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REVIEW ARTICLE

Superior effect of nature based solutions in soil and water management for sustainable agriculture

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Abstract

The world's natural resources are under extreme pressure as a result of the planet's rising population and irregular climate. The two most important natural resources for agriculture are soil and water and yet another crucial factor for environmental and economic sustainability of all kinds of forestry and agriculture systems is the preservation of water and soil resources. So, there is a need to address the present global issues like water and food insecurity, biodiversity loss and livelihood risks meanwhile taking human safety and functions of the ecosystem into account. Ecosystem integrity and function are threatened globally by soil loss, where supply of important food and resources to human societies can be severely affected. Freshwater is a valuable resource and a vital media for many different economic domains and residential purposes; however its usage is often at the cost of natural habitats. Therefore, for agricultural sustainability as well as the preservation of the natural ecosystem, integrative management of soil and water resources is essential. To prevent soil and water deterioration, it is imperative to develop and adopt new technologies, use natural resources sensitively and implement appropriate management techniques. Nature-based solutions, sustainable soil and water management and ecosystem based acclimation are some of the extensively used approaches that address some of the challenges in a target aimed approach. Nature-based solutions are low price initiatives that could promote resilience in agricultural produce while reducing climatic effects and improving the environment. This review highlights various soil and water conservative strategies for agricultural sustainability.

Keywords

Nature-based solutions; Sustainable agriculture; Soil erosion; Plant growth Promoting Rhizobacteria; Mulching

Introduction

To combat the impact of climate change, rise in population, land development and ecological degradation, there is a global demand to enhance food supply through sustainable approaches (1). Our food security mainly relies on the sustainable maintenance of natural ecosystem. Despite this, more than half of the global agricultural land and marine habitats have been destroyed to some level. Globally, around 1.9 billion ha of land was degraded (2). Annually, land degradation is thought to cost the world economy $18 - 20 trillion USD yearly (3). Agriculture is the primary cause of

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80 % of natural habitat degradation, owing to the loss of fertile land and growing food demand. As per the FAO report, recent developments made agro-based systems, the world's primary driver of biodiversity loss and contribute to more world's greenhouse gas emissions (4). In this regard, FAO has emphasized the importance of speeding up the global transition to sustainable agricultural and food systems, proposing an integrated strategy to assure sustainability in crop yield, livestock, forest management, agriculture and aquaculture as well as in natural resource management. The most frequently cited statistic, which derives from an FAO briefing paper, stipulates that by 2050 in order to feed everyone on the planet, food production must rise by 70 % globally (5). It's a challenge to meet the estimated population food demand which will put more stress on the environment, especially agricultural land. However, inappropriate land resource usage and depletion generated huge pressure, resulting in degradation and in addition soil erosion is leading to the loss of about 24 billion tonnes of fertile soil every year (https://www.globalagriculture.org/report-topics/soil-fertility-and-erosion.html). By 2050, almost 90 % of the earth's soil might be degraded, with 33 % already deteriorated (6). Moreover, it was estimated that soil erosion can lead to about 50 % loss of crop yield (https://www.fao.org). For the restoration of degraded land and to evaluate their ability to carry out ecological functions and offer financial returns to the growers, Kumar *et al.* (2019) (7) recently analyzed various soil moisture conservation strategies in India like continual contour trenches, startled contour trenches, vegetative hedges and stone mulch. This group of researchers suggested that horti-pasture systems with *Psidium guajava* and *Emblica officinalis* trees and pastures with staggered trenching might improve degraded land and increase income.

Other major issue is scarcity of water to meet the needs of agriculture. Most of the water shortage issues in risky regions were being impelled by agricultural irrigation endangering the public water supply, food systems and ecosystem well-being. Moreover, land transformation and fossil fuel reliant farming techniques were accountable for over a part of global emissions, conferring to the environmental disasters and moreover increasing various threats like food insecurity and environmental loss. Nearly twice less than the global population resides in regions that experience acute water stress and further, environmental variations will make the condition worse. Reforestation, preservation of wetlands and water effective agriculture methods can increase the quality and amount of the water and further minimize the effects of natural catastrophes. Presently, over 3.6 billion people reside in regions, where water may be scarce for at least a month per year and there will be increase in this number to 5.7 billion by 2050 (8). According to the UN World Water Development Report 2019, world's water demand has been rising at an average of around 1 % per year during the past few decades because of population increase and ever changing consumption practices (9).

As modern agriculture enriched food availability and supply, enhanced sustainability, affirmed the food safety and increased the biofuel production, it also led to environmental issues since it is reliable on high input output approach utilizing high yielding hybrid varieties, as well as ample water sources, pesticides and fertilizers. Further, this led to various environment effects like enhanced soil erosion, decreased soil organic carbon and different types of land degradation (10). It also led to other problems like water logging and salinity, eutrophication and contamination of ground water. Previous farming and ecological management approaches to accommodate the global food demand has placed burden on soil resilience and other biological processes been engaged in maintaining the global balance of matter and energy. These constraints have resulted in extensive and top requests for a change in the process of making food. In this context, by 2030 Sustainable Development Goal 2.4 assures sustainable agricultural practices and employ resilient farming methods that boost productiveness and yield, facilitate to conserve ecosystems and strengthen ability for climate change adaptation. Agricultural producers all over the planet should drive a shift to farming methods that rejuvenate greenery in an effort to ensure the sustainability of food chains. Growing Better report (2019) by the Food and Land Use Coalition presented the scientific data and economic events for ten crucial modifications of our food system (11). One among them are nature based solutions in which by 2030, it might hopefully drive climatic modifications under check, protect the biodiversity, maintain nutritious diet for everyone, significantly enhance food supply and generate better integrated agricultural livelihoods. So, in these circumstances sustainable methods are required to achieve global transformation in agriculture to improve the soil health and to conserve the agro ecosystems. Organic matter in the soil is a crucial component of soil health and crop yield. Developing and sustaining healthy soil with high organic matter can help to provide a strong base for better yields and resilience to environmental pressures. Improved soil organic matter levels are usually transformed into sustainable strategies that generate higher and consistent yields.

Actions "to preserve, effectively regulate, and revive normal or transformed ecosystems, that handle societal issues efficiently, while simultaneously furnishing benefits to human wellbeing and biodiversity" are referred to as nature-based solutions (NBS) (12) and also as ‘‘Living solutions influenced by, continually endorsed by and employing nature that are intended to tackle diverse societal difficulties in a resource-proficient and flexible way and to have positive effects on the economy, society and environment at the same time”(13). In this review we attempted to explore various nature based strategies in achieving sustainable soil and water for enhanced crop yields. Further, we emphasized the various effects of natural farming on crop yield, soil quality and the ecosphere.

Evolution of the nature-based solution concept

The phrase "Nature-Based Solutions" (NBS) was coined in

2002 as a significant step toward shifting the perspective from people being dependents of nature to people having the ability to actively participate in conserving, maintaining and recovering ecosystems to handle various difficulties (14). These issues were related to climate change adaption and mitigation, living quality enhancement and safeguarding the ecosystems and biodiversity (14). Natural resources provided by the ecosystems will be used in nature based solutions to handle environmental issues like global warming, food and nutrition security and natural calamities. Nature-based solutions are explained as employing nature in addressing social challenges and manage biodiversity in a sustainable way. They are elucidated by the IUCN as "*Efforts to preserve, sustainably handle and regenerate modified or natural ecosystems which could efficiently and adaptively solve social issues and at the same time promoting biodiversity and social well-being*" (14). Nature-based solutions are economic strategies that can increase the agricultural yields, while alleviating the climatic changes and improving the environment. The term 'nature -based solutions' could be considered as a phrase for a variety of fields like ecosystem based strategies (for climate adaption), organic farming, natural remedies, ecological engineering or green technology, etc. In addition, when it comes to solving ecological issues, integrating NBS techniques may produce better outcomes.

Importance of nature-based solutions in agriculture

Agricultural nature based solutions are proficient, economically effective and everlasting approaches in managing the climatic variations and sustainable land & water resources. These applications could facilitate in improving the quality and availability of water and moreover restore the natural soils and ecosystems globally, while contributing to significant health benefits and attaining universal food security. Thus, NBS's and other natural climate solutions will be crucial in the near future as we move toward a carbon-neutral economy by the middle of the century. Farmers are excellent agriculture NBS drivers as they can integrate their traditional expertise with emerging techniques to conserve the ecosystems that support our food supply. Nature-based solutions provide various advantages like enhancing the farmers livelihood and agricultural resilience, conforming to the climatic alterations with forest carbon sequestration, wetlands, soil, enhancing the biodiversity and nature, etc. In order to nurture the food systems, farmers all over the world are set to drive a transition to production techniques that rejuvenate and recreate nature while improving effective and sustainable food systems. Many nature-based solutions in agriculture are in line with environmental friendly farming methods like conservation or regenerative agriculture. These procedures can boost productivity and enhance innate methods resulting in increased yields and lowering expenses. Thus, these efforts illustrate that they can both enhance ecosystem health and provide farmers with economic benefits. According to a study, preserving the environment is more profitable than unearthing it. Thus, by maintaining the nature and employing the benefits of the ecosystems, farmers can assure the fortune of their farming practices and their livelihoods (https://chloridefree.org/en/nature based-solutions-the-key-to-sustainable-agriculture).

