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INNOVATIVE TECHNOLOGIES FOR SOIL WATER CONSERVATION ON DEGRADED AND ERODED LANDS

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Abstract: Soil water conservation represents a major challenge in the management of degraded, erosion–prone lands, with a direct impact on agricultural productivity and ecosystem sustainability. This paper explores innovative technologies aimed at reducing water loss and enhancing soil moisture retention capacity through methods adapted to eroded land conditions. Solutions analyzed include the use of compartmentalized furrows, biochar to improve water retention capacity, application of organic mulch and hydro–absorbent amendments, implementation of soil conservation practices, and the use of cover vegetation to stabilize the soil surface. Efficient irrigation systems and rainwater management strategies are also evaluated to maximize infiltration and reduce surface runoff. The article includes a set of validated agricultural technologies that can be integrated into both organic and conventional farming systems.
Keywords: soil, erosion, technologies, conservation

1. INTRODUCTION

Ensuring a sustainable and secure food supply represents a major global challenge in an increasingly dynamic world, with the global population projected to reach 9 billion by 2050. However, the agricultural sector faces numerous complications and constraints in expanding and diversifying production, largely due to climate change and various land degradation processes such as soil erosion. Soil erosion has significantly impacted agriculture–based economies, contributing to a marked increase in food prices over recent decades, ranging between 0.4% and 3.5%, depending on the category of food products [35].

Soil erosion generally refers to the displacement of the uppermost soil layer; it is a form of land degradation driven by natural phenomena. This process may occur slowly, going largely unnoticed, or it may progress at an alarming rate, resulting in severe soil loss. The dynamic activity of erosive agents—including water, ice (glaciers), snow, wind, vegetation, and animals—contributes to the phenomenon [29]. In recent decades, accelerated soil erosion has been increasingly associated with anthropogenic factors, particularly intensive and extensive agricultural practices.

Soil erosion is commonly classified into natural and accelerated types, depending on its severity. Natural erosion occurs under the influence of environmental factors, and within this category, it can be further subdivided into water erosion, glacial erosion, snow erosion, wind (aeolian) erosion, zoogenic erosion, and anthropogenic erosion.

(a) (b)

Figure 1. a) Soil erosion in a cornfield; b) Erosion on a deforested plot [44]

By contrast, accelerated soil erosion occurs as a result of anthropogenic activities such as deforestation, inappropriate agricultural practices, and overgrazing, which significantly increase the rate of soil loss [22]. Accelerated soil erosion has been identified as a major concern in both agriculture and ecosystem sustainability, contributing to soil degradation, nutrient depletion, reduced soil fertility, sedimentation, and eutrophication, while also diminishing the capacity of downstream water bodies—thereby increasing the risk of flooding. The loss of soil from agricultural lands can manifest in reduced agricultural productivity, lower surface water quality, and damaged drainage infrastructure. Moreover, soil erosion may also lead to the formation of sinkholes [21], [29].

2. MATERIALS AND METHODS

A wide range of erosion control methods are used to mitigate soil erosion caused by various erosive agents such as water, wind, animals, and human activities. The following section outlines several established techniques and current trends in soil erosion control.

The compartmentalized furrow, also known simply as the furrow dike, is a result of mechanized plowing that creates interrupted furrows at customizable intervals to collect water in small basins. During rainy periods, excess water accumulates in these micro–basins, gradually infiltrating into the soil and preventing runoff beyond the planted perimeter [15].

Furrow construction is also beneficial in fields where irrigation is performed using fixed or mobile sprinkler systems, particularly when the terrain has irregularities or slopes that facilitate water runoff and pooling in micro–depressions [31].

Another area where this technology proves especially valuable is on land with turbulent micro–relief and gentle slopes—areas unsuitable for conventional irrigation—where rainwater tends to flow quickly downslope, inducing erosion [20]. This scenario is particularly relevant to vineyards, which are typically established in hilly regions prone to frequent landslides. Vineyards located in hard–to–reach areas often struggle to maintain an optimal irrigation regime, and the loss of the fertile topsoil is a common occurrence. Erosion caused by heavy rainfall (which washes away the soil), as well as wind erosion (driven by intense winds) on sloped land, can be effectively mitigated by implementing compartmentalized furrows. The purpose of these dikes is to create large sections of micro–basins that can capture and retain as much water as possible [4], [21].

