemayehu, G., Adego, E., & Assefa, A. (2019). Boosting land use efficiency, profitability and productivity of finger millet by intercropping with grain legumes. *Cogent Food & Agriculture*, 5(1), 1702826.
Blary, C., Kerbiriou, C., Le Viol, I., & Barré, K. (2021). Assessing the importance of field margins for bat species and communities in intensive agricultural landscapes. *Agriculture, Ecosystems & Environment*, 319, 107494.
Blessing, D. J., Gu, Y., Cao, M., Cui, Y., Wang, X., & Asante-Badu, B. (2022). Overview of the advantages and limitations of maize-soybean intercropping in sustainable agriculture and future prospects: A review. In Chilean Journal of Agricultural Research (Vol. 82, Issue 1, pp. 177–188). Instituto de Investigaciones Agropecuarias, INIA. https://doi.org/10.4067/S0718-58392022000100177
Bohan, D. A., Raybould, A., Mulder, C., Woodward, G., Tamaddoni-Nezhad, A., Bluthgen, N., Pocock, M. J. O., Muggleton, S., Evans, D. M., Astegiano, J., Massol, F., Loeuille, N., Petit, S., & Macfadyen, S. (2013). Networking agroecology. integrating the diversity of agroecosystem interactions. In Advances in Ecological Research (Vol. 49, pp. 1–67). Academic Press Inc. https://doi.org/10.1016/B978-0-12-420002-9.00001-9
Bonciarelli, U., Onofri, A., Benincasa, P., Farneselli, M., Guiducci, M., Pannacci, E., Tosti, G., & Tei, F. (2016). Long-term evaluation of productivity, stability and sustainability for cropping systems in Mediterranean rainfed conditions. *European Journal of Agronomy*, 77, 146–155. https://doi.org/10.1016/j.eja.2016.02.006
Borrelli, L., Castelli, F., Ceotto, E., Cabassi, G., & Tomasoni, C. (2014). Maize grain and silage yield and yield stability in a long-term cropping system experiment in northern Italy. *European Journal of Agronomy*, 55, 12–19. https://doi.org/10.1016/j.eja.2013.12.006
Bosc, P.-M., Berdegué, J., Goïta, M., van der Ploeg, J. D., Sekine, K., & Zhang, L. (2013). Investing in smallholder agriculture for food security. HLPE. https://edepot.wur.nl/265052
Brito, J. M. C., Ferreira, D., Guerrero, C. A. C., Machado, A. V., & Beltrão, J. (2007). Soil pollution by nitrates using sewage sludge and mineral fertilizers. *Improved Crop Quality by Nutrient Management*, 223–227. https://doi.org/10.1007/978-0-585-37449-9_51

Buchenrieder, G., Brandl, J., & Balgah, A. R. (2021). The Perception of Flood Risks: A Case Study of Babessi in Rural Cameroon. *International Journal of Disaster Risk Science*, 12(4), 1–21. https://doi.org/10.1007/S13753-021-00345-7/TABLES/6

Bybee-Finley, K. A., & Ryan, M. R. (2018). Advancing intercropping research and practices in industrialized agricultural landscapes. *Agriculture*, 8, 1–24. https://doi.org/10.3390/agriculture8060080

Canali, S., Ortolani, L., Campanelli, G., Robačer, M., von Fragstein, P., D'Oppido, D., & Kristensen, H. L. (2017). Yield, product quality and energy use in organic vegetable living mulch cropping systems: Research evidence and farmers' perception. *Renewable Agriculture and Food Systems*, 32(3), 200–213. https://doi.org/10.1017/S1742170516000314

Carpio, A. J., Castro, J., Mingo, V., & Tortosa, F. S. (2017). Herbaceous cover enhances the squamate reptile community in woody crops. *Journal for Nature Conservation*, 37, 31–38. https://doi.org/10.1016/j.jnc.2017.02.009

Cavicchioli, R., Ripple, W. J., Timmis, K. N., Azam, F., Bakken, L. R., Baylis, M., Behrenfeld, M. J., Boetius, A., Boyd, P. W., Classen, A. T., Crowther, T. W., Danovaro, R., Foreman, C. M., Huisman, J., Hutchins, D. A., Jansson, J. K., Karl, D. M., Koskella, B., Mark Welch, D. B., … Webster, N. S. (2019). Scientists' warning to humanity: microorganisms and climate change. *Nature Reviews Microbiology*, 17(9), 569–586. https://doi.org/10.1038/s41579-019-0222-5

Chen, X., Liang, Y., Wan, L., Xie, Z., Easton, C. D., Bourgeois, L., Wang, Z., Bao, Q., Zhu, Y., Tao, S., & Wang, H. (2019). Construction of porous N-doped graphene layer for efficient oxygen reduction reaction. *Chemical Engineering Science*, 194, 36–44. https://doi.org/10.1016/j.ces.2018.04.004

Chen, Y. F., Chen, W., Huang, X., Hu, X., Zhao, J. T., Gong, Q., Li, X. J., & Huang, X. L. (2013). Fusarium wilt-resistant lines of Brazil banana (Musa spp., AAA) obtained by EMS-induced mutation a micro-cross-section cultural system. *Plant Pathology*, 62(1), 112–119. https://doi.org/10.1111/j.1365-3059.2012.02620.x

Chen, Y., Hu, S., Guo, Z., Cui, T., Zhang, L., Lu, C., Yu, Y., Luo, Z., Fu, H., & Jin, Y. (2021). Effect of balanced nutrient fertilizer: A case study in Pinggu District, Beijing, China. *Science of the Total Environment*, 754. https://doi.org/10.1016/j.scitotenv.2020.142069

Chien, F., Chau, K. Y., & Sadiq, M. (2023). Impact of climate mitigation technology and natural resource management on climate change in China. *Resources Policy*, *81*, 103367. https://doi.org/10.1016/j.resourpol.2023.103367

Chikte, P., Thakare, S. M., & Bhalkare, S. K. (2008). Influence of various cotton-based intercropping systems on population dynamics of thrips, Scircothrips dorsalis Hood and whitefly, Bemisia tabaci Genn. *Research on crops*, 9(3), 683–687.

Cisneros-Saguilán, P., Gallardo-López, F., López-Ortíz, S., Ruiz Rosado, O., Herrera-Haro, J. G., & Hernández-Castro, E. (2015). Current Epistemological Perceptions of Sustainability and Its Application in the Study and Practice of Cattle Production: A Review. *Agroecology and Sustainable Food Systems*, 39(8), 885–906. https://doi.org/10.1080/21683565.2015.1050148

Clapp, J. (2023). Concentration and crises: exploring the deep roots of vulnerability in the global industrial food system. *The Journal of Peasant Studies*, 50(1), 1–25. https://doi.org/10.1080/03066150.2022.2129013

Clergue, B., Amiaud, B., Pervanchon, F., Lasserre-Joulin, F., & Plantureux, S. (2005). Biodiversity: Function and assessment in agricultural areas. A review. *Agronomie*, 25(1), 1–15. https://doi.org/10.1051/agro:2004049

Cook, R. J. (2006). Toward cropping systems that enhance productivity and sustainability. *Proceedings of the National Academy of Sciences*, 103(49), 18389-18394. https://doi.org/doi10.1073pnas.0605946103

Cooper, J., Baranski, M., Stewart, G., Nobel-de Lange, M., Bàrberi, P., Fließbach, A., Peigné, J., Berner, A., Brock, C., & Casagrande, M. (2016). Shallow non-inversion tillage in organic farming maintains crop yields and increases soil C stocks: a meta-analysis. *Agronomy for Sustainable Development*, 36(1), 1–20. https://doi.org/https://doi.org/10.1007/s13593-016-0354-1

Córdoba Vargas, C. A., Hortúa Romero, S., & León Sicard, T. (2020). Key points of resilience to climate change: a necessary debate from agroecological systems. *Climate and Development*, 12(6). 564–574. https://doi.org/10.1080/17565529.2019.1664376

Cornu, P. (2021). La systémique agraire à l'INRA : Histoire d'une dissidence (Quae). https://library.oapen.org/bitstream/handle/20.500.12657/51624/1/9782759231768.pdf

Corwin, D. L. (2021). Climate change impacts on soil salinity in agricultural areas. *European Journal of Soil Science*, 72(2), 842–862. https://doi.org/10.1111/EJSS.13010

Coudrain, V., Hedde, M., Chauvat, M., Maron, P. A., Bourgeois, E., Mary, B., Léonard, J., Ekelund, F., Villenave, C., & Recous, S. (2016). Temporal differentiation of soil communities in response to arable crop management strategies. *Agriculture, Ecosystems and Environment*, 225, 12–21. https://doi.org/10.1016/j.agee.2016.03.029

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J.-P., Iglesias, A., Lange, M. A., Lionello, P., Llasat, M. C., & Paz, S. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change*, 8(11), 972–980. https://doi.org/https://doi.org/10.1038/s41558-018-0299-2

Cuartero, J., Pascual, J. A., Vivo, J.-M., Özbolat, O., Sánchez-Navarro, V., Egea-Cortines, M., Zornoza, R., Mena, M. M., Garcia, E., & Ros, M. (2022). A first-year melon/cowpea intercropping system improves soil nutrients and changes the soil microbial community. *Agriculture, Ecosystems & Environment*, 328, 107856. https://doi.org/10.1016/j.agee.2022.107856

Cui, J., Liu, H., Wang, H., Wu, S., Bashir, M. A., Reis, S., Sun, Q., Xu, J., & Gu, B. (2023). Rice-Animal Co-Culture Systems Benefit Global Sustainable Intensification. *Earth's Future*, 11(2), e2022EF002984. https://doi.org/10.1029/2022EF002984

Dachraoui, M., & Sombrero, A. (2020). Effect of tillage systems and different rates of nitrogen fertilisation on the carbon footprint of irrigated maize in a semiarid area of Castile and Leon, Spain. *Soil and Tillage Research*, 196, 104472. https://doi.org/https://doi.org/10.1016/j.still.2019.104472

Dai, A., Zhao, T., & Chen, J. (2018). Climate Change and Drought: a Precipitation and Evaporation Perspective. *Current Climate Change Reports*, 4(3), 301–312. https://doi.org/10.1007/s40641-018-0101-6

Dainese, M., Martin, E. A., Aizen, M. A., Albrecht, M., Bartomeus, I., Bommarco, R., Carvalheiro, L. G., Chaplin-Kramer, R., Gagic, V., Garibaldi, L. A., Ghazoul, J., Grab, H., Jonsson, M., Karp, D. S., Kennedy, C. M., Kleijn, D., Kremen, C., Landis, D. A., Letourneau, D. K., … Steffan-Dewenter, I. (2019). A global synthesis reveals biodiversity-mediated benefits for crop production. *Science Advances*, 5(10). https://doi.org/10.1126/sciadv.aax0121

Dale, B. (2020). Alliances for agroecology: from climate change to food system change. Agroecology and Sustainable Food Systems, 44(5), 629–652. https://doi.org/10.1080/21683565.2019.1697787

Dawson, C. J., & Hilton, J. (2011). Fertiliser availability in a resource-limited world: Production and recycling of nitrogen and phosphorus. *Food Policy*, 36(1), S14–S22. https://doi.org/10.1016/J.FOODPOL.2010.11.012

Debray, V., Wezel, A., Lambert-Derkimba, A., Roesch, K., Lieblein, G., & Francis, C. A. (2019). Agroecological practices for climate change adaptation in semiarid and subhumid Africa. *Agroecology and Sustainable Food Systems*, 43(4), 429–456. https://doi.org/10.1080/21683565.2018.1509166

Deguine, J.-P., Gloanec, C., Laurent, P., Ratnadass, A., & Aubertot, J.-N. (2017). Feedback and Common Approaches to Agroecological Crop Protection: Further Examples. *Agroecological Crop Protection*, 109–162. https://doi.org/https://doi.org/10.1007/978-94-024-1185-0_4

Delgado-Baquerizo, M., Eldridge, D. J., Ochoa, V., Gozalo, B., Singh, B. K., & Maestre, F. T. (2017). Soil microbial communities drive the resistance of ecosystem multifunctionality to global change in drylands across the globe. *Ecology Letters*, 20(10), 1295–1305. https://doi.org/10.1111/ele.12826

Demirdogen, A., Guldal, H. T., & Sanli, H. (2023). Monoculture, crop rotation policy, and fire. *Ecological Economics*, 203, 107611. https://doi.org/10.1016/J.ECOLECON.2022.107611

Deutsch, C. A., Tewksbury, J. J., Tigchelaar, M., Battisti, D. S., Merrill, S. C., Huey, R. B., & Naylor, R. L. (2018). Increase in crop losses to insect pests in a warming climate. *Science*, 361(6405), 916–919. https://doi.org/10.1126/SCIENCE.AAT3466

Dhankhar, N., & Kumar, J. (2023). Impact of increasing pesticides and fertilizers on human health: A review. *Materials Today: Proceedings*. https://doi.org/10.1016/J.MATPR.2023.03.766

Dincă, L. C., Grenni, P., Onet, C., & Onet, A. (2022). Fertilization and Soil Microbial Community: A Review. *Applied Sciences*, 12(3), 1198. https://doi.org/10.3390/app12031198

