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Review

Conceptualizing Multiple Stressors and Their Consequences in Agroforestry Systems

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Abstract: The natural environment of crops is exposed to a complex collection of biotic and abiotic pressures. Abiotic stresses cover a diversity of environmental elements that cannot be avoided, such as temperature, drought, salinity, cold, heat, light, and water stress. Biotic stress is caused by living organisms with which plants coexist and interact. Pathogens and herbivores are examples of biotic stressors that can threaten food security and result in significant economic losses. Agricultural production systems differ in the extent of stress towards cultivated crops; agroforestry is considered to provide a protective function against environmental stress. The concept of this review was to assess the impact of environmental change and the atmospheric variability on the plants in agroforestry systems. The application of trees in field crop production has become more and more involved in practice, especially in areas with an extreme climate and unfavorable soil conditions. The main reasons for the rising interest are the effects of climate change, soil degradation, and erosion. Most of the trees are used as hedgerows or farm boundaries, or as scattered planting on the farm to control soil erosion as well as to improve farm productivity, which requires a thorough understanding of each stress element.

Keywords: biotic and abiotic stress; temperature stress; water stress; environments

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1. Introduction

Herbaceous plants and trees develop together in a wide range of natural environments that are neither uniform nor managed. Even if they are only temporary, many changes or alterations from the ordinary can have a negative influence on plants. Abiotic and biotic stress can have a massive effect on a plant's development and, ultimately, on crop yield. While certain stress factors can be predicted and avoided, the majority must be dealt with once they occur. It is difficult to forecast the effects of abiotic stress on crop production [1]. Stress is the main constraint to natural species distribution and an ecosystem's structure and function in a broad sense. Continuous stress-inducing factors, as well as stochastic disturbance events, maintain forest ecosystems in a dynamic equilibrium [2].

Plants experience stress as a natural component of their lives. Drought, pests, diseases, and salinity are all possibilities. Plants that are damaged while they are young may never fully recover. Depending on the plant type, these typical problems, which can reduce plant productivity, can be both beneficial and harmful. Through interactions between topography, plant composition, and the organizational structure of trees in agroforestry systems, trees modify climatic parameters over a given area and generate a complex microclimate [3]. The interaction of climatic variables at various scales produces unique local conditions that alter the energy balance and flow in the air layers above the soil surface [4]. Variables such as aboveground biomass, surface temperature and humidity, air temperature, relative humidity, solar radiation, evapotranspiration, wind speed and direction, precipitation, and so on are used to characterize these conditions. In general, these are large-scale climatic fluctuations that are separated from the atmospheric level, at least briefly [5].

Combinations of abiotic and biotic stress, drought, heat, salinity, cold, or pathogen infections are all examples of environmental stress conditions that can influence plant growth and productivity in the field (Figure 1). Nonetheless, the impacts of these stresses on plants are normally examined in the laboratory under controlled growing conditions. However, the field environment is quite different from the controlled circumstances utilized in laboratory experiments, and it frequently entails plants being exposed to multiple chemicals at the same time [6,7]. In addition to abiotic stressors, plants are threatened by diseases (including bacteria, fungi, and viruses) and herbivore pests, such as nematodes in natural circumstances; climate change has the potential to affect the habitat range of pests and pathogens [8]. Furthermore, many abiotic stress situations have been proven to decrease plant defense mechanisms, making them more susceptible to pest and pathogen infection. One study showed that the major crops in our future fields are likely to be exposed to a wider range of abiotic and biotic stresses, as well as their combinations [9]. The "disease triangle" has previously examined the connection between these pressures and their influence on plants. Plant development may be affected negatively or favorably by the combination of the two types of stress conditions. A co-existing drought, for example, might influence the interaction of various diseases and plants in different ways, resulting in pathogen growth suppression or an increase. As a result, studying the interaction between biotic and abiotic stressors is critical in order to fully understand the overall impact of stress combinations on plants [10].

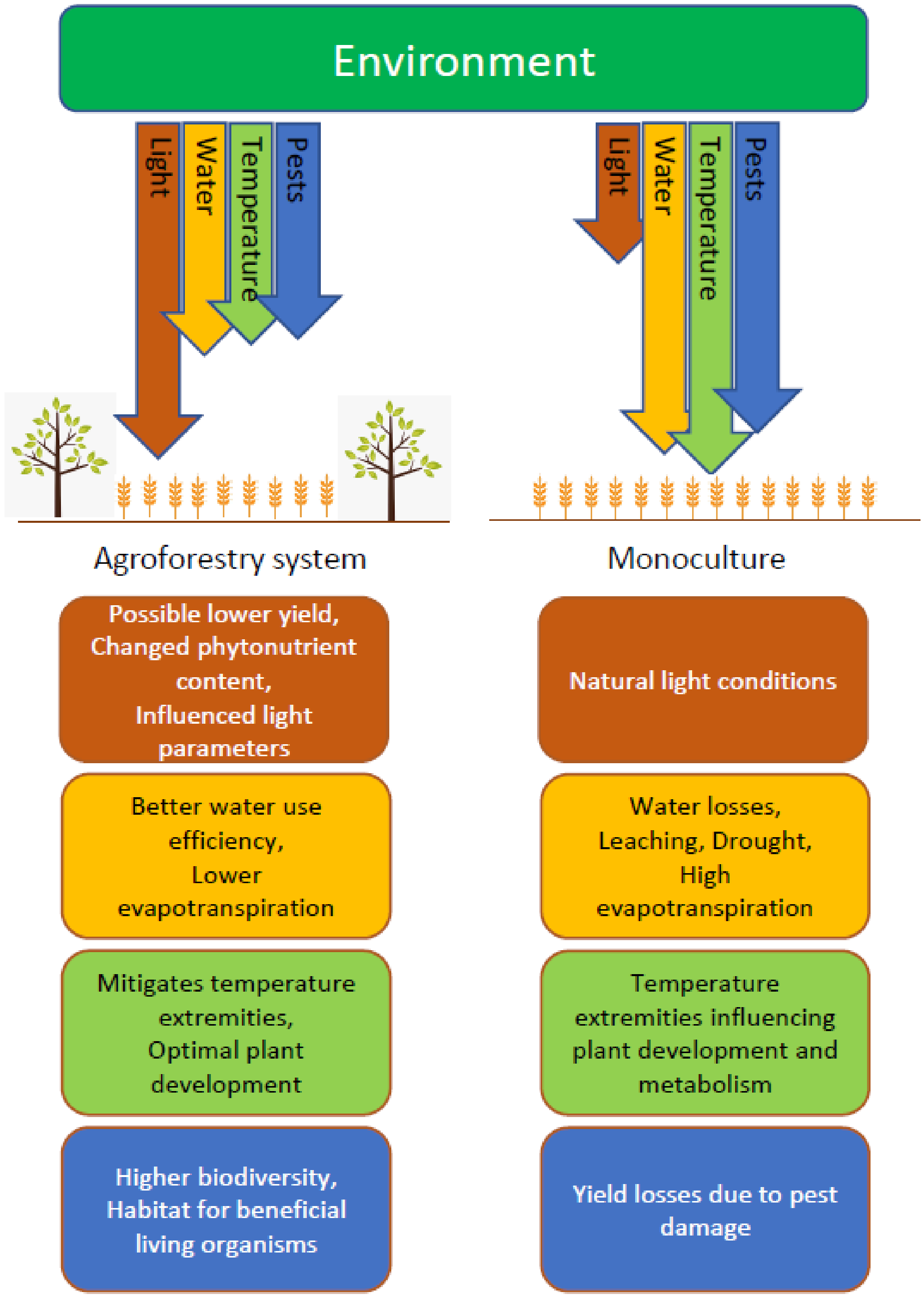

Figure 1. The relevance of different stress factors in agroforestry and arable cropping systems. The length of the arrows corresponds to the severity of these factors in a given system.

2. Materials and Methods

Studies dealing with the comparison of stress factors occurring in agroforestry and other conventional agricultural systems were collected using the keywords "agroforestry AND stress", "agroforestry", "agroforestry abiotic stress", and "agroforestry biotic stress" from bibliographic research databases (ScienceDirect, www.sciencedirect.com; accessed on 10 May 2022, MDPI, www.mdpi.com on 11 May 2022). The most relevant studies published in the last two decades are included in Table 1.