Figure 2. Modeling compartmentalized segments in the furrow diking system for sunflower culture [30]

Wind can also exert a significant negative impact on hilly and low–yield lands. It can rapidly dehydrate the upper soil layer, leading to vegetation desiccation, while strong winds may even displace the fertile soil layer, thereby contributing to landslides [21]. Under such harsh conditions, the use of interrupted furrows may prove beneficial for storing water in the lower soil layers, thus minimizing erosion phenomena induced by both precipitation and wind [28].

In furrow diking technology, the shape and structural properties of micro–basins must be customized. For instance, on sandy soils, the dikes must be smaller and spaced farther apart to maintain stability throughout the season. Although several technical solutions for creating

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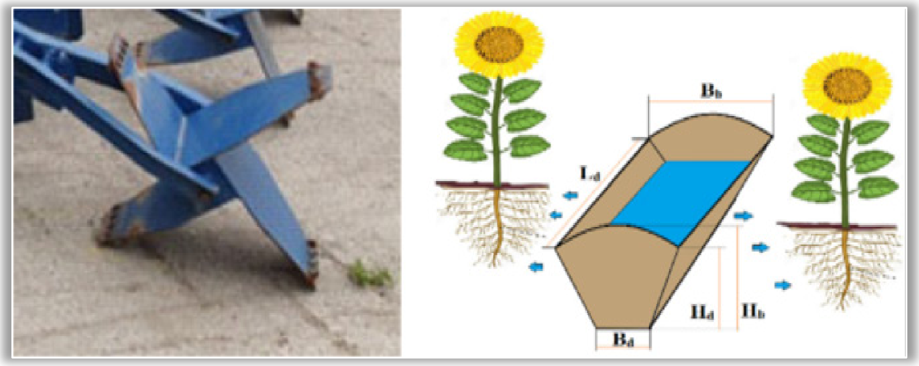
compartmentalized furrows exist, they often do not allow for personalized basin shapes that account for specific crop requirements and soil types [15].

Research studies on the use of compartmentalized furrows have demonstrated a significant increase in subsoil water reserves and crop productivity. For example, one study evaluating the effectiveness of furrow diking technology for cotton cultivation on a 5% slope reported an average yield increase of 116 kg/ha, while for sorghum, the average yield rose by 176% [17].

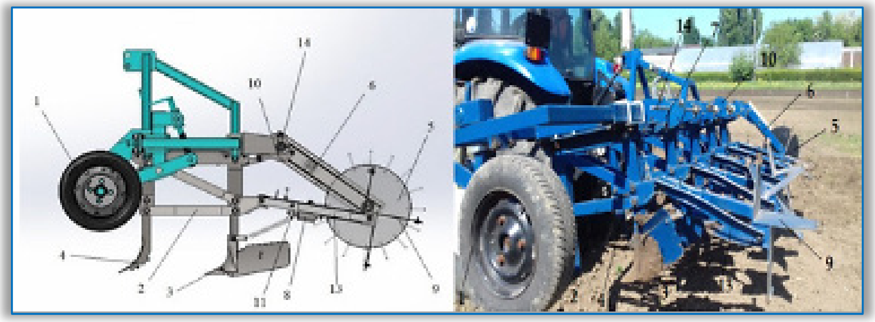
However, commercial implementations of such systems face several limitations, including the reduced capacity to construct high–precision earthen dikes, the high cost of hydraulically powered variants, and the inability to customize micro–basins with optimized geometries.



(a) (b)

Figure 3. Furrow diking technology in detail with the active component, consisting of a soil–modeling rotor (a) that shapes the earth into prismatic patterns (b) [30]

Micro–basins are formed using specialized equipment mounted on an agricultural tractor. In this study, an experimental prototype was employed to create compartmentalized furrows on agricultural land with a 7–degree slope—an area particularly prone to soil erosion. The equipment includes chisel–type scarifiers for soil loosening, a blade system for weed removal and irrigation channel formation, and five rotary blades specifically designed to shape the compartmentalized furrows. Figure 4 provides a detailed description of the furrow diking system.



