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REVIEW ARTICLE

Conservation Tillage: A Sustainable Approach for Carbon Sequestration and Soil Preservation. A Review

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Abstract

Minimum tillage is a soil conservation tillage aimed at minimizing soil disturbance required for productive crop production. Unlike intense tillage, which uses ploughs to alter the soil's structure, this tillage technique does not turn the soil over. Only secondary tillage is used sparingly in minimum tillage, with primary tillage being totally avoided. Practices like minimum furrowing, using organic fertilizer, using biological pest control techniques, and using less pesticides are all included in minimum tillage. Soil erosion and soil degradation have been increased by the use of conventional agricultural techniques, such as extensive tillage centered on the removal of crop residue. Global interest in finding various sustainable ways to lower the concentration of greenhouse gases in the atmosphere has grown in recent years as a result of the gradual increase in their concentration. The amount of carbon stored in soil is 2-4 times greater than that in the atmosphere and four times greater than that in vegetation. In order to prevent or, carbon sequestration (CS) delay dangerous climate change entails storing other forms of carbon or transferring CO2 from the atmosphere into the soil. The potential of soils to store carbon and reduce the accelerated greenhouse effects by implementing various agricultural management strategies is covered in the current review. Conservation tillage techniques improve carbon sequestration in agricultural soils. Conservation tillage can be a practical way to store carbon in the soil and minimize the effects of climate change. Conservation tillage reduced the green house gas. Zero tillage has been identified as the most environmentally friendly tillage practice for the mitigation and adaptation to climate change processes. No-till farming is thought to make it possible to increase crop production sustainably in order to fulfill future agricultural demands.

Keywords: climate change; carbon sequestration; soil conservation; global warming; zero tillage; Soils degradation

Introduction

The growing concern for food security through improved soil management techniques demands identification of an environmentally friendly and crop yield sustainable system of tillage. Tillage is defined as the mechanical manipulation of the soil for the purpose of crop production affecting significantly the soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes. This suggests that tillage exerts impact on the soil purposely to produce crop and consequently affects the environment. As world population is increasing so the demand for food is increasing and as such the need to open more lands for crop production arises.

The yearning for yield increases to meet growing demand must be done in a way that soil degradation is minimal and the soil is prepared to serve as a sink rather than a source of atmospheric pollutants. Thus, conservation tillage, along with some complimentary practices such as soil cover and crop diversity (Corsi, Friedrich, Kassam, Pisante, & de Moraes Sà, 2012) has emerged as a viable option to ensure sustainable food production and maintain environmental integrity. This implies that conservation tillage is a component of conservation agriculture (CA).

Conservation Agriculture

define as a method of managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. They added that minimum mechanical soil disturbance, permanent organic soil cover and crop diversification are the three basic principles of CA (Corsi *et al.*,2012). According to CTIC (2004), conservation tillage is any tillage system that leaves at least 30% of the soil surface covered with crop residue after planting to reduce soil erosion by water. (Lal *et al.*,1990) described conservation tillage as the method of seedbed preparation that includes the presence of residue mulch and an increase in surface roughness as the key criteria. Conservation tillage is an ecological approach to soil surface management and seedbed preparation. Conversion from conventional to conservation tillage, when this is done in line with the principle of CA, may improve soil structure, increase soil organic carbon, minimize soil erosion risks, conserve soil water, decrease fluctuations in soil temperature and enhance soil quality and its environmental regulatory capacity. Crop residue is an important and a renewable resource. Developing techniques for effective utilization of this vast resource is a major challenge. Improper uses of crop residues (e.g. removal, burning or ploughing under) can aid accelerated erosion, soil fertility depletion and environmental pollution through burning. The principle of conservation tillage involves maintenance of surface soil cover through retention of crop residues achievable by practicing zero tillage and minimal mechanical soil disturbance. Retention of crop residue protects the soil from direct impact of raindrops and sunlight while the minimal soil disturbance enhances soil biological activities as well as soil air and water movement. The aim of this review, therefore, was to examine the effects of conservation tillage on soil, crop and the net effect on the environment. This may provide farmers and other land users the information on the desirability of a conservation tillage system for sustainable crop yield increases with minimal negative impact on the soil and the environment.

Types of conservation tillage

Conservation tillage practices range from zero tillage (No-till), reduced (minimum) tillage, mulch tillage, ridge tillage to contour tillage. No tillage (NT) involves land cultivation with little or no soil surface disturbance, the only disturbance being during planting while minimum tillage means reduced level of soil manipulation involving ploughing using primary tillage implements. In mulch tillage, the soil is prepared or tilled in such a way that the plant residues or other materials are left to cover the surface to a maximum extent. Ridge tillage involves planting crops in rows either along both sides or on top of the ridges which are prepared at the commencement of the cropping season. When tillage is at right angles to the direction of the slope it is referred to as contour tillage. Table 1. Differences between conservation tillage and conventional tillage (Shahane et al., 2021)

Table 1. Differences between conservation tillage and conventional tillage (Shahane et al., 2021)

S.No.	Particulars	Conventional Tillage	Conservation Tillage
1	Soil health	Poor/degraded	Healthy soil
2	Tillage System	High Intensity plough based tillage system	Minimal tillage or zero tillage
3	Energy requirement	higher	Lower
4	Fallowing System	Ideal fallow land without any crop cover on soil surface	Growing of cover crops
5	sustainability	lower	Higher
6	Residue Management	Complete removal or burning of crop residue	Maintaining 30% soil surface covered with residues
7	Foot print on natural resources	Higher	Lower
8	Nutrient Management	Chemical based nutrient management or intensive use of chemical fertilizers	Integrated nutrient management with inclusion of organic sources and microbial inoculations
9	Fallowing System	Ideal fallow land without any crop cover on soil surface	Growing of cover crops

Conservation tillage and soil properties

Tillage impact is noticeable on soil physical, chemical and biological properties though in different magnitudes. Tillage impact also includes the effect on the soil environment in the form of runoff and soil erosion (Bhatt & Khera, 2006).

Soil physical properties

The effects of conservation tillage on soil properties are variable and depend on the specific system implemented. No-till (NT) systems, which maintain high soil coverage, have shown significant changes in soil properties, particularly in the upper few centimeters (Anikwe & Ubochi, 2007). Lal (1997a) suggests that soil physical properties generally favor no-till systems over traditional tillage-based systems. Many researchers have observed that NT improves both saturated and unsaturated hydraulic conductivity due to the continuity of pores (Benjamin, 1993) or flow through larger pores (Allmaras, Rickman, Ekin, & Kimball, 1977). Well-drained soils with lighter to medium textures and low humus content are particularly responsive to conservation tillage, especially no-till (Butorac, 1994).

NT technologies, according to Lal, Reicosky, and Hanson (2007), effectively reduce soil and crop residue disturbance, moderate soil evaporation, and minimize erosion losses. No-till soils also tend to exhibit more stable aggregates in the upper surface, resulting in higher total porosity. In a long-term experiment in Gottingen, Germany, Jacobs, Rauber, and Ludwig (2009) found that minimum tillage (MT) increased aggregate stability and concentrations of soil organic carbon (SOC) and nitrogen (N) in the upper 5-8 cm depth after several decades of tillage treatments.

In terms of water conservation, NT has shown greater effectiveness in humid and sub-humid tropics. Kargas, Kerkides, and Poulovassilis (2012) found that untilled plots retain more water compared to tilled plots. Minimum tillage has been reported to improve the soil pore system, increasing storage pores and elongated transmission pores (Pagliai, Vignozzi, & Pellegrini, 2004). Higher water holding capacity and moisture content have also been observed in the topsoil under NT compared to conventional ploughing (McVay et al., 2006). Therefore, replacing traditional tillage with conservation tillage has been proposed by many researchers to improve soil water storage and increase water use efficiency (WUE) (Fabrizzi et al., 2005, Silburn et al., 2007). Reduced tillage systems, including NT, have been found to result in greater water use efficiency compared to traditional tillage (McVay et al., 2006; Li, Huang, & Zhang, 2005). A study by Su et al. (2007) demonstrated that soil water storage and WUE were significantly higher in zero-tillage (ZT) than in conventional tillage (CT) over a six-year period.

In a study conducted in southwestern Nigeria, Busari and Salako (2012) observed higher unsaturated water flow parameters and infiltration rates under CT and MT than under ZT during the first year, but ZT showed higher infiltration parameters compared to CT by the end of the second year. This is because CT initially created fast-draining macro-pores (FDP) that facilitated infiltration, but these FDP decreased over time due to soil aggregate repackaging (Martínez, Fuentes, Silva, Valle, & Acevedo, 2008), resulting in lower infiltration rates under CT in the long term. Other studies (Pikul and Aase, 1995; Shukla et al., 2003) have also found higher infiltration rates under NT due to the protective effect of surface residue and the influence of SOC.

Additionally, less intense tillage practices not only preserve crop residue at the soil surface but also increase the activity of surface-feeding earthworms, creating numerous surface-connected macro-pores and inter-pedal voids, leading to higher rates of infiltration (Kemper, Trout, Segeren, & Bullock, 1987).

Aims and Objectives

1. To investigate the conservation agriculture is improve plant growth and soil health.
2. To discusses the potential of soils in sequestering carbon and mitigating the accelerated greenhouse effects by adopting different agricultural management practices.
3. To Investigate soils degradation soil degradation cause

Major Causes and Factors Affecting Soil Organic Carbon Depletion

The soil organic carbon pool is being quickly depleted as natural habitats give way to farmed ones. The amount of soil organic carbon pool depletion is 25–50% over 20–50 years in temperate temperature zones and 50–75% over 5–20 years in tropical climate zones after deforestation (Lal et al., 2004). When the C inputs in managed ecosystems (via crop residue retention, combined with the application of other biosolids) are greater than the outputs, the degree of depletion is minimal. The latter includes soil organic carbon losses due to leaching, mineralization, and increased erosion (caused by humans removing natural vegetation). By moving organic carbon-rich sediment from an agricultural land unit and surface runoff, agricultural soil erosion has been shown to disturb the global carbon cycle (Olson et al., 2016; Lal et al., 2009). Additionally, it has been noted that the emission of CO2 and the depletion of the source of soil organic carbon are positively correlated (Navarro-Pedreño et al., 2021). According to reports, the loss of the soil organic carbon pool has a negative effect on soil quality and the equilibrium of nutrients and elements. Through runoff losses and high evaporation rates, it also affects the equilibrium of soil water and can cause a significant decline in soil biodiversity, including the activity of soil microbes. (Lal et al., 2004). asserts that deteriorating soil quality has a detrimental impact on net primary productivity and reduces the quantity and quality of plant biomass produced, leading to a significant depletion of the soil organic carbon pool.

Management of Soil Organic Carbon

The process of moving atmospheric carbon dioxide into the soil's C pool via humifying agricultural waste and other organic soil components (such biosolids), which are not quickly released back into the atmosphere, is known as soil organic carbon sequestration (Olson et al., 2014). The main determinants of soil organic carbon sequestration are an increase in soil organic carbon content, its management through soil-based and crop-based management, applied by the use of C-enriched material (including mulches and biochar) prudent use of land resources and organic fertilizers. Low carbon agriculture is referred to as a sustainable method for reducing the effects of global warming, enhancing crop yields, and conserving the environment. Low-C agriculture practices are characterized by low GHG (including carbon dioxide) emissions and high soil organic carbon and vegetation storage. Utilizing best management practices to safeguard the environment, natural resources, and eventually crop productivity is the strategy's main objective. It is one of the best methods for reducing GHG emissions Zhang et al., 2017; Lal et al., 2018; De Gouvello et al., 2010; Gebara et al.,2013; de Magalhães et al., 2014). Table 2. Function of Soil organic Carbon (Shahane *et al.*, 2021)

Table 2. Function of Soil organic Carbon (Shahane *et al.*, 2021)

Plant	Improvement	Soil Maintenance	Reduce	Ecosystem
Increase in duration of shifting cultivation area available for cultivation	Enhanced the decomposition of soil pollutants Microbial population and diversity Biogeochemical cycling of nutirents	N/A	N/A	N/A
Crop Yield Improvement	Agregate Stability	Temperature	Bulk Density	Increase in Carbon Sequestration
Sustainability in Production System	Cation Exhanage Capacity and base saturation	PH	Soil crusting and compaction	N/A
Quality improvement	Porosity	Soil Consistence	Erodibility and Erosion	Reduce greenhouse gas emission
Enhance resource and use efficiency	Infilitration	Air Circulation	Accumulation of toxic Material	Prevent station of tanks and enhance and their storage capacity and life
Profitability enhancement	Chelation of Micronutrients	Optium soil moisture	Reduce the leaching loss of nutrients	N/A
Reduced bioaccumulation of soil pollutants in the plants products	Water and nutrient retention capacity	Desirable soil structure spheriodal granular and crumby structure	N/A	N/A

Mechanism of Soil C Sequestration

The three main processes that lead to soil carbon sequestration are the formation of soil microaggregates, the soil's long-term stability, and the enhancement of soil structure through the deep insertion of SOC in the subsoil layers Lal et al., 1997; Tisdall et al.,1982 Six Bossuyt et al.,2000). The stability of macro-aggregates might protect soil organic matter (OM) from microbial activity. The concentration of clay and mineralogy have a major impact on aggregation. Furthermore, a positive relationship between aggregate size and total soil organic carbon content was shown by Beare *et al.*,1994; Puget *et al.,* 2005). The way biomass C humifies is also influenced by soil properties, tillage practices, climate, and soil nutrient availability. The humidification efficiency of biomass C is lower in warm, dry regions compared to cold, humid conditions. In addition, large surface area clayey soils perform better in terms of humification efficiency than coarse-textured soils. The no-till farming method had a positive effect on the effectiveness of humification. (Puget et al.,2005) found that 8.3% of the total carbon in crop residue for plow-tillage crops and 11.9% for no-till practices was converted to sulfur dioxide soil organic carbon in maize crops grown in Coshocton, Ohio. In a separate study, (Allmaras et al.,2004) discovered that humification was 26% more successful for no-till soils than it was for traditional tillage methods like using moldboard plows and chisels, which were reported to be 11% more effective. The availability of soil components such as N, P, S, Zn, and Cu affects the efficiency of humification because C is the main component of humus. (Himes et al., 2018). found that 28 mg of carbon in 62 mg of oven-dry residue is needed to store the 10 mg of carbon in crop residue into 17.241 mg of humus. It also requires 143 kg S, 200 kg P, and 833 kg N, according to the writers. Consequently, for the leftover C to be humified, essential nutrients like Nitrogen, Phosphrous, and Sulfur must be present. Regarding this, (Jacinthe et al., 2002).found that residue-C conversion into soil organic carbon for Luvisol in central Ohio was 32% when fertilizer treatment was applied, compared to 14% when it wasn't. Under the mulched soils, comparable soil organic carbon stocks (25.6 Mg C ha 1) have been identified, both with and without fertilizer treatment. Nevertheless, additional SOC deposition only occurs in regions where more fertilizer was applied when mulching material is employed. The no-till approach does not greatly increase the soil organic carbon pool in the absence of adequate fertilizer (Campbell et al., 2001). The amount of SOC sequestered is significantly influenced by the rates and locations of N fertilizer application Gregorich et al., 1995; Wanniarachchi et al., 1999; Murungu et al., 2011). The illuviation and translocation of C into the subsurface layers is another important mechanism. The results of the bioturbation generated by earthworms, termites, and the deep root system are climate changes and the translocation of deep C away from the anthropogenic zone (Lavelle et al., 1989; Lorenz et al., 2005).

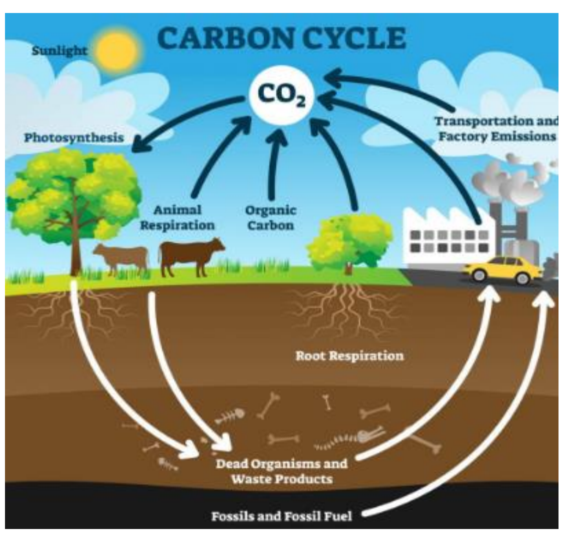

Figure 1. Sequestering Carbon in Soils to Reduce Climate Change

Conventional Tillage and Soil Carbon Stocks (CS)

Developing a soil environment that is favourable to improved plant growth and development is the primary goal of any tillage technique. One of the key elements determining soil C stocks is tillage. SOM is significantly reduced as a result of the aggressive tillage techniques. While ground cover removal exposes the organic-rich topsoil layers to wind and water erosion, tillage exposes soils to air, which promotes SOM decomposition by soil bacteria (Wani et al., 2016). Moreover, soil microbial activity and the holes left by plant roots are disturbed by intensive tillage techniques. The SOM is rapidly degraded and lost as a result of the fast-mechanical cultivation; the SOM gets protected within the soil aggregates. Tillage techniques also cause the soil aggregates to break down, increasing the amount of oxygen available and the surface area that organic material is exposed to.

Physiochemical Properties of Conventional Tillage Practices

Poor Infiltration and excess runoff. Deep layers compaction and structure disability. Nutrient loss and reduced CEC. Salainization and acidification.

Biological Properties of Convential Tillage Practices

Reduced diversity of soil organisms. Reduced enzymatic activity and affect nutrient cycling. Reduced number of plants associated microorganisms. (Hussain et al.,2021)

Conservation Agriculture and NT for SOC

A different approach to increasing agricultural output in a sustainable way has been mentioned: the conservation agriculture (CA) system. In agricultural environments, this technique is widely thought to increase infiltration rates, lessen erosion problems and improve soil quality and organic C levels (Kahlon et al., 2013). According to a different study by (Prasad et al., 2016). conservation agriculture lessens the problems with soil degradation associated with rainfed agriculture. Conservation agriculture includes crop mulching, proper crop rotation, and no-till farming, which involves less soil disturbance. (Somasundaram et al., 2020). Conservation agriculture, in contrast to traditional agriculture operations, primarily aims to maximize yields at the expense of the environment. (Dumanski et al., 2006) state that conservation agriculture involves the supply of modern agricultural technology to improve crop production and maintain the health and integrity of the eco-system. The FAO recognized that the CA system lessens the negative effects of climate change, improves sustainable land management, and improves crop productivity without endangering the environment. (Pisante et al., 2015; Pisante et al., 2012). Over the past few years, Californian agriculture (CA) has been more well-known because of its many advantages, which include improved soil fertility and water retention, long-term sustainable productivity, and the reduction of climate change (González-Sánchez et al., 2012; Palm et al., 2014; Busari et al., 2015). Contrary to traditional systems, conservation agricultural methods in highland crop production systems enhance soil water and nutrient status, residual water content, soil infiltration rate, and organic carbon content (Thierfelder et al., 2009; Ella et al., 2016). Three fundamental ideas underlying CA: minimizing soil disturbance through no-till practices, keeping soil cover with mulching, and modifying crop rotation and intercropping techniques. Using woody crops to increase yields in low-fertility soils without impacting the environment was also suggested by several researchers (Assessment et al., 2015). Based on integrated nutrient management, (Lal et al., 1990).

