NIASM Technical Bulletin No. 15

Soil Health Status of NIASM Southern Farm Land

भाकृअनुप-राष्ट्रीय अजैविक स्ट्रैस प्रबंधन संस्थान

ICAR-National Institute of Abiotic Stress Management

An ISO 9001:2015 Certified Institute

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An ISO 9001:2015 Certified Institute

July, 2018

Published by
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ICAR-National Institute of Abiotic Stress Management
Malegaon, Baramati - 413 115, Pune, Maharashtra

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Citation: Rajagopal, V., Choudhary, R.L., Kumar, N., Krishnani, K.K., Singh, Y., Bal, S.K., Minhas, P.S. and Singh, N.P. 2018. Soil Health Status of NIASM Southern Farm Land. NIASM Technical Bulletin-15, ICAR-National Institute of Abiotic Stress Management, Baramati- 413 115, Pune, Maharashtra, India, p 64.

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Printed at
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Content

Preface

Achieving the food security in India from the sustainable use of available natural resources would be a great challenge when abiotic stresses limitation to crop yield has been acerbated enormously due to climate change while the population are continue to increase. The land is almost finite resources that there is a limited scope for lateral expansion of cultivation on the available marginal land. Although the fact that the marginal land is poor fertile inheritance regard of crop cultivation but it has potential to contribute food bowl after converting to some suitable agriculture enterprises for the larger area coverage. The land allotted for the development of NIASM farm land were one kind of barren gravelly land is being with shallow soil depth, high gravel content, low organic matter and other minerals content were poised a lot of challenges to bring into a cultivable land. The naturally abiotic stressed land opened, on other hand, opportunities to study the soil developmental process including soil depth, root volume, decline of coarseparticle content, soil profile development and improvement of soil fertility status. The vegetation, one of the soil farming factors, has a greater role in soil development while providing some economic returns particularly the land which is having rocky parent materials at the shallow soil surface depth.

The skewed fertilizer distribution and application, land degradation for mono cropping systems and other faulty management practices would impair crop production potential of land. Soil test based fertilizer application is a need based programme to reverse the soil degradation implemented recently throughout the country with an intention to avoid mal practices and increase the nutrient use efficiency, reduce agriculture financial burden of fertilizer subsidy and contribute doubling farm income with the reduction of fertilizer cost. This bulletin is prepared with intention to educate how to develop a farm land on the barren land and know the soil data base of NIASM farm land for making decision on various farm planning and activities as well as to enable researchers to draw the inference of their treatments response. It also give information on effect of fodder crops as biological effect on soil development on the barren land which are exist vastly in the rain shadow region of the Deccan Plateau.

01-July-2018

(Narendra Pratap Singh)

Executive Summary

ICAR-NIASM is a premier institute at national level to coordinate research work and education in technology innovation for adaptation, mitigation and policy intervention of abiotic stress of crops, animals and fish was set up on 21 February, 2009 at Baramati, western part of Deccan plateau in India representing the rain shadow area after the Sahyadri Ranges frequented by famine calamities. The Model Research Farm for abiotic stress of crop, animal and fish was established area about 56.5 ha on the marginal barren and gravelly land had the shallow soil depth of around 20-35 cm. The land development was started with preliminary survey and cutting of land into appropriate size of 68.5 m x 72.5 m area. The land was ripped with heavy machinery about two to three times at an interval of three month after spent wash application. The land was levelled with use of tractor mounted dozer in front of the engine. Before converting the land into research work, the native and black soil field uniformity were tested with growing dhaincha after enrichment of soil organic matter by application of mushroom spent wash substrate and FYM. The south side farm (16 ha) is divided into six blocks which are sub-divided into 37 rectangular/trapezoidal plots including agro-met observatory and fish ponds. Of the farm plots, nine were converted into black soils covering an area of 2.69 ha. The soil samples of 500 gms in four replication were collected form each plots analysed for soil pH, EC, OC, available nitrogen, phosphorus and potassium in addition to micro nutrients such as Fe, Mn, Zn, Cu and B. With adapting the standard procedure, the soil analysis is carried out, accurately. The plant roots activity and their exudation help for the quick conversion of barren gravelly land to suit for crops cultivation by various mechanisms. The native lands got an improvement with less than 2 mm particles of agriculture importance ranged from 20.4 to 35.8% across the field. Rock eating ability of crop varies and the napier grass found to recommend for fast murrum disintegration on the barren gravelly land. It is also important that every farmer should know what is being applied to soils in turn removal from soils for maintenance of soil quality of the farm. As said, above, the technical bulletin prepared to pour the information how to convert the barren land to farm and the crops are differing in their role in development of farm.

1. Introduction

The abiotic stresses can be classified into three categories based on the source of origin. The plant stressors are basically derived from soil, water and atmosphere. The major edaphic stress has been experiencing by crop, animals and other living and non-living things in the world are elevated and low temperature (global warming effect), frost, clouds, drought, water logging, salinity, sodicity, erosion, low pH, nutrient deficiency and toxicities, shallow soils, gravelly, and pollutant effect from herbicide, heavy metals, aerosols and others. On whole, the abiotic stresses are responsible for the loss of more than 50% of total food grain production in India as well as world and expected to hit further for the impact of global warming on the edaphic stressors. According to recent literatures, emerging of nutrient deficiencies with annual mining of 8-10 million tons of NPK along with acidity (17.93 Mha), salinity (6.73 Mha) and soil contaminants are the major chemical stressors in Indian agriculture. In addition to that, soil erosion (water 82.47 Mha and wind 12.40 Mha), shallow soils (26.4 Mha), soil hardening (21.4 Mha) and low water holding capacity (13.75 Mha) are the physical stressors threaten heavily the soil productivity. In India, about 60% of total net sown area comes under rainfed lands. The rainfed crops account for 48 per cent area under food crops and 68 per cent under non-food crops. As the rainfall event is being highly governed by climatic variables, it become very irregular in terms of amount and distribution. The agriculture drought is become very regular at wide areas and the yield from the rain fed crops become unpredictable and hapless that the livelihood option of the people depended on agriculture in those areas highly victimized when the drought intense is very severe. The pouring event about 4 to 5 cm per day for two days duration particularly at crop critical time (vegetative and reproductive stage) affect the crop yield more than 60% of the normal year.

The global warming is one of the major issues in the contemporary agriculture. In the last one decade, there has been a record of 1.5 degree Celsius temperature increase over the pre-industrial time and expected further in the upcoming time will severely impact food security of the nation. Recently, brown clouds, low and high light intensity effect on agriculture has also experienced. Realising a paramount pressure on food security due to crop stress, there is a need to strengthen the knowledge system, development of technology for adaption and mitigation of stress, capacity building, training of farmers and policy making, the National Institute of Abiotic Stress Management, a state of the art and science in the abiotic stress of crops was established in 2009.

Geographical location of the NIASM

The National Institute of Abiotic Stress Management (NIASM), is situated at 18°09′ N latitude and 74°30′ E longitude with an altitude of 550 m MSL. In political division, it comes under the Pune district, part of the western Maharashtra region of India. As per the agro-climatic zonation, the area falls under the scarcity zone (NARP zone: AZ-95) that farmers has already been experiencing impact of many edaphic stress on crops. It is a well governed place of Deccan plateau.

Geology of the land

The outpouring of lava in Deccan trap continued through fissures and made a horizontal sheet of varying thickness about 75 million years period from Upper cretaceous to early Eocene time. They have been referred as Deccan trap contains mostly the minerals of basaltic rocks. Based on rock thickness they traps are classified into upper, middle and low and the study site comes under the middle trap of the rocks has thickness of 1200 m. The site is part of the basaltic subdued plateau sloping towards south with an elevation ranging from 547 to 565 m.The landscape can be divided geomorphologically into summit side slope shoulder slope and back slopes. The peculiar radial drainage in all the directions lesser the length of the slope that a severe stony surface cover with gully formation in north west and north east of landscape causing head ward erosion.

The ground natural features associated with north-slope parts are gullies wherein sparse scrub/grass cover on weathering front or soft sheet rock with rock out crops (>40% cover area) is common. In eastern side, 1/3 part is excavated for murrum with break up slopes of convex and concave pattern. The south eastern part is under quarry wherein landscape is totally disturbed. The summit and back slope are associated with 1-3% slope and side and shoulder slope is totally disturbed. The terracing on summits and back slopes has been a modified natural slopes and are planted with neeem, aonla, shisham and acacia spp. The basaltic basic flows are horizontal deposition massive, dark grey coloured fine jointed fractured and vesicular zeolite in nature. Deccan trap consist of Labroderite and bytonite minerals calcic nature and important sources of trace elements to the soils.

Table 1. Taxonomical classification of NIASM flam land soils and their morphological characteristics

Soil series	Phases	Characteristics
Malegaon series-1: [Loamy skeletal, mixed hyperthermic (calcareous) Lithic Ustorthents]		
	MIg1d2(g2)B3st2R2	Shallow (8-16 cm deep), brown (10 YR 4/3 and 10YR 5/3), pale brown to 10 YR 6/3 gravelly sandy loam occurring very gently sloping summit associated with severe erosion, moderately stony and rocky. Soils are underlain by saporlite up to 24 cm and thereafter hard rock
Malegaon series-2: [Loamy-skeletal, mixed isohyperthermic Lithic Ustrothrents]		
	MIg2d2(g1)D2g1st1	Shallow (8-13 cm deep), reddish brown (5YR 4/3), Gravelly sandy clay loam occurring on shoulder slopes (5-10%) but terraced one and associated with slightly gravelly and stony. These soils are underlain by saprolite up to 29 cm and thereafter hard rock.
Malegaon seires-3: [Loamy-skeletal, mixed hyperthermic lithic ustrothrent]		
	MIg3d1(g2)D3st1R3	Very shallow (<7.5 cm deep), pale brown to brown (5YR 4/3), sandy loam soils occurring on moderately slopping (5-10%). These re severly eroded moderately stony and associated with severely rock out crops (non-calcareous). These soils are underlain by saproliteupto 15 cm and then hard rock.

Soil series	Phases	Characteristics
Malegaon series-4: [Loamy –skeletal, mixed (calcareous) isohypethermic lithic ustrothrents]		
	4.0MIg4d2C(g2)C3stR2	Shallow , brown (7.5 YR 4/3) sandy loam moderately gravelly gently sloping (3 to 5%) severely eroded slightly stony moderately covered with surface rock out crops
	4.1MIg4d2C(g2)c3st2R2	Shallow (11-17 cm), brown (7.5 Yr 4/3) sandy clay loam moderately gravelly, gently sloping (3 to 5%) severely eroded, slightly stony, moderately covered with rock out crops
	4.2MIg4d2C(g3)C3R3	Shallow (9-18 cm), brown (7.5 YR 4/3) Sandy loam severely gravelly gently sloping (3 to 5%) strongly covered with rock out crops
	4.3MIg4d1c(g1)C3st2	Very shallow(<7.5 cm) brown (7.5 YR 3/3), sandy loam slightly gravelly gently sloping (3 to 5%) moderately stony
Malegaon seires-5: [Sandy skeletal (non-calcareous, isohyperthermic lithic Ustrorthents]		
	5.1 MIg5db(g1):	Very shallow (<7.5 cm) brown (10YR 5/3, 4/3) loamy sand, slightly gravelly, Quarried land
	5.2 g5dlb (g2)D3st2R3	Very shallow (<7.5 cm) brown (7.5 YR 5/3), loamy sand, moderately gravelly moderately sloping (5-10%) severely eroded, moderately stony and rocky
Malegaon seires-6:[Loamy mixed (calcareous), Isohyperthermic Lithic Ustorthents		
	6.0 MIg6d2h(g1)B2	Shallow (9-20 cm) brown (10 YR 5/3). Sandy clay loam, slightly gravelly, very gently sloping, moderately eroded

Soil series	Phases	Characteristics
	6.1MIg5d1b(g1)	Very shallow(<7.5 cm), brown (10YR 5/3,4/3), loamy sand, slightly gravely quarried land
	6.2MIg5dIb(g2)st2R 3	Very shallow(<7.5 cm), brown (7.5 YR 5/3), loamy sand, moderately gravelly, moderately sloping (5-10%), severely eroded, moderately stony and rocky

(Information obtained from the preliminary survey report of NBSS & LUP)

Weather condition

According to the available data, the area comes under dry land region with an average annual rainfall of 55 cm. The rainfall distribution is also a highly skewed nature. Most of the rainfall occurs in the period from June to October. The July to August usually relatively a dry period with low rainfall occurrence while September is wet one. The temperature of this region ranged from a low of 13.6 degree Celsius to the maximum at 38.9 degree Celsius.

Natural vegetation

The area is wasteland (upland with shrub). The social forestry department has tried for the plantation of neem, shisham, karanj and aonla in pits (4-7 m apart) prepared through drillings. The survival of these plant is meagre and few plant stands are visible in back slopes off south-west and north-east (the above the quarry land). The grasses are haryali (*Cynadon dactylon*), lavala (*Cyprus rotundus*), kunda (*Ischemum pidasum*), Tanduja (*Amaranthus polygamus*), Ekdandi (*Tridex procumbens*), Tarwad (*Cassia quadriculata*) and calatropis spp.

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2. Development of NIASM Southern Research Farm Land

The land allotted for the development of NIASM was originally a barren waste land and has the limitation of soil content, root volume, poor water retention, gravelly, nutrient deficiency and shallow soil depth. In addition to that, the land was not even supported for the development of natural vegetation at an annual rainfall of 45-55 cm. The south side of the farm was a naturally gently sloping land at 2-3% that it had been planned to undertake research activities on crop production, livestock and fisheries. This farm is spread over an area of 16 ha separated from the north farm side by a central east-west road. The murrum excavation and contour lines running across the slope gives a dissected appearance to the south farm. The rocky barren land area is hapless for underground water and limited irrigation water supplies from the adjoining NIRA canal that the layout of the south farm was designed on the basis of the considerations of contours for soil and water conservation. Since, the field uniformity and cost of land preparation is a major thing that the following principles considered while the preparation of southern land. 1. The experimental field should be large enough to conduct experiment while minimizing the cost incurved for cutting and levelling of coarse fragments. 2. The field should have sufficient area for farm road and field path for easy moving of tractors and farm implements and field drainage work. 3. The preferable plot size should be in rectangular or square enable to accommodate the seedling or planting in lines and easy measurement of soil and plant parameters. Totally 32 experimental field are created each covering area of 0.5 ha (68.5 m x 72.5 m) over 16 ha with considering all the above said points. However, all the plots are not in equal size and the peripheral plots are in trapezoidal shape due to limited area availability by margin of the boundary wall and field. The barren basaltic rocky terrain land had soil depth seldom exceeded 0.3 m with an underlying of murrum especially in south-farm. Therefore hastening to increase soil depth, mururm disintegration and soil development, the principles of physical (mechanical) and chemical weathering processes were adopted. These are briefed as follows:

Step 1: Initially, the land was fragmented into different sub plots in the size of 68.5 m x 72.5 m after creating field into different terraces in across the slope. The land was dominated with coarse fragments of different sizes targeted for mechanical disintegration by ripping of mururm using a heavy machine, Dozer with ripper (Model No. D355) obtained from the Mechanical Division, Irrigation Department, Govt. of Maharashtra. Before ripping the field, the available soil particles are collected to the corner of the plots using front dozer attached with tractor. The field was ripped up to the maximum depth of 40-45 cm by crushing and grinding the coarse murrum particles into small one so that field depth gets uniform in favour of conducting field experiments. The collected soil particles levelled into the field doing the grid survey of 15 m x 15 m with a dumpy level and a tractor which had attached with front dozer such way that well levelled filed obtained. The processes of ripping, chaining and pushing were repeated 2-3 times till the terrace/plots got uniformly levelled. Though majority of the stone got crushed into small size, the reaming big boulders are collected and removed manually with an idea of reusing it for farm road preparation.

Initial state of the field

Ripping of the field

Blasting of the field

Spent wash application

Fig 1. Chronological land developmental activities executed at NAISM farm land

Step 2: Even after the repeating of ripping and chaining process, there is a patch of hard rocks exist in the field therefore micro blasting was adapted to break that into pieces. For this purpose series of holes of approximately in size of 50mm were drilled using semi-automated tractor operated drill machine at spacing 0.5-1 m and 0.6-0.9 m depth depending upon the hardness of the rock along a line defining where the rocks could split. Then detonating cords, a flexible tubes containing a centre core of high-velocity, electric cap-sensitive nitrate explosive used as blasting material were inserted into the holes. With proper electrical and blasting circuit, these cords were connected perpendicular together to single current source at a safe location from the blast area. The generator blasting machines type exploder consist of a small, hand-driven electric generator was used for firing of electrical cap. When activated, it produces a direct current pulse that fires the electric blasting caps. The generator connects to the blasting circuit when the blaster pushes down the handle. The low to high initiation impulse ranged from 1.5-2500 mJ/ohm and corresponding current 1.5-35 A were used for blasting depending upon nature of hard rock. Blasting releases energy in the form of fragmentation and displacement of rock, vibration of ground and air blast. The rock cracked during the blasting were collected and used for road filling. The remaining material thus generated was again chained, ripped and pushed for levelling.

Step 3: The spent was is the major agro bio-product in the Baramati region has been used in agriculture as a nutrient source. However, the high amount of soluble organic carbon and acidic pH, it can be a good material for augmentation of murrum disintegration. The organic carbon presents in the spent wash able to complex with minerals of the rock materials and alters the process of cations leaching. The cation leaching is a principal of weathering mechanism can be induced by the application of spent wash besides aide in flourishing of microorganisms. All the field plot and terraces were applied spent wash about 24 million litres of raw spent wash (acidic nature) obtained from Malegaon Corporative sugar factory in two times with an interval of 6-12 months. It seems the coarse particles water imbibing capacity get increased after treating with spent was that the boulders easily permits for break down into smaller pieces for ploughing and other heavy machinery operation involved in the field operation.