Table 1. Studies on the comparison of stress factors in agroforestry vs conventional agricultural systems.

Type of Stress	Crop Species	Tree Species	Effect	Impact of AF on Crop(s)	Reference
Light stress	Soybean (*Glycine max)*	Silver maple *(Acer sacharrinum)*	Positive	Soybean yield and development	[11]
	Apple (*Malus domestica*)	Black locust (*Robinia pseudoacacia*).	Positive	Crop yield components	[12]
	Palisade grass (*Urochloa brizantha)*	Oak (*Quercus sp.*)	Negative	N rates derived from atmosphere	[13]
	Wheat (*Triticum aestivum*)	Walnut(*Juglans regia*)	Neutral	Wheat yield	[14]
	Wheat (*Triticum aestivum).*	Jujube (*Zizyphus jujuba*)	Positive	Wheat yield and development	[15]
	Sweet potato (*Ipomoea batatas*)	Apricot (*Prunus armeniaca*)	Positive	Productivity	[16]
	Cotton (*Gossypium hirsutum*)	Jujube (*Zizyphus jujuba*)	Neutral	Yield	[17]
	Robusta coffee (*Coffea canephora*)	Erythrina (*Erythrina spp.*) and Santos mahogany (*Myroxylon balsamum*)	Neutral	Yield	[18]
Temperature stress	Coffea arabica *(Coffea arabica*)	Pau-abóbora (*Erythrina verna*)	Positive	Shifts in areas suitable for coffee production in 2050	[19]
	Palisade grass (*Urochloa brizantha)*	Hybrid eucalyptus (*Eucalyptus urograndis*)	Positive	Microclimate	[20]
	Sunflower (*Helianthus annuus*)	Tree strips (*Populus nigra x P. maximowiczii, P. maximowiczii x P. trichocarpa, P. koreana x P. trichocarpa*)	Neutral	Yield and growth	[21]
	Wheat (*Triticum aestivum*)	Aspen (*Populus sp.*)	Positive	Yield components	[22]
	Lettuce (*Lactuca sativa var. angustata*)	Walnut (*Juglans nigra*)	Neutral	Yield	[23]
Soil Stress	Carrot (*Daucus carota subsp. sativus*)	Walnut(*Juglans nigra x Juglans regia*)	Positive	Soil fertility and soil life	[24]
	Alfalfa (*Medicago sativa*)	Aspen (*Populus sp.*)	Negative	Soil water content	[24]
	Barley (*Hordeum vulgare*)	Walnut (*Juglans regia × nigra cv.* NG23)	Negative	Soil nutrient content	[25]
	Berseem clover (*Trifolium alexandrium*)	Red irongum (*Eucalyptus tereticornis*)	Positive	Utilization of moderately alkaline soils	[26]
	Red gum (*Corymbia calophylla*)	Marri (*Corymbia calophylla*)	Positive	Crop productivity	[27]
Water stress	Sea-buckthorn (*Hippophae rhamnoides*)	Siberian pea tree(*Caragana arborescens*)	Negative	Drought tolerance	[28]
	Red clover (*Trifolium pretense*)	Eastern cottonwood trees (*Populus deltoides*)	Neutral	Water quality	[29]
	Durum Wheat (*Triticum durum*)	Olive (*Olea europaea*)	Negative	Soil water conservation	[30]
	Banana (*Musa x paradisiaca*).	Cacao (*Theobroma cacao*)	Positive	Yield	[31]
Salt stress	-	Forest red gum (*Eucalyptus tereticornis*)	Positive	Salt tolerance	[32]
	Guinea grass (*Panicum maximum*)	Samphire (*Tecticornia pergranulata*)	Positive	Farming system components	
	White clover (*Trifolium repens*)	-	Negative	Productivity and clover ratio	[33]
Pest and Disease stress	Papaya (*Carica papaya*)	Cassava (*Manihot esculenta*)	Positive	Yield	[34]
	Pea (*Tephrosia spp.*)	African locust bean (*Parkia biglobosa*)	Positive	Pest management	[35]

3. Light Stress Consequences

Light-related stress is mainly caused by the lack of it in agroforestry systems. Plants require light for germination, development, flowering, fruiting, and proper ripening. In terms of sensory properties and nutritional composition, light is critical for vegetable quality. Lighting solutions that are well-planned enable effective production and extend the production season, even for the entire year. Climate change, urbanization (urban plant factories), and uneven seasonal workload are all factors to consider [36].

Even the length of lighting can be essential for photoperiodic plants. In agroforestry systems too, shade affects all plants physiologically and morphologically, and shade tolerance varies greatly [37,38]. Species with the C3 photosynthetic pathway are usually more shade tolerant than those with the C4 pathway [39]. Many plants in this group have evolved to warm temperatures, low soil moisture, and high natural lighting. In a previous study, as the yields of several forage crops increased in the shade, it may be sufficient to justify their use in agroforestry systems, and the yield can be improved by adjusting the microenvironment's shade level. A better understanding of plant response to its real microenvironment will be required to successfully use these forages in agroforestry systems [40].

In semi-arid regions, agroforestry systems, which combine annual crops with trees, are commonly used to reduce wind erosion and increase resource (e.g., water)-use efficiency. There is a lack of information about how to optimize such systems by choosing crop species with certain physiological features (i.e., C3 vs C4, N-fixing vs non-N-fixing). In a relevant study, an increase in light usage efficiency (LUE) contributed less to understory crop productivity, than an increase in light capturing did in agroforestry-generated benefits and income from carbon sequestration, firewood production, increased soil fertility, and improved local climate conditions. A complex agroforestry system provides ecosystem services and reduces human impacts on natural forests as well. The majority of these advantages aid local adaptation while also contributing to global efforts to reduce greenhouse gas levels in the atmosphere. [41]. According to the study, in a semi-arid climate, agroforestry systems with apricot trees and annual crops can improve light utilization, photosynthesis, and dry matter production. Meanwhile, these agroforestry systems can also contribute to regional sustainability and climate change adaptation [16].

Light interception (LI) is primarily determined by the leaf area index (LAI) and the light extinction coefficient, and it may be influenced by intercropping due to spatial configuration and changes in species' morphological features [42]. However, in a research experiment on cotton, light interception was reduced in a jujube/cotton agroforestry system, while light usage efficiency increased due to the shading effect of the trees, which is dependent on the distance between the crop rows and the trees [43]. In agroforestry, trees obstruct a considerable portion of the available light for the crops, and trees and crops compete for water and nitrogen. As a result, crop LI and LUE in agroforestry are likely to be influenced by species' characteristics such as C3 vs C4 photosynthetic pathway and the ability to fix nitrogen: C4 plants can maintain a higher carbon assimilation rate when exposed to high light intensity or temperature, and N-fixing legumes in crop mixtures can improve nitrogen uptake [16].

According to a recent study, shade is recognized as an important abiotic stress that has an impact on the growth and development of shade-intolerant plants [44]. *Arabidopsis* hypocotyls and petioles were considerably elongated under shade circumstances, and leaf lamina growth was impeded. Leaf expansion was restricted in *Glycine max* and *Zea mays* growing in the shade, which had an impact on seed yield [45]. In the case of vegetable crops such as tomato, cucumber, and eggplant, seedlings often develop abnormally under low light circumstances, resulting in lower yields in the field [17]. Phytochromes (PHY), which sense changes in both light intensity and quality, can sense changes in the light under canopy shade [46].

Photosynthetic activity is linked not only to the individual leaf area of a plant but also to the most efficient use of light, taking light penetration through the canopy into consideration. This demonstrates that the effectiveness of photosynthesis can be influenced by the form of the canopy, with the optimum results coming from a large number of small-to-medium-sized leaves [47]. Light availability and quality are expected to be the most limiting factors in temperate agroforestry systems throughout the growing season. When the tree canopy was removed from the silvopastoral aspen stand in Alberta, Canada, the understory's net primary production increased by up to 275%, compared to the unshaded control with a full tree canopy [48]. In transition zones of alley cropping agroforestry systems, solar radiation has a significant impact on the microclimate. Shading reduces air temperature and, as a result, changes relative humidity. The impact of shade on plant growth is complicated, and it varies depending on the crop and the tree species [49]. Light assessment in Central European agroforestry systems has received little empirical investigation so far. In temperate agroforestry systems, further research is needed to see how shadow affects yield, and the quality of food and/or fodder crops. Furthermore, the processes of shade tolerance are still largely undefined [50].

