The Potential of Vetiver as the Finest Bio-Engineering Plant in the KTFT

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Abstract

The natural ground's initial strength is lost and it becomes unstable as a result of human and natural activity. Natural disasters like landslides, mass movement, soil erosion, the slow deterioration of rocks, and so forth are examples of natural activity. Artificial activities on the natural ground include blasting in the surrounding areas; building roads, dams, and high-rise structures in the vicinity that cause a lot of vibration in the ground; haphazard cut and fill operations on the stable ground; adding overburden pressures on ground, etc. From the perspective of soil protection, civil engineering structures were constructed during construction to protect unstable soil mass from weathering. On the other hand, it might not always be feasible or cost-effective to build supporting civil engineering structures or components. Therefore, the planting of living plants is done using a systematic pattern and standard methods to gradually improve the soil strength over time, either in conjunction with or independently of civil engineering structures; known as bio-engineering. The novel, useful bio-engineering grass known as "vetiver grass" is the main topic of this article, along with its potential in the Kathmandu Terai Fast Track (KTFT) road project.

Keywords: soil instability, natural disasters, artificial activities, bio-engineering, vetiver grass, KTFT

INTRODUCTION

Bio-engineering Background

Bio-engineering is the partial or full application of the living vegetation with or without civil engineering structure to make the soil stable in its site condition. The ratio of by engineering plant and civil engineering structure depends on the nature of the work to which engineering is applied.

The main concept of bio engineering is that take support from civil engineering structures in the initial day of plantation if needed and improve in strength of the unstable soil mass with the growth of the living vegetation. At last, a civil engineering structure is a null structure as per the strength provided parameter and the overall strength of the soil mass is carried by matured living vegetation only.

It should be made clear that civil engineering structures cannot be replaced by bio engineering from strength, economic, and durability perspectives. Bio-engineering needs the support of civil engineering structures as per site conditions for its meaningful implementation. But bio-engineering is more flexible with loads and adaptable to natural environments than civil engineering structures, so it can be used more effectively in small-scale sediment movement control on steep slopes, habitat restoration and enhancement projects, and landslide mitigation in seismic regions. According to a study, vetiver grass is a novel and highly effective bio-engineering vegetation when compared to other vegetation types.

Bio-Engineering in Nepal

Nepal's first application of bio- engineering was done in 1980 for the Dharan-Dhankuta road project, which protected the roadside slopes. Since this is thought to be a good time for soil bio engineering,

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when cutting survival rates are greater and rooted plant survival rates are higher during monsoon. Bio engineering projects in infrastructure development work are primarily carried out in Nepal during the pre-monsoon season. Via brush layering, jute netting along with seeding, live check dams, fascines and so on; bioengineering is mostly employed in Nepal (Lekhak & Bhatta, 2022) .

The following are a few typical engineering techniques in Nepal:

1. Soil bio-engineering at Krishna Bhir
2 Bio-terracing along all hillside roadside
3. Bio-engineering measures at Dipayal-Mellekh road
4. Roadside bio-engineering at Muglin Narayangath
5. Roadside bio-engineering at Dhangadi Dadeldhura
6. The Hill of Dhankuta

Introduction to Vetiver

Vetiver grass: Chrysopogon Zizanioides L Roberty is an inexpensive, fast-growing, versatile grass that can withstand a variety of environmental factors. Since the 1980s, the World Bank has been introducing vetiver grass to prevent landslides and soil erosion through soil stabilization.

Since the Vetiver system is a vegetal product in and of itself, it is initially fruitful to the environment; from ecological perspective. If vetiver grass planted in a single rows in an interval also create a hedge in a certain time interval that is highly successful in reducing soil erosion, spreading runoff water, retaining moisture in the earth, and trapping sediments. The vetiver plant's extremely longer and dense root system reinforced the soil and makes it incredibly difficult for high-velocity water flows to remove. Vetiver's deep and rapidly expanding root structure also confers drought tolerance, making it an excellent choice for stabilizing steep slopes (Truong et al., 2008).

Introduction to KTFT

The ability of roads to link people is a stronger media in and of itself. From the standpoint of a country's growth, road connectivity is more important for trade and transactions, industries education, cultural interchange, and economic perspectives. Therefore, a strategically planned road network defines as the Kathmandu Terai Fast Track (KTFT); was built to connect the capital of Nepal with the Terai region in accordance with Asian Highway Design Standard-1993 (Primary Class A).