(a) (b)

Figure 4. Equipment for opening and partitioning water furrows. (a) Equipment overview. (b) Simplified technical scheme consisting of: 1—support wheel, 2—supporting frame, 3—gripping triangle, 4—arrow knife for hoeing, 5—spur wheel for driving the compartmenting mechanism, 6—chain drive, 7—camshaft support, 8—locking element, 9—vane rotor, 10—camshaft, 11—ground pressing mechanism, 12—lever, 13—rotor support, 14—camshaft axle [33]

Furrow diking equipment is typically operated shortly after crop establishment and, under ideal conditions, can enhance productivity. However, maintaining consistent protective effects of micro–basins under variable environmental conditions is sometimes challenging. Several studies have examined how rainfall and slope gradients affect the durability and efficiency of furrow–based conservation systems [11], [41]. Simulated rainfall experiments involving four intensities and three slope angles were conducted to investigate how rainfall intensity and slope influence the integrity of compartmentalized soil structures and the development of water runoff.

The experiments indicated that furrow reservoirs could experience severe overflow under increased rainfall intensity and slope conditions, leading to the deterioration and collapse of soil structures. During the process, runoff and soil loss accelerated rapidly, and severe erosion occurred on the dikes, which significantly reduced their capacity to absorb rainwater and sediments, thereby diminishing the overall effectiveness of water and soil conservation.

Extended drought periods during the crop's vegetative stage necessitate supplemental irrigation to avoid water stress that limits yield. To assess the water retention and erosion control capacity of furrow dikes, researchers evaluated runoff and soil loss in furrowed and non–furrowed tillage systems. The study demonstrated that this technique offers a cost–effective management solution for farmers in the southeastern United States, supporting natural resource conservation, increasing profit margins, and improving environmental quality.

Due to technological limitations, weed pressure, inconsistent crop yield responses, the adoption of conservation tillage, and the use of intensive chemical treatments, furrow diking has been largely abandoned. However, this technology has recently regained significant interest, as it can be successfully integrated into regenerative agriculture as a soil and water conservation method—particularly during summer, when runoff potential is highest. Key benefits include increased surface depression storage, enhanced capture of rainfall and irrigation, improved infiltration, and reduced runoff and soil loss, which align well with the principles of regenerative agriculture [2].

Improving water use efficiency is an important response to increasing water demands, which involves ensuring that sufficient fresh water remains in rivers and lakes to support ecosystems while also meeting the growing needs of urban and industrial users [38]. Water use efficiency is commonly defined as the amount of carbon assimilated as biomass or the grain yield produced per unit of water consumed by the crop [16]. The current focus on water productivity has evolved to also include the broader benefits and costs of water use in agriculture, with the goal of delivering more food, income, employment, and environmental gains at a lower social and environmental cost per unit of water used [37].

Furrow diking systems can enhance overall production potential and profit margins by allowing farmers to utilize more natural rainfall and/or irrigation while also extending the intervals between additional watering events. Long–term experiments [40] have shown that furrow dikes are capable of retaining between 25 and 30 mm of runoff annually, with maximum exceptional results exceeding 100 mm per year. Several studies have employed rainfall simulators to model runoff behavior under various basin and reservoir treatments [5]. However, the properties of rainwater (such as intensity, duration, and volume) can differ significantly from those of linear move sprinkler irrigation systems. Therefore, the actual effect of water on earthen dikes must be studied further.

Our general objective is to identify new techniques for improving water use efficiency, particularly in sunflower cultivation on lands with challenging characteristics—such as steep slopes, low water retention capacity, or tendencies toward desertification. This paper addresses the technology of soil moisture preservation through the use of the compartmentalized furrow diking system. Based on standard furrow diking equipment, the active components were recalculated and enhanced, and new structural configurations were tested in conjunction with this technology. Subsequently, we evaluated and compared the outcomes to determine which design variant yields the most promising results in improving rainfall water efficiency for sunflower crops [30].

