Effect of forage grass (Pennisetum pedicellatum) and legume (Stylosanthes hamata) revegetation on recovery of soil fertility in a reclaimed hazardous waste dump

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Abstract

Dumping of hazardous waste causes land degradation, air, and water pollution, deteriorates landscape and aesthetics, which can be controlled by reclaiming with grass-legume seeding. The study aimed to examine the effect of grass-legume revegetation between 1- and 5-years in a restored waste dump (hazardous waste of an integrated steel plant) reclaimed with coir-matting, topsoil blanketing followed by grass (Pennisetum pedicellatum) and legume (Stylosanthes hamata) seeding. We hypothesized that the synergistic effect of the grass-legume mixture would lead to an increase in productivity and soil fertility. To assess the effects, changes in root and shoot biomass, mulch accumulation, nitrogen (N) mineralization, and its effect on soil fertility were measured. Our results showed between 1- to 5-years legume and grass biomass increased by 44% and 37%, respectively. An increase in mulch density and thickness along with revegetation age potentially increased the soil moisture by 7.5% and lowered soil temperature by 9°C at 10 cm depth. Cumulative N-mineralization by legume was three-fold higher than the grass. Soil organic carbon (SOC), available N, total N, N-stock, and soil respiration was doubled after 5-years of revegetation. Dehydrogenase and urease activity increased by 44% and 56% respectively, indicating greater C and N accumulation at the dump surface. The study concluded that grass (P. pedicellatum) and legume (S. hamata) mixture can be used for reclamation of the waste dump that accelerates recovery of the fertility of disturbed topsoil by contributing mulch with increasing age of revegetation.

Abstract

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increasing age of revegetation.

Keywords: Reclamation; topsoil; mulch; nitrogen; soil CO_2 flux; waste dump

INTRODUCTION

Soils are being degraded worldwide due to industrial activities and the inevitable dumping of solid wastes. The solid waste generated from an integrated sponge iron plant consists of dolochar, slag, and fly ashes, dumped together causes deterioration of aesthetics, and acts as continuous sources of pollution. They caused severe air pollution problems during the summer, while in monsoon, the loose waste was easily carried away along with run-off to pollute the nearby water bodies. The waste is very homogenous, loose, and devoid of nutrients, hence stabilization of this type of waste poses a severe challenge. Additionally, the dumping of waste materials alters the surface soil horizon (native topsoil) at the disposal site. Therefore, proper handling and sustainable management of hazardous waste are essential to minimize land degradation and environmental pollution.

Ecological restoration is the only remedy that causes the degradation of solid wastes with time and regenerating the natural aesthetics of the land. The restoration method may involve the application of fertile topsoil, covering the exposed slope area with geotextile mat, different soil amendments, revegetation with grass-legume seed mixture, and selective plantation. Every step involved its associated primary benefit which aids in the process of restoration. Geotextile mats are beneficial for topsoil water retention and vegetation growth on abandoned wastelands (Shao et al., 2014). To develop quick vegetation cover, control erosion, and minimize pollution, seeding of grass-legume mixtures has now become a widely used technique to restore soil fertility of wastelands (Maiti, 2012; Shang et al., 2014). With time, grass and legume litter eventually dry and produces mulch which decomposes to form humus and regenerates the soil organic layer (Maiti & Maiti 2015).

A variety of plant species has been used to stabilize dump surface but the selection of plant species that can provide an adequate vegetation cover has an added advantage. Grasses and legumes quickly aid in developing thick ground cover and decomposition of biomass residues contribute organic matter (Maiti, 2012; Maiti & Maiti, 2015; Shang et al., 2014). For instance, proportional seeding of the grass-legume mixture showed improvement in the soil nutrients in degraded pasture soil of Cerrado, Brazil (Marques et al., 2016). Seeding of grass (*Cynodon dactylon* and *Paspalum notatum,*) and legume (*Medicago sativa, Indigofer tinctoria* , *Amorpha fruticose,*and *Lespedeza bicolor*) mixture attributed significant improvement in the initial vegetation cover of highway slopes along with recovery of soil physicochemical properties (Yang et al., 2016). Natural regeneration of exotic legume *Leucaena leucocephala* showed the potential to recover soil fertility compared to grasses predominant on mine waste dumps of varying ages in Brazil (Lima et al., 2018). The introduction of legume (*M. sativa*) on abandoned farmlands increased biomass cover as well as soil N concentrations during 1 to 11 years of revegetation (Yuan et al. 2016). Addition of legume *M. sativa* also increased aboveground net primary productivity along with soil carbon (C), nitrogen (N) and phosphate (P) storage in a sandy grassland amended with sediment (Wu et al., 2019). Grass species, such as *Chrysopogon zizanioides* , *Pennisetum macrourum* ,*Pennisetum polystachion,* and *Pennisetum purpureum* were used to restore wastelands in Southwest Ethiopia (Talema et al., 2019). Under drought stress conditions, root length and root area of grasses are more than legumes at the 30-60 cm depth of soil (Wang et al., 2020). A greenhouse study reported that an increase in soil N concentrations and development of diverse microbial communities were observed when invasive legume (*Lespedeza cuneate*) introduced with native grass (*Schizachyriu mscoparium)* in a mixture (Fill, Pearson, Knight, & Crandall, 2020).