Conservation Tillage Enhanced the Biodiversity

In addition to reducing soil and nutrient erosion, conservation tillage techniques like RT and ZT improve soil microflora and faunal variety, SOC, and related soil characteristics (Das et al., 2019; Raj et al., 2022).

Soil Degradation

When a land-use system's potential productivity becomes detrimental and the land is unable to fulfill its environmental regulatory roles of absorbing, storing, and recycling nutrients, water, and energy, this is referred to as land degradation (Oldeman et al., 1992). Once more, the measured loss or decline of a soil's present or showed ability to yield plant materials of the right amount and quality is commonly referred to as soil degradation. Some scholars Blaikie et al., 2015;Chisholm et al., 1987;Blum et al., 2004).Contend that the phrase "land degradation" is more inclusive than "soil degradation." However, as land and soil are alike in the majority of soil management literature, the terms land degradation and soil degradation will be used synonymously in the parts that follow. Soil degradation is caused by a number of chemical, physical, and biological processes Lal et al., 2020; Eswaran et al., 2001). Crusting, hard setting, Deterioration of soil structure desertification, erosion, are some of the physical processes. fertility loss, Leaching, salinization, acidification and pollution are some of the chemical processes. The decrease in soil biodiversity and the depletion of carbon are two examples of the biological processes causing soil deterioration. A difference between land quality and land usage causes land deterioration, claims (Beinroth et al., 1994). In certain root-restrictive shallow soils in West Africa, yield decreases of 30–90% due to erosion have been reported by (Mbagwu et al., 1984; Lal et al., 1987). In Ohio and other Midwestern USA states, erosion decreased row crop yields by 20–40% (Fahnestock et al., 1996). In the Colombian Andes, (Schumacher et al., 1994)have noted significant losses on certain sites as a result of rapid erosion. Soil erosion and desertification have caused a 50% decrease in the production of some African farms (Dregne, 1990). Due to historical soil erosion, Africa's yield decline can vary from 2 to 40%, with a mean loss of 8.2% across the continent (Ruppenthal et al., 1995). Furthermore, Asia, which includes China, India, Israel, Iran, Lebanon, Jordan and Pakistan, Nepal, has significant productivity losses (20%) as a result of erosion (Lal *et al.*, 1995).Over a seven-year period, agricultural product decreases in 20% for soybeans, Ohio are 25% for maize and 30% for oats. (Lal *et al.*, 1996). Table 3. Impacts of soil deterioration on crop output and growth. (Shahane et al., 2021). Table 4. Characteristics of healthy soil(Shahane et al., 2021)

Table 3. Impacts of soil deterioration on crop output and growth. (Shahane et al., 2021)

S.No.	Crop	Soil degradation related problem	effect	Correction measure suggested
1	Wheat	Salinity due to irrigation water	decrease in wheat growth parameters, harvest index, and grain and straw yields as irrigation water's electric conductivity rises from 0.7 to 12 dS m−1	When Azospirillum sp. isolated from saline soil is used, wheat grain yield significantly increases over control.
2	Rice bean	Soil acidity	Soil acidity reduced crop growth and yield as well as	Utilizing lime at a rate of 0.6 t ha−1 improves all growth and yield

			economic metrics (gross and net return, B:C ratio, production efficiency, and economic efficiency).	characteristics, leading to an increase in yield of 0.42 t ha−1, or 221.31 and 164.34 US dollars in gross and net returns ha−1, respectively.
3	Rice	Acidity of soil (acid sulfate soil) and aluminum toxicity	decrease in rice output brought on by more aluminum toxicity and acidity in the soil; decreased availability of exchangeable cations (Ca, Mg, and K)	Positive effect of addition of amendments such as magnesium limestone, sugarcane based organic fertilizers and fused magnesium phosphate
4	Chickpea	Sensitivity of sodium salt (sodium chloride)	The rise in sodium chloride concentration has a considerable impact on vegetative and reproductive growth, or the quantity of flower buds and pods; the crop's podding stage was shown to be the most vulnerable.	N/A
5	Garden Pea	Acidic soil	Acidity of the soil has a negative impact on garden pea development and soil characteristics	Application of corn or lantana camera biochar (@ 6 to 18 t ha−1) had a positive impact on crop growth metrics. Improvements in the soil's total nitrogen, accessible

				phosphorus, potassium concentration, and porosity following crop harvest.
6	Pea	Acidity of soil	N/A	Lime application at 7.5 t ha−1 increased grain yield and dry matter production by 0.50–0.55 t ha−1 and 1.37–1.72 t ha−1, respectively.
7	Wheat	Waterlogging	After 21 days of sowing, waterlogging for 15 days lowers wheat yields in neutral soil (pH of 7.0), salty soil (pH of 8.2), acidic soil (pH of 9.0), and sodic soil (pH of 9.4).	N/A
8	Rice	Saline sodic soil	Saline sodic soil's detrimental effects on plant growth and yield	Rice growth and yield parameters were significantly improved by the use of gypsum at 9.5 t ha−1 and irrigation spaced four days apart. There was also a considerable increase in rice grain and straw yield.
9	French Bean	Chemical degradation (nutrient deficiency) in acidic soil	reduced growth and yield characteristics as a result of infertile soil	Growth and yield attributes improved as a result of applying three primary nutrients at the

		appropriate rate in addition to boron.

Table 4. Characteristics of healthy soil(Shahane et al., 2021)

S. No	Attributes	Description
1	Resilience	Healthy soils can bounce back fast from adverse events like compaction.
2	Important function of healthy soil	Carbon cycles, nutrient cycles, preservation of soil structure, control of pests and diseases
3	Resistance to being degraded	Good tilth, internal drainage, low plant parasite populations, and these characteristics help soils resist the damaging impacts of compaction and wet durations.
4	Sufficient supply of nutrients although	For plants to flourish, there must be a sufficient supply of nutrients; at the end of the growing season, there shouldn't be an excessive amount of phosphorous and nitrogen left in highly soluble forms or enriching the soil's surface. The most likely times for fertilizer leaching and runoff are after crops are harvested and before the next crops are well-established.
5	Good soil tilth	Compared to soil with poor tilth, excellent tilth soil is less compacted, spongier, and allows roots to grow more fully. Water infiltration and storage for plant use later on is additionally supported by a soil with a stable and beneficial soil structure.
6	No chemicals that harm plants	Naturally occurring hazardous substances can include excess salts in arid areas or soluble aluminum in acidic soils. Human activity can introduce potentially dangerous chemicals through the application of sewage sludge containing high concentrations of toxic components or fuel-oil spills.
7	Low weed pressure	It is crucial to have minimal weeds so that the crop has less competition for nutrients, water, and light.
8	Sufficient depth	Full root system growth is supported by soils that are deep enough to contain a layer that can impede drainage and/or root development.
9	Good internal drainage	Soils that dry up rapidly can benefit from timely field operations. Additionally, for the best possible root health, oxygen needs to be able to enter the root zone, and proper drainage makes this possible.
10	high numbers of microbes that promote plant growth	Earthworms and a variety of bacteria, fungus, and actinomycetes are examples of organisms that aid in the cycling of nutrients and make them available to plants. Also, soil organisms generate compounds that stimulate plant growth.

Causes of Soil Degradation

Both natural and man-made factors can lead to soil degradation. Natural reasons include topographic and climatic elements like, frequent floods and tornadoes, steep slopes ,storms and strong winds, leaching in humid areas, intense rains and drought in arid areas. Anthropogenic causes of soil degradation include overextraction of ground water, shifting farming, desurfacing of the soil, excessive grazing, indiscriminate use of agrochemicals, and deforestation and overexploitation of vegetation.

Types of Soil Degradation

In 1991, ISRIC, in collaboration with FAO and UNEP, released a global map showing the state of soil degradation caused by human activity. A generic classification known as the GLASOD classification was created in advance of the map., Water erosion chemical deterioration, wind erosion, physical deterioration, and loss of biological activity are the five primary kinds of soil degradation, according to (Global Assessment of Soil Deterioration) (Oldeman *et al.*, 1992). Every type has multiple subtypes, with the exception of biological deterioration. The following lists these varieties and subtypes. Table 5. Soil degradation types and subtypes.

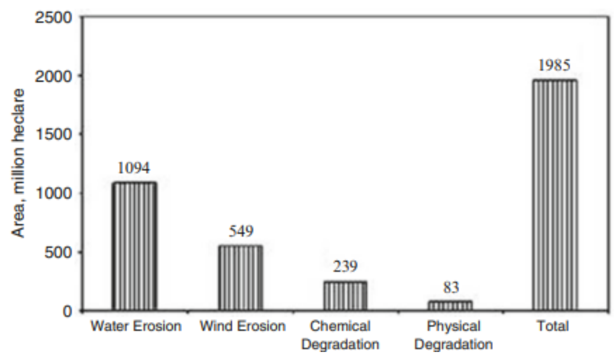

Figure 2. Land area so far degraded by different processes (Data) (Lal et al., 1996)

Table 5. Soil degradation types and subtypes

Type	Subtypes
Water Erosion	Loss topsoil Terrain deformation/mass movement site effect Reservior sedimentation Flooding Sea weed destruction
Wind Erosion	Loss topsoil Terrain deformation Overblowing
Chemical deterioration	Loss of Nutrient and organic matter Salination Acidification

	Eutrification
Physical deterioration	Compaction,sealing, and crusting Water Logging Lowering of water table Subsidence of organic soils

Extent of Soil Degradation

Approximately 38% of the planet's agricultural land have been deemed degraded. Africa has 65% of degraded territory, Central America has 74%, and South America has 45%. There is a significantly lower percentage of damaged grassland and forests—21% and 18%, respectively. If we simply take into account land that has been utilized (forests, permanent pasture, and agricultural areas), the percentage of degraded land is 14% and the percentage of severely degraded land is 23%. The area impacted by human-induced soil degradation was judged to be mildly deteriorated in 38% of the cases (749 M ha), moderately degraded in 46% of cases (910 M ha), strongly degraded in 15% of cases (296 M ha), and extremely degraded in fewer than 1% of cases (9.3 M ha) (Lal et al., 1996) In Asia, nutrient imbalances in the soil, overfertilization, pollution, and soil loss processes have a negative impact on soil health and quality.

The soil's organic stuff is deteriorating daily. With the growth in the nation's population over the past few decades, it has grown increasingly intense. On Earth, 25% of all species are found in soil. Table 6. Indicators of soil health and their measurements (Shahane et al., 2021)

Table 6. Indicators of soil health and their measurements (Shahane et al., 2021)

Soil health indicator	**Unit of measurement**	**Ideal values for health soil indicators (agricultural soil) and Method**
Texture	tweleve classes based on the relative proportion of sand, clay and silt	For most crops, a soil texture of 7–27% clay, 28–50% silt, and 23–52% sand is thought to be optimal. (Bouyoucos hydrometer method andInternational pipette method)
Bulky density	Mg m−3 or Gram cm−3	1.33-1.35 g cm−3 (Direct and indirect methods)
Penetration resistance	MegaPascal (MPa); N m−2 (cone index N cm−2)	N/A Cone penitromete)
Aggregate stability	Mean weight diameter (mm); Geometric mean diameter (mm)	N/A (Wet sieving and dry sieving method)
Water holding capacity	mm m−1 depth of soil	Crops specific (Pressure plate and membrane apparatus)
Infiltration rate	mm hour−1	N/A (Ring infiltrometer)
Depth of hardpan	Indicated as depth from the surface at which hardpan observe	Based on the effective root zone depth and characteristics of plant (Determined by compaction of soil at different layers)

Depth ofwater table	Depth from the surface in meters	N/A (Paizometer and open well)
Porosity	Percentage%	50% of the total soil volume (Mercury intrusion porosimetry; Image analysis and soil micromorphology)
Erosive potential	Mg ha−1 soil lossyear−1	≤ 11 Mg ha−1 soil loss/year (permissible limit) (Universal soil loss equation)
Soil Structure	Expressed as types (Platy, prismatic, blocky and spheroidal),class (Very fine, fine/thin, medium, coarse/thick and very course) and grade (structureless, weak, moderate and strong)	N/A
Soil crust	Qualitative property indicated by either types of crust or by surface hardness measured by cone penitrometer	Soil should be crust free as all crust has adverse from cultivation point of view except soil biological crust in some cases (Optical and scanning electron microscopy)
PH	In scale of 1–14	Neutral (6.7–7.3) pH for most of the crops and soil functioning is considered as ideal
Electrical conductivity	dS m−1	N/A (Saturation soil extract or soil-water suspension)
Minor nutrients Maganese Copper zinc Boron	2.0 mg kg−1 soil Zinc (Zn) 0.6 mg kg−1 soil Copper (Cu) 0.2 mg kg−1 soil Boron (B) mg kg−1 0.5 mg kg−1 soil	N/A
Urease Enzyme	N/A	Soil incubation in tri(hydroxymethyl) aminomethane buffer
Microbial biomass carbon	(µg microbial biomass carbon g−1 soil)	N/A (Fumigation method)

Results

Important conclusions on conservation tillage's effects on soil preservation and carbon sequestration can be gathered from a survey of the research.

Conservation tillage techniques improve carbon sequestration in agricultural soils

It is well known that conservation tillage, a commonly used agricultural technique, protects soil resources by increasing soil organic carbon (SOC) (Zhu *et al.*, 2022).

(Lal *et al.*, 1997) one of the information collected the two main ways that conservation tillage sequesters carbon are by deep storing SOC in the subsoil horizons and promoting micro-aggregation. Increased biomass output through conservation tillage and related agricultural methods (e.g., soil fertility enhancement, improved crops and species, cover crops and fallowing, improved pastures and deep-rooted crops) are also beneficial.
(Haddaway *et al.*, 2017) reported conservation tillage, such as decreased fuel usage and erosion, there are also negative effects, such as N2O etc.
(Hussain *et al.*,2021) It has been suggested that the main goal of conservation agriculture is to enhance soil health and plant development without causing adverse effects on the environment.
(Francaviglia *et al.*, 2023) studied By improving soil organic carbon (SOC) sequestration in soils and its associated co-benefits, sustainable agricultural practices—such as reducing tillage, cultivating cover crops, and in place crop residue retention measures—have been suggested as low-cost solutions that can address land degradation, food security, and climate change mitigation and adaptation. Accordingly, a great deal of research has shown that conservation agriculture (CA) enhances the biological, chemical, and physical features of soil, all of which are essential for preserving soil health and improving the adaptability of agroecosystems to climate change.
as numerous studies have repeatedly shown. The fundamental reason for this is the decrease in soil disturbance, which promotes a favorable environment for carbon storage and aids in maintaining organic matter levels.

Conservation tillage can be a practical way to store carbon in the soil and minimize the effects of climate change

(Deng *et al.,* 2022) one of the information collected thus, conservation tillage improves climatic resilience and minimizes the effects of climate change on agriculture.
(Rahman *et al.*, 2021) suggested Intensive soil tillage and crop residue removal in conventional agricultural systems may have a greater severe impact on the environment.
(Alhassan *et al.*, 2021) reported shown that NTS, in particular, enhanced soil water content and decreased soil temperature through conservation tillage techniques.
(Yao *et al.,* 2023) investigated if conservation tillage techniques may decrease the impact of climate change on soil CO2 emissions from arid farms.
Based on our research, zero tillage may be a major factor in reducing greenhouse gas emissions from soils and aiding in the fight against climate change.
Moreover, conservation tillage is essential to preserving soil health, according to the examination of soil preservation indicators.
Under conservation tillage systems, studies regularly show benefits in soil structure, moisture retention, and nutrient levels. Improved water infiltration and decreased erosion are noted, which over time will lead to better soil maintenance. The findings support the sustainability of agricultural ecosystems by confirming that conservation tillage practices have a positive impact on a number of soil quality factors.

Conservation tillage reduce greenhouse gas intensity in organic farming

(D.E et al., 2001) showed that tillage has an organic soil-saving effect that can lower greenhouse gas emissions and future farm fuel usage while also preserving energy for increased profit.
(Rahman et al., 2021) suggests MT and ZT practices to reduce adverse environmental impacts in Bangladeshi wheat agriculture, as the results support CTS. When comparing the techniques, the MT method—which keeps the crop residue (20 cm) and applies CA principles—is more suited for Bangladesh's wheat agriculture, both for CSA and SI. This is because it can enhance SOC formation while preventing water loss and greenhouse gas emissions without compromising output.

(Valujeva et al., 2022) There have been suggestions for reduced tillage and alternative crops to lower greenhouse gas emissions from agricultural soils.
(Gryze et al., 2010) reported organic farming, winter cover crops, and conservation tillage have all been suggested as strategies to lower soil greenhouse gas emissions from agriculture.
(Khresat et al., 2016) showed that conservation agriculture practices lower the greenhouse gas emissions of farming systems. (Khan *et al.*, 2023) studied Carbon sequestration can reduced the green house gas emission.

Discussion

The findings are consistent with the idea that conservation tillage is a viable strategy for reducing the effects of climate change and maintaining soil health. Increased soil organic carbon content is a result of both crop residues remaining on the field surface as well as decreased soil disturbance. This thus helps with carbon sequestration, resolving the issue of greenhouse gas emissions. The benefits for preserving soil are examined in relation to better water management and erosion prevention. Conservation tillage techniques reduce soil erosion by keeping surface leftovers in place, which serve as a protective layer. Sustainable soil management necessitates improved water infiltration and moisture retention, both of which increase resistance to drought.
It is important to recognize potential challenges and limitations linked to conservation tillage. In some situations, localized variables like crop rotation techniques, soil composition, and climate might affect how effective conservation tillage is. Farmers may face initial difficulties if these practices are adopted since they may call for changes to machinery and management.
The debate and overall findings highlight the significance of conservation tillage as a sustainable farming method for soil protection and carbon sequestration. The results provide insightful information to guide future investigations as well as promote the adoption of strategies that improve agricultural systems' long-term sustainability.