The route is 72.5 km long, with a start point in Khokana, Lalitpur, and an endpoint in Nijgadh, Bara. The estimated travel time is 1 hour and 2 minutes. It consists of a 55.5 km long roadway, three 6.4 km long tunnels, and 87 (10.59 km long) bridges, of which sixteen are special type bridges. The expressway is four lanes wide, with 25m in width in the mountainous zone and 27m width in the Terai region. Between the stations, this highway intersects the Kanti Rajpath and the Madan Bhandari Highway, two important roadways. There are altogether three entries and exit points between the end stations of this expressway of places Khokana, Budhune, and Nijgadh. Khokana connects the outer ring road, Nijgadh connects the east-to-west highway and Budhune connects the Madan Bhandari highway and Kanti Rajpath (Nepal Army, 2020) .

OBJECTIVE

1. To familiar vetiver is finest bio engineering vegetation among conventional practiced native bioengineering plants/grass.
2. To explain the characteristics of vetiver which are suitable in KTFT.

LITERATURE REVIEW

Vetiver for slope consolidation

In the first year, the massive, intricately structured, and incredibly deep root system of vetiver can reach depths of 2-3 meters. Numerous experiments indicate that this grass can grow to 3.6 meters (12 feet) on a fill slope in a year. The average tested tensile strength of these roots is approximately 85 Mega Pascal (MPa) (Cheng et al., 2003) .

The thick, widespread roots of vetiver bind the soil, making it incredibly drought-tolerant and difficult to remove. Vetiver roots are best anchor for fill and topsoil because they can pierce compacted soil profiles like hardpan and blocky clay pan (i.e. which are typical in tropical soils). vetiver does not delve very far into the groundwater thus it is safer in area having higher level of ground water table.

Vetiver grass plantation in a row grow with anchoring and reinforcing each other togetherly by creating dense hedges; which divert runoff water, lowers flow velocity, and act as an extremely powerful erosion control filter. Vegetable hedges function as a highly efficient filter, lowering the turbidity of surface run-off by slowing down and spreading the flow, which gives water more time to seep into the ground. Local plant seeds are usually present in the fertile sediment, aiding in the re-establishment of those plants, which makes bio-engineering work more effective.(Tran Tan Van,2008)

Vetiver can withstand in varying weather conditions, such as protracted droughts, flooding, submergance and temperature extremes between -14°C and +55°C (Truong et al., 1996).

Vetiver shows a high level of tolerance to soil acidity, salinity, and acid sulfate conditions and other adverse soil condition; such that they can sustain greater in these criteria than other conventional vegetations and re-growth when these adverse effects are removed (Le van Du and Truong, 2003).

Application of the vetiver system to reduce erosion of river banks

Following are some used cases for river bank erosion control using the vetiver system:

Case 1: Vetiver System use for riverbank erosion mitigation in Central Vietnam

In Da Nang City, vetiver was planted to stop erosion on a road embankment, the bank of a shrimp pond, and riverbanks. Additionally, the local Dike Department also initiated mass-plantation work of vetiver grass on multiple riverbank areas in October 2002. Following that, the city government decided to provide funding for a project to stabilize a cut slope in Da Nang by planting vetiver along the hilly route that leads to the Banana project. Some pictorial evidence of it is shown below:

Figure 1: Left: March 2002: VS trial at the edge of a shrimp pond, where a canal drains flood water to Vinh Dien River; right: November 2002: mass planting combined with rock riprap to protect bank along Vinh Dien river.

Source: (Truong et al., 2008)

Figure 2: planted by local farmers, vetiver protects their shrimp ponds

Source: (Truong et al., 2008)

Figure 3: a bend on Perfume Riverbank in Hue

Source: (Truong et al., 2008)