Soil organic matter (SOM) and available N instantly declines in topsoil due to land degradation which usually takes time to recover (Maiti & Maiti, 2015). Plant-derived biomass residues in the form of mulch can accelerate the accretion of soil nutrients. The quantity and chemical composition (N concentration and C:N ratio) of the organic mulch residues are variables which determines decomposition rate, predict the amount of potentially mineralizable N (PMN) and nutrients release affecting soil quality (Halde & Entz, 2016; Ibrahim, Abaidoo, Fatondii, & Opoku, 2018; Radicetti et al., 2017). Mulching thickness shows a direct positive effect on soil moisture content and reduces soil surface temperature (Kader, Senge, Majid, & Ito, 2017; Pramanik et al., 2015; Wang et al., 2017). Indirectly, decomposition of litter/organic mulches by microbes also adds to the SOM that simultaneously augments the C and N pools and helps in carbon sequestration (Frouz, 2018; Guoju et al., 2020; Zhang et al., 2019). Organic mulching has been preferred for years because it is eco-friendly, saves labor cost and after decomposition, adds biomass nutrients to soils.

We investigated the effect of forage grass (Deenanath grass;*Pennisetum pedicellatum* Trin.) and legume (Caribbean stylo;*Stylosanthes hamata* (L.) Taub.) revegetation and gradual enrichment of mulch on soil fertility of the reclaimed waste dump. We hypothesized that the synergistic effect of grass-legume revegetation would lead to an increase in the restoration of productivity and soil fertility with time. The objectives of the present study were to (i) assess the changes in soil physicochemical and biological properties under grass-legume mixture at two developmental ages of revegetation (between 1- and 5-years), (ii) examine the effect of biomass residue (mulch) on soil fertility of the revegetated waste dump, and (iii) analyze the role of grass and legume biomass residue in N-mineralization.

2. MATERIALS AND METHODS

2.1 Study area

The experimental plot was established on the solid waste dump of the Nalwa Steel and Power Limited (NSPL) located in the Raigarh district of Chhattisgarh, India (Figure 1). NSPL is an operating integrated steel plant that manufactures sponge iron by the direct reduction process. The aerial extent of the waste dump lies between 83^{o}22'35"E to 83^{o}23'27"E and 22^{o}00'51"N to 22^{o}02'10"N covering an area of approximately 7 hectares. The dump height ranged between 40-50 m with a slope of more than 60–70^{o} inclination. The area experience subtropical climate with temperature ranged between 8–49°C and the mean annual precipitation was 750 mm. The waste materials were dumped externally at the outskirts of the steel plant surrounded by *Shorea robusta*dominated forest.

The main stages involved in sustainable closure and subsequent reclamation of the waste dump were as follows (Figure 2): (a) leveling of the surface, compaction and maintaining slope of 1:3 for proper surface runoff, (b) re-grading of slopes and blanketed with coirmats followed by topsoil and seeded with grass-legumes seeds, (c) safety measures like stone pitching at the toe of the dump and construction of garland drain, (d) re-grading the surface before applying forest topsoil up to 0.6-1 m depth, (e) for stabilization of the slope and sidewalls coir mats of dimension (1m × 30m) were used, (f) for the development of green cover in the initial stage, seed mixture of grass (*P. pedicellatum*) and legume (*S. hamata*) in a 1:1 ratio was sown. the view of stabilized dumps after 5 years, with the development of mulch covers in lean season (summer), is shown in Figure 3. In the berm of dumps, tillers of lemongrass (*Cymbopogon citratus*) were planted. Tree species like *Azadirachta indica* , *Leucaena leucocephala* , *Acacia nilotica, Pongamia pinnata* were also planted on the edges to increase dump stability.

2.3 Biomass sampling and analysis

A total of 10 sampling points was randomly selected at the waste dump and an area of 1 m^2 at each point was marked for vegetation sampling. We used the harvest method to estimate shoot and root biomass. Soil particles attached to roots were separated by soaking and washing with a fine jet of water with ultrasonicator. During soil sampling, rooting depth was measured (i.e., depth of root penetration). Shoot and root biomass was separated and oven-dried at 65°C for 48 hours to measure the weight of the dry biomass. Biomass samples were finely grounded and a sieved (<1mm) to determine the total carbon (C) and nitrogen (N) using an elemental analyzer (Euro EA 3000 Eurovactor, Italy). Dry mulch accumulated on the surface layer was collected by using quadrate (size: 30 cm × 30 cm), from the same location where soil and vegetation samples were collected.

2.4 Nitrogen mineralization

Grass and legume residues (0.2 gm on a dry weight basis; <1mm size) mixed with topsoil (20 gm; <2mm) were packed in a plastic container and incubated at 28^{0}C for 14 weeks to measure N-mineralization. Soil moisture content was maintained at 50% of field capacity throughout the experiment. Soil samples without plant residue were also incubated as control. The incubated soil samples were extracted with 100 ml 1M KCl solution by shaking for 1 h in an orbital shaker and filtered through Whatman #42 filter paper at an interval of 1, 2, 3, 4, 6, 8, 10, 12 and 14 weeks. The inorganic N concentration in the soil extract was analyzed by the steam distillation method (Keeney & Nelson, 1983).