Conclusions and future perspectives

The best way to combat the negative consequences of climate change on agriculture, a sector that is extremely sensitive to changing weather patterns, is to manage natural resources carefully. Transferring atmospheric CO2 into the soil through a process known as "soil C sequestration" is a mutually beneficial strategy that addresses both climate adaptation and mitigation. Plant photosynthesis is the main process that converts atmospheric CO2 into soil, and it entails defending the soil's carbon-based pools from soil microbial populations that would otherwise release the carbon back into the atmosphere. The no-till farming method is regarded as an efficient way to restore soil and absorb atmospheric carbon since it maintains ecosystems and soil health. In addition to improving the efficiency of water and fertilizer use, zero- or no-tillage when combined with keeping crop residue in the field or using it as mulch helps sequester a sizable amount of atmospheric CO2. Crop rotation has the potential to improve soil health and sequester carbon under a conservation agriculture system by accelerating SOC accumulation rates at different soil levels. The majority of agricultural management methods that support carbon sequestration also enhance soil fertility, increase soil aggregate stability, retain water better, and guarantee food security. However, taking action shouldn't be contingent on having a thorough understanding of soil C and the sequestration capacity. Numerous techniques to improve the sequestration of atmospheric C have recently been presented by diverse research projects on various agricultural management methods. The adaptation of conservation tillage practices is comparatively more effective than several other options for atmospheric drawdown, and it may be adapted soon. Risks involved in this system are low, and there are several established advantages to enhancing soil quality and sequestering C.

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REVIEW ARTICLE

Assessments on the Impacts of Climate Change on Food Production, Nutrition, Quality, and Resource Use Efficiency: A Review

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Abstract
Nowadays, climate change is a hot issue all over the world which mainly affects crop production and productivity. Thus, it causes food insecurity all over the globe mainly in Sub-Saharan African countries like Ethiopia. This paper provides a comprehensive overview bonded to the appraisal of climate change impacts on nutrition, quality, and resource use, effectiveness using climate, water, and crop yield models. The studies present that climate change models with advanced spatial resolution can be a way forward for coming climate protrusions. The variability of downfall and the adding temperature was a cause of frequent failure and shortage and had a disastrous impact on the livelihood of the people. Climate change exacerbates the enormous being burden of undernutrition. It affects food and nutrition security and undermines current sweats to reduce hunger and promote nutrition. Undernutrition in turn undermines climate adaptability and the managing strategies of vulnerable populations. Climate change is now a global miracle with growth, poverty, food security, and stability counteraccusations. Because of significant dependence on the agrarian sector for product, employment, and import earnings, Ethiopia is seriously hovered by climate change, which contributes to frequent failure, flooding, and rising average temperatures. The most vulnerable sectors to climate variability and change in the country are husbandry, water, and mortal health. Agricultural sectors are severely affected by Climate change; thus, it causes the production and productivity of animals and plants. To enhance productivity, biotechnology in breeding is therefore essential; nonetheless, optimization is needed for every crop and circumstance. While some newly released crop varieties can increase yield and improve resource use efficiency, others can produce crops on marginal land that are sufficient.

Keywords: Climate, Food security, Nutrition, Resource use efficiency, Temperature

Introduction

Currently, climate change is the most the most factor affecting the environment globally, and also its effects will continue in the coming periods (Temesgen et al., 2014). The climate change is due to the various ways in which it

has destructive effects. Natural variables including volcanic eruptions, changes in the Earth's orbital components, and variations in solar output, as well as human-induced factors, namely the release of greenhouse gases, all contribute to global climate change. Although it is not a new phenomenon, the rate at which it is changing now is unparalleled. The average surface temperature of the Earth increased by $0.6–0.2^0{}_C$ in the 20^{th} century as reported by the IGP (Intergovernmental Panel) on Climate Change's 3^{rd} Assessment Report (TAR). According to Parry et al. (2005), this trend is predicted to continue, with temperatures increasing by 1.4 - $5.8^0{}_C$ by 2100.
On average, the Ethiopian's annual temperature increased by $1.3^0{}_C$, or $0.28^0{}_C$ between 1960 and 2006 in every decade. By the 2060s and 2090s, respectively, it is predicted that the mean annual temperature will rise by 1.1 to $3.1^0{}_C$ and 1.5 to $5.1^0{}_C$. As reported by McSweeney et al. (2007) reported that in many models, the expected changes under a single emissions scenario range up to $2.1^0{}_C$. Moreover, climatic projections indicated that as a result of global warming, rainfall unpredictability will rise and extreme flooding and droughts will occur more frequently (World Bank, 2010).
The various reports showed that the most common cause of climate change is the emission of Greenhouse Gases. Similarly, the IPCC (Intergovernmental Panel on Climate Change's) (2007) evidence is now overwhelmingly persuasive that the change in the environment mainly the change in climate resulting due to greenhouse gases (GHGs) is real and that the most vulnerable and disadvantaged people will suffer the most. Moreover, the IPCC (2014a), reported that the global change temperature by 2100 on average may vary from 1.8-4.0^0c. In the case of plants and animals, about 20 to 30% of the species are forecasted to be under extinction due to the rise in temperature by 1.5-$2.5^0{}_C$ (FAO, 2010; IPCC, 2014a, b), which will have a significant impact on crop production and maintaining food security in underdeveloped nations as reported by Mekuriaw et al. (2014).
The relationship between climate change and maintaining food security through the production of crops and animals has primarily focused on how it affects agricultural sectors ultimately causing the production of food crops. As an example, Gregory et al. (2002) reported that the wheat and rice crops, showed a reduction in crop length and consequently production of wheat crops as a result of heating and yield decreases of around 5% per ${}^0{}_C$ increase beyond $32^0{}_C$ for rice. According to Cline's 2007 projection, agricultural productivity will decline globally by 15.9%, falling 19.7% more sharply in developing nations. Similarly, a simulation of maize output in Latin America and Africa for the year 2055 anticipated a 10% total decrease (Jones and Thornton, 2003, Addisu et al., 2020).
Unambiguous evidence of climate system warming includes rising global average sea levels, higher air and ocean temperatures on average, and resulted in extended snow and melting of ice (IPCC 2007). The seasonal mean temperature has risen in several parts of Ethiopia, according to the IPCC (2014a) study. By 2006, Ethiopia's average annual temperature had risen by $1.1–3.1^0{}_C$, and likewise, McSweeney et al. (2007) explained that there were hotter days and also hot nights on average each year. Animal health and food production are both negatively impacted by this.
Currently, the concerns of crop production and being secure in food will be increased due to the effects of climate change, thus it will make more difficult conditions to produce more production of crops and livestock products to maintain food security in the world. Among these, the most powerful and frequently occurring one is natural disasters. Accordingly, Gregory et al. (2008) and UNFCCC (2009) explained that the consequences of natural disasters are profound for underdeveloped countries that are malnourished, impoverished, and still under food security. This paper's goal was to examine how climate change has affected possibilities for adaptation and mitigation as well as crop production, food security, nutrition, quality, and resource use efficiency.

The Impacts of Climate Change

Impact of Climate Change on Nutrition

The influence of climate change on food security, undernourishment, and agricultural productivity in poor nations is the single greatest health risk, according to World Health Organization research, because so many people are affected (Confalonieri et al., 2007). Global hunger and malnutrition risks are increasing due to climate change, impacting food security, livelihoods, health, water, sanitation, and socioeconomic determinants, affecting food access, maternity care, and sanitation (Easterling et al., 2007).

Women, children, and marginalized populations are among those who are the poorest and most at risk of suffering from anticipated climate change effects (World Food Program 2009). They are highly vulnerable to natural disasters, directly depend on resources that are unstable due to climate change, and have limited capacity to adjust or mitigate its effects. Pastoralists, artisanal fishermen, and smallholder and subsistence farmers will be especially exposed to the intricate, regional consequences of climate change (Easterling et al., 2007).

According to the IPCC (2007), there will be 200–600 million more hungry people by 2080, and 24 million more people will be undernourished by 2050 as a result of developing nations' reduced access to calories. Furthermore, it has been projected that in 2050, there will be a relative increase in mild stunting of 1% to 29% due to climate change as opposed to a world without it. Climate change is expected to cause rates of severe stunting to increase by 23% in central sub-Saharan Africa and 62% in South Asia (Lloyd et al., 2011).

Climate change causes direct and indirect effects. It can cause direct effects on the production and productivity of crops and livestock, the food systems of the country, and its food security, whereas, the reduction and varying nutritional values of the products are the indirect effects of it. Many plant crops used by humans have lower protein concentrations as a result of increased carbon dioxide. The amount of atmospheric carbon dioxide that is expected in the next (22^{nd}) century will have a significant impact on plant physiology and growth, which is anticipated to have an impact on agricultural output and food quality. Under warmer and drier conditions, raised Co_2 is anticipated to have a stronger effect on the levels of grain protein (WHO, 2010 and 2013).

Impacts of Climate Change on Health

Scientists have conjectured about the potential effects of climate change on human health due to the correlation between weather-related conditions and seasonality. Two recent studies are White and Hertz-Picciotto (1985) and Haile (1988). There is insufficient scientific evidence to conclusively demonstrate a link between human health and climate change. Human health is impacted by the climate both directly and indirectly. Heat stress, heart problems, preterm delivery, lung ailments including asthma and bronchitis, and infections spread by mosquitoes and ticks are examples of direct consequences. Premature birth, lung disorders associated with smog, and illnesses like pneumonia and influenza are examples of indirect consequences. For instance, Asthma, hay fever, pneumonia, influenza, and other illnesses are associated with particular climates and weather patterns, including winter, which impact the distribution and life cycles of fungi and plants.

Human health may be impacted by climate-related changes in crop and animal production, surface and subsurface water, coastal resources, social and economic conditions, and more. Poorer diets could ensue from decreased food production, and decline of irrigation or agricultural drainage due to increasing the levels of the sea and altered patterns of precipitation could have serious negative effects on human health and the economy (Harrington et al. 1989). The ranges in topographical and vulnerability of humans to numerous factors like diseases may change as a result of increased human migration from one place to another. Human health will typically be negatively impacted by any situation that lowers standards of life (Chappie and Lave 1982).

Many problems still need to be rectified. Without reliable predictive information on the local temperatures, relative humidity, and precipitation amounts, it is impossible to anticipate the health effects. Confounding variables have an impact on human health, some much more so than the weather. Due to the complicated interrelationships between these components (both with weather and among themselves), global climate change may frequently have an impact on two or more factors at once. We lack the knowledge necessary to fully evaluate all the synergistic and compensating effects. Finally, we lack knowledge of the potential social and economic effects that variations in mortality and morbidity brought on by the climate or ozone might produce. We also don't know a lot about the social and financial consequences associated with such effects. It is difficult to find information, in particular, on the productivity losses and out-of-pocket medical expenses linked to rises in morbidity.

Implications of Climate Change in Food Security

The literature has a wealth of information about the negative effects of climate change on East Africa's agricultural industry. Climate change affects agriculture and food production in several ways. By influencing the rise and distribution of incomes, it indirectly impacts food production by influencing the demand for agricultural products (Gregory et al. 2008). Altering agroecological circumstances (e.g., variations in rainfall causing drought or flooding, or variations in temperature causing changes in the length of the growing season), directly impacts food production. In semi-arid and dry regions, the amplification of high temperatures and little precipitation will be the most noticeable effect of climate change on smallholder and subsistence farmers (Mendelson and Dinar, 2010). The fifth report from the IPCC warns that, particularly for farmers in semi-arid regions, climate change in East Africa could worsen food insecurity, cause people to lose their rural livelihoods, and lower agricultural production. The 2013 IPCC report noted that extreme weather events can be dangerous to critical infrastructure networks and services such as emergency response, water and power supply, and healthcare.
The yields of major cereal crops in the African region are expected to be considerably negatively impacted by climate change (Niang et al. 2014). Mild warming rates of 1 to $20^{0}{}_{C}$ are putting rare ecological systems in jeopardy and may have an impact on water supply, human health, and food production in some regions. According to "worst-case" projections, warming by $2^{0}{}_{C}$ by the middle of the century might result in losses of 27–32% for maize, sorghum, millet, and peanuts (Schlenker and Lobell, 2010). According to the IPCC, global warming of $4^{0}{}_{C}$ or more will raise the possibility of severe, all-encompassing, and permanent effects to which it will be challenging to adapt. Because of numerous factors, including land degradation or nutrient deficiency, quick growth of population, and unavailability of adequate technologies such as newly released crop species, plant nourishments, mechanization, and irrigation have sparked the development of agricultural sectors all over the world. These factors are in common in Ethiopia which makes it a great problem for the governments and other development organizations to maintain food security and alleviate the poverty (Mekuriaw et al. 2014). According to Gebreegziabher et al. (2016); Tadesse and Alemayehu (2019) and Tamirat (2019) reported that the agricultural sector plays a vital role by creating job opportunities for the people, as a result, in Ethiopia more than 85% of the populations are highly engaged in these activities, and also, it aids to GDF of the country approximately $40 billion; it earns 88% of export revenues, and fulfills 73% of the domestic industries depends on agricultural raw materials needs of the country. Therefore, the primary sector that contributes to food security is agriculture because it is a significant means of food and also, it is important in producing excess capital to hasten the social and economic growth of the nation. However, due to unpredictable and irregular rainfall, this sector is highly at risk in the degraded areas and semi-arid areas of the country. Moreover, Zenebe et al. (2011), reported that climate change has a detrimental effect on financial sectors through reducing revenues by worsening agricultural activities. As a result, if this trend continues in the world mainly in developing countries, there will be a decline in salaries by 2050. According to the World Economic

Forum in 2023, By 2050, unchecked climate change might force over 200 million people to migrate, resulting in poverty and undoing decades of development gains. According to the no-total factor productivity-growth scenario model, income is lost due to climate change by about 30% when compared to the no-climate-change baseline.

Impact of Climate Change on Quality and Resource Use Efficiency

Climate change impacts on water resources

The hydrologic cycle is expected to quicken due to global warming, increasing precipitation and evaporation by 7 to 15% on a worldwide scale (Bolin et al. 1986). For many locations, climate models cannot agree on the direction of yearly precipitation change, hence the consequences on local water supplies are uncertain (Fredenck and Gleick 1989). In areas like northern California, where winter snowfall dominates precipitation and spring snowmelt dominates runoff, warmer temperatures may result in more winter rain, earlier spring melting, and seasonal runoff patterns (Gleick 1987a,b).

Water's relative values for alternate uses are likely to change. Variations in the seasonal and yearly availability of water can affect how water is used and reservoir capacity used for irrigation, fish habitat, flood control, and power generation. According to Frederick and Gleick (1989), hydroelectric power may become more appealing as a way to reduce the greenhouse effect while also coping with potential increases in energy needs. Water must be available at current or suitable new locations to produce more hydroelectric power, but water is running out in many parts of the world.

The building of dams, interbasin water transfers, desalination, waste recycling, and weather modification are examples of climate change adaptations that necessitate the development of non-conventional water sources. To increase performance, water managers might spend money on research and technology developments as well as infrastructure improvement plans, but they might not be able to justify these expenditures until climate change plays a major role (Frederick and Kneese, 1989). The possibility of future climate change could encourage further investment in these fields.

Impacts of climate change on Forests, Unmanaged Ecosystems, and Biodiversity

Within a few decades, the anticipated global warming might occur, possibly surpassing the millennium-scale natural rates of forest migration (Batie and Shugart, 1989). If this is the case, stressed-out existing woodlands become more susceptible to disease, pest infestation, and eventually fire (Clark, 1988). They will eventually replace the current forests with new forms of vegetation or forests that have a combination of species (Sedjo and Solomon 1989; Tamirat and Mekides, 2020).

In high latitudes, a lack of summer warmth and a lack of water limit tree development, while in the middle latitudes, heat and a lack of water limit growth. The consequences on forests would likely be negligible in the tropics, where temperature increases are predicted to be the least severe. As a result of climate change, the boreal forests will most likely migrate northward onto the tundra that is not now covered in trees, if there is enough precipitation and suitable soils. The biggest transitions, according to simulations, happen along the boundary between the boreal and cool temperate regions. Especially if higher CO_2 and better plant water use efficiency do not result in the predicted improvements in tree growth and moisture-saving benefits (Tamirat and Mekides, 2020), some mid-latitude forests may perish. According to Sedjo and Solomon (1989), species in mountainous areas would migrate to higher altitudes as temperatures rose.

Ecosystem biodiversity is at risk from rapid climate change, according to Batie and Shugart (1989). Certain extant plant and animal species would not be able to adapt because they are not mobile enough to migrate at the rate required for existence (Davis, 1989a, b). Although it is difficult to quantify, biodiversity has a significant economic worth. The forest industry must remove early species, try to salvage, thin, seed expensively, and actively plant trees in harvested stands to adapt to changing climates (Sedjo and Solomon, 1989).
In comparison to agriculture, the introduction of new types occurs much more slowly in forestry. Changes in the species mix may result from adaptation, at least in the early decades, and may necessitate expensive modifications to the logging and processing industries. Long tree growth cycles further increase the financial risk of selecting the wrong species for the changing climate, discouraging investment in trees and mills to process them. Production forestry will shift geographically, with some areas becoming more and more significant providers of wood products while others experience a loss. Only those locations where high-yield plantation forestry can still be carried out profitably will actively manage their woods.
Other unmanaged terrestrial and freshwater ecosystems have nonmarket value to humans because of their rarity (they might be protected in national parks, for example), significance in maintaining genetic and biotic diversity (Peters and Darling 1985; Graham 1988; Wilson 1988), and general ecological context they provide for natural resources that humans exploit. Research has indicated that the distribution of biotic communities and vegetative life zones, such as grasslands and tundra (Emanuel et al. 1985), arid communities (Neilson, 1986, 1987), and forests (Pickett and White 1985, Overpeck et al. 1990, Tamirat and Mekides, 2020), may be affected by global warming. Mainly the arid regions are particularly vulnerable (Adam et al. 1978; Dregne, 1893). Changes in former climates have been found to have a significant impact on vegetal patterns in pale ecological studies (Davis and Botkin 1985; Webb, 1986; Woodward 1987; Davis, 1989a, b). Concern is growing over how global warming may affect arctic and alpine communities, highly specialized terrestrial species, and species with weak dispersion systems (Peters and Darling 1985). Since aquatic communities are intimately linked to their terrestrial environments through energy, nutrients, and water, changes in terrestrial vegetation could have a substantial impact on freshwater systems, even though the effects of global warming on aquatic communities are still unknown (Minshall et al. 1985; Tamirat, 2019).