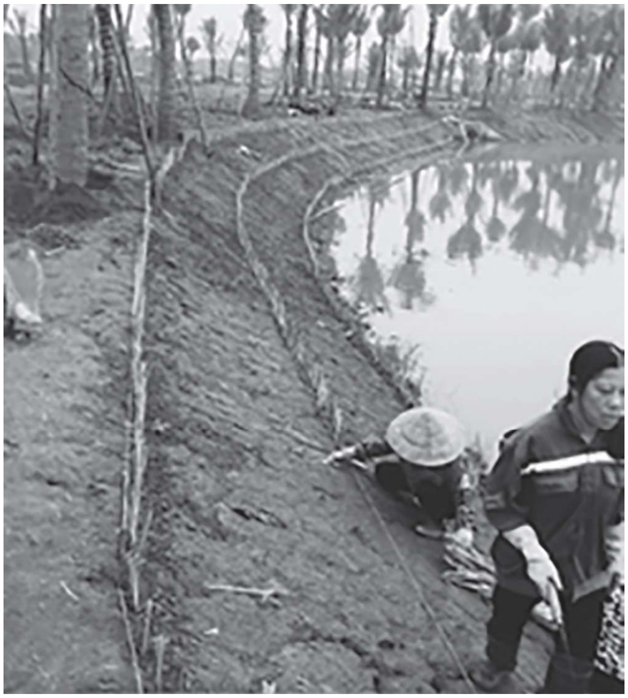


Figure 4: Riverbank stabilization in Vietnam

Source: https://www.vetiver.org/wp-content/uploads/2021/11/59-9.jpg

Case 2: Quang Ngai's vetiver system trial and advocacy for riverbank preservation

Vetiver was used in another AusAID-funded initiative in Quang Ngai province aimed at reducing natural disasters. Vo Thanh Thuy and his colleagues from the provincial Agricultural Extension Center initiates plantation of vetiver grass on multiple locations (ie irrigation canals in multiple different districts, seawater intrusion prevention dikes areas) in July 2003 with technical assistance from Tran Tan Van. Vetiver flourished everywhere and, even withstood a flood occurred at same year. Some pictorial evidences of it were shown below:

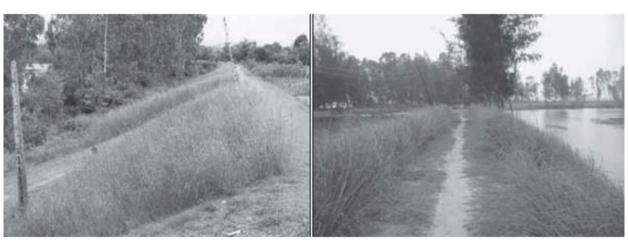


Figure 5: Left: Vetiver planted on river dike along Tra Bong River; right: lining the sides of an anti-salinity estuary dike along the same river.

Source: (Truong et al., 2008)

Figure 6: a section of the irrigation canal, surface erosion mars the opposite bank

Source: (Truong et al., 2008)

Figure 7: Left: Community members plant vetiver; right: November 2005: bank remains intact following the flood season

Source: (Truong et al., 2008)

Case 3: Mekong Delta River bank erosion control with the Vetiver System

Getting fundings from William Donner Foundation and technical guidance from Paul Truong; Le Viet Dung and his colleagues at Can Tho University initiated riverbank erosion control projects in the Mekong Delta. Riverbanks of these area consist of varying nature of soils (i.e. alluvial silt to loam soil range); which are heavily erodible when increase in saturation level on it. But it was found that after establishment of vetiver, it improves soil strength and thus protects large areas of valuable and productive agricultural zones from erosion on saturation condition. Some pictorial evidences of it were shown below (Truong et al., 2008):

Figure 8: Vetiver plantation on a natural river bank

Source: (Truong et al., 2008)

Figure 9: Vetiver borders the edge of flood resettlement centers

Source: (Truong et al., 2008)

Figure 10:MEKONG DELTA VIETNAM: protecting bank against wave erosion

Source:https://www.vetiver.org/TVN_VS_GAL_HR/VS_River_bank.pdf

VS use for road batter stabilization

Ho Chi Minh City Agro-Forestry University and the Ministry of Transport gives approval for largescale use of vetiver grass in 2003 to stabilize cut slopes in Central Vietnam on recently built roadways (i.e. Ho Chi Minh highway and other national provincial roads) on hundreds of kilometers area . Undoubtedly, it is one of the fruitful trials of vetiver application for infrastructure security in the world . Over 3,000 kilometers make up the Ho Chi Minh Highway in its entirety. Vegetables are planted to protect it in a varying range of climates and soil types, from very acidic soil and hot, humid climates in the North to skeleton mountainous soils and cold winters in the South.

Figure 11: Steep batter stabilized with vetiver – Ho Chi Minh Highway, Vietnam

Source: https://www.vetiver.org/wp-content/uploads/2021/11/35-1.png

From this successful trial of vetiver, some conclusions of vetiver are presented, which are as follows:

- Vetiver is often used to consolidate cut slopes because it primarily reduces erosion generated by run-off that would otherwise cause havoc in down areas.
- It significantly stabilizes cut slopes by preventing exposed surface failures at shallow depth, which significantly minimizes the formation of deep slope failures. But if occur (in rear instances), vetiver still perform excellent job of decreasing the failure mass and slowing down the failures.
- It keeps the road's rustic charm and environmental friendliness (Truong et al., 2008).