Dolezal, A. G., Clair, A. L. S., Zhang, G., Toth, A. L., & O'Neal, M. E. (2019). Native habitat mitigates feast–famine conditions faced by honey bees in an agricultural landscape. *Proceedings of the National Academy of Sciences of the United States of America*, 116(50), 25147–25155. https://doi.org/10.1073/PNAS.1912801116

Domergue, O. (2017). Diversité fonctionnelle des rhizobia associés à la féverole en agro-écosystème Sud de France [Université de Paris sciences et lettres]. https://theses.hal.science/tel-02107043/file/2017PSLEP067_archivage.pdf

Douxchamps, S., Van Wijk, M. T., Silvestri, S., Moussa, A. S., Quiros, C., Ndour, N. Y. B., Buah, S., Somé, L., Herrero, M., Kristjanson, P., Ouedraogo, M., Thornton, P. K., Van Asten, P., Zougmoré, R., & Rufino, M. C. (2016). Linking agricultural adaptation strategies, food security and vulnerability: evidence from West Africa. *Regional Environmental Change*, 16(5), 1305–1317. https://doi.org/10.1007/s10113-015-0838-6

Drakopoulos, D., Kägi, A., Gimeno, A., Six, J., Jenny, E., Forrer, H. R., Musa, T., Meca, G., & Vogelgsang, S. (2020). Prevention of Fusarium head blight infection and mycotoxins in wheat with cut-and-carry biofumigation and botanicals. *Field Crops Research*, 246. https://doi.org/10.1016/j.fcr.2019.107681

Dubey, P. K., Singh, G. S., & Abhilash, P. C. (2020). Adaptive agronomic practices for sustaining food production. *Adaptive Agricultural Practices*, 11–43. https://doi.org/10.1007/978-3-030-15519-3_2

Duchene, O., Vian, J. F., & Celette, F. (2017a). Intercropping with legume for agroecological cropping systems: Complementarity and facilitation processes and the importance of soil microorganisms. A review. In *Agriculture, Ecosystems and Environment*, 240, 148–161. https://doi.org/10.1016/j.agee.2017.02.019

Duchene, O., Vian, J.-F., & Celette, F. (2017b). Intercropping with legume for agroecological cropping systems: Complementarity and facilitation processes and the importance of soil microorganisms. A review. *Agriculture, Ecosystems & Environment*, 240, 148–161. https://doi.org/10.1016/j.agee.2017.02.019

Duru, M., Therond, O., & Fares, M. (2015). Designing agroecological transitions; A review. In Agronomy for Sustainable Development (Vol. 35, Issue 4, pp. 1237–1257). Springer-Verlag France. https://doi.org/10.1007/s13593-015-0318-x

Eekhout, J. P. C., & De Vente, J. (2019). How soil erosion model conceptualization affects soil loss projections under climate change. *Progress in Physical Geography: Earth and Environment*, *44*(2), 212-232. https://doi.org/10.1177/0309133319871937

El Mountassir, O., Bahir, M., Ouazar, D., Chehbouni, A., & Carreira, P. M. (2022). Temporal and spatial assessment of groundwater contamination with nitrate using nitrate pollution index (NPI), groundwater pollution index (GPI), and GIS (case study: Essaouira basin, Morocco). *Environmental Science and Pollution Research*, 1–18. https://doi.org/https://doi.org/10.1007/s11356-021-16922-8

Elad, Y., & Pertot, I. (2014). Climate Change Impacts on Plant Pathogens and Plant Diseases. *Journal of Crop Improvement*, *28*(1), 99-139. https://doi.org/10.1080/15427528.2014.865412

Elgendy, K., & Abaza, N. (2020). Urbanization in the MENA region: A Benefit or a Curse? Friedrich Ebert Stiftung. https://www.carboun.com/energy/urbanization-in-the-mena-region-a-benefit-or-a-curse/

Elouattassi, Y., Ferioun, M., El Ghachtouli, N., Derraz, K., & Rachidi, F. (2023). Enhancing onion growth and yield through agroecological practices: Organic fertilization and intercropping. *Acta Ecologica Sinica*. https://doi.org/10.1016/j.chnaes.2023.09.004

Esnarriaga, D. N., Mariotti, M., Cardelli, R., & Arduini, I. (2020). The importance of root interactions in field bean/triticale intercrops. *Plants*, 9(11), 1–26. https://doi.org/10.3390/plants9111474

Ewert, F., Baatz, R., & Finger, R. (2023). Agroecology for a Sustainable Agriculture and Food System: From Local Solutions to Large-Scale Adoption. *Annual Review of Resource Economics*, *15*, 351-381. https://doi.org/10.1146/ANNUREV-RESOURCE-102422-090105

FAO. (2016). Achieving Sustainable Rural Development through Agricultural Innovation. www.fao.org

Farghly, S., Mohamed, M. F., El-Dekashey, M. H. Z., & El-Shuwaikh, D. H. (2021). Effect of intercropping systems on yield and its component in onion / faba bean crops. *SVU-International Journal of Agricultural Sciences*, 3(3), 205–231. https://doi.org/10.21608/SVUIJAS.2021.82736.1121

Fathallah, F. A. (2010). Musculoskeletal disorders in labor-intensive agriculture. *Applied Ergonomics*, 41(6), 738–743. https://doi.org/10.1016/j.apergo.2010.03.003

Faye, J. B., & Braun, Y. A. (2022). Soil and human health: Understanding agricultural and socio-environmental risk and resilience in the age of climate change. *Health & Place*, 77, 102799. https://doi.org/10.1016/J.HEALTHPLACE.2022.102799

Ferioun, M., Srhiouar, N., Bouhraoua, S., El Ghachtouli, N., & Louahlia, S. (2023). Physiological and biochemical changes in Moroccan barley (Hordeum vulgare L.) cultivars submitted to drought stress. *Heliyon*, 9(2). https://doi.org/10.1016/j.heliyon.2023.e13643

Finckh, M. R., Gacek, E. S., Goyeau, H., Lannou, C., Merz, U., Mundt, C. C., Munk, L., Nadziak, J., Newton, A. C., de Vallavieille-Pope, C., & Wolfe, M. S. (2000). Cereal variety and species mixtures in practice, with emphasis on disease resistance. *Agronomie*, 20(7), 813–837. https://doi.org/10.1051/agro:2000177

Finn, J. A., Suter, M., Haughey, E., Hofer, D., & Lüscher, A. (2018). Greater gains in annual yields from increased plant diversity than losses from experimental drought in two temperate grasslands. *Agriculture, Ecosystems & Environment*, 258, 149–153. https://doi.org/10.1016/J.AGEE.2018.02.014

Fitzgerald, D. K. (1990). The business of breeding: Hybrid corn in Illinois, 1890-1940. (No Title).

Francaviglia, R., Di Bene, C., Farina, R., Salvati, L., & Vicente-Vicente, J. L. (2019). Assessing "4 per 1000" soil organic carbon storage rates under Mediterranean climate: a comprehensive data analysis. *Mitigation and Adaptation Strategies for Global Change*, 24(5), 795–818. https://doi.org/https://doi.org/10.1007/s11027-018-9832-x

Francis, C., Lieblein, G., Gliessman, S., Breland, T. A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C., & Poincelot, R. (2003). Agroecology: The Ecology of Food Systems. *Journal of Sustainable Agriculture*, 22(3), 99–118. https://doi.org/10.1300/J064v22n03_10

Frye, W. W., Ebelhar, S. A., Murdock, L. W., & Blevins, R. L. (1982). Soil Erosion Effects on Properties and Productivity of Two Kentucky Soils. *Soil Science Society of America Journal*, 46(5), 1051–1055. https://doi.org/10.2136/SSSAJ1982.03615995004600050033X

Fustec, J., Lesuffleur, F., Mahieu, S., & Cliquet, J.-B. (2010). Nitrogen rhizodeposition of legumes. A review. *Agronomy for Sustainable Development*, 30(1), 57–66. https://doi.org/10.1051/agro/2009003

Gallardo-López, F., Hernández-Chontal, M. A., Cisneros-Saguilán, P., & Linares-Gabriel, A. (2018). Development of the Concept of Agroecology in Europe: A Review. *Sustainability*, 10(4), 1210. https://doi.org/10.3390/SU10041210

Gao, X., Wu, M., Xu, R., Wang, X., Pan, R., Kim, H.-J., & Liao, H. (2014). Root interactions in a maize/soybean intercropping system control soybean soil-borne disease, red crown rot. *Plos One*, 9(5), e95031. https://doi.org/10.1371/journal.pone.0095031

Garcia, L., Celette, F., Gary, C., Ripoche, A., Valdés-Gómez, H., & Metay, A. (2018). Management of service crops for the provision of ecosystem services in vineyards: A review. *Agriculture, Ecosystems & Environment*, 251, 158–170. https://doi.org/https://doi.org/10.1016/j.agee.2017.09.030

Gautam, A., Sekaran, U., Guzman, J., Kovács, P., Hernandez, J. L. G., & Kumar, S. (2020). Responses of soil microbial community structure and enzymatic activities to long-term application of mineral fertilizer and beef manure. *Environmental and Sustainability Indicators*, 8. https://doi.org/10.1016/j.indic.2020.100073

Giménez, E. H., & Shattuck, A. (2011). Food crises, food regimes and food movements: Rumblings of reform or tides of transformation? *Journal of Peasant Studies*, 38(1), 109–144. https://doi.org/10.1080/03066150.2010.538578

Girard, N., Duru, M., Hazard, L., & Magda, D. (2008). Categorising farming practices to design sustainable land-use management in mountain areas. *Agronomy for Sustainable Development*, 28(2), 333–343. https://doi.org/10.1051/agro:2007046

Girjesh, G. K., & Patil, V. C. (1991). Weed management studies in groundnut and sunflower intercropping system. *J. Oilseeds Res*, 8, 7–13.

Glande, D. R., & Simon, S. (2019). Effect of intercropping on purple blotch (Alternaria porri) of onion (Allium cepa L.). *Intl J Curr Microbiol App Sci*, 8(2), 1105–1111.

Gliessman, S. (2018). Defining Agroecology. *Agroecology and Sustainable Food Systems*, *42*(6), 599-600. https://doi.org/10.1080/21683565.2018.1432329

González-Rosado, M., Parras-Alcántara, L., Aguilera-Huertas, J., Lozano-García, B., Di Bene, C., Farina, R., Francaviglia, R., & Álvaro-Fuentes, J. (2021). Soil Productivity Degradation in a Long-Term Eroded Olive Orchard under Semiarid Mediterranean Conditions. *Agronomy*, Vol. 11, Page 812, 11(4), 812. https://doi.org/10.3390/AGRONOMY11040812

Gouda, S., Kerry, R. G., Das, G., Paramithiotis, S., Shin, H.-S., & Patra, J. K. (2018). Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture. *Microbiological Research*, 206, 131–140. https://doi.org/https://doi.org/10.1016/j.micres.2017.08.016

Griffin, K. (1979). The political economy of agrarian change: An essay on the Green Revolution. Springer.

Guardia, G., Abalos, D., García-Marco, S., Quemada, M., Alonso-Ayuso, M., Cárdenas, L. M., Dixon, E. R., & Vallejo, A. (2016). Effect of cover crops on greenhouse gas emissions in an irrigated field under integrated soil fertility management. *Biogeosciences*, 13(18), 5245–5257. https://doi.org/10.5194/bg-13-5245-2016

Guo, S., Wang, P., Wang, X., Zou, M., Liu, C., & Hao, J. (2020). Microalgae as biofertilizer in modern agriculture. *Microalgae Biotechnology for Food, Health and High Value Products*, 397–411. https://doi.org/10.1007/978-981-15-0169-2_12

Gupta, A. (1998). Postcolonial developments: Agriculture in the making of modern India. Duke University Press.

Gupta, A. (2008). Impact of pesticides on human and ecosystem health: Scientific, ethical and policy issues. Proceedings of National Seminar on Toxicity of Chemicals and Their Hazards with Special Reference to Heavy Metals (St. Edmund's College, Shillong), 61–72.

Hanif, I., Aziz, B., & Chaudhry, I. S. (2019). Carbon emissions across the spectrum of renewable and nonrenewable energy use in developing economies of Asia. *Renewable Energy*, 143, 586–595. https://doi.org/10.1016/J.RENENE.2019.05.032

Harvey, C. A., Chacón, M., Donatti, C. I., Garen, E., Hannah, L., Andrade, A., Bede, L., Brown, D., Calle, A., & Chará, J. (2014). Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservation Letters*, 7(2), 77–90. https://doi.org/10.1111/conl.12066

Harwood, J. (2019). Was the Green Revolution intended to maximise food production? *International Journal of Agricultural Sustainability*, 17(4), 312–325.