Climate Change Adaptation and Mitigation Measures

According to FAO (2010), the most important strategy to maintain food security and reduce the impacts on the environment is Biotechnology. In the meanwhile, modified crop types that can withstand extreme weather conditions including drought, waterlogging, salt, and climate change might increase the area that can be planted with crops, like in eroded soils, to improve the availability of foods for the future.
There is a great deal of worry that the rising levels of greenhouse gases in particular, carbon dioxide contribute to global warming by absorbing long-wave radiation reflected off the earth's surface. Carbon in the atmosphere has increased by 30% over the previous 150 years. According to Stavins and Richards (2005), the majority of scientists concur that elevated atmospheric carbon dioxide concentrations and increasing global temperatures are causally linked.
Increasing the worldwide storage of carbon in soils is one strategy suggested for lowering atmospheric carbon dioxide. However, storing carbon in soil benefits everyone. According to Kumar et al. (2009), Adesodun and Odejim (2010), and others, it boosts soil quality, improves agronomic production, advances food security, and mitigates climate change by offsetting anthropogenic emissions. Programs for conservation and reforestation have been implemented in this scenario throughout the past three decades (Tamirat and Mekides, 2020). To adapt to climate change, smallholder farmers must manage agricultural risk through climate-smart agriculture, enhance

climate information services, and accelerate adaptation over decadal time scales using integrated technology, agronomy, and policy alternatives.

Conclusion

Numerous studies have established the validity of climate change, the likelihood that it will worsen, and the likelihood that the most vulnerable and disadvantaged people will suffer the most. The security of food and nutrition is directly impacted by climate change, undermining present initiatives to combat food insecurity, the vitally important yet less addressed social, economic, and human health-related issues in the world. Human health may be impacted by climate-related changes in agricultural production mainly crop production, aquaculture, water and coastal resources, social and economic conditions, and more. The variability of climate such as the presence of unpredictable rainfall, floods, and droughts; and the variation in temperature, and precipitation can cause an impact on agricultural sectors. To achieve the necessary scale and rate of climate change, the following points should be considered; a) the integration of climate change policies and their implementation, b) the policies and implementations should be evidence-based, c) to maintain food security at all levels of the nations, the usage of climate-smart approach should be mandatory. The major effects of climate change on the yield of crops and livestock feeds, the availability of water, the occurrence of pandemics and unexpected diseases, and flood damage will result from variations in rainfall and rise in temperature. Improved rotation systems, reduced tillage carbon-sequestration practices, and higher crop cover including agroforestry, are just a few of the CSA strategies for climate change adaptation and mitigation that should be strengthened. Construction of additional dams and reservoirs, inter-basin water transfers, and the creation of "unconventional" sources of water, such as desalination, reutilizing of various waste materials from the industry, municipal sectors, and agricultural sectors, as well as weather modification, could all be considered adaptations to climate change.

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RESEARCH ARTICLE

Urinary outputs of nickel in association with their concentration levels in water, soil, and selected foods among farmers in the industrial estate of district swabi

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Abstract

Diet is the main route of exposure to trace metals, so the assessment risk of these elements to human via dietary intake is important. The non-carcinogenic health risk of Nickel (Ni) to the farmers via dietary intake in the Gadoon Amazai Industrial Estate (GAIE) Swabi of Kyber Pakhtunkwa was assessed. A cross sectional study was carried out in the GAIE to estimate the concentration of Nickel in all types of vegetables, grains, drinking water, irrigation water, soil and in urine of the farmers. A total of 22 farmers, living within the 2km distance in all four directions were selected and enrolled in the study after signing consent form. Atomic absorption spectrophotometer was used for the Ni analysis in the collected samples of water (both drinking and irrigation water), soil, foods and in urine of farmers. Results shows that the mean age of the farmers using tube well water and wastewater for irrigation purposes was 43.5±21.01 and 44.75±16.44 years, height was 167.6±3.7 and 165.75±6.02 cm, weight was 61±12.52 and 64.75±9.63 kg and BMI was 21.65±3.73 and 23.7±4.4 respectively. The concentration of the Ni in the wastewater irrigated field was significantly higher than the tube well irrigated field. The mean concentration of Ni in the soil irrigated with wastewater was 123.50±54.74 mg/kg respectively and in the tube-well irrigated field was 54.25±10.14 mg/kg. The Ni concentration in the wastewater irrigated garlic, fodder grass, potato, wheat and maize were 9.15±0.50 mg/kg, 8.82±1.30mg/kg, 7.70±1.04mg/kg and 7.56±1.24mg/kg respectively compared to tube-well irrigated land i.e., 0.97±0.25 mg/kg, 0.64±0.42 mg/kg, 1.08±0.35 mg/kg, 1.05±0.013 mg/kg and 1.02±0.39 mg/kg. A positive correlation was observed between the water, soil, and all crops grown in the GAIE . The bio-accumulation factor was higher for Ni in both the site. The Hazzard Quotient (HQ) for Ni exceeded the 1 for crops irrigated with industrial wastewater compared with tube-well irrigated crops and thus pose adverse health affect to farmers health. This study concluded that a strong association was evident between the Ni concentration in crops and cereals and waste-water irrigation.

Keywords: Dietary intake; Health risk; Hazzard Quotient (HQ); Farmer's health; Nickel; Industrial Wastewater

Introduction

Heavy metals are found on the earth crust naturally and their exposure to the environment occurs through both human and natural activities. Metals have crucial biological effects to both plants and animals but they became toxic after exceeding a certain limits, when enter to body these heavy metals combine with biomolecule of body (such as proteins and enzymes) form stable bio-toxic compounds (Mahurpawar, 2015).

Heavy metals are not degradable in nature and possess to accumulate in different parts, due to no proper mechanism to eliminate from the body these heavy metals even at low concentration damage the health of both humans and animals (Arora, Kiran, Rani, Rani, Kaur, & Mittal, 2008). Each metals possess specific toxicity signs and their effect may be acute, chronic, or sub-chronic (Hossain, Ahmed, Abdullah, Akbor, & Ahsan, 2015).

Diet is essential component for human body, fruits and vegetables provide nutrients (CHO, Protein, minerals and vitamins) to body, therefore contamination of fruits and vegetables by metals cannot be underestimated (Itanna, 2002). The heavy metals enter to food chain by the consumption of vegetables (Wang, Shan, Zhang, & Wen, 2004). Consumption of unsafe contaminated heavy metals for long time through foodstuff results deposition of metals in the kidney and liver, which causing disturbance in various processes and leads to some kind of diseases like nervous, cardiovascular, kidney and bone (Järup, 2003). Some nutrients are depleted by the intake of contaminated food which causes intrauterine growth retardation, lower immunological defenses, impaired psycho-social behaviour and the gastrointestinal cancer (Arora, Kiran, Rani, Rani, Kaur, & Mittal, 2008). The nature of effect can be neurotoxic, mutagenic, carcinogenic, or teratogenic (Duruibe, Ogwuegbu, & Egwurugwu, 2007).

In the economy of any nation good health and productive agriculture is important especially in the poverty. Pakistan is an agriculture country, and the farmers are considered to be the backbone of Pakistan economy. Agriculture system can be affected by health of producer's (farmers). The poor health of farmers decreases the work capacity and ability to explore various farming practices and also result in loss of workdays, decrease innovation ability. The agriculture production process and its output effected by both good and poor health of the farmers as well as in the society (Corinna & Ruel, 2006)

Due to the adverse health effects, heavy metals became an important concern in the agricultural products. Heavy metals even at very low concentrations are significantly very toxic due to its cumulative nature. The heavy metals accumulated at toxic level in the crop by the long term application of wastewater to irrigated field (Juste & Solda). Enormous volumes of wastewater is released by rapid urbanization and industrialization, which is used as a source for irrigation practices. The wastewater irrigation are creating problems and opportunities for agriculture production, as this wastewater contains considerable amount of toxic heavy metals and plants nutrients respectively (Singh, Mohan, Sinha, & Dalwani, 2004). The wastewater treatment does not remove the heavy metals and thus causes risk to food chain by heavy metals contamination by soil (Fytianos, Katsianis, Triantafyllou, & Zachariadis, 2001).

Vegetables are grown on small scale as compared with commercial main crops like, maize, wheat, and rice, but the productivity of vegetable totally depends on the good quality water availability for irrigation purposes. However, because of recently increase in the exportation of vegetables to other countries, in Pakistan the area of vegetables cultivation is increasing by the time. Like, vegetables were cultivated during 2007 and 2008 at about 253,800ha (M. Abbas, Parveen, Iqbal, Riazuddin, Iqbal, Ahmed, et al., 2010). However, the most commonly consumed vegetables are grown in the areas of peri-urban where formers using polluted waste-water for irrigation purpose coming from sewage with no proper filtration. Thus, it is expected that from the peri-urban locations of have polluted irrigation water, all the grown vegetables accumulate a considerable amount of heavy metals (Firdaus-e & Tahira, 2011). A variety of heavy metals are present in wastewater, by extensive uses of contaminated waste-water as source of irrigation for cereals and vegetables accumulate toxic metals (Adhikari, Manna, Singh, & Wanjari, 2004). These heavy metals easily enter the food chain, because the removal of these toxic metals from the water and soil is very difficult (Wilson & Pyatt, 2007).

Several approaches have been proposed to estimate the potential health risks of contaminants, distinguished mainly by carcinogenic and non-carcinogenic effects. United States Environmental Protection Agency (USEPA) current methods of assessing non-cancer risk and cancer risks are very different. The standard cancer risk assessment methods can be used to quantify the magnitude of risk, while similar methods are not available for quantifying the non-cancer risks (U. EPA, 1989). The non-cancer risk assessment is based on the use of hazards quotient (HQ), which is a ratio of the estimated dose of a contaminant to the Reference Dose (reference dose or RfD is the level below which there will not be any appreciable risk of the contaminant). If the estimated dose for an exposed population is equal to or greater than the RfD, then the population is at risk of contracting the adverse effect associated with the contaminant (U. EPA, 1989; USEPA). To assess the overall potential risk of more than one contaminant for non-carcinogenic effects, a Hazard Index (HI) approach has been developed based on the United States Environmental Protection Agency (Urban & Cook, 1986) Guidelines for Health Risk Assessment of Chemical Mixtures. The HI represent the total non-cancer hazard for all exposure pathways presented. The HI is equal to the sum of all the hazard quotients in USEPA-1989 (A. EPA, 1989). When the hazard index exceeds unity, there may be concern for potential health effects. Any single contaminants with exposure level greater than toxicity value will cause the hazard index to exceed unity, the hazard index can also be exceeded for multiple chemicals even if no single chemical exceed its RfD (A. EPA, 1989). We have carried out this study to estimate the concentration of Nickel (Ni), and to assess the hazard quotient and target hazard quotient of the Ni via the foodstuff for the local farmers in the Industrial Estate of District Swabi. A variety of heavy metals are present in wastewater, by extensive uses of contaminated wastewater as source of irrigation for cereals and vegetables accumulate toxic metals (Adhikari, Manna, Singh, & Wanjari, 2004). These heavy metals easily enter the food chain because the removal of these toxic metals from the water and soil is very difficult (Wilson & Pyatt, 2007). The target hazard quotients (THQs) and hazard index (HI) were calculated to assess non-carcinogenic health effects from individual and combined heavy metals because of daily foodstuff consumption.

Material and Methods

Study site

The Gadoon Amazai Industrial Estate (GAIE) is in district Swabi, Khyber Pakhtunkhwa, and is 325 meters elevated above the sea level, bounded north, east, west and south by Baisak, Maini, Gandaf, and Topi. GAIE contains a total of 330 active units and was established in 1986-1987(Khan, Ahmad, Shah, Rehman, & Khaliq, 2009). The main active units in the industrial state are steel, marble, textiles, chemicals, soap and soap, plastic, and ghee and cooking oil (Khan, Ahmad, Shah, Rehman, & Khaliq, 2009).

Inclusion Criteria and sample size

All those farmers having farms within 2 kilometers from industrial estate were orientated about the study. A total of 22 farmers were randomly selected and data were collected from the agreed farmers.

Anthropometric Assessment:

Farmer’s body weight and height were assessed through WHO standard methods. Weight was measured through digital scale, while weighing, the farmers were asked to remover heavy clothes, shoes and all un-necessary things. The height of farmers were measured through studio-meter. BMI was calculated through the height and weight data.

Sampling and pre-treatment

The study area was divided into 4 directions (North, South, West and East) from the mid-point. The samples of water, soil, crops, vegetables (Potato, Garlic) Milk, and Urine were selected for the study. Water of both the irrigation and drinking purpose were collected, for drinking purpose water from different sources (Tube-well, hand-pump, Open-well and tape water) were used in the Industrial estate. The farmers use two types of water for irrigation of fields 1) Industrial wastewater and 2) Tube-well water. The water samples and milk of animals were directly collected in polythene bottles, all the bottles were washed with acidify water and dried, the morning urine samples were collected with the addition of 2 drops of HCL to reduce the decomposition of urine by bringing its PH to below 4. The crops samples which were grown in the industrial area were collected in polythene bags, labelled, and brought in ice-cold boxes to the Department of Human Nutrition, The University of Agriculture Peshawar for further analysis. In the laboratory the vegetable samples were thoroughly washed firstly by ordinary tape water followed by distilled water to eliminate soil and air burn pollutant. Edible portion of vegetables samples were cut into pieces and placed in oven for 48 hours at 80^0 C to completely dry. After the heating the samples were kept overnight to cool down to room temperature. Each sample was ground to fine powder and stored for further chemical treatment.

Digestion and treatment

All the required glassware was first washed with standard detergent followed by tap water, soaked in an acid bath (10% HCL) and placed in oven to dry. I gm of sample was taken into the digestive tube, 12 ml concentrated nitric acid was added to the tubes and kept overnight. The next day 4 ml of perchloric acid was added and placed in heat-block, gradually increased the temperature from 80^0 C until a white fume started AOAC, 2000 (Cuniff, 2003). After heating the solution was cooled down at room temperature filtered in 50 ml volumetric flask, diluted by distilled water up to the mark (50 ml). The powdered soil was treated with solutions of HNo_3, perchloric acid and sulphuric acid with a 4:1:1, samples were filtered using Whatman No.42 filter paper to eliminate suspended substances. Prepared samples were stored in the clean bottle prior analysis (Shakya & Khwaounjoo, 2013). Atomic absorption spectrophotometer was used as standard method of AOAC 2000(Cuniff, 2003) for the determination of nickel in the samples.

Health Risk Assessment:

The health risk from the consumption of contaminated food was calculated by the following quotient hazards equation (Huang, Zhou, Sun, & Zhao, 2008) (Muhammad, Ullah, & Jadoon, 2019).

$$HQ = \frac{CDI}{RfDo}$$

$$CDI = \frac{CF \times IR \times EF \times ED}{BW \times AT}$$

Where CDI is the chronic daily intake of metal from food expressed in mg kg^{-1} day^{-1}, RfDo is the oral reference dose (in mg kg^{-1} day^{-1}). CF is the concentration of metal in plants, IR is the ingestion rate, EF is the exposure frequency (365 days per year), ED is the exposure duration, BW is the body weight and AT is the averaging exposure time(364×ED). The RfDo values for Ni was 0.02 mg/kg according to US-EPA. If the HQ values exceed the unity, there will be potential effect to the body.

Daily Intake of Metal:

The daily intake of metals (DIM) from the food sources was calculated by the following equation (Bi, Zhou, Chen, Jia, & Bao, 2018) (Orisakwe, Nduka, Amadi, Dike, & Bede, 2012).

$$DIM = \frac{C\text{fveg} \times \text{Wveg}}{BW}$$

Where Cveg is the concentration of metal in in vegetables or food (mg/kg), Wveg (mg/day) is the ingestion rate of food contaminated by particular metal and BW is the Body weight (kg)

Bio-accumulation Factor:

The bio-accumulation factor also known as transfer factor, which is the transfer of heavy metals from the soil to the crops grown in an area. The bio accumulation factors is an index reflecting the ability of a plant species to accumulate a particular metal regards to its concentration in the soil (Galal & Shehata, 2015; Ghosh & Singh, 2005) It is calculated as the metal concentration in the plants (dried weight basis) divided by the concentration of that particular metal in the soil on which it grows (Cui, Zhu, Zhai, Chen, Huang, Qiu, et al., 2004; Liu, Zhao, Ouyang, Söderlund, & Liu, 2005), (Ahmad, Khan, Ashfaq, Ashraf, & Yasmin, 2014), (Muhammad, Ullah, & Jadoon, 2019).

$$TF = \frac{CP}{CS}$$

Where CP is the concentration of metal in plants and CS is the concentration of metal in the soil. The bio-accumulation shows the bio-availability of metals and nutrients to the plants.

Health Risk Assessment:

The health risk from the consumption of contaminated food was calculated by the following quotient hazards equation (Huang, Zhou, Sun, & Zhao, 2008) (Muhammad, Ullah, & Jadoon, 2019).

$$HQ = \frac{CDI}{RfDo}$$

$$CDI = \frac{CF \times IR \times EF \times ED}{BW \times AT}$$

Where CDI is the chronic daily intake of metal from food expressed in mg kg^{-1} day^{-1}, RfDo is the oral reference dose (in mg kg^{-1} day^{-1}). CF is the concentration of metal in plants, IR is the ingestion rate, EF is the exposure frequency (365 days per year), ED is the exposure duration, BW is the body weight and AT is the averaging exposure time(364×ED). The RfDo values for the Ni is 0.02 mg/kg according to US-EPA. If the HQ values exceed the unity, there will be potential effect to the body.

Results and discussion

The body mass index (BMI) gives the best gauge for estimate of the nutritional status of the farmers, As the farmers characterize an occupational group which required heavy amount of physical activity for their field work in farm. Because of this heavy workload the farmers might tend to decrease risk for development of overnutrition. The farmers use tube well water for irrigation purposes had BMI within normal range (18.5-24.9 kg/m^2) as compared to farmers uses wastewater for irrigation as shown in table 1. Different studies reported different obesity status of farmers in different countries like in Australia only 15.2% of the farmers reported to overweight (Dorner, Leitner, Stadlmann, Fischer, Neidhart, Lawrence, et al., 2004) and in Greece 86.1% of the farmers reported to overweight (Vardavas, Linardakis, Hatzis, Saris, & Kafatos, 2009).