4. Temperature Stress Consequences

High-temperature stress is one of the major environmental factors limiting the productivity of grain crops and agroforestry in general. Grain yield is decreased by temperature stress, which impacts various physiological, growth, and yield processes [51]. High temperature is most often accompanied by decreasing water availability, thus the combined effect of both heat and drought on the yield of many crops is stronger than the effects of each stress alone [52]. The growth, physiological, and metabolic responses of plants to a combination of heat and drought stresses are unique and cannot be directly extrapolated from the responses to each of these stresses separately [53,54].

The onset and duration of developmental phases are altered by high-temperature stress. When temperature rises within the optimum range, the time between emergence and the start of the reproductive phase is shorter. However, under extremely high-temperature stress, the time it takes for panicles to form and the time required for sepals to form until anthesis can be delayed [55]. Compared to crops grown in pure agricultural fields covered with only herbaceous plant species, trees further influence the microclimate experienced by crops in agroforestry systems. The shading effect of the trees reduces the temperature during the day, potentially protecting crops from extreme heat, while the tree canopy's protecting effect increases night temperatures by reducing radiative cooling, which may be beneficial to crops in the case of frost but may also reduce yield in other cases [56]. Heat stress, winter hardiness, vernalization, cold-hardening, and winterkilling effects are all dependent on extreme day temperatures, therefore this dissymmetry between day and night temperature change has a significant impact on plant physiology. The temperature has different effects on respiration and photosynthesis, resulting in a shift in the balance between photosynthesis and respiration, and, consequently, a change in carbon uptake [56].

The influence of the trees on the microclimate was consistent between years in a mature agroforestry plot, with lower temperatures in the daytime but higher temperatures during the night in agroforestry, compared to a full sun plot. These results indicate that agroforestry has the potential to reduce the risk of heat stress by decreasing the amplitude of daily temperature increases, culminating in a temperature difference of up to 4 °C in the warmest periods of the hottest days. Unfortunately, agroforestry raises the risk of yield loss owing to insufficiently cold nights, which may not be a concern for vernalization because agroforestry's effect is limited in winter, but may increase night respiration and therefore reduce biomass increment and yield [57].

5. Soil Stress Consequences

Soil microorganisms provide nutrient supply to plants in forestlands and in agroforestry systems as well [26–58]. Nevertheless, microbial biomass has a function in the decomposition of organic matter and, as a result, in the nutrient cycle of the soil. It is also utilized in various agroecosystems as an early indicator of changes in soil quality caused by soil management and environmental stress [59,60]. Agroforestry has the potential to sequester carbon, to reduce soil erosion, and, with appropriate management, to improve water quantity and quality regulation [26]. Many studies have quantified the effect of an agroforestry implementation on soil erosion across five countries. Of these, 71% found a significant positive effect of the intervention. This result is expected given that tree planting is widely used as an appropriate strategy to stabilize slopes and reduce soil erosion globally. In particular, the experiment found that widespread planting has occurred on Australian and New Zealand livestock farms in recent decades in an attempt to reverse the negative consequences of extended vegetation clearing following European settlement [61].

By influencing how plants match water uptake with demand, soil conditions can exert a considerable effect on the development of stress from primary climatic factors. Plant water uptake can be hindered in frozen soils, although a mismatch in water uptake and demand is typical in drought-stressed plants. Even when soils are saturated, a delay in the warming up of frozen soils compared to air warming at the end of winter can cause plant water deficits in boreal forest ecosystems [62,63]. However, in an experimental study the effects on wheat development under controlled drought and flood circumstances, soil biochemical properties, and microbial resistance in agroforestry systems were investigated. According to the study, agroforestry systems may improve soil biochemical properties and microbial resilience, which could improve crop productivity and tolerance to severe water stress [64]. Drought causes osmotic stress and resource competition in soil microbes. Soil bacteria are similarly stressed when they are rewetted after a period of drought because they must rapidly dispose of their osmolytes to counteract the increases [65].

Agroforestry systems may also modify the composition of soil microbial communities, which have been connected to the soil's physicochemical qualities [66]. Enhancing soil nutrient availability as well as the diversity of microbial communities may assist the recovery of microbial functions (i.e., soil microbial resilience) following a periodic disturbance or chronic stresses such as soil drying [67]. Another research showed that, when compared to typical agricultural soils, agroforestry soils have a significant impact on crop productivity due to the better soil biochemical characteristics. Depending on different kinds of soil disturbances or stresses, the extent of the effect of soil land-use type on crop productivity may also vary [68,69]. However, the availability and use of mineral nutrients (such as P, K, Fe, Mn, Zn, and Cu) by plants can be enhanced by using biochar, as well as their tolerance to salinity stress being supported [70]. Calcium absorption in the growing medium is reduced under salinity stress circumstances, probably due to an osmotic problem. Under saline conditions, calcium regulation was one of the most important plant modifications, resulting in physiological disorders such as blossom end rot in sweet pepper, eggplant, and tomato [71].

6. Water Stress Consequences

Water stress has a negative effect on many elements of plant and tree physiology, including photosynthetic potential. Plant development and productivity are significantly damaged if the stress is extended. To adjust and adapt to a variety of environmental challenges, plants have evolved extensive physiological and biochemical adaptation abilities [72].

Water-use efficiency (WUE) is a functional parameter associated with plant growth and performance during drought. As a result, when trees are planted in arid areas, both productivity and WUE should be taken into account. The connection between WUE and plant development is still being debated. Water stress improves plants' water-use efficiency, according to a large amount of evidence [73]. However, microclimatic variations in agroforestry systems reduce soil moisture evaporation in general, whereas other researchers have discovered that agroforestry systems increase infiltration and soil water storage [74]. Moderate water stress can also promote the production of secondary metabolites in stems, resulting in greater resistance to pests such as stem borers and fungus [75]. During times of extreme water stress, the plant's ability to divert carbohydrates to the production of defense chemicals starts to deteriorate [76]. When compared to conventional agriculture, agroforestry systems may improve local water balance, soil health, visual aesthetics, and carbon sequestration [27]. Water-stressed plants improve their relative water content (RWC) to increase water uptake from the soil, maximizing the water potential gradient between the soil and plant. During extreme droughts, the relative water content (RWC) of plants typically reaches 50–60%, and in rare times, less than 50% [77,78].

According to a recent study about the effects of water stress on the water-use efficiency and water balance components of *Hippophae rhamnoides* and *Caragana intermedia* in the soil–plant–atmosphere continuum, water usage efficiency varied between species, sizes, and levels of water stress. Under moderate water stress, water-use efficiency at the leaf scale was strongest, but at the community scale, WUE dropped as water stress increased. However, in response to water stress, both species' daily and seasonal transpiration rates were modified [79].

Water stress decreased the leaf's RWC, specific leaf area, leaf area ratio, and water-use efficiency of a leguminous plant in a similar study, whereas it increased biomass allocation to roots, resulting in a higher root–stem mass ratio under drought [79]. Modifications in the dynamics of water balance components and water usage efficiency (WUE) are the main consequences of water stress on plants. Furthermore, plant response patterns are related to the degree of water stress [29]. Due to decreased CO_2 availability caused by stomatal closure [80,81] and changes in photosynthetic metabolism, water stress has a direct effect on photosynthesis rates [82]. Water stress might cause modifications in the physiological function of wax synthesis as well. Recent studies of Ayaz et al. showed that LACS2 mutation also resulted in reduced wax accumulation under submergence growth conditions, which further confirmed that LACS2 is involved in wax synthesis under stress conditions [83].

7. Salt Stress Consequences

Salt is the primary limiting factor for plant growth among abiotic stresses, and it will soon become an even more severe factor as all arable land is expected to have salinity problems by 2050 [84]. Plant productivity is hindered by a variety of conditions, including environmental stresses [85]. Salinity is one of the most damaging pressures among these. Agriculture's future in the world's most productive places may be hampered by salinization [86]. Plants have evolved various methods to cope with osmotic and ionic stress caused by high salinity [87]. Alternative solutions for the rehabilitation of saline soils include agroforestry approaches as well. The significance and cause-and-effect relationship of possible agroforestry systems for the productive usage of salty soil are highlighted here. Agroforestry as an alternative land-use system is an excellent option for these circumstances, utilized with salt-tolerant forest and fruit trees, fodder grasses, and low-water-demanding conventional and non-conventional crops, including ornamental plants. Using conventional plant breeding and molecular techniques, it is possible to improve the salt tolerance of existing crops [88].