2.5 Soil sampling and analysis

Soil samples were collected by laying random quadrats of 10m × 10m on the surface of the waste dump after 1 and 5-years of revegetation and natural forest (NF) as reference. Within each quadrat, composite soil samples were obtained by mixing five subsamples. A total of 110 composite soil samples were collected in a similar manner, 10 samples each at a consecutive depth of 0-10 and 10-20cm from the forest and both the revegetated dumps and 10 samples from 5-years old revegetated dumps under 0, 3, 6, 9 and 12 cm mulch thickness using a stainless-steel soil corer of 10 cm height and 8 cm internal diameter. The collected soil samples were air-dried at room temperature (25-29^{0}C) for a week and lightly crushed with a mortar and pestle. The coarse soil particles (>2 mm size) were separated from the crushed soil using standard mesh size gravimetrically. Bulk density (BD) was determined by the soil core method (Blake & Hartge, 1986). Soil pH was determined potentiometrically in soil: water (1:2.5, w/v) by the multi-parameter probe (HI2020, Hanna Instruments India). Soil organic carbon (SOC) was estimated by using the rapid dichromate oxidation technique (Nelson & Sommers, 1996). Soil organic matter (SOM) was determined as the weight differences after a loss on ignition (LOI) between 105°C and 375°C. Soil microbial biomass carbon (MBC) and nitrogen (MBN) were measured by chloroform fumigation /0.5 M K_2SO_4extraction method (Vance et al., 1987; Brookes et al., 1985). Soil urease activity (UA) was measured by the colorimetric method and the released $NH_4{}^+$ was quantified by UV-VIS Spectrophotometer (Guan, 1986). Dehydrogenase activity (DHA) in soil was estimated using 2, 3, 5-triphenyl tetrazolium chloride as a substrate (Casida, Klein, & Santoro, 1964). Plant available N (Av-N) and total N concentration were determined using a semiautomatic nitrogen estimation system (KJELODIST-EAS VA, Pelican Equipment, India) (Subbiah &Asija, 1956). Available phosphorus (Av-P) was determined by the Bray's method (Bray & Kurtz, 1945) and Cation exchange capacity(CEC) of the soil was determined by Na-saturation method (soil was saturated with 1N sodium acetate solution, washed with ethanol and subsequently treated with 1N ammonium acetate) and measured by a flame photometer (ESICO-1388, Microprocessor flame photometer, India) (Jackson, 1973). Soil organic carbon and total N stock was calculated by using respective elemental concentration in soils, specific soil depth and bulk density as follows:

$$\text{SOC or N stock } \left(\text{Mg ha}^{-1}\right) = [SOC\ or\ N\ conc \times \text{BD} \times T\ \times 100](1)$$

Where SOC is soil organic carbon concentration (%), N is total nitrogen concentration (%), BD is bulk density (Mg m^{-3}), T is soil thickness (m).

2.6 Soil CO_2flux measurement

Rate of soil CO_2 flux was measured at the revegetated dump surface during two developmental ages and natural Sal forest for a week (24 hours every 20 min interval for 90 seconds) by LICOR LI-8100 Infrared gas analyzer (LICOR Inc. Lincoln, NE, USA). Temperature probe (type E-thermocouple, p/n 8100-201; 6.4 mm diameter, 25 cm length) was inserted up to a depth of 10cm to record soil temperature. Similarly, soil moisture was measured by a moisture probe (ECHO Model EC-5, p/n 8100-202; 5 cm length). The Probe output is given as mV (700–1300 mV), and volume of water content is expressed as m^3/m^3 by using the following regression equation as given in the LI-8100 instruction manual:

$$\text{VWC } \left(\frac{m^3}{m^3}\right) = \ -\ 3.14\ \times 107\ x\ mV\ +\ 1.16\ \times\ 103\ x\ mV\ -\ 0.612\ (2)$$

In the laboratory, the calibration curve was prepared between millivolts (mV) and moisture content (percent, w/w basis) ranging from 525 to 1190mV and corresponding moisture percentage ranging from 0.5 % (dry soil) to 20.4 % (wet soil) was calculated as follows:

$$Moisture\ (\%,\ w/w\ basis) = 0.03 \times \mathrm{mV} - 14.41\ [R^2 = 0.909]\ (3)$$

2.7 Statistical analysis

The significant differences between the mean under different land covers were tested using analysis of variance (ANOVA) and compared by Tukey post hoc test at α [?] 0.05 significance level. The statistical relationship between different parameters and factors influencing them was assessed using Pearson correlation analysis. Regression analysis was carried out to investigate the relationship between the dependent variable (N-mineralization) with independent variables (TN and C:N ratio). All statistical analyses in this study were performed using SPSS21.0

3. RESULTS

3.1 Changes in plant biomass and N-mineralization potential

Growth of *S. hamata* and *P. pedicellatum* showed significant changes in rooting depth, shoot and root biomass, and mulch stock between the developmental ages of revegetation. The results showed that legumes biomass (26.82 Mg ha^{-1}) was higher than the grass biomass (19.02 Mg ha^{-1}) after 5 years of revegetation (Table 1). Biomass accumulation with the age since revegetation and their subsequent conversion to dead biomass increase mulch density from 11.4 to 28.0 Mg ha^{-1} (Figure 4). Continuous increase in mulch density resulted in greater mulch accumulation on the dump surface that has a significant effect on soil temperature and moisture content. The biomass residues showed a greater amount of C in grasses while N concentration was higher in legumes (Table 2). Inorganic N concentration in legume residue ranged from 2.18 – 2.55 g kg^{-1}compared to 0.32-1.44 g kg^{-1} in the grass with shoot biomass contributing the highest concentration. The biomass residues used for incubation showed differences in C:N ratio for a shoot (12.4) and root (22.6) of *S. hamata* and shoot (20.3) and root (31.1) of *P. pedicellatum* . Changes in labile N pool from soil extract amended with biomass residues were greater by legume than grass with incubation time (Figure 5). The mineralization rate showed greater values (25-27 mg N kg^{-1} wk^{-1}) during the first 3-weeks of incubation and declined to 15 mg N $kg^{-1}wk^{-1}$ toward the 14^{th} week by the legume. Similarly, shoot biomass of grass showed the lowest N mineralization ranging from 7-8 mg N $kg^{-1}wk^{-1}$ in first 3-weeks and 2 mg N kg^{-1} wk^{-1} by the end of the incubation period. The cumulative N mineralization rate was greater by legume shoot biomass (166 mg N kg^{-1}soil) compared to grass (58 mg N kg^{1} soil). Linear regression analysis showed that the percentage of mineralized N was highly dependent on TN pool of decomposing biomass and negative curvilinear relationship with biomass C:N ratio in both shoot and root biomass of legume and grass (Figure 6).