Table 1. Anthropometric, Socio-demographic features of the farmers

Variables		Tube Well Mean±SD/Frequency (%)	Wastewater Mean±SD/Frequency (%)
Age (Years)		43.50±21.01	44.75±16.44
Weight (kg)		61±12.5	64.75±9.63
Height (cm)		167.5±3.9	165.8±6.02
BMI (kg/m$^{2)}$		21.61±3.73	23.7±4.4
Household size		8.25±1.3	7.25±1.5
Area of Farming (kanals)		62.5±28.7	42.00±33.9
Living since (Years)		8.25±6.0	11.25±6.1
Educational Level	Illiterate	70%	50%
	Literate	30%	50%

The farmers living in the study location were not of permanent resident that's why the mean time of residency for both the categories of farmers were 8.25±6.0 and 11.25±6.1 years. Education is positively related to the production of farmers the literacy rate of farmers in the study location was very low. Because of poverty and workload in the field, the farmers are unable to enroll their children for education. The literacy rate of farmers in underdeveloped and developing countries remain the lowest as reported in Odisha (Das & Sahoo, 2012). In south Nigeria about 33.8% of the farmers were reported uneducated (Fabunmi, Aba, & Odunaiya, 2005).

The industries effluents were fallen directly to nearest small canal of water, theses small canals were then used for the irrigation purposes, so the waste from the industries were transferred through canals water to the farming land. The study area was divided in to four directions (North, East, West and South) from the mid-point to estimate the Ni in all the industries effluents in irrigation water.

Figure 1 shows the Nickel concentration in the irrigation water sources in the GAIE. The wastewater used for irrigation purposes had significantly high concentration of nickel compared to the tube-well irrigated water. The highest mean of 3.87 ppm nickel was present in the North side followed by East 3.57 ppm, West 2.19 ppm and South 1.87 ppm in the wastewater sources for irrigation. No nickel was found in the East site in tube-well irrigation source. The nickel concentration in the waste-water irrigation crossed the permissible limit of 0.2 ppm set by the US Irrigation Water Quality standards, while in the tube-well irrigation water were in the safe limit for irrigation.

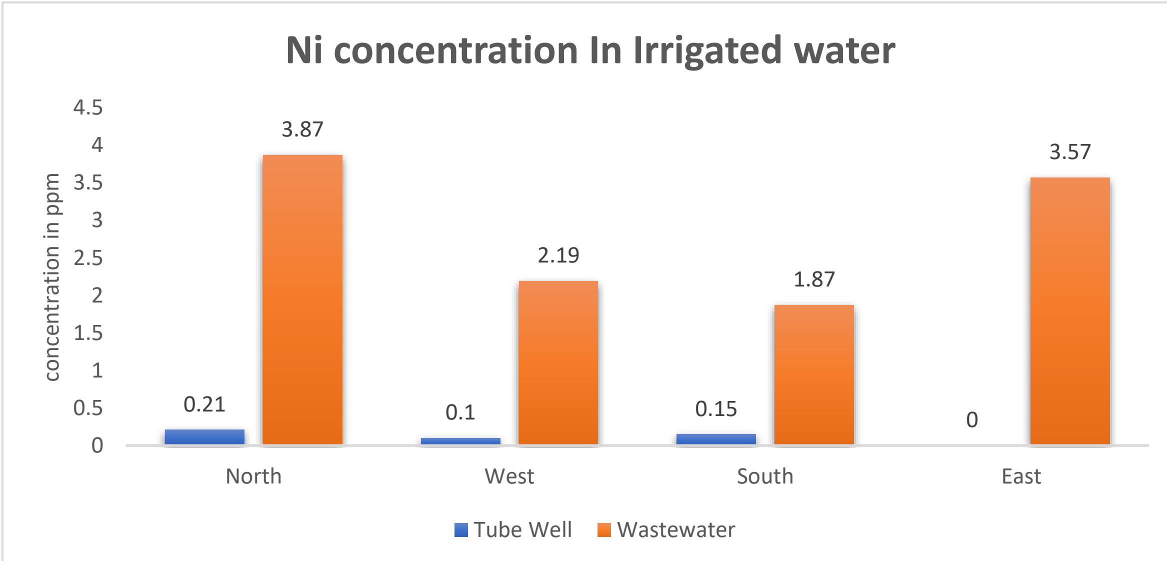

Figure 1. Nickel concentration in the irrigated water

This high amount of nickel was due to the nickel-cadmium batteries, steel and ghee and oil, kitchen appliances, surgical instruments and steel alloys industries in GAIE (Tariq, Ali, & Shah, 2006). These industries released a vast amount of nickel to the environment. Industrial activities such as mining, electroplating, and manufacturing of essential commodities produce a huge volume of wastewater as effluents containing heavy metals and other toxicants, which deteriorate the quality of aquatic system (S. Abbas, Sarfraz, Mehdi, & Hassan, 2007), (Bose & Bhattacharyya, 2008). In the study area, drinking water was consumed from the four types of sources, from tube-well, tape water hand pump and well-water in the home.

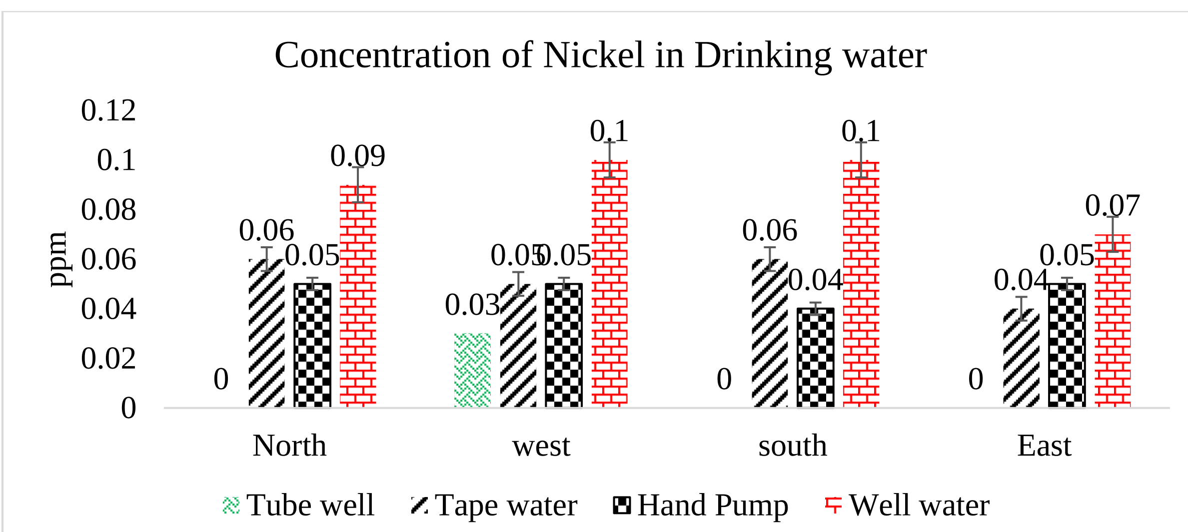

Figure 2. Nickel concentration in the Drinking water

Figure 2 shows the concentration of nickel in the drinking water sources used in the Industrial zone of GAIE. The results showed the Ni concentrations was significantly higher in the open well-water used for drinking. The Ni concentration in tube-well and hand pump drinking sources was found within the safe limit of 0.05 ppm set by the Pakistan National Standard for Drinking water (NSDWQ-Pak). The highest concentration of Ni contamination was found in the Well-water in West and South site of 0.1 ppm, while 0.09 ppm and 0.07 ppm in North and East site. No nickel was detected in the tube-water in the East, South and North regions (detection limit for nickel is 0.02). The highest concentration in the tap-water was recorded in the North and South region of 0.06 ppm followed by West and East of 0.05 ppm and 0.05 ppm respectively. Compared with concentration of Ni of 0.037 ppm in Karachi (Karim, 2011) the current concentration was higher.

Table 2 illustrate the nickel concertation in the soil, wheat, maize, potato, garlic and fodder grass gown in the industrial estate by the waste-water irrigation. The mean concentration of nickel in all the vegetables, soil and milk samples in waste-water irrigation was significantly higher than in the tube-well irrigation. The nickel concentration in soil samples irrigated by tube-well and wastewater was measured as 54.25±10.14 mg/kg and 123.50±54.74 mg/kg. In the tube-well irrigated wheat the Ni concentration was in range from 0.93 to 1.2 mg with a mean of 1.05±0.13 mg compared to the wastewater irrigated wheat of range from 6.14 mg to 8.93 mg. Whereas the mean concentration of Ni in the maize was recorded as 1.02±0.39 mg in the tube-well irrigated compared with the wastewater irritated of 6.31±0.76mg.

Table 2. Concentration of Nickel in Food, grown in the industrial estate irrigated through Tube Well and Industries-wastewater

Variables	Tube Well Source	Wastewater Source	p-value
Soil	54.25±10.14	123.50±54.74	.047
Wheat	1.05±0.13	7.56±1.24	.001*
Maize	1.02±0.39	6.31±0.76	.004*
Potato	1.08±0.35	7.70±1.04	.002*
Garlic	0.97±0.25	9.15±0.50	.003*
Fodder	0.64±0.42	8.82±1.30	0.00**

*Significant difference observed at $p< 0.05$ ** Significant difference observed at $p< 0.01$

Among all the food sources in the waste-water irrigation, the highest mean value of Ni was recorded in the garlic 9.15±0.50mg, while in the tube-well sources was recorded in the potato samples of 1.08±0.35mg. The Ni mean concentration in the wastewater irrigated potato was 7.70±1.04 mg while in the tube-well irrigated was 1.08±0.35 mg. The average value in the fodder grass was recorded as 8.82±1.30 mg in the water-water irrigation compared to tube-well irrigation of 0.64±0.42 mg.

The results of this study is resembles with the finding of (Hussain, Khattak, Shah, & Ali, 2015) who studies the contamination of soils by the industrial effluents, and resulted that the mean concentration of nickel in the waste-water soil was 119.8mg. compared with the reference or tube-well irrigated soil which was 58.8mg. The highest concentration in the industrial waste-water was due to the stainless steel, alloys industries, which direct expelled their waste to the environment without any treatment. A study (Al-Othman, Ali, Al-Othman, Ali, & Habila, 2016) reported that the mean nickel concentration in the wheat grains grown by tube-well water in district Swabi was 0.087mg lower than the finding of this study. The average concentration of Ni in the wheat and maize irrigated with un-polluted water was 0.04±0.01mg and 0.11±0.01mg, significantly lower than that of the crops grown with the polluted water which was 0.1±0.01 mg in wheat and o.10±0.01mg in maize. The soil contamination with toxic metals and pathogens was due to the long term irrigation with waste-water (Farahat & Linderholm, 2013). The extractable concentration of nickel in the present study was lower than the soil irrigated by canal water and waste-water of Hyderabad city in southern Pakistan (Jamali, Kazi, Arain, Afridi, Jalbani, & Memon, 2007). Nickel is utilized in certain industrial applications and can be a potential contaminant in food products. Ni is also an essential element for human health but may become toxic above certain levels. There is currently no published permissible limit of Ni in milk; however, researchers still maintain a focus on Ni contamination in milk due to its potential for negative health impacts (Ismail, Riaz, Akhtar, Goodwill, & Sun, 2019) and the concentration of nickel in milk was found in the range of 0.0070-2.631mg/l.

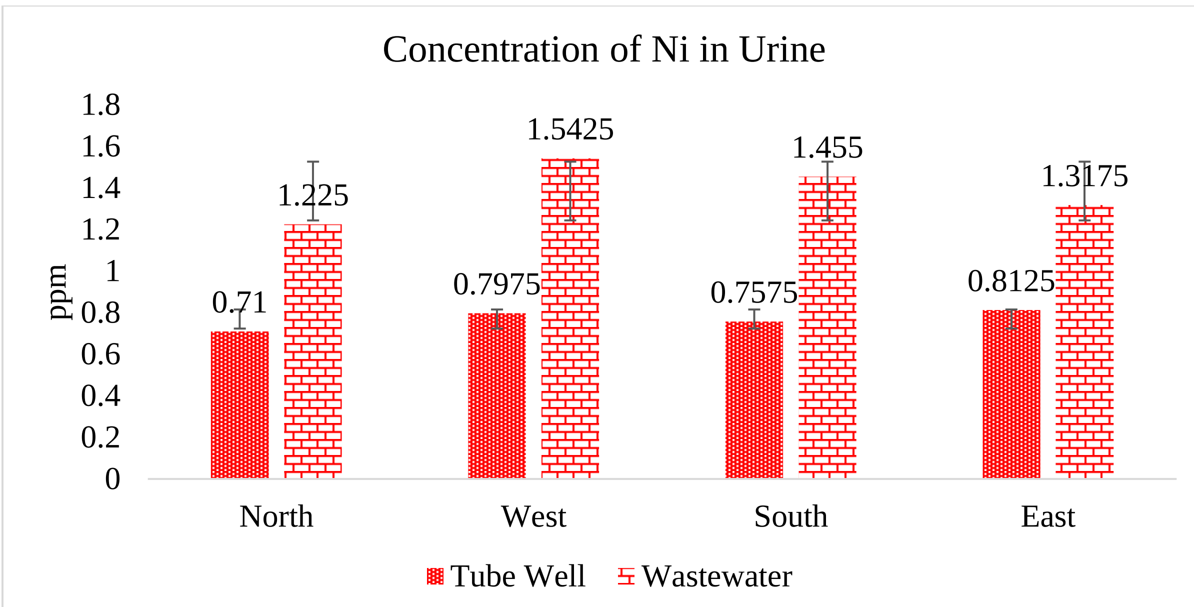

Figure 3. Nickel Concentration in Urine

Figure 3 shows the Ni concentration in the urine of farmers using food from wastewater irrigated land and tube-well irrigated land. The waste-water farmers urine showed significantly high concentration of nickel compared to the farmers urine using tube-well water for irrigation. The highest concentration of 1.5 ppm was observed in the farmers urine of West side to industries, while the lowest was recorded in the North side farmers, who were using wastewater for the irrigation purposes. While in the farmers who was using tube-well water for irrigation, the highest mean concentration 0.81 ppm of nickel was recorded in the farmers urine to the East side to industries, followed by the West, South and North. According to the Korea National survey for environmental pollutants in the human body 2018, and heavy metals in the blood and urine of the Korean population (Lee, Lee, Moon, Choi, Lee, Yi, et al., 2012) reported that the high level of heavy metals in the urine and blood was due to the high intake of contaminated foods, the level of toxic metals in urine was strongly related to its oral intake.

The bio-accumulation and transfer factor is used to estimate the plants potential to attract the particular metal or nutrients from the soil through roots (Farahat & Linderholm, 2015) (Galal & Farahat, 2015). Table 4.3 shows the bio-concentrations factors of Ni for crop-soil system. The crops grown on Wastewater possess higher accumulation factors compared with crops grown on tube-well water.

Table 3. Nickel content for tube well and wastewater for different crops

Crops	Nickel	
	Tube well	Wastewater
Wheat	0.021±0.006	0.050±0.014
Maize	0.021±0.012	0.042±0.012
Potato	0.022±0.011	0.051±0.013
Garlic	0.020±0.008	0.033±0.011
Fodder grass	0.014±0.011	0.057±0.10

Table 4. Correlation between Soil and Crops

Soil crops	Ni
Soil-Wheat	.807*
Soil-maize	.771*
Soil-potato	.813*
Soil-garlic	.725*
Soil-Fodder	.802*
Fodder-Milk	.987**

* Correlation is significant at the 0.05 * Correlation is significant at the 0.01

Table 4 shows the Pearson correlation among the soil and crops, soil and fodder and fodder to milk was determined to check the route of the nickel from soil to crop, fodder and from fodder to milk. It was found that a strong correlation (significant at 0.05) was found for nickel.

Health risk is defined as the quotient between the estimated to daily metal intake from the soil through food chain and oral reference dose for each metal. An index under the value 1 assumed as safe. The hazard quotient from nickel is presented in figure 4.

The HQ value for nickel exceed the unity in the food grown by waste-water irrigation water and pose adverse health effect to farmers health as shown in figure 4.4. All the foods grow with tube-well water pose no health effect from nickel.

The present study resemble with the study (Qin, Zou, & Qiu, 2008) stated that the health risk of chromium was less compared to nickel because of the high RfDo value of 1.5mg/day. They calculated the health risk of the heavy metals to the general public of Guangzhou China. There result showed the HQ value for chromium in the safe limit of below the unity.

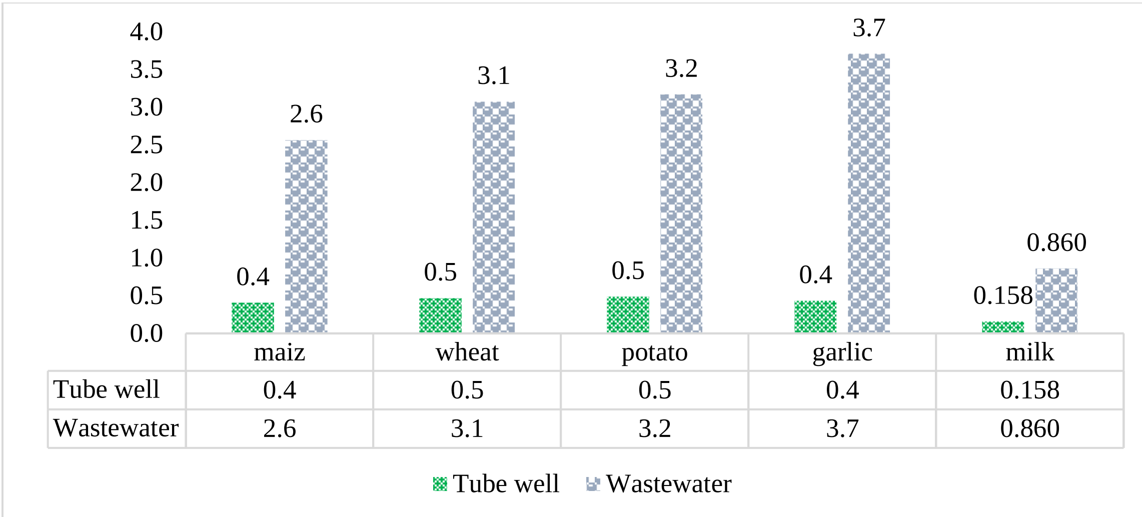

Figure 4 . Hazard Quotient for Nickel

Conclusion

The wastewater from the industries in the Gadoon Amazai Industrial Estate (GAIE) contained significant amount of nickel. Soil, vegetables, cereals and fodder for cattle from the agriculture land irrigated through wastewater from GAIE contained significant amount of nickel. Food consumption had been identified as the major pathway of human exposure to heavy metals. Farmers of GAIE area shows significant amount of nickel in their Urine. The health risk assessment indicates that the farmers of GAIE were at high risk of nickel toxicity.