Ion toxicity and nutritional imbalance in plants are caused by salinity stress, which alters the physiological processes of plants and trees, resulting in a significant reduction in final yield. Salinity stress reduces seed germination, and changes the development and reproductive activity in plants, resulting in considerable production losses. Salt stress also causes oxidative stress and disrupts enzyme activity, photosynthesis, the membrane structure, hormone balance, and water and nutrient intake [31]. Secondary stresses such as oxidative stress frequently occur as a result of osmotic and ionic stress [89], causing damage to membrane lipids, proteins, and nucleic acids. The stress response shows itself at morpho-physiological, biochemical, and molecular levels, and also changes in antioxidant enzyme activity [90]. These responses aim for the restoration of ionic homeostasis, the maintenance of cellular turgor, and the development of stress tolerance in the form of salt stress adaption [91].

Growing multipurpose tree species on salt-affected soils has numerous advantages. Trees have a higher transpiration rate than agronomic crops, which could assist to reduce salt accumulation on the upper soil surface [92]. Furthermore, the shade of trees serves to lower the pace of evaporation as well as the accumulation of salts in the upper soil layer by slowing the upward movement of salt-containing water [93].

The effect of three different forms of biochar on the eco-physiological response of significant agroforestry tree species under salt stress was recently examined. The study was designed to aim at the effects of biochar on the physicochemical properties of soil and characteristics of three important agroforestry tree species; the results showed that the effect of biochar was species-specific and different types of biochars do not have the same effect on agroforestry tree species either [94].

8. Pest and Disease Stress Consequences

Pathogens (bacteria, fungi, viruses) infect plants in natural conditions, and pests (e.g., nematodes) attack plants [95]. Pests and pathogens' ranges will be influenced by climate change, with increasing temperatures promoting pathogen spread. In one study, a sample plantation was observed to determine the resistance of an agroforestry system. The results showed that pitch canker disease *Fusarium circinatum* caused losses in several pine plantations [8]. Crops and also wild plant species are exposed to a series of biotic stresses caused by other living organisms, ranging from viruses to mammals (Figure 2), and many of these stresses affect photosynthesis by altering their underlying metabolism (primary photochemistry, electron transport, Calvin cycle), gas diffusion, or reducing photosynthetic leaf area [96]. Invasive pests can also result in significant losses in forestry operations. The gall wasp *Leptocybe invasa*, for example, has decimated the examined Eucalyptus plantations [97]. At the same time, disease and pest epidemics are exacerbated as a result of global climate change [98].

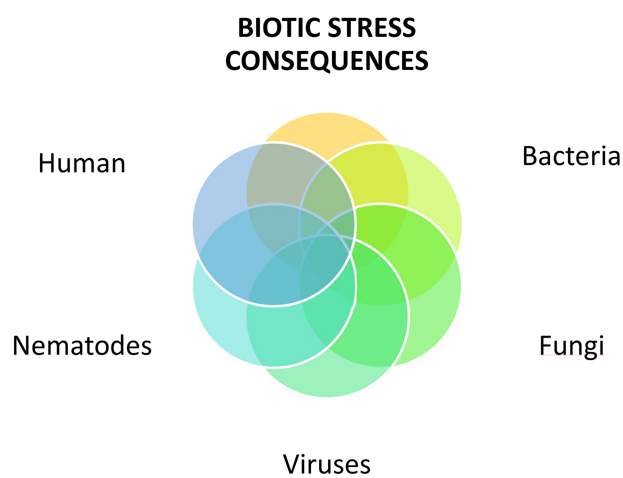

Figure 2. Interlinked effect of different biotic stresses on the plant.

The increased incidence of pests and diseases has often been observed directly at the tree–plant interface due to the humid microclimate, the physical protection of mammal and bird pests by trees, and the declining tolerance due to the competition between plants. Tree strips and hedges affect the spread of small insects and diseases by wind, the active emigration and immigration of pests, and natural enemies. Similarly, the shadow effect at the edge also affects the microclimatic conditions under which biotic effects develop [35].

Plants are the motionless party in these biotic interactions, so they have evolved advanced biochemical and physiological mechanisms to detect, signal, and respond to the dangers posed by pathogens, constructing defensive barriers that pathogens must overcome to colonize the host and spread disease [99]. While there are genetic factors that determine plant susceptibility or resistance to pathogen infection, the degree of tolerance is also influenced by the plant's age, nutritional status, and environmental conditions. Infections are classified as biotrophic, hemibiotrophic, or necrotrophic, depending on whether they require living host cells to proliferate infection (biotrophic) or induce necrosis to feed on the collapsing host tissue, hemibiotrophic and necrotrophic pathogens [100].

The meta-analysis of Pumariño et al. [101] indicates that agroforestry is generally beneficial in most aspects of natural pest control. Natural enemies of pests had significantly higher numbers in agroforestry. Agroforestry significantly reduced the number of non-parasitic weeds and had a marginally significant negative effect on parasitic weeds. Crop damage caused by pests and plant diseases was significantly reduced by agroforestry, but the number of pests was not significantly affected. However, there were differences in the reduction between perennial and annual crops, to the advantage of perennial crops. In the field of agroforestry and agriculture in general, weeds typically form and flourish in poor soil conditions, but by providing appropriate nutritional components to the root area, weed development and the side effects on plant growth can be avoided. Plant vigor will be improved when nutrient-use efficiency is improved, and they will be able to overcome weed development [102]. Plant diseases also have a complicated relationship with minerals available for the plants [103]. Extra nitrogen content combined with a high humidity level, for example, is ideal for infections such as *Pythium* and *Phytophthora* to thrive and develop in plants. Turfgrasses overcome disease more easily and quickly when Mn and Si are added to the nutritional solution. Plants with adequate nutrient sources recover from insect damage more quickly and fully than those with insufficient nutrient supplies. In studies, the addition of Al and Si to a turfgrass growth medium shielded the plants from insect attacks while also assisting them in producing an unattractive substance for the insects to consume [104]. The concept of agroforestry is based on the predicted contribution of on-farm and off-farm tree production in providing sustainable land use and natural resource management [105]. At the site level, the system's aboveground and belowground diversity provides better stability and resilience, while at the landscape and bioregion levels, the system provides connectivity with forests and other natural landscapes [106]. Agroforestry systems' ecological foundations manifest themselves in environmental services such as soil protection, carbon storage, biodiversity conservation, and water quality enhancement.

9. Conclusions

Climate change and variability highlight the need to explore genetic variability and new sources of tolerance more quickly, as well as harness all present genetic resources, identify new resources, and protect them for the future [51]. The reintegration of trees and farming systems through a broad set of methods known as agroforestry has the potential to mitigate these environmental effects, at least in part [107]. According to [108,109], the effects of climate change and the ever-growing demand of the increasing world population are putting stress on the efficacy of crop production. By 2050, global agricultural production may need to be doubled to meet increasing demands. Several studies have indicated that increasing agricultural productivity, rather than clearing more land for food production, is the best sustainable solution for food security. However, according to several reports, yields are not improving quickly enough to meet the estimated demand in 2050, and the world will undoubtedly confront a food crisis [109].

Climate variability matters as much to crop output as the mean values of climate variables during the crop season, according to agricultural scientific research and an examination of agricultural production statistics. Crop productivity in the World faces weather adversities, especially extreme events that jeopardize socioeconomic demands; therefore, there is a need to create a better policy and plan for disaster risk reduction for the future. This study can serve as baseline knowledge for the development of agricultural production systems in the view of climate change. According to recent studies [21], and the knowledge gap, agroforestry system methods include short-duration enhanced fallows where a single horticulture crop is grown such as vegetables or medicinal plant species. The changes in the physical dimensions, life expectancies, and physiological reactions between the component species in simultaneous systems such as monoculture cropping can lead to complicated interactions between the tree and the crop species. Microclimatic variables are affected by how trees are grown and maintained in relation to crops in an agroforestry system. Pest incidence in the system can be modified by both the bottom-up effects of the abiotic environment and the top-down effects of herbivores and their natural enemies. In some systems that either induce stress (plant stress hypothesis) or improve crop vigor (crop vigor hypothesis and carbon–nutrient balance hypothesis), pest problems may increase [21].