3.2 Changes in soil properties

Changes in soil physicochemical and biological properties after 1 and 5-years of grass-legume revegetation were significantly different from natural forest soils (Table 3). The disturbed topsoil prior to grass-legume seeding had a pH (4.7), BD (1.26 g cm^{-3}), Av-N (46.68 mg kg^{-1}), TN (389.60 mg kg^{-1}), SOM (0.81%), SOC (0.34%), Av-P (0.74 mg kg^{-1}), UA (1.26 µg NH_4^+ $g^{-1}h^{-1}$), DHA (1.57 µg TPF $g^{-1}h^{-1}$) and CEC (5.23 cmol (p^+) kg^{-1}). Changes in soil pH (5.8-5.6) with increasing age of revegetation were not significant ($p>0.05$). BD showed an increasing trend with soil depth and found highest in 1-year revegetated soil. A significant increase in the mulch density over the years resulted in favorable soil conditions which help increase the topsoil moisture content of the reclaimed waste dump from 3.8 to 11.8% compared to a natural forest (7.20%) and decrease soil temperature (26-23^0C) at the top layer (0-10 cm) (Table 3; Figure 4). SOC concentrations doubled in 5-years and significantly different ($p<0.05$) in both the soil depth. SOM concentration improved due to enrichment of grass-legume mulch which decomposed over the years but significantly lower compared to forest soil. Soil Av-N and Total-N concentrations were significantly greater after 5-years (132 and 1165 mg kg^{-1}) compared to initial concentrations (54 and 579 mg kg^{-1}) in the top layer. Decrease soil C:N ratio justifies greater accumulation of N over C due to an abundance of legume biomass residue. Both DHA and UA reduced with soil depth as maximum interaction of soil microbes was found to occur in the top surface (0-10 cm). Highest DHA was observed in forest soil (10.14 µg TPF g^{-1} h^{-1}) whereas DHA in reclaimed soil increased significantly ($p<0.05$) from 3.7 to 5.32 µg TPF g^{-1} h^{-1} (Table 3). Similarly, UA also showed a significant increase from 4.57 – 7.11 µg NH_4^+ $g^{-1}h^{-1}$ among the revegetated sites during 1 to 5-years but non-significant when compared to forest soil. Soil C and N stocks increased significantly with revegetation age and decreased with the soil depth (Table 4). After 5-years of grass-legume revegetation SOC stock increase by 66% in the top layer. Soil N stock was also significantly higher ($p<0.05$) after 5-years of revegetation (1.47 ± 0.21 Mg ha^{-1}) compared to forest N stock (1.00 ± 0.32 Mg ha^{-1}).

Additionally, an increase in mulch thickness (0, 3, 6, 9, and 12 cm) on the dump surface accelerated the soil microbial biomass C and N even in the early stages of revegetation promoting soil fertility. The level of improvement was highest with 12 cm mulch thickness for all the assessed soil parameters (Figure 7). The amount of potentially mineralizable biomass residues in the soil correlated positively with N pool, SOM, microbial, and enzyme activity (Table 5). Soil CO_2 flux rates differ significantly under different land covers and showed peak values for NF (Figure 8). The mean soil CO_2 flux was found in the order of natural forest (3.17 ± 0.55µmol m^{-2} s^{-1}) > 5-years (1.21 ± 0.15µmol m^{-2} s^{-1}) >1-year (1.01 ± 0.62µmol $m^{-2}s^{-1}$) reclaimed waste dump over the experimental periods of revegetation.

4. DISCUSSION

4.1 Effect of grass-legume mixture on N-mineralization

The growth of grass-legume mixture after 5 years of revegetation on the waste dump has substantially increased the biomass by 41% and mulch stock by 93% (Table 1). An increase in grass-legume mulch thickness up to 12 cm in 5-years showed a positive effect on moisture and temperature in the upper layer (0-10 cm) of soil. Due to an increase in mulch accumulation maximum soil temperature was dropped by 9°C which increased moisture content of the reclaimed dump surface by 7.5% compared to bare soil (Figure 2). These changes are attributable to thick surface mulch formed over the dump surface which creates a cooler soil environment, reduces evapotranspiration, and holds soil moisture by ameliorating the surface temperature. Our results are consistent with the findings of Wang, Liu, Wu, Li, & Wang, (2017).

Microbial decomposition of biomass residue releases potential nutrients available to plant depends on the rate of mineralization which regulates the conversion of organic to inorganic N pool (Abdelhafez et al., 2018; Ansong Omari et al., 2018; Marzi, Shahbazi, kharazi, & Rezaei, 2020). Inorganic N concentration in legume shoot and root biomass accounted for 0.91% and 0.42% respectively of the biomass total N pool whereas cumulative N-mineralization by legume residues were three-folds greater than the grass (Table 2; Figure 5). The study of C and N mineralization reported that net N mineralization was greater by legumes (33%) than non-legumes (20%) species and differs across shoot and root biomass of both the species (Li et al., 2020; Li et al. 2019). The increase in labile N pool in the reclaimed dump soil indicates the presence of mineralizable organic N contributed by legume and grass biomass in the mixture after one to five years of revegetation.

