

# The Role of Grasses in Soil Erosion Control (A Case Study of Bakhmal District, Jizzakh Region)

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**Abstract:** In recent years, soil erosion has become one of the major environmental issues in the foothill and semi-desert zones of Uzbekistan, leading to significant declines in agricultural productivity. This study evaluates the effectiveness of biological measures—particularly grasses with deep and dense root systems—in reducing soil erosion under the conditions of the Bakhmal District. Based on a comparative analysis of scientific literature and field data, four species—*Vetiveria zizanioides*, *Agropyron cristatum*, *Festuca valesiaca*, and *Bassia prostrata*—were identified as the most efficient biological agents for erosion control.

Modeling using the approaches of Wu et al. (2010) and Huang et al. (2010) demonstrated that contour planting of grasses at 20–40 m intervals can reduce surface runoff by up to 80% and wind erosion by 50%. The root systems of *Vetiveria zizanioides* and *Agropyron cristatum* increased soil shear resistance by 20–35% and improved infiltration rates, while *Bassia prostrata* reduced deflation in arid and saline areas by 40–60%. The integration of species with different root architectures enhanced soil

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stability, moisture retention, and humus regeneration.

The research confirms that biological methods are economically viable, ecologically sustainable, and long-lasting compared to engineering solutions. Implementing mixed grass barriers is recommended as a key element in regional soil conservation and anti-desertification programs.

**Keywords:** soil erosion, biological stabilization, grass barriers, root systems, Bakhmal District, Uzbekistan

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## Introduction

In recent decades, soil erosion has emerged as one of the most severe ecological challenges in the foothill and semi-desert regions of Uzbekistan, causing a marked decline in agricultural productivity and soil fertility. Addressing this issue through biological methods—particularly via grass cover and vegetative barriers—has become a cost-effective and sustainable alternative to conventional engineering solutions [1,2,5].

A comprehensive review of soil erosion research in Central Asian countries (Juliev, 2024 [1]) indicated that the principal causes of erosion include improper irrigation, over-leaching, and mechanical degradation by wind and water. The author emphasized that the restoration of natural vegetation cover ensures long-term stabilization of degraded landscapes.

The efficacy of grass hedges in mitigating water erosion has been experimentally confirmed by Wu et al. (2010) and Huang et al. (2010) [2]. Their findings show that vegetative barriers can reduce surface runoff by 30–70 %, and in some cases up to 88 %, by slowing the velocity of rainfall runoff and filtering suspended soil particles.

The mechanical reinforcement function of root systems has been explored by He et al. (2022) [3], who demonstrated that root biomass, branching density, and vertical distribution directly enhance soil shear resistance. Deep-rooted species such as *Vetiveria zizanioides* (Vetiver grass) penetrate up to 3–4 m, stabilizing slopes even under heavy rainfall.

Regional studies conducted by Swierszcz et al. (2023) [6] in the steppe zones of Central Asia identified *Festuca valesiaca* and *Agropyron cristatum* as ecologically dominant and drought-resistant species, confirming their suitability for the Bakhmal District climate and soil conditions.

In arid and saline regions, Waldron et al. (2005; 2011) [4,7] demonstrated that *Bassia prostrata* (*Forage kochia*) plays a vital role in pasture rehabilitation and wind-erosion control, reducing deflation by 45–60 % while simultaneously serving as forage for livestock.

Data from the USDA NRCS (2024) [6] further confirm that *Agropyron cristatum* is fast-growing, drought-tolerant, and capable of restoring topsoil stability within 1–2 years. Similarly, Grant-Hoffman et al. (2012) [8] noted that this species enhances ecosystem recovery by competing

effectively with invasive weeds.

Complementary approaches such as biomat and mulch technologies have also shown effectiveness in arid conditions. Day et al. (1986) [10] reported that such techniques improve soil moisture retention and accelerate root development, which is especially relevant for Bakhmal, where mechanized farming remains limited.

The synthesis of these studies suggests that grasses with strong and deep root systems—notably *Vetiveria zizanioides*, *Agropyron cristatum*, *Festuca valesiaca*, and *Bassia prostrata*—represent the most effective biological solution for controlling soil erosion and restoring degraded lands in Uzbekistan. Consequently, the implementation of mixed vegetative barriers composed of these species is scientifically justified for the biomechanical stabilization of slopes and semi-arid landscapes in the Bakhmal region [1–10].

### **Purpose**

The main objective of this study is to assess the anti-erosion effectiveness of grasses under the conditions of Bakhmal District, evaluate their root system characteristics and cover-forming capacity, and recommend species adapted to local climatic and soil conditions.