Step 4: The land without levelling has huge impact on soil moisture distribution, seed germination and growth and development crop hence, the levelling is an important precursor practice in agriculture. In otherwise, the levelling operation improves water use efficiency and yield by optimum crop stand in the field. The uneven dummy surface in the ripped and chained plots was levelled with the available soils and small size gravels using the tractor operated front dozer (75 HP). For easy and accuracy of levelling performance, the terraces/plot were made into sub-plots by taking up grid survey at the area of 15 x 15 m. The elevation of all plots was decided initially so that plane passing through the centroid can be made with equal volumes of murrum materials cut and fill in the subplots. The materials spread in the direction of irrigation channel so that the field elevation will get the recommended safe limit of the slope 0.1 - 0.4%. After completion of levelling operation, level of the farm plots was checked by filling it by water. Low lying spots were again filled up until standard and recommended slope was achieved in the field.

Step 5: Field uniformity test is a mandate for conduction research experiments that once the field plots in the south-side were ready after the process of ripping/blasting, chaining, spent wash application, removal of boulders and levelling, the dhaincha was grown AS TEST CROP. It served as source materials for nitrogen through biological nitrogen fixation and carbon source to flourish microorganism and their related benefits. However, the overall growth of the dhaincha crop was poor on these virgin soils that recorded only about 7-11 Mg ha^{-1} of fresh weight (N-2.06, P-0.18, K-2.09 % on dry wt. basis) within a period of 8 to 10 weeks. Of course being arid land, the low rainfall and inadequate irrigation water availability also the reason for low biomass production. Hence, further attempts were made to enrich the soil fertility status through addition of other organic sources such FYM, compost and other agro-waste materials. It was decided to add 20-25 Mg of FYM per hectare. However, due to scattered dairies, inadequate availability good quality fodder and high demand for sugarcane cultivation, the required quantity of FYM was not met out and the institute could procure only about 340 m^3 of FYM (N, P, K 0.45, 0.19 and 0.42 %; bulk density 0.72 Mg/m^3) even with repeated attempt made for purchasing of it.

A mushroom farm, Shri Tirupathi Balaji Agrio Pvt Ltd. located at almost 30 km distance from NIASM at Someshwar supplies the left out product of mushroom as substrate for field application. This is a cheap material in comparison to FYM contains considerable amount of nutrients and organic carbon source (C: N 30:1, N, P, K 2.35, 0.32, 0.17 %) that it was decided to procure SMS. Taking advantage of different organic materials a research study was also made on impact of different organic materials on murrum disintegration which is given as case study in the later section of the manual. After application of organic materials, the dhaincha was again grown on the fields supplied with FYM and SMS. The crop performance was better (27-33 Mg/ha) and it was again ploughed in the field for green manure purpose.

Development of black soil field

The native field of NIASM is not representing farmer's field that the committee decided to establish the field of real situation. The institute was started with mandate of addressing different edaphic stresses impact on crops which are varied with soil types. Since the institute intended to provide for farm facilities to conduct research with varying degree of severity and extent of edaphic stresses in diversified soil types, it was planned to develop specified fields representative of black soils, red soil, river sand, salty soils and others at research farm itself. These are very laborious and huge time consuming task initiatives were taken to develop a black soil as they represent a large area and easy availability in nearby areas of the institute. It covered about 16% (2.69 ha) of the land area in the southern farmland converted into black soils of nine out of 32 plots. The 20,381 m^3 of good quality black soil was procured in which 16,990 m^3 (6000 brass) was applied to 9 research plots and the rest was utilised for establishing orchards in the northern farm and boundary/roadside plantations. The procured soils after dumping in the respective plots levelled subsequently using the tractor attached with a front dozer. To ensure the proper levelling, soils setting and uniformity, pre irrigation and growing dhaincha crop was adapted. The patchy of poor dhaincha crop stand in the field was observed due to improper levelling. Therefore, the black soils of the field once again levelled using tractor attached with a laser leveller before converting the field into research studies. .

After identifying the uniform fields, multidisciplinary experiments were initiated both on black and native soils since 2012. The rice, wheat, soybean, maize, sugarcane, napier grass, marvel grass, stylo, subabul, chickpea, sorghum are the major crops grown in the experimental field. A small field has been put under cactus (fruit/fodder type cultivars) and these are being tested to decipher traits and genes associated with tolerance to drought and edaphic stresses. Either the general crops of wheat, chickpea, soybean, sorghum and maize or dhaincha for green manure is being regularly cultivated on rest of the field plots for enhancing their uniformity and organic matter.

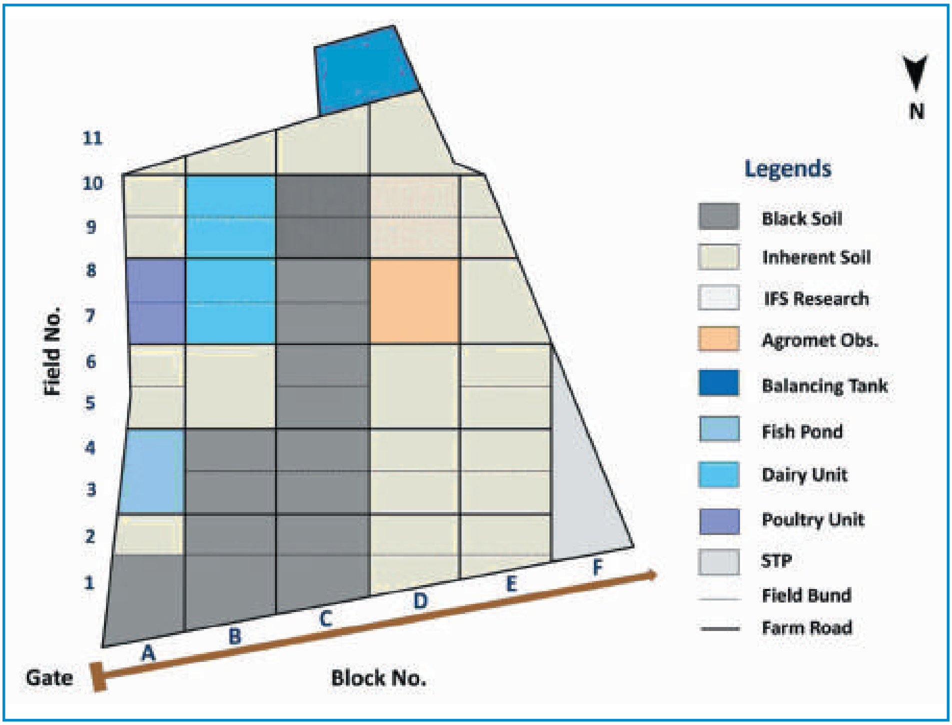

Fig 2. NIASM southern FARM land

Description of profile development in the NIASM landscape

The barren land with directly exposed parent materials and negligible soil content has no horizon development said to be at initial stage of soil development. The horizons of different thickness use to be observed in the well-developed and matured lands are foot prints of soil process which has operated over long periods of time. Thickness of horizons are depends on kinds and length of time took for the soil process and function operated in the given place. Like soil process, different flow and solidification pattern of lava after it eruption favoured the condition for the development of different zeolites rock materials.

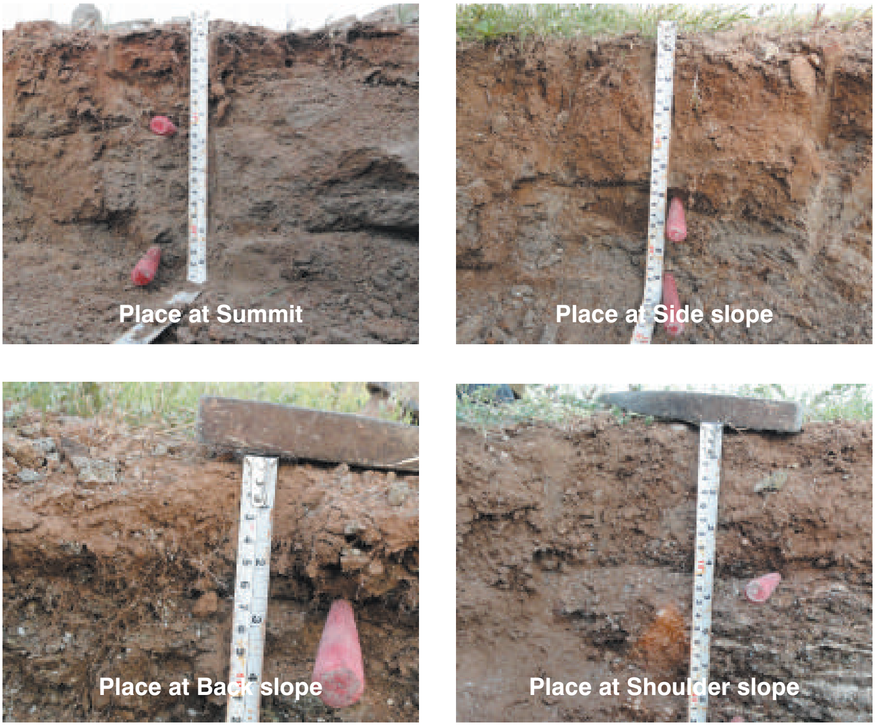

Fig 3. Profile development at different position of NIASM farm land

The intermediate materials between soils and parent rock termed as saprolite differed markedly with them in terms of chemical composition and physical properties. The thickness of sparolitic materials are getting varied for weathering intensity and materials deposition by run-off which is highly associated for position in the landscape. The soils would have uniformly washed away from the summit to shoulder slope where the whole native farm lands are lying within back boulder slope. It may be the reason why the expected soil thickness is not observed in the small patchy of plain area developed in the summit. The depth of loose materials developed in the NIASM farm land determined based on manual digging till the hard rocks are exist is almost same at 23-24 cm except back slope where only 12 cm was observed (Fig. 3). If we closely examine the particle distribution in the profile, vesicular materials are present in the surface layer and getting decreased with depth.

3. Role of Vegetation on Mineral and Rocks Weathering

The soil development has been influenced by the interaction of soil farming factors namely climate, vegetation, parent materials, relief and time. The amount of each factor influence on soil formation varied from one place to others. It is well recognized the role of vascular plants in soil development with the analysis of rate of carbon di oxide evolution in the soils with depth. The mechanism of rocks coarse fragments conversion can be categorized into physical and chemical process modified by the biological factors. The rocks are generally made up of minerals of different kinds joined each other at different proportions, forces and angles. The weathering grades of rocks are assessed based on the strength at which it resist the external forces and they ranged from easily weatherable of limestone, calcite and shale to very hard rocks such as quartzite, zircon and diamond. The weathering of rock associated with discoloration, formation of creeks and crevices, increase of external and internal porosity, bulk density, and change of particle content, geochemical cycle and supplying power of nutrients to crops. The discoloration includes organic staining, apparent iron oxides, and combinations of the twos. With increase of porosity with addition of small particle content, the terrestrial environment is becoming a good habitat for flora and fauna in the environments and this can be evidenced by studying the flora and fauna diversity and their population in the shallow rocky land and well developed soils.

Physical weathering and plant roots

Over time, parent rock can be physically broken down without any chemical alteration of the minerals. The most commonly observed forms of physical weathering include crystal growth (e.g., water as ice), insolation weathering (diurnal temperature changes) and pressure release. Although less commonly observed, the regolith can also be physically altered by plant roots, which can exploit small cracks in the bedrock and as they grow the root will expand the crack, eventually leading to the bedrock breaking along the crack. Plant roots are responsible for binding and stabilising the regolith, and slowing drainage and therefore increasing the residence time of water in the regolith.

They can also create pores in the regolith and add organic matter, through root cell death and decomposition. These physical effects can also have implications for other weathering processes by providing greater surface area and time for chemical reactions to occur, and by providing habitat for microorganisms that can chemically alter the regolith.

Chemical weathering and plant

Roots Chemical weathering has been broadly defined as "the action of a set of chemical processes operating at the atomic an molecular levels to break down and reform rocks and minerals. The process of weathering by which chemical weathering reactions such as hydrolysis, hydration, oxidation, carbonaion, ion exchange, and solution between minerals, air, water and its dissolved chemicals transform rocks and minerals into new chemical combinations more stable under conditions prevailing at or near the Earth's surface; e.g., the alteration of orthoclase to kaolinite, or the solution of the calcium carbonate in limestone by carbonic acid derived from rainwater containing carbon dioxide. Some of the more common means by which plant roots can directly affect chemical weathering processes are through nutrient uptake, cell respiration, release of organic matter in the form of sloughed off cells, exudates and secretions. These life processes can be particularly important in changing regolith properties like nutrient content, pH and redox potential, and drive forward chemical weathering reactions like oxidation, dissolution, hydrolysis and hydration. Some physical effects, like increases in water retention can also indirectly affect chemical weathering processes, by increasing, or decreasing the time available for chemical weathering reactions to occur.

Microorganisms in the Rhizosphere

The rhizosphere is also habitat for microbial populations that feed on mineral nutrients and organic materials in regoith. In many cases, there are direct symbiotic relationships between plant roots and microorganisms, mycorrhiza, that enable more efficient uptake of nutrients that might otherwise be unavailable for plant growth, e.g., phosphorous (P) and potassium (K). In addition, there are symbioses where elements and ions such as N, specifically as

NO_3 and NH_4 are actively added to the regolith. The chemistry of the system must then include the action of these ions, e.g., add H_2O to NO_3 and acidification of soils results. So, in addition to the direct physical and chemical effects of plant roots, there are many indirect associations between them and the regolith, especially by providing habitat for microorganisms. Further, microorganisms are essentially responsible for the decomposition of leaf litter and other organic materials in the regolith, while requiring elements from weathering in order to carry out vital life processes. Microorganisms can have an influence on reactions like pH, redox potential, hydrolysis and dissolution, amongst other chemical weathering reactions. An additional example, at a very different timescale, could well be in the study of fossil rhizosphere features such as "root channels" in ferricretes and alucretes.

Agriculture activities and murrum disintegration

The crop cultivation involves number of activities from seedbed preparation to harvesting of crops namely application of spent wash, FYM, SMS, fertilizers, green manure and green leaf manure, summer plough, cultivator for seed bed preparation, intercultural operation such as manual and mechanical weeding, herbicide and pesticide application, regular irrigation and harvesting. Instead of leaving the barren land as such without cultivation, the land under agriculture subjected to the above said interventions helps in the improvement of soil in terms of gravel reduction either directly or indirectly. They aids directly by mechanical effect from heavy machinery and plant root pressure and indirectly by supplying organic matter which involved in increases of microbial population and chemical weathering's. Further, the microbes and plant exudates organic compounds which can play main role through the chemical interaction with minerals present in coarse as well as soil materials. This is highly supported with the previous research finding of weathering of black mica with release of potassium and solubilisation of phosphorus for the low molecular weight organic acid exudations by plant roots. The spent wash applied in the NIASM field was untreated one has acidic pH and large amount of reactive organic carbon. It will have effect on medium in both ways that it can lower the value of pH and lower down the weatherable minerals content from the coarse particles present in the surface layers. As the soluble organic carbon binds strongly with minerals, the get easily leached down along with minerals and imbalances the charges in favour destabilisation of the crystal structure. The irrigation practices to crops impacts the particles for the effect of diurnal change of temperatures. The soil moisture content was high with lowering about few units of temperature after the irrigation gets dried gradually up with increase of temperatures till the next irrigation given to crops. As a cycle it imitates drying and wetting of coarse particles, the selective minerals gets expended more than others causes mineral stress eventually loosening of materials that can be identified in the form feeling of layers away on the coarse particles.

Application of spent wash to the field (a) and its effect on murrum disintegration (b)

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4. Soil Heath Status of NIASM Farm Land; Macro and Micro Nutrients Content and their Distribution

NIASM farmland is a virgin barren land has not been exposed for crop cultivation. It is necessary to generate soil data bank of farm land as an initial state for studying the cropping systems or land use impact on soil properties over a period of time if any. It is important in the perspective of resource flow of the farm, decision making of farm policy, improvement of resource use efficiency and achieves the targeted productivity and production of food grains besides identification of any faulty things from the adapted practices. It is also very much necessary to account the interference of edaphic factors to crops which are under various treatments. Like human being, the soils are also getting sick if they have not been properly used in agriculture. The soils are also getting improved upon adaptation specific management practices which are comparable to prescription of drugs to patients by a doctor. With respect to crop nutrition, there are two things observed naturally in the land which are under cultivations, nutrient mining and conservations. The excessive removal of nutrients from soils referred as degradation need a change of management practices while net additions are the conservation of nutrients. The soils of surface layer at 20 to 30 cm contains most part of the roots subject to addition, removal and transformation of organic matters and mineral nutrients gets a major change of soil properties therefore monitoring has mostly been restricted to that depth. The samples which are collected randomly three to five place from a single plot quartered to get a single and representative sample of fields. They again divided into four replicated samples before subjected to the analysis of major soil properties such as soil particle distribution, soil pH, EC, OC, available N, P and K. The ICPMS is modernized instruments used for micronutrients such as Fe, Mn, Zn, Cu & B are inbuilt to do the statistical analysis and son only representative samples are used here. The macro nutrients such as N, P and K are required huge amounts for successful completion of crop cycle. Nutrient deficient in soils impairs physiological function and affect the crop yield significantly. It is also necessary for proper scheduling and quantity of fertigation to different crops.