Few illustrations of nature based methods in agriculture and their advantages are:

1. Cover crops cultivation

For decades, advantages of cover crops for the environmental and the farming communities have been well-known. During off-season alfalfa, vetch and other cover crops can be cultivated between the main plant rows when the land is dry. These will induce in preventing soil erosion, replenishing soil nutrients, enhance water holding capability, control weeds and maintain soil health by decreasing the usage of herbicides (https://www.ucsusa.org/resources/what-sustainable-agriculture). Pesticides application may increase or decrease with the cover crops cultivation. Use of pesticides can rise if cover crops are difficult to manage. In South America, 95 % of the regions use cover crops with no tillage to assist in weed suppression by dense plantations and competing with weeds for nutrients, water and sunlight. It has been demonstrated that rye cereal has an allelopathic affect on weeds for over six weeks (https://ohioline.osu.edu/factsheet/anr-57). Cover crops could enhance nutrient efficacy through decreased soil erosion (reduced loss of soil organic nutrients in the top soil). Cover crops consume leftover nitrogen (N), transforming it to proteins (hormones, amino acids, enzymes) (https://ohioline.osu.edu/factsheet/anr-57).

2. No till/ Conservation tillage

Conventional or intensive agriculture degrades the soil physically and chemically, looses organic matter, reduces soil biological activity and as a result reduces crop yield. On the other hand, sustainable agriculture envisions a profitable and sustainable agricultural system depending on three fundamental principles comprising soil free farming, crop rotation and continual soil surface topped with plant debris or plants (15).

3. Crop rotation

It is an approach of generating different products in the field sequentially from year to year, where various parts of the soil are employed with various products. This helps in preventing the spread of pests and diseases which are unique to each product. Further, crop rotation enables the uptake of different nutrients from season to season depending on the crop as no two crops have the similar nutrient requirements. In addition, including a legume crop in the crop rotation will enhance the non-fertilizing nitrogen supply by its symbiosis with nitrogen fixing bacteria (16). Further, crop rotation could enhance the amount of promising bacteria in the soil and decrease the number of pathogenic soil microbes, thereby decreasing the number of crop diseases and pests resulting from climate change, thus assuring crop growth, enhancing crop quality, and minimizing loss to the planting system generated extreme weather (17). Some more examples are: potatoes yield better after corn and few former crops like oats, peas, barley enhance the prevalence of scab on potatoes. Further, beans and corn are not highly affected by the previous crop (http://sustainablesettings.org/crop-rotation).

4. Biochar usage

Biochar, one of the many conservation agricultural practices, may prove to be a crucial and affordable component for sustainable agriculture because it can effectively store significant amounts of carbon in soil over the long time, increase crop yield and reduces global warming. Moreover, biochar increases crop yield ability under various abiotic and biotic stresses and advances global food security. The application of biochar could improve soil quality, boost agro-ecosystem and agroforestry resilience, and promote their ability to adapt to changing climatic conditions (18).

5. Nutrient management

In the process of fertilization, the method and application time are of utmost important to fulfill the nutrients requirement (potassium, nitrogen, phosphorous) which were adequate in agricultural soils. Whereas, data like weather and climatic conditions, product types and soil nature are significant in identifying the relevant time of fertilization (https://www.agrivi.com/blog/importance-of-weather-monitoring-in-farm-production). For the development of soil microorganisms and the enhancement of the physical qualities of the soil, Integrated Nutrient Management (INM) serves as an energy source, organic carbon, and available nitrogen. It also has a significant long-term impact on succeeding crops. Studies have shown that applying organic manure together with artificial fertilizers by INM (Integrated Nutrient Management) system has a potent role in enhancing the physio-chemical properties of the soil. This indeed improves water infiltration, moisture holding ability and flow of water down, which in turn enhances the commercial use of water and water usage potency and encourages high water conservation without having any adverse effect on crops (19).

Contrarily, other researchers have found that the impacts of organic manures are not always beneficial and that some organic materials may even hinder plant growth. This could be because they contain large amounts of phytotoxins and have more C/N ratio, especially in young organic materials (20). The improper use of fertilizers posed environmental problems in some Asia-Pacific nations which generated more than 10 tons/ha of high-yielding rice annually but discarded around 350 kg of soil nutrients per hectare (21). As advanced fertilizer management techniques (like PAT, technology acceptance model (TAM), SPAD, LCC, etc.) are hardly ever used, excessive fertilizer usage depletes the minimum organic soil ratio and results in soil acidification, development of harmful algae in water, high emission of N_2O and other negative environmental effects (22). In order to find an approach to generate better yields for longer periods of time, encourage resource conservation, mitigate the effects of ecological changes, and adapt to global climate change, as well as to match with other agriculture activities aiming to increase production and protect the environment, the contrary practices are thus both necessary and essential. Thus, INM technology may fulfill this function and tend to be the most fruitful way to provide food security, enhance quality of the environment, and satisfy the increasing global food demand without causing any negative consequences, especially in nations with high population growth.

6. Growing trees in crop lands

Throughout their lifetime, trees imbibe and store enormous amounts of carbon. On cropland, trees can be planted to protect crops from the wind and weather, prevent erosion, diversify the productivity, regulate water content and reduce carbon emissions. Trees that will be planted in crop lands comprise of fruit trees, wind breaks, living barriers, fuel wood trees, timber, fodder trees, cash crops and medicinal trees (23). These trees contribute wide range of products like food, timber, fuel wood, fruits and herbal medicines (23). Square pattern is the most commonly used pattern and it is relatively simple to lay out. In this pattern, trees are implanted on every corner of a square, no matter how far apart they are placed.

7. Water storage pools

For irrigated areas, agricultural ponds are crucial water sources. They efficiently store water from small sources, use it at high flow rates when necessary and help to regulate water flow (24).

Importance of protecting soil and water for sustainable agriculture

Soil is important for healthy and high quality products. So, organic farmyard manure and other natural fertilizers should be added to the soil to improve its nature. Compared to chemical fertilizers, natural fertilizers are better for the soil, crops, water, air and humans (24). Besides this, water and water resources should also be preserved, as it is important for agriculture. In arid areas, the finest approach to preserve water is to cultivate plants that are appropriate for the local environment or which only require water over the rainy season (24). Mulch and green manure are effective at retaining moisture in the soil. By obstructing the water movement, the contour barriers safeguard the water. Applying drip irrigation in place of conventional irrigation techniques and planning irrigation schedules are two additional approaches for conserving water (24).

Now we will discuss in detail about the nature-based solutions in management of soil and water for sustainable agriculture.

Soil management

Many energy-consuming agricultural techniques were implemented to increase yields in the second part of the 20th century in course of the modern scientific strategy. The major drivers of the prevailing production prototype were heavy tillage, regular weed management, extensive fertilization and surface water mobility across huge fields through pumping. Particularly in popular modern farming, plough dependent soil cultivation has been so prevalent that the word "tillage" is frequently used as an alternate word for "agriculture" (25). However, constant soil disruption through farming, particularly from soil inversion, has resulted in soil compaction, deterioration of soil structure and a decline in the amount of organic matter present in the soil. In turn, this has led to a variety of negative environmental effects, such as soil erosion, eutrophication, increased carbon emissions emitted from the soil as a result of the usage of highly energy-intensive machinery and a significant decline in beneficial soil creatures and mammals (25). Over the ages, soil aggregation furnished a medium where plants can grow and plants in turn helped to prevent soil erosion. This relationship has been interrupted by the human agricultural activities. Due to increased irregular rainfall events and increased frequency of storms brought on by climate change, the issues of degradation and variability have also become worse. To reduce these negative effects on the farming environment and to achieve the Sustainable Development Goals (Figure 1), imparting newly developed methods called as nature based solutions is important.

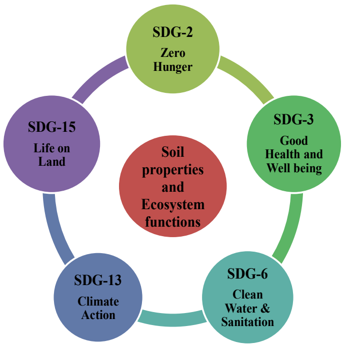

Figure 1 Sustainable Development Goals associated with NBS

Nature based solutions for sustainable soil management

Nature based solutions pave a way to unfold sustainable soil management strategies in order to handle number of issues like science based land-use planning, the reclamation of alkalinity, salinity and soil acidity, accurate soil diagnosis, prudent use of synthetic fertilizers and water sources, lack of micronutrients and maintenance of soil health for enhanced land and soil productivity.