After 5-years of revegetation, increase in soil moisture and the enrichment of mulch stock constituting high-quality N rich legume biomass with low C:N ratio enhances the N-mineralization process (Figure 6; Figure 7) and makes it desirable for the functioning of microbial populations (Jilkova, Strakova, & Frouz, 2020; Lei & McDonald, 2019; Li et al., 2019). Legume biomass with low C:N ratio can be readily decomposed by soil microbes leaving excess N in soil that can be used by associated plant species whereas, higher C:N ratio of grass biomass contributes to soil C but in long term, the accumulation of SOC can be controlled by N concentration. These difference in the chemical characteristics of the biomass residues of grass-legume mixture incorporated in soil shifts the nutrient cycling via mineralization which stimulated the soil microbial activities (Amorim et al.,2020; Bhandari, West, & Acosta-Martinez, 2020; Prommer et al., 2020) and enzymatic activities (Joniec, 2018; Sekaran et al., 2020; Tian et al., 2017). Therefore, understanding the N mineralization patterns of grass and legume biomass returned to the soil during revegetation is important for the management of soil N dynamics in nutrient cycling.

4.2 Effect of grass-legume mixture on SOM and enzymes activity

Soil fertility in terms of SOM, C and N concentration readily declines in topsoil during initial use at the waste dumpsite, which can be recovered through revegetation and subsequent nutrient cycling via decomposition and mineralization (Campos, Etchevers, Oleschko, & Hidalgo, 2014; de Oliveira et al., 2015; Semenov et al., 2019). Analysis of variance (ANOVA) showed that the growth of grass-legume mixture on dump surface bought significant changes in both above and below-ground soil systems (Table 3). Enrichment of grass-legume mulch over 5-years of revegetation increased the SOC and SOM concentration by 94% and 35% respectively in 0-10 cm depth. However, when compared with forest soil, both SOC and SOM concentration was still 23% and 111% lower in reclaimed soil. Similarly, SOC and N stock in the blanketed soil also showed increment by 66% and 122%, respectively, after 5-years compared to initial concentration (Table 4). These differences are mainly attributed to the presence of rapidly decomposing legume residue, impedes the recovery of SOM, and potentially available forms of C and N pool governed by soil microbes and plant rooting depth will absorb a large amount of the nutrient, leading to increased microbial activity. Previous studies have also reported that the incorporation of legume biomass helps in the recovery of soil C (Guan et al., 2016; Wu, Liu, Tian, & Shi, 2017) and N stock in the early stage of biological reclamation (Ahirwal, Maiti, & Reddy, 2017a; Elgersma & Soegaard, 2016).

The changes in root and shoot biomass and mulch accumulation in mixture modifies the composition of mulch residue added to the soil, which resulted from an increase in N mineralization, promotes C and N recovery link to increase soil microbial biomass C and N (Figure 7). At the same time, enzymes related to soil C and N decomposition processes i.e. dehydrogenase and urease enzyme activity demonstrate 56 and 44% increase, respectively after 5 years of revegetation compared to 1st year which probably reflected the general build-up of the microbial biomass. These results show the positive correlation and linkage between nutrient parameters, microbial and enzyme activities in a high decomposition driven soil environment (Table 5) that are in agreements with the similar trends explained in other studies (Hou et al., 2018; Luo et al., 2018; Zuber & Villamil, 2016). During land use change, plantation of legume (*M. sativa*) significantly improved the soil N concentration and urease enzyme activity after 3-years of the plantation (Yu, Lin, Liu, & Wang, 2020). Our finding illustrates the fact that reclaimed soils under grass-legume revegetation have higher N mineralization potential and beneficial for the growth of soil microbial biomass that is related to enzyme activities that play a crucial role in effective recovery of soil nutrients during revegetation.

4.3 Effect of grass-legume mixture on soil CO_2flux

The decomposition of grass-legume mulch over 5-years of revegetation, influence microbial respiration and increased CO_2 flux of the reclaimed waste dump by 19%. Soil CO_2 flux attributed by natural forest was 1.5 times greater than the 5-years old reclaimed waste dump (Figure 8). Variation in the rate of soil CO_2 fluxes can be due to the difference in soil temperature, litter/biomass input, and plant root growth (Frouz, 2017). Higher N concentration of the legume shoot and root residues showed an efficacious effect on soil N pool whereas higher root C in grass residue built soil C pool and increases CO_2 efflux and their addition as mulch available for microbes increases the soil microbial respiration throughout the stages of decomposition. An increase in labile C pool would increase soil respiration as the grass biomass residues reduce N leaching i. e. positive priming effect (Frouz, Novotna, Cermakova, & Pivokonsky, 2020; Wu et al., 2020). Root biomass-derived C compared to shoot biomass C have been reported to contribute greater and relatively stable soil C pools (Ghafoor, Poeplau, & Katterer, 2017). Apparently, these differences gradually declined during microbial decomposition because soil C:N ratio decreased after 1-5 years of revegetation (Table 3). Liu et al. (2020) reported the benefits of legume biomass (*Caragana korshinskii*) on the Loess Plateau of China showed greater potential to sequester soil C. Similarly, 7-years of perennial legume *M. sativa, Lespedeza davurica,* and *Astragalus adsurgens* growth increased the soil C sequestration of arable land by 79, 68 and 74% (Guan et al., 2016). The rate of CO_2 flux, unlike other soil parameters, respond more quickly under varying soil temperature and the quality of organic matter to assess soil fertility (Ahirwal, Maiti, & Singh, 2017b; Munoz-Rojas, Erickson, Dixon, & Merritt, 2016) indicating whether the soil conditions are favorable for decomposition process in long term revegetation.