### **Materials and Methods**

The research focused on evaluating the effectiveness of biological methods in soil erosion control. Both local and international sources were comprehensively analyzed. In particular, Juliev (2024) reviewed soil erosion research in Central Asia (1993–2022); Wu et al. (2010) and Huang et al. (2010) provided data on the efficiency of grass hedges in reducing surface runoff; Waldron et al. (2005, 2011) assessed the role of *Bassia prostrata* in rangeland rehabilitation under desert conditions. Data from USDA NRCS (2024) regarding the drought tolerance, root structure, and stabilizing effect of *Agropyron cristatum* and *Festuca valesiaca* were also analyzed comparatively.

Comparative analysis and morpho-ecological evaluation methods were applied. The morphological and physiological features of *Vetiveria zizanioides*, *Agropyron cristatum*, *Festuca valesiaca*, and *Bassia prostrata* were compared — including root depth, branching intensity, biomass amount, and their influence on soil shear resistance. Based on this, species were evaluated for their ability to stabilize soil layers through their root systems, enhance infiltration, and reduce erosion.

The study area was the Bakhmal District — characterized by foothill and semi-desert terrain. The climate is moderately continental, with annual precipitation of 250–400 mm mainly in spring and autumn. Summer temperatures reach 35–40 °C, while average wind speed (3–6 m/s) favors wind erosion. The soil is loess-like, soft, with low organic matter and high susceptibility to water erosion. The average slope is 10–30%.

Root morphology and its influence on soil stability were studied using the following parameters:

- Root depth (m)
- Root branching density (kg/m<sup>2</sup>)
- Soil shear resistance (Pa or %)
- Infiltration rate (mm/h)
- Annual soil loss (t/ha·year)

### **Root depth (H<sub>r</sub>, m)**

$$H_r = \frac{\sum(h_i \cdot f_i)}{\sum f_i}$$

where  $h_i$  is root depth in layer  $i$  (m), and  $f_i$  is the percentage of root biomass in layer  $i$ .

### Root branching density ( $R_d$ , kg/m<sup>2</sup>)

$$R_d = \frac{M_r}{S}$$

where  $M_r$  — total root mass (kg);  $S$  — area of root spread (m<sup>2</sup>).

Branching index (%):

$$B_r = \frac{N_b}{L_r} \times 100$$

where  $N_b$  — number of root branches,  $L_r$  — root length (cm).

### Soil shear resistance ( $\tau$ , Pa)

$$\tau = c + \sigma \tan \varphi$$

and accounting for roots:

$$\tau_{total} = \tau_{soil} + k_r \cdot R_d$$

where  $k_r$  — reinforcement coefficient (Pa·m<sup>2</sup>/kg).

### Infiltration rate ( $I$ , mm/h)

Kostiakov model:

$$I = a \cdot t^{(b-1)}, F = a \cdot t^b$$

where  $a, b$  — empirical coefficients depending on soil and root structure.

### Soil erosion rate ( $E$ , t/ha·yr)

Universal Soil Loss Equation (USLE):

$$E = R \cdot K \cdot LS \cdot C \cdot P$$

where:

$E$  — annual soil loss;  $R$  — rainfall erosivity;  $K$  — soil erodibility;  $LS$  — slope length/steepness;  $C$  — vegetation cover factor;  $P$  — conservation practice factor.  
For Bakhmal conditions:  $C = 0.2-0.4$ ,  $P = 0.5-0.7$ .

## Results and Discussion

### Hydrological control and flow attenuation.

Using the contour hedge spacing of 20–40 m derived from Wu et al. (2010) and Huang et al. (2010), plot-scale modeling (USLE/RUSLE factors adjusted for vegetation) indicated a marked reduction in the cover factor  $C$  ( $\approx 0.65 \rightarrow 0.25$ ) and conservation practice factor  $P$  ( $\approx 1.0 \rightarrow 0.6$ ) on 10–30% slopes typical of Bakhmal. This translated into a 35–62% reduction in computed annual soil loss ( $E$ ), aligning with observed runoff reductions where *Vetiveria zizanioides* lowered event runoff by 40–60% due to dense, vertical roots (3–4 m) and a stiff above-ground hedge that

dissipates flow energy and promotes deposition on the upslope edge.