According to Doran and Parkin (1994) (26), soil quality is the ability of the soil to work within the constraints of an ecosystem to uphold ecological functions to sustain ecological quality, to enhance plant and animal wellbeing and to promote crop yield and development. Agricultural practices, particularly tillage, can lower soil quality and lead to events that could harm the natural soil habitat. Plow-based tillage results in soil compaction, particularly when multiple tractor passes are made to create a seed bed or to keep a clean fallow. It also ruins the native soil structure by separating macro-aggregates into micro-aggregates (27), which change a variety of physical parameters. These comprise the aggregate stability of > 2 mm (28) which is broadly identified as a significant determinant (29) of soil quality, size distribution, pore size, soil moisture content and water holding capacity. This results in poor infiltration and enhanced runoff (30).

Some of the nature based solutions to address soil issues are:

Control of soil erosion and slope protection

The integrity and efficiency of earth's ecosystems are threatened globally by soil depletion. Soil degradation and depletion can be hastened by erosion and landslides, which are both common natural disasters. Rainfall frequently causes these risks to occur because it affects the mechanical integrity and soil structure. As a result of the reinforcement of the hydrological cycle anticipated over the climatic changes, high intensity and frequency of soil erosion and landslides will be probably enhanced leading to additional soil loss and deterioration (31) (Figure 2). This is a rare opportunity to study nature and understand how it works in order to discover long-term solutions to problems like the acceleration of erosion and landslides and further support the human populations in becoming resilient to climatic changes.

The prevention and management of natural calamities like erosion and landslides requires strategies that link principles of engineering with ecosystem functions and in many instances, with appropriate methods of land management. Numerous examples of environmental dependent integrative methods used to handle erosion, flooding and landslides could be identified amongst fields of water and soil engineering. Water and soil bioengineering often employs methods that unite hydrology, soil mechanics, landscape architecture, ecosystems service management and plant ecology. These methods could be referred to as plant dependent nature based solutions, since vegetation is a crucial functional and structural component of a particular nature based solutions approach. Thus, vegetation assures that nature based solutions initiatives are sustainable, effective, resilient, and integrated into the local habitat. Apollonio *et al.* (2021) (32) developed a novel method for establishing on-site tests and measuring levels of erosion at various monsoon scenarios and vegetation. In a similar investigation, Stanchi *et al.* (1991) (33) investigated how management of soil affected mountain vineyards erosion. Capobianco *et al.* (2021) employed a new, numerical modeling method to investigate the hydro-mechanical influence of various riparian cropping amalgamations on stream bank stability in Norway besides analyzing the effect of foliage on soil fortification to handle mudslide and erosion risks (34). The subsequent study concentrated on how crucial NBS's are in preventing erosion and mudslides. In this scenario, they concentrated on wood land vegetation and on offering a statistical modeling tool to measure NBS's potential to control the firmness of stream banks that is closely associated to the severity of floods. In regard to the earlier investigation, Gonzalez-

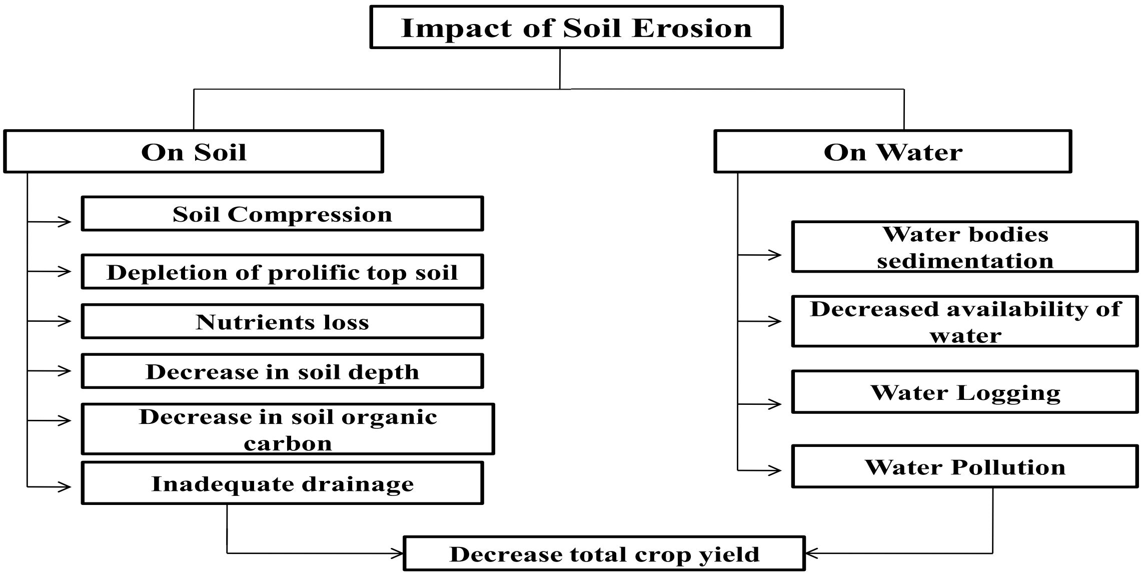

Figure 2 Various impacts of soil erosion on the nature of soil and water

Ollauri and Mickovski (2020) developed a strategy that was supported by primary data, demonstrating the hydraulic impact of willow on water soil dynamics (35). It is important to note that willow is a regular genre employed in soil bioengineering as it can regenerate from cuttings and has a high resistance to soil contamination and water logging. Regarding this, Sorolla *et al.* (2021) investigated how vegetation developed in NBS programs intended to increase slope stability (36).

Importance of crop rotation in improving the soil health

The wellness of the soil refers to the viability of the soil as a major ecological system to sustain the existence of the plants, human beings and animals. In this aspect, crop rotation efficiently enhances the soil health. Primarily, it could strengthen the soil's structure, ameliorate the physical and chemical characteristics of the soil, enhances the nature of resistance to soil's erosion and successfully withstand the risks of extreme climatic conditions like droughts and floods. Additionally, it can also boost the activity of soil enzymes thus enhancing the soil fertility. This is essential for crop development and enhances tolerance to severe weather. Eventually, crop rotation could raise the useful bacteria number in the soil and decrease the soil microbial pathogens number, thereby decreasing the intensity of crop diseases and pests resulted by climatic changes, assuring crop growth and quality (17).

Crop rotation significantly increases the soil's physical & chemical characteristics, as well as the nutrients availability like potassium, nitrogen and phosphorous. While crops like root vegetables, leafy veggies and fruits leave less nutrients into the soil, crop stalks, roots, fallen leaves and stubble roots constitute significant soil nutrient additives. The answer for this is to plant gramineous and legume crops using ecological carbon sequestration to manage the balance of the nitrogen content of the soil (37). Further, farmers can enhance soil fertility by rotating soybeans and corn (Figure 3). On the other hand, crop rotation could amplify the quantity of organic soil matter to ameliorate soil fertility and enhance the system's resistance to severe weather like drought and gales. In a study conducted in Auckland, New Zealand, Wright *et al.* (2015) discovered that soil nitrogen and soil organic matter increased after onion and potato rotation compared to continual potato cropping by 12 % and 11 %, respectively and microbial nitrogen and carbon was indeed risen by 7.8 % and 9.9 % (38). Further, field experiments carried out by Dayegamiye *et al.* (2017) in Quebec on potato rotations revealed that following a rotation between potato and oats, soil nitrogen and organic matter enhanced by 12.5 % and 9.5 % (39). In an experiment conducted by Chen *et al.* (2015) (40) in Yunnan, China noticed that, a rotation model of tobacco vetch rice

Figure 3 An example of crop rotation between corn and soybean crops

can efficiently rise the nutrient content of the organic soil by enhancing the organic material by 45 %, alkali hydroxyl nitrogen by 32.5 % and available phosphorous and potassium by 227.5 % and 13.3 %. Moreover, crop rotation could efficiently improve resistance to soil scour's and erosion, reduce the damage induced by soil erosion caused by intense weather and decrease the sensitivity of the cropping system (41).

Planting of shallow and deep rooted plants in alternate rows leads to uniform distribution of roots, loose soil, maximum soil permeability and porosity, decreased soil bulk density, enhanced soil aggregate stability, maximum water stability and increased tolerance to soil erosion by extreme weather (42). In a study carried out by Goff (2021) in Iowa, USA noticed that, rotating maize with alfalfa can improve the soil aggregates stability by 35 % related to continuous cropping (43). In an area with dual cropped rice in Jiangxi Province, Wang *et al.* (2018) experimented with crop rotation by alternating dual cropped rice with other crops like rapeseed and milk vetch (44). The findings demonstrated that rice fields could efficiently minimize micro-aggregates and generate large aggregates by using rotation and multiple cropping. Because the soil was more persistent, it decreased the rate of water and soil erosion and further decreased the chance of floods induced by extreme weather. In the meantime, it protected the environment and reduced the washout of pollutants in farming soil from leaching into waterways.