NIASM farmland soil properties

1. Particles distribution: The native land is gravelly nature contains agriculturally important particles of less than 2 mm varied from 20.4 to 35.8% (w/w). The remained was the coarse particles of different size presents at different proportions. This wide range of soil and gravel particles content was mainly for some field put into different crop cultivations with varying intensity of management practices while few of them left without any cultivation. The energy driven activities such application of organic matter, dhaincha cultivation and incorporation, spent wash application and ploughing field with heavy machinery all favors decline of the coarse fractions through integrated of mechanical, chemical and biological actions and change of other soil properties too. The change of particles content also depends on parent materials types and their physical, chemical and mineralogical properties. The land physically contains two types of coarse fragment materials namely vesicular and non-vesicular types. The vesicular types are more porous nature and mostly distributed in the surface layers of land while non-vesicular dominated in the subsurface layer depth. The data spread also stands with relatively high variation in the surface layers for the particle distribution the native farm land. The black soils are having clay percent of more than 64% classified into clayey soils with the silt and sand content of 19% and 12%, respectively.

2. Soil pH and EC: The PH and EC are an important soil properties states about condition of the land medium for various chemical and biological actions. The maximum and minimum pH and EC values of the native farmland soils are 6.7 and 7.87 and 0.11 and 0.23 dS m^{-1} respectively and it was about 7.78 to 8.44 and 0.13 to 0.31 dS m^{-1} for black soils. With respect to soil pH and EC values, the land can be said a well optimized medium for selection of wide range of crops for cultivation and growth and development of beneficial microorganism. The high pH of black soil seems some limitation for crops in terms of high exchangeable of sodium ions. The black soils have exchangeable calcium overly in the complex that they behave like normal soils even at high pH value. The coefficient of variation for EC is higher than that of pH and the values are high for surface layer and native soils for the account of high variability in the southern farm land.

3. Soil organic carbon: This is an important soil property for sustainable crop production as well as mitigation of global warming for an increase of soil carbon content. Crop yield is highly associated with soil carbon content. Because of low soil carbon content at 0.22 to 0.42% (excluding gravel content), the native land can be said to poorly support the natural vegetation growth and development. The low quality and quantity organic matter input from native fallow land, high decomposition rate induced by low soil content and high gravel content and tropical climate condition are the main reason for low soil organic carbon content. The co-efficient variation of soil organic carbon data spread was almost 12%. This variation was for the repeated application of organic matter in terms of spent wash, FYM and mushroom spent wash substrate in the cultivated field and relatively low biomass returns in the native

Table 2. Summary statistics : Soil variables of Native land of NIASM farm

Soil properties	Number of obs. (N)	Mean	Mini-mum	Maxi-mum	Range	Std. Dev.	Coeff of Variation
Surface layer (0-15 cm)							
< 2 mm (%)	72	25.18	20.40	35.80	15.40	3.01	11.96
Coarse frac.> 2 mm (%)	72	74.82	64.20	79.60	15.40	3.01	4.03
Sand (%)	72	81.93	75.74	86.20	10.46	2.04	2.49
Silt (%)	72	10.48	7.00	14.24	7.24	1.47	13.99
Clay (%)	72	7.59	5.30	10.02	4.72	1.01	13.37
pH (1:2)	72	7.30	6.70	7.87	1.17	0.31	4.28
EC (dSm^{-1})	72	0.15	0.11	0.23	0.12	0.03	17.80
OC (%)	72	0.32	0.22	0.42	0.20	0.04	11.58
N (kg ha^{-1})	72	67.45	50.34	88.32	37.98	8.64	12.81
P (kg ha^{-1})	72	1.78	1.30	2.65	1.35	0.32	18.09
K (kg ha^{-1})	72	78.23	64.54	93.20	28.66	5.53	7.07
S (kg ha^{-1})	72	7.40	5.65	8.92	3.27	0.74	9.94

Soil properties	Number of obs. (N)	Mean	Mini-mum	Maxi-mum	Range	Std. Dev.	Coeff of Variation
Sub-surface layer (15-30 cm)							
< 2 mm (%)	72	23.48	19.50	30.95	11.45	2.27	9.65
Coarse frac.> 2 mm (%)	72	76.52	69.05	80.50	11.45	2.27	2.96
Sand (%)	72	83.63	78.00	87.48	9.48	1.81	2.17
Silt (%)	72	9.50	6.52	12.35	5.83	1.32	13.85
Clay (%)	72	6.87	4.60	9.65	5.05	0.99	14.38
pH (1:2)	72	7.40	6.75	8.05	1.30	0.33	4.48
EC (dSm^{-1})	72	0.16	0.12	0.22	0.10	0.02	15.07
OC (%)	72	0.30	0.21	0.40	0.19	0.03	11.36
N (kg ha^{-1})	72	65.15	49.65	86.54	36.89	8.32	12.77
P (kg ha^{-1})	72	1.69	1.22	2.51	1.29	0.30	17.98
K (kg ha^{-1})	72	75.28	60.56	89.95	29.39	5.50	7.31
S (kg ha^{-1})	72.	6.80	4.65	8.21	3.56	0.72	10.59

fallow land. Therefore, the partially weathered basaltic land upon cultivation brings on soil organic matter improvements in the native fallow land. In contrast, the soil organic carbon content was high due to high clay content. The expanding clays are easily complex with organic carbon at strong bonds that prevents chemical and biological oxidation of organic carbons and retain in soil for long time. The carbon content of black soil is varied from 0.53 to 0.68% which are comes in between low and high. As the soil carbon content in the sub-surface layer is low and has high potential to get increased upon adaptation of required management practices.

Available soil nitrogen, phosphorous, potassium and sulphur

The primary nutrients are required in large quantity to meet out various physiological demand of the cop. Each primary nutrients plays multirole in plants before recycled into the soils. However, there are many factors limits nitrogen in soil solution before make it available to crops. Among the nutrients, the nitrogen is highly deficient in soils required a large quantity due to low use efficiency of crops and maximum lose in the soils. The native fallow land is nutritionally stressed need an altered fertilization strategy to get the maximum grain yield. The soil available nitrogen is 50 to 87 kg ha^{-1} in the native soils and 136 to 174 kg ha^{-1} in black soils classified into low category of less than 280 kg N ha^{-1} as per the adapted classification systems. The nitrogen content decreased with depth and highly associated for soil organic matter and clay content. Because of low soil and high gravel content it seems a false impression for nutrient dilution to gravel content. The soil available nitrogen which is mostly derived from the soil organic matter not present an adequate amount in the soils

Table 3 . Summary statistics of soil variables potted black soils of NIASM farm land

Soil properties	Number of obs. (N)	Mean	Mini-mum	Maxi-mum	Range	Std. Dev.	Coeff of Variation
Surface layer (0-15 cm)							
Sand (%)	56	11.87	6.67	19.44	12.77	3.13	26.36
Silt (%)	56	18.86	13.10	23.60	10.50	2.19	11.63
Clay (%)	56	69.26	64.52	74.32	9.80	2.46	3.56
pH (1:2 ratio)	56	8.19	7.78	8.44	0.66	0.13	1.65
EC (dSm^{-1})	56	0.24	0.13	0.31	0.18	0.03	13.51
OC (%)	56	0.61	0.53	0.68	0.15	0.04	5.94
N(kg ha^{-1})	56	158.58	135.60	174.30	38.70	9.65	6.08
P (kg ha^{-1})	56	7.88	6.63	8.71	2.08	0.51	6.45
K (kg ha^{-1})	56	150.79	143.56	164.34	20.78	4.71	3.12
S (mg kg^{-1})	56	10.45	8.52	13.12	4.60	1.18	11.33

Soil properties	Number of obs. (N)	Mean	Mini-mum	Maxi-mum	Range	Std. Dev.	Coeff of Variation
Sub-surface layer (15-30 cm)							
Sand (%)	56	9.82	4.28	16.60	12.32	2.94	29.96
Silt (%)	56	20.02	15.20	24.60	9.40	2.22	11.08
Clay (%)	56	70.16	64.52	74.60	10.08	2.43	3.46
pH (1:2 ratio)	56	8.28	7.96	8.51	0.55	0.11	1.31
EC (dSm^{-1})	56	0.25	0.15	0.33	0.18	0.03	11.71
OC (%)	56	0.60	0.50	0.70	0.20	0.04	6.75
N(kg ha^{-1})	56	151.95	138.52	168.32	29.80	7.02	4.62
P (kg ha^{-1})	56	7.65	6.50	8.53	2.03	0.50	6.54
K (kg ha^{-1})	56	147.22	137.20	160.32	23.12	5.20	3.53
S (mg kg^{-1})	56	9.17	7.01	12.12	5.11	1.11	12.05

therefore the plant requirement should come from the nitrogenous fertilizers or huge amount of organic matter application. Being the native lands are limited with soil particles, the nitrogen are expected to get maximum loses through leaching process. This has to be planned carefully particularly for plantation crops, cash crop required huge amount of nutrients for their yield bearing capacity.

The phosphorus plays a major role of energy transfer required for photosynthesis, genetic transfer and nutrient transport functions in the plants. The deficient of nutrients cannot be replaced by others and manifested in terms of delayed maturity, reduced quality of forage, fruit, vegetable, and grain crops, and decreased disease resistance in plants. The soil available phosphorous in the native soils are ranged from 1.2 to 2.5 kg ha^{-1}. The black soils are fall into the low category with respect to soil available phosphorus of 6.6 to 8.7 kg ha^{-1}. According to the existing soil fertility classification, they come under the low category group (<11 kg P ha^{-1}). The application of phosphorous fertilizers would get lost through fixation by secondary minerals and it is also reported of leaching loses due to nature of ion in the sandy soils. Hence, integrated nutrient supply of phosphorus is required in which the mychorhizae will play a major role in the rocky land as the fungi can intrude into the even tinny forces for water and nutrient absorptions. Potassium is highly associated with the function of movement of water, nutrients, and carbohydrates in the plant tissue. The potassium also helps to regulate the opening and closing of the stomata and exchange of water vapour, oxygen, and carbon dioxide. If K is deficient or not supplied in adequate amounts, growth is stunted and yield is reduced. The mean value of potassium for the surface and subsurface soil layer of 15 cm thickness in the native farm land was 78.23 (64.54- 93.20) and 75.3 (60.6-90.0 kg ha^{-1}) and 150 (144 to 164 kg ha^{-1}) and 147 kg ha^{-1} (137 to 160 kg ha^{-1}) in the black soils are getting decreased with depth. The total K content of soils is very much higher than that of plant requirements. Nearly all of this K presents in the structural component of soil minerals not available for plant growth because of large differences between weathering of minerals present in the parent materials and soils and crop needs. Thus, the amount of K supplied by soils gets varied with time and space so need a different fertilization strategy to crops. Plant roots absorb sulphur in the form of SO_4^{2-} from the soil solution. Keeping this fact in view, the soil under study may be classified as deficient (< 10 ppm), medium (10-20 ppm) and sufficient (>20 ppm) category as per the categorization given by Hariram and Dwivedi (1994). Unlike macro nutrients, there is no absolute fertilizer for the supplement of sulphur and therefore plants have to derive most of the requirements from soils. The inorganic source of sulphur constitutes very less amount that the organic become major sulphur source for crops. In both surface and subsurface layer of native farm land soils, the sulphur content was very low and decreased with depth. The sulphur content in the surface and subsurface layer was 5.5 to 8.9 kg ha^{-1} and 4.7 to 8.2 kg ha^{-1} and 8.52 to 13.5 and 7.0 to 12.1 mg kg^{-1}, respectively in the surface and subsurface layers. The sulphur nutrients are very much linked with animals' health particularly sheep, this is very much required for wool production. The livestock is a major source of income from agriculture in the dry land region and the marginal land is getting converted faster for fodder production, it is very much necessary for sulphur fertilization to fodder crops in view of forage quality and animal health.

Micro nutrients

Micro nutrients present only in trace level in soils and plants but they are very much essential to complete life cycle as they are involved directly in many plant metabolic activities. There is a narrow range between sufficient and deficient of nutrient content in soils and plants and the critical content of nutrient also varies from one crop to others. Among the trace metals, the iron, manganese, copper, zinc and boron are the agriculturally important mineral elements have been considered for the addition of external nutrient to get the optimized and sustainable crop yield. Though there are no much intensive studies as many as available for macro nutrients but it is very much important to know the micro nutrients status of soils before recommending fertilizer application to the crops and cropping systems. The mineral nutrients are interrelated each other in the significance of plant nutrition that the deficiency of even one trace elements highly impair the nutrient uptake and nutrient use efficiency of macro nutrients.

Table 4. Summary statistics of available micro nutrients in the native soils of NIASM farm land

Variables	Number of obs. (N)	Mean	Std Dev	Minimum	Maximum	Coeff of Variation
Surface layer (0-15 cm)						
B	18.00	0.09	0.02	0.03	0.12	22.05
Cu	18.00	0.15	0.11	0.02	0.42	34.20
Fe	18.00	0.54	0.39	0.12	1.37	22.06
Mn	18.00	1.47	0.81	0.02	2.50	15.30
Zn	18.00	0.22	0.15	0.06	0.61	16.77

Variables	Number of obs. (N)	Mean	Std Dev	Minimum	Maximum	Coeff of Variation
Sub-Surface layer (15-30 cm)						
B	18.00	0.09	0.02	0.02	0.12	25.85
Cu	18.00	0.20	0.19	0.02	0.84	29.19
Fe	18.00	0.61	0.39	0.10	1.40	24.45
Mn	18.00	1.72	0.86	0.06	2.84	10.00
Zn	18.00	0.23	0.11	0.06	0.38	17.66

The micro nutrients were observed to be deficient in both the layers of black soils except cupper. However, the manganese was deficient about 50% of soils samples and the remaining's were just above the sufficient level. The overall mean indicate that there is a need of serious concern about manganese as they were near at critical level of concentration and the value may get down if we fail to include the manganese containing fertilizers. There is also a need to include appropriate micro nutrient fertilizers application which are highly deficient in black soils (refer table). Similarly, overall value of available micro nutrient status revealed that there is a serious concern about micro nutrient deficiency in the NIASM native farm land. In depth analysis of native soils

Table 5. Summary statistics of available micro nutrients in the native soils of NIASM farm land

Variables	Number of obs. (N)	Mean	Std Dev	Minimum	Maximum	Coeff of Variation
Surface layer (0-15 cm)						
B	14.0	0.2	0.1	0.1	0.3	31.4
Cu	14.0	0.5	0.1	0.3	0.8	18.0
Fe	14.0	1.1	0.2	0.6	1.4	18.5
Mn	14.0	2.2	1.2	0.8	5.0	32.8
Zn	14.0	0.2	0.1	0.1	0.5	38.1

Variables	Number of obs. (N)	Mean	Std Dev	Minimum	Maximum	Coeff of Variation
Sub-surface layer (15-30 cm)						
B	14	0.19	0.07	0.12	0.33	34
Cu	14	0.45	0.10	0.31	0.65	23
Fe	14	1.05	0.15	0.67	1.25	14
Mn	14	2.14	0.97	1.18	4.35	45
Zn	14	0.22	0.18	0.08	0.69	44

revealed that the copper and manganese deficiency observed just 22 and 27% of the soil samples, respectively. Among nutrients spread data of black and native soils, the micro nutrients are getting highly varied with space due to inherent soil character and varied intensity of management practices. It is concluded that there is need to include micro nutrients of recommended dose for crop production. With respect to nutrient availability for soil type, the potting of black soils would be wise decision but there are other factors need to be considered.

5. Case study: Effect of Perennial Crops on Land Development of Partially Weathered Shallow Basaltic Gravelly Land

Abstract

The gravel content in the landscape varied in time and space in response to interaction of external factors namely climate and vegetation. The vegetation plays a significant role on gravel disintegration at the earliest stage of soil development in the landscape can be studied keeping other factors at a constant. Objective of this study was firstly, account the change of particle content, particle movements, regolith depth, bulk density, soil organic carbon, cation exchange capacity, pH and potential mineralizable nitrogen for the intervention of fodder crops and secondly, quantification of biomass production. In this regard, locally suitable fodder crops such as napier grass, stylo grass, marvel-stylo grass intercrop and marvel grass was adapted. Representative soil samples about 45-50 kgs were collected from the surface as well as subsurface layers and separated into different sizes for four consecutive years i.e. 2012-13, 2013-14, 2014-15 and 2015-16. The gravel disintegration decreased with increase in gravel size, time and depth. Over all, the gravel reduction for napier grass, stylo-marvel inter cropping system, stylo and marvel grass cultivation were 90, 64, 52 and 21 mg kg^{-1}, respectively on the partially weathered basaltic gravelly land. With lowering of gravel content, the soil content, the regolith depth, soil organic carbon content and potential mineralizable nitrogen get increased while the decrease of bulk density and soil pH observed across the treatments. To conclude, the short period cultivation of napier grass recommended for maximum fodder production and quick land development besides benefiting the subsequent crops.