5. Conclusions

Dense grass-legume mulch cover formed over 5-years of revegetation created a buffer zone between soil and atmospheric temperature and helps retain soil moisture content. Legume with low biomass C:N ratio favor rapid N mineralization conversely, high C:N ratio of grass biomass reduces N leaching by enhancing microbial N uptake and synergistically contributing balanced mineralization of N in the soil. Soil fertility in terms of SOM, SOC, N, microbial biomass, and enzyme activity was significantly increased after 5-years of grass-legume revegetation that are close to the natural forest soils. Growth of grass-legume mixture also enhanced the microbial activity, SOC and N stocks, and doubling the rate of CO_2 flux in 5-years. Field-scale reclamation of waste dumps requires a massive amount of mulch and often impractical to import. Therefore, we recommend grass-legume revegetation, as they provide sufficient shoot and root biomass and subsequent mulch stock over time. In conclusion, this study shows that legume (*S. hamata*) is compatible with grass (*P. pedicellatum*) species affecting above and below ground soil systems during revegetation, increase nutrient concentrations, and accelerates recovery of soil fertility.

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FIGURE CAPTION

FIGURE 1 (a) Location map of the study area Chhattisgarh, India (b) satellite view of the reclaimed waste dump of Nalwa Steel and Power Limited (c) Early-revegetated waste dump surface showing growth of grass-legume mixture in the slope (after 1 year).

FIGURE 2 Sequence of reclamation of waste dump (a) regrading of dump slope, (b) blanketing the dump surface with topsoil, (c) slope is blanketed with coir mat and soil with grass-legumes seeded, and (d) the growth of grass-legume mixture on the dump slope.

FIGURE 3 Reclaimed dumps after 5-years (a) growth of grass-legumes at the dump surface, (b) growth of grass-legume at the dump slope, (c) accumulation of grass-legume mulch at the dump surface, and (d) accumulation of mulches on the waste dump slope.

FIGURE 4 Variation in mulch thickness, mulch density, soil moisture, soil temperature and air temperature at the reclaimed wasted dump with developmental ages of grass-legume revegetation.

FIGURE 5 Net N mineralization (mg $kg^{-1}week^{-1}$) in topsoil with shoot and root biomass residues of (a) legume (*Stylosanthes hamata),* and (b) grass (*Pennisteum pedicellatum*).

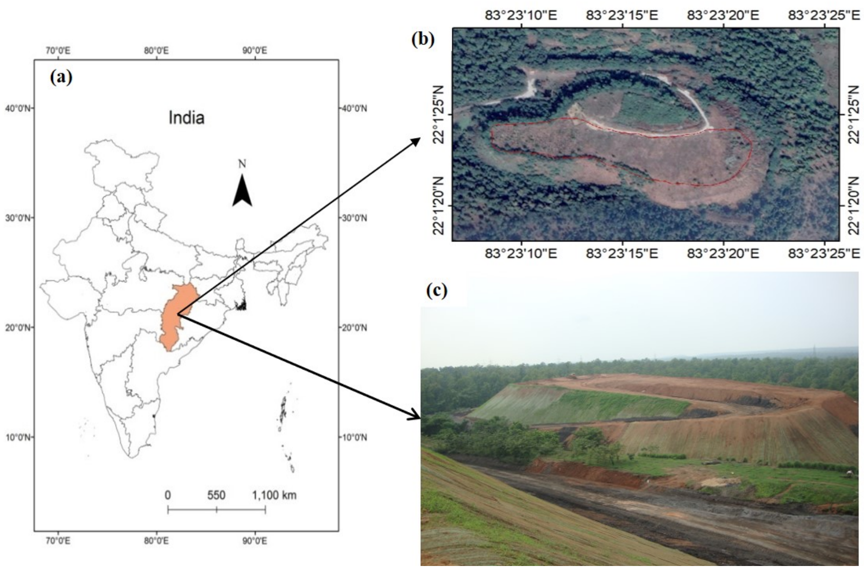
FIGURE 6 Correlations between (a) mineralized N (%) and total nitrogen (TN%) concentration in legume biomass, (b) mineralized N (%) and total nitrogen (TN%) concentration in grass biomass, (c) mineralized N (%) and C:N ratio of legume biomass and, (d) mineralized N (%) and C:N ratio of grass biomass.

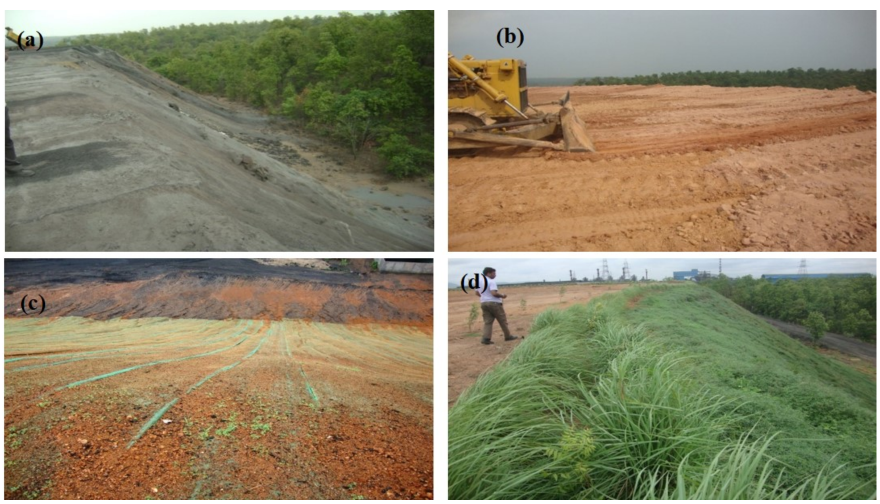
FIGURE 7 Effect of grass-legume mulch thickness on reclaimed soil properties (a) moisture, (b) soil organic matter (SOM), (c) microbial biomass carbon (MBC), (d) microbial biomass nitrogen (MBN), and (e) potentially mineralizable nitrogen (PMN) relative to bare soil (without mulch) with developmental ages of revegetation.