He, X., Xie, H., Gao, D., Khashi, M., Zhou, X., & Wu, F. (2021). Biochar and Intercropping With Potato–Onion Enhanced the Growth and Yield Advantages of Tomato by Regulating the Soil Properties, Nutrient Uptake, and Soil Microbial Community. *Frontiers in Microbiology*, 12. https://doi.org/10.3389/fmicb.2021.695447

Hei, Z., Xiang, H., Zhang, J., Liang, K., Zhong, J., Li, M., & Ren, X. (2022). Intercropping of Rice and Water Mimosa (Neptunia oleracea Lour.): A Novel Model to Control Pests and Diseases and Improve Yield and Grain Quality while Reducing N Fertilizer Application. *Agriculture*, 12(1), 13. https://doi.org/https://doi.org/10.3390/agriculture12010013

Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M. C., Thornton, P. K., Blümmel, M., Weiss, F., Grace, D., & Obersteiner, M. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences of the United States of America*, 110(52), 20888–20893. https://doi.org/10.1073/pnas.1308149110

Herrero, M., Thornton, P. K., Power, B., Bogard, J. R., Remans, R., Fritz, S., Gerber, J. S., Nelson, G., See, L., & Waha, K. (2017). Farming and the geography of nutrient production for human use: a transdisciplinary analysis. *The Lancet Planetary Health*, 1(1), e33–e42. https://doi.org/https://doi.org/10.1016/S2542-5196(17)30007-4

Hill, S. B., & MacRae, R. J. (1996). Conceptual Framework for the Transition from Conventional to Sustainable Agriculture. *Journal of Sustainable Agriculture*, 7(1), 81–87. https://doi.org/10.1300/J064v07n01_07

HLPE. (2019). Other Innovative Approaches for Sustainable Agriculture and Food Systems that Enhance Food Security and Nutrition. A Report by High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security: Rome, Italy. https://www.fao.org/3/ca5602en/ca5602en.pdf

Hofer, D., Suter, M., Haughey, E., Finn, J. A., Hoekstra, N. J., Buchmann, N., & L€ Uscher, A. (2016). Yield of temperate forage grassland species is either largely resistant or resilient to experimental summer drought. *Journal of Applied Ecology*, 53(4), 1023–1034. https://doi.org/10.1111/1365-2664.12694

Hssaisoune, M., Bouchaou, L., Sifeddine, A., Bouimetarhan, I., & Chehbouni, A. (2020). Moroccan groundwater resources and evolution with global climate changes. *Geosciences*, 10(2). https://doi.org/10.3390/geosciences10020081

Idris, O. A., Opute, P., Orimoloye, I. R., & Maboeta, M. S. (2022). Climate Change in Africa and Vegetation Response: A Bibliometric and Spatially Based Information Assessment. *Sustainability*, 14(9), 4974. https://doi.org/10.3390/SU14094974

IPCC. (2014). Climate change 2014 : synthesis report. https://climateanalytics.org/media/ipcc_syr_ar5__2014_.pdf

Iqbal, N., Hussain, S., Ahmed, Z., Yang, F., Wang, X., Liu, W., Yong, T., Du, J., Shu, K., & Yang, W. (2019). Comparative analysis of maize–soybean strip intercropping systems: A review. *Plant Production Science*, 22(2), 131–142. https://doi.org/10.1080/1343943X.2018.1541137

Irhza, A., Nassiri, L., El Jarroudi, M., Rachidi, F., Lahlali, R., & Echchgadda, G. (2023). Description of the Gap between Local Agricultural Practices and Agroecological Soil Management Tools in Zerhoun and in the Middle Atlas Areas of Morocco. *Land*, 12(2), 268.

Isaac, M. E., Isakson, S. R., Dale, B., Levkoe, C. Z., Hargreaves, S. K., Méndez, V. E., Wittman, H., Hammelman, C., Langill, J. C., Martin, A. R., Nelson, E., Ekers, M., Borden, K. A., Gagliardi, S., Buchanan, S., Archibald, S., & Ciani, A. G. (2018). Agroecology in Canada: Towards an integration of agroecological practice, movement, and science. *Sustainability*, 10(9). https://doi.org/10.3390/su10093299

Itelima, Bang, W. J., Onyimba, I. A., Sila, & Egbere, O. J. (2018). Bio-fertilizers as key player in enhancing soil fertility and crop productivity: A Review. 6(3), 73–83. https://doi.org/10.26765/DRJAFS.2018.4815

Jacobsen, S. E., Sørensen, M., Pedersen, S. M., & Weiner, J. (2013). Feeding the world: Genetically modified crops versus agricultural biodiversity. *Agronomy for sustainable development*, *33*, 651-662. https://doi.org/10.1007/s13593-013-0138-9

Jacoby, R., Peukert, M., Succurro, A., Koprivova, A., & Kopriva, S. (2017). The role of soil microorganisms in plant mineral nutrition—current knowledge and future directions. *Frontiers in Plant Science*, 8, 1617. https://doi.org/https://doi.org/10.3389/fpls.2017.01617

Jeanneret, P., Aviron, S., Alignier, A., Lavigne, C., Helfenstein, J., Herzog, F., Kay, S., & Petit, S. (2021). Agroecology landscapes. *Landscape Ecology*, 36(8), 2235–2257. https://doi.org/10.1007/s10980-021-01248-0

Jose, S. (2012). Agroforestry for conserving and enhancing biodiversity. *Agroforestry Systems*, 85(1), 1–8. https://doi.org/10.1007/s10457-012-9517-5

Kabore, P. N., Barbier, B., Ouoba, P., Kiema, A., Some, L., & Ouedraogo, A. (2019). Farmers' perceptions of climate change, environmental impacts and endogenous adaptive strategies in the North Central of Burkina Faso. *VertigO-La Revue Electronique En Sciences de l'Environment*, 19(1). https://id.erudit.org/iderudit/1065432ar

Kaka, H., Opute, P. A., & Maboeta, M. S. (2021). Potential Impacts of Climate Change on the Toxicity of Pesticides towards Earthworms. *Journal of Toxicology*, 2021. https://doi.org/10.1155/2021/8527991

Kaur, G., Gupta, G., & Hooda, K. (2021). Intercropping Systems in Wheat (Triticum sativum L.) for Insect Pests and Disease Management – A Review. *Journal of Pharmaceutical Research International*, 122–129. https://doi.org/10.9734/jpri/2021/v33i53b33688

Kay, S., Graves, A., Palma, J. H. N., Moreno, G., Roces-Díaz, J. v, Aviron, S., Chouvardas, D., Crous-Duran, J., Ferreiro-Domínguez, N., & de Jalón, S. G. (2019). Agroforestry is paying off–Economic evaluation of ecosystem services in European landscapes with and without agroforestry systems. *Ecosystem Services*, 36, 100896.

Kaye, J. P., & Quemada, M. (2017). Using cover crops to mitigate and adapt to climate change. A review. *Agron. Sustain. Dev*, 37, 4. https://doi.org/0.1007/s13593-016-0410-x

Kew, S. F., Philip, S. Y., Hauser, M., Hobbins, M., Wanders, N., Van Oldenborgh, J., Van Der Wiel, K., Veldkamp, T. I. E., Kimutai, J., Funk, C., & Otto, F. E. L. (2021). Impact of precipitation and increasing temperatures on drought trends in eastern Africa. *Earth Syst. Dynam*, 12, 17–35. https://doi.org/10.5194/esd-12-17-2021

Khan, M., Mobin, M., … Z. A.-E. of the, & 2018, undefined. (2018). Fertilizers and their contaminants in soils, surface and groundwater. *Fac.Ksu.Edu.Sa*, 5, 225–240. https://doi.org/10.1016/B978-0-12-809665-9.09888-8

Kloppenburg, J. R. (2005). First the seed: The political economy of plant biotechnology. Univ of Wisconsin Press.

Pascal, A. T. K., Alain, K. A. J., Sidiky, B., Emmanuel, K. K., Norbert, K. N. D., Boaké, K., ... & Bassirou, B. (2019). Effets d'engrais organique liquide (NPK 5-9-18) et minéral (NPK 12-11-18) sur la matière organique du sol et du rendement de la tomate au Sud et au Centre-Ouest de la Côte d'Ivoire. *International Journal of Innovation and Applied Studies*, *27*(4), 955-964. https://doi.org/10.35759/janmplsci.v41-3.8

Kremen, C., Iles, A., & Bacon, C. (2012). Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. *Ecology and Society*, 17(4). https://doi.org/10.5751/ES-05103-170444

Kumar, R. (2016). Rethinking revolutions: Soyabean, choupals, and the changing countryside in Central India.

Kuzucu, M. (2017). Effects of water harvesting techniques and using humic acid on soil moisture, plant evaporation, growth and yield in pistachio orchards in southeastern of Turkey. *Fresenius Environmental Bulletin*, 26(12), 7521–7528.

Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID-19 risks to global food security. *Science*, 369(6503), 500–502). https://doi.org/10.1126/science.abc4765

Lacetera, N. (2019). Impact of climate change on animal health and welfare. *Animal Frontiers*, 9(1), 26–31. https://doi.org/10.1093/AF/VFY030

Lacey, H., & Lefèvre, M. (2015). Agroécologie: la science et les valeurs de la justice sociale, de la démocratie et de la durabilité. *Ecologie & Politique*, 51(2), 27. https://doi.org/10.3917/ecopo.051.0027

Lal, R. (1988). Monitoring soil erosion's impact on crop productivity. *Soil Erosion Research Methods*, 1, 187–200.

Lal, R. (2001). Soil degradation by erosion. *Land Degradation & Development*, 12(6), 519–539. https://doi.org/10.1002/LDR.472

Lal, R. (2004). Agricultural activities and the global carbon cycle. *Nutrient Cycling in Agroecosystems*, 70, 103–116. https://doi.org/10.1023/b:fres0000048480.24274.0f

Leal Filho, W., Nagy, G. J., Setti, A. F. F., Sharifi, A., Donkor, F. K., Batista, K., & Djekic, I. (2023). Handling the impacts of climate change on soil biodiversity. *Science of The Total Environment*, 869, 161671. https://doi.org/10.1016/J.SCITOTENV.2023.161671

Lee, H., Lautenbach, S., Nieto, A. P. G., Bondeau, A., Cramer, W., & Geijzendorffer, I. R. (2019). The impact of conservation farming practices on Mediterranean agro-ecosystem services provisioning—a meta-analysis. *Regional Environmental Change*, 19(8), 2187–2202.

Leippert, F., Darmaun, M., Bernoux, M., Mpheshea, M., Müller, A., Geck, M., Herren, M., Irungu, W., Nyasimi, M., & Sene, J. M. (2020). The potential of agroecology to build climate-resilient livelihoods and food systems. Food and Agriculture Organization of the United Nations FAO and Biovision.

Levidow, L., Pimbert, M., & Vanloqueren, G. (2014). Agroecological Research: Conforming—or Transforming the Dominant Agro-Food Regime? *Agroecology and Sustainable Food Systems*, 38(10), 1127–1155. https://doi.org/10.1080/21683565.2014.951459

Li, C., Hoffland, E., Kuyper, T. W., Yu, Y., Zhang, C., Li, H., Zhang, F., & van der Werf, W. (2020). Syndromes of production in intercropping impact yield gains. *Nature Plants*, 6(6), 653–660. https://doi.org/10.1038/s41477-020-0680-9

Li, S. M., Li, L., Zhang, F. S., & Tang, C. (2004). Acid phosphatase role in chickpea/maize intercropping. *Annals of Botany*, 94(2), 297–303. https://doi.org/https://doi.org/10.1093/aob/mch140

Li, X. F., Wang, C. B., Zhang, W. P., Wang, L. H., Tian, X. L., Yang, S. C., Jiang, W. L., van Ruijven, J., & Li, L. (2018). The role of complementarity and selection effects in P acquisition of intercropping systems. *Plant and Soil*, 422(1–2), 479–493. https://doi.org/10.1007/s11104-017-3487-3

Li, X.-W., Lu, X.-X., Zhang, Z.-J., Huang, J., Zhang, J.-M., Wang, L.-K., Hafeez, M., Mandela Fernández-Grandon, G., & Lu, Y.-B. (2021). Intercropping Rosemary

(Rosmarinus officinalis) with Sweet Pepper (Capsicum annum) Reduces Major Pest Population Densities without Impacting Natural Enemy Populations. *Insects*, *12*(1), 74. https://doi.org/10.3390/insects

Li, Y., Ye, W., Wang, M., & Yan, X. (2009). Climate change and drought: a risk assessment of crop-yield impacts. *Climate Research*, 39(1), 31–46. https://doi.org/10.3354/CR00797

Liang, J., He, Z., & Shi, W. (2020). Cotton/mung bean intercropping improves crop productivity, water use efficiency, nitrogen uptake, and economic benefits in the arid area of Northwest China. *Agricultural Water Management*, 240, 106277. https://doi.org/10.1016/J.AGWAT.2020.106277

Lieberei, J., & Gheewala, S. H. (2017). Resource depletion assessment of renewable electricity generation technologies—comparison of life cycle impact assessment methods with focus on mineral resources. *International Journal of Life Cycle Assessment*, 22(2), 185–198. https://doi.org/10.1007/S11367-016-1152-3/METRICS

Lin, B. B. (2011). Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change. *BioScience*, 61(3), 183–193. https://doi.org/10.1525/bio.2011.61.3.4

Lin, B. B., Egerer, M. H., Liere, H., Jha, S., Bichier, P., & Philpott, S. M. (2018). Local- and landscape-scale land cover affects microclimate and water use in urban gardens. *Science of the Total Environment*, 610–611, 570–575. https://doi.org/10.1016/j.scitotenv.2017.08.091