ARRANGEMENT GUIDELINES

For highlands, sloping terrain naturally, road batter, and so on.To consolidate the soil for highlands, sloping terrain naturally, road batter and so on; listed specifications may apply:

1. A gradient of 1.5:1 is advised, and the bank slope should not be greater than 45º with horizontal. It is advisable to use shallower gradients whenever feasible, where high rainfall occurs or on erodible soils.
2. Plant the vetiver along the slope's approximate contour lines, spaced 1.0–2.0 meters apart in vertical intervals. On soil having less cohesion and largely erodible nature, spacing of 1 meter is recommended but on stable soil, spacing can reach 1.5–2.0 meters.
3. The top edge of the batter is where the first row should be placed, while plant the lowest row along the foot of the slope. Any batter that is taller than 1.5 meters must have greater than single row plantation.
4. Vegetables should be sown as directed above in the spaces between these rows for making slope more stable.
5. Average benching or terracing is done 4-6.5m in width It is advised to use a vertical interval on slopes taller than 10 meters (30 feet).

Erosion along the shore, unstable water-retaining structures, and riverbanks

For erosion control along the shores, unstable water retaining structures and riverbanks; following guidelines may be necessary:

1. The highest bank slope can't be greater than 1.5(H):1(V). A 2.5:1 bank slope is advised in normal condition.
2. There are two directions in which plantation work is carried out. Vetiver should be planted in rows in flow direction with contour interval of 0.8–1.0 m to stabilize banks and in right angle to the flow direction columns of spacing 2.0 meters for erodible soil and 4.0 meters for stable soil, to decrease flow velocity effectively.
3. But, normal rows are also planted 1.0 m apart in critical situations where extra protection is needed(e.g., a river dike in Quang Nagi).

Vetiver system can also be used in collaboration with other conventional structural measures, including retaining walls and rock or concrete riprap, for all situations. For instance, vetiver hedgerows can be used to protect the upper portion of slope while civil engineering materials or structures cover the lower portion (Truong et al., 2008).

GUIDELINES FOR VETIVER PLANTATION WORK

Following are some essential guidelines for plantation work of the vetiver system:

1. Make trenches that are between 15 and 20 cm in depth and width.
2. In infertile slopes, it is better to add a small amount of high-quality soil-manure slurry.
3. Tube stock should be recommended for large-scale plantation work and for work needed quick establishment.
4. Well-rooted plants should be planted (with 2-3 crop plants in each) in the middle of platform(ground) at 10-12cm intervals for erodible soils, and at 15cm intervals for ordinary soils.
5. Open root planting is enough to preserve natural riverbanks if initial irrigation can be guaranteed without additional work and the soil is often rich.
6. Add 20–40 mm of ground cover to the roots and then compacted it firmly.
7. For the establishment year, a pre-emergent herbicide may be applied for weed control growth (Truong et al., 2008).

ADVANTAGES OF VETIVER OVER OTHER BIO-ENGINEERING PLANTS

1. **Establish in high-temperature differences:** On temperature swings between -15°C and +55°C, vetiver can withstand severe weather conditions such as drought, floods, and submersion.

2. **Fast-grown root system:** The massively fine structured root system of vetiver was grown very fast compared to other bio-engineering vegetation. Its root can grow 3-4 m in depth in the first year.

3. Its deep root system provides greater anchorage properties to soil mass. Also, it is a more drought-resistant plant and difficult to dislocate by strong wind among other contemporary bio-engineering vegetation.

4. **Low-cost and long-lasting grass:** In Australia, Extremely economical, saving 73% on culvert protection, 64% on table drain and other protection works, and 60% on road shoulder protection. (Bracken & Truong, 2000). In poor, highly erodible, and dispersible soils vetiver seem to be more effective and long-lasting vegetation.

5. **Low maintenance:** It is rigid in case of plant disease affection, can survive without periodic watering and fertilization, and requires only trimming in regular intervals. Thus, it reduces the overall cost and labor of maintaining the vegetation.