Declaration

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REVIEW ARTICLE

A review of agroforestry as a sustainable and resilient agriculture

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Abstract

The agricultural sector is confronted with the formidable challenge of providing sustenance for a global population of 9 billion individuals by the year 2050, all the while mitigating adverse ecological and societal impacts. An attempt to address this difficulty has been made through the implementation of organic farming practices, which have yielded predominantly favorable results. Nevertheless, there are still certain obstacles that need to be addressed. Organic agricultural practices exhibit lower yields compared to conventional methods, while concerns persist regarding greenhouse gas emissions and fertilizer leaching. This paper provides an overview of existing organic and conventional agriculture systems and proposes that agroforestry, a deliberate integration of trees and shrubs with crops or livestock, may represent a promising avenue for advancing sustainable agriculture. Agroforestry possesses the capacity to sustain productivity and concurrently provide many ecosystem services through the use of nature-inspired methods. This study presents an overview of the prevalent methods and products associated with agroforestry, while also highlighting the positive environmental and social impacts it brings about. The present study aims to examine the obstacles encountered in the implementation of agroforestry practices and to suggest potential strategies for policy modification that could enhance the uptake of such practices among farmers. The findings of this review study indicate that agroforestry emerges as a very effective land use strategy for addressing both food security and environmental degradation concerns.

Keywords: Agroforestry; Organic agriculture; Land use; Agroecology; Food security; Environmental sustainability

Introduction

The field of agriculture exerts a significant influence on the Earth's ecosystem (Bishaw et al., 2022; Raihan, 2023a). According to Ahmed and Ambinakudige (2023), around 38% of the Earth's land surface is allocated for agricultural purposes, rendering it the most significant anthropogenic land utilization. The primary driver of deforestation and the subsequent loss of native habitats is the expansion of agricultural land (Begum et al., 2020; Jayathilake et al., 2021). This phenomenon has resulted in the collapse of various wildlife populations, including avian, insect, and mammalian species, some of which are currently classified as endangered (Shah et al., 2022). The process of nutrient leaching from fertilizer contributes to the phenomenon of eutrophication in water bodies, hence causing the formation of oxygen-depleted areas known as "dead zones" in various aquatic environments globally (Zahoor & Mushtaq, 2023). Agriculture stands as the primary anthropogenic source of greenhouse gas emissions, which have been linked to climate change. The impacts of these repercussions are not exclusive to the human population.

Derouiche et al. (2023) have observed the presence of detectable levels of pesticides in several habitats, including the human body. The economic burden of pesticide poisoning in the United States has been approximated to be $1.2 billion annually (Donley, 2019). Additionally, the presence of excessive nitrate in drinking water resulting from over-fertilization can lead to health issues and necessitate costly remediation efforts (Zahoor & Mushtaq, 2023). In addition to the potential environmental and societal consequences, the resilience of our agricultural systems is also a matter of concern (Dipu et al., 2022; Raihan & Tuspekova, 2022a). According to Xu et al. (2022), a mere fifteen crops are responsible for generating 90% of the global food calorie supply. Among these crops, wheat, rice, and maize alone contribute to 60% of the total food calories. The cultivation of the majority of these crops predominantly occurs in expansive areas characterized by yearly monocultures, hence posing a significant susceptibility to pest and disease outbreaks (Khatri et al., 2023). The Irish potato famine, which occurred from 1845 to 1850, resulted in the loss of more than one million lives. This historical event serves as a poignant illustration of the consequences that might arise when a singular crop, upon which a population substantially depends, is devastated by disease (Read, 2022). Monocultures necessitate annual replanting, substantial resource inputs, and weed management (Zhang et al., 2023). It has been posited that this repetitive pattern of planting, fertilizing, and spraying primarily benefits major agribusiness corporations that provide the necessary inputs, rather than effectively addressing global food security objectives (Gerhardt et al., 2022). In order to ensure the enduring viability of an agricultural system, it is imperative that the soil maintains its productivity and that the essential inputs remain accessible in subsequent periods (Paul et al., 2023). Nevertheless, it is important to note that in numerous agricultural settings, the rate of soil loss surpasses that of soil formation, leading to a deterioration in the quality of the remaining soil (La et al., 2023). The agricultural sector is vulnerable to variations in fuel pricing and supplies due to its significant dependence on fossil fuels, particularly in the form of liquid fuel and fertilizer (Majeed et al., 2023; Raihan, 2023b). Simultaneously, the unidirectional flow of fertilizer nutrients contributes to both pollution and scarcity. Phosphorus serves as a pertinent illustration in this context. This indispensable nutrient for plants is projected to undergo a rise in mining and processing costs. Concurrently, the discharge of phosphorus into water bodies contributes to the phenomenon of eutrophication (Mancho et al., 2023).

In the foreseeable future, it is anticipated that our agricultural systems will need to undergo adjustments in response to a shifting climate, characterized by an augmented occurrence of severe weather phenomena such as droughts and floods (Brick et al., 2022; Raihan, 2024a). Furthermore, there is an expected rise in the prevalence of diseases and pests affecting agricultural production (Balasundram et al., 2023). The impact of climate change is expected to be more pronounced in developing regions due to socioeconomic factors such as poverty, which might impede individuals' capacity to effectively respond and adapt (Bedeke, 2023; Raihan, 2023c). The Dust Bowl phenomenon that occurred during the 1930s serves as an illustrative case of the detrimental outcomes resulting from unsustainable farming methods in conjunction with an unprecedented period of severe aridity (Yuan et al., 2023). The collapse of civilizations, such as the ancient Mesopotamians and the Mayans, can be attributed to agricultural overreach and the failure to effectively respond to climate change. The agricultural sector is confronted with the formidable challenge of providing sustenance to a global population of 9 billion individuals by the year 2050, all the while mitigating detrimental impacts on the environment and society (Wijerathna-Yapa & Pathirana, 2022; Raihan, 2023d). Hence, the primary objective of this study is to critically examine the existing organic and conventional agricultural systems, while proposing agroforestry as a potential advancement towards achieving sustainable agriculture. Agroforestry possesses the capacity to sustain productivity and concurrently provides many ecosystem services through the use of systems that imitate the activities observed in nature. This study provides an overview of the prevalent methods and products associated with agroforestry, while also highlighting the positive environmental and social impacts that result from its implementation. This study additionally examines the obstacles encountered in the implementation of agroforestry practices and investigates potential strategies for modifying policies to enhance farmer engagement and uptake. This review study could provide valuable insights for the development of agricultural and environmental policies aimed at promoting food security through effective land use management, while also mitigating environmental degradation and the adverse effects of climate change.

Methodology

The objective of this study is to assess the potential impact of agroforestry on global sustainability, with a specific focus on ensuring food security and improving environmental quality. The present study employed the systematic literature review methodology as suggested by Tawfik et al. (2019). The systematic literature review framework is considered to be a dependable approach (Benita, 2021; Raihan & Bijoy, 2023; Raihan & Himu, 2023; Raihan, 2023e; 2023f; 2023g). A preliminary review of the literature was conducted to identify pertinent articles, validate the proposed idea, avoid redundancy with previously covered issues, and ensure the availability of sufficient articles for conducting a comprehensive analysis of the subject matter. Moreover, the focal point of the themes should revolve around the inquiries on the significance of agroforestry in ensuring food security and improving environmental quality. According to Tawfik et al. (2019), it is crucial to enhance the retrieval of results by acquiring a comprehensive understanding and familiarity with the study topic through the examination of pertinent materials and active engagement in relevant debates. This objective can be achieved by conducting a thorough examination of pertinent literature and actively participating in pertinent academic conversations.

The present study examined various strategies aimed at mitigating the influence of prejudice. One of the methods employed was performing a systematic manual search to identify any document that might have been missed during the original search process. This investigation, employing the methodology employed by Vassar et al. (2016), discovered no discernible indications of bias. In the context of this investigation, a comprehensive set of strategies was employed to carry out manual searches. The method employed encompassed many strategies, such as conducting an exhaustive literature search to identify relevant references from the studies and reviews under consideration. Furthermore, supplementary materials, including related papers and articles cited within reputable academic databases such as Google Scholar, Scopus, and Web of Science, were thoroughly examined. The manual search results were initially enhanced and polished through the process of examining the reference lists of the included publications. The initial stage of the process was undertaken. Subsequently, the author engaged in the practice of citation tracking, a method involving the systematic monitoring of all the scholarly works that reference each of the papers incorporated in the collection. In conjunction with the manual search, an online search of databases was also undertaken as an integral component of the comprehensive search process.

This study exclusively relied on research articles published in peer-reviewed journals, ensuring the reliability and validity of the findings. The results of this study serve as a valuable basis for future research endeavors that aim to explore the potential impact of agroforestry on achieving sustainability, with a specific focus on ensuring food security and improving environmental quality. Both qualitative and quantitative secondary literature on agroforestry were considered. The publications were thereafter evaluated to ascertain whether their main subject matter bore a resemblance to that of the present inquiry. Priority consideration was given to papers published after the year 2000. The primary justifications for the elimination of papers are their lack of relevance, duplication, incomplete textual content, or limited presence of abstracts. The predetermined exclusion criteria were established to safeguard the researcher against potential biases that could influence their findings. Figure 1 illustrates the progression of review criteria employed for the selection of suitable documents for review analysis.

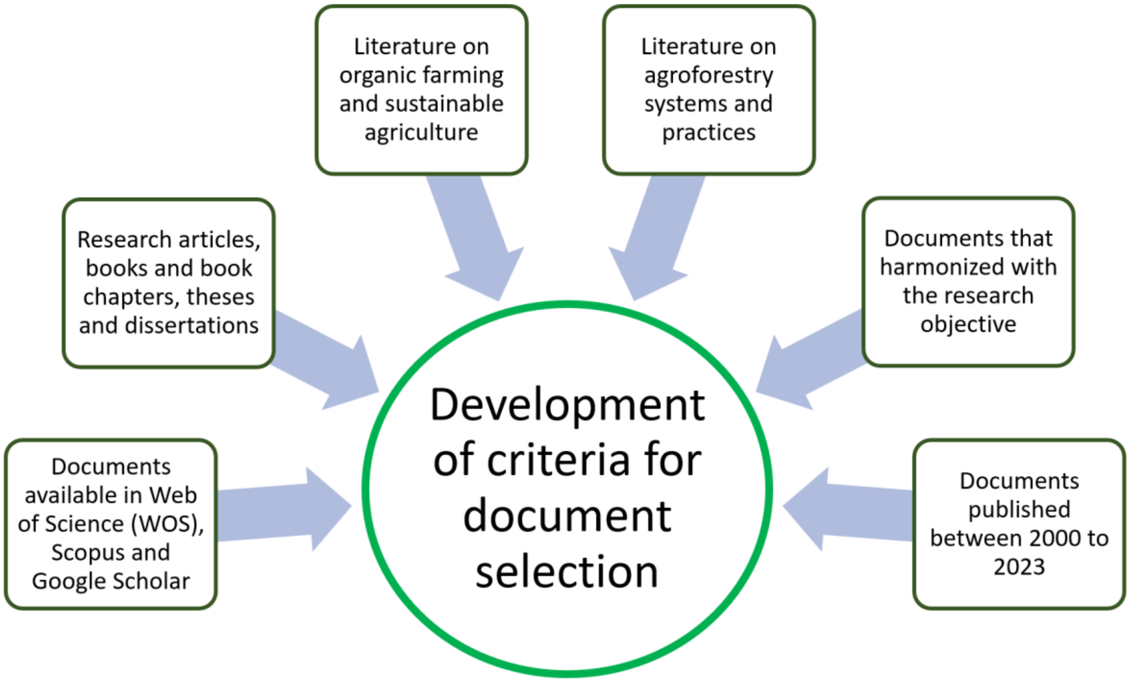

Figure 1. The development of criteria for the selection of documents.

The initial search with the keywords led to 4463 documents. After scanning the documents based on the selection criteria and to remove possible duplication, 512 articles were selected for the next step of scanning. After screening those article's titles and abstracts, the comprehensive literature review encompassed a total of 146 distinct scholarly articles. The present study implemented a data verification process, wherein each included article was cross-checked with its corresponding entry in an extract sheet using visual evidence. It is noteworthy to mention that of the 146 papers subjected to qualitative synthesis, only those publications containing relevant material were cited in the reference list contained in the manuscript. This implies that certain articles were not included in the reference list. Figure 2 illustrates the systematic review procedure utilized in the current study. After the research topic was chosen, this study proceeded to find and locate relevant articles, do an analysis and synthesis of diverse literature sources, and create written materials for article review. The synthesis phase encompassed the collection of a wide range of publications, which were subsequently amalgamated into conceptual or empirical analyses that were relevant to the finalized research.

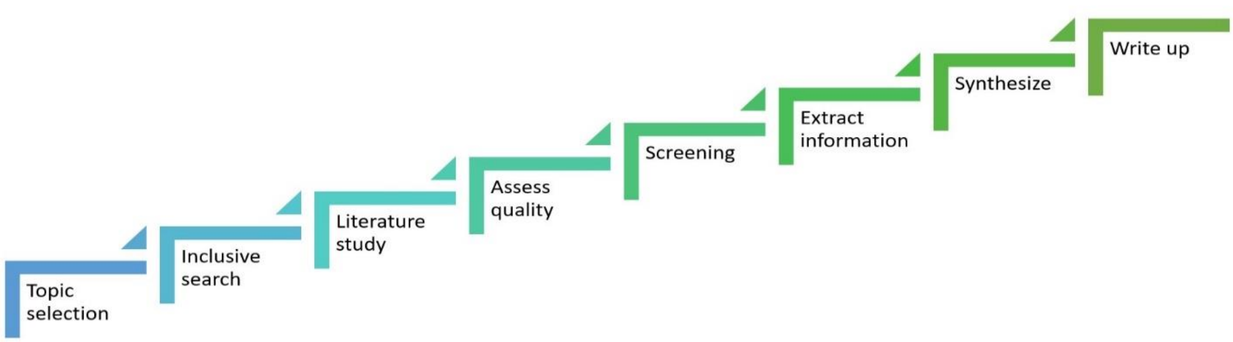

Figure 2. The procedure of systematic review conducted by the study.

Organic Farming and Associated Challenges

The emergence of organic agriculture can be attributed to its role as a viable alternative to the prevailing conventional farming paradigm. While there may be subtle variations across countries and certification agencies, the primary principles governing organic management generally entail the prohibition of synthetic pesticides and fertilizers, genetically modified organisms (GMOs), and the preventive application of antibiotics in cattle feed (Mie et al., 2017). In order to preserve soil quality, it is imperative to employ a range of strategies, including but not limited to crop rotation, cover cropping, and mulching (Crystal-Ornelas et al., 2021). According to Davis et al. (2022), animals that are managed under organic practices are required to consume feed that has been certified as organic. Additionally, ruminant animals must be provided with a designated amount of time to access pasture. The maintenance of fertility in agricultural systems is commonly achieved by the utilization of leguminous cover crops, the application of organic materials like manure and compost, the use of biologically generated inputs such as blood and feather meal, and the incorporation of mined mineral compounds (Tei et al., 2020).

The management of weeds in organic grain and vegetable systems typically involves the utilization of tillage as a primary control method. However, it is worth noting that cover cropping and crop rotation also hold significant importance in disrupting weed cycles (Pantović & Sečanski, 2023). The management of pests involves the implementation of strategies such as the provision of suitable habitats for advantageous predators, the careful selection of plant stock that exhibits resistance, and the utilization of biologically produced pesticides as a final recourse, if necessary (Monteiro & Santos, 2022). The implementation of organic production standards typically results in better sustainable outcomes in practical applications (Raihan et al., 2023a). According to Beaumelle et al. (2023), organic farms have been found to support greater levels of biodiversity compared to conventional farms. This enhanced biodiversity encompasses various organisms such as insects, plants, soil biota, as well as avian and larger animal species. According to Pergner and Lippert (2023), organic farms frequently exhibit greater diversity in their cropping systems as a result of including livestock and implementing longer crop rotations. According to Monteiro and Santos (2022), the implementation of mechanical and cultural control strategies in managing weeds and pests can result in residual populations at reduced levels, hence promoting biodiversity. According to Prout et al. (2021), the implementation of organic management practices has been observed to enhance soil quality, as indicated by measures of soil organic matter. However, it is worth mentioning that several studies have reported the highest levels of soil quality in the context of no-till conventional agriculture (Montgomery et al., 2022). While conventional farming often outperforms organic farming in terms of yields, research has demonstrated that in drought years, the situation can be reversed. This phenomenon is related to the superior water retention capabilities of soils managed under organic practices (Martín-Lammerding et al., 2021). In general, organic production demonstrates a lower energy consumption per production unit as a result of the elevated energy expenditures associated with conventional fertilizers and pesticides (Mousavi et al., 2023).

It is important to acknowledge that while organic certification imposes strict criteria for the application of pesticides, synthetic fertilizers, and GMO technologies, both conventional and organic growers have access to a diverse range of techniques that can yield positive environmental results. Cover cropping, integrated pest management, the application of manure and composts to enhance soil organic matter, crop rotation, and the integration of livestock and crops are crucial strategies that warrant careful consideration when assessing their benefits. Several studies have examined the comparison between organic and conventional crop systems and have found that the observed enhancements in organic management can be attributed to specific practices such as the application of manure and the implementation of cover cropping. These practices, which are integral to the organic system, have the potential to yield similar benefits if adopted in a conventional system (Scavo et al., 2022; Chinthalapudi et al., 2023). Figure 3 illustrates the fundamental concepts and resultant impacts of organic farming.