Abiotic stress tolerance and tree responses are complicated biological processes that are best studied at a systems level using genetic, genomic, metabolomic, and phenomics techniques. This will speed up the examination of stress-sensing and signaling networks, which will assist in the design of more efficient genetic improvement programs. Within several forest-tree species, an enormous genetic variety for stress tolerance exists, and the molecular genetic foundation for this diversity has been quickly emerging in recent years due to advances in gene sequencing technology. Moreover, the application of developing phenotyping technology expands the range of features that may be measured, enabling us to gain a better knowledge of stress tolerance. Through genetic engineering, the understanding of abiotic stress-tolerance processes will allow for the efficient pyramiding of various tolerances in a single tree [110].

The present review describes the current level of knowledge about potential climate change effects on agroforestry systems and the consequences of biotic stress factors, such as insects, diseases, and weeds, and also the abiotic factors. Only a few studies could be found that use quantitative stress factor measurement methodologies to look for a general pattern in the reactions of individual biotic and abiotic stressors in agroforestry systems to changes in climate and atmospheric factors and the production of the crop environments. In the future, more quantitative reviews will be required. A gap in the ecological literature has been identified by comparing tropical agroforests and forests: future research might benefit from the replication of enclosure experiments in complex tropical agroforestry systems [25]. The current review focuses on the possible consequences of climate change on the distribution and prevalence of biotic and abiotic factors; however, a few researchers have also looked at mitigation strategies in case of potential future repercussions of a changing climate on crop protection.

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References

1. Cramer, G.R.; Urano, K.; Delrot, S.; Pezzotti, M.; Shinozaki, K. Effects of abiotic stress on plants: A systems biology perspective. *BMC Plant Biol.* **2011**, *11*, 163. https://doi.org/10.1186/1471-2229-11-163.
2. Boisvenue, C.; Running, S.W. Impacts of climate change on natural forest productivity-evidence since the middle of the 20th century. *Glob Change Biol.* **2006**, *12*, 862–882.
3. Karvatte, N.; Miyagi, E.S.; de Oliveira, C.C.; Barreto, C.D.; Mastelaro, A.P.; Bungenstab, D.J.; Alves, F.V. Infrared thermography for microclimate assessment in agroforestry systems. *Sci. Total Environ.* **2020**, *731*, 139252. https://doi.org/10.1016/j.scitotenv.2020.139252.
4. Zellweger, F.; De Frenne, P.; Lenoir, J.; Rocchini, D.; Coomes, D. Advances in Microclimate Ecology Arising from Remote Sensing. *Trends Ecol. Evol.* **2019**, *34*, 327–341. https://doi.org/10.1016/j.tree.2018.12.012.

5. Bramer, I.; Anderson, B.J.; Bennie, J.; Bladon, A.J.; De Frenne, P.; Hemming, D.; Hill, R.A.; Kearney, M.R.; Körner, C.; Korstjens, A.H.; et al. Advances in Monitoring and Modelling Climate at Ecologically Relevant Scales. *Adv. Ecol. Res.* **2018**, *58*, 101–161. https://doi.org/10.1016/bs.aecr.2017.12.005.
6. Menzel, C.M. Effect of Temperature on Soluble Solids Content in Strawberry in Queensland, Australia. *Horticulturae* **2022**, *8*, 367. https://doi.org/10.3390/horticulturae8050367.
7. Suzuki, N.; Rivero, R.M.; Shulaev, V.; Blumwald, E.; Mittler, R. Abiotic and biotic stress combinations. *New Phytol.* **2014**, *203*, 32–43. https://doi.org/10.1111/nph.12797.
8. Atkinson, N.J.; Urwin, P.E. The interaction of plant biotic and abiotic stresses: From genes to the field. *J. Exp. Bot.* **2012**, *63*, 3523–3543. https://doi.org/10.1093/jxb/ers100.
9. Amtmann, A.; Troufflard, S.; Armengaud, P. The effect of potassium nutrition on pest and disease resistance in plants. *Physiol. Plant.* **2008**, *133*, 682–691. https://doi.org/10.1111/j.1399-3054.2008.01075.x.
10. Pandey, P.; Irulappan, V.; Bagavathiannan, M.V.; Senthil-Kumar, M. Impact of Combined Abiotic and Biotic Stresses on Plant Growth and Avenues for Crop Improvement by Exploiting Physio-morphological Traits. *Front. Plant Sci.* **2017**, *8*, 537. https://doi.org/10.3389/fpls.2017.00537.
11. Reynolds, P.E.; Simpson, J.A.; Thevathasan, N.V.; Gordon, A.M. Effects of tree competition on corn and soybean photosynthesis, growth, and yield in a temperate tree-based agroforestry intercropping system in southern Ontario, Canada. *Ecol. Eng.* **2007**, *29*, 362–371. https://doi.org/10.1016/j.ecoleng.2006.09.024.
12. Gao, L.; Xu, H.; Bi, H.; Xi, W.; Bao, B.; Wang, X.; Bi, C.; Chang, Y. Intercropping Competition between Apple Trees and Crops in Agroforestry Systems on the Loess Plateau of China. *PLoS ONE* **2013**, *8*, e70739. https://doi.org/10.1371/journal.pone.0070739.
13. Sanna, F.; Re, G.A.; Piluzza, G.; Campesi, G.; Sulas, L. Forage yield, nutritive value and N-fixation ability of leg-ume based swards are affected by light intensity in a Mediterranean agroforestry system. *Agrofor. Syst.* **2019**, *93*, 2151–2161.
14. Jia, J.; Xu, M.; Bei, S.; Zhang, H.; Xiao, L.; Gao, Y.; Zhang, Y.; Sai, L.; Xue, L.; Lei, J.; et al. Impact of reduced light intensity on wheat yield and quality: Implications for agroforestry systems. *Agrofor. Syst.* **2021**, *95*, 1689–1701. https://doi.org/10.1007/s10457-021-00668-w.
15. Zhang, W.; Wang, B.J.; Gan, Y.W.; Duan, Z.P.; Hao, X.D.; Xu, W.L.; Li, L.H. Different tree age affects light competition and yield in wheat grown as a companion crop in jujube-wheat agroforestry. *Agrofor. Syst.* **2019**, *93*, 653–664.
16. Zhang, D.; Du, G.; Sun, Z.; Bai, W.; Wang, Q.; Feng, L.; Zheng, J.; Zhang, Z.; Liu, Y.; Yang, S.; et al. Agroforestry enables high efficiency of light capture, photosynthesis and dry matter production in a semi-arid climate. *Eur. J. Agron.* **2018**, *94*, 1–11. https://doi.org/10.1016/j.eja.2018.01.001.
17. Lu, D.; Liu, B.; Ren, M.; Wu, C.; Ma, J.; Shen, Y. Light Deficiency Inhibits Growth by Affecting Photosynthesis Efficiency as well as JA and Ethylene Signaling in Endangered Plant *Magnolia sinostellata*. *Plants* **2021**, *10*, 2261. https://doi.org/10.3390/plants10112261.
18. Piato, K.; Subía, C.; Lefort, F.; Pico, J.; Calderón, D.; Norgrove, L. No Reduction in Yield of Young Robusta Coffee When Grown under Shade Trees in Ecuadorian Amazonia. *Life* **2022**, *12*, 807. https://doi.org/10.3390/life12060807.
19. Gomes, L.; Bianchi, F.; Cardoso, I.; Fernandes, R.; Filho, E.F.; Schulte, R. Agroforestry systems can mitigate the impacts of climate change on coffee production: A spatially explicit assessment in Brazil. *Agric. Ecosyst. Environ.* **2020**, *294*, 106858. https://doi.org/10.1016/j.agee.2020.106858.
20. Magalhães, C.A.; Zolin, C.A.; Lulu, J.; Lopes, L.B.; Furtini, I.V.; Vendrusculo, L.G.; Zaiatz, A.P.; Pedreira, B.C.; Pezzopane, J. Improvement of thermal comfort indices in agroforestry systems in the southern Brazilian Amazon. *J. Therm. Biol.* **2020**, *91*, 102636. https://doi.org/10.1016/j.jtherbio.2020.102636.
21. Swieter, A.; Langhof, M.; Lamerre, J. Competition, stress and benefits: Trees and crops in the transition zone of a temperate short rotation alley cropping agroforestry system. *J. Agron. Crop Sci.* **2021**, *208*, 209–224. https://doi.org/10.1111/jac.12553.
22. Dufour, L.; Dupraz, C.; Lauri, P.É.; Gosme, M. Effect of Agroforestry on phenology and components of yield of different varie-ties of durum wheat. 3rd European Agroforestry Conference – Montpellier, 23-25 May 2016, Book of abstracts, p.317.
23. Wang, Q.; Xu, Z.; Hu, T.; Rehman, H.U.; Chen, H.; Li, Z.; Ding, B.; Hu, H. Allelopathic activity and chemical con-stituents of walnut (Juglans regia) leaf litter in walnut–winter vegetable agroforestry system. *Nat. Prod. Res.* **2014**, *28*, 2017–2020.
24. D'hervilly, C.; Marsden, C.; Capowiez, Y.; Béral, C.; Delapré-Cosset, L.; Bertrand, I. Trees and herbaceous vegeta-tion strips both contribute to changes in soil fertility and soil organism communities in an agroforestry system. *Plant Soil* **2021**, *463*, 537–553.
25. Ledesma, N.A.; Kawabata, S. Responses of two strawberry cultivars to severe high temperature stress at different flower devel-opment stages. *Sci. Hortic.* **2016**, *211*, 319–327. https://doi.org/10.1016/j.scienta.2016.09.007.
26. Kaur, B.; Gupta, S.R.; Singh, G. Soil carbon, microbial activity and nitrogen availability in agroforestry systems on mod-erately alkaline soils in northern India. *Appl. Soil. Ecol.* **2000**, *15*, 283–294.
27. Jose, S. Agroforestry for ecosystem services and environmental benefits: An overview. *Agrofor. Syst.* **2009**, *76*, 1–10. https://doi.org/10.1007/s10457-009-9229-7.
28. Clivot, H.; Petitjean, C.; Marron, N.; Dallé, E.; Genestier, J.; Blaszczyk, N.; Santenoise, P.; Laflotte, A.; Piutti, S. Early effects of tem-perate agroforestry practices on soil organic matter and microbial enzyme activity. *Plant Soil.* **2020**, *453*, 189–207.