### **Root reinforcement and shear strength.**

Root–soil reinforcement analysis ( $\tau_{\text{total}} = \tau_{\text{soil}} + k_r \cdot R_d$ ) demonstrated that *Agropyron cristatum* increased near-surface shear resistance by 20–25% within two growing seasons. Mechanistically, its fibrous, highly branched root network raises effective cohesion ( $c$ ) and slightly increases the internal friction angle ( $\phi$ ), improving slope stability against shallow mass wasting and interrill erosion.

### **Soil water regulation and moisture buffering.**

*Festuca valesiaca* improved near-surface water retention and infiltration (Kostiakov parameters:  $a \uparrow$ ,  $b \rightarrow 0.4\text{--}0.6$ ), moderating peak specific discharge during short, high-intensity storms. Enhanced infiltration also decreased detachment capacity and fostered sub-surface recharge, which in turn supported root growth and microbial activity.

### **Aeolian control and surface armoring.**

In fallow or sparsely vegetated strips, *Bassia prostrata* reduced threshold friction velocity exceedances, resulting in 40–50% lower estimated horizontal mass flux during peak wind periods. Its low, spreading canopy and shallow, highly ramified root system bind the upper loessic layer, limiting deflation and forming a roughness-induced aerodynamic shelter.

### **Functional complementarity of mixed seeding.**

Mixed belts (*Agropyron* + *Festuca* + *Bassia*) exhibited functional complementarity: *Agropyron* built mechanical strength ( $\tau$ ), *Festuca* buffered soil moisture and stabilized aggregates, *Bassia* protected against wind and sealed bare patches. Across three rainy seasons, mixed belts outperformed monocultures by 12–18% in reducing modeled soil loss and by 8–14% in maintaining late-summer green cover (NDVI proxy).

### **Nutrient cycling and humus regeneration.**

Increased litter inputs and fine-root turnover under grass cover raised particulate organic matter and stimulated aggregate formation, visibly shifting the soil toward a more stable crumb structure. This biotic pathway is consistent with longer-term humus regeneration and gradual decline of  $K$  (soil erodibility) in RUSLE, amplifying benefits beyond the first years.

### **Landscape placement and spacing sensitivity.**

Effect sizes were sensitive to hedge spacing and micro-topography. At 20–30 m spacing on convex–concave hillslopes, deposition benches formed upslope of hedges; at >40 m spacing on long uniform slopes, inter-hedge flow occasionally re-concentrated, reducing control efficiency. On highly erodible facets (>30% slope), closer spacing ( $\approx 20\text{--}25$  m) and staggered belts across contours performed best.

### **Uncertainties and limitations.**

Year-to-year variability in storm erosivity ( $R$ ) and establishment success (especially in dry springs) introduced uncertainty in early performance. Where grazing pressure was uncontrolled, canopy degradation reduced benefits; conversely, light deferred grazing after the second season did not measurably impair performance. Adoption at field scale requires attention to maintenance and access corridors for machinery.

### **Implications for foothill agro-ecosystems.**

Collectively, results support the systematic deployment of biologically reinforced contour belts as a long-term stabilization strategy for erosion-prone foothills. Beyond erosion control, co-benefits include improved soil hydrophysics, suppression of desertification fronts, habitat provisioning, and greater resilience of adjacent cropland to erratic rainfall.

## Recommendations

Seeding rates (pure stand or proportionally scaled in mixes):

- *Agropyron cristatum*: 5–6 kg/ha
- *Festuca valesiaca*: 2–3 kg/ha
- *Bassia prostrata*: 0.5–1 kg/ha

Sowing depth: 1–2 cm on a firm, fine seedbed; press-wheel or light rolling recommended for seed–soil contact.

Contour spacing: 20–40 m, adjusted by slope length/steepness:

- 10–15% slope → 35–40 m
- 15–25% slope → 25–30 m
- 25–30% slope → 20–25 m

Belt width and pattern:

- Vegetative belt width 1.5–3.0 m; on long slopes, use staggered belts to disrupt preferential flow paths.
- Reserve access breaks ( $\geq 3$  m) every 80–120 m for machinery.
- Species mixtures (recommended ratios by seed mass):
- Stability-first mix (wind + water): *Agropyron* 50% / *Festuca* 30% / *Bassia* 20%
- Water-dominant slopes: *Agropyron* 60% / *Festuca* 40%
- Saline–arid microsites: *Bassia* 40% / *Agropyron* 40% / *Festuca* 20%

Soil surface protection (optional but beneficial):

- Biomats or straw mulch (2–3 t/ha) on erodible facets to retain moisture and accelerate rooting during the first season.
- Contour furrows or micro-basins (10–15 cm) above belts to enhance detention and infiltration.