SUITABILITY OF VETIVER IN KTFT

KTFT project includes the program's start point Khokana with its forward roadway lying left-right of Bagmati River; which requires control of river bank erosion control. This project covers the regions of central Nepal including lesser Himalayan, Siwalik, and Indo-Gangetic plain, and soil formation is by phyllite and schist rock; which have a higher potential of sliding the soil mass in the presence of water and are thus unstable in the rainy season. Lesser Himalaya is highly prone to landslides due to its steep slopes and high levels of seismic activity. In addition, heavy monsoon creates vulnerable conditions due to its fragile geological formation. Similarly, Siwalik hills are also prone to landslides due to loosen unconsolidated sediments present and are very risky to frequent landslide occurrences. Indo-Gangetic plain was flat terrain thus it was safe in the landslide case but was victim of the flood.

The transportation sector was a major source of greenhouse gas emissions. In 2022, 7.97 billion metric tons of carbon dioxide (GtCO_2) was emitted from transportation sector in world which was a 4.7% increase above 2021 levels. Emission of greenhouse gases rise by more than 70% form global transportation sector between 1990 and 2022 (Ian, 2023) . As we know that transportation sector of Nepal was also a small-scale contributor in carbon emission and KTFT will become a busy transportation route of the nation so its carbon emission should be under control situation for safe travel and to breathe in a healthy environment for connected people on a regular basis.

Some field observation shows that the vetiver system is effectively used in the control of river bank erosion work. Also, it was famously used to stabilize road batters. Its effective performance in landslide-prone areas and flooded areas was appreciable. It has greater carbon sequestration properties. Thus, the vetiver was very suitable for the KTFT project.

COMPARISON OF VETIVER WITH OTHER BIO-ENGINEERING PLANTS

A few important variables determine the most successful bioengineering of plants from a comparative perspective. Tensile strength, dry biomass, root cohesiveness, root length, and survival rate are the similar main parameters that are compared between the bioengineered vegetation. Key factors' identities are listed as follows:

- Root length: Longer roots improve soil rigidity and strength by penetrating deeper soil. By more firmly anchoring the soil, they lessen soil erosion, which is particularly beneficial for averting soil flushing in landslides and preserving river banks. Longer roots improve soil stability and structure by penetrating the soil deeper.

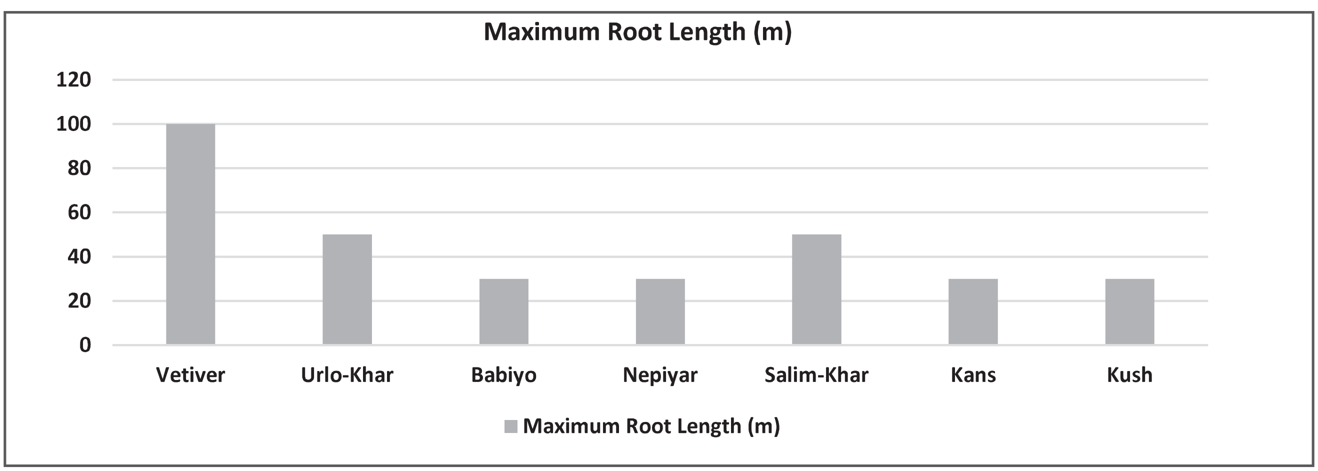
- Root Cohesion: Cohesiveness lowers the chance of landslides and topsoil slippage on hills and embankments. This is especially crucial in areas that frequently experience earthquakes or heavy rainfall. Root cohesion can shield buildings, bridges, and other infrastructure from soil movement-related damage by stabilizing the soil.
- Tensile Strength: The stability of earth constructions can be considerably improved by roots possessing high tensile strength. Their mechanism of holding soil particles together lowers the chances of soil erosion and landslides. This is particularly crucial in regions that frequently experience earthquakes or severe rainfall.
- Dry biomass: Using plant dry biomass in bioengineering has several important applications in environmental remediation, material science, and energy production.
- Survival rate: The survival rate of bioengineering vegetation is a crucial aspect since it is directly linked to the vegetation's ability to survive in harsh environmental conditions or to exist in the first place.