Plant growth promoting Rhizobacteria (PGPR) for sustainable Agriculture

Ever since the moment of their discovery, soil microorganisms have been recognized as an important components in promoting plant growth and play a significant part in the sustainability of the environment and agriculture. Soil microorganisms interconnected with the plants have the ability to be employed as biofertilizers to suppress the problems like fertility, soil salinity, habitat loss, reducing environmental stress and degradation (45). It is an example of a biotechnology method from the late 1980s that uses soil microorganisms to practice sustainable and climate-resilient agriculture without utilizing chemical fertilizers. Plant growth promoting rhizobacteria (PGPR), a name coined by Kloepper and Schroth in 1978 are free-living soil bacteria that flourish in the rhizosphere, actively colonize plant roots and promote plant development (46). These are divided into two categories: endophytic (symbiotic) and ectophytic (non-symbiotic). Rhizobacteria like *Pseudomonas*, *Bacillus*, *Serratia*, *Arthrobacter*, *Burkholderia*, *Micrococcus*, *Flavobacterium*, *Agrobacterium*, *Azotobacter*, *Azospirillum*, *Mesorhizobium*, *Bradyrhizobium*, *Rhizobium*, *Azorhizobium*, *Frankia* and *Allorhizobium* could be employed as PGPR (47).

Apart from the bacterial species, some fungal species such as *Aspergillus*, *Trichoderma*, *Pencillium* and *Alternaria* could be employed as plant growth promoters. The plant growth promoting fungi apart from helping in plant growth development, root extension and safeguarding from different types of phytopathogens, it also aids in soil improvement. Further, it was thought to have the capability in enhancing the yield of agricultural crops, rare medicinal and herbal plants and indeed they would be helpful to the public health and our ecosystem (48). Through a number of direct or indirect mechanisms, including biological nitrogen fixation, improving nutrient availability in the rhizosphere, promoting iron absorption through siderophore formation, and phytohormone production, the PGPR encourages plant growth and development. It was reported that diazotrophic species like *Azotobacter* species (*Azotobacter vinelandii* and *Azotobacter chroococcum*) and *Azospirillum* species fix nitrogen in leguminous and other variety of crops (49). In fields it was noticed that, inoculation of *Rhizobium* species displays enhanced development and yield of the plants related to the plants lacking *Rhizobium* species (50). According to studies done by several scientists, PGPR also facilitates the intake of mineral nutrients by solubilizing organic acids and forming siderophores (51). *Azotobacter vinelandii*, *Bacillus megaterium* and *B. cereus* are soil bacterial strains said to enhance siderophore formation, which in turn encourages plant development and disease control (47).

Role of PGPR's as nature based solution in attaining sustainability

As discussed above PGPR's play a major role in combating various ecological problems in different plants. Thus, direct interaction between PGPR (soil microorganisms) and plant roots results in mineral uptake from the soil, the breakdown of organic matter, the acquisition of nutrients, as well as the encouragement of plant growth and the control of phytopathogens. As PGPR plays a significant role in biodegradation, bioremediation, mitigating climate change, stress control and enhancing soil fertility, attention in it has grown significantly in addition to promoting plant growth and development (47). Environmental pollution caused by excessive fossil fuel use, generation of waste from various anthropogenic activities, land degradation, and climate change caused by greenhouse gas emissions are the main environmental problems, where these environmental issues can be managed by the incorporation of useful soil microorganisms (47).

Zhuang *et al.* (2007) (52) and Glick (2010) claimed that soil bacteria like *Enterobacter cloacae*, *Azospirillum lipoferum*, *P. fluorescens* and *Pseudomonas putida* are capable of remediating soil by reacting with dangerous substances like petroleum hydrocarbons, aromatic hydrocarbons and trichloroethane (53). Rhizobacteria are employed to remediate soil that has been contaminated with metals like cadmium, mercury, lead, copper and zinc since they have a high metal tolerance capacity. Rhizoremediation is therefore an efficient method for incorporating rhizospheric microorganisms for the breakdown of contaminants, increasing soil quality, and protecting plants from the harmful effects of these contaminants. Apart from rhizobacteria, fungi may play a major part in nature based solutions to wildlife extinction and climate change. They help in regulating atmospheric carbon dioxide. For instance, in boreal forests fungi sequestrate significant quantities of carbon in their root symbiosis with plants. They can also clean the polluted soils acting as decomposers. Further, they could also furnish a good food substitute to animal food, which is an incentive behind climate change and deforestation, as most of the global tropical forests are removed for cattle rearing and soybean cultivation to feed the livestock and cattle (https://www.iucn.org/news/species-survival-commission/202108). Thus, it can be stated that soil microorganisms have a variety of processes that determine their effectiveness in the management of the environment and sustainable agriculture. As they are utilized as biocontrol agents, biofertilizers and soil fertility enhancers to promote agriculture in an environmentally responsible way, PGPRs can be referred to as a sustainability criterion in respect to agriculture and the environment (47).

Water management

The maintenance of livelihoods, human welfare and socio-economic development depends on the availability of water. Because of factors like population increase, economic growth and varying consumption habits, among others, the world's water demand was accelerating at a percentage of around 1 % annually and will continue to increase over the next twenty years (54). The global water cycle is also growing more intense as a result of climate change, with drier parts becoming more drier and wetter ones typically becoming wetter. Even though agriculture will continue to be the greatest overall user industrial and home demand for water will rise more rapidly. Over the coming decades, it is anticipated that the degradation of water quality will worsen even more, posing greater risks to human health, environment and sustainable development (54). Nutrient loading, which varies by region and is frequently linked to pathogen loading, is the most common problem with water quality worldwide. The quality of the water is also impacted by hundreds of pollutants (54).

Water management methods in the agriculture sector have historically been seen as a contributing factor to the degradation of natural habitats and as an intentional impediment to the running of ecosystem services (55). These issues were evident, for instance, in the wetlands management, lakes and rivers, while providing ecosystem services by offering water for farming, however the water quality was negatively impacted by excessive pesticide concentrations. Moreover, it is clear that measures that sustain or enhance the condition and integrity of ecosystems also have positive effects on agricultural development and agricultural water management. Furthermore, it is projected that the agricultural industry would continue to be the largest user of water during the coming decades (56). NBS's had the potential to be a potent strategy for reshaping the agriculture industry so that it benefits from and protects ecosystems. Adoption of NBS's offers chances to integrate the relationship between agriculture, ecosystems and water to enhance sustainable food security and benefit from a healthy ecosystem (56).

Nature based solutions for sustainable water management

Nature-based solutions can help with some of the major problems related to water security, which are on the rise. Rising worldwide water requirements, demographic expansion, increasing farming needs to sustain food security, climate change & urbanization are all the sources of water insecurity. Since weather changes are affecting the universal water cycle and enhancing the prevalence and seriousness of utmost disasters like droughts and floods water supply is getting more erratic and unpredictable. Achieving sustainable development goals will require scaling up nature based solutions because water is crucial to it in the scenario of climate change (54).

Ecosystem degradation

Globally, nutrient loading, which varies by region and is frequently linked to pathogen loading, is the most common problem with water quality. The quality of the water is also impacted by hundreds of pollutants. Because of over population and economic expansion as well as the absence of wastewater management mechanisms, low and lower-middle income nations are predicted to see the highest increase in exposure to contaminants (57). The irrigation and quality patterns are correlated with predicted alterations in drought & flood hazards. Approximately 1.6 billion people (almost 20 % of the global population) are expected to be at risk from floods by 2050 (https://www.oecd.org/publications/applying-the-oecd-principles-on-water-governance-to-floods-d5098392-en.htm). In reference to morbidity and economic effect compared to GDP per capita, land degradation and drought are currently affecting approximately 1.8 billion people, forming them the major class of natural disaster. The answer to these queries will rely at least partially on our ability to make the transition from going against nature to start cooperating with it, such as through improved NBS's adoption (54).

NBSs can boost water availability and quality, help to lower the risk of disaster, and offer a range of co-benefits by enhancing the position, time and water quality. NBSs can help in providing water for a variety of uses, including agriculture, sanitation, water and hygiene in both rural and urban locations. Orientating NBSs within broader debates of water distribution between various users and authorities could also assist to reduce conflicts and trade-offs and possibly boost collaboration as benefits to river health and environmental inflows benefiting all consumers. Water supply safety, watershed management, restoration of wetlands, ground water harvesting, effective farming management methods, reforestation, sustainable sewage infrastructure and safeguarding mangroves are just a few of the approaches and activities that fall under the broad category of nature based solutions. Most of these techniques and efforts like integrated water management, efficient sewage systems and afforestation were not brand new. But, the word NBS's is still rather new, especially in terms of how frequently policymakers and practitioners use it. Advancement in public healthcare, biodiversity and adaption to climate change are all potential advantages of NBS's. For instance, water harvesting and land conservation in Rajasthan, India, have improved women's status, boosted water security and raised agriculture productivity and also made it easier for wildlife to repopulate the area (54).