Mulching is a temporary or permanent erosion control mechanism in which crop residues, garden waste, wood chips, wood fibers, gravel, and other materials are used to cover the soil surface. Mulching is highly recommended as a sustainable, low–cost practice for controlling soil erosion. Both organic materials (such as compost, grass clippings, straw, bark, leaf litter) and inorganic or synthetic materials (such as stones and plastics) can be used effectively as mulching agents [26].

In modern agriculture, eight types of synthetic mulch films are commonly used in developed countries: transparent, black, white, yellow, black–and–white, silver, thermal brown, and green. By understanding the properties of each type, farmers can select the most appropriate option for creating optimal growth conditions for specific crops—such as vegetables, melons, potatoes, strawberries, etc. One of the most widely used synthetic mulching materials is opaque black polyethylene film. It is particularly effective for cultivating early thermophilic crops (tomatoes, peppers, eggplants, watermelons, cantaloupes) using seedlings. Black film attracts and retains more heat, which is vital for root development, especially during the early growth stages.

Such technologies can be applied in temporary agro–fiber shelters or low film tunnels. In vegetable cultivation using drip irrigation, perforated black polyethylene film is frequently used as a mulch material to create optimal soil temperature regimes during the warm season. The primary function of black mulch film is to protect young plants from weeds. Often, by early to mid–June—just as vegetable crops begin to emerge—rainy weather promotes intensive weed growth. Under high humidity conditions, mechanical weed control becomes nearly impossible, while herbicides can significantly stunt plant growth and have limited efficacy. In the rows covered by black film, weed development is virtually eliminated, and in the uncovered pathways between rows, standard cultivation is carried out.

(a) (b)

Figure 5. Mulching methods: (a) Gravel and wood chip mulching; (b) Plastic film mulching [43]

However, the direct application of wood or straw to agricultural land may reduce nitrogen availability. According to a study conducted in a semi–arid Mediterranean environment, the impact of adding organic mulch was clearly observed. In their research, a drastic reduction in soil loss (80%) was recorded with the application of 17.5 t/ha of olive pruning residues [6]. The effectiveness of straw application for soil erosion control in asparagus cultivation was documented in the United Kingdom, where a significant reduction in soil loss was observed following the addition of straw. Moreover, the study compared the effectiveness of straw with compost, and the results showed that the impact of straw was particularly impressive [32].

Sawdust is also used as mulch, especially when it is necessary to deter harmful insects such as slugs and mites. Additionally, conifer sawdust inhibits the development of pathogenic bacteria in the soil.

(a) (b)

Figure6. (a) Sawdust mulching; (b) Straw mulching [42]

Plastic and rubber mulching materials are commonly used today in raised–bed vegetable production. Beyond erosion control, these mulches serve additional functions such as soil warming, weed suppression, soil moisture conservation, and certain landscape applications, including