Litrico, I., & Violle, C. (2015). Diversity in Plant Breeding: A New Conceptual Framework. *Trends in Plant Science*, 20(10), 604–613. https://doi.org/10.1016/j.tplants.2015.07.007

Litskas, V. D., Irakleous, T., Tzortzakis, N., & Stavrinides, M. C. (2017). Determining the carbon footprint of indigenous and introduced grape varieties through Life Cycle Assessment using the island of Cyprus as a case study. *Journal of Cleaner Production*, 156, 418–425. https://doi.org/10.1016/j.jclepro.2017.04.057

Liu, C., Cai, Q., Liao, P., Jiang, X., Tang, X., Yang, Q., & Zhou, L. (2021). Effects of Fallopia multiflora–Andrographis paniculata intercropping model on yield, quality, soil nutrition and rhizosphere microorganisms of F. multiflora. *Plant and Soil*, 467(1–2), 465–481. https://doi.org/10.1007/s11104-021-05106-5

Liu, D. L., Zeleke, K. T., Wang, B., Macadam, I., Scott, F., & Martin, R. J. (2017). Crop residue incorporation can mitigate negative climate change impacts on crop yield and improve water use efficiency in a semiarid environment. *European Journal of Agronomy*, 85, 51–68. https://doi.org/10.1016/j.eja.2017.02.004

Liu, L., Zheng, X., Wei, X., Kai, Z., & Xu, Y. (2021). Excessive application of chemical fertilizer and organophosphorus pesticides induced total phosphorus loss from planting causing surface water eutrophication. *Scientific Reports*, 11(1). https://doi.org/10.1038/s41598-021-02521-7

Liu, X., Zhang, J., Gu, T., Zhang, W., Shen, Q., Yin, S., & Qiu, H. (2014). Microbial Community Diversities and Taxa Abundances in Soils along a Seven-Year Gradient of Potato Monoculture Using High Throughput Pyrosequencing Approach. *PLoS ONE*, 9(1), e86610. https://doi.org/10.1371/journal.pone.0086610

Liu, Y., Ma, W., He, H., Wang, Z., & Cao, Y. (2021). Effects of Sugarcane and Soybean Intercropping on the Nitrogen-Fixing Bacterial Community in the Rhizosphere. *Frontiers in Microbiology*, 12. https://doi.org/10.3389/fmicb.2021.713349

Lobo, D., Lozano, Z., & Delgado, F. (2005). Water erosion risk assessment and impact on productivity of a Venezuelan soil. *CATENA*, 64(2–3), 297–306. https://doi.org/10.1016/J.CATENA.2005.08.011

López-García, D., Cuéllar-Padilla, M., de Azevedo Olival, A., Laranjeira, N. P., Méndez, V. E., Peredo y Parada, S., Barbosa, C. A., Barrera Salas, C., Caswell, M., Cohen, R., Correro-Humanes, A., García-García, V., Gliessman, S. R., Pomar-León, A., Sastre-Morató, A., & Tendero-Acín, G. (2021). Building agroecology with people. Challenges of participatory methods to deepen on the agroecological transition in different contexts. *Journal of Rural Studies*, 83, 257–267. https://doi.org/10.1016/j.jrurstud.2021.02.003

Lovarelli, D., & Bacenetti, J. (2017). Seedbed preparation for arable crops: Environmental impact of alternative mechanical solutions. *Soil and Tillage Research*, 174, 156–168. https://doi.org/10.1016/j.still.2017.06.006

Lu, P., Zhang, Z., Sheng, Z., Huang, M., Agronomy, Z. Z.-, & 2019, undefined. (2019). Effect of Surface Straw Incorporation Rate on Water–Salt Balance and Maize Yield in Soil Subject to Secondary Salinization with Brackish Water Irrigation. *Agronomy*, *9*(7), 341. https://doi.org/10.3390/agronomy9070341

Lulie, B. (2017). Intercropping Practice as an Alternative Pathway for Sustainable Agriculture: A review. *Acad. Res. J. Agri. Sci. Res.*, 5(6), 440–452. https://doi.org/10.14662/ARJASR2017.057

Lupwayi, N. Z., Zhang, Y., Hao, X., Thomas, B. W., Eastman, A. H., & Schwinghamer, T. D. (2019). Linking soil microbial biomass and enzyme activities to long-term manure applications and their nonlinear legacy. *Pedobiologia*, 74, 34–42. https://doi.org/10.1016/j.pedobi.2019.04.001

Ma, S., Wang, H.-Y., Zhang, X., Wang, L.-J., & Jiang, J. (2022). A nature-based solution in forest management to improve ecosystem services and mitigate their trade-offs. *Journal of Cleaner Production*, 351, 131557. https://doi.org/10.1016/j.jclepro.2022.131557

Maathuis, F. J. (2009). Physiological functions of mineral macronutrients. *Current Opinion in Plant Biology*, 12(3), 250–258. https://doi.org/10.1016/j.pbi.2009.04.003

Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A., & Tribedi, P. (2017). Biofertilizers: a potential approach for sustainable agriculture development. *Environmental Science and Pollution Research*, 24(4), 3315–3335. https://doi.org/10.1007/s11356-016-8104-0

Maitra, S. (2019). Potential of Intercropping System in Sustaining Crop Productivity. *International Journal of Agriculture Environment and Biotechnology*, 12(01). https://doi.org/10.30954/0974-1712.03.2019.7

Maja, M. M., & Ayano, S. F. (2021). The Impact of Population Growth on Natural Resources and Farmers' Capacity to Adapt to Climate Change in Low-Income Countries. *Earth Systems and Environment*, 5(2), 271–283. https://doi.org/10.1007/S41748-021-00209-6

Malek, Ž., Verburg, P. H., R Geijzendorffer, I., Bondeau, A., & Cramer, W. (2018). Global change effects on land management in the Mediterranean region. *Global Environmental Change*, 50, 238–254. https://doi.org/10.1016/j.gloenvcha.2018.04.007

Mandal, A., Sarkar, B., Mandal, S., Vithanage, M., Patra, A. K., & Manna, M. C. (2020). Impact of agrochemicals on soil health. In *Agrochemicals detection, treatment and remediation* (pp. 161-187). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-103017-2.00007-6

Mandal, D., Chandrakala, M., Alam, N. M., Roy, T., & Mandal, U. (2021). Assessment of soil quality and productivity in different phases of soil erosion with the focus on land degradation neutrality in tropical humid region of India. *CATENA*, 204, 105440. https://doi.org/10.1016/J.CATENA.2021.105440

Mandal, D., Patra, S., Sharma, N. K., Alam, N. M., Jana, C., & Lal, R. (2023). Impacts of Soil Erosion on Soil Quality and Agricultural Sustainability in the North-Western Himalayan Region of India. *Sustainability*, 15(6), 5430. https://doi.org/10.3390/SU15065430

Manici, L. M., Kelderer, M., Franke-Whittle, I. H., Rühmer, T., Baab, G., Nicoletti, F., Caputo, F., Topp, A., Insam, H., & Naef, A. (2013). Relationship between root-endophytic microbial communities and replant disease in specialized apple growing areas in Europe. *Applied Soil Ecology*, 72, 207–214. https://doi.org/10.1016/j.apsoil.2013.07.011

Marull, J., Cattaneo, C., Gingrich, S., de Molina, M. G., Guzmán, G. I., Watson, A., MacFadyen, J., Pons, M., & Tello, E. (2019). Comparative Energy-Landscape Integrated Analysis (ELIA) of past and present agroecosystems in North America and Europe from the 1830s to the 2010s. *Agricultural Systems*, 175, 46–57. https://doi.org/10.1016/j.agsy.2019.05.011

Massicotte, M. J., & Kelly-Bisson, C. (2019). What's wrong with permaculture design courses? Brazilian lessons for agroecological movement-building in Canada. *Agriculture and Human Values*, 36(3), 581–594. https://doi.org/10.1007/s10460-018-9870-8

Matthan, T. (2022). Beyond bad weather: climates of uncertainty in rural India. *The Journal of Peasant Studies*, *50*(1), 114-135. https://doi.org/10.1080/03066150.2022.2116316

Mazzola, M., & Manici, L. M. (2012). Apple replant disease: Role of microbial ecology in cause and control. *Annual Review of Phytopathology*, 50, 45–65. https://doi.org/10.1146/annurev-phyto-081211-173005

Mballo, I., Sy, O., & Faye, C. (2019). Variabilité climatique et productions vivrières en Haute Casamance (SUD-SENEGAL). *Espace Géographique et Société Marocaine*, 28/29. file:///Users/mac/Downloads/17394-44507-1-PB%20(1).pdf

Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P. A., & Kowero, G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability*, 6, 61–67. https://doi.org/https://doi.org/10.1016/j.cosust.2013.10.014

Mebrate, A., Zeray, N., Tadesse, K., & Haile, G. (2022). Determinants of soil fertility management practices in Gedeo Zone, Southern Ethiopia: Logistic regression approach. *Heliyon*, e08820. https://doi.org/https://doi.org/10.1016/j.heliyon.2022.e08820

Mendelsohn, R., & Mendelsohn, R. (2009). The Impact of Climate Change on Agriculture in Developing Countries. *Journal of Natural Resources Policy Research*, 1(1), 5–19. https://doi.org/10.1080/19390450802495882

Méndez, V. E., Bacon, C. M., & Cohen, R. (2013). Agroecology as a transdisciplinary, participatory, and action-oriented approach. *Agroecology and Sustainable Food Systems*, 37(1), 3–18. https://doi.org/10.1080/10440046.2012.736926

Meragiaw, M. (2017). Role of agroforestry and plantation on climate change mitigation and carbon sequestration in Ethiopia. *J Tree Sci*, 36(1), 1–15.

Migliorini, P., & Wezel, A. (2017). Converging and diverging principles and practices of organic agriculture regulations and agroecology. A review. *Agronomy for sustainable development*, *37*, 1-18. https://doi.org/10.1007/s13593-017-0472-4

Moghbeli, T., Bolandnazar, S., Panahande, J., & Raei, Y. (2019). Evaluation of yield and its components on onion and fenugreek intercropping ratios in different planting densities. *Journal of Cleaner Production*, 213, 634–641. https://doi.org/10.1016/j.jclepro.2018.12.138

Mohammadi, K., Seyed, ·, Fathi, A. A., Razmjou, J., Naseri, · Bahram, & Seyed, *. (2021). Evaluation of the effect of strip intercropping green bean/ garlic on the control of Tetranychus urticae in the field. *Experimental and Applied Acarology*, 83, 183–195. https://doi.org/10.1007/s10493-020-00583-2

Moldavan, L., Pimenowa, O., Wasilewski, M., & Wasilewska, N. (2023). Sustainable Development of Agriculture of Ukraine in the Context of Climate Change. *Sustainability*, 15(13), 10517. https://doi.org/10.3390/SU151310517

Mommer, L., & Visser, E. J. W. (2005). Underwater Photosynthesis in Flooded Terrestrial Plants: A Matter of Leaf Plasticity. *Annals of Botany*, 96(4), 581–589. https://doi.org/10.1093/AOB/MCI212

Mondédji, A. D., Silvie, P., Nyamador, W. S., Martin, P., Agboyi, L. K., Amévoin, K., Ketoh, G. K., & Glitho, I. A. (2021). Cabbage Production in West Africa and IPM with a Focus on Plant-Based Extracts and a Complementary Worldwide Vision. *Plants*, 10(3), 529. https://doi.org/10.3390/plants10030529

Montagnini, F., & Metzel, R. (2017). The Contribution of Agroforestry to Sustainable Development Goal 2: End Hunger, Achieve Food Security and Improved Nutrition, and Promote Sustainable Agriculture (pp. 11–45). https://doi.org/10.1007/978-3-319-69371-2_2

Montesinos, X. A., & Pérez, S. O. (2015). La ruralidad del 15-M. Iniciativas desde el movimiento agroecológico alicantino. *ACME: An International Journal for Critical Geographies*, 14(1), 185–199. https://acme-journal.org/index.php/acme/article/view/1146

Moreno, G., Aviron, S., Berg, S., Crous-Duran, J., Franca, A., de Jalón, S. G., Hartel, T., Mirck, J., Pantera, A., Palma, J. H. N., Paulo, J. A., Re, G. A., Sanna, F., Thenail, C., Varga, A., Viaud, V., & Burgess, P. J. (2018). Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem services. *Agroforestry Systems*, 92(4), 877–891. https://doi.org/10.1007/s10457-017-0126-1

Mousavi, S. R., & Eskandari, H. (2011). A general overview on intercropping and its advantages in sustainable agriculture. *Journal of Applied Environmental and Biological Sciences*, 1(11), 482–486. https://www.researchgate.net/profile/Sayed-Roholla-Mousavi/publication/220000362_A_General_Overview_on_Intercropping_and_Its_Advantages_in_Sustainable_Agriculture/links/0912f50470281eea2e000000/A-General-Overview-on-Intercropping-and-Its-Advantages-in-Sustainable-Agriculture.pdf

Mukhopadhyay, R., Sarkar, B., Jat, H. S., Sharma, P. C., & Bolan, N. S. (2021). Soil salinity under climate change: Challenges for sustainable agriculture and food security. *Journal of Environmental Management*, 280, 111736. https://doi.org/10.1016/J.JENVMAN.2020.111736

Mutengwa, C. S., Mnkeni, P., & Kondwakwenda, A. (2023). Climate-Smart Agriculture and Food Security in Southern Africa: A Review of the Vulnerability of Smallholder Agriculture and Food Security to Climate Change. *Sustainability*, *15*(4), 2882. https://doi.org/10.3390/su15042882

Nakhro, N., & Dkhar, M. S. (2010). Impact of organic and inorganic fertilizers on populations and biomass carbon in paddy field soil. *Agron J*, 9(3), 102–110. http://www.grazingbestprac.com.au/research/chemicals/102-110.pdf

Nalluri, N., & Rama Karri, V. (2018). Use of groundnut shell compost as a natural fertilizer for the cultivation of vegetable plants. *International Journal of Advanced Research on Science and Engineering*, 7(1).