Examples of effective water conservation practices

Due to the increasing demand for food and the sector's predominance in water use, sustainable water for agriculture is essential, where it uses 70 % of all ground water. NBS's can promote increase in crop productivity by enhancing the water supply for rain-fed farming practices. Conservation agriculture, composting, vegetative covers/ strips, water recycling and agroforestry are some of the activities that focus on water and soil conservation. In some situations, alternatives like sand dams can also add extra water for irrigation by enabling groundwater infiltration. The most common global problem with water quality is controlling diffuse outflow of extra fertilizers from agriculture. NBS could enhance the water quality by minimizing fertilizers and sediments outflow from farmlands into water basins using practices like tree buffers & riparian grass and vegetative rivers. Few illustrations of NBS's in water conservation are:

Water funding and protection of ground water sources

Water is collected, filtered and stored in watersheds, which is crucial for the provision of metropolitan water. Proper water supply management can lower the cost of water treatment for cities, help local communities to have better access to clean drinking water, enhance water quality for hydropower generation and promote resilience. Water funds are governing bodies that unite various water consumers to induct in upstream ecosystem restoration and land management jointly and to generate creative funding sources. A 10$ million capital in watershed maintenance measures, according to the Upper Tana-Nairobi Water Fund, may generate a return of 21.5$ million, comprising benefits from treatment of wastewater, greater electricity output and higher agricultural output (58).

Crop Rotation's Impact on Water Dynamics

Crop rotation can enhance soil moisture content, decrease water evaporation from the plantation and decrease surface water run-off, resulting in increased crop water usage efficiency. This results directly from water retention, which can enhance a farm's agriculture practices and guarantee adequate water supply for crops. As a result of the water being held in crops or soil, there is less ground water, which significantly lowers the frequency and severity of flood catastrophes and improves the planting system's climatic resilience (59). According to Bowles *et al.* (2020) (60), diverse crop rotation could successfully increase crop yields and provide significant economic advantages by breaking the cycle of diseases, weeds, and herbivores.

Enhanced soil water storage preservation and efficiency of crop water usage

Extreme weather conditions (zero temperatures, droughts, etc.) have significantly slowed down precipitation in recent years by causing evaporation of water present in the soil. The health of the soil and crop yield has been significantly impacted by prolonged soil moisture deficiencies. The agricultural system is now more vulnerable than it was previously. However, research has demonstrated that by appropriately rotating crops, agricultural system can become more resistant to extreme weather (60). On the other hand, crop rotation could retain or enhance water storage ability by intensifying the capacity of the soil to preserve water. In Gansu, China, Wang *et al.* (2021) carried out a maize-potato experiment (61). The findings revealed that, after six years of planting, constant potato farming would decrease the soil's ability to store water by 186.31 mm, whereas constant maize-potato cropping would enhance it by 11.29 mm. Crop rotation, on the other side, could improve crops water usage efficiency by rising crop production and reducing soil water evaporation and canopy transpiration. According to Wang *et al.* (2021) studies, relative to constant maize farming, maize-potato rotation reduced soil water usage rate by 16.81-24.83 % and boosted crop water usage efficiency potency in 3 years by 15.5-23.4 % (61). In the Loess Plateau of China, Han *et al.* 2021 carried out a crop rotation study with various alfalfa amalgamations after tillage and they discovered that after rapeseed was planted amid the winter, the mean grain water usage efficiency was enhanced by 44.4 % in comparison to constant winter rapeseed cropping plantation and by 42.9 % in comparison to constant cultivation of winter wheat. So, crop rotation can significantly raise the soil's moisture content, which improves the crops ability to use water efficiently, encouraging the soil-atmosphere water cycle and increases crops resilience to extreme weather (62).

Mulching - A water saving technique in dry land agriculture

All water conservation methods aim to optimize productivity utilizing the less amount of water. During the seasons of crop growth, proper water utilization is a vital aspect that can significantly increase production. Mulching could therefore be an effective conservative strategy in maintaining soil moisture, controlling temperature, decreasing soil evaporation and at the same time increasing the productivity of dry land farming (63). Agrometeorology and soil are connected by the use of mulching techniques, which can alter the environment in which crops thrive. It is a material that is applied to the soil's surface as a coating. The technique of mulching involves enveloping the top of the soil around plants with natural or inorganic mulch in an effort to promote plant development and enhanced crop yield (63). It wraps soil to safeguard living things and plant roots from various weather conditions. Mulching improves water consumption besides enhancing crop growth and production. Mulches come in two varieties: inorganic,

Figure 4 Biodegradable mulching used for growing iceberg lettuce

which is primarily formed of plastic-based substances and organic, or biodegradable (Figure 4), which are made of organic substances (63). It is yet unknown, which approach is better for agriculture, despite ongoing research. To collect rainwater in regions with intermittent rains, plastic mulching has been placed employing a ridge-furrow or raised-bed system (64). The Losses Plateau region of China employs ridge-furrow mulching technology extensively for the productive cultivation of dry land crops such as potato, wheat, maize and cotton (65). Additionally, one of the key purposes of mulch is to control erosion, which is achieved by spreading vegetative material like pruning's, leaves and grass (66). Mulch application can be categorized as a successful soil conservation technique and it was established that the usage of different biodegradable and synthetic mulches has an impact on crop efficacy and the hydrothermal habitat of the soil in different environmental regions when rain is prevalent.

Mulching is a water conservation strategy in dry land regions to maintain soil moisture, controlling temperature and decreasing soil evaporation (63). In rain-fed agricultural system, surface mulching is a common technique for water conservation. Compared to wheat straw mulch, plastic sheet mulch is much more efficient in conserving soil water (67). The primary benefit of mulching is that it maintains soil moisture by preventing soil erosion, minimizing surface evaporation and regulates soil temperature that reduces the demand of irrigation during cropping seasons. To boost the system's availability for effective utilization of mulching, the soil water and heat transmission system underneath the mulching is crucial (68).

Grey water treatment

According to the estimations, about 1/3rd of people on the earth lack access to safe drinking water (69). Population expansion, economic development involving considerable water use in industry and agriculture and rising standards of living, dietary modifications and extreme weather contributes to the global water problem (70). Additionally, standards for processing civic wastewater constantly needs better results in the eradication of both conventional and novel contaminants, enhancing energy usage and operational expenses. Thus, it is crucial to manage water resources sustainably. Reusing grey water could play a major role in transforming a significant portion of waste water from the waste to a priceless water source (71). The term "Grey water" is used to describe any domestic wastewater (including that produced in washing machines, bathtubs and showers) expect from toilet flushes (72). A significant opportunity for the sustainable management of water resources is the recognition of grey water as a useful supplementary source of nutrients and water. Numerous studies have investigated the ecological, financial and energy aspects of recycling grey water that has been treated using nature based methods over the past two decades. NBS's for the treatment of grey water initially emerged about 20 years ago. In the observation of Li *et al.* (2009) (73) on technological methods for grey water remediation the only approach recorded was manmade wetlands. The recent application of grey water treatment is the use of green walls and roofs, where the earliest study was published in 2008 (74).

Wetlands Restoration

In the perspective of NbS, the significance of wetlands as natural infrastructures is frequently highlighted, with an emphasis on nutrient and pollution retentivity, flow regulation, and erosion prevention (75). Wetland systems, either "natural" or "built," or a hybrid of both are better affordable methods for reducing pollution, storm water management and coastline areas conservation compared to rigid structure alternatives, while also offering a variety of ecological benefits. Native wetlands are intricate ecosystems that involve biological, chemical and physical activities. These wetlands are crucial for safeguarding marine and freshwater ecosystems from excess pathogens, nutrients, silt, metals, oxygen demand, organic, and dissolved inputs, in addition providing a storm-buffer, soil stability, and habitat for wildlife (76). A global foundation for the preservation of natural wetlands was established by the Convention on Wetlands of International Importance, also known as the Ramsar Convention, which took place in 1971. Worldwide estimates of the extent of wetland eco-systems range over 1270 Mha (77) to 917 Mha (78). There are currently 1052 sites classified as wetlands of international importance in Europe, 175 places in South America, 211 places in North America, 289 places in Asia, 359 places in Africa and 79 places in Oceania (79). Irrespective of these global initiatives, surveillance of 1000 Ramsar wetlands from 1970 to 1999 revealed that these habitats decreased by 40% on average (77). In the world's most urbanized areas, such as China (80) and India (81), the wetlands loss is especially severe. But, natural wetlands have been threatened by urbanization, industrialization, and the spread of agriculture everywhere in the world, but mainly in metropolitan regions (82).