29. Guo, W.; Li, B.; Zhang, X.; Wang, R. Effects of water stress on water use efficiency and water balance components of *Hippophae rhamnoides* and *Caragana intermedia* in the soil–plant–atmosphere continuum. *Agrofor. Syst.* **2010**, *80*, 423–435. https://doi.org/10.1007/s10457-010-9337-4.
30. Panozzo, A.; Huang, H.-Y.; Bernazeau, B.; Meunier, F.; Turc, O.; Duponnois, R.; Prin, Y.; Vamerali, T.; Desclaux, D. Impact of Olive Trees on the Microclimatic and Edaphic Environment of the Understorey Durum Wheat in an Alley Orchard of the Mediterranean Area. *Agronomy* **2022**, *12*, 527. https://doi.org/10.3390/agronomy12020527.
31. Dagar, J.C.; Minhas, P.S. *Saline Irrigation for Productive Agroforestry Systems. Agroforestry for the Management of Water-Logged Saline Soils and Poor-Quality Waters*; Springer: New Delhi, India, 2016; pp. 145–161.
32. Singh, D.; Kumar, A. Multivariate screening approach indicated adaptive tolerance to salt stress in the seedlings of an agroforestry tree, *Eucalyptus tereticornis* Sm. *Plant Cell Tissue Organ Cult.* **2021**, *145*, 545–560. https://doi.org/10.1007/s11240-021-02025-2.
33. Udawatta, R.P.; Garrett, H.E.; Kallenbach, R.L. Agroforestry and grass buffer effects on water quality in grazed pastures. *Agrofor. Syst.* **2010**, *79*, 81–87. https://doi.org/10.1007/s10457-010-9288-9.
34. Ehret, M.; Gras, R.; Wachendorf, M. The effect of shade and shade material on white clover/perennial ryegrass mixtures for temperate agroforestry systems. *Agrofor. Syst.* **2015**, *89*, 557–570. https://doi.org/10.1007/s10457-015-9791-0.
35. Schroth, G.; Krauss, U.; Gasparotto, L.; Aguilar, J.A.D.; Vohland, K. Pests and diseases in agroforestry systems of the humid tropics. *Agrofor. Syst.* **2000**, *50*, 199–241. https://doi.org/10.1023/a:1006468103914.
36. Sipos, L.; Boros, I.F.; Csambalik, L.; Székely, G.; Jung, A.; Balázs, L. Horticultural lighting system optimalization: A review. *Sci. Hortic.* **2020**, *273*, 109631. https://doi.org/10.1016/j.scienta.2020.109631.
37. Boardman, N.K. Comparative photosynthesis of sun and shade plants. *Annu. Rev. Plant Physiol.* **1977**, *28*, 355–377.
38. Björkman, O.; Holmgren, P. Adaptability of the photosynthetic apparatus to light intensity in ecotypes from ex-posed and shaded habitats. *Physiol. Plant* **1963**, *16*, 889–914.
39. Kephart, K.D.; Buxton, D.R.; Taylor, S.E. Growth of C3 and C4 perennial grasses in reduced irradiance. *Crop Sci.* **1992**, *32*, 1033–1038.
40. Lin, C.H.; McGraw, R.L.; George, M.F.; Garrett, H.E. Shade effects on forage crops with potential in temperate ag-roforestry practices. *Agrofor. Syst.* **1998**, *44*, 109–119.
41. Mbow, C.; Smith, P.; Skole, D.; Duguma, L.; Bustamante, M. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Curr. Opin. Environ. Sustain.* **2013**, *6*, 8–14. https://doi.org/10.1016/j.cosust.2013.09.002.
42. Wang, Q.; Han, S.; Zhang, L.; Zhang, D.; van der Werf, W.; Evers, J.B.; Sun, H.; Su, Z.; Zhang, S. Density responses and spatial distribution of cotton yield and yield components in jujube (*Zizyphus jujube*)/cotton (*Gossypium hirsutum*) ag-roforestry. *Eur. J. Agron.* **2014**, *79*, 58–65.
43. Zhang, D.; Zhang, L.; Liu, J.; Han, S.; Wang, Q.; Evers, J.; Liu, J.; van der Werf, W.; Li, L. Plant density affects light interception and yield in cotton grown as companion crop in young jujube plantations. *Field Crop. Res.* **2014**, *169*, 132–139. https://doi.org/10.1016/j.fcr.2014.09.001.
44. Gong, W.; Qi, P.; Du, J.; Sun, X.; Wu, X.; Song, C.; Liu, W.; Wu, Y.; Yu, X.; Yong, T.; et al. Transcriptome Analysis of Shade-Induced Inhibition on Leaf Size in Relay Intercropped Soybean. *PLoS ONE* **2014**, *9*, e98465. https://doi.org/10.1371/journal.pone.0098465.
45. Gao, J.; Liu, Z.; Zhao, B.; Liu, P.; Zhang, J.-W. Physiological and comparative proteomic analysis provides new insights into the effects of shade stress in maize (Zea mays L.). *BMC Plant Biol.* **2020**, *20*, 60–13. https://doi.org/10.1186/s12870-020-2264-2.
46. Franklin, K.A.; Praekelt, U.; Stoddart, W.M.; Billingham, O.E.; Halliday, K.; Whitelam, G.C. Phytochromes B, D, and E Act Redundantly to Control Multiple Physiological Responses in Arabidopsis. *Plant Physiol.* **2003**, *131*, 1340–1346. https://doi.org/10.1104/pp.102.015487.
47. Alarcon, V.J.; Sassenrath, G.F. Optimizing canopy photosynthetic rate through PAR modeling in cotton (*Gossy-pium* spp.) crops. *Comput. Electron. Agric.* **2015**, *119*, 142–152.
48. Powell, G.W.; Bork, E.W. Aspen canopy removal and root trenching effects on understory vegetation. *Ecol Manag.* **2006**, *230*, 76–90.
49. Schmidt, M.; Lischeid, G.; Nendel, C. Microclimate and matter dynamics in transition zones of forest to arable land. *Agric. For. Meteorol.* **2019**, *268*, 1–10. https://doi.org/10.1016/j.agrformet.2019.01.001.
50. Lin, C.H.; McGraw, R.L.; George, M.F.; Garrett, H.E. Nutritive quality and morphological development under the partial shade of some forage species with agroforestry potential. *Agrofor. Syst.* **2001**, *53*, 269–281.
51. Djanaguiraman, M.; Prasad, P.V.V. High-temperature stress. In: *Jackson, M., Ford-Lloyd, B., Parry, M. (Eds.):* Plant Genetic Resources and Climate Change, **2014**, CAB eBooks, 201–220. https://doi.org/10.1079/9781780641973.0201.
52. Dreesen, F.E.; De Boeck, H.J.; Janssens, I.A.; Nijs, I. Summer heat and drought extremes trigger unexpected changes in productivity of a temperate annual/biannual plant community. *Environ. Exp. Bot.* **2012**, *79*, 21–30. https://doi.org/10.1016/j.envexpbot.2012.01.005.
53. Rizhsky, L.; Liang, H.; Mittler, R. The combined effect of drought stress and heat shock on gene expression in tobac-co. *Plant Physiol.* **2002**, *130*, 1143–1151.