Narla, R. D., Muthomi, J. W., Gachu, S. M., Nderitu, J. H., & Olubayo, F. M. (2011). Effect of intercropping bulb onion and vegetables on purple blotch and downy mildew. *Journal of Biological Sciences*, 11(1), 52–57.

Narotzky, S. (2016). Where have all the peasants gone? *Annual Review of Anthropology*, 45, 301–318. https://doi.org/https://doi.org/10.1146/annurev-anthro-102215-100240

Natarajan, M., & Willey, R. W. (1986). The effects of water stress on yield advantages of intercropping systems. *Field Crops Research*, 13(C), 117–131. https://doi.org/10.1016/0378-4290(86)90015-8

Nations, F. (2015). World fertilizer trends and outlook to 2018. Rome: FAO.

Nawaz, A., & Farooq, M. (2016). Weed management in resource conservation production systems in Pakistan. *Crop Protection*, 85, 89–103. https://doi.org/10.1016/j.cropro.2016.04.002

Naylor, D., Sadler, N., Bhattacharjee, A., Graham, E. B., Anderton, C. R., McClure, R., Lipton, M., Hofmockel, K. S., & Jansson, J. K. (2020). Soil Microbiomes Under Climate Change and Implications for Carbon Cycling. *Annual Review of Environment and Resources*, *45*(1), 29-59. https://doi.org/10.1146/ANNUREV-ENVIRON-012320-082720

Nguyen, Q., Hoang, M. H., Öborn, I., & van Noordwijk, M. (2013). Multipurpose agroforestry as a climate change resiliency option for farmers: An example of local adaptation in Vietnam. *Climatic Change*, 117(1–2), 241–257. https://doi.org/10.1007/s10584-012-0550-1

Nguyen, T. N., Tuan, P. A., Mukherjee, S., Son, S., & Ayele, B. T. (2018). Hormonal regulation in adventitious roots and during their emergence under waterlogged conditions in wheat. *Journal of Experimental Botany*, 69(16), 4065–4082. https://doi.org/10.1093/JXB/ERY190

NING, C. chuan, GAO, P. dong, WANG, B. qing, LIN, W. peng, JIANG, N. hao, & CAI, K. zheng. (2017). Impacts of chemical fertilizer reduction and organic amendments supplementation on soil nutrient, enzyme activity and heavy metal content. *Journal of Integrative Agriculture*, 16(8), 1819–1831. https://doi.org/10.1016/S2095-3119(16)61476-4

Nyéléni, M. (2015). Declaration of the international forum for agroecology. *International Planning Committee for Food Sovereignty. Consultado o*, 18. http://foodsovereignty.org/wp-content/uploads/2015/02/Download-declaration-Agroecology-Nyeleni-2015.pdf

Osanai, Y., Tissue, D. T., Bange, M. P., Anderson, I. C., Braunack, M. V., & Singh, B. K. (2017). Plant-soil interactions and nutrient availability determine the impact of elevated CO 2 and temperature on cotton productivity. *Plant and Soil*, 410, 87-102. https://doi.org/10.1007/s11104-016-2981-3

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical Fertilizers and Their Impact on Soil Health. In G. H. Dar, R. A. Bhat, M. A. Mehmood, & K. R. Hakeem (Eds.), Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs (pp. 1–20). Springer International Publishing. https://doi.org/10.1007/978-3-030-61010-4_1

Pal, S. C., & Chakrabortty, R. (2019). Simulating the impact of climate change on soil erosion in sub-tropical monsoon dominated watershed based on RUSLE, SCS runoff and MIROC5 climatic model. *Advances in Space Research*, 64(2), 352–377. https://doi.org/10.1016/J.ASR.2019.04.033

Pan, X., Lv, J., Dyck, M., & He, H. (2021). Bibliometric Analysis of Soil Nutrient Research between 1992 and 2020. *Agriculture*, 11(3), 223. https://doi.org/10.3390/AGRICULTURE11030223

Pantera, A., Burgess, P. J., Mosquera Losada, R., Moreno, G., López-Díaz, M. L., Corroyer, N., McAdam, J., Rosati, A., Papadopoulos, A. M., Graves, A., Rigueiro Rodríguez, A., Ferreiro-Domínguez, N., Fernández Lorenzo, J. L., González-Hernández, M. P., Papanastasis, V. P., Mantzanas, K., Van Lerberghe, P., & Malignier, N. (2018). Agroforestry for high value tree systems in Europe. *Agroforestry Systems*, 92(4), 945–959. https://doi.org/10.1007/s10457-017-0181-7

Parmesan, C., Morecroft, M., & Trisurat, Y. (2022). Climate change 2022: Impacts, adaptation and vulnerability. *Impacts, adaptation and vulnerability* (Doctoral dissertation, GIEC). https://hal.science/hal-03774939/document

Pathak, P., Singh, C., Chaudhary, N., Rathi, A., & Vyas, D. (2021). Fertilizing with spent mushroom compost. *Recent Trends Mushroom Biol. 1st Ed., Delhi: Global Books Organisation*, 175–186.

Peeters, A., Dendoncker, N., & Jacobs, S. (2013). Enhancing ecosystem services in Belgian agriculture through agroecology: a vision for a farming with a future. *Ecosystem Services*, 285–304. https://doi.org/https://doi.org/10.1016/B978-0-12-419964-4.00022-6

Peltre, C., Nyord, T., Bruun, S., Jensen, L. S., & Magid, J. (2015). Repeated soil application of organic waste amendments reduces draught force and fuel consumption for soil tillage. *Agriculture, Ecosystems & Environment*, 211, 94–101. https://doi.org/https://doi.org/10.1016/j.agee.2015.06.004

Pérez, J. L. H. (2016). Regímenes alimentarios y cuestiones agrarias. *Revista Mexicana de Sociología*, 78(3), 551–554. https://doi.org/https://doi.org/10.2307/26383458

Petit, S., Muneret, L., Carbonne, B., Hannachi, M., Ricci, B., Rusch, A., & Lavigne, C. (2020). Landscape-scale expansion of agroecology to enhance natural pest control: A systematic review. *Advances in Ecological Research*, 63, 1–48. https://doi.org/10.1016/bs.aecr.2020.09.001

Phocas, F., Belloc, C., Bidanel, J., Delaby, L., Dourmad, J. Y., Dumont, B., Ezanno, P., Fortun-Lamothe, L., Foucras, G., Frappat, B., González-García, E., Hazard, D., Larzul, C., Lubac, S., Mignon-Grasteau, S., Moreno, C. R., Tixier-Boichard, M., & Brochard, M. (2016). Review: Towards the agroecological management of ruminants, pigs and poultry through the development of sustainable breeding programmes. II. *Breeding strategies. Animal*, 10(11), 1760–1769. https://doi.org/10.1017/S1751731116001051

Pimbert, M. (2015). Agroecology as an alternative vision to conventional development and climate-smart agriculture. Springer. https://doi.org/10.1057/s41301-016-0013-5

Pimentel, D., & Burgess, M. (2013). Soil Erosion Threatens Food Production. *Agriculture*, 3(3), 443–463. https://doi.org/10.3390/AGRICULTURE3030443

Pogrzeba, M., Rusinowski, S., & Krzyżak, J. (2018). Macroelements and heavy metals content in energy crops cultivated on contaminated soil under different fertilization—case studies on autumn harvest. *Environmental Science and Pollution Research*, 25(12), 12096–12106. https://doi.org/10.1007/s11356-018-1490-8

Prashar, P., & Shah, S. (2016). Impact of Fertilizers and Pesticides on Soil Microflora in Agriculture. *Sustainable Agriculture Reviews,* 19, 331-361. https://doi.org/10.1007/978-3-319-26777-7_8

Rafaela, F. C., Engil, I. P. P., Abdul, N., Maria, I. A., & Johan, S. (2022). Identifying available resources and agricultural practices useful in soil fertility management to support orange-fleshed sweet potato cultivation on smallholder farms in

Mozambique. *African Journal of Agricultural Research*, 18(1), 58–72. https://doi.org/10.5897/AJAR2021.15868

Rahman, M. M. (2023). Alternatives to Rice Monoculture in Bangladesh: The Way of Cleaner Production and Responsible Consumption. *SSRN Electronic Journal*. https://doi.org/10.2139/SSRN.4429979

Raj, A., Jhariya, M. K., Banerjee, A., Khan, N., Meena, R. S., Oraon, P. R., & Yadav, S. K. (2021). Agroecosystem Service Management and Environmental Sustainability. *Sustainable Intensification for Agroecosystem Services and Management*, 379–402. https://doi.org/10.1007/978-981-16-3207-5_12

Rajeshwar, M., & Khan, M. A. A. (2010). Effect of biofertilizers on crop yield and soil available nutrients of rice and maize in alfisols of Nagarjuna Sagar left canal command area of Andhra Pradesh, India. *Asian Journal of Soil Science*, 5(1), 200–203.

Renwick, L. L. R., Kimaro, A. A., Hafner, J. M., Rosenstock, T. S., & Gaudin, A. C. M. (2020). Maize-Pigeonpea Intercropping Outperforms Monocultures Under Drought. *Frontiers in Sustainable Food Systems*, 4. https://doi.org/10.3389/fsufs.2020.562663

Reuter, T., Brinkmeyer, T., Schreiber, J., Freese, V., Trautz, D., & Kühling, I. (2022). Effects of mixed intercropping on the agronomic parameters of two organically grown malting barley cultivars (Hordeum vulgare) in Northwest Germany. *European Journal of Agronomy*, 134, 126470. https://doi.org/https://doi.org/10.1016/j.eja.2022.126470

Reza, M. S., & Sabau, G. (2022). Impact of climate change on crop production and food security in Newfoundland and Labrador, Canada. *Journal of Agriculture and Food Research*, 10, 100405. https://doi.org/10.1016/J.JAFR.2022.100405

Rezaei-Chiyaneh, E., Amirnia, R., Amani Machiani, M., Javanmard, A., Maggi, F., & Morshedloo, M. R. (2020). Intercropping fennel (Foeniculum vulgare L.) with common bean (Phaseolus vulgaris L.) as affected by PGPR inoculation: A strategy for improving yield, essential oil and fatty acid composition. *Scientia Horticulturae*, 261. https://doi.org/10.1016/j.scienta.2019.108951

Rhioui, W., Al Figuigui, J., Lahlali, R., Laasli, S.-E., Boutagayout, A., El Jarroudi, M., & Belmalha, S. (2023). Towards Sustainable Vegetable Farming: Exploring Agroecological Alternatives to Chemical Products in the Fez-Meknes Region of Morocco. *Sustainability*, 15(9), 7412. https://doi.org/10.3390/su15097412

Riaz, U., Mehdi, S. M., Iqbal, S., Khalid, H. I., Qadir, A. A., Anum, W., Ahmad, M., & Murtaza, G. (2020). Bio-fertilizers: eco-friendly approach for plant and soil environment. *Bioremediation and Biotechnology: Sustainable Approaches to Pollution Degradation*, 189–213. https://doi.org/10.1007/978-3-030-35691-0_9

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., Wetterstrand, H., DeClerck, F., Shah, M., Steduto, P., de Fraiture, C., Hatibu, N., Unver, O., Bird, J., Sibanda, L., & Smith, J. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, 46(1), 4–17. https://doi.org/10.1007/s13280-016-0793-6

Rodríguez, M. P., Domínguez, A., Moreira Ferroni, M., Wall, L. G., & Bedano, J. C. (2020). The diversification and intensification of crop rotations under no-till promote earthworm abundance and biomass. *Agronomy*, 10(7), 919.

Rosa-Schleich, J., Loos, J., Mußhoff, O., & Tscharntke, T. (2019). Ecological-economic trade-offs of diversified farming systems–a review. *Ecological Economics*, 160, 251–263. https://doi.org/https://doi.org/10.1016/j.ecolecon.2019.03.002

Rosati, P. J. B. A., Burgess, P. J., & Rosati, A. (2018). Advances in European agroforestry: results from the AGFORWARD project. Agroforest Syst, 92, 801–810. https://doi.org/10.1007/s10457-018-0261-3

Rosenzweig, C., Iglesius, A., Yang, X. B., Epstein, P. R., & Chivian, E. (2001). Climate change and extreme weather events-Implications for food production, plant diseases, and pests. https://digitalcommons.unl.edu/nasapub/24/

Rosset, P. M., & Altieri, M. A. (1997). Agroecology versus input substitution: A fundamental contradiction of sustainable agriculture. *Society & Natural Resources*, 10(3), 283–295. https://doi.org/10.1080/08941929709381027

Rosset, P. M., & Altieri, M. A. (2017). Agroecology: science and politics. Practical Action Publishing.