Restoring damaged wetland habitats completely or partial functional has been one strategy for reversing this tendency. As an alternative, wetlands can be developed to provide particular ecological solutions, like retention of pollutants, wastewater treatment and providing habitat for wildlife (83). Since both natural and artificial wetlands can perform a number of ecological processes, these particular ecosystem services don't necessarily have to be mutually exclusionary (84). The potency of wetlands as NBS for reduction of disaster risk is demonstrated by a fascinating case from the Yangtze River basin in China. This basin, which is home with over 400 million people, witnessed a massive storm in 1998, which resulted in 4000 fatalities and 25 billion dollars in property damage. The "32 Character Policy" in China led to the recovery of 2900 km^2 of flood plain wetlands with the ability to conserve or 13 km^3 or 13 billion m^3 of water as a disaster risk management approach (85). To maintain water quality, protect regional biodiversity and to extend wetland-based nature reserves, long lasting wetland dependent natural reserves were throughout the Yangtze River basin.

Another advantage of wetlands containing various species of plants is their capability of carbon sequestration (86) which is contributing in reducing the impacts of climate changes (87). Apart from making up only a small portion of our world, they are crucial carbon sinks because they can simultaneously operate as a source or a sink for DOC (Dissolved Organic Carbon) (88). Studies report that they store up to 1/3rd of the soil organic carbon of the world (89). The Carbon dioxide equilibrium of a formulated wetland was evaluated by De Klein and Van der Werf (2014) and was calculated to be between 0.27 and 2.4 kg per m^2 annually (90). In addition to this, carbon equilibrium of the Tadham Moor, a plain wet grassland was investigated by Lloyd (2006) and it was discovered that in 2002, more carbon was integrated into the wetland than was produced which is of a difference of 169 gr per m^2 (91). By taking into consideration of various estimates of wetlands, Souliotis and Voulvoulis (2022) calculated the mean amount of 8.02 carbon dioxide equivalent/ha annually (92).

Water conservation projects initiated in India

The Jal Shakti Abhiyan was introduced in 2019 by the Indian government's Ministry of Jal Shakti. Aiming to encourage water conservation at the basic scale, it is a national initiative that strives to encourage citizen participation. Two phases of the water conservation initiative were started, from July 1st to September 30th and from October 1st to November 30th. The government introduced the "Jal Shakti Abhiyan: Catch the Rain" (JSA:CTR) on March 22nd, 2021, World Water Day, with the slogan "*Catch the rain, Where it Falls, When it Falls*." It includes all districts in India's rural and urban regions during the pre-monsoon and monsoon seasons, till November 30th, 2021. The government's emphasizes on watershed development, intense afforestation, rehabilitation of various conventional water containers, reusing water and replenishing deep wells and construction of water conservation and rainwater harvesting structures (https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1740374).

Jal Sanchay

In the Bihar district of Nalanda, the Jal Sanchay project was launched as a water conservation effort. The construction of check dams and renovation of the irrigation system, as well as conventional water bodies, were the main objectives of the water conservation project. In order to maintain the water table rates, it also involved in raising awareness of conventional water saving practices and rainwater harvesting methods. Further, this initiative was carried out with the aid of campaigns and local farmers. The Mahatma Gandhi National Rural Employment Guarantee Program's 2017 national award for excellence was given to this project (MGNREGP) (https://www.indiatoday.in/education-today/gk-current-affairs/story/jal-sanchay-project-national-award-982523-2017-06-13).

Conclusion

An efficient utilization of resources, limited supply chains and climate resilient farming methods are necessary for the establishment of a sustainable food supply chain. For this, the only option is to maximize the area of cultivable land as it is very less and is gradually shrinking as a consequence of the rising rates of numerous forms of degradation. Additionally it is required to enhance crop productivity or we have to restore the degraded areas. All types of terrestrial systems need healthy soil with better bio-physico-chemical qualities, as well as access to water. This is because plants need these conditions for appropriate development and growth. Usage of water & soil preservation initiatives, biological (agriculture and agroforestry) and mechanical (trenching, bunding, check dams, terracing, etc.) processes is essential to minimize runoff and soil erosion as well as to enhance soil health, quality of water, moisture restoration and ultimately crop outcome in a sustainable manner. The conservation of groundwater and soil resources can be accomplished through the use of economically viable, eco friendly biological techniques which also enhance soil characteristics. Besides this, combining mechanical and biological techniques together will aid in enhancing the agricultural productivity. In this regard, nature based solutions are being used in many places to preserve plants, store food grains and in decreasing post-harvest losses. Further, nature based soil rejuvenation maintains crop yield while simultaneously improving soil quality with low negative environmental effects and on a long term basis, these methods will be viable. This review discussed about various promising examples of nature based solutions to achieve sustainable soil and water for enhanced agricultural outcomes.

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Authors contributions

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References

1. Godfray HC, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C. Food security: the challenge of feeding 9 billion people. science. 2010;327(5967):812-8. https://doi.org/10.1126/science.1185383
2. Ahmad N, Pandey P. Assessment and monitoring of land degradation using geospatial technology in Bathinda district, Punjab, India. Solid Earth. 2018 Feb 8;9(1):75-90.
3. UNCCD (2019). Land-Based Adaptation and Resilience: Powered By Nature. Report retrieved from https://www.eld-initiative.org/fileadmin/pdf/Land_Based_Adaptation_ENG_Sall_web.pdf
4. Benton TG, Bieg C, Harwatt H, Pudasaini R, Wellesley L. Food system impacts on biodiversity loss. Three levers for food system transformation in support of nature. Chatham House, London. 2021 Feb 3.
5. Van Dijk M, Morley T, Rau ML, Saghai Y. A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. Nature Food. 2021 Jul;2(7):494-501.
6. IPBES. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In: Brondizio ES, Settele J, Diaz S, Ngo HT, editors. IPBES secretariat, Bonn, Germany 2019.
7. Kumar S, Singh AK, Singh R, Ghosh A, Chaudhary M, Shukla AK, Kumar S, Singh HV, Ahmed A, Kumar RV. Degraded land restoration ecological way through horti-pasture systems and soil moisture conservation to sustain productive economic viability. Land Degradation & Development. 2019 Jul 30; 30(12):1516-29. https://doi.org/10.1002/ldr.3340
8. Boretti A, Rosa L. Reassessing the projections of the world water development report. NPJ Clean Water. 2019 Jul 31;2(1):1-6.
9. United Nations. (2019). World Water Development Report 2019: Leaving no one behind (Unesco, Ed.). UNESCO.
10. Srinivasarao CH, Venkateswarlu B, Lal R, Singh AK, Kundu S, Vittal KP, Patel JJ, Patel MM. Long-term manuring and fertilizer effects on depletion of soil organic carbon stocks under pearl millet-cluster bean-castor rotation in Western India. Land Degradation & Development. 2014 Mar; 25(2):173-83. https://doi.org/10.1002/ldr.1158
11. Iseman T, Miralles-Wilhelm F Nature-based solutions in agriculture: The case and pathway for adoption. Food & Agriculture Org. 2021
12. IUCN. A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0. First edition. Gland, Switzerland: IUCN; 2016. ISBN: 978-2-8317-1835-4.
13. European Commission (EC) Towards an EC research and innovation policy agenda of nature-based solutions and re-naturing cities. European Commission (EC), Brussels; 2015
14. Cohen-Schacham E, Walters G, Janzen C, Maginnis S. Nature-based solutions: from theory to practice. (Iucn, ed.). Nature-based Solutions to Address Global Societal Challenges; 2016. https://doi.org/10.2305/IUCN.CH.2016.13.en
15. Pittelkow CM, Linquist BA, Lundy ME, Liang X, Van Groenigen KJ, Lee J, Van Gestel N, Six J, Venterea RT, Van Kessel C. When does no-till yield more? A global meta-analysis. Field crops research. 2015 Nov 1;183:156-68. https://doi.org/10.1016/j.fcr.2015.07.020
16. Kebede E. Contribution, Utilization, and Improvement of Legumes-Driven Biological Nitrogen Fixation in Agricultural Systems. Front. Sustain. Food Syst. 5: 767998. https://doi:10.3389/fsufs. 2021 Nov 16.
17. Yin C, Jones KL, Peterson DE, Garrett KA, Hulbert SH, Paulitz TC. Members of soil bacterial communities sensitive to tillage and crop rotation. Soil Biology and Biochemistry. 2010 Dec 1;42(12):2111-8.
18. Ayaz M, Feizienė D, Tilvikienė V, Akhtar K, Stulpinaitė U, Iqbal R. Biochar role in the sustainability of agriculture and environment. Sustainability. 2021 Jan 27;13(3):1330.
19. Nazli RI, Inal I, Kusvuran A, Demirbas A, Tansi V. Effects of different organic materials on forage yield and nutrient uptake of silage maize (Zea mays L.). Journal of Plant Nutrition. 2016 Jun 6;39(7):912-21.
20. Bertoldi MD. Production and utilization of suppressive compost: environmental, food and health benefits. In Microbes at Work 2010 (pp. 153-170). Springer, Berlin, Heidelberg.
21. FAO (Food and Agriculture Organization of the United Nations). Case Studies on Policies and Strategies for Sustainable Soil Fertility and Fertilizer Management in South Asia; Office of Knowledge Exchange, Research and Extension: Bangkok, Thailand, 2011; pp. 1–3. ISBN 978-92-5-106914-1.
22. Manono BO. Carbon dioxide, nitrous oxide and methane emissions from the Waimate District (New Zealand) pasture soils as influenced by irrigation, effluent dispersal and earthworms. Cogent Environmental Science. 2016 Dec 31;2(1):1256564.
23. Ya T. Role of trees in croplands. Forests and Forest Plants-Volume III. 2009 Feb 24:77.
24. Tugrul KM. Soil management in sustainable agriculture. *In* Sustainable crop production 2019 Sep 5. London, UK: IntechOpen.
25. Dick WA, Durkalski JT. No-tillage production agriculture and carbon sequestration in a Typic Fragiudalf soil of northeastern Ohio. In Management of carbon sequestration in soil 2019 Aug 8 (pp. 59-71). CRC Press.
26. Doran JW, Parkin TB. Defining and assessing soil quality. Defining soil quality for a sustainable environment. 1994 May 1; 35:1-21. https://doi.org/10.2136/sssaspecpub35.c1
27. Angers DA, Pesant A, Vigneux J. Early cropping-induced changes in soil aggregation, organic matter, and microbial biomass. Soil Science Society of America Journal. 1992 Jan; 56(1):115-9. https://doi.org/10.2136/sssaj1992.03615995005600010018x