54. Rizhsky, L.; Liang, H.; Shuman, J.; Shulaev, V.; Davletova, S.; Mittler, R. When defense pathways collide. The re-sponse of Arabidopsis to a combination of drought and heat stress. *Plant Physiol.* **2004**, *134*, 1683–1696.
55. Prasad, P.V.; Pisipati, S.R.; Mutava, R.N.; Tuinstra, M.R. Sensitivity of Grain Sorghum to High Temperature Stress during Reproductive Development. *Crop Sci.* **2008**, *48*, 1911–1917. https://doi.org/10.2135/cropsci2008.01.0036.
56. García, G.A.; Dreccer, M.F.; Miralles, D.J.; Serrago, R.A. High night temperatures during grain number determination reduce wheat and barley grain yield: A field study. *Glob. Chang. Biol.* **2015**, *21*, 4153–4164. https://doi.org/10.1111/gcb.13009.
57. Gosme, M.; Dufour, L.; Inurreta-Aguirre, H.; Dupraz, C. Microclimatic effect of agroforestry on diurnal tempera-ture cycle. In Proceedings of the 3rd European Agroforestry Conference, Montpellier, France, *25-26* May 2016; pp. 183–186.
58. Sharma, P.; Rai, S.C.; Sharma, R.; Sharma, E. Effects of land-use change on soil microbial C, N and P in a Himalayan wa-tershed. *Pedobiologia* **2004**, *48*, 83–92.
59. Dinesh, R.; Chaudhuri, S.G.; Ganeshamurthy, A.N.; Dey, C. Changes in soil microbial indices and their relationships fol-lowing deforestation and cultivation in a wet tropical forest. *Appl. Soil. Ecol.* **2003**, *24*, 17–26.
60. Ndaw, S.M.; Gama-Rodrigues, A.; Sales, K.R.; Rosado, A.S. Relationships between bacterial diversity, microbial biomass, and litter quality in soils under different plant covers in northern Rio de Janeiro State, Brazil. *Can. J. Microbiol.* **2009**, *55*, 1089–1095. https://doi.org/10.1139/w09-066.
61. Mead, D.J. The role of agroforestry in industrialized nations: The southern hemisphere perspective with special emphasis on Australia and New Zealand. *Agrofor. Syst.* **1995**, *31*, 143–156. https://doi.org/10.1007/bf00711722.
62. Repo, T.; Kalliokoski, T.; Domisch, T.; Lehto, T.; Mannerkoski, H.; Sutinen, S.; Finér, L. Effects of timing of soil frost thawing on Scots pine. *Tree Physiol.* **2005**, *25*, 1053–1062. https://doi.org/10.1093/treephys/25.8.1053.
63. Repo, T.; Lehto, T.; Finér, L. Delayed soil thawing affects root and shoot functioning and growth in Scots pine. *Tree Physiol.* **2008**, *28*, 1583–1591. https://doi.org/10.1093/treephys/28.10.1583.
64. Rivest, D.; Lorente, M.; Olivier, A.; Messier, C. Soil biochemical properties and microbial resilience in agroforestry systems: Effects on wheat growth under controlled drought and flooding conditions. *Sci. Total Environ.* **2013**, *463–464*, 51–60. https://doi.org/10.1016/j.scitotenv.2013.05.071.
65. Schimel, J.; Balser, T.C.; Wallenstein, M. Microbial stress-response physiology and its implications for ecosystem function. *Ecology* **2007**, *88*, 1386–1394. https://doi.org/10.1890/06-0219.
66. Bainard, L.D.; Klironomos, J.N.; Gordon, A.M. Arbuscular mycorrhizal fungi in tree-based intercropping systems: A review of their abundance and diversity. *Pedobiologia* **2011**, *54*, 57–61. https://doi.org/10.1016/j.pedobi.2010.11.001.
67. Orwin, K.H.; Wardle, D.A. Plant species composition affects belowground properties and the resistance and resil-ience of the soil microflora to a drying disturbance. *Plant Soil* **2005**, *278*, 205–221.
68. Banning, N.C.; Murphy, D. Effect of heat-induced disturbance on microbial biomass and activity in forest soil and the relationship between disturbance effects and microbial community structure. *Appl. Soil Ecol.* **2008**, *40*, 109–119. https://doi.org/10.1016/j.apsoil.2008.03.011.
69. Unger, I.M.; Kennedy, A.C.; Muzika, R.-M. Flooding effects on soil microbial communities. *Appl. Soil Ecol.* **2009**, *42*, 1–8. https://doi.org/10.1016/j.apsoil.2009.01.007.
70. Ghassemi-Golezani, K.; Farhangi-Abriz, S.; Abdoli, S. How can biochar-based metal oxide nanocomposites counter salt toxicity in plants?. *Environ. Geochem. Health* **2020**, *43*, 2007–2023. https://doi.org/10.1007/s10653-020-00780-3.
71. Pessarakli, M.H.M.; Sheibanirad, A. Plant Responses under Environmental Stress Conditions. *Adv. Plants Agric. Res.* **2015**, *2*, 73. https://doi.org/10.15406/apar.2015.02.00073.
72. Osakabe, Y.; Osakabe, K.; Shinozaki, K.; Tran, L.-S.P. Response of plants to water stress. *Front. Plant Sci.* **2014**, *5*, 86. https://doi.org/10.3389/fpls.2014.00086.
73. Li, F.L.; Bao, W.K.; Wu, N. Effects of water stress on growth, dry matter allocation and water-use efficiency of a leguminous species, Sophora davidii. *Agrofor. Syst.* **2009**, *77*, 193–201. https://doi.org/10.1007/s10457-008-9199-1.
74. Anderson, S.H.; Udawatta, R.P.; Seobi, T.; Garrett, H.E. Soil water content and infiltration in agroforestry buffer strips. *Agrofor. Syst.* **2008**, *75*, 5–16. https://doi.org/10.1007/s10457-008-9128-3.
75. Jactel, H.; Petit, J.; Desprez-Loustau, M.L.; Delzon, S.; Piou, D.; Battisti Akoricheva, J. Drought effects on damage by forest insects and pathogens: A meta-analysis. *Glob. Change Biol.* **2012**, *18*, 267–276.
76. Rouault, G.; Candau, J.-N.; Lieutier, F.; Nageleisen, L.-M.; Martin, J.-C.; Warzée, N. Effects of drought and heat on forest insect populations in relation to the 2003 drought in Western Europe. *Ann. For. Sci.* **2006**, *63*, 613–624. https://doi.org/10.1051/forest:2006044.
77. Ngugi, M.R.; Doley, D.H.; Mark, A.; Dart, P.; Ryan, P. Leaf water relations of *Eucalyptus cloeziana* and *Eucalyptus argophloia* in re-sponse to water deficit. *Tree Physiol.* **2003**, *23*, 335–343.
78. Singh, B.; Singh, G. Effects of controlled irrigation on water potential, nitrogen uptake and biomass production in Dalbergia sissoo seedlings. *Environ. Exp. Bot.* **2006**, *55*, 209–219. https://doi.org/10.1016/j.envexpbot.2004.11.001.
79. Galle´, A.; Haldimann, P.; Feller, U. Photosynthetic performance and water relations in young pubescent oak (Quercus pubescens) trees during drought stress and recovery. *New Phytol*. 007, 174, 799–810. https://doi.org/10.1111/j.1469-8137.2007.02047.x.