Ruiz-Colmenero, M., Bienes, R., Eldridge, D. J., & Marques, M. J. (2013). Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. *Catena*, 104, 153–160. https://doi.org/10.1016/j.catena.2012.11.007

Rusch, A., Delbac, L., & Thiéry, D. (2017). Grape moth density in Bordeaux vineyards depends on local habitat management despite effects of landscape heterogeneity on their biological control. *Journal of Applied Ecology*, 54(6), 1794–1803. https://doi.org/10.1111/1365-2664.12858

Rusinamhodzi, L., Dahlin, S., & Corbeels, M. (2016). Living within their means: Reallocation of farm resources can help smallholder farmers improve crop yields and soil fertility. *Agriculture, Ecosystems & Environment*, 216, 125–136. https://doi.org/10.1016/j.agee.2015.09.033

Saghai, Y. (2021). Subversive Future Seeks Like-Minded Model: On the Mismatch between Visions of Food Sovereignty Futures and Quantified Scenarios of Global Food Futures. *Ethics and International Affairs*, 35(1), 51–67. https://doi.org/10.1017/S0892679421000071

Saj, S., Torquebiau, E., Hainzelin, E., Pages, J., & Maraux, F. (2017). The way forward: An agroecological perspective for Climate-Smart Agriculture. *Agriculture, Ecosystems and Environment*, 250, 20–24. https://doi.org/10.1016/j.agee.2017.09.003

Salaheen, S., & Biswas, D. (2019). Organic farming practices: Integrated culture versus monoculture. In Safety and Practice for Organic Food (pp. 23–32). Elsevier. https://doi.org/10.1016/B978-0-12-812060-6.00002-7

Samberg, L. H., Gerber, J. S., Ramankutty, N., Herrero, M., & West, P. C. (2016). Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters*, 11(12), 124010. https://doi.org/10.1088/1748-9326/11/12/124010

Sánchez-Guillén, R. A., Córdoba-Aguilar, A., Hansson, B., Ott, J., & Wellenreuther, M. (2016). Evolutionary consequences of climate-induced range shifts in insects. *Biological Reviews*, 91(4), 1050–1064. https://doi.org/10.1111/BRV.12204

Sarker, P. K., Rahman, M. M., & Das, B. C. (2007). Effect of intercropping of mustard with onion and garlic on aphid population and yield. *Journal of Biological Science*, 15, 35-40. http://www.banglajol.info/index.php/JBS/index

Sasidharan, R., & Voesenek, L. A. C. J. (2015). Ethylene-Mediated Acclimations to Flooding Stress. *Plant Physiology*, 169(1), 3–12. https://doi.org/10.1104/PP.15.00387

Savci, S. (2012). An Agricultural Pollutant: Chemical Fertilizer. *International Journal of Environmental Science and Development*, 73–80. https://doi.org/10.7763/IJESD.2012.V3.191

Schoeny, A., Jumel, S., Rouault, F., Lemarchand, E., & Tivoli, B. (2010). Effect and underlying mechanisms of pea-cereal intercropping on the epidemic development of ascochyta blight. *European Journal of Plant Pathology*, 126(3), 317–331. https://doi.org/10.1007/s10658-009-9548-6

Sekine, T., Masuda, T., & Inawashiro, S. (2021). Suppression effect of intercropping with barley on Thrips tabaci (Thysanoptera: Thripidae) in onion fields. *Applied Entomology and Zoology*, 56(1), 59–68. https://doi.org/10.1007/s13355-020-00708-4

Sélingué, M. (2007). Forum for food sovereignty. Declaration of Nyéléni, 27 February.

Šeremešić, S., Šeremešić, S., Manojlović, M., Ilin, Ž., Vasić, M., Gvozdanović-Varga, J., Subašić, A., & Vojnov, B. (2018). Effect of intercropping on the morphological and nutritional properties of carrots and onions in organic agriculture. *Journal on Processing and Energy in Agriculture*, 22, 80–84. https://doi.org/10.5937/JPEA1802080S

Shah, T. M., Tasawwar, S., Bhat, M. A., & Otterpohl, R. (2021). Intercropping in rice farming under the system of rice intensification—an agroecological strategy for weed control, better yield, increased returns, and social–ecological sustainability. *Agronomy*, 11(5). https://doi.org/10.3390/agronomy11051010

Shahzad, K., Sintim, H., Ahmad, F., Abid, M., & Nasim, W. (2022). Importance of Carbon Sequestration in the Context of Climate Change. *Building Climate Resilience in Agriculture* (pp. 385–401). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-79408-8_23

Sharma, A. (2017). A Review on the Effect of Organic and Chemical Fertilizers on Plants. *International Journal for Research in Applied Science and Engineering Technology*, V(II), 677–680. https://doi.org/10.22214/ijraset.2017.2103

Sharma, R., Chauhan, S. K., & Tripathi, A. M. (2016). Carbon sequestration potential in agroforestry system in India: an analysis for carbon project. *Agroforestry Systems*, 90(4), 631–644. https://doi.org/10.1007/s10457-015-9840-8

Shattuck, A. (2021). Generic, growing, green?: The changing political economy of the global pesticide complex. *The Journal of Peasant Studies*, 48(2), 231–253.

Shen, W., Ni, Y., Gao, N., Bian, B., Zheng, S., Lin, X., & Chu, H. (2016). Bacterial community composition is shaped by soil secondary salinization and acidification brought on by high nitrogen fertilization rates. *Applied Soil Ecology*, 108, 76–83. https://doi.org/10.1016/J.APSOIL.2016.08.005

Shepherd, M. A., Harrison, R., & Webb, J. (2006). Managing soil organic matter - implications for soil structure on organic farms. *Soil Use and Management*, 18, 284–292. https://doi.org/10.1111/j.1475-2743.2002.tb00270.x

Shiming, L., & Gliessman, S. R. (2017). Agroecology in China: Science, Practice, and Sustainable Management. *Agroecology and Sustainable Food Systems*, 1–2. https://doi.org/10.1080/21683565.2017.1358961

Shrestha, S. (2019). Effects of climate change in agricultural insect pest. *Acta Scientific Agriculture*, 3(12), 74–80.

Shukla, P. R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H. O., Roberts, D. C., Zhai, P., Slade, R., Connors, S., & Van Diemen, R. (2019). IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.

Silici, L. (2014). Agroecology What it is and what it has to offer. www.iied.org

Singh, D., Thapa, S., Geat, N., Mehriya, M. L., & Rajawat, M. V. S. (2021). Biofertilizers: Mechanisms and application. *Biofertilizers* (pp. 151–166). Elsevier. https://doi.org/10.1016/B978-0-12-821667-5.00024-5

Singh Malhi, G., Kaur, M., & Kaushik, P. (2021). Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. *Sustainability*, *13*(3), 1318. https://doi.org/10.3390/su13031318

Sirami, C., Gross, N., Baillod, A. B., Bertrand, C., Carrié, R., Hass, A., Henckel, L., Miguet, P., Vuillot, C., & Alignier, A. (2019). Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. *Proceedings of the National Academy of Sciences*, 116(33), 16442–16447. https://doi.org/10.1073/pnas.19064191

Skorupka, M., Nosalewicz, A., Krasilnikov, P., & Taboada, M. A. (2021). Ammonia Volatilization from Fertilizer Urea—A New Challenge for Agriculture and Industry in View of Growing Global Demand for Food and Energy Crops. *Agriculture*, 11(9), 822. https://doi.org/10.3390/AGRICULTURE11090822

Smith, L. G., Williams, A. G., & Pearce, B. D. (2015). The energy efficiency of organic agriculture: A review. *Renewable Agriculture and Food Systems*, 30(3), 280–301. https://doi.org/10.1017/S1742170513000471

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-Kerr, R., & Kanyama-Phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences*, 107(48), 20840–20845. https://doi.org/10.1073/pnas.10071991

Solanki, M. K., Wang, F. Y., Li, C. N., Wang, Z., Lan, T. J., Singh, R. K., Singh, P., Yang, L. T., & Li, Y. R. (2020). Impact of Sugarcane–Legume Intercropping on Diazotrophic Microbiome. *Sugar Tech*, 22(1), 52–64. https://doi.org/10.1007/s12355-019-00755-4

Somarriba, E. (1992). Revisiting the past: an essay on agroforestry definition. *Agroforestry Systems*, 19(3), 233–240. https://doi.org/10.1007/BF00118781

Sommer, S. G., Olesen, J., Petersen, S. O., Weisbjerg, M., Valli, L., Rodhe, L., & Béline, F. (2009). Region-specific assessment of greenhouse gas mitigation with different manure management strategies in four agroecological zones. *Global Change Biology*, 15(12), 2825–2837. https://doi.org/10.1111/j.1365-2486.2009.01888.x

Soriano-Martín, M. L., Porras-Piedra, A., & Porras-Soriano, A. (2006). Use of microwaves in the prevention of Fusarium oxysporum f. sp. melonis infection during the commercial production of melon plantlets. *Crop Protection*, 25(1), 52–57. https://doi.org/10.1016/j.cropro.2005.03.016

Steenwerth, K., & Belina, K. M. (2008). Cover crops and cultivation: Impacts on soil N dynamics and microbiological function in a Mediterranean vineyard agroecosystem. *Applied Soil Ecology*, 40(2), 370–380. https://doi.org/10.1016/j.apsoil.2008.06.004

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., De Vries, W., De Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223). https://doi.org/10.1126/science.1259855

Strom, N., Hu, W., Haarith, D., Chen, S., & Bushley, K. (2020). Interactions between soil properties, fungal communities, the soybean cyst nematode, and crop yield under continuous corn and soybean monoculture. *Applied Soil Ecology*, 147, 103388. https://doi.org/10.1016/J.APSOIL.2019.103388

Suarez, A., Conservation, W. G.-B., & 2023, undefined. (2023). On the relation between monocultures and ecosystem services in the Global South: A review. Elsevier, 278, 109870. https://doi.org/10.1016/j.biocon.2022.109870

Sulman, B. N., Phillips, R. P., Oishi, A. C., Shevliakova, E., & Pacala, S. W. (2014). Microbe-driven turnover offsets mineral-mediated storage of soil carbon under elevated CO2. *Nature Climate Change*, 4(12), 1099–1102. https://doi.org/10.1038/nclimate2436

Sun, T., Zhao, C., Feng, X., Yin, W., Gou, Z., Lal, R., Deng, A., Chai, Q., Song, Z., & Zhang, W. (2021). Maize-based intercropping systems achieve higher productivity and profitability with lesser environmental footprint in a water-scarce region of northwest China. *Food and Energy Security*, 10(1). https://doi.org/10.1002/FES3.260

Tang, X., Jiang, J., Huang, Z., Wu, H., Wang, J., He, L., Xiong, F., Zhong, R., Liu, J., Han, Z., Tang, R., & He, L. (2021). Sugarcane/peanut intercropping system improves the soil quality and increases the abundance of beneficial microbes. *Journal of Basic Microbiology*, 61(2), 165–176. https://doi.org/10.1002/jobm.202000750

Tang, X., Zhang, Y., Jiang, J., Meng, X., Huang, Z., Wu, H., He, L., Xiong, F., Liu, J., Zhong, R., Han, Z., & Tang, R. (2021). Sugarcane/peanut intercropping system improves physicochemical properties by changing N and P cycling and organic matter turnover in root zone soil. *PeerJ*, 9, e10880. https://doi.org/10.7717/peerj.10880

Taschen, E., Amenc, L., Tournier, E., Deleporte, P., Malagoli, P., Fustec, J., Bru, D., Philippot, L., & Bernard, L. (2017). Cereal-legume intercropping modifies the dynamics of the active rhizospheric bacterial community. *Rhizosphere*, 3, 191–195. https://doi.org/10.1016/J.RHISPH.2017.04.011

Tetteh, E. N., Owusu Danquah, E., Abunyewa, A. A., Melenya Ocansey, C., Boakye, E. A., Tuffour, H. O., Logah, V., Twum-Ampofo, K., Dzomeku, B. M., Yeboah, S., & Barnes, V. R. (2021). Plantain-Tree Rubber Intercropping Systems Improved Productivity in the Tropical Humid Zone of Ghana, West Africa. *International Journal of Agronomy*, 1–16. https://doi.org/10.1155/2021/3240686

Thiesen, T., Bhat, M. G., Liu, H., & Rovira, R. (2022). An Ecosystem Service Approach to Assessing Agro-Ecosystems in Urban Landscapes. *Land*, 11(4). https://doi.org/10.3390/land11040469

Tian, X., Li, C., Zhang, M., Wan, Y., Xie, Z., Chen, B., & Li, W. (2018). Biochar derived from corn straw affected availability and distribution of soil nutrients and cotton yield. *PLOS ONE*, 13(1), e0189924. https://doi.org/10.1371/JOURNAL.PONE.0189924

Torralba, M., Fagerholm, N., Burgess, P. J., Moreno, G., & Plieninger, T. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture, Ecosystems & Environment*, 230, 150–161. https://doi.org/10.1016/j.agee.2016.06.002

Utomo, B., Prawoto, A. A., Bonnet, S., Bangviwat, A., & Gheewala, S. H. (2016). Environmental performance of cocoa production from monoculture and agroforestry systems in Indonesia. *Journal of Cleaner Production*, 134(Part B), 583–591. https://doi.org/10.1016/j.jclepro.2015.08.102

Vaarst, M., & Alrøe, H. F. (2012). Concepts of animal health and welfare in organic livestock systems. *Journal of Agricultural and Environmental Ethics*, 25(3), 333–347. https://doi.org/10.1007/s10806-011-9314-6

Valenzuela, H. (2016). Agroecology: A global paradigm to challenge mainstream industrial agriculture. *Horticulturae*, *2*(1), 2. https://doi.org/10.3390/horticulturae2010002

van de Wiel, C. C. M., van der Linden, C. G., & Scholten, O. E. (2016). Improving phosphorus use efficiency in agriculture: opportunities for breeding. *Euphytica*, 207(1), 1–22. https://doi.org/10.1007/S10681-015-1572-3 van der Bom, F., Nunes, I., Raymond, N. S., Hansen, V., Bonnichsen, L., Magid, J., Nybroe, O., & Jensen, L. S. (2018). Long-term fertilisation form, level and duration affect the diversity, structure and functioning of soil microbial communities in the field. *Soil Biology and Biochemistry*, 122, 91–103. https://doi.org/10.1016/j.soilbio.2018.04.003

Vandenberghe, C., Palm, R., Lambert, R., Detoffoli, M., & Marcoen, J. M. (2012). Implementation of the Nitrates Directive. Analysis of the assessment's methodology for the control of the soil nitrate nitrogen residue in the farm's fields of Wallonia. *Biotechnologie, Agronomie, Société et Environnement*, 16(1), 25–32.