Key words

Fodder Crops, Gravel Disintegration, Gravel-Temporal Dynamics, Soil Production, Biomass Production

Introduction

The rocky barren marginal lands are mostly characterized of very shallow to shallow soil depth, high coarse fragments, high permeability and poor soil fertility estimated to cover about 336.3 Mha in the world and 13.75 Mha in India [1-3].The coarse fragment isone of the major limiting factors for crop production in these barren lands subject to decline into small particles along improvement soil properties with time for the interaction of soil forming factors. This is evidenced from the spatial and temporal variation of gravel content across the landscape [4,5].The vegetation, one of the soil farming factors, plays a major role in the gravel reduction at the early stage of land development particularly where the parent material located at the earth surface. According to Phillips et al., 2008, [6] the murrum land which was left after blasting without an intended dam construction brought an increase of soil depth around 1 to 1.5 cm per annum for the establishment of natural vegetation. They did not attempt for change of particle content due to high labour intensive working nature. Though the vegetation role on the development of gravelly land recognised long ago, there has been no much of detailed study. According to Jenny 1941[7], one variable role on soil development can be quantified by keeping all others at a constant. The root exudates, organic matter and root pressure aid directly and indirectly the weakening of coarse particles strength. The organic acid from decomposition of crop residues and root materials solubilise significant amount of minerals and reduce the breaking strength and increase the porosity and water retention of the particle fragments present at the control sections of shallow soil depth [8-10]. In arid and semi-arid environment, plants which survive in the rocky land absorb most part of the water required for survival from the coarse particles and increase the porosity and water retention capacity [11-13].

The physiological and mechanical activities differed from one plants to others attributed in varying of gravels content. However, on other side, the gravelly land naturally having most of the edaphic stress limit severely the metabolism, growth and development of crops mainly for low soil content, root volume and soil depth, poor water retention and dilution of available nutrient content [14]. The soil potting of land is a very familiar management option in the rocky land area even it requires a high initial investment for procurement and transportation of soils over the large distance. The removal of large size gravels in part of gravelly barren land development is obviously not a sustainable practice as they are source for soil production and fresh mineral nutrients to crops. Based on available technologies for crop stress management on the barren land, the high gravel content has been considered economically most limiting edaphic factor for crop cultivation on this barren land [15]. Therefore, it is necessary to have a crop based technology for high subsidence of gravels and improvement of soil properties while ensuring some monetary returns and benefit to the subsequent crops. The large proportion of small and marginal farmers' family income in the rocky barren dominated dry land area comes from animal components of agriculture going to be impacted due to the shrinking of fodder cultivated arable land while increasing of green fodder deficit [16].The fodder crops doesn't required fertile land as good as for food crops that now slowly getting extended on the marginal barren land to meet out partially the fodder demands [17]. However, the fodder crops cultivation impacts on the development of gravelly land has been given much less attention, thus the paper targeted with following three objectives 1.The selection of suitable fodder crops for acceleration of high gravel disintegration on the shallow barren land 2. To account the change of soil property such as bulk density, regolith depth, pH,

1. Initial field Condition


2. Placing gelatin sticks


3. Microblasting of land


4. Ripping after blasting

Fig 1. Land preparation activities and various experimental grass plots at ICAR-NIASM

soil organic carbon and potential mineralizable nitrogen for the cultivation of fodder crops. 3. The effects of gravel disintegration on above and below ground biomass production on the barren land.

Materials and Methods

The place of study, "National Institute of Abiotic Stress Management" comes under Indian Council of Agriculture Research, Ministry of Agriculture and Farmers Welfare is located at the latitude and longitude of 18° 09′ 30.62′′N and 74° 30′ 03.08′′E.The parent materials vulnerability or rock strength of the study place assessed with the parking weathering index value and classified into a partially weathered materials (PI value around 2500) [18]. The shallow native fallow land initially had 21 to 23% soil (w/w) and the remained was large proportion of gravels of different sizes hardly suited for cultivation of commercial food grain crops.The soil organic carbon, plant available nitrogen, phosphorous and potassium of the native fallow land was very low and they were 0.5 g kg^{-1}, 24.28 mg kg^{-1}, 2.3 kg ha^{-1} and 81 kg ha^{-1}, respectively. Due to low fertility and high gravel content, the barren land did not support growth and development of the natural vegetation though there was numerous species of grasses, trees and shrubs present in the site [19]. The water was also a limiting factor for both gravel subsidence and growth and development of crops in the study area as it comes under rain shadow region with an annual precipitation of 500 to 600 mm [20]. The barren land blasted with minor intensity dynamites and ripped using heavy machineries to increase the depth (Fig 1) before the fragmentation of land into number of fields each covering about 4000 m^2 area. Subsequently, the fodder crop treatments were shown but they were failed to germinate in most part of the barren land. Thus, green manure crops rose before conduction of experiment in order to test field uniformity and enrich of soil organic matter. The overall growth of the dhaincha crop was poor on these virgin soils recorded only about 7-11 Mg ha^{-1} of fresh weight (N-2.06, P-0.18, K-2.09 % on dry weight basis) within a period of 40-45 days [21]. After incorporation of dhaincha, the napier grass, stylo legume crop and marvel grass were established well in the rabi season in 2012. The Phule Jaywant, Phule kranti and Marvel grass-7 are the ruling varieties of napier grass, stylo and marvel grass in the western region of Maharashtra adapted in the experiment.

The napier grass seedling were planted at 1m x 1m spacing with basal application of one fourth dose of nitrogenous and full dose of phosphorous and potassium fertilizers. The remaining amount of fertilizer applied later equally after every harvest usually came after three to four month period of time. Being the lands was poor fertile, the fertilizer application of 400 kg N: 120 kg P: 300 kg K per ha per annum was adapted for the napier grass cultivation. The stylo is a legume fodder crop mostly cultivated under arid and semi-arid region where the annual rainfall is around 600 to 750 mm adapted here. The seedling materials of stylo planted at spacing of 0.75 x 0.75 m^2. The standard cultivation practice of the fodder crop regularly followed as per guidelines given by the state agriculture university. The marvel grass is a well-known dry land fodder crop for cultivation on marginal gravelly land in the arid region. Initially, the seed were failed to germinate in the marginal land that the seedling materials planted laterat spacing of 0.50 x 0.50 m^2. The fertilizer dose of 35 kg N: 25 kg P: 80 kg K per ha was applied an every year at the time of just before planting of seedlings. As the age of planting affects crop performance, new seedlings were planted every year to monitor the crops biophysical aspects and coarse fragment disintegration. The average fodder yield obtained from the non-gravelly land of this region were collected from the national institute, Indian Institute of Grassland and Fodder Research [22], Jhansi, Uttar Pradesh State for yield comparison with that of gravelly land. They are 150, 25-30 and 30-35 t ha^{-1} for napier grass, stylo and marvel grass [23].

Soil and plant samples collection and analysis

Before initiation of the experimentation, representative soil samples about 45-50 kgs were being collected from surface (0-15 cm) and sub-surface layers (15-30 cm) of each experiment plots as the normally recommended sample size do not provide required accuracy in measuring particle fractions [24]. Firstly, the soil samples were dried under shadow condition and then separated with use of sieves of different sizes namely 2mm, 4 mm, 6.3 mm, 8 mm, 10 mm 16 mm and 20 mm. Secondly, all the gravel particles were size-wise washed with distilled water till clear water was obtained to ensure complete removal of adhering soil particles. Thirdly, the collected water having soil particles was kept overnight period for the decanting of clear water. Finally, the muddy water remained in the bottom and washed-gravels were dried under direct sunlight till the constant weight was obtained. The soil and gravels content of different size were quantified and expressed as percentage. The below ground biomass production of fodder crops was estimated by adopting soil profile sampling method, in which soils and murrum including roots collected from the area of 1 x 1 m^2 in the napier grass, 0.75 x 0.75 m^2 in the stylo and 0.5 x 0.5 m^2 in the marvel grass field. The plant root was separated by manual and density separation methods and subsequently dried in the hot air oven by keeping at 60 °C for two days before weighing it out. The root and shoot biomass production, soil and gravel content monitored an each year till 2015-16. On fourth year, the soil properties such as sand, silt and clay size particles distributions, bulk density, oxidizable soil organic carbon content, pH, CEC and potential mineralizable nitrogen was determined in both the layers from grasses cultivated field as well as native fallow land. The regolith depth was also measured after three years of cultivation by digging down into the field till the hard rock exists and further digging became harder. The soil organic carbon and potential mineralizable nitrogen content of fine earth soils was determined following the standard procedure given in the literatures [25, 26]. The bulk density (BD) of gravelly land cannot be measured with usual core sampler method recommended for non-gravelly soils since erroneous results are expected for the horizontal variability and inadequate representation of particle fractions. Therefore, the core sampler of 0.15 x 0.5 m^2 size (10 litres volumetric capacity) used for BD measurement in the field contain 80 % gravels as per recommendation given by Vincent & Chadwick, 1992 [27]. The bulk density of fine earth fractions and the gravels of all sizes by wax coating methods checked out separately.

Calculation of soil organic carbon and nitrogen in the gravelly land

The labile or oxidizable organic carbon and nitrogen from gravels are negligible as they are mostly come from fine earth fractions. The nutrient content expression of fine earth fraction without account of soil dilution by gravel content gives a false impression and therefore we have followed the below given formula to obtain result.

The soil organic carbon per hac of gravelly land (kg/ha) =

(A x D x BD x SOCF x S) / 1000

Where, A= Area (m^2), D =Depth (m), BD = Bulk density (Mg m^{-3}), SOC_f = Soil organic carbon content of fine earth fractions < 2 mm (g kg^{-1}) and S= Proportion of fine earth fractions.

The normal distribution and equality of error variance of data analysed with the Shapiro-wilk test and levene's test, respectively. The one way anova was performed using SAS 9.2 software to test the temporal change of soil proportion, gravel dynamics, regolith depth, bulk density, soil carbon and potential mineralizable nitrogen content among the treatments. The separation of treatment means was performed using Duncan's Multiple Range test at the 0.05 probability level.

Results and Discussion

The temporal increase of above and below ground biomass production

The shallow gravelly land significantly affected fodder production varied from 43 to 69 % fodder yield obtained from the gravel-free land of this study region. The temporal increase of biomass production was highly associated with gravel reduction and increase of soil content, soil organic carbon and mineralizable nitrogen differed significantly between the fodder crop treatments. The napier grass performed relatively better with the production of 65-76 t ha^{-1} green fodder. It must be for a high demand of water and fertilizer for superior crop genetic potential and more dilution of gravel content over other treatments [28]. However, the perennial fodder crops comparison for the fodder yield of gravelly over the non-gravelly land revealed that the stylo (69%) and marvel grass (58%) outperformed the napier grass (it was just 43 % of the average yield of 150 t ha^{-1} recorded in non-gravelly land of the region as reported by the Indian Institute of Fodder and Grassland Research, Jhansi, Madhya Pradesh) with relatively high biomass production. It was mainly due to soil moisture conservation and biological nitrogen fixation of legume crop and drought resistance of marvel grass [29].Similarly, the below ground biomass production of napier grass was high at 3.9 t ha^{-1} and got a high and marginal increase in the next two consecutive years over other treatments. As the partially weathered murrum land was not even supported to the natural grass growth and development, the above and below biomass production were just 0.21 t ha^{-1} and 0.1 t ha^{-1}, respectively under the native fallow land (Fig 2). The temporal increase of biomass production including in the native fallow land was

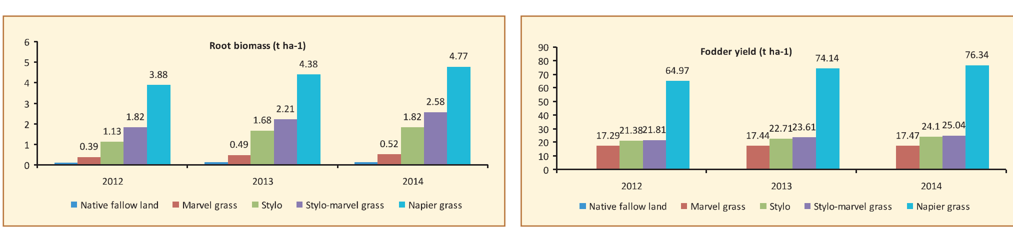


Fig 2. Temporal change of above and below ground biomass production of fodder crops on the shallow basaltic gravelly land

accordance with the report of shoot and root biomass increase with lowering of gravel content by Ungar et al., 1971 and Babalola & Lal, 1977[30,31].

Temporal increase of soil proportion on the shallow gravelly land for fodder crops cultivation

The soil production refers to breaks down of gravels into less than 2 mm particles measured by dry weight basis. The temporal increase of soil proportion was observed from all the treatments including native fallow land. A one way ANOVA showed that time and fodder crops had a significant impact on soil proportion increase (<2 mm) in both surface and sub-surface layer at 15 cm thickness on the barren gravelly land. The soil content increase was faster and high in surface of 0-15 cm depth over subsurface layers (15-30 cm) but it was not an equal with time. The soil proportion increase was high under napier grass (254 and 111 g kg^{-1}) followed by the stylo based cropping systems (147 to 161 g kg^{-1} and 86to 100 g kg^{-1}), marvel grass (75 and 41 g kg^{-1}) and native fallow land (44 and 20.5 g kg^{-1}) in both surface and subsurface layers over three years period (Fig 3 and 4). The soil content increase was highly associated with increase of soil organic carbon and potentially mineralizable nitrogen and decrease of gravel content and soil pH.

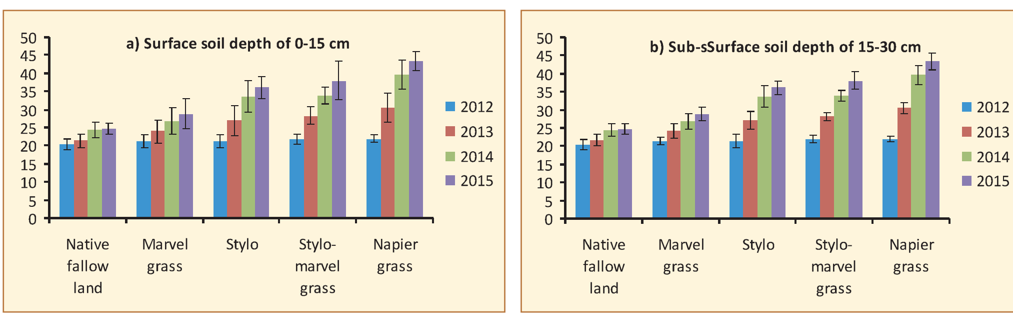


Fig 3. The temporal change of soil proportion (%) in the surface and sub-surface depth on the barren land.

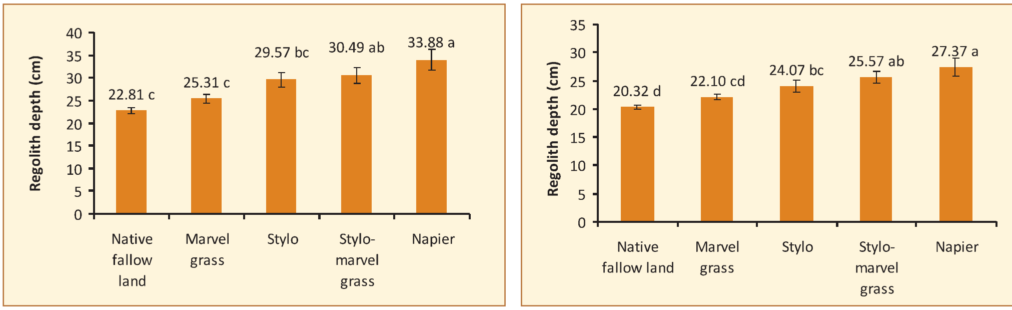


Fig 4. The effect of fodder crops on soil proportion (%) in the surface and sub-surface depth on the barren land over three years period.

The temporal change of gravel content for fodder crops cultivation and regolith depth on shallow gravelly land

The declines of gravel content after blasting of the barren land getenhanced for fodder crops cultivation. The gravel content from all the size classes decreased with time indicated that most of the gravels followed in the granular defoliation pattern over the irregular breaks down [32]. However, the thickness of defoliation layer or permeability of gravels for disintegration differed with depth and time under fodder crops, thus the number of gravel size underwent for significant change was not same in all the treatments. The fodder crop influence on gravel size is very much clear in both for the surface and sub-surface layers. The native fallow land and marvel grass impact mostly restricted to gravel size up to 6.3 mm size. The gravels of up to 8 mm size under stylo and 10 mm size under stylo-marvel intercropping systems are highly attributed into less than 2 mm particles as other size reduction was not statistically significant. The napier grass is a very efficient crop impacted all the sizes in the surface layer while it was up to 20 mm in the subsurface layer (Fig 5 and 6). Over all, the amount of gravel content change for size followed in the order 2-4 mm> 4-6.3 mm> 6.3- 8 mm> more than 20 mm> 8-10 mm> 10-16 mm under all the fodder crop treatments. It might be for the change of gravel vulnerability for break down with its size, relative gravels content under given size impacted by roots and interaction with root exudates and organic matter differed between treatments[33]. Similarly for crop treatment effect, it was in the order of napier grass ≥ stylo-marvel intercropping systems>stylo>marvel grass=native grass land (Fig 6). The gravel reduction (> 2 mm size) of 30 cm depth under napier grass, stylo-marvel inter cropping systems, stylo and marvel grass were 91, 65, 52 and 21 g kg^{-1} respectively over the native fallow land.