playgrounds [26]. Geotextile materials are also used as mulch in specific applications, such as facilitating water infiltration into soil in exceptional cases, including engineered landfill covers. These materials also aid in material separation and filtration. Geotextiles may be biodegradable—such as jute, wood fiber, paper, and cotton—or synthetic, including plastic and matting.
The use of jute and coconut fiber as mulching materials is considered a form of erosion control blanket or hydro–mulch, applicable in permanent vegetative areas. Hydro–mulches are applied with tackifiers to bind the mulch together and adhere it to the soil surface. Seeds and fertilizers can also be added to the hydro–mulch to enhance planting effectiveness and site stabilization [26].
Erosion control blankets are another advanced application, particularly suitable for steep slopes. These blankets can be composed of chopped straw, wood fiber, or coconut fiber layered between jute mesh or UV–degradable netting. There are various applications for these erosion control blankets, depending on factors such as slope gradient, water flow velocity, desired longevity, and targeted vegetation type [26].
Anchor materials—such as jute mesh, mulch tackifiers, and crimping tools—are also employed in mulch stabilization. Jute mesh can be applied over mulch to protect it from damage caused by wind and water. Tackifiers help bind mulch to the soil and are typically used with hydro–mulch. Organic tackifiers are made from plant–based materials like guar gum, Plantago, coconut fiber, or cornstarch, and are best suited for flat to moderately sloped terrain. Polyacrylamide (PAM) tackifiers last longer than organic alternatives and are commonly used to bind soil particles together. Crimping tools press mulch into the soil to ensure proper soil–mulch adhesion.
A study evaluating the effectiveness of various soil mesh materials in erosion control found that all tested materials significantly reduced erosion. In this study, jute matting (JM), polyester matting (PM), and polyester netting (PN) were installed on slopes, with erosion estimated through both laboratory and field analyses. Laboratory observations showed runoff reductions of 62.1%, 57.7%, and 16.6%, and corresponding soil loss reductions of 99.4%, 98.5%, and 5.5%, respectively, for JM, PM, and PN. Furthermore, field studies conducted in Beijing, China, indicated that the incorporation of JM, PM, and PN increased soil moisture by 54.5%, 36.3%, and 18.7%, respectively, while the associated reduction in soil temperature encouraged crop growth. Based on these findings, the researchers advocate the use of geotextiles on neglected lands to prevent soil erosion by fostering favorable crop growth conditions [36].
Figure 7 illustrates plastic mesh types suitable for use in soil erosion control.

(a) (b)

Figure 7 (a) Polyethylene mesh for land stabilization; (b) Slope stabilization mesh [45]

Fiber rolls or wattles are tubular meshes filled with grasses, straw, coconut husk dust, coconut fiber, and similar materials. These meshes are typically made from biodegradable materials such as jute, coir, burlap, or from synthetics like polypropylene. These rolls reduce runoff velocity and protect the soil from sheet flows while enhancing sediment deposition by acting as physical barriers. They are typically installed as a final step following all other earthworks, ensuring protection of the topsoil layer.

The use of coconut mesh is also an emerging trend in soil erosion mitigation. A study conducted in India using coconut mesh revealed a dramatic reduction in soil loss during the monsoon period. The researchers recorded reductions in soil loss of 99.6% in the pre–monsoon phase, 95.7% during the monsoon, and 78.1% in the post–monsoon period in plots covered with coconut mesh, compared to unprotected control plots. Furthermore, the annual soil loss from protected plots was found to be 94.9% lower than that from unprotected ones [24].

Rock blankets are applied by layering loose small aggregates over the soil surface. These blankets are commonly used in areas where revegetation is difficult and are frequently employed on steep slopes, though not steeper than a 2:1 ratio. This method may be combined with other applications, such as rock joint planting, to further stabilize the soil. In some cases, geotextile fabric is used beneath the rock blanket—depending on the slope—in order to minimize erosion. Rock blankets generally require little maintenance unless dislodgement of the stones occurs [13].

Contour farming is another effective method of soil erosion control. In this practice, crops are planted along the contour lines of a slope. These contour lines act as barriers to water flow, reducing the formation of rills and gullies during periods of heavy rainfall. The interruption of water flow also provides additional time for water to infiltrate the soil. Erosion can be effectively reduced by implementing contour farming on sloped terrain, alongside other structural conservation practices. In addition to minimizing erosion, contour farming has been shown to reduce fertilizer loss, energy consumption, time, and equipment wear, while improving crop yields.

Even better results can be achieved when contour farming is combined with other techniques such as strip cropping, terracing, and water diversion. The mechanism by which contour planting controls soil erosion is simple yet effective: when eroded soil particles encounter a contour barrier, their velocity slows, encouraging deposition and water infiltration.

Strip cropping involves performing tillage and all technological procedures across the slope, along the contour lines. Strip cropping typically involves alternating strips of different crops, such as corn–winter wheat, corn–rye, corn–rapeseed, sunflower–soybean (or beans), soybean–Sudan grass, and sorghum–alfalfa. The alternating strips should be of equal width. Strip width is determined based on slope steepness, erosion risk, and the working width of the equipment.