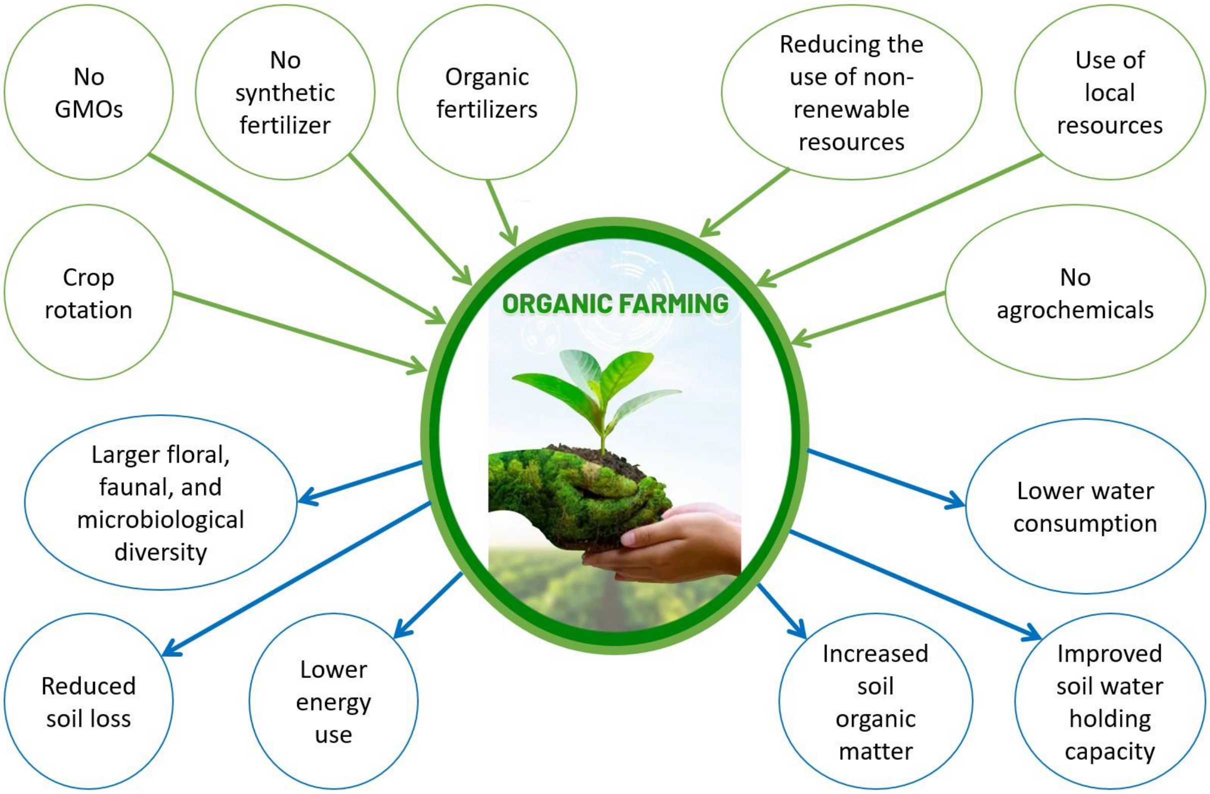

Figure 3. The fundamental concepts and resultant impacts of organic farming.

Nevertheless, despite the commendable goals underlying organic certification methods, it is worth mentioning that a significant number of organic crop production systems employ similar fundamental methodologies as conventional farming, hence potentially resulting in comparable adverse outcomes (Telwala, 2023). The practice of producing annual monocultures, which necessitates annual replanting, the use of fertilizers, rigorous weed management, and the employment of mechanical equipment, has exhibited limited alteration, particularly when implemented on a broader scale beyond local market gardens (Feng et al., 2022). The substitution of conventional instruments with less detrimental alternatives is evident in the adoption of organic seeds in place of genetically modified organism (GMO) seeds, the utilization of cultivation or mulch as alternatives to pesticides for weed management, and the implementation of cover crops and manure as substitutes for fertilizers derived from fossil fuels (Caporali, 2021). While these modifications have the potential to reduce environmental impacts, it is important to note that complete elimination of such problems may not be achievable.

The phenomenon of nitrogen leaching serves as a pertinent illustration of environmental consequences that are not completely eradicated. While several studies indicate a potential reduction in nitrate leaching when employing organic management practices, it is important to note that the resulting quantities of nitrate may still provide a risk of contributing to groundwater pollution. Pimentel and Burgess (2014) conducted a comparison of three different rotations that varied in terms of nitrogen sources. These rotations included an organic rotation that incorporated legume cover crops, an organic rotation that utilized animal manures, and a conventional rotation that relied on synthetic fertilizers. The researchers discovered that the leachate samples from all three treatments occasionally surpassed the regulation threshold of 10 ppm for nitrate concentration in potable water. According to Pimentel and Burgess (2014), the nitrogen given to the crops in the form of nitrate experienced a reduction of 20% in the organic animal rotation, 32% in the organic legume rotation, and 20% in the conventional rotation. The leaching of nitrogen from organic sources was found to be higher compared to that of conventional fertilizers. According to Valenzuela (2023), the application of manures and legume cover crops resulted in the highest nutrient release during periods of fallow or during times that did not align with the crop's nitrogen need.

While it is acknowledged that organic management can lead to an enhancement in soil quality compared to conventional management (Lin et al., 2023), it is important to note that the utilization of tillage for weed control and the incorporation of biomass from cover crops still pose hazards of soil loss and degradation (Francaviglia et al., 2023). The deleterious impacts of tillage, as demonstrated by Pearsons et al. (2023), encompass compaction, erosion, and a reduction in soil biological activity. According to the findings presented in the study conducted by Arnhold et al. (2014), research examining erosion rates in organic and conventional agricultural systems has yielded inconsistent outcomes, which can be attributed to factors such as the specific crop rotation, types of crops employed, and the methods of tillage employed. According to Arnhold et al. (2014), the study conducted by the authors in mountainous regions of Korea revealed that soil erosion rates, regardless of whether conventional or organic management practices were employed, were deemed excessive and unsustainable for long-term productivity. There has been a growing interest in the adoption of no-till techniques for organic farming due to the recognition of the advantages associated with minimizing tillage (Szczepanek et al., 2023). The typical procedure involves cultivating a cover crop before the primary cash crop, followed by mechanically crushing it and afterward planting through the resulting residue (Lamichhane et al., 2023). When executed accurately, the application of mulch effectively inhibits the growth of weeds, hence eliminating the necessity for cultivation in relation to the specific crop. Nevertheless, cultivating the requisite biomass in the cover crop to achieve efficient weed management might pose a formidable obstacle, and the feasibility of this approach may be constrained in arid regions where the cover crop competes for scarce water resources (Nosratti et al., 2023). Perennial weeds present a distinct challenge due to their inherent ability to penetrate and thrive within mulch layers (Ruch et al., 2023).

According to Gou et al. (2022), when considering the measurement of organic systems on a per-area basis, they may exhibit superior performance compared to conventional systems. However, it is important to account for the yield gap in organic systems, as this factor may contribute to higher emissions per unit of output. According to Jones et al. (2023), the rise in soil carbon levels in annual systems is accompanied by the emission of other gases, such as nitrous oxide, which counteract the potential benefits by contributing to climate change. The potential environmental ramifications of differences in yields between organic and conventional systems are also of significance. It is widely acknowledged in academic discourse that organic systems tend to exhibit lower productivity, typically resulting in a reduction in yield ranging from approximately 20% to 25%. However, scholarly literature indicates that this range can vary significantly, spanning from 5% to 50%, contingent upon factors such as the specific crop, soil conditions, level of management intensity, and the methodologies employed in the respective studies (Prairie et al., 2023; Santoni et al., 2023). Critics contend that the implementation of organic management practices would necessitate the allocation of additional land for agricultural purposes to ensure the sustenance of global food security. The consequences of this action would include deforestation and the subsequent loss of habitats, resulting in an adverse environmental outcome (Wijerathna-Yapa & Pathirana, 2022; Raihan & Tuspekova, 2022b). In light of the aforementioned issues inherent in the ongoing discourse between organic and conventional approaches, it appears prudent to explore alternative methodologies and strategies that could potentially offer viable resolutions. Rather than adopting a binary perspective when considering our agricultural landscapes, it may be more advantageous to embrace a mindset that incorporates both options, sometimes referred to as a "yes-and" approach. Numerous scholars have advocated for the use of a multidisciplinary and multifunctional framework in the design of agroecosystems, as evidenced by the works of Taylor and Lovell (2021), Thiesen et al. (2022), and Stokes et al. (2023). When considering the challenge of simultaneously providing sustenance to the global population and ensuring the long-term viability of the planet, Foley aptly asserts that a singular approach is inadequate for addressing all the associated issues. Consider the utilization of silver buckshot rather than relying solely on a silver bullet.

Agroforestry Systems

Agroforestry is a multifunctional method that involves the deliberate integration of trees and shrubs with crops or livestock within our food system. The sustainable agricultural technique of agroforestry has been acknowledged for around 50 years (Aryal et al., 2023). The integration of trees into the agricultural landscape is a concept that has existed since the inception of land cultivation. Agroforestry has been found to yield several advantageous results. These include the mitigation of nutrient and pesticide runoff, the sequestration of carbon, the enhancement of soil quality, the control of erosion, the improvement of wildlife habitat, the reduction of fossil fuel consumption, and the promotion of resilience in the context of an unpredictable agricultural future (Sollen-Norrlin et al., 2020; Temegne et al., 2021; Jinger et al., 2022). In summary, the incorporation of trees and other perennial vegetation into a landscape has the potential to alleviate the adverse impacts associated with agricultural practices. Agroforestry exhibits significant potential as a land use plan in both developed and developing regions due to its capacity to concurrently deliver economic, ecological, and cultural advantages (Telwala, 2023; Viñals et al., 2023). Furthermore, agroforestry has the capacity to provide a wide range of goods including timber, crops, fruits, nuts, mushrooms, forages, cattle, biomass, Christmas trees, and herbal medicine (Sollen-Norrlin et al., 2020). A comprehensive assortment of products in a portfolio would facilitate the distribution of revenue streams over different time horizons. These items encompass short-term options such as crops, pasture, livestock, mushrooms, and certain fruits like currants. Additionally, medium-term possibilities include nuts, fruits such as apples or persimmons, biomass, and medicinal plants. Lastly, long-term prospects involve lumber and the potential for increasing property value. The presence of a wide range of products can potentially mitigate risks for farmers while necessitating innovative marketing strategies (Jacquet et al., 2022; Raihan & Tuspekova, 2022c).

Various forms of agroforestry are implemented in different regions worldwide. The field of tropical agroforestry has historically received greater attention and has been more extensively implemented compared to temperate agroforestry. According to Piato et al. (2021), shade-grown coffee and tea systems have undergone significant advancements, and the presence of manual labor renders some tropical agroforestry approaches more feasible compared to regions where mechanized harvesting is prevalent. Agroforestry has held significant cultural significance in indigenous tropical regions as well as temperate locales such as Europe. However, the prevalence of land abandonment and agricultural intensification in northern territories has resulted in a reduction of conventional agroforestry methods (Nair et al., 2021). There exist five widely acknowledged agroforestry approaches, including alley cropping, silvopasture, riparian buffers, windbreaks, and forest farming (Bishaw et al., 2022). These approaches are applicable across diverse farming systems, topographical features, and climatic regions. Figure 4 illustrates various agroforestry approaches.

Alley cropping

Alley cropping is a sustainable agricultural practice that entails cultivating row crops within the spaces between rows of trees (Gagliardi et al., 2022). Trees have the potential to be cultivated for the purpose of producing lumber or fruits and nuts. On the other hand, alley crops encompass a diverse range of cereals, vegetables, or forages that can be harvested for hay. The cultivation of crops yields immediate financial returns, whereas the growth of trees generates money over an extended period of time.

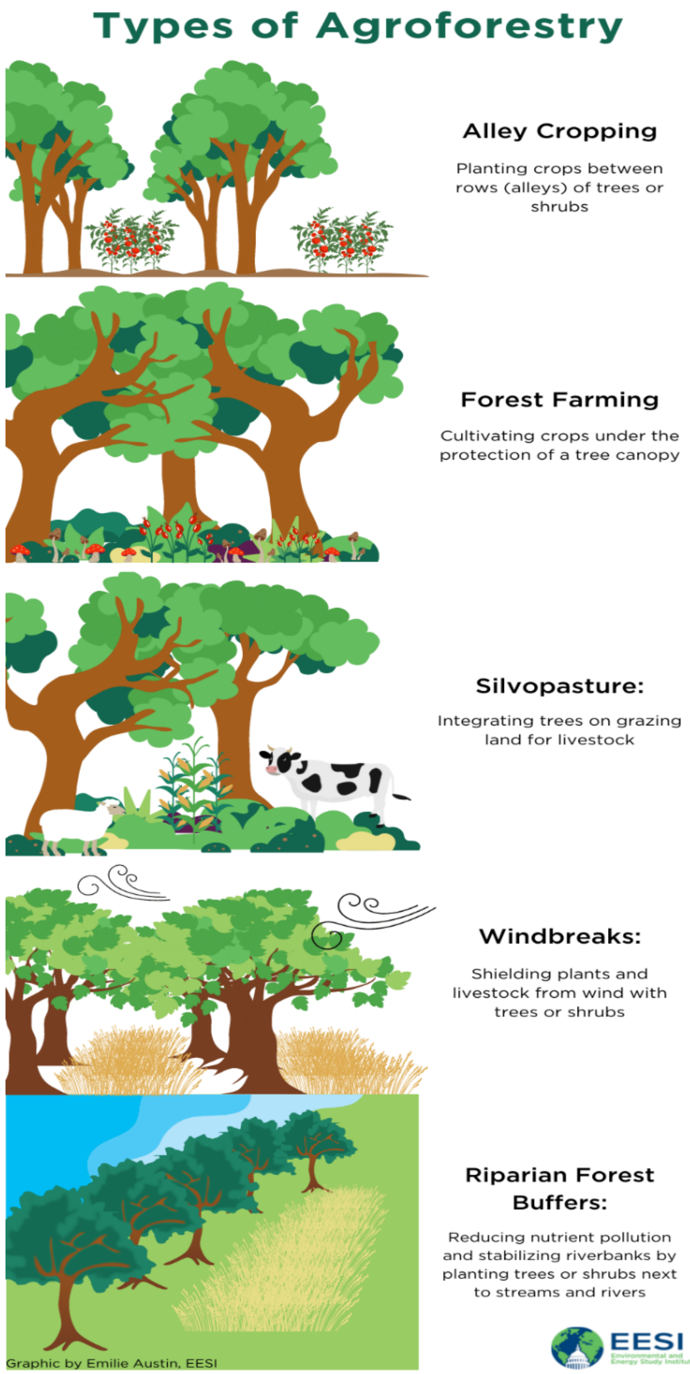

Figure 4. Different types of agroforestry practices.

The potential for enhanced production can arise from the interactions between tree and crop species, facilitated by their distinct ecological niches (Fahad et al., 2022). An illustrative instance can be found in a study conducted in France, which demonstrated the favorable compatibility between walnuts and winter wheat due to their distinct growth periods and divergent rooting depths. According to the findings of Dupraz et al. (2021), it was determined that the integrated cultivation technique yields a 40% higher product output per unit area compared to the separate cultivation of the two crops.

Forest farming

Forest farming encompasses a range of activities, including the cultivation of mushrooms, the collection of medicinal herbs such as ginseng and goldenseal, and the commercialization of woody ornamental resources (Chamberlain et al., 2019). The agroforestry method described in this study typically takes place within mature forests that have been cultivated for lumber production, enabling the generation of income without significant disruption (Frey et al., 2023). The management of forest farming systems can vary in intensity, with the level of management determined by the specific product being cultivated and the target market preferences (Raihan & Tuspekova, 2022d). As an illustration, the cultivation of ginseng in woodland environments necessitates substantial pre-planting measures such as site preparation, application of fertilizers, tillage practices, and the use of fungicides. While these interventions have the potential to enhance crop yields, they also incur higher costs and thus introduce greater financial and operational uncertainties. In contrast, the cultivation of wild-simulated ginseng may encompass the practice of gently displacing fallen foliage, sowing seeds, and allowing the ginseng to mature over a span of multiple years prior to its eventual harvest (Yousefi et al., 2020).

Silvopasture

The practice of silvopasture involves the deliberate integration of cattle within a carefully planned combination of trees and pastureland. Silvopasture distinguishes itself from conventional woodland grazing practices by implementing a deliberate arrangement of trees that ensures adequate sunlight penetration for the underlying fodder vegetation, while simultaneously preventing any detrimental impact on the trees caused by animals. According to Smith et al. (2022), the presence of trees provides animals with shelter by offering shade during the hot summer months and reducing wind exposure during the cold winter season. Furthermore, it has been observed that the quality of pasture in areas with partial shade may exhibit an improvement, but with a minor decrease in biomass productivity (Hidalgo-Galvez et al., 2022). According to Poudel et al. (2022), there is no significant difference in the weight gains of livestock when comparing silvopasture with open pasture grazing systems. According to Huang et al. (2023), if the trees are cultivated for lumber purposes as well, it is expected that the farmer's long-term financial performance will enhance without compromising the current level of production.

Windbreaks

Windbreaks, sometimes referred to as shelterbelts, were promptly acknowledged as a valuable agroforestry technique. Windbreaks play a crucial role in mitigating wind erosion, supporting wildlife habitats, and enhancing water availability for adjacent crops through reduced evapotranspiration and snow capture effects (Subbulakshmi et al., 2023). According to Mallareddy et al. (2023), an increased water supply has the potential to enhance agricultural productivity, hence yielding significant economic advantages for farmers. Windbreaks have the potential to mitigate the heating and cooling requirements of residential and occupational areas on a farmstead by minimizing the infiltration of outdoor air induced by wind (Mume & Workalemahu, 2021). The initiation of the Prairie States Forestry Project by the U.S. government was a response to the Dust Bowl years in North America, aiming to establish a substantial shelterbelt spanning from Canada to Texas (Li, 2021). Another noteworthy illustration pertains to the Three-North Shelter Forest Program in China, which stands as the most extensive afforestation endeavor globally. The initiative commonly referred to as "China's Great Green Wall" was initiated in 1978 and is projected to reach completion by 2050 (Gravesen & Funder, 2022). Comparable approaches have been utilized in Russia, the northern regions of Europe, Australia, New Zealand, and many other nations.

Riparian forest buffers

Riparian buffers refer to vegetated zones established along watercourses that are susceptible to erosion, nutrient leaching, or habitat degradation (Fahad et al., 2022). Typically, there exist two to three distinct "zones" of vegetation, which exhibit variations in their composition as influenced by factors such as proximity to the waterway, slope, and the requirements of primary producers (Lind et al., 2019). Riparian zones have limited suitability for agricultural production, rendering them highly suitable for alternate utilization. The United States Department of Agriculture (USDA) has made a deliberate and coordinated endeavor to enforce conservation practices in the vicinity of water bodies, owing to their advantageous effects on the quality of water and soil. The Environmental Quality Incentive Program (EQIP), administered by the Natural Resources Conservation Service (NRCS), and the Conservation Reserve Program (CRP), managed by the Farm Service Agency (FSA), serve as illustrations of government-funded efforts.

It is important to highlight that, among the five practices mentioned, alley cropping and silvopasture are commonly implemented on land that is deemed appropriate for conventional agriculture. Despite this, it is common practice to engage in conventional cropping for multiple years until the trees reach their full maturity (Dasgupta et al., 2023). Riparian buffers, windbreaks, and forest farming typically manifest in the periphery of fields or on land that is unsuitable for agricultural use. However, it is worth mentioning that in certain instances, the allocation of a portion of cropland may be necessary to achieve the desired width for optimal efficacy (Englund et al., 2021). Hence, these methods have a tendency to serve as a supplement rather than a rival to current production systems, perhaps offering avenues to enhance food security through the utilization of underutilized resources. Agroforestry has the potential to make significant contributions to both conventional and organic agricultural systems in practical applications. In both scenarios, the advantageous impacts of agroforestry have the potential to enhance environmental results beyond the existing capabilities of each respective system. Agroforestry has the potential to mitigate several of the aforementioned issues associated with organic agriculture, such as soil erosion, emissions of greenhouse gases, and leaching of nutrients.