The coarse fragments which brought up to the surface from sub-surface layer by minor blasting and deep ploughing with heavy machineries in part of land development usually release a huge amount of pressure in the short period of time that the natural breaks-down of gravel particles observed in the native fallow land [34]. The gravel disintegration in the surface depth of native fallow land was 4% on third year. As there were few native grasses in the controlled plot, the hailstorm which occurred on second week of February, 2014 had some effect on gravel disintegration in the native fallow land [35]. Apart from hailstorm, there are many process namely, oxidation of ions present in the matrix, cation exchange process, wetting and drying of gravels, leaching of cations from the surface of particles causes mechanical stress and reduce the gravel strength [36, 37]. As the experimental site is under rain shadow region, the water was also a limiting factor for physical and chemical weathering of rock materials in the Deccan plateau. In comparison to native fallow land, irrigation as when required by crop imitated drying and wetting cycle could have brought more gravel disintegration and production of particles (<2 mm size) of agriculture importance. Thus, cultivation of fodder crops after blasting of shallow barren land accelerated gravel disintegration about 70 g kg^{-1} in surface and 45 g kg^{-1} in the sub-surface layers. All gravels could not interacted with roots and organic matter from crop residues that amount of gravel change varied between sizes in the native fallow land as well as fodder crops. The amount of external energy and root activities is relatively high in the surface layer and decreased with depth that the gravel disintegration was high at 45 g kg^{-1} over the subsurface layer (data hidden). The napier grass with fibrous root biomass might exudates large amount of organic compounds exploited effectively mineral cations from the gravels impacted more number gravel size and produced large amount of particles of less than 2 mm size. Next to napier grass, the sytlo is a legume crop produce a deep root system accelerated more gravels decline than that of marvel grass. In comparison to stylo and marvel grass sole crop, the stylo-marvel inter cropping system has high amount of root activities and organic matter contribution in both surface and subsurface layers reduced more amount of gravels over the sole crops.

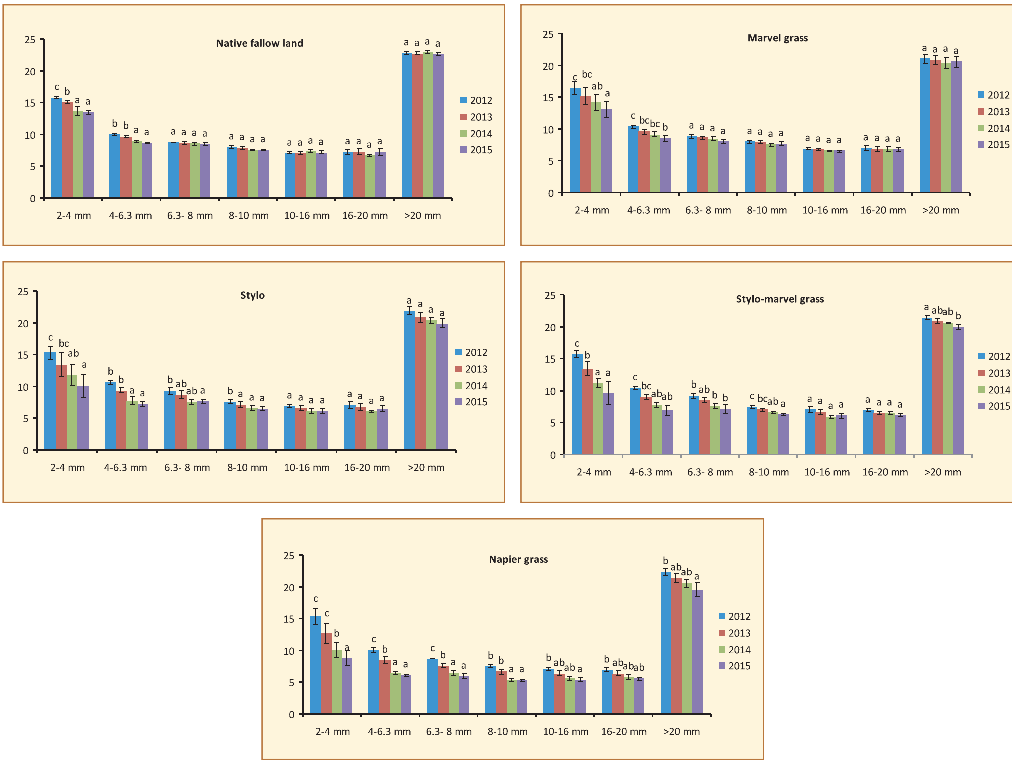


Fig 5. Temporal change of gravels content on surface layer (0-15 cm depth) for different fodder crops cultivation on the shallow basaltic gravelly land.

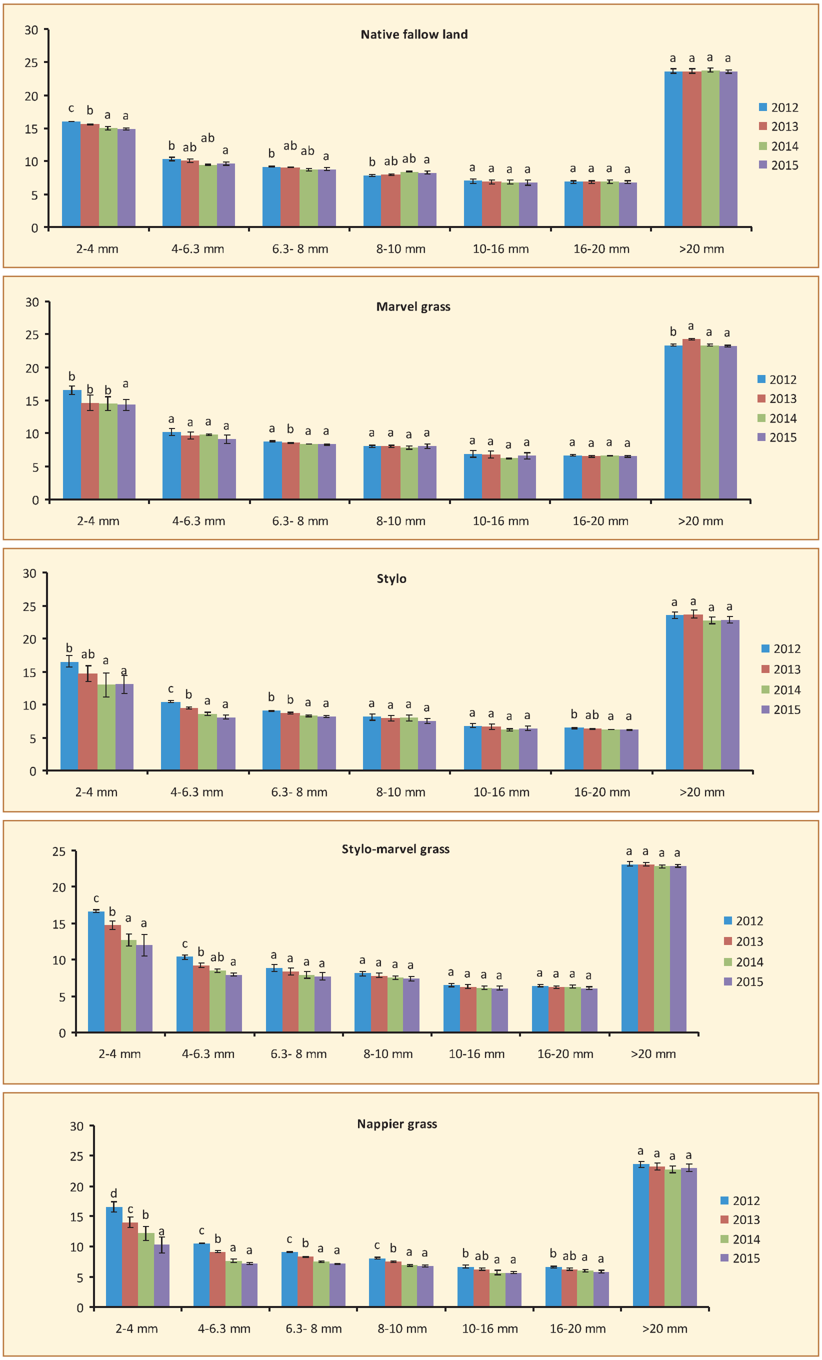
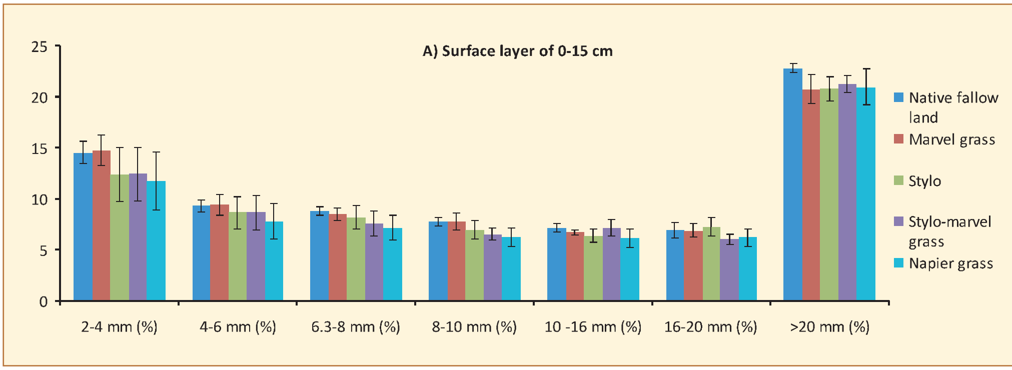


Fig 6. Temporal change of gravels content on sub-surface layer (15-30 cm depth) for different fodder crops cultivation on the shallow basaltic gravelly land.



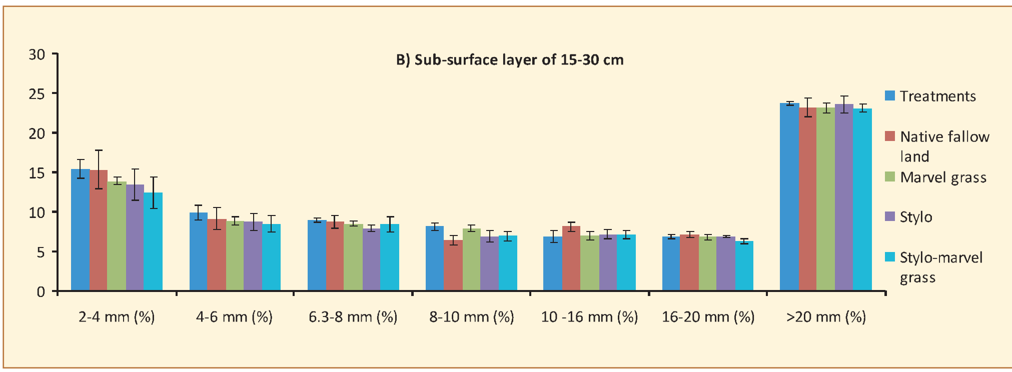


Fig 7. The effect of fodder crops on gravels of different size (%) in the surface (A) and sub-surface (B) depth on the barren land over three years period.

The research results supported to the report of Humphreys and Wilkinson, 2007 [38] that the soil production function follows the exponential pattern in place where soil depth is zero and rocks exposed to atmosphere. It also an evidence to hump model of soil development in place where the rock parent materials are near to earth surface. Phillips et al. 2008 [6] also reported the similar kind of high intensive soil production and development of soil cover about 15-20 cm thickness in 30 years period on the gravelly land for the rapid establishment of tree covers and other flora and fauna activities at Ouachita mountain. Arachchi & Liyanage, 1996 [39] had also reported maximum disintegration of >12 mm gravels size in the subsoil surface for alley cropping of Gliricidia sepium in coconut plantation in Angadima soils series in Sri Lanka. Unlike clayey soils, the gravelly land with high amount of macro pores allowed maximum amount of roots to reach the subsurface depth. The vertical extension of plant root is relatively large in the arid and semi-arid region due to large amount root move down for search of water [40]. According to Graham et al. 2010 [12], the gravels could supply a substantiate amount of water to crops where the land is being dominated with gravels though it has a low water holding capacity. The water retention in the surface layer is very less that a large portion of irrigation water leached down to the plough layer depth and would not be available for evaporative loss [41]. The regolith is consisted of soil particles, organic matter and other unconsolidated materials lay above the solid rocks. The regolith depth differed statically for fodder crops raised in the shallow land. The depth increase was maximum at 1.6 cm yr^{-1} under napier grass, and 0.8 to 1.0 cm yr^{-1} to stylo based cropping system (Fig 8). The continuous presence of moisture for long time, the porous rock particles become soft with lose of strength allowed maximum roots get through the pores over the native fallow land. An enhanced root activity and the microbial activities for relatively high organic matter from fodder crops effectively accelerated coarse particles conversion into small particles in the subsurface layer that increased the regolith depth over the native fallow land.

Effect of fodder crops on soil properties of the shallow gravely land

The short term period of fodder crops cultivation brought a significant change of few physical and chemical properties on the shallow gravelly land. The sand of content of the surface and subsurface layers of napier grass differed statistically with other treatment by an increase of almost 18 g kg^{-1} in the surface layer and decrease of around 8.9 g kg^{-1} in the subsurface layer over that of native fallow land. The sustained application irrigation in napier grass leached down

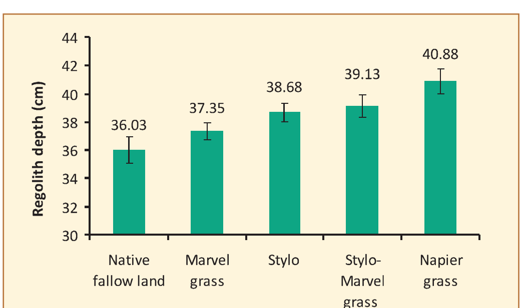


Fig 8. Effect of fodder crops on regolith depth on the shallow basaltic barren land after three years period of cultivation

Table 1. Effect of fodder crops cultivation on basic properties of shallow basaltic gravelly land

Treatments	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	BD (Mg m^{-3})	OC (g kg^{-1})	pH_e	CEC (cmol (p$^+$) kg^{-1})	Potential minerali-zable nitrogen (kg ha^{-1})
Native fallow land	0-15	87.26±0.27b	7.73±0.36a	5.01±0.36a	2.43±0.01c	0.37±0.04c	6.6±0.12d	5.93±0.28b	16.26±0.84c
	15-30	86.66±0.38b	8.01±0.51a	5.34±0.42a	2.54±0.05d	0.29±0.01c	6.6±0.08c	5.56±0.08b	13.25±0.58c
Marvel grass	0-15	87.12±0.30 b	7.86±0.33a	5.03±0.28a	2.32±0.06c	0.43±0.08c	6.4±0.12cd	5.59±0.25b	19.01±2.75c
	15-30	86.65±0.24b	7.99±0.34a	5.37±0.48a	2.40±0.03c	0.35±0.05c	6.5±0.08c	5.96±0.18ab	15.88±2.32c
Stylo	0-15	87.32±0.37ab	7.54±0.37a	5.14±0.44a	2.17±0.02b	0.67±0.06b	6.2±0.12bc	5.71±0.22b	26.46±2.75b
	15-30	86.64±0.16b	8.07±0.33a	5.30±0.21a	2.23±0.01b	0.48±0.05b	6.3±0.08b	5.90±0.3ab	20.79±1.95b
Stylo-marvel grass	0-15	87.61±0.48ab	7.23±0.33a	5.16±0.4a	2.06±0.03ab	0.73±0.13b	6.0±0.09ab	5.74±0.37b	28.56±4.98b
	15-30	86.43±0.14b	8.21±0.33a	5.37±0.24a	2.16±0.05b	0.54±0.09b	6.3±0.08b	5.97±0.27ab	21.25±3.72b
Napier grass	0-15	89.10±0.31a	6.73±0.46a	4.18±0.22a	1.95±0.07a	1.03±0.11a	5.8±0.10a	4.68±0.1a	35.62±4.27a
	15-30	85.79±0.43a	8.35±0.3a	5.86±0.25a	2.01±0.05a	0.76±0.09a	5.9±0.06a	6.53±0.18a	26.19±2.18a
P > 0.05 (0-15 cm)		0.0015s	0.1918 ns	0.2578ns	0.0000s	0.0000s	0.0005s	0.0034s	0.0000s
P > 0.05 (15-30 cm)		0.0159s	0.0159ns	0.2257ns	0.0000s	0.0000s	0.0010s	0.0078s	0.0000s

silt and clay particles and brought significant difference of sand content over other treatments when porosity was not a limiting factor for particles movement in the gravelly land [42,43]. The bulk density (BD) in the surface and sub-surface of 15 cm thickness layers differed significantly for fodder crops cultivation on the barren gravelly land. The bulk density get reduced under all the fodder crops cultivated field and the reduction of 20% and 21% respectively in the surface and sub-surface layer under napier grass was the maximum impact. The lowering of BD under stylo-marvel intercropping system and stylo was almost same and they had a significant difference with marvel grass by a low about 6.8% in the surface layer and 13.6% in the sub-surface layer and a decline of 15% in both the layers over the native fallow land. For depth, the bulk density reduction was high from sub-surface layer particularly due to high compaction, gravel content and low organic matter content. The napier grass brought a high amount of BD decline in the subsurface layer due to more amount of root activities, organic matter increase and gravel reduction over that of other crops and native fallow land. The soil particles proportion increase for fodder crops cultivation in the gravelly land which at the early stage of development played a major role in improvement of soil organic matter and bulk density [44]. The oxidizable organic carbon content in the soils was very low due to low amount of clay mineral content and organic matter input in the native fallow land (refer figure 2 and table 1). The oxidizable organic carbon content of the gravelly land differed significantly for fodder crops cultivation. However, the size of treatment effect was very meagre for an increase of around 0.7 and 0.3 g kg^{-1} in both layers respectively for napier grass and the stylo and stylo-marvel grass inter cropping systems due to high coarse fragments reduced the space which would be occupied by the fine earth particles and encouraged decomposition rate of organic matter for high enzymatic activities at the junction of gravels and fine soil particles [45, 46]. It is equal to an increase of almost 718 kg ha^{-1} yr^{-1} (0.3 m depth after taking into account of gravel content and BD) under the napeir grass. Similarly, the carbon increase was 420, 474 and 356 kg ha^{-1} yr^{-1} respectively for stylo-marvel grass intercropping system, stylo and marvel grass (Appendix-I). The soil carbon increase for fodder crops cultivation on the gravelly land was very less in comparison to previous studies for land use on the non-gravelly land; however they have more potential for positive soil carbon feedback upon conversion of barren gravelly land into the grasses cultivation [47-49].