This method also includes alternating row crops with densely sown crops or perennial grasses and legumes on sloped land. Crop strips are arranged so that a row crop is followed by a strip of densely sown crops or perennial grasses. Cereal grains and perennial grasses provide a protective cover, reduce soil erosion, enhance water infiltration, and trap sediments and nutrients. Rotating strips from row crops to legumes enables crops to benefit from the nitrogen fixed in the soil by leguminous plants. This practice also incorporates crop rotation principles, making it a highly effective soil conservation strategy.

Figure 8. Strip cropping [46]

The use of biological hedgerows is another conventional practice in soil erosion management that continues to benefit from modern technologies, enhancing soil protection. Trees within hedgerows serve as vegetative barriers along contour lines, offering sustainable alternatives for erosion control in areas where large–scale management is no longer feasible. Hedgerows may be composed of live or dead biological material, helping to trap eroded soil on slopes while contributing organic matter and enhancing soil water infiltration by slowing runoff velocity. Alley cropping systems, classified hedgerows, and SALT (Sloping Agricultural Land Technology) hedges all fall into this category. Common plant species used for hedgerows include Gliricidia, Tithonia diversifolia, and Erythrina variegata. A study conducted in Kenya found that hedgerow application was effective for erosion control, with soil loss reduced by 50% on fields planted with natural hedges [1].

Grassy hedgerows are also established on slopes using recommended species such as Vetiveria zizanioides (Figure 4), Cymbopogon nardus, and Cymbopogon citratus. Vetiver grass, a fast–growing plant that was relatively unknown until recently, exhibits unique characteristics shared by both grasses and trees. It has a deep root system that can prevent erosion and control the shallow movement of surface soil layers. The Vetiver Grass Technology (VGT) involves the application of this unique grass for erosion and sediment control on agricultural land, slope stabilization in civil construction, mine site rehabilitation, and flood mitigation.

The benefits of this technology are numerous. One key advantage of VGT over conventional engineering measures is its low cost. Furthermore, like other engineering solutions, VGT provides a natural and environmentally friendly method for erosion control [34].

Microbially Induced Calcite Precipitation (MICP) is another well–established phenomenon applied to improve the engineering properties of porous geomaterials. Urea hydrolysis (ureolysis) is commonly used as a chemical process to facilitate calcite precipitation, increasing the stiffness and shear strength of granular soils. The application of ureolysis–based technology can reduce internal soil erosion caused by the physical and chemical interactions of fluid flow. Bacterially induced ureolysis has proven to be significantly more effective than conventional methods. A selected species of bacteria is injected into the soil to accelerate the process and enhance its efficiency [18]. Figure 9 illustrates a Scanning Electron Microscope (SEM) image of a gravel–sand mixture treated with MICP, as observed in the same study.

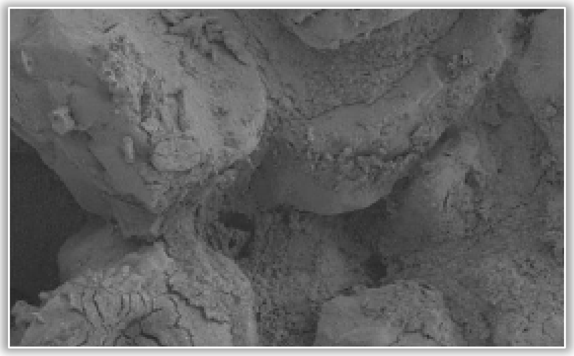


Figure 9. Scanning Electronic Microscope (SEM) graphs of MICP treated gravel–sand mixture [21]

Check dams are applied in areas subject to severe erosion as physical structures intended to mitigate water runoff in gullies. These dams are designed to capture and safely discharge water by reducing the slope of gullies through a series of stepped drop structures. Check dams are typically constructed as a stepped channel bed profile, which decreases the velocity of flowing water and ultimately halts soil erosion. There are various types of check dams—including rock–filled check dams, stone check dams, and wooden check dams—selected based on site location and topography.

Live check dams represent another model, composed of living plant material. In this approach, large woody cuttings are planted along the gully, generally following the contour lines of the terrain. These structures serve as substantial barriers that prevent sediment and other materials from being transported downslope.