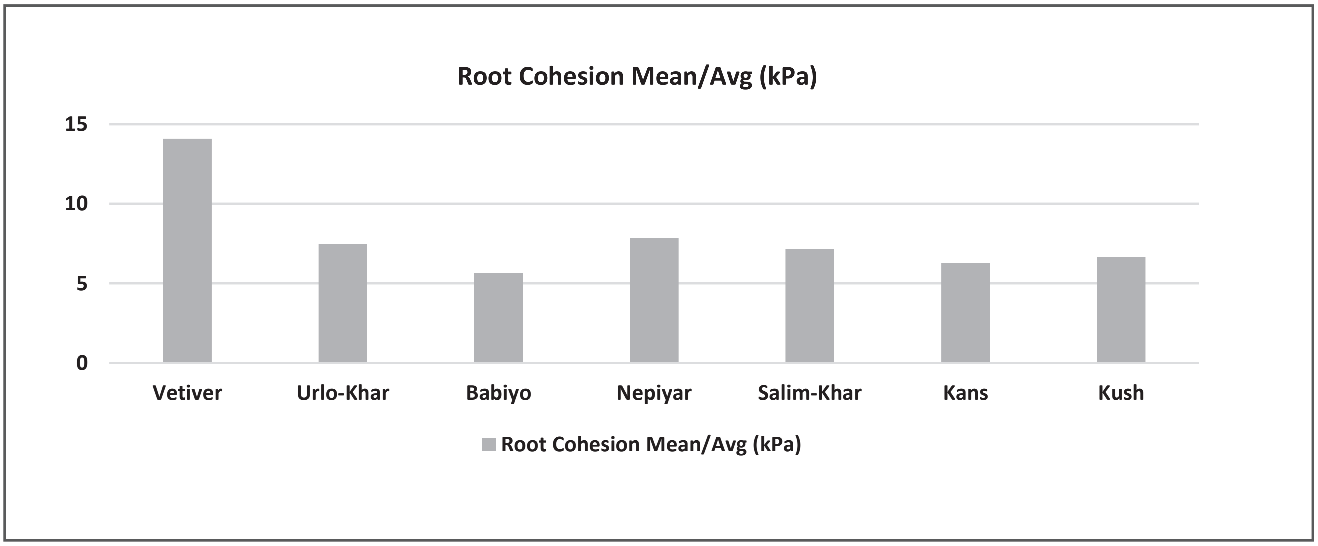
Below is a comparative table of important native soil data and its key parameters (from Nepal's central-western region) and corresponding charts:

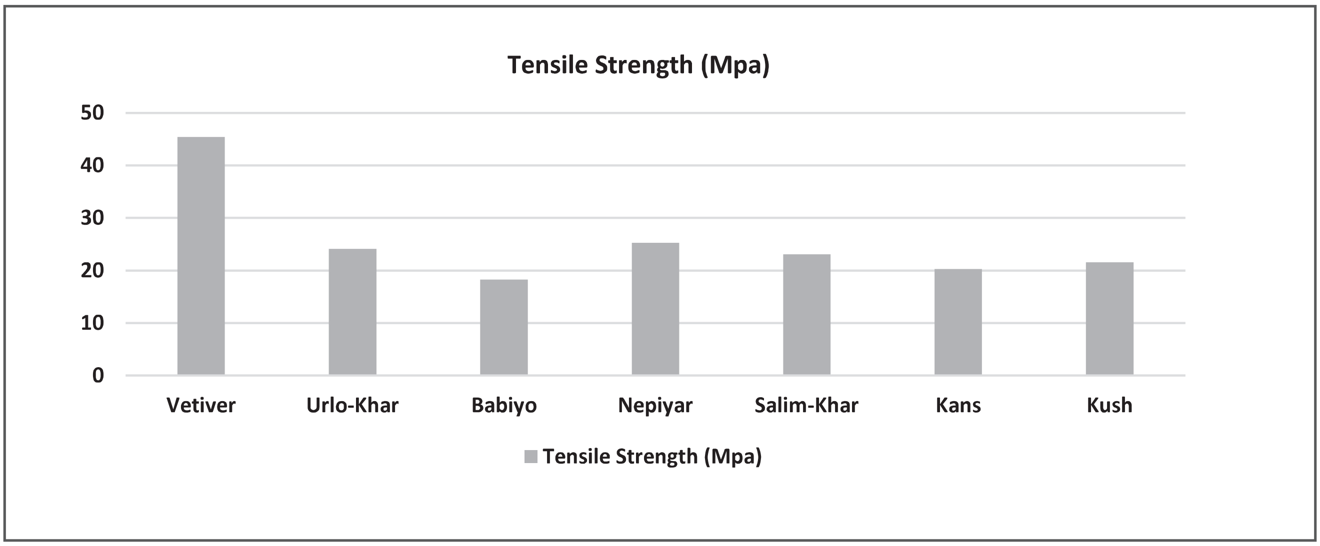
Species Local Named	Species Name	Survival (%)	Canopy Cover (%)	Biom-s-Dry (kg)	Biom-r-Dry (kg)	RAR-Deep	RAR-Shallow	Rooting Depth (cm)	Tr (MPa)	cr (kPa)
Vetiver	C .zizanioids	80.00	70.57	0.83	0.32	0.0018	0.0241	0-100	45.4	14.08
Urlo-Khar	C. microtheca	78.67	48.33	0.63	0.33	0.0018	0.0092	0-50	24.11	7.48
Babiyo	P. purpurreum	81.33	86.67	0.78	0.54	0.0001	0.0128	0-30	18.25	5.66
Nepiyar	C. gryllus	76.00	60.27	0.39	0.28	0.004	0.0082	0-30	25.28	7.84
Salim-Khar	E. binata	66.67	51.43	0.18	0.19	0.0003	0.0104	0-50	23.1	7.17
Kans	D. bipinnata	65.33	29.70	0.26	0.19	0.0006	0.0119	0-30	20.24	6.28
Kush	S. spontaneum	62.00	41.10	0.33	0.15	0.0010	0.0084	0-30	21.53	6.68
Amriso	T. maxima	70.67	78.63	0.62	0.30	0.0099	0.657	0-80	26.65	8.27

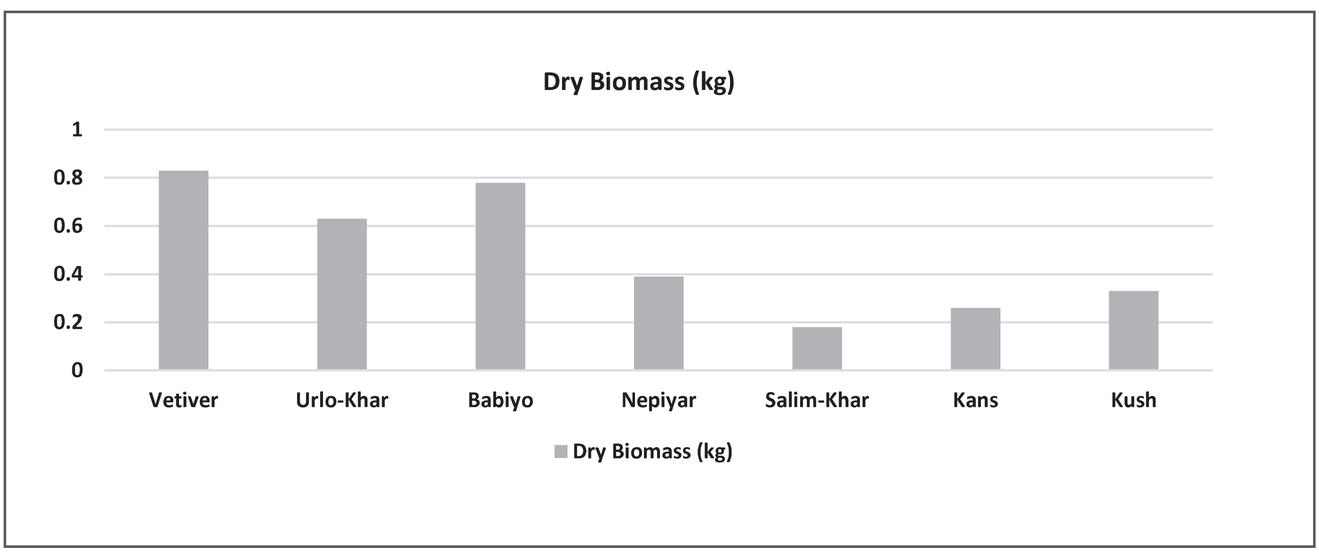
Biom-s-dry = drybiomass of shoot, Biom-r-dry= dry biomass of root, RAR-deep = root area ratio of deep roots, RAR-shallow = root area ratio of shallow roots, T_r = tensile strength, c_r = root cohesion.