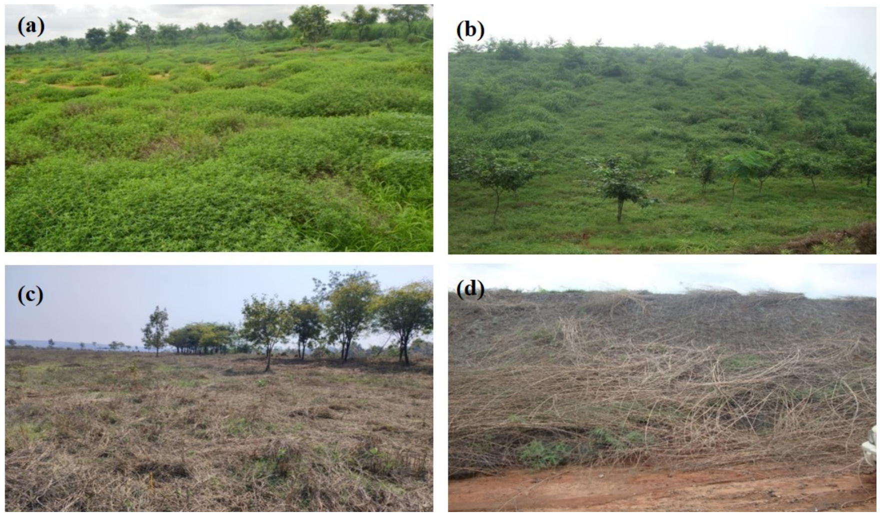
FIGURE 8 Averaged soil CO_2 flux measured at reclaimed waste dump after 1 and 5-years of revegetation with grass-legume mixture and natural forest (NF).

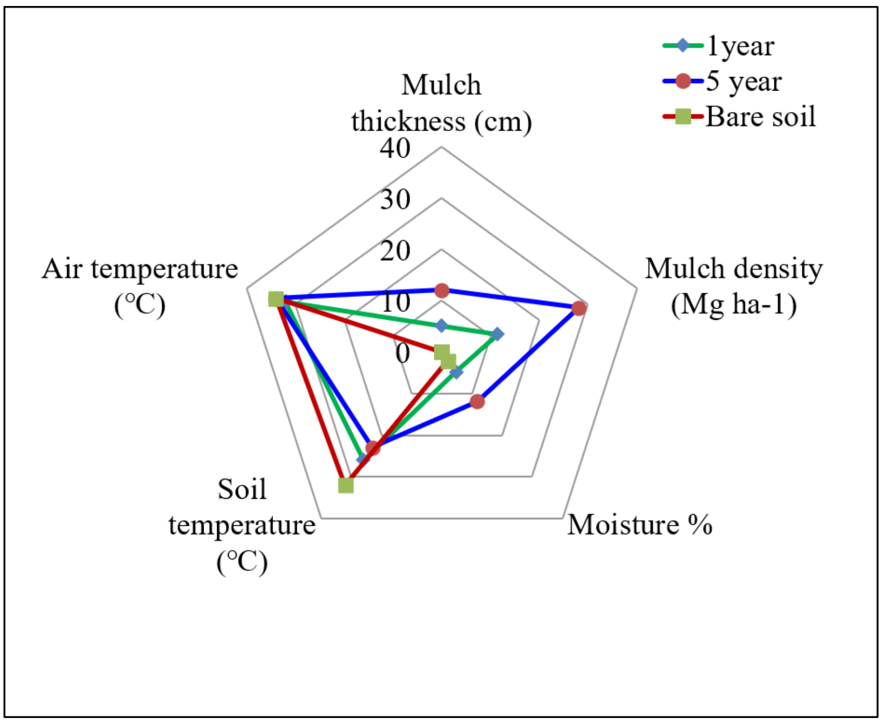
Hosted file

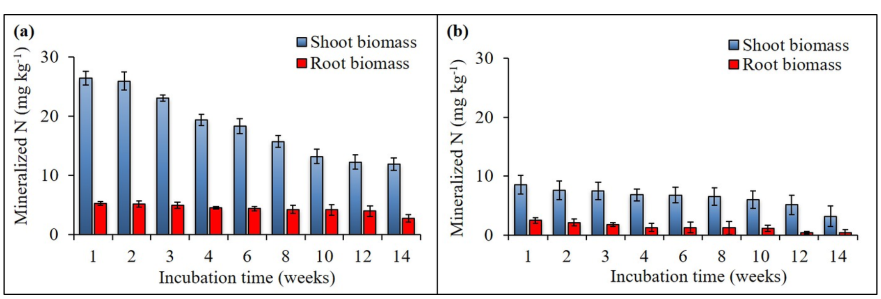
Tables (16-07-2020).docx available at https://authorea.com/users/343769/articles/470365-effect-of-forage-grass-pennisetum-pedicellatum-and-legume-stylosanthes-hamata-revegetation-on-recovery-of-soil-fertility-in-a-reclaimed-hazardous-waste-dump