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A study conducted in China found that the implementation of check dams had a substantial impact on erosion control. The field study reported 100% soil sediment retention, leading to recommendations for strengthening construction standards and management practices related to check dam technologies [3].

Figure 10 illustrates different types of check dams: (a) wooden check dam, (b) rock–filled check dam, and (c) stone check dam.

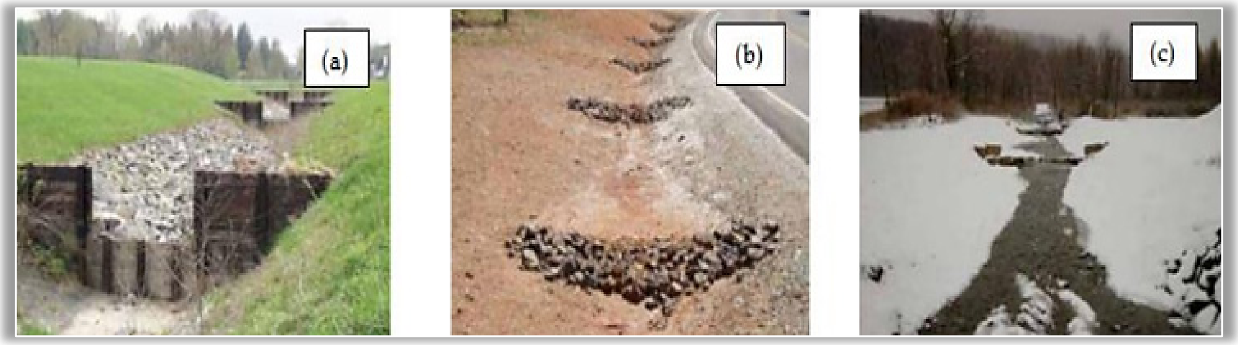

Figure10. Different types of Check dams, (a) Wooden check dam, (b) Rock–filled check dam, and (c) Stone check dam [21]

Biochar is a carbon–rich product developed through the slow pyrolysis of biomass materials and is commonly used as a soil amendment. The application of biochar can improve various soil properties, such as increasing soil organic matter (SOM) content, enhancing water retention capacity, and improving several other physicochemical characteristics. Enriching soil with SOM contributes to improved soil aggregation and stability, as biochar functions as a recalcitrant carbon source and provides organic functional groups on its surface.

According to [19], amending very dry soils with biochar drastically reduced soil loss; reductions of 50% and 64% in soil erosion were observed with biochar application rates of 2.5% and 5%, respectively. Furthermore, their study reported improvements in soil properties including pH, cation exchange capacity, water holding capacity, and microbial biomass carbon following biochar application.

A study conducted in Kuwait also demonstrated the effectiveness of soil amendments in reducing wind erosion. Their findings revealed a substantial decrease in aeolian erosion when biochar and manure were applied to vegetated soils. Therefore, biochar may be introduced as a sustainable approach to controlling soil erosion in desert environments [8].