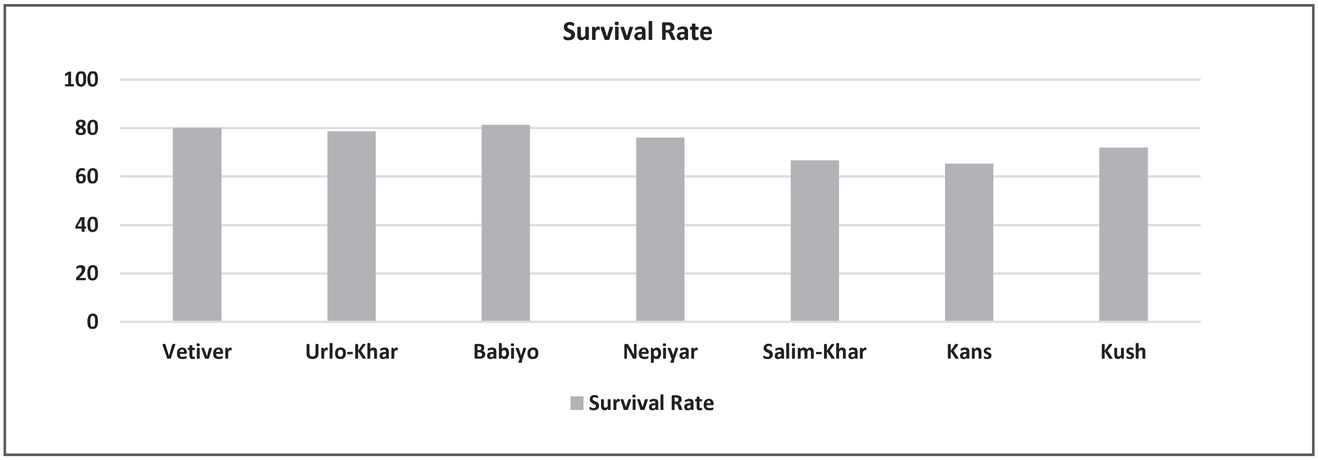
Source: (Devkota & Shakya, 2019)




Root Cohesion Mean/Avg (kPa)
15
10
5
0
Vetiver
Urlo-Khar
Babiyo
Nepiyar
Salim-Khar
Kans
Kush
Root Cohesion Mean/Avg (kPa)


Tensile Strength (Mpa)
50
40
30
20
10
0
Vetiver
Urlo-Khar
Babiyo
Nepiyar
Salim-Khar
Kans
Kush
Tensile Strength (Mpa)


Dry Biomass (kg)
1
0.8
0.6
0.4
0.2
0
Vetiver
Urlo-Khar
Babiyo
Nepiyar
Salim-Khar
Kans
Kush
Dry Biomass (kg)



According to the above table and chart, vetiver performs best at anchoring on soil mass and supplying enough strength to ground since it has higher rooting depth, tensile strength, and root cohesion values. Furthermore, its high survival rate and dry biomass values show that it performed well in its current capacity and environmental remediation.

CONCLUSION

Bioengineering has been performed for a long time in Nepal however, the science behind it is not well understood. For agricultural area protection projects and small-scale run-off management in steeply sloped locations, the use of native bioengineering vegetations like bamboo, kans, kush, amriso, khair, simali, and so forth with non-living materials (i.e., wood, stone, etc.) has been common practice. Because bioengineering's function and appropriate application in each field were unclear, its application in infrastructure development was uncommon until only civil engineering structures became unfit for functioning.

We were initially briefly introduced to vetiver grass through this writing. In a similar vein, we were able to describe several useful applications of this vegetation in the real world through a survey of the literature, with positive outcomes. We talked about its specification criteria during plantation in this approach. The vetiver comparison chart indicates that it was the best vegetation among other modern bio-engineered vegetations, and the vetiver suitability in KTFT section demonstrates the vegetation's applicability in KTFT. Finally, we would like to state that the utilization of vetiver on the Kathmandu Terai Fast Track (KTFT) has been shown to improve bioengineering practices in Nepal based on previous research conducted on this grass.

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