The soil pH of the gravelly land was slightly acidic to neutral pH varied from 5.8 to 6.6 across the treatments. It increased with depth in all the treatments except native fallow land. The newly introduced fodder crops slightly acidified the low buffered and partially weathered shallow gravelly land within short period of time. The maximum reduction of pH about 0.89 units in the surface and 0.7 units in the subsurface layers under napier grass. According to Jobbagy & Jackson, 2003 [50], the perennial fodder crops produces relatively high amount of carbonic acid from the respiration of large plant population over that of native fallow land might cause weathering of minerals and release of base cations. The cations could probably have leached down to the plough layer as the poor fertile land has low in cation holing parameters namely soil organic carbon andclayminerals.The CEC of the gravelly land was low and varied from 4.7 to 6.5 cmol (p+) kg^{-1} across the treatments. The CEC values are relatively high in the subsurface layer of all the grass land. As the CEC of 0-30 cm layer was not different significantly, the distribution of napier grass differed highly with other treatments. The CEC get increased almost about 21.1% in the surface layer and declined about 16.4% in the subsurface layer over that of native fallow land due to the soil organic carbon increase was highly associated with the soil CEC over the accumulation of clay content in the subsurface layers [51].Similarly, the potential mineralizable nitrogen of the gravelly land varied from 24.1 to 29.5 mg kg^{-1} across the treatments. The nitrogen content of the gravelly land differed significantly among the treatments. The nitrogen increase in the surface and sub-surface layer of napier grass was 4.4 and 4.0 mg kg^{-1}, respectively. The improvement of soil particle proportion and organic matter over the period increased the soil capacity to retain residual input nitrogen comes from the application of inorganic fertilizers, organic matter inputs of root biomass and residues coms from above ground biomass and root exudation (nitrogen containing compounds such as amino acids, proteins and carbohydrates). As expected, the nitrogen increase was high in the surface soil layer due to more amount of input remained in the surface layer of 0-15 cm depth over subsurface layer of 15-30 cm. For fodder crops effect on plant available nitrogen, the napier grass found more effective in increase of soil nitrogen compared to other treatments

Conclusion

The short term period of perennial fodder crops cultivation brought following changeson the shallow gravely barren land. The gravel content were declined about 90, 65, 53 and 21 mg kg^{-1}, respectively for napier grass, stylo-marvel inter crops, stylo and marvel grass cultivation. The fodder crops altogether accounted disintegration of 57 g kg^{-1} more than that of native grass land. The gravel disintegration was relatively high in the surface layer at 46 g kg^{-1} reduction across the treatments. The gravel decay was high from fine gravels and decreased with increase of gravel size till 20 mm. The regolith depth got increased for fodder crops cultivation significantly under napier (1.6 cm yr^{-1}) and stylo based cropping systems (1 cm yr^{-1}) over others. The soil properties of bulk density and pH reduced while an increase of oxidizable organic carbon and potential mineralizable nitrogen observed under the fodder crops. The sand content get increased in the surface and decreased in the subsurface layer due to movement of silt and clay size particles. Overall, the napier grass cultivation on the shallow barren land would bring quick gravels (murrum) disintegration and improvement of soil properties which would benefit subsequent crops besides high remuneration of fodder yield.

Acknowledgement

This work is financially supported by ICAR-National Institute of Abiotic Stress Management, Malegaon Khurd, Baramati Pune-413115 Maharashtra is gratefully acknowledged. The authors declare that there are no financial/ commercial conflicts of interest.

References

[1] NRSA. 2005. Wasteland Atlas of India. Ministry of Rural Development and NRSA Publ. NRSA, Hyderabad. URL: http://www.dolr.nic.in/wasteland2010/wateland%20Introduction-%20forword%20.pdf

[2] Minhas PS, Obi Reddy GP (2015). Edaphic Stresses and Agriculture Sustainability: An Indian perspective. Agricultural Research.

[3] Friedrich HB, Hari-Eswaran, Reich PF (2008) Edaphc Constraints on food production, In encylopdia of soils (W. Chesworth,Ed.), Springe: Netherlands: 202-206

[4] Batjes NH (1997) A world dataset of derived soil properties by FAO-UNESCO soil unit for global modelling. Soil Use & Manage13: 9-16. DOI : 10.1111/j.1475-2743.1997.tb00550.x

[5] Wald JA, Graham RC, Schoeneberger PJ (2012) Distribution and properties of soft weathered bedrock at ≤ 1m depth in the contiguous United States. Earth Surf. Process. Landforms. 38:614-626 DOI: 10.1002/esp.3343.

[6] Phillips JD, Turkington AV, Marion DA (2008) Weathering and vegetation effects in early stages of soil formation. Catena 72: 21–28. URL:http://dx.doi.org/10.1016/j.catena.2007.03.020

[7] Jenny H. 1941. Factors of Soil Formation-a System of Quantitative Pedology. McGraw-Hill, New York. URL: http://soilandhealth.org/wp-content/uploads/01aglibrary/010159.Jenny.pdf Accessed on 12.10.2016.

[8] Chen J, Blume HP, Beyer L (2000) Weathering of rocks induced by lichen colonization- a review. Catena 39:121-146. http://dx.doi.org/10.1016/S0341-8162(99)00085-5

[9] Drever JI (1998) The effect of land plants on weathering rates of silicate minerals. GeochimCosmochimActa 58:2325-2332.DOI:org/10.1016/j.gca.2008.06.020

[10] Khorassani R, Hettwer U, Ratzinger A, Steingrobe B, Karlovsky P, Claassen N (2011) Citramalic acid and salicylic acid in sugar beet root exudates

solubilize soil phosphorus. BMC Plant Biology 11: 121 URL:http://www.biomedcentral.com/1471-2229/11/121

[11] Hubbert KR, Beyers JL, Graham RC (2001) Roles of weathered bedrocks and soils in seasonal water relations of pinusjeffreyi and Arctostaphylospatula: Canadian J Forest Rese 31:1947-1957. DOI: 10.1139/cjfr-31-11-1947

[12] Graham RC, Rossi AM, Hubbert KR (2010) Rock to regolith conversion: Producing hospitable substrates for terrestrial ecosystems. GSA Today 20: 1-7. DOI: 10.1130/GSAT57A.1

[13] Graham RC, Guertal WR, Tice KR (1994) Thepedologic nature of weathered rock, in Cremeens, DL, Brown RB, and Huddleston JH. eds., Whole RegolithPedology: Soil Science Society of America Special Publication Number 34: 21–40

[14] Diallo D (2014) Properties and Management of Gravelly soils developed on Ferrugenious cuirass in Mali. Journal of Soil Sci& Environ Manage 6:35-43. DOI:10.5897/JSSEM 12.084

[15] Kumbhar JS, Pawar PP, Patole SD, Gavali AS (2015) Economic analysis of green fodders in western Maharashtra. Intern Rese J AgriEconom& Stat 6:150-154

[16] GoI (Government of India) (2015) Year-wise Area under Crops-All India. Available URL: http://dacnet.nic.in/eands/LUS-2006-07/ Summary/ tb3.13.pdf.

[17] Birthal PS, Jha AK (2005) Economic losses due to various constraints in dairy production in India. Indian Journal of Animal Sciences, 75: 1476-1480.URL: file:///C:/Users/Rajgopal/Downloads/Economic%20losses %20dairy9411-19961-1-PB.pdf

[18] Maurya UK, Vittal KPR, (2011) Identification of Abiotic Edaphic Stressors of Deccan Trap at NIASM site, Malegaon. A geotechnical and Geological Study. NIASM technical Bulletin-2. National Institute of Abiotic Stress Management. Baramati 40 p.

[19] NIASM, Second Annual report, (2010) National Institute of Abiotic Stress Management, Malegaon Khurd, Baramati Pune-413115 Maharashtra.

[20] Saha S, Minhas PS, Bal SK, Singh Y (2015) Trends in Climatic Features and Greenhouse Gas Exchange of Crops in Scarcity Zone (Baramati) of Western Maharashtra.NIASM Technical Bulletin - 6.ICAR-National Institute of Abiotic Stress Management, Malegaon, Baramati- 413 115, Pune, Maharashtra, India.p. 42.

[21] Minhas PS, Bal SK, Suresh Kumar P, Singh Y, Wakchaure GC, Ghadge SV, Nangare DD, Taware PB (2015) Turning Basaltic Terrain into Model Research Farm: Chronicle Description. NIASM Technical Bulletin 8, ICAR - National Institute of Abiotic Stress Management, Baramati, Pune, Maharashtra (India) p. 64. URL:http://www.niam.res.in/sites/default/files/pdfs/Tech_Bulletin-8.pdf

[22] Pandey KC, Roy AK (2011) Forage Crops Varieties. Indian Grassland and Fodder Research Institute. Jhansi (India). URL:http://www.igfri.res.in/pdf/bulletin_09/Forage_Crop_Varieties.pdf

[23] ICAR-IFGRI; Indian Fodder and Grass land Research Institute.2013. Vision document 2050.Materials available at http://www.igfri.res.in/2013/Vision-2050.pdf.

[24] Lyford WH (1964) Coarse fragments in the Gloucester soils of the Harvard forest. Harvard Forest paper 9. Harvard University, Harvard Forest, Petersham, Massachusetts P1-16. URL:http://harvardforest.fas.harvard.edu/sites/harvardforest.fas.harvard.edu/files/publications/pdfs/HFpubs/paper9.pdf Accessed on 10.12.2016.

[25] Benedetti A, Sebastiani G (1996) Determination of potentially mineralizable nitrogen in agricultural soil. Biology and Fertility of Soils 21:114-120. DOI: 10.1007/BF00336002

[26] Walkley A, Black IA (1934) An Examination of Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method. Soil Sci. 37:29-37. http://journals.lww.com

/soilsci/citation/1934/01000/an_examination_of_the_degtjareff_method_for.3.aspx

[27] Vincent KR, Chadwick OA (1992) Synthesizing Bulk Density for Soils with Abundant Rock Fragments. Soil Science Society of American Journal58: 455-464. DOI:10.2136/sssaj1994.03615995005800020030x

[28] Flores RA, Urquiaga S, Alves, Collier BJR, Leonardo SC, Boddey, RM (2012) Yield and quality of elephant grass biomass produced in the cerrados region for bioenergy. Engenharia Agricola, 32:831-839. https://dx.doi.org/10.1590/S0100-69162012000500003

[29] Grewal SS, Singh K, Dyal S. 1984. Soil profile gravel concentration and its effect on rainfed crop yields. Plant & Soil 81: 75-83. URl: URL: http://www.jstor.org/stable/42935898

[30] Babalola O, Lal R (1977) Sub soils gravel horizon and Maize root growth 1. Gravel concentration and Bulk Density effects. Plant & Soil 46: 337-346 URL: http://www.jstor.org/stable/42935142

[31] Ungar PW (1971) Soil profile gravel layers I. Effect on growth and water storage distribution and evaporation. Soil Science Society of American proceedings 35: 980-983.DOI:10.2136/sssaj1971.03615995003500040041x

[32] Blackwelder, E (1925) Exfoliation as a Phase of Rock Weathering. The Journal of Geology 33(8):793-806 URL: http://www.jstor.org/stable/30055637

[33] Al-Qinna MI, Salahat MA, Shatnawi ZN (2008) Effect of Carbonates and Gravel Contents on Hydraulic Properties in Gravely-Calcareous Soils. Agricultural Sciences 35:3 145-158

[34] Dobereiner L, Durville JL, Restituito J (1993) Weathering of the Massiac Gneiss (Massif Central, France). Bulletin of the International Association of Engineering Geology 47: 79–96. DOI:10.1007/BF02639596

[35] Bal, SK, Saha S, Fand BB, Singh NP, Rane J, Minhas PS (2014) Hailstorms: Causes, Damage and Post-hail Management in Agriculture. Technical

Bulletin No. 5, National Institute of Abiotic Stress Management, Malegaon, Baramati.413115. Pune, Maharashtra (India). p. 44. URL http://www.niam.res.in/sites/default/files/pdfs/Tech_ Bulletin-5.pdf.

[36] Zhang D, Chen A, Xiong D, Liu G (2013) Effect of moisture and temperature condition on the decay rate of a purple mudstone in south western china. Geomorphology 182:125-132.DOI:org/10.1016/j.geomorph.2012.11.003

[37] Buss HL, Sak, PB, Webb SM, Brantley SL (2008) Weathering of the Rio Blanco quartz diorite, Luquillo Mountains, Puerto Rico: Coupling oxidation, dissolution, and fracturing. GeochimCosmochimActa 72: 4488-4507. DOI: http://dx.doi.org/10.1016/j.gca.2008.06.020

[38] Humphreys GS, Wilkinson MT (2007) The Soil Production Function: A brief history and Its Rediscovery. Geoderma. 139:73-78 URL: http://dx.doi.org/10.1016/j.geoderma.2007.01.004

[39] ArachchiLPV,Liyanage MS (1996) Role of Gliricidiasepiumon Physical Improvement of Gravelly Soil. Cocos 11: 40-52 URL: file:///C:/Users/Rajgopal/Downloads/2157-7686-1-PB%20(8).pdf

[40] Luo T, Brown S, Pan Y, Shib P, Ouymg H, yub Z, Zhub H (2005) Root biomass along subtropical to alpine gradients: global implication from Tibetan transect studies. Forest Ecology &Manageme. 206: 349-363 URL: http://dx.doi.org/10.1016/j.foreco.2004.11.016

[41] Xiaoyan L, Ruiling Z, Jiadong G, Zhongkui X (2012) Soil and Water Accumulation by Gravel and Sand Mulches in Western Loess Plateau of Northwest. In: 12th International Soil Conservation Organization Conference, Beijing, China.

[42] Hallsworth EG (1963) An examination of some factors affecting the movement of clay in an artificial soil. European journal of Soil Science 14(2):360-371 DOI: 10.1111/j.1365-2389.1963.tb00959.x

[43] Adugna A, Abegaz A (2015) Effects of soil depth on the dynamics of selected soil properties among the highlands resources of Northeast

Wollega, Ethiopia: are these sign of degradation?. Solid Earth Discuss 7: 2011–2035. DOI:10.5194/sed-7-2011-2015

[44] Rucknagel J, Gotze P, Hofmann B, Christen O, Marschall K (2013) The influence of soil gravel content on compaction behaviour and pre-compression stress. Geoderma 209-210: 226-232. URL:http://dx.doi.org/10.1016/j.geoderma.2013.05.030

[45] De Baets S, Meersmans J, Vanacker V, Quine TA, Oost KV (2013) Spatial variability and change in soil organic carbon stocks in response to recovery following land abandonment and erosion in mountainous drylands. Soil Use & Manage 29: 65-76. DOI:10.1111/sum.12017

[46] Leifeld J, Bassin S, Fuhrer J (2005) Carbon stocks in Swiss agricultural soils predicted by land-use soil characteristics, and altitude. Agri, Ecosys& Environ 105: 255–266. DOI: http://dx.doi.org/10.1016/j.agee.2004.03.006

[47] Qin Y, Yi S, Jianjun C, Ding Y (2014) Effects of gravel on soil and vegetation properties of alpine grassland on the Qinghai-Tibetan Plateau. Ecological Engine 74:351-355 URL:http://dx.doi.org/10.1016/j.ecoleng.2014.10.008

[48] Wang X, Liu G, Liu S (2011) Effects of gravel on grassland soil carbon and nitrogen in the raid region of Tibetan Plateau. Soil Sci Society of American J 76: 1280-1289.DOI: org/10.1016/j.geoderma.2011.07.028

[49] Sekiya N, Abe J, Shiotsu F, Morita S (2014) Cultivation of Erianthus and Napier grass at an Abandoned Mine in Lampung, Indonesia. American J Plant Sci 5:1711-1720. URL:http://dx.doi.org/10.4236/ajps.2014.511186

[50] Jobbagy EG, Jackson RB (2003) Patterns and mechanisms of soil acidification in the conversion of grasslands to forests. Biogeochem 64: 205–229 DOI: 10.1023/A:1024985629259.