28. Chan KY. Soil particulate organic carbon under different land use and management. Soil use and management. 2001 Dec; 17(4):217-21. https://doi.org/10.1079/SUM200180

29. Nael M, Khademi H, Hajabbasi MA. Response of soil quality indicators and their spatial variability to land degradation in central Iran. Applied soil ecology. 2004 Nov 1; 27(3):221-32. https://doi.org/10.1016/j.apsoil.2004.05.005

30. Ferreras LA, Costa JL, Garcia FO, Pecorari C. Effect of no-tillage on some soil physical properties of a structural degraded Petrocalcic Paleudoll of the southern “Pampa” of Argentina. Soil and Tillage research. 2000 Mar 1; 54(1-2):31-9. https://doi.org/10.1016/S0167-1987(99)00102-6

31. Gonzalez-Ollauri A. Sustainable Use of Nature-Based Solutions for Slope Protection and Erosion Control. Sustainability. 2022 Feb 9;14(4):1981.

32. Apollonio C, Petroselli A, Tauro F, Cecconi M, Biscarini C, Zarotti C, Grimaldi S. Hillslope erosion mitigation: An experimental proof of a nature-based solution. Sustainability. 2021 Jan; 13(11):6058. https://doi.org/10.3390/su13116058

33. Stanchi S, Zecca O, Hudek C, Pintaldi E, Viglietti D, D’Amico ME, Colombo N, Goslino D, Letey M, Freppaz M. Effect of soil management on erosion in mountain vineyards (NW Italy). Sustainability. 2021 Feb 12; 13(4):1991. https://doi.org/10.3390/su13041991

34. Capobianco V, Robinson K, Kalsnes B, Ekeheien C, Høydal Ø. Hydro-mechanical effects of several riparian vegetation combinations on the streambank stability-A benchmark case in southeastern Norway. Sustainability. 2021 Apr 6; 13 (7):4046. https://doi.org/10.3390/su13074046

35. Gonzalez-Ollauri A, Mickovski SB. The effect of willow (Salix sp.) on soil moisture and matric suction at a slope scale. Sustainability. 2020 Nov 24; 12(23):9789. https://doi.org/10.3390/su12239789

36. Sorolla A, Piera E, Mota-Freixas B, Sorolla Salvans G, Rueda I, Lochner Prats A, Unzeta C. Improvement of the Plantation Success in a Crib Wall in a Mediterranean Hydro-Meteorological Risks Scenario-Practical Results. Sustainability. 2021 Oct 25; 13(21):11785. https://doi.org/10.3390/su132111785

37. de Torres MA, Carbonell-Bojollo RM, Moreno-Garcia M, Ordonez-Fernandez R, Rodriguez-Lizana A. Soil organic matter and nutrient improvement through cover crops in a Mediterranean olive orchard. Soil and Tillage Research. 2021 Jun 1;210:104977.

38. Wright PJ, Falloon RE, Hedderley D. Different vegetable crop rotations affect soil microbial communities and soilborne diseases of potato and onion: literature review and a long-term field evaluation. New Zealand Journal of Crop and Horticultural Science. 2015 Apr 3; 43(2):85-110. https://doi.org/10.1080/01140671.2014.979839

39. N’Dayegamiye A, Nyiraneza J, Grenier M, Bipfubusa M, Drapeau A. The benefits of crop rotation including cereals and green manures on potato yield and nitrogen nutrition and soil properties. Advances in Crop Science and Technology. 2017; 5(3):279. https://doi.org/10.4172/2329-8863.1000279

40. Chen D, Chen X, Liang Y, Huo X, Zhang C, Duan Y, Yang Y, Yuan L. Influence of crop rotation on soil nutrients, microbial activities and bacterial community structures. Acta Prataculturae Sinica. 2015; 24:56–65.

41. Troeh FR, Thompson LM. Soils and Soil Fertility. 6th ed. New York:Blackwell NY, USA; 2005. p. 1–10.

42. Yu T, Mahe L, Li Y, Wei X, Deng X, Zhang D. Benefits of crop rotation on climate resilience and its prospects in China. Agronomy. 2022 Feb 10;12(2):436.

43. Goff, B. Putting Some Pop Back in Your Crop: Alfalfa in Crop Rotations. Available online: https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1006&context=ky_grazing

44. Wang ZQ, Liu Y, Yang WT, Zhao Q, Muhammad A, Wang H, Huang GQ, Zhao QG. Effects of rotation and fallow in paddy field on distribution and stability of soil aggregates. Acta Pedologica Sinica. 2018; 55:1143-55.

45. Glick BR. Using soil bacteria to facilitate phytoremediation. Biotechnology advances. 2010 May 1;28(3):367-74.

46. Dutta S, Podile AR. Plant growth promoting rhizobacteria (PGPR): the bugs to debug the root zone. Critical reviews in microbiology. 2010 Aug 1;36(3):232-44.

47. Srivastava RA, Singh AN. Plant growth promoting rhizobacteria (PGPR) for sustainable agriculture. Article International Journal of Agricultural Science and Research (IJASR). 2017;7(4):505-10.

48. Kumari B, Solanki AC, Mallick MA. Microbiomes in some cereal crops: diversity and their role in geochemical nutrient recycling. InMicrobiomes and Plant Health 2021 Jan 1 (pp. 429-448). Academic Press.

49. Sajjad Mirza M, Ahmad W, Latif F, Haurat J, Bally R, Normand P, Malik KA. Isolation, partial characterization, and the effect of plant growth-promoting bacteria (PGPB) on micro-propagated sugarcane in vitro. Plant and soil. 2001 Nov; 237 (1):47-54. https://doi.org/10.1023/A:1013388619231

50. Akhtar M, Siddiqui Z. Effects of phosphate solubilizing microorganisms and Rhizobium sp. on the growth, nodulation, yield and root-rot disease complex of chickpea under field condition. African Journal of Biotechnology. 2009; 8(15).

51. Biswas JC, Ladha JK, Dazzo FB, Yanni YG, Rolfe BG. Rhizobial inoculation influences seedling vigor and yield of rice. Agronomy Journal. 2000 Sep; 92(5):880-6. https://doi.org/10.2134/agronj2000.925880x

52. Zhuang X, Chen J, Shim H, Bai Z. New advances in plant growth-promoting rhizobacteria for bioremediation. Environment international. 2007 Apr 1; 33(3):406-13. https://doi.org/10.1016/j.envint.2006.12.005

53. Glick BR. Using soil bacteria to facilitate phytoremediation. Biotechnology advances. 2010 May 1; 28(3):367-74. https://doi.org/10.1016/j.biotechadv.2010.02.001

54. Water UN. 2018 UN World Water Development Report, Nature -based Solutions for Water.

55. Coates D, Pert PL, Barron J, Muthuri C, Nguyen-Khoa S, Boelee E, Jarvis DI. Water-related ecosystem services and food security. Managing water and agroecosystems for food security. 2013; 10:29. https://doi.org/10.1079/9781780640884.0029

56. Sonneveld BG, Merbis MD, Alfarra A, Ünver O, Arnal MF. Nature-based solutions for agricultural water management and food security. FAO Land and Water Discussion Paper. 2018(12).

57. UNWWAP W. The United Nations World Water Development Report 2017-Wastewater: The untapped resource.

58. Cooper R. Nature-based Solutions and Water Security. 2020

59. Pala M, Ryan J, Zhang H, Singh M, Harris HC. Water-use efficiency of wheat-based rotation systems in a Mediterranean environment. Agricultural water management. 2007 Nov 16;93(3):136-44.