Varghese, S., & Hansen-Kuhn, K. (2013). Scaling up agroecology: Towards the realization of the right to food. Institute for Agriculture and Trade Policy. *Institute for Agriculture and Trade Policy*.

Verma, S., Subehia, S. K., & Sharma, S. P. (2005). Phosphorus fractions in an acid soil continuously fertilized with mineral and organic fertilizers. *Biology and Fertility of Soils*, 41(4), 295–300. https://doi.org/10.1007/s00374-004-0810-y

Vicente-Vicente, J. L., García-Ruiz, R., Francaviglia, R., Aguilera, E., & Smith, P. (2016). Soil carbon sequestration rates under Mediterranean woody crops using recommended management practices: A meta-analysis. *Agriculture, Ecosystems & Environment*, 235, 204–214. https://doi.org/https://doi.org/10.1016/j.agee.2016.10.024

Vodounou, J. B. K., & Doubogan, Y. O. (2016). Agriculture paysanne et stratégies d'adaptation au changement climatique au Nord- Bénin. *CyberGeo*. https://doi.org/10.4000/cybergeo.27836

Vogel, A., Scherer-Lorenzen, M., & Weigelt, A. (2012). Grassland resistance and resilience after drought depends on management intensity and species richness. *PLoS ONE*, 7(5). https://doi.org/10.1371/JOURNAL.PONE.0036992

Wang, T., Duan, Y., Liu, G., Shang, X., Liu, L., Zhang, K., Li, J., Zou, Z., Zhu, X., & Fang, W. (2022). Tea plantation intercropping green manure enhances soil functional microbial abundance and multifunctionality resistance to drying-rewetting cycles. *Science of The Total Environment*, 810, 151282. https://doi.org/10.1016/j.scitotenv.2021.151282

Wasaya, A., Ahmad, R., Hassan, F. U., Ansar, M., Manaf, A., & Sher, A. (2013). Enhancing crop productivity through wheat (Triticum aestivum L.)-fenugreek intercropping system. *J. Anim. Plant Sci*, 23(1), 210–215.

Wezel, A. (2017). Agroecological practices for sustainable agriculture: principles, applications, and making the transition. World Scientific.

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., & David, C. (2009). Agroecology as a science, a movement and a practice. A review. *Agronomy for Sustainable Development*, 29(4), 503–515. https://doi.org/10.1051/agro/2009004

Wezel, A., Casagrande, M., Celette, F., Vian, J.-F., Ferrer, A., & Peigné, J. (2014). Agroecological practices for sustainable agriculture. A review. *Agronomy for Sustainable Development*, 34(1), 1–20. https://doi.org/https://doi.org/10.1007/s13593-013-0180-7

Wezel, A., Herren, B. G., Kerr, R. B., Barrios, E., Gonçalves, A. L. R., & Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, 40(6). https://doi.org/10.1007/S13593-020-00646-Z

Wezel, A., & Jauneau, J.-C. (2011). Agroecology – Interpretations, Approaches and Their Links to Nature Conservation. *Integrating agriculture, conservation and ecotourism: Examples from the field*, 1-25. https://doi.org/10.1007/978-94-007-1309-3_1

Wezel, A., & Silva, E. (2017). Agroecology and agroecological cropping practices. In Agroecological Practices for Sustainable Agriculture: Principles, Applications, and Making the Transition (pp. 19–51).

Wheeler, S. A., Zuo, A., & Loch, A. (2015). Watering the farm: Comparing organic and conventional irrigation water use in the Murray–Darling Basin, Australia. *Ecological Economics*, 112, 78–85. https://doi.org/10.1016/j.ecolecon.2015.02.019

Wibbelmann, M., Schmutz, U., Wright, J., Udall, D., Rayns, F., Kneafsey, M., Trenchard, L., Bennett, J., & Turner, M. L. (2013). Mainstreaming agroecology: Implications for global food and farming systems. Centre for Agroecology and Food Security, Coventry University. http://www.fao.org/agroecology/database/detail/en/c/455332/

Willey, R. W. (1990). Resource use in intercropping systems. *Agricultural Water Management*, 17(1–3), 215–231. https://doi.org/10.1016/0378-3774(90)90069-B

Willey, R. W., & Rao, M. R. (1980). A competitive ratio for quantifying competition between intercrops. *Experimental Agriculture*, 16(2), 117–125. https://doi.org/10.1017/S0014479700010802

Wojtkowski, P. (2019). Productive Intercropping. *Agroecology* (pp. 75–87). Springer International Publishing. https://doi.org/10.1007/978-3-319-93209-5_5

Woźniak, A. (2020). Effect of Cereal Monoculture and Tillage Systems on Grain Yield and Weed Infestation of Winter Durum Wheat. *International Journal of Plant Production*, 14(1), 1–8. https://doi.org/10.1007/s42106-019-00062-8

Wright, A. J., de Kroon, H., Visser, E. J. W., Buchmann, T., Ebeling, A., Eisenhauer, N., Fischer, C., Hildebrandt, A., Ravenek, J., Roscher, C., Weigelt, A., Weisser, W., Voesenek, L. A. C. J., & Mommer, L. (2017). Plants are less negatively affected by flooding when growing in species-rich plant communities. *New Phytologist*, 213(2), 645–656. https://doi.org/10.1111/NPH.14185

Wu, H., Zhang, Z., Wang, J., Qin, X., Chen, J., Wu, L., Lin, S., Rensing, C., & Lin, W. (2021). Bio-Fertilizer Amendment Alleviates The Replanting Disease By Reshaping Leaf And Root Microbiome. *Microbial ecology*, 1-13. https://doi.org/10.21203/rs.3.rs-582632/v1

Wu, S., Thapa, B., Rivera, C., & Yuan, Y. (2021). Nitrate and nitrite fertilizer production from air and water by continuous flow liquid-phase plasma discharge. *Journal of Environmental Chemical Engineering*, 9(2), 104761. https://doi.org/10.1016/J.JECE.2020.104761

Xiong, W., Li, Z., Liu, H., Xue, C., Zhang, R., Wu, H., Li, R., & Shen, Q. (2015). The Effect of Long-Term Continuous Cropping of Black Pepper on Soil Bacterial Communities as Determined by 454 Pyrosequencing. *PloS one*, *10*(8), e0136946. https://doi.org/10.1371/journal.pone.0136946

Xiong, W., Zhao, Q., Zhao, J., Xun, W., Li, R., Zhang, R., Wu, H., & Shen, Q. (2015). Different Continuous Cropping Spans Significantly Affect Microbial Community Membership and Structure in a Vanilla-Grown Soil as Revealed by Deep Pyrosequencing. *Microbial Ecology*, 70(1), 209–218. https://doi.org/10.1007/s00248-014-0516-0

Xu, Y., Tang, H., Xiao, X., Li, W., Li, C., Sun, G., & Cheng, K. (2018). Effects of long-term fertilization management practices on soil microbial carbon and microbial biomass in paddy soil at various stages of rice growth. *Revista Brasileira de Ciencia Do Solo*, 42. https://doi.org/10.1590/18069657rbcs20170111

Xu, Z., Li, C., Zhang, C., Yu, Y., van der Werf, W., & Zhang, F. (2020). Intercropping maize and soybean increases efficiency of land and fertilizer nitrogen use; A meta-analysis. *Field Crops Research*, 246, 107661. https://doi.org/10.1016/j.fcr.2019.107661

Yadav, S., & Anand, S. (2022). Green revolution and food security in India: a review. *National Geographical Journal of India*, 65(3), 312–323.

Yu, T., Mahe, L., Li, Y., Wei, X., Deng, X., & Zhang, D. (2022). Benefits of Crop Rotation on Climate Resilience and Its Prospects in China. *Agronomy*, *12*(2), 436. https://doi.org/10.3390/agronomy12020436

Zhang, F., & Li, L. (2003). Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant and Soil*, 248, 305–312. https://doi.org/10.1023/A:1022352229863

Zhang, R., Meng, L., Li, Y., Wang, X., Ogundeji, A. O., Li, X., Sang, P., Mu, Y., Wu, H., & Li, S. (2021). Yield and nutrient uptake dissected through complementarity and selection effects in the maize/soybean intercropping. *Food and Energy Security*, 10(2), 379–393.

Zhang, X., Teng, Z., Zhang, H., Cai, D., Zhang, J., Meng, F., & Sun, G. (2021). Nitrogen application and intercropping change microbial community diversity and physicochemical characteristics in mulberry and alfalfa rhizosphere soil. *Journal of Forestry Research*, 32(5), 2121–2133. https://doi.org/10.1007/s11676-020-01271-y

Zhao, Q., Xiong, W., Xing, Y., Sun, Y., Lin, X., & Dong, Y. (2018). Long-Term Coffee Monoculture Alters Soil Chemical Properties and Microbial Communities. *Scientific Reports*, 8(1), 6116. https://doi.org/10.1038/s41598-018-24537-2

Zhou, L., Wang, Y., Xie, Z., Zhang, Y., Malhi, S. S., Guo, Z., Qiu, Y., & Wang, L. (2018). Effects of lily/maize intercropping on rhizosphere microbial community and yield of Lilium davidii var. unicolor. *Journal of Basic Microbiology*, 58(10), 892–901. https://doi.org/10.1002/jobm.201800163

Zhou, W., Chen, F., Meng, Y., Chandrasekaran, U., Luo, X., Yang, W., & Shu, K. (2020). Plant waterlogging/flooding stress responses: From seed germination to maturation. *Plant Physiology and Biochemistry*, 148, 228–236. https://doi.org/10.1016/J.PLAPHY.2020.01.020

Ziaie-Juybari, H., Pirdashti, H., Abo-Elyousr, K. A. M., & Mottaghian, A. (2021). Abiotic benefits of intercropping legumes and maize to reduce pests. *Archives of Phytopathology and Plant Protection*, 54(17–18), 1539–1552. https://doi.org/10.1080/03235408.2021.1919592

Zwicke, M., Alessio, G. A., Thiery, L., Falcimagne, R., Baumont, R., Rossignol, N., ... & Picon-Cochard, C. (2013). Lasting effects of climate disturbance on perennial grassland above-ground biomass production under two cutting frequencies. *Global Change Biology*, *19*(11), 3435-3448. https://doi.org/10.1111/gcb.12317

Zyada, H. G., Mohsen, A. A. M., & Nosir, W. S. (2022). Using intercropping systems to obtain high yield and good competitive indices of fennel and onion under different potassium fertilizer levels. *Zagazig Journal of Agricultural Research*, 49(2), 193–207.

Table 1 - Examples of associated crops and their impacts on productivities (yield and agronomic parameters, natural enemies (diseases, pests, weeds), physical properties, microbiological parameters of soil and LER

Effects of intercropping / Intercrops	Yield and agronomic parameters	Diseases, pests and weeds	Physical properties and resources	Microbial parameters of soil	LER
- Onion + Pepper - Onion + Fennel - Onion + Carrot With organic and/ or inorganic fertilization (Elouattassi et al., 2023)	Significant increases in plant height, stem diameter, number of leaves/ plant, plant fresh weight, and bulb weight, as well as improved yield, with inorganic fertilization (NPK) and onion-carrot intercropping, showcasing their positive impacts on onion cultivation.			-	-
Onion + Fenugreek (Moghbeli et al., 2019)	Improvement of bulb diameter, fresh and dry weight, and total yield. Increasing in biological yield, fresh, dry weight and plant height of fenugreek.		Reducing competition between resources, carbon dioxide, humidity and light.	-	> 1 Onion and fenugreek are favorable for intercropping because they are complementary, and contribute interactively to the increase in yield per unit area.
Onion or garlic + Cabbage (Mondédji et al., 2021)		Reduction of cabbage worms (*Hellula undalis*) : Volatile compounds emitted by other cultivated species repel cabbage pests, for example onion or garlic produce an ally compound, allyl propyl disulphide which repeals aphids.		-	-
Wheat + fenugreek (Wasaya et al., 2013)	Net crop yield increase at (1:3) ratio: Yield of wheat grains, wheat straw (Kg/ha) Fenugreek yield Gross income (Rs/ha)				>1 LER has shown a 19 to 38% yield increase for intercropping systems compared to monocropping.