[51] Parfitt RL, Giltrap DJ, Whitton JS (1995) Contribution of organic matter and clay minerals to the cation exchange capacity of soils. Communications in Soil Science and Plant Analysis 26: 9-10.http://dx.doi.org/10.1080/00103629509369376

Appendix-I: Soil Properties of Black Soils

A) Surface layer (0-15 cm)

Field No	Repl	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
B1	1	8.12	0.21	0.60	12.25	21.10	66.65	7.70	161.45	148.50	9.02
	2	8.00	0.26	0.61	14.48	20.32	65.20	7.97	168.00	147.56	9.32
	3	8.11	0.18	0.66	11.53	19.26	69.21	8.34	173.70	157.32	9.82
	4	8.25	0.29	0.66	13.68	18.22	68.10	8.30	174.30	157.27	8.52
B2	1	7.78	0.23	0.56	9.25	18.65	72.10	7.35	166.40	147.50	8.82
	2	8.21	0.19	0.60	14.94	16.56	68.50	7.91	165.00	149.00	10.62
	3	8.16	0.30	0.58	8.30	18.25	73.45	7.51	170.20	146.20	9.72
	4	8.21	0.26	0.62	12.63	20.25	67.12	8.22	165.00	151.30	8.92
B3	1	8.11	0.13	0.62	9.58	18.12	72.30	8.19	156.70	152.21	9.62
	2	8.26	0.26	0.60	7.54	19.25	73.21	7.88	164.50	147.36	8.92
	3	8.31	0.22	0.63	7.00	20.80	72.20	8.20	160.30	150.24	11.82
	4	8.20	0.24	0.59	8.54	21.21	70.25	7.45	160.60	145.60	9.02
B4	1	8.19	0.23	0.55	10.27	16.52	73.21	7.02	164.30	150.25	10.12
	2	8.00	0.21	0.58	6.67	21.21	72.12	7.46	163.61	146.00	9.82
	3	7.85	0.24	0.56	9.27	20.21	70.52	7.00	157.20	147.30	9.02
	4	8.16	0.23	0.60	6.72	18.96	74.32	7.89	165.60	147.54	10.62
C1	1	8.40	0.21	0.62	11.05	23.30	65.65	8.22	171.20	150.10	9.92
	2	8.29	0.25	0.56	11.26	20.12	68.62	7.04	155.40	146.20	9.42
	3	8.21	0.24	0.58	11.78	19.12	69.10	7.60	161.30	145.80	11.02
	4	8.16	0.26	0.60	13.78	17.12	69.10	7.67	164.30	147.36	13.12
C2	1	8.14	0.27	0.58	15.18	20.30	64.52	7.44	170.20	146.70	9.52
	2	8.16	0.20	0.53	14.16	18.52	67.32	6.76	155.40	143.56	9.02
	3	8.21	0.23	0.55	11.78	19.10	69.12	7.02	165.40	145.60	8.94
	4	8.18	0.22	0.57	15.85	17.63	66.52	7.34	160.30	145.30	9.34
C3	1	8.24	0.21	0.67	11.18	21.10	67.72	8.51	166.30	159.20	9.84
	2	8.26	0.26	0.63	10.68	20.20	69.12	8.21	155.40	152.25	9.52
	3	8.31	0.27	0.65	12.88	17.12	70.00	8.31	150.20	153.62	11.92
	4	8.20	0.24	0.64	15.96	17.52	66.52	8.31	154.20	153.21	11.02

Field No	Repl	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
C4	1	8.35	0.23	0.66	7.04	23.60	69.36	7.80	165.40	154.52	10.82
	2	8.28	0.25	0.64	8.58	20.21	71.21	8.26	162.20	152.62	10.04
	3	8.33	0.28	0.65	11.52	22.22	66.26	8.44	160.20	154.50	9.03
	4	8.24	0.31	0.63	10.78	21.12	68.10	8.10	156.50	164.34	11.73
C5	1	8.32	0.20	0.58	16.45	18.30	65.25	7.56	165.50	144.30	9.72
	2	8.40	0.21	0.60	13.27	18.52	68.21	7.77	167.70	148.00	9.74
	3	8.21	0.23	0.59	12.23	21.21	66.56	7.65	173.20	145.90	9.52
	4	8.30	0.25	0.61	11.88	19.00	69.12	8.03	174.20	150.25	9.93
C6	1	8.37	0.20	0.68	8.39	20.40	71.21	8.71	165.50	160.10	10.73
	2	8.21	0.22	0.66	11.76	18.24	70.00	8.46	159.20	156.63	11.08
	3	8.16	0.24	0.67	10.70	19.10	70.20	8.47	155.60	159.00	10.64
	4	8.30	0.25	0.65	12.08	18.32	69.60	8.43	148.20	154.25	9.52
C7	1	8.21	0.23	0.62	9.12	19.63	71.25	6.63	152.21	152.30	11.73
	2	8.00	0.24	0.60	11.85	15.65	72.50	7.83	146.50	147.52	11.08
	3	8.12	0.26	0.59	8.70	18.18	73.12	7.55	135.60	146.30	10.73
	4	8.06	0.27	0.61	10.44	16.56	73.00	8.00	148.70	149.20	10.63
C8	1	8.21	0.22	0.65	12.25	22.10	65.65	8.40	161.30	154.00	12.64
	2	8.10	0.27	0.62	18.50	15.00	66.50	8.21	158.23	150.26	11.64
	3	8.05	0.28	0.64	11.65	17.25	71.10	8.16	152.00	153.20	11.84
	4	8.08	0.30	0.63	14.10	15.65	70.25	8.19	146.70	151.20	11.93
C9	1	7.94	0.25	0.68	7.80	21.10	71.10	8.67	155.60	160.32	12.14
	2	8.05	0.26	0.63	19.40	13.10	67.50	8.18	145.50	153.21	11.83
	3	8.08	0.28	0.60	15.59	15.56	68.85	7.64	138.50	147.30	11.10
	4	8.21	0.29	0.66	19.44	14.00	66.56	8.54	140.20	155.25	12.26
C10	1	8.32	0.24	0.66	11.90	18.50	69.60	8.51	143.40	155.60	12.62
	2	8.40	0.22	0.58	9.90	20.00	70.10	7.34	140.30	146.30	11.13
	3	8.44	0.24	0.63	16.77	16.60	66.63	7.74	150.20	150.52	11.54
	4	8.36	0.23	0.60	14.59	17.20	68.21	7.31	145.60	147.20	11.32

B) Sub-surface layer (15-30 cm)

Field No	Repl	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
B1	1	8.26	0.15	0.57	9.68	23.12	67.20	145.62	7.00	145.3	8.51
	2	8.30	0.28	0.59	11.58	22.22	66.20	138.52	7.60	143.2	7.65
	3	8.18	0.26	0.62	10.67	20.12	69.21	142.10	8.24	146.2	8.00
	4	8.26	0.31	0.63	10.69	19.10	70.21	154.20	8.00	148.1	7.01
B2	1	7.96	0.24	0.53	4.28	21.12	74.60	144.52	7.19	143.3	8.00
	2	8.30	0.23	0.57	13.77	17.12	69.11	148.20	7.34	144.2	9.21
	3	8.24	0.24	0.57	6.77	20.23	73.00	144.10	7.28	140.1	8.56
	4	8.29	0.28	0.60	9.88	22.10	68.02	146.20	8.00	146.2	7.68
B3	1	8.16	0.20	0.70	7.55	19.89	72.56	152.10	8.10	150.1	7.63
	2	8.20	0.26	0.58	6.52	20.48	73.00	160.10	7.78	144.3	8.00
	3	8.32	0.25	0.60	6.20	21.70	72.10	156.65	7.98	146.2	9.62
	4	8.22	0.26	0.57	6.38	22.77	70.85	154.24	7.28	141.6	7.53
B4	1	8.26	0.20	0.54	7.96	17.52	74.52	161.20	6.96	148.4	8.62
	2	8.20	0.23	0.56	6.60	21.84	71.56	159.21	7.16	144.1	7.86
	3	8.31	0.26	0.54	8.14	20.62	71.24	154.21	6.92	146.4	7.92
	4	8.22	0.25	0.58	7.75	19.00	73.25	160.21	7.56	144.5	8.23
C1	1	8.51	0.23	0.60	7.15	24.60	68.25	168.32	8.06	149.5	8.84
	2	8.30	0.26	0.54	8.68	22.32	69.00	152.10	6.96	145.3	8.20
	3	8.29	0.24	0.56	9.68	20.12	70.20	156.20	7.41	144.6	9.26
	4	8.40	0.28	0.58	8.68	20.12	71.20	160.10	7.52	146.5	12.12
C2	1	8.21	0.27	0.55	12.48	21.20	66.32	165.56	7.00	143.2	8.56
	2	8.20	0.25	0.50	11.80	19.10	69.10	151.10	6.56	138.1	8.00
	3	8.26	0.24	0.52	8.69	20.10	71.21	162.10	6.82	143.6	8.42
	4	8.30	0.24	0.55	11.20	19.60	69.20	158.10	7.10	142.1	9.00
C3	1	8.37	0.24	0.65	12.48	23.00	64.52	164.21	8.11	154.2	8.32
	2	8.30	0.27	0.61	7.78	21.12	71.10	152.10	8.02	146.6	9.00
	3	8.36	0.28	0.63	8.17	19.62	72.21	148.20	8.10	151.5	10.56
	4	8.22	0.26	0.62	14.70	18.10	67.20	150.00	8.05	148.2	10.23

Field No	Repl	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
C4	1	8.40	0.25	0.64	7.49	24.30	68.21	150.25	7.65	150.2	10.20
	2	8.30	0.21	0.62	6.70	20.20	73.10	148.36	8.00	146.5	8.65
	3	8.33	0.24	0.63	8.10	21.00	70.90	149.20	8.21	147.2	8.52
	4	8.30	0.33	0.62	7.54	21.25	71.21	160.21	8.00	160.3	10.62
C5	1	8.40	0.23	0.57	13.95	19.70	66.35	161.21	7.21	138.2	8.56
	2	8.42	0.23	0.59	13.00	19.00	68.00	160.86	7.56	140.1	8.21
	3	8.30	0.25	0.58	8.70	23.20	68.10	140.25	7.60	137.2	8.32
	4	8.36	0.27	0.60	9.69	19.21	71.10	146.32	7.92	142.1	8.86
C6	1	8.42	0.21	0.67	9.24	21.20	69.56	154.25	8.53	158.1	9.56
	2	8.20	0.23	0.65	8.80	19.10	72.10	150.10	8.10	154.8	10.21
	3	8.30	0.26	0.66	6.80	21.10	72.10	156.62	8.00	157.6	10.34
	4	8.33	0.28	0.64	11.07	18.68	70.25	149.32	8.11	153.5	9.12
C7	1	8.30	0.24	0.60	7.45	20.30	72.25	148.56	6.50	150.6	9.62
	2	8.21	0.26	0.59	9.21	18.12	72.67	141.23	7.51	144.9	10.11
	3	8.20	0.27	0.58	6.56	19.44	74.00	140.52	7.02	145.6	9.62
	4	8.12	0.29	0.60	9.90	17.00	73.10	141.12	7.62	148.5	9.10
C8	1	8.37	0.23	0.63	11.03	23.00	65.97	150.26	8.10	152.1	9.89
	2	8.16	0.25	0.60	16.24	16.56	67.20	146.62	8.02	148.6	10.21
	3	8.20	0.29	0.61	8.51	18.28	73.21	151.20	8.00	151.5	9.56
	4	8.12	0.27	0.60	10.80	16.00	73.20	146.00	8.05	148.6	9.89
C9	1	8.00	0.26	0.66	6.19	23.60	70.21	156.25	8.21	157.3	10.21
	2	8.12	0.27	0.61	16.60	15.20	68.20	151.10	8.00	151.6	10.56
	3	8.18	0.29	0.58	14.66	16.10	69.24	144.63	7.56	144.6	9.96
	4	8.26	0.31	0.65	16.60	15.20	68.20	151.20	8.39	154.3	11.21
C10	1	8.40	0.27	0.64	11.38	19.62	69.00	150.62	8.36	153.2	11.00
	2	8.48	0.28	0.56	9.68	21.10	69.22	144.82	7.21	140.1	10.65
	3	8.46	0.26	0.59	13.20	17.48	69.32	158.21	7.56	146.6	10.30
	4	8.42	0.25	0.57	14.69	18.20	67.11	150.50	7.10	144.7	10.00

Appendix-II: Soil Properties of Native Soils

A) Surface layer (0-15 cm)

Field No	Repl	<2 mm (%)	>2 mm (%)	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
B5	1	24.5	75.5	7.07	0.135	0.30	81.18	11.20	7.62	1.76	78.48	85.45	5.65
	2	23.9	76.1	6.77	0.12	0.36	81.78	10.12	8.10	1.97	79.46	91.21	7.00
	3	25	75.0	7.07	0.11	0.32	84.18	9.32	6.50	1.50	74.00	88.34	6.50
	4	23.1	76.9	7.25	0.132	0.29	82.70	10.10	7.20	1.54	77.40	90.40	6.20
B6	1	25.1	74.9	6.97	0.169	0.25	79.34	12.30	8.36	2.10	61.85	79.82	7.62
	2	24.5	75.5	7.12	0.2	0.22	81.28	11.60	7.12	1.41	75.68	78.35	8.21
	3	26	74.0	7.25	0.16	0.24	78.76	12.62	8.62	2.07	65.56	79.93	7.32
	4	21.9	78.1	7.35	0.14	0.26	81.68	10.32	8.00	1.83	66.76	79.42	7.00
B7	1	23.1	76.9	6.90	0.186	0.30	79.67	13.12	7.21	1.53	58.98	77.82	8.16
	2	21.7	78.3	7.16	0.19	0.29	82.10	11.10	6.80	1.43	62.10	74.82	7.54
	3	24.7	75.3	7.46	0.14	0.27	83.55	10.25	6.20	1.63	60.10	72.32	7.00
	4	20.95	79.1	7.57	0.16	0.31	84.86	9.32	5.82	1.52	65.79	66.21	6.12
B8	1	24.7	75.3	7.06	0.118	0.32	83.83	9.85	6.32	1.48	87.81	73.36	7.32
	2	23.5	76.5	7.37	0.13	0.29	84.04	10.10	5.86	1.45	83.21	67.87	7.02
	3	20.5	79.5	7.51	0.15	0.30	84.45	10.25	5.30	1.40	84.21	64.54	6.52
	4	21.48	78.5	7.57	0.18	0.31	84.25	9.65	6.10	1.34	88.32	71.23	7.12
D1	1	27.15	72.9	6.73	0.11	0.34	78.17	13.21	8.62	1.97	68.20	79.95	7.82
	2	28.5	71.5	7.21	0.15	0.32	82.18	10.62	7.20	1.62	65.30	77.26	6.86
	3	27.7	72.3	6.97	0.13	0.30	83.40	9.00	7.60	1.72	63.10	78.60	7.00
	4	24.5	75.5	7.17	0.12	0.31	82.90	9.10	8.00	1.79	60.44	79.54	7.32
D2	1	27.8	72.2	7.06	0.14	0.33	82.10	10.25	7.65	1.60	67.70	86.54	7.44
	2	26.9	73.1	7.37	0.13	0.32	80.50	12.50	7.00	1.52	60.23	89.90	7.12
	3	25.8	74.2	7.55	0.12	0.29	80.00	13.10	6.90	1.60	64.20	93.20	6.56
	4	29.1	70.9	7.46	0.11	0.31	80.00	12.00	8.00	1.84	65.50	90.20	8.10
D3	1	35.8	64.2	6.70	0.17	0.34	78.56	12.32	9.12	2.43	73.20	80.62	8.14
	2	33.7	66.3	7.25	0.18	0.32	81.20	10.60	8.20	1.96	75.60	79.60	7.62
	3	31.71	68.3	7.37	0.19	0.35	81.38	11.00	7.62	1.76	71.20	78.52	6.56
	4	30.6	69.4	7.27	0.16	0.36	81.08	10.82	8.10	1.97	69.30	79.50	7.52

Field No	Repl	<2 mm (%)	>2 mm (%)	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
D4	1	22.84	77.2	6.79	0.13	0.24	79.67	13.21	7.12	1.65	63.40	77.00	6.84
	2	24.7	75.3	7.56	0.15	0.26	82.30	11.10	6.60	1.46	66.40	74.50	6.30
	3	23.95	76.1	7.21	0.14	0.29	82.00	12.00	6.00	1.40	60.43	69.87	6.32
	4	24.82	75.2	7.35	0.16	0.28	83.80	9.00	7.20	1.54	62.15	77.12	6.92
D5	1	25.1	74.9	6.87	0.12	0.33	82.59	9.89	7.52	1.78	59.76	78.40	7.82
	2	25.3	74.7	7.37	0.13	0.32	83.95	9.05	7.00	1.52	62.12	74.78	7.00
	3	26	74.0	7.27	0.15	0.32	85.19	8.21	6.60	1.44	65.40	74.70	6.36
	4	23.1	76.9	7.56	0.17	0.33	85.68	7.32	7.00	1.56	64.00	76.46	6.86
D6	1	24.7	75.3	6.86	0.11	0.30	75.74	14.24	10.02	2.65	72.30	81.44	8.56
	2	23.62	76.4	7.43	0.14	0.31	80.68	11.20	8.12	1.88	68.98	79.52	8.02
	3	21.5	78.5	7.10	0.13	0.29	82.79	9.65	7.56	1.80	74.30	78.28	7.66
	4	20.84	79.2	7.46	0.12	0.30	84.79	8.21	7.00	1.61	70.40	76.50	7.12
D7	1	23.82	76.2	6.93	0.11	0.30	80.87	10.21	8.92	1.99	56.65	80.00	8.12
	2	25.82	74.2	7.46	0.16	0.32	79.56	10.82	9.62	2.61	61.20	80.70	8.92
	3	22.9	77.1	7.37	0.17	0.33	80.80	11.20	8.00	1.80	52.00	79.70	7.98
	4	24	76.0	7.56	0.14	0.35	79.48	11.00	9.52	2.48	51.20	80.46	8.66
D8	1	20.4	79.6	7.00	0.12	0.31	79.96	11.12	8.92	1.99	56.76	79.96	8.36
	2	23.73	76.3	7.57	0.19	0.33	79.38	12.12	8.50	2.00	59.40	79.90	8.12
	3	22.1	77.9	7.55	0.21	0.29	79.80	11.20	9.00	2.25	60.20	80.26	8.36
	4	20.6	79.4	7.66	0.23	0.31	82.38	10.62	7.00	1.48	61.30	75.89	7.65
D9	1	23.62	76.4	7.01	0.129	0.34	81.82	10.26	7.92	1.62	60.23	79.10	7.86
	2	22.04	78.0	7.70	0.13	0.31	82.38	10.00	7.62	1.60	56.40	78.62	7.54
	3	24.84	75.2	7.51	0.14	0.30	81.26	11.62	7.12	1.57	51.20	76.84	7.71
	4	25.6	74.4	7.71	0.16	0.33	81.66	11.32	7.02	1.60	50.34	75.21	7.62
E3	1	29.9	70.1	6.95	0.149	0.33	83.02	8.96	8.02	1.90	76.70	79.42	8.12
	2	29.04	71.0	7.61	0.12	0.36	80.14	10.26	9.60	2.56	80.21	80.60	8.62
	3	26.93	73.1	7.49	0.13	0.33	80.40	11.10	8.50	1.90	83.43	76.52	8.32
	4	30	70.0	7.87	0.15	0.38	82.68	9.52	7.80	1.76	79.60	73.21	7.72
E4	1	24.93	75.1	6.72	0.15	0.33	82.58	9.21	8.21	2.02	67.60	79.72	7.92
	2	24.15	75.9	7.66	0.16	0.36	82.88	8.32	8.80	2.17	71.20	79.92	8.36
	3	25.15	74.9	7.66	0.15	0.35	82.80	9.60	7.60	1.84	70.30	78.50	7.46
	4	25.84	74.2	7.71	0.14	0.34	82.98	10.00	7.02	1.60	63.20	76.23	7.05