60. Bowles TM, Mooshammer M, Socolar Y, Calderon F, Cavigelli MA, Culman SW, Deen W, Drury CF, Garcia AG, Gaudin AC, et al. Long-term evidence shows that crop-rotation diversification increases agricultural resilience to adverse growing conditions in North America. One Earth. 2020; 2:284-

293. https://doi.org/10.1016/j.oneear.2020.02.007

61. Wang H, Zhang X, Yu X, Hou H, Fang Y, Ma Y, Zhang G. Maize⊠potato rotation maintains soil water balance and improves productivity. Agronomy Journal. 2021 Jan; 113(1):645-56. https://doi.org/10.1002/agj2.20434

62. Han L, Ding J, Han Q, Ding R, Nie J, Jia Z, Li W. Effects of alfalfa-grain (oil) crop plowing rotation on soil moisture and crop yield in Loess Plateau. Trans. Chin. Soc. Agric. Eng. 2021; 28:129–137.

63. Kader MA, Senge M, Mojid MA, Ito K. Recent advances in mulching materials and methods for modifying soil environment. Soil and Tillage Research. 2017 May 1; 168:155-66. https://doi.org/10.1016/j.still.2017.01.001

64. Li C, Wang C, Wen X, Qin X, Liu Y, Han J, Li Y, Liao Y, Wu W. Ridge–furrow with plastic film mulching practice improves maize productivity and resource use efficiency under the wheat–maize double–cropping system in dry semi–humid areas. Field crops research. 2017 Mar 1; 203:201-11. https://doi.org/10.1016/j.fcr.2016.12.029

65. Zhao H, Wang RY, Ma BL, Xiong YC, Qiang SC, Wang CL, Liu CA, Li FM. Ridge-furrow with full plastic film mulching improves water use efficiency and tuber yields of potato in a semiarid rainfed ecosystem. Field Crops Research. 2014 May 1; 161:137-48. https://doi.org/10.1016/j.fcr.2014.02.013

66. Adekalu KO, Olorunfemi IA, Osunbitan JA. Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. Bioresource technology. 2007 Mar 1; 98(4):912-7. https://doi.org/10.1016/j.biortech.2006.02.044

67. Li R, Hou X, Jia Z, Han Q, Ren X, Yang B. Effects on soil temperature, moisture, and maize yield of cultivation with ridge and furrow mulching in the rainfed area of the Loess Plateau, China. Agricultural Water Management. 2013 Jan 1; 116:101-9. https://doi.org/10.1016/j.agwat.2012.10.001

68. Kader MA, Nakamura K, Senge M, Mojid MA, Kawashima S. Numerical simulation of water-and heat-flow regimes of mulched soil in rain-fed soybean field in central Japan. Soil and Tillage Research. 2019 Aug 1; 191:142-55. https://doi.org/10.1016/j.still.2019.04.006

69. Ghaitidak DM, Yadav KD. Characteristics and treatment of greywater—a review. Environmental Science and Pollution Research. 2013 May; 20(5):2795-809. https://doi.org/10.1007/s11356-013-1533-0

70. Kummu M, Ward PJ, de Moel H, Varis O. Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. Environmental Research Letters. 2010 Aug 16; 5(3):034006. https://doi.org/10.1088/1748-9326/5/3/034006

71. Friedler E, Hadari M. Economic feasibility of on-site greywater reuse in multi-storey buildings. Desalination. 2006 Apr 15; 190(1-3):221-34. https://doi.org/10.1016/j.desal.2005.10.007

72. Eriksson E, Auffarth K, Henze M, Ledin A. Characteristics of grey wastewater. Urban water. 2002 Mar 1; 4(1):85-104. https://doi.org/10.1016/S1462-0758(01)00064-4

73. Li F, Wichmann K, Otterpohl R. Review of the technological approaches for grey water treatment and reuses. Science of the total environment. 2009 May 15; 407(11):3439-49. https://doi.org/10.1016/j.scitotenv.2009.02.004

74. Frazer-Williams R, Avery L, Winward G, Jeffrey P, Shirley-Smith C, Liu S, Memon F, Jefferson B. Constructed wetlands for urban grey water recycling. International Journal of Environment and Pollution. 2008 Jan 1; 33(1):93-109. https://doi.org/10.1504/IJEP.2008.018470

75. Thorslund J, Jarsjo J, Jaramillo F, Jawitz JW, Manzoni S, Basu NB, Chalov SR, Cohen MJ, Creed IF, Goldenberg R, Hylin A. Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management. Ecological Engineering. 2017 Nov 1; 108:489-97. https://doi.org/10.1016/j.ecoleng.2017.07.012

76. Sierszen ME, Morrice JA, Trebitz AS, Hoffman JC. A review of selected ecosystem services provided by coastal wetlands of the Laurentian Great Lakes. Aquatic Ecosystem Health & Management. 2012 Jan 1; 15(1):92-106. https://doi.org/10.1080/14634988.2011.624970

77. Finlayson CM, Davidson NC. Global review of wetland resources and priorities for wetland inventory. Preface iv Summary Report. 1999; 15.

78. Lehner B, Doll P. Development and validation of a global database of lakes, reservoirs and wetlands. Journal of hydrology. 2004 Aug 20; 296(1-4):1-22. https://doi.org/10.1016/j.jhydrol.2004.03.028

79. Secretariat R The list of wetlands of international importance. The Ramsar Convention Bureau, Gland, Switzerland; 2013

80. Jiang TT, Pan JF, Pu XM, Wang B, Pan JJ. Current status of coastal wetlands in China: degradation, restoration, and future management. Estuarine, Coastal and Shelf Science. 2015 Oct 5; 164:265-75. https://doi.org/10.1016/j.ecss.2015.07.046

81. Bassi N, Kumar MD, Sharma A, Pardha-Saradhi P. Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies. Journal of Hydrology: Regional Studies. 2014 Nov 1; 2:1-9. https://doi.org/10.1016/j.ejrh.2014.07.001

82. Hettiarachchi M, Morrison TH, McAlpine C. Forty-three years of Ramsar and urban wetlands. Global Environmental Change. 2015 May 1; 32:57-66. https://doi.org/10.1016/j.gloenvcha.2015.02.009

83. Guittonny-Philippe A, Masotti V, Höhener P, Boudenne JL, Viglione J, Laffont-Schwob I. Constructed wetlands to reduce metal pollution from industrial catchments in aquatic Mediterranean ecosystems: A review to overcome obstacles and suggest potential solutions. Environment International. 2014 Mar 1; 64:1-6. https://doi.org/10.1016/j.envint.2013.11.016

84. Hsu CB, Hsieh HL, Yang L, Wu SH, Chang JS, Hsiao SC, Su HC, Yeh CH, Ho YS, Lin HJ. Biodiversity of constructed wetlands for wastewater treatment. Ecological Engineering. 2011 Oct 1; 37(10):1533-45. https://doi.org/10.1016/j.ecoleng.2011.06.002

85. Wang Y, Li L, Wang X, Yu X, Wang Y. Taking stock of integrated river basin management in China. World Wildlife Fund China, Science Press, Beijing, Peoples Republic of China; 2007

86. Du Y, Pan K, Yu C, Luo B, Gu W, Sun H, Min Y, Liu D, Geng Y, Han W, Chang SX. Plant diversity decreases net global warming potential integrating multiple functions in microcosms of constructed wetlands. Journal of Cleaner Production. 2018 May 20; 184:718-26. https://doi.org/10.1016/j.jclepro.2018.02.273

87. Vymazal J. Enhancing ecosystem services on the landscape with created, constructed and restored wetlands. Ecological Engineering. 2011; 1(37):1-5. https://doi.org/10.1016/j.ecoleng.2010.07.031

88. Melton JR, Wania R, Hodson EL, Poulter B, Ringeval B, Spahni R, Bohn T, Avis CA, Beerling DJ, Chen G, Eliseev AV. Present state of global wetland extent and wetland methane modelling: conclusions from a model inter-comparison project (WETCHIMP). Biogeosciences. 2013 Feb 4; 10(2):753-

88. https://doi.org/10.5194/bg-10-753-2013

89. Villa JA, Bernal B. Carbon sequestration in wetlands, from science to practice: An overview of the biogeochemical process, measurement methods, and policy framework, Ecol. Eng. 114 2018; 115–128. doi: 10.1016/j.ecoleng.2017.06.037 . https://doi.org/10.1016/j.ecoleng.2017.06.037

90. de Klein JJ, van der Werf AK. Balancing carbon sequestration and GHG emissions in a constructed wetland. Ecological Engineering. 2014 May 1; 66:36-42. https://doi.org/10.1016/j.ecoleng.2013.04.060

91. Lloyd CR. Annual carbon balance of a managed wetland meadow in the Somerset Levels, UK. Agricultural and Forest Meteorology. 2006 Aug 29; 138(1-4):168-79. https://doi.org/10.1016/j.agrformet.2006.04.005

92. Souliotis I, Voulvoulis N. Operationalising nature-based solutions for the design of water management interventions. Nature-Based Solutions. 2022 Dec 1; 2:100015. https://doi.org/10.1016/j.nbsj.2022.100015