80. **Error! Hyperlink reference not valid.**Kato, T.; Kimura, R.; Kamichika, M. Estimation of evapotranspiration, transpiration ratio and water-use efficiency from a sparse canopy using a compartment model. *Agric. Water Manag.* **2004**, *65*, 173–191. https://doi.org/10.1016/j.agwat.2003.10.001.
81. Flexas, J.; Bota, J.; Galmés, J.; Medrano, H.; Ribas-Carbó, M. Keeping a positive carbon balance under adverse conditions: Responses of photosynthesis and respiration to water stress. *Physiol. Plant.* **2006**, *127*, 343–352. https://doi.org/10.1111/j.1399-3054.2006.00621.x.
82. Chaves, M.M.; Flexas, J.; Pinheiro, C. Photosynthesis under drought and salt stress: Regulation mechanisms from whole plant to cell. *Ann. Bot.* **2009**, *103*, 551–560. https://doi.org/10.1093/aob/mcn125.
83. Ayaz, A.; Saqib, S.; Huang, H.; Zaman, W.; Lü, S.; Zhao, H. Genome-wide comparative analysis of long-chain acyl-CoA synthetases (LACSs) gene family: A focus on identification, evolution and expression profiling related to lipid synthesis. *Plant Physiol. Biochem.* **2021**, *161*, 1–11. https://doi.org/10.1016/j.plaphy.2021.01.042.
84. Lawlor, D.W. Limitation to Photosynthesis in Water-stressed Leaves: Stomata vs. Metabolism and the Role of ATP. *Ann. Bot.* **2002**, *89*, 871–885. https://doi.org/10.1093/aob/mcf110.
85. Vinocur, B.; Altman, A. Recent advances in engineering plant tolerance to abiotic stress: Achievements and limitations. *Curr. Opin. Biotechnol.* **2005**, *16*, 123–132. https://doi.org/10.1016/j.copbio.2005.02.001.
86. Boyer, J.S. Plant Productivity and Environment. *Science* **1982**, *218*, 443–448. https://doi.org/10.1126/science.218.4571.443.
87. Ashraf, M. Breeding for salinity tolerance proteins in plants. *Crit. Rev. Plant Sci.* **1994**, *13*, 17–42.
88. Meloni, D.; Gulotta, M.; Martinez, C.; Oliva, M. The effects of salt stress on growth, nitrate reduction and proline and gly-cine betaine accumulation in Prosopis alba. *Braz. J. Plant Physiol.* **2004**, *16*, 39–46.
89. Shabala, S.; Munns, R. Salinity stress: physiological constraints and adaptive mechanisms. In *Plant Stress Physiology*; Shabala, S., Ed.; Oxford: London, UK, 2012; pp. 59–93.
90. Pérez-López, U.; Robredo, A.; Lacuesta, M.; Sgherri, C.; Muñoz-Rueda, A.; Navari-Izzo, F.; Mena-Petite, A. The oxidative stress caused by salinity in two barley cultivars is mitigated by elevated CO_2. *Physiol. Plant.* **2009**, *135*, 29–42.
91. Ahanger, M.A.; Tomar, N.S.; Tittal, M.; Argal, S.; Agarwal, R.M. Plant growth underwater/salt stress: ROS produc-tion; antioxidants and significance of added potassium under such conditions. *Physiol. Mol. Biol. Plants* **2017**, *23*, 731–744.
92. Tahjib-Ul-Arif, M.; Sohag, A.A.M.; Afrin, S.; Bashar, K.K.; Afrin, T.; Mahamud, A.G.M.S.U.; Polash, M.A.S.; Hossain, M.T.; Sohel, M.A.T.; Brestic, M; et al. Differential Response of Sugar Beet to Long-Term Mild to Severe Salinity in a Soil–Pot Culture. *Agriculture* **2019**, *9*, 223. https://doi.org/10.3390/agriculture9100223.
93. Awan, A.R.; Mahmood, K. Tree plantation in problem soils. In *Text Book of Appl Forestry*; Tahir Siddiqui, M., Nawaz, F., Eds.; University of Agriculture: Faisalabad, Pakistan, 2017; p. 140–159.
94. Dagar, J.C.; Tewari, V.P. (Eds.) *Agroforestry: Anecdotal to Modern Science*; Switzerland AG Springer Nature: Cham, Switzerland, 2018; p. 879.
95. Bin Yousaf, M.T.; Nawaz, M.F.; Rehman, M.Z.U.; Gul, S.; Yasin, G.; Rizwan, M.; Ali, S. Effect of three different types of biochars on eco-physiological response of important agroforestry tree species under salt stress. *Int. J. Phytoremediation* **2021**, *23*, 1412–1422. https://doi.org/10.1080/15226514.2021.1901849.
96. **Error! Hyperlink reference not valid.**Gordon, T.R.; Reynolds, G.J. Plasticity in plant-microbe interactions: A perspective based on the pitch canker pa-thosystem. *Phytoparasitica* **2017**, *45*, 1–8.
97. Barón, M.; Flexas, J.; Delucia, E.H. Photosynthetic responses to biotic stress. In: Flexas, J., Loreto, F., Medrano, H. (Eds): Terrestrial Photosynthesis in a Changing Environment - A Molecular, Physiological and Ecological Approach. **2012** Cambridge University Press 331–350.
98. Dittrich-Schroder, G.; Wingfield, M.J.; Hurley, B.P.; Slippers, B. Diversity in Eucalyptus susceptibility to the gall-forming wasp *Leptocybe invasa*. *Agric. For. Èntomol.* **2012**, *14*, 419–427.
99. Das, T.; Majumdar, M.H.D.; Devi, R.T.; Rajesh, T. Climate change impacts on plant diseases. *SAARC J. Agric.* **2017**, *14*, 200–209. https://doi.org/10.3329/sja.v14i2.31259.
100. Abramovitch, R.; Anderson, J.C.; Martin, G.B. Bacterial elicitation and evasion of plant innate immunity. *Nat. Rev. Mol. Cell Biol.* **2006**, *7*, 601–611. https://doi.org/10.1038/nrm1984.
101. Pumariño, L.; Sileshi, G.W.; Gripenberg, S.; Kaartinen, R.; Barrios, E.; Muchane, M.N.; Midega, C.; Jonsson, M. Effects of agroforestry on pest, disease and weed control: A meta-analysis. *Basic Appl. Ecol.* **2015**, *16*, 573–582. https://doi.org/10.1016/j.baae.2015.08.006.
102. Horbach, R.; Navarro-Quesada, A.R.; Knogge, W.; Deising, H.B. When and how to kill a plant cell: Infection strat-egies of plant pathogenic fungi. *J. Plant Physiol.* **2011**, *168*, 51–62.
103. Busey, P. Cultural management of weeds in turfgrass: A review. *Crop Sci.* **2003**, *43*, 1899–1911.
104. Turgeon, A.J.; McCarty, L.B.; Christians, N. *Weed Control in Turf and Ornamentals*; Prentice-Hall: Hoboken, NJ, USA, 2009.
105. Datnoff, L.E. Silicon in the Life and Performance of Turfgrass. *Appl. Turfgrass Sci.* **2005**, *2*, 1–6. https://doi.org/10.1094/ats-2005-0914-01-rv.
106. Nair, P.K.R.; Gordon, A.M.; Mosquera-Losada, M.-R. Agroforestry. In *Encyclopedia of Ecology*; Jorgensen, S.E., Faith, B.D., Eds.; 2018 Volume 1, p. 101.

107. Garrett, H.E. (Ed.) *North American Agroforestry: An Integrated Science and Practice*; 2nd ed. ASA: Madison, WI, USA, 2009.
108. Gordon, A.; Newman, S.; Coleman, B. *Temperate Agroforestry Systems*, 2nd ed.; CABI: Wallingford, UK, 2018.
109. Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 20260–20264. https://doi.org/10.1073/pnas.1116437108.
110. Weiguo, F.; Pingping, L.; Yanyou, W.; Jianjian, T. Effects of different light intensities on anti-oxidative enzyme activity, quality and biomass in lettuce. *Hortic. Sci.* **2012**, *39*, 129–134. https://doi.org/10.17221/192/2011-hortsci.