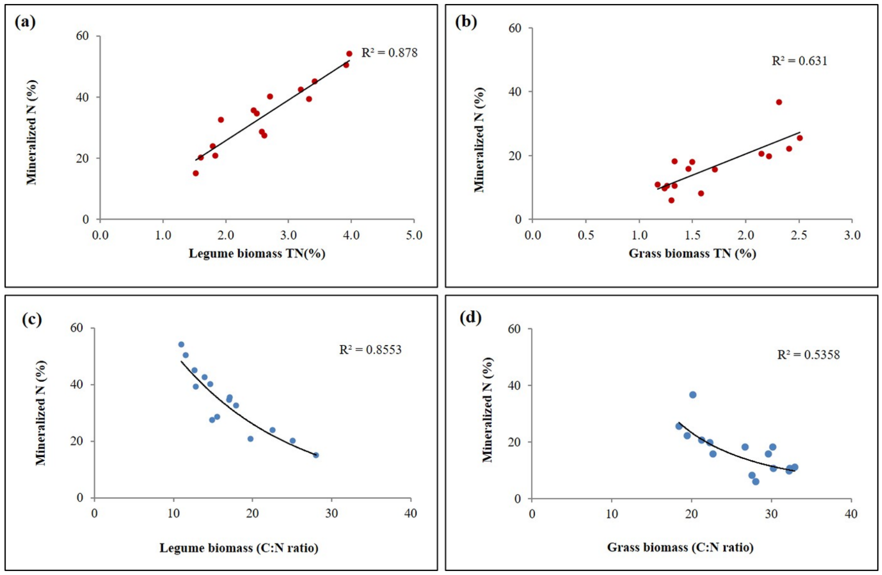


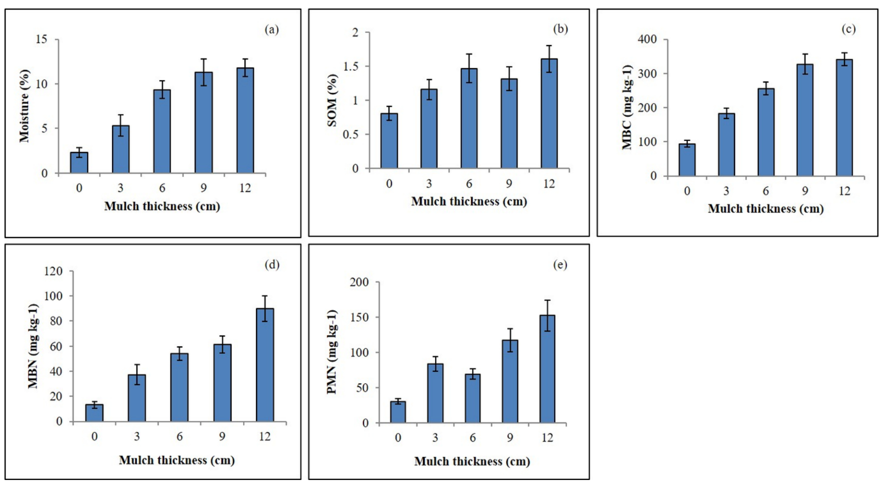


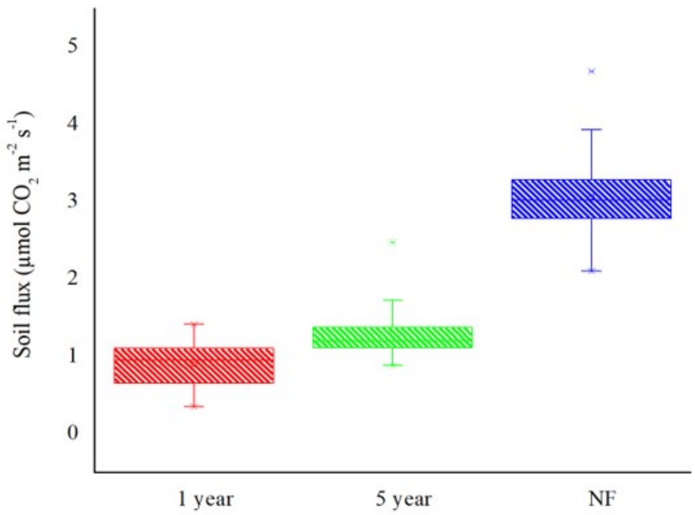

(a)
(b)
(c)
(d)


1year
5 year
Bare soil
Mulch thickness (cm)
40
30
20
10
0
Mulch density (Mg ha-1)
Moisture %
Soil temperature (°C)
Air temperature (°C)


(a)
Shoot biomass
Root biomass
Mineralized N (mg kg-1)
30
20
10
0
1 2 3 4 6 8 10 12 14
Incubation time (weeks)
(b)
Shoot biomass
Root biomass
Mineralized N (mg kg-1)
30
20
10
0
1 2 3 4 6 8 10 12 14
Incubation time (weeks)


(a)
R² = 0.878
Mineralized N (%)
Legume biomass TN(%)
(b)
R² = 0.631
Mineralized N (%)
Grass biomass TN (%)
(c)
R² = 0.8553
Mineralized N (%)
Legume biomass (C:N ratio)
(d)
R² = 0.5358
Mineralized N (%)
Grass biomass (C:N ratio)


(a)
Moisture (%)
Mulch thickness (cm)
(b)
SOM (%)
Mulch thickness (cm)
(c)
MBC (mg kg-1)
Mulch thickness (cm)
(d)
MBN (mg kg-1)
Mulch thickness (cm)
(e)
PMN (mg kg-1)
Mulch thickness (cm)


Soil flux (µmol CO2 m-2 s-1)
5
4
3
2
1
0
1 year
5 year
NF