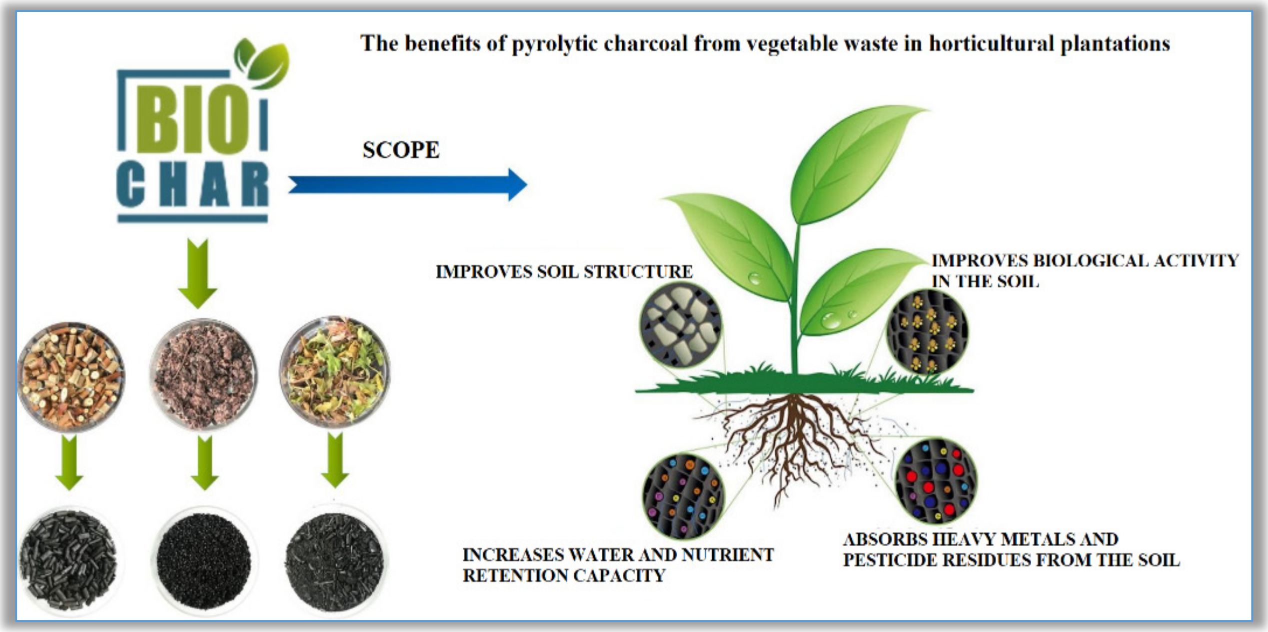

Figure11. Benefits of Pyrolytic Charcoal from Plant Waste [47]

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Certain chemical substances such as vinyl, asphalt, rubber, anionic and non–ionic polyacrylamide are used for temporary soil stabilization. Once these chemicals are sprayed onto the ground, they bind soil particles together, effectively preventing erosion caused by water or wind. This is a typical application, especially during earthworks. Chemical treatments are also applicable in areas where vegetation cannot be established, such as temporary storage zones or rough grading sites. Biopolymers such as chitosan, cellulose, cotton microfibrils, and starch also facilitate the binding of soil particles. The use of biopolymers is promoted in many countries due to their lower health and environmental impact compared to synthetic chemical alternatives [7], [9].

The soil erosion prediction method has led to a new generation of erosion forecasting technologies grounded in the scientific principles of hydrology and erosion processes. Predicting soil erosion is essential for assessing future risks and implementing mitigation mechanisms before conditions become severe [20].

Various tools and computer–based models are employed to forecast future soil erosion losses and risks, based on the Universal Soil Loss Equation (USLE). Remote sensing and sediment transport modeling can be integrated to enhance these models further. Erosion risk maps may be generated by assessing soil erosion in specific areas. Through mapping systems, erosion is identified and the most effective soil conservation measures are selected accordingly.

Designated areas identified through mapping can support a wide range of erosion control technologies—from simple techniques to more advanced models. As computer–based tools and databases become more widely adopted, soil erosion prediction technologies will become increasingly accessible and user–friendly. New avenues are opening, as this activity plays a major role in effective erosion control [10], [12], [14], [19], [23], [25], [39].

3. CONCLUSIONS

Soil erosion is considered a critical factor in land resource management. Soil degradation diminishes land value, reduces land productivity, and places significant stress on agriculture–based economies. Effective soil erosion management is therefore essential, and a number of conventional erosion control techniques are already in use.

However, in light of the increasing rate of soil erosion driven by human activities, there is a clear need for new advancements. In this review study, a set of emerging techniques used in agriculture and geotechnical applications has been identified and examined for their effectiveness. The use of innovative mulching materials, geotextile meshes, rock fiber rolls, and physical barriers such as check dams, stone dikes, silt fences, and chemical stabilizers has been recognized as part of a new wave of physico–chemical approaches to erosion control.

Moreover, several biological measures have been identified as emerging trends, including novel planting materials such as vegetative hedgerows, microbially induced soil stabilization, and bio–based soil amendments. The continued improvement and investigation of these technologies and innovations must be prioritized, particularly when considering the alarming rates of annual soil loss.

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