	Reduction in the number of kernels, weight per ear of wheat, weight of 1000 seeds, harvest index and biological yield of wheat in association with fenugreek.				
Tea + soybean Tea + soybean+ milk vetch (Wang et al., 2022)	-	-	Increase in total soil carbon, nitrogen and phosphorus.	Tea+ soybean, tea+ soybean+ milk vetch significantly increasing in multifunctional resistance by 12.07 and 25.86% respectively.	-
Fallopia Multiflora + *Andrographis paniculata* (C. Liu et al., 2021)	Improvement of yield and quality of *F. Multiflora.* Increase in plant height and maximum fresh weight of root tubers Increase in rod diameter and fresh weight of root by 15 and 12.9%, respectively.	-	Decrease in organic matter, nitrogen, phosphorus and potassium by 23.3, 21.6, 66,8 and 26.6%, respectively. pH (monoculture) = 4.48 a < pH (intercropping) = 4.92	Improvement of urease and invertase enzyme activities by 10.1 and 9.7%, respectively. Increase in bacteria and actinomycetes by 76.9 and 35.1%, respectively. Increase in bacterial abundance indices (ACE and Chao1) and diversity indices (Shannon and Simpson).	-
Potato onion + tomato with biochar concentrations (0, 0,3, 0,6 et 1,12%). (He et al., 2021)	Increase in yield tomato with 0.6 and 1.12% biochar. Increase in height and dry weight of tomato, with and without biochar.	-	Increase in soil moisture and pH and decrease in NO_3^-–N and AK, with and without biochar.	Increase in total bacteria abundance with 1.12% biochar. Increase in total fungi abundance with the application of biochar. Increase in beneficial microorganisms *Pseudeurotium* and *Solirubrobacte.* Reduction of pathogenic microorganisms: *Kribbella* and *Ilyonectria.*	
Wheat + Mustard (Drakopoulos et al., 2020)		Systematic suppression of the *Fusarium* infection and reduction of mycotoxin content in wheat grains:			

		Deoxynivalenol up to 50, 58 and 56%, Zearalenone up to 76, 71, and 87%.		
White mulberry+ Alfalfa + N application (X. Zhang et al., 2021)	-	-	Decrease in pH and soil moisture in mulberry treatments, with and without N. Decrease in organic matter content and soil moisture in alfalfa treatments, with and without N.	Increase in the values of McIntosh, Simpson and Shannon-Weaver diversities in mulberry treatments, with or without N. Reduction of Shannon-Weaver and Simpson diversities in alfalfa treatments.
Soybean + sugarcane (two cultivars ZZ1 et ZZ9) (Y. Liu et al., 2021)	Increase in crop yield and promoting sustainable development of the sugarcane industry.	-	-	Increase in bacterial community and accumulation of N-fixing bacteria (ZZ9/soybean > ZZ1/soybean).
Onion + Barley (Sekine et al., 2021)	Influencing onion growth by causing a reduction in bulb size.	Significant decline in the thrips tabaci population (*Thysanoptera: Thripidae*) throughout the cultivation period.	-	-
Sugarcane + Peanut (Tang, Jiang, et al., 2021)	Improvement of the economic benefit by 87.84 and 36.38% for peanut and sugarcane, respectively.		Increase in total N, available N and pH in peanut soil. Increase in available K and pH in sugarcane soil. Increase in N and P content in the soil.	Increase in acid phosphatase activity by 44.93 and 32.45% in sugarcane and peanut, respectively. Increase in protease and sucrase activities in peanut soil, by 32.22 and 46.02%, respectively. Increase in microbial abundance (bacteria, fungi and actinomycetes) and total microbial abundance. Increase in microbial rhizospheric abundance such as: *Acidobacteriaceae subgroup 1*, *DA111* and acidobacteria.

Rubber fig + Plantain (Tetteh et al., 2021)	-	-	Improvement of the SOC content. Cropping systems with plantain (monoculture or intercropping) had high bulk density values in the 15-30cm depth and lower values in the 0-15cm depth. Improvement of the hydraulic properties of the soil.	Increase in microbial biomasses (Cmic), N (Nmic) and P (mic)	
Rice + Vegetable Neptunia (Hei et al., 2022)	Improvement of rice yield. Increase of the number of panicles per unit, especially with N reduced. Improvement of rice grain quality. Increase in economic return of rice, with reduced N.	Decrease in the incidence of rice borer (*Chilo suppressalis*). Reduction in the appearance of leaf folds in rice compared to the monoculture treatments. Reduction in the incidence of sheath blight in rice. Decrease in the incidences of rice leaf blight, leaf folding and sheath blight, with reduced N.	-	-	
Green bean + Garlic (Mohammadi et al., 2021)	Improvement of green bean yield.	Reducing egg densities and motile forms of *Tetranychus urticae* Koch at all green bean growth stages. Seven predators of *T. urticae* were collected from infested green bean plants of which *Stethorus gilvifrons* et *Orius niger* were the main predators. Significant increase of *O. niger* density during the	-	-	>1 The LER was greater than 1 in all the intercropping treatments, especially in the ratio (3:5).

		vegetative and flowering stage. No significant difference was observed in *S. gilvifrons* densities between intercropping and monoculture. Increase of the values of Shannon diversity index and those of the Pielou evenness index of the composition of *T. urticae*.			
Rosemary+ pepper (X.-W. Li et al., 2021)	-	Significant effect on the dynamics of pest populations: Significant decrease in the densities of *Frankliniella intonsa*, *Myzus persicae* and *Bemisia tabaci* compared to pepper monoculture; No effect observed on the population densities of the predator *Orius sauteri* or parasitoïd *Encarsia formosa*.	-	-	
Maize + different bean varieties (pinto bean, dwarf bean, kidney bean, white bean and sword bean) (Ziaie-Juybari et al., 2021)	Improvement of bean plant height, especially in maize/ pinto bean treatment.	Significant decrease of *Tetranychus urticae* density by 83% and 62% in maize/ white bean and maize/ sword bean treatments, respectively. Significant decrease of the severity of minor leaf (*Delia platura*) by 30%; Increase of *Thrips tabaci population* by 30%. Significant reduce of the rust disease caused by the pathogen *Uromyces appendiculatus* in maize/ pinto bean and maize/ sword bean treatments by 37% and 98%, respectively.	-	-	>1 The most effective LERs 1,13 et 1,21 were obtained in maize/ dwarf bean and maize/pinto bean treatments, respectively.

		The Shannon-Wiener index and the Simpson index indicate that the pest diversity in the intercropping treatments (4.5%) was higher than that in the monoculture treatments (1.6%). Increase in the degree of pest control by maize/ pinto bean and maize/ kidney bean treatments with increasing pest community in the monocrop treatments			
Rice + bean (Shah et al., 2021)	Improvement of rice plant height, tiller number and panicle lenght. Positive effect on number of spikelets per panicle. Increase in the seeds per panicle. Improvement of the total rice yield.	Decrease in weed incidence by 65% throughout the trial period.	Increase in the content of N, P and K.	-	
Faba bean + Onion (Farghly et al., 2021)	Significant increase in: Onion yield, plant height, bulb diameter, number of leaves and plant fresh weight, especially in (1 :3) ratio. Faba bean yield, especially in (3:1) ratio.	-	The most efficient N, P and K uptake was recorded in (3 :1) ratio.	-	>1 Highest LERs were obtained in the following ratios (3 :1) and (1 :3) which could be a new model to get better land use and irrigation.
Maize + soybean (Berdjour et al., 2020)	Decrease in total yields of maize and soybean.	Decrease in the weed biomass compared to the maize monoculture system. Reducing of the number of grass and broadleaf weed species. Decrease in the weed species diversity index with maize maturity type,	-	-	>1 Indicating better productivity of intercropping yields and an average of 40% land retained.

		increasing soybean row spacing, and in intercropping.			
Two barley cultivars (Marthe et Odilia) + Peas Two barley cultivars (Marthe et Odilia) + linseed (Reuter et al., 2022)	Monoculture of the two barley cultivars recorded the highest barley yields. Marthe barley/ peas was more productive than that with linseed. Unlike Odilia barley which showed a more interesting yield by combining it with linseed. The highest percentage of barley grain protein was recorded in the association of the two cultivars with pea, followed by their association with linseed.				>1 The highest LER was obtained in the association of Odilia barley/ peas, then Odilia barley/ linseed, showing their ability to use land more efficiently.
Melon + cowpea (Cuartero et al., 2022)	Improvement of melon yield, especially in melon/ cowpea arranged in the same line and in (2:1) ratio. Increase in the number of melons. Decrease in cowpea yield.	-	Significant increase in total organic N and C, compared to melon monoculture treatments. Increase in available P. No significant difference was noticed for available K.	No significant difference in Shannon or Chao1 diversity indices was found between the agrosystems, on the other hand there was a significant difference in the structure of the bacterial community between the cropping systems. Intercropping treatments were characterized by a greater abundance of beneficial microorganisms such as *Pseudomonas*, *Bacillus*, *Streptomyces* and *Sphingomonas*. Phosphatase and Β-glucosidase enzyme activities were significantly increased in the intercropping systems,	-

	compared to the melon monoculture.	

Table 2: Agroecological solutions for the major problems in contemporary agriculture.

Major problems	Agroecological solution	Relevance	REFERENCE
Climate change	Agroforestry	Offers benefits such as soil erosion control, improved soil fertility, and regulation of temperatures.	(Jose, 2012; Kay et al., 2019; Mbow et al., 2014; Montagnini & Metzel, 2017; Pantera et al., 2018; Rosati et al., 2018; R. Sharma et al., 2016)
	Crop rotation	Effective strategies for climate change adaptation, preventing soil erosion and enhancing water use efficiency.	
	Cover crop	Contribute to erosion reduction, nitrogen fixation, improved soil health, and organic matter accumulation	(Abdelmajid et al., 2021; Bonciarelli et al., 2016; Borrelli et al., 2014; Debray et al., 2019; Rosa-Schleich et al., 2019; Shahzad et al., 2022; Yu et al., 2022)
	Organic amendements	Compost, crop residues and mulch help retain water, especially in arid environments, while reducing greenhouse gas emissions.	
	Reducing tillage	Aids carbon sequestration, provide a high level of soil organic matter and lowers energy input dependence.	(Carpio et al., 2017; Debray et al., 2019; Garcia et al., 2018; Guardia et al., 2016; Kaye & Quemada, 2017; Ruiz-Colmenero et al., 2013; Vicente-Vicente et al., 2016)
Monoculture	Intercropping	Improves soil fertility by increasing the abundance of beneficial microbes and the nutrient-use efficiency	
		Higher yields can be achieved through intercropping due to increased growth rate, biomass production, and efficient resource use.	(Aguilera et al., 2020; Francaviglia et al., 2019; D. L. Liu et al., 2017; Wheeler et al., 2015)
		Play a role in pest control, reducing the need for chemical inputs, and can suppress weed growth and manage diseases. The functional diversity provided by intercropping limits the spread of pathogens.	

Chemical fertilization	Crop diversification with legumes	Crop rotations and legumes are practiced to improve soil organic carbon and nutrient availability. Legumes, with their nitrogen-fixing ability and carbon release, contribute to soil fertility and microbial growth.	(Aguilera et al., 2013, 2020; Dachraoui & Sombrero, 2020; Lee et al., 2019; Litskas et al., 2017; Lovarelli & Bacenetti, 2017; Peltre et al., 2015; Smith et al., 2015)
	Cover crops	Vegetation covers are widely used in agroecology to reduce chemical fertilizer usage, prevent water contamination, and improve soil fertility and water quality.	(Iqbal et al., 2019; X. F. Li et al., 2018; Šeremešić et al., 2018; Solanki et al., 2020; Tang, Jiang, et al., 2021; Taschen et al., 2017; Willey, 1990; R. Zhang et al., 2021)
	Split fertilization	Split application of fertilizers over time can match supply and demand, improving efficiency and limiting contamination	
	Organic fertlization	Such as manure and compost, positively influence carbon and nitrogen dynamics, enhance microbial communities, and increase enzymatic activities in the soil	(Bi et al., 2019; Elouattassi et al., 2023; He et al., 2021; Hei et al., 2022; Liang et al., 2020; Rezaei-Chiyaneh et al., 2020; Shah et al., 2021; Sun et al., 2021; Zyada et al., 2022)
	Biofertilizers	Bacteria, fungi, algae or biological compounds including plant growth-promoting bacteria, are an eco-friendly alternative to synthetic fertilizers, ensuring nutrient availability to host plants.	