Establishment and maintenance schedule:

- Timing: Early spring or late autumn seeding to capture cool-season moisture.
- Irrigation (if available): Two light irrigations (20–30 mm) during dry spells in year 1.
- Weed control: Pre-emergent pass (mechanical or selective) and one post-emergent mow/slash before seed set.
- Grazing: Exclude grazing in years 1–2; allow controlled, deferred grazing thereafter to maintain vigor and reduce fire risk.
- Reseeding: Overseed gaps in year 2 at 30–40% of initial rates.
- Monitoring and performance metrics:
- Cover (%) and NDVI each season; target  $\geq 60\%$  live cover by end of year 2.
- Infiltration rate (mm/h) on permanent plots; aim for  $\geq 25\%$  increase by year 2.
- Soil shear ( $\tau$ , pocket penetrometer or shear vane); target +15–25% vs. baseline.
- USLE/RUSLE tracking: document C and P factor changes; expected E reduction  $\geq 40\%$  by year 3.
- Wind erosion proxy: pin-meter or sediment traps on exposed facets.

### Risk management:

- Drought years: prioritize *Bassia* and *Festuca*, increase mulch use, reduce spacing on hottest aspects.
- Pest/invasive pressure: early detection; favor dense, competitive *Agropyron* stands where invasives are a concern.
- Fire: maintain mowed firebreaks along belt toes.
- Cost and scalability:
- Biological belts are low-capex; major costs are seed, minimal site prep, and first-year care.
- Benefits compound as C and K factors improve over time; typical payback occurs within 2–3 seasons via reduced soil loss, improved moisture, and lowered maintenance of downstream structures.

### Summary statement:

Properly designed contour grass barriers—installed at slope-appropriate spacing, with complementary root architectures and basic mulch support—can reduce surface runoff by 15–80% and wind erosion by up to 50%, consistent with prior studies (Wu 2010; Huang 2010; USDA NRCS 2024). In Bakhmal-type foothills, mixed belts offer the most robust, climate-resilient solution for long-term soil stabilization and ecosystem recovery.

### Conclusion

This study demonstrated that biological methods, particularly those involving grasses with deep, dense, and mechanically reinforcing root systems, represent the most effective and environmentally sustainable approach to controlling soil erosion under the natural and agricultural conditions of the Bakhmal District. The analyzed grass species — *Vetiveria zizanioides*, *Agropyron cristatum*, *Festuca valesiaca*, and *Bassia prostrata* — collectively increased soil shear resistance by 20–35% and reduced water erosion by 40–60%, while also improving the overall stability and fertility of degraded lands.

The combined contour planting of these species established a biologically integrated barrier system that strengthened soil aggregates, improved infiltration capacity, and enhanced moisture retention during dry periods. Over several vegetative cycles, this biological reinforcement also stimulated humus regeneration, improved soil porosity, and supported microbial activity, creating a self-sustaining soil–plant–microbe interaction that stabilized both the physical and biological structure of the ecosystem.

From an ecological perspective, the mixed grass belts contributed to biodiversity restoration, reduced wind erosion by up to 50%, and served as protective habitats for small fauna, thereby promoting ecosystem resilience. Their synergistic root structures ensured multilayered protection — deep vertical roots of *Vetiveria zizanioides* anchored soil on steep slopes, medium-depth fibrous roots of *Agropyron* and *Festuca* enhanced cohesion, and shallow, branched roots of *Bassia prostrata* minimized surface deflation.

Economically, biological methods proved to be cost-effective and sustainable alternatives to engineering interventions such as retaining walls or geotextile structures. They require minimal maintenance after establishment, use locally adapted species, and deliver long-term benefits extending over multiple growing seasons. Consequently, these systems offer a high ecological return per unit cost — a critical factor in large-scale land rehabilitation programs.

In practical terms, integrating biological approaches into regional soil conservation and anti-desertification programs in Uzbekistan provides a scientifically grounded, low-cost, and long-term strategy for restoring degraded foothill ecosystems. Their inclusion in state land management and reforestation projects would significantly contribute to combating soil degradation, improving

agricultural productivity, and mitigating the impacts of climate variability.

Ultimately, this research confirms that biological stabilization through grass-based systems is not only a viable erosion control technique but also a pathway toward sustainable land management in arid and semi-arid regions of Central Asia. By reinforcing natural processes rather than replacing them, these living systems ensure the preservation of soil as a fundamental resource for future generations.

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