Field No	Repl	<2 mm (%)	>2 mm (%)	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
E5	1	26	74.0	6.85	0.168	0.35	81.32	10.12	8.56	1.88	69.70	79.92	8.00
	2	26.6	73.4	7.85	0.172	0.34	79.69	11.21	9.10	2.46	73.40	80.35	8.32
	3	26	74.0	7.77	0.162	0.36	81.50	10.50	8.00	1.80	76.40	75.25	7.62
	4	27.1	72.9	7.77	0.17	0.37	81.06	11.62	7.32	1.64	68.90	78.00	7.12
E6	1	24.7	75.3	6.82	0.181	0.42	80.67	12.12	7.21	1.50	64.30	77.50	7.02
	2	21.6	78.4	7.51	0.19	0.39	86.20	7.00	6.80	1.30	60.32	72.50	6.51
	3	21.28	78.7	7.60	0.2	0.40	85.88	8.12	6.00	1.46	64.50	68.20	6.02
	4	24.7	75.3	7.65	0.18	0.38	85.95	8.00	6.05	1.52	59.00	66.00	6.00
E7	1	25.8	74.2	6.80	0.174	0.33	80.79	11.21	8.00	1.84	75.46	79.86	7.54
	2	27.15	72.9	7.37	0.134	0.31	83.58	9.10	7.32	1.64	70.20	78.00	7.12
	3	28.62	71.4	7.37	0.15	0.29	84.38	9.32	6.30	2.30	73.23	73.43	6.86
	4	27.8	72.2	7.37	0.16	0.30	82.78	9.00	8.22	2.10	68.60	79.80	8.20

B) Sub-surface layer (15-30 cm)

Field No	Repl	<2 mm (%)	>2 mm (%)	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
B5	1	23.6	76.4	7.17	0.14	0.33	82.93	10.45	6.62	76.54	1.66	80.2	4.65
	2	23.1	76.9	6.87	0.13	0.32	83.39	9.61	7.00	74.52	1.850	86.8	6.21
	3	23.8	76.2	7.15	0.12	0.30	85.05	8.95	6.00	71.21	1.460	84.2	6.00
	4	22.0	78.0	7.30	0.14	0.28	83.93	9.65	6.42	75.21	1.500	88.8	5.86
B6	1	23.9	76.1	7.08	0.18	0.21	81.13	11.21	7.66	59.62	2.000	77.1	6.96
	2	23.5	76.5	7.30	0.15	0.27	81.35	10.65	8.00	72.21	1.310	74.5	7.12
	3	24.6	75.4	7.61	0.17	0.24	81.67	11.21	7.12	60.21	2.000	75.5	6.90
	4	21.5	78.5	7.50	0.15	0.26	82.98	10.00	7.02	66.00	1.720	78.1	6.62
B7	1	21.6	78.4	6.98	0.19	0.28	81.04	12.12	6.84	56.26	1.460	76.3	7.54
	2	21.5	78.5	7.25	0.21	0.27	84.23	10.56	5.21	60.00	1.400	73.3	7.00
	3	23.6	76.4	7.66	0.15	0.26	83.00	11.00	6.00	58.21	1.560	69.6	6.45
	4	20.5	79.5	7.81	0.17	0.29	85.15	9.85	5.00	63.21	1.460	64.2	5.86
B8	1	23.0	77.0	7.11	0.12	0.31	87.23	7.61	5.16	85.16	1.390	71.7	7.00
	2	22.7	77.3	7.47	0.15	0.27	86.08	8.92	5.00	80.12	1.400	65.6	6.56
	3	20.1	79.9	7.61	0.17	0.30	86.40	9.00	4.60	82.12	1.320	60.6	6.12
	4	21.0	79.0	7.65	0.19	0.28	86.35	8.65	5.00	86.54	1.300	69.3	6.80

Field No	Repl	<2 mm (%)	>2 mm (%)	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
D1	1	25.5	74.5	6.90	0.14	0.30	81.26	11.62	7.12	66.23	1.900	74.3	7.00
	2	27.1	72.9	6.97	0.17	0.31	84.40	9.10	6.50	61.24	1.520	71.6	6.21
	3	25.6	74.4	7.16	0.16	0.30	84.70	8.30	7.00	60.52	1.650	72.5	6.12
	4	24.0	76.0	7.27	0.13	0.29	84.72	7.68	7.60	59.21	1.700	77.9	6.56
D2	1	24.9	75.1	7.15	0.16	0.30	83.42	9.56	7.02	64.35	1.500	83.2	7.00
	2	25.5	74.5	7.43	0.15	0.30	82.60	11.10	6.30	58.12	1.520	85.6	6.56
	3	24.6	75.4	7.61	0.15	0.28	81.90	12.10	6.00	61.21	1.510	90.0	6.25
	4	28.0	72.0	7.66	0.13	0.30	81.34	11.66	7.00	60.21	1.710	87.6	7.54
D3	1	28.7	71.3	6.78	0.18	0.31	81.29	10.12	8.59	70.10	2.120	79.1	7.60
	2	31.0	69.1	7.37	0.19	0.30	83.58	9.10	7.32	72.12	1.820	78.0	7.43
	3	29.7	70.3	7.46	0.17	0.33	83.70	9.30	7.00	69.34	1.700	77.6	6.00
	4	26.0	74.0	7.57	0.19	0.34	83.58	9.21	7.21	66.58	1.900	78.1	6.96
D4	1	22.5	77.5	6.85	0.14	0.28	81.78	11.21	7.01	60.12	1.600	75.2	6.32
	2	24.2	75.9	7.66	0.16	0.25	83.80	10.20	6.00	64.31	1.360	71.4	6.00
	3	23.4	76.6	7.27	0.14	0.27	83.60	11.10	5.30	58.21	1.350	66.2	5.86
	4	24.5	75.5	7.47	0.17	0.27	85.26	8.12	6.62	60.10	1.500	75.6	6.00
D5	1	24.0	76.1	6.95	0.13	0.30	84.86	8.12	7.02	56.62	1.680	76.3	7.02
	2	23.8	76.2	7.45	0.15	0.27	86.70	7.10	6.20	60.12	1.460	71.5	6.25
	3	23.6	76.4	7.35	0.17	0.26	86.38	8.00	5.62	64.21	1.340	71.2	6.00
	4	22.8	77.2	7.66	0.19	0.27	86.90	7.00	6.10	63.12	1.500	75.6	6.35
D6	1	21.5	78.5	6.87	0.13	0.29	78.00	12.35	9.65	70.52	2.510	78.9	8.00
	2	23.1	76.9	7.51	0.15	0.30	81.90	11.00	7.10	67.38	1.780	77.7	7.46
	3	20.4	79.6	7.30	0.17	0.27	84.18	9.00	6.82	71.21	1.720	76.5	7.26
	4	21.3	78.7	7.47	0.14	0.28	85.88	8.02	6.10	68.25	1.560	73.2	6.92
D7	1	21.7	78.3	6.97	0.15	0.29	83.52	9.32	7.16	54.25	1.890	78.9	6.26
	2	22.5	77.5	7.66	0.18	0.32	82.44	9.00	8.56	60.12	2.510	76.5	7.00
	3	21.1	78.9	7.47	0.20	0.31	82.80	10.20	7.00	51.11	1.700	76.0	5.80
	4	22.0	78.1	7.54	0.13	0.34	82.08	9.62	8.30	50.62	2.380	78.1	6.86
D8	1	21.3	78.7	7.05	0.13	0.30	83.36	9.62	7.02	55.74	1.790	77.5	7.92
	2	21.7	78.3	7.66	0.18	0.32	83.00	9.00	8.00	59.00	1.920	76.0	7.65
	3	20.6	79.4	7.66	0.20	0.28	81.49	10.65	7.86	58.21	2.200	77.9	8.00
	4	19.5	80.5	8.00	0.22	0.30	83.98	9.36	6.66	60.21	1.360	73.2	7.21

Field No	Repl	<2 mm (%)	>2 mm (%)	pH (1:2 ratio)	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	P (kg ha^{-1})	N (kg ha^{-1})	K (kg ha^{-1})	S (mg ha^{-1})
D9	1	21.6	78.4	6.79	0.14	0.33	83.83	9.65	6.52	58.56	1.520	77.8	7.00
	2	20.8	79.2	7.75	0.15	0.28	84.02	8.96	7.02	55.65	1.550	76.4	6.92
	3	22.7	77.3	7.56	0.14	0.29	81.78	11.20	7.02	50.02	1.500	75.3	7.00
	4	23.7	76.3	7.77	0.17	0.30	82.59	10.85	6.56	49.65	1.460	73.1	6.76
E3	1	25.8	74.2	7.04	0.18	0.32	84.44	8.00	7.56	73.21	1.810	77.2	7.82
	2	24.7	75.3	7.69	0.14	0.33	81.38	9.62	9.00	78.52	2.420	78.3	8.12
	3	26.1	73.9	7.61	0.12	0.35	82.38	9.62	8.00	80.51	1.850	74.5	8.21
	4	28.6	71.4	8.05	0.18	0.36	83.78	9.00	7.22	76.21	1.700	71.0	7.35
E4	1	23.8	76.2	6.75	0.17	0.30	83.88	9.12	7.00	64.24	1.910	75.6	7.21
	2	22.7	77.3	7.81	0.18	0.33	84.00	8.00	8.00	70.05	2.120	74.5	8.00
	3	21.7	78.3	7.61	0.17	0.30	84.38	8.62	7.00	68.56	1.760	73.5	7.00
	4	24.7	75.3	7.95	0.15	0.32	83.88	9.21	6.91	60.52	1.520	71.1	6.86
E5	1	24.5	75.5	6.97	0.17	0.34	83.87	9.21	6.92	66.71	1.680	75.6	7.56
	2	24.5	75.5	7.99	0.18	0.34	80.90	10.10	9.00	72.00	2.250	78.1	8.00
	3	23.6	76.4	7.71	0.18	0.35	82.50	9.65	7.85	74.42	1.710	71.5	7.10
	4	22.5	77.5	7.87	0.18	0.36	82.77	10.21	7.02	64.52	1.580	74.5	6.92
E6	1	23.5	76.5	6.99	0.19	0.40	82.79	10.21	7.00	61.21	1.400	73.5	6.80
	2	20.8	79.2	7.60	0.18	0.37	87.48	6.52	6.00	59.62	1.220	70.5	6.00
	3	20.7	79.3	7.65	0.21	0.38	87.06	7.12	5.82	61.24	1.320	64.4	5.86
	4	22.5	77.5	7.57	0.20	0.37	86.86	7.02	6.12	57.24	1.500	63.1	5.65
E7	1	23.8	76.2	7.00	0.20	0.27	83.11	9.68	7.21	73.21	1.780	74.5	6.45
	2	24.7	75.3	7.57	0.14	0.29	84.38	8.62	7.00	68.52	1.540	75.3	6.20
	3	22.7	77.3	7.49	0.20	0.27	85.00	9.00	6.00	71.10	2.250	70.1	6.00
	4	23.8	76.2	7.46	0.18	0.29	84.12	8.26	7.62	65.60	2.010	76.3	7.76

Appendix-III: Micro Nutrient Content (ppm) in the Black Soil Fields of NIASM Farm Land

S. No.	Depth (cm)	Fe	Mn	Zn	Cu	B
B1	0-15	1.16	4.95	0.26	0.41	0.25
	15-30	1.20	4.35	0.55	0.50	0.29
B2	0-15	1.42	2.79	0.27	0.79	0.30
	15-30	1.25	2.54	0.21	0.65	0.33
B3	0-15	1.17	2.16	0.21	0.63	0.16
	15-30	0.98	2.35	0.24	0.62	0.17
B4	0-15	1.17	3.00	0.16	0.50	0.21
	15-30	1.09	2.50	0.19	0.42	0.23
C1	0-15	1.07	3.89	0.13	0.38	0.22
	15-30	0.94	3.69	0.09	0.35	0.12
C2	0-15	0.97	1.67	0.54	0.34	0.21
	15-30	1.14	2.00	0.69	0.40	0.13
C3	0-15	0.84	1.56	0.11	0.43	0.13
	15-30	0.67	1.20	0.08	0.31	0.12
C4	0-15	1.17	1.42	0.14	0.46	0.13
	15-30	0.90	1.19	0.09	0.31	0.19
C5	0-15	0.63	0.84	0.11	0.26	0.19
	15-30	1.12	1.44	0.15	0.45	0.17
C6	0-15	1.04	1.30	0.20	0.43	0.13
	15-30	1.11	2.40	0.13	0.48	0.12
C7	0-15	1.07	1.21	0.16	0.39	0.11
	15-30	1.11	1.24	0.16	0.41	0.21
C8	0-15	1.28	2.47	0.14	0.58	0.18
	15-30	1.15	1.47	0.12	0.52	0.14
C9	0-15	0.93	2.14	0.22	0.48	0.12
	15-30	0.99	2.40	0.24	0.43	0.21
C10	0-15	1.29	1.24	0.09	0.47	0.25
	15-30	1.09	1.18	0.08	0.38	0.23

Appendix-IV: Micro Nutrient Status (ppm) of Native Farm Land Fields

S.No.	Depth (cm)	Fe	Mn	Zn	Cu	B
B5	0-15	0.95	1.94	0.19	0.13	0.10
	15-30	0.82	1.60	0.17	0.14	0.10
B6	0-15	1.06	2.13	0.33	0.16	0.12
	15-30	1.23	2.20	0.32	0.19	0.10
B7	0-15	1.01	1.27	0.29	0.12	0.09
	15-30	1.01	1.20	0.28	0.12	0.08
B8	0-15	1.14	2.12	0.30	0.17	0.02
	15-30	1.37	2.50	0.40	0.20	0.03
D1	0-15	0.65	2.35	0.10	0.35	0.10
	15-30	0.56	1.52	0.14	0.32	0.09
D2	0-15	0.61	1.63	0.12	0.31	0.12
	15-30	0.54	1.60	0.10	0.26	0.11
D3	0-15	0.66	1.47	0.12	0.26	0.09
	15-30	0.64	1.42	0.11	0.25	0.08
D4	0-15	0.87	1.53	0.37	0.41	0.10
	15-30	0.96	1.99	0.35	0.42	0.09
D5	0-15	1.40	2.77	0.24	0.84	0.07
	15-30	0.23	1.61	0.18	0.05	0.09
D6	0-15	0.48	2.84	0.31	0.14	0.10
	15-30	0.39	2.22	0.32	0.11	0.10
D7	0-15	0.36	2.05	0.30	0.11	0.09
	15-30	0.38	2.03	0.30	0.11	0.08
D8	0-15	0.26	1.96	0.28	0.12	0.10
	15-30	0.28	2.20	0.26	0.13	0.12
D9	0-15	0.31	2.00	0.25	0.10	0.10
	15-30	0.30	1.90	0.21	0.15	0.09
E3	0-15	0.49	2.71	0.38	0.15	0.09
	15-30	0.35	1.96	0.61	0.17	0.07
E4	0-15	0.34	1.98	0.30	0.10	0.06
	15-30	0.00	0.02	0.06	0.02	0.07
E5	0-15	0.00	0.11	0.07	0.02	0.09
	15-30	0.00	0.10	0.06	0.02	0.10
E5	0-15	0.01	0.12	0.06	0.02	0.07
	15-30	0.01	0.15	0.06	0.02	0.09
E7	0-15	0.00	0.06	0.08	0.02	0.09
	15-30	0.00	0.19	0.06	0.02	0.10

Appendix-V: Calculation of Carbon Stocks for Intervention of Fodder Crops on the Gravelly Barren Land

Treatments	< 2mm (%)		BD (Mg m^{-3})		SOC of < 2mm particles (g kg^{-1})		SOC (kg ha^{-1})	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Native fallow land	24.82	21.21	1.59	1.65	2.28	2.12	5437.8	5247
Marvel grass	28.85	27.65	1.53	1.64	2.28	2.16	5232.6	5313.6
Stylo	36.07	30.01	1.55	1.62	2.6	2.4	6045	5832
Stylo-marvel grass	38.03	23.81	1.48	1.52	2.68	2.52	5949.6	5745.6
Napier grass	43.39	34.06	1.35	1.37	3.4	3.28	6885	6740.4

Treatments	SOC carbon for inclusion of gravels content (kg ha^{-1})		SOC over three years period (kg ha^{-1})	Treatments effect (kg ha^{-1})	Treatment effect (kg ha^{-1} yr^{-1})
	0-15 cm	15-30 cm	0-30 cm	0-30 cm	0-30 cm
Native fallow land	1350	1113	1231.2	-	-
Marvel grass	1510	1469	1489.5	1181.693	394
Stylo	2181	1750	1965.6	1657.765	553
Stylo-marvel grass	2263	1368	1815.5	1507.665	503
Napier grass	2988	2296	2641.6	2333.825	778

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