Agroforestry Benefits

The practice of agroforestry has been found to have beneficial impacts on both soil and water quality. The enhancement of soil quality is facilitated by heightened amounts of organic matter, greater diversity in microbial populations, and enhanced nutrient cycling, hence potentially augmenting crop output and bolstering resilience against drought conditions (Fahad et al., 2022). The incorporation of agroforestry vegetative buffer strips has been found to reduce non-point source pollution from row crops, resulting in improvements in water quality (Zahoor & Mushtaq, 2023). Fahad et al. (2022) observed that the implementation of agroforestry and grass buffer strips had a significant impact on reducing the loss of phosphate and nitrogen from a corn-soybean cycle. Perennial vegetation exhibits the capacity to enhance above-ground biomass, thereby impeding runoff and effectively capturing up to 95% of susceptible sediment from being lost (Liu & Lobb, 2021). Additionally, the subterranean roots of these plants have the ability to absorb 80% or more of surplus nutrients, while concurrently serving as a habitat for microbial communities capable of metabolizing pesticides (Behera et al., 2021).

The augmentation of soil organic matter through carbon content not only enhances soil health but also contributes to the mitigation of atmospheric carbon dioxide, which is recognized as a significant factor in climate change (Paul et al., 2023; Raihan et al., 2022a; Raihan & Tuspekova, 2022e; Raihan & Tuspekova, 2023a). According to Lugo-Pérez et al. (2023), the inclusion of trees and shrubs in an agricultural landscape results in a higher degree of carbon sequestration when compared to a monoculture of crops or grassland. In a study conducted by Kim et al. (2016), a meta-analysis was performed to assess the impact of agroforestry on greenhouse gas emissions. The findings of the study revealed a significant reduction in emissions, with an average mitigation rate of 27±14 tons of CO_2 per hectare per year. Approximately 70% of carbon sequestration was attributed to biomass, while the remaining 30% was sequestered in the soil. According to a study conducted by Udawatta and Jose (2011) in North America, the implementation of agroforestry methods on a small scale has the potential to store around 548.4 Tg of carbon annually. This amount is significant enough to offset almost 34% of the carbon emissions produced by the United States from the burning of coal, oil, and gas. The strategies for enhancing carbon sequestration encompass improved erosion management, heightened carbon storage in woody perennial plants, diminished decomposition of organic matter, and the limited harvesting of crop biomass in agroforestry systems compared to conventional systems (Sivaranjani & Panwar, 2023). The potential significance of the relationship between perennial systems and climate change should not be overlooked. The study conducted by Robertson et al. (2020) examined the possible impact of various annual and perennial systems on global warming. The research findings indicate that all of the annual cropping systems examined, including conventional, no-till, reduced input, and organic, did not result in a reduction of global warming potential. While the farming techniques did indeed result in the accumulation of carbon in the soil, the benefits derived from this were counteracted by the emissions of nitrous oxide. Nevertheless, the implementation of perennial and early successional forest treatments, such as the utilization of alfalfa, hybrid poplar, and the restoration of abandoned early successional sites, resulted in a notable decrease in global warming potential. As the mid-successional and late-successional systems progressed in their development, the annual carbon storage capacity exhibited a decline. The study's findings indicated that the early successional forest system emerged as the most effective strategy for mitigation (Raihan & Tuspekova, 2022f; Raihan & Tuspekova, 2023b). Numerous agroforestry practices demonstrate a high degree of resemblance to the characteristics and dynamics of early successional forests.

The mitigation of climate change is furthered by the adoption of an additional significant strategy, namely the reduction of fossil fuel consumption (Raihan & Tuspekova, 2022g; Raihan et al., 2023b; Raihan, 2023h; Raihan, 2024b). The utilization of bioenergy presents a potential solution for mitigating reliance on fossil fuels (Raihan, 2023i; 2023j). However, apprehensions arise regarding the allocation of important arable land for cultivating energy crops instead of food crops (Kalogiannidis et al., 2023). At present, a significant proportion of the corn yield in the United States, specifically 40%, is allocated towards the production of ethanol. This allocation raises concerns over its potential counterproductivity in relation to the overarching objective of alleviating global food scarcity. According to Ntawuruhunga et al. (2023), the integration of biomass production from trees and food cultivation on the same site holds potential as an agroforestry approach to provide a sustainable energy future without compromising food production capacities. The Land Equivalent Ratio (LER) is a valuable metric for evaluating the comparison between polycultures, which consist of mixed species, and individual crops. This metric takes into account the productivity of the polyculture and computes the land area that would be necessary if the individual crops were cultivated independently. In a study conducted by Haile et al. (2016), a comparison was made between loblolly pine and switchgrass mixes and pure stands of each crop. The researchers observed that while the individual crop yields were lower in the mix, the overall Land Equivalent Ratio (LER) reached 1.47. This implies that cultivating switchgrass and loblolly pine individually would necessitate an additional 47% of land compared to the agroforestry system in order to produce an equivalent quantity of biomass. The Yield-SAFE (Yield Estimator for Long-term Design of Silvoarable Agroforestry in Europe) model was employed to simulate agroforestry systems in Europe. The results of this modeling exercise indicated that integrating trees and crops in Spain, France, and the Netherlands led to higher productivity, as evidenced by the predicted LER (Land Equivalent Ratio) values ranging from 1 to 1.4. This finding was reported by Graves et al. (2007). In a separate study conducted in Switzerland, the implementation of agroforestry models centered around walnut (Juglans hybrid) and wild cherry showed that, in 12 out of 14 instances, the integration of multiple crops resulted in a higher Land Equivalent Ratio (LER) above unity. Furthermore, Sereke et al. (2015) revealed that a significant majority, specifically 68%, of the financial scenarios in Switzerland exhibited higher profitability compared to existing methods.

Agroforestry demonstrates a greater capacity for biodiversity conservation in comparison to conventional and organic monocultures. The inclusion of trees, bushes, and other permanent vegetation within an agricultural landscape has been found to enhance wildlife habitat, resulting in increased abundance and higher diversity of wildlife populations (Ntawuruhunga et al., 2023). In addition to possessing inherent worth, biodiversity has the potential to offer valuable services. According to Ghosh et al. (2023), an increased presence of avian species and predatory insects can effectively regulate pest populations. The provision of suitable habitats for pollinator species has been found to positively impact the pollination of horticulture crops, as demonstrated by Miñarro et al. (2023). According to Ribas et al. (2023), there is typically a decline in the occurrence of diseases in populations that exhibit higher levels of diversity, encompassing both plant and wildlife species. Agroforestry can also provide advantages for livestock. According to Smith et al. (2022), windbreaks serve as a protective barrier against strong winds, safeguarding animals from their adverse effects. Additionally, the provision of shade by trees can enhance thermal comfort during the summer season, potentially promoting more uniform grazing patterns across a paddock. According to Kumar et al. (2023), the implementation of forest-based foraging systems for poultry and hogs has the potential to reduce reliance on grain and create environments that closely resemble the natural habitats of these animals. The cork oak dehesas found in the Mediterranean region exemplify a multifunctional landscape that has persisted for several centuries. These landscapes serve as a source of sustenance for grazing cattle through the provision of grass and acorns, while also offering a lucrative cash crop in the form of bark that is utilized in the production of traditional corks (Acha & Newing, 2015).

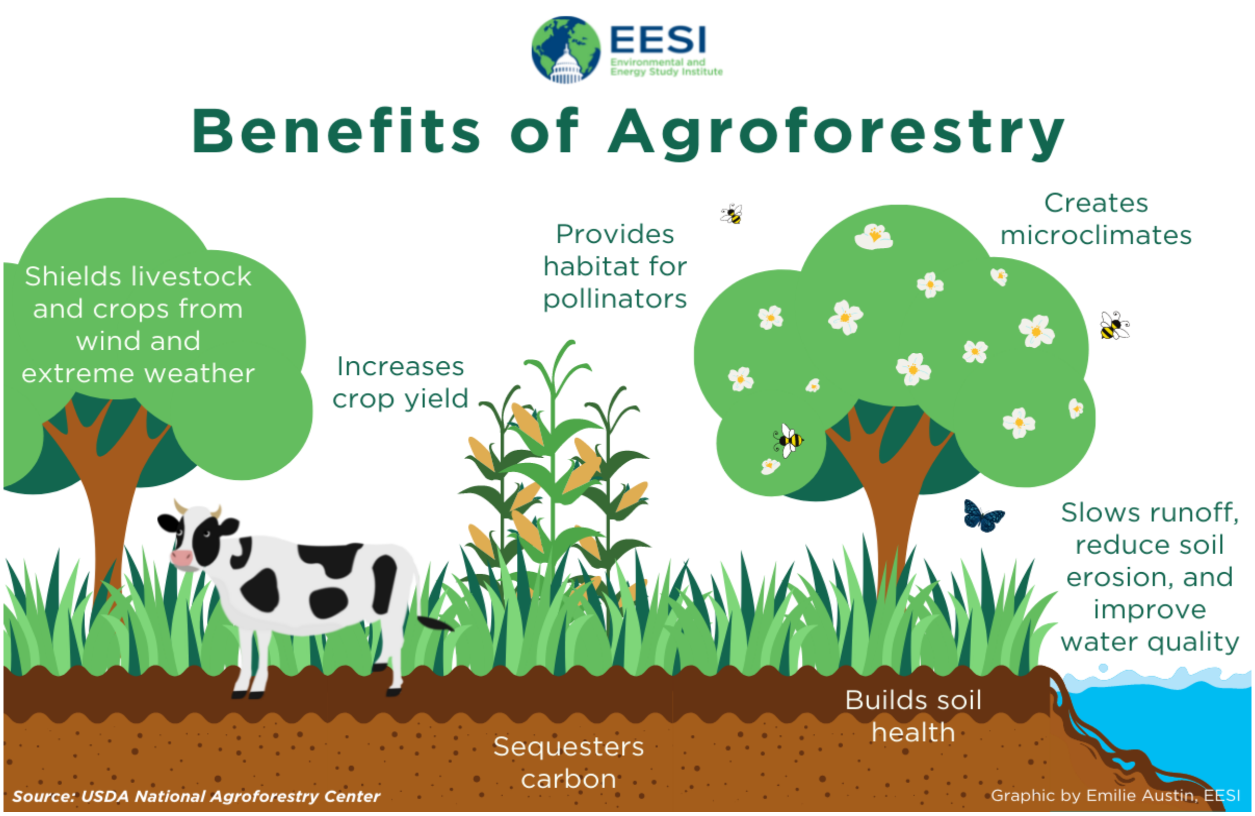

Figure 5. The benefits of agroforestry.

According to Chenyang et al. (2021), perennial polycultures such as agroforestry exhibit more intrinsic stability when confronted with global market volatility and extreme climatic events, in comparison to annual monocultures. In the hypothetical scenario of a scarcity of fossil fuels, it is anticipated that mature fruit and nut trees will sustain their production with minimal disruption, albeit necessitating the substitution of labor for alternative inputs. Agroforests possess the capacity to store greenhouse gases, which are recognized as the primary drivers of global climate change (Wilson & Lovell, 2016; Raihan et al., 2022b; Jubair et al., 2023; Raihan, 2024c). Additionally, these agroforests have a heightened ability to withstand and adapt to the anticipated impacts of climate change. According to Rajanna et al. (2023), enhanced root systems and increased capacity for infiltration and water retention contribute to mitigating the effects of drought. Additionally, trees exhibit superior resilience to floods compared to field crops due to their capacity to extract surplus water from the soil and endure inundation. Despite being frequently disregarded, agroforestry offers supplementary cultural advantages. The preservation of nature is highly esteemed by several landowners due to its aesthetic appeal and perceived advantages, such as enhanced well-being and the tranquility associated with rural living (Tindale et al., 2023). According to a study conducted by Jiang et al. (2023), rural dwellers exhibit a preference for aesthetics that are enhanced by the use of measures such as vegetative buffers. Etongo et al. (2023) highlight several recreational activities available, such as bird watching, outdoor excursions, and hunting. The benefits of agroforestry are illustrated in Figure 5.

Agroforestry Adoption Challenges and Future Directions to Overcome

The prospects for agroforestry are promising, albeit not devoid of obstacles. The adoption of agroforestry has exhibited a notable deficiency, despite the existence of extensively demonstrated advantages (Syano et al., 2022). Various obstacles have been identified, such as the financial burden associated with setting up tree plantations, landowners' limited familiarity with tree cultivation, and the considerable time and expertise necessary for effective management (Irwin et al., 2023). According to Wienhold and Goulao (2023), extension employees and agricultural product merchants are commonly relied upon by farmers for acquiring knowledge about novel agricultural methods. However, it is worth noting that these experts generally lack formal training or practical expertise in the field of agroforestry. Furthermore, the absence of well-defined demonstration plots poses a challenge for landowners in observing the practical implementation of these systems (Zang et al., 2022). Given the intangible or long-term nature of numerous beneficial outcomes associated with agroforestry, landowners may encounter challenges in visualizing them (Jacobs et al., 2023).

The logistics associated with the harvest of edible goods, such as fruits and nuts, in agroforestry systems can pose significant challenges. In order to enhance the economic competitiveness of agroforestry systems, the implementation of mechanization may be necessary for larger-scale plantings (Korneeva & Belyaev, 2022). The complexity of the situation arises when numerous types of fruit or nut are cultivated simultaneously. According to Irwin et al. (2023), non-traditional markets and delayed rewards can also serve as deterrents. Previous studies have demonstrated that certain agroforestry systems, like silvopasture, exhibit economic viability and generate profits. However, other practices such as biomass plantings or riparian buffers may require the establishment of markets that provide compensation for the ecosystem services, they offer in order to be financially feasible (Mosquera-Losada et al., 2023; Ntawuruhunga et al., 2023). Additionally, the process of social change and networking will also be influential as attitudes shift to embrace alternative approaches (Annosi et al., 2022).

In light of the aforementioned obstacles, several techniques have been presented with the aim of advancing the field of agroforestry. Potential policy adjustments may involve the augmentation of financial resources allocated towards government cost-sharing initiatives aimed at facilitating the implementation of sustainable practices. Additionally, the provision of incentives, such as credits, for the provision of environmental services, including but not limited to pollination and carbon sequestration, might be considered. The existing programs offered by the United States Department of Agriculture (USDA) through the Natural Resources Conservation Service (NRCS) and the Farm Service Agency (FSA) frequently include provisions that prohibit the harvesting of land designated for conservation purposes. However, the implementation of agroforestry systems has the potential to allow for the cultivation of harvestable products while still maintaining the conservation objectives. The implementation of a policy modification that permits the non-destructive extraction of consumable products from agroforestry systems could potentially incentivize a greater number of farmers to embrace agroforestry methods, hence resulting in improved conservation outcomes. While it is justifiable that a significant portion of government financing is allocated to support prominent cropping systems like maize and soybean, it is worth considering that agroforestry possesses the potential to mitigate the adverse impacts associated with these systems. Consequently, it is advisable to allocate greater attention and resources to agroforestry practices. A portion of this assistance has the potential to be allocated towards educational initiatives, specifically through the implementation of extension and university programs. Indeed, education emerges as a critical determinant for the adoption of conservation techniques, since numerous research investigating the adoption phenomenon consistently identify limited access to knowledge and technical support as a prominent obstacle.

The potential for expanding the output capacity of agroforestry systems remains largely untapped. Further investigation is required to examine the utilization of trees and shrubs in the production of commercially viable goods. In recent times, there has been a surge in interest in the advancement of multifunctional, consumable polycultures that emulate natural ecosystems, such as the indigenous oak savannas found in the Midwest region. These polycultures encompass the cultivation of various crops in a stacked arrangement, enabling the utilization of diverse ecological niches and the generation of multiple revenue streams. Field trials were conducted at the University of Illinois at Champaign-Urbana to investigate the cultivation of a combination of chestnuts, hazelnuts, apples, currants, and raspberries. The inclusion of control plots in a conventionally managed corn and soy rotation enables the opportunity to conduct a comprehensive examination of various environmental, ecological, and economic variables for comparison purposes. A comprehensive and repeatable investigation was conducted to examine various spatial arrangements of polycultures in comparison to monocultures of individual species, as they would typically be cultivated in a commercial orchard setting. Additionally, the study allowed for a comparison between these polycultures and a corn/soybean rotation. The treatments encompass the incorporation of indigenous trees and shrubs that possess consumable produce, such as aronia, elderberry, pecan, pawpaw, persimmon, plum, and serviceberry. This study investigates the potential scope of cultivating native culinary plants within conservation easements that require the exclusive utilization of indigenous species.

Conclusion

This paper aims to provide a review of agroforestry toward sustainable and resilient agriculture for the future world. Numerous strategies have been suggested to effectively and durably address the challenge of providing nourishment to an expanding global populace. Organic farming exhibits the potential to reduce the reliance on agrichemicals and enhance specific environmental and human health indicators. Conversely, advocates of conventional farming systems highlight the benefits associated with the utilization of genetic engineering, fertilizers, and pest control methods to enhance crop productivity. The implementation of broader methods encompasses various approaches, such as the restriction of farmland expansion through the prevention of deforestation, the reduction of food waste, the adoption of a less meat-intensive diet, the closure of yield gaps in underperforming cropland within emerging nations, and the enhancement of resource efficiency pertaining to water, fertilizer, and fuel utilization. These aforementioned endeavors, together with additional strategies, will be imperative components of a comprehensive approach in order to effectively and enduringly address global food security.

The natural environment yields its abundance without necessitating the use of plowing, fertilizers, or pest control measures, hence obviating the need for any external inputs. The system operates only on solar energy and does not produce any detrimental waste byproducts. The presence of biological diversity enables the capacity for dynamic adaptation in response to environmental changes. By emulating the operation of natural ecosystems, agricultural systems have the potential to enhance their stability and resilience. Constructing such a system undoubtedly presents a formidable undertaking, necessitating a diverse array of technologies. Agroforestry has the potential to serve as a progressive approach in the realm of sustainable agriculture. It achieves this by advocating for and implementing integrated and biodiverse practices that aim to enhance crop yields, mitigate adverse impacts, and deepen our comprehension of the intricate interdependencies inherent in augmenting food production while mitigating harm. Agroforestry could lead to long-term sustainable change with a balance between short-term economic benefits and long-term sustainability goals. Sustainable agroforestry systems have the potential to help farmers harness the interactions occurring between the different components of the system for a multitude of benefits such as increased yield, environmental benefits, and animal welfare. Therefore, agroforestry should be given higher priority as a nature-based solution in policies and programs aimed at ecosystem restoration, land degradation neutrality, and climate change mitigation goals, particularly for developing countries.

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