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Nutrient Index Value as a Tool for Evaluating Soil Fertility in Diverse Agroecosystems of Indo-Gangetic plains of India

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ABSTRACT

This study evaluates the soil fertility status of diverse agro-ecosystems in Samastipur District, Bihar, using the Nutrient Index Value (NIV) approach. Soil samples from five land use patterns – mango orchard, forest land, sugarcane field, dhab land, and uncultivated land – were analyzed for key physical, chemical, and biological properties. The highest NIV for organic carbon (2.08) was observed in mango orchard and forest land, while uncultivated land had the lowest (1.00). Nitrogen availability followed a similar trend, with mango orchards showing a medium NIV (2.00) and other systems classified as low. Phosphorus and potassium levels varied, with sugarcane fields exhibiting the highest phosphorus NIV (2.08) and forest land showing the highest potassium NIV (2.00). Biological parameters, such as microbial biomass carbon, were significantly higher in mango orchards (124.47 mg kg^{-1}) compared to uncultivated land (64.67 mg kg^{-1}). These findings emphasize the importance of tailored soil management practices to enhance land-use sustainability. This paper highlights NIV's role as a pragmatic tool for soil fertility assessment, aiding in informed agricultural decision-making.

Keywords: *Nutrient Index Value (NIV), Soil Fertility, Agroecosystems, Samastipur District, Indo-Gangetic Plains, Soil Health, Sustainable Agriculture, Land Use Patterns, Mango Orchard, Forest Land, Sugarcane Field, Dhab Land, Uncultivated Land*

Introduction

Soil health is fundamental to agricultural productivity [45] and environmental sustainability [1, 16]. As the cornerstone of terrestrial ecosystems, soil supports food [7, 8], fiber, and fuel production while maintaining water and nutrient cycles [40]. However, soil degradation is a growing challenge in India [18, 44], where 146.8 million hectares are affected, leading to significant economic and ecological losses [16, 20]. Addressing these challenges requires robust, data-driven strategies [14, 21] for assessing and managing soil fertility [41, 42]. The Indo-Gangetic Plains (IGP), particularly in states like Bihar, face critical challenges related to land degradation [22, 31] and declining soil fertility. In this region, soil quality deterioration is primarily attributed to intensive agricultural practices [2, 4], improper fertilizer use [5, 43], and water mismanagement [46, 26]. These factors exacerbate the loss of soil organic carbon [10, 15], depletion of nutrients and disruption of microbial communities [3, 47, 48, 49]. In Samastipur District, a semi-arid region dominated by diverse land use patterns [11], understanding the variability in soil properties [14, 32] is crucial for sustainable land management. The Nutrient Index Value (NIV), proposed by Parker et al. [50], offers a systematic approach to evaluating soil fertility. By categorizing nutrient availability into low, medium, and high levels, NIV provides a comprehensive assessment of soil health across different

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Agroecosystems [9, 12, 13]. This study applies the NIV framework to assess soil fertility in five distinct land use systems in Samastipur: mango orchards, forest lands, sugarcane fields, dhab lands and uncultivated lands. The objectives of this study are as follows: To quantify the physico-chemical and biological properties of soils under different land use patterns in Samastipur; To evaluate the suitability of these agro-ecosystems based on their nutrient index values and To recommend targeted soil management practices to enhance soil health and agricultural productivity. This paper aims to demonstrate the utility of NIV as a decision-support tool for sustainable agricultural practices, providing insights into the interplay between land use and soil fertility [51, 54] in a region of critical agricultural importance.

Materials and Methods

Study Area

The study was conducted in Samastipur District, Bihar, located between latitudes 25°35'N and 26°05'N and longitudes 85°45'E and 86°15'E. The district experiences a humid subtropical climate with average annual rainfall of 1,100 mm and temperatures ranging from 7°C to 38°C [6].

Soil Sampling and Analysis

Soil samples were collected from five land use types: mango orchard, forest land, sugarcane field, dhab land, and uncultivated land. Sampling was conducted at two depths: 0-15 cm and 15-30 cm, with three replicates per site. Samples were air-dried, sieved (2 mm), and analyzed for the following properties: Physical properties: Mechanical analysis Particle sizes of soils were estimated by hydrometer method as described by Bouyoucos, and textural classes were determined by using USDA textural triangle, bulk density (The method outlined by Black [52] was employed to determine the bulk density (Pb) and porosity. Chemical properties: pH, electrical conductivity (EC), following the method described by Jackson [53]. Organic carbon, available nitrogen, phosphorus, potassium, sulphur, and micronutrients (zinc, boron, copper).

Table 1: Details of sampling location along with Geo coordinates

Different Land Use Patterns	Latitude	Longitude	Sampling Site
Agriculture	N25º57'37.15"	E85º47'14.54"	Sugarcane field in kalyanpur farm
Horticulture	N25º59'11.11"	E85º40'45.00"	Mango orchard in SRI – RPCAU, Pusa
Forestry or Forest land	N25º97'27.86"	E85º67'60.73"	Semal plantation in biodiversity park of RPCAU, Pusa
Dhab land	N25º59'2.74"	E85 º40'16.45"	*Sesbania aculeate* seed production area
Uncultivated land	N25º97'50.86"	E85.67'96.33"	Nearby budhi gandak river

Nutrient Index Value (NIV) NIV was calculated using the formula (Parker et. al., 1951):

$$NIV = \frac{(\text{No. of samples under low category} \times 1 + \text{No. of samples under medium category} \times 2 + \text{No. of samples under high category} \times 3)}{\text{Total No. of samples}}$$

Values were categorized as follows:

Category	Value
Low	less than 1.67
Medium	1.67 -2.33
High	More then 2.33

Fig. 1. Location map of the study area

Statistical analysis

The data generated from the above experiment such as standard error, Analysis of variance (ANOVA) and critical difference at 5% significance level were examined with the help of OPSTAT 6.8 version software.

Results and Discussion

Physico-Chemical Properties of Soil

Table 1 summarizes the physico-chemical properties of soils across land use types. Mango orchards exhibited the highest organic carbon (0.65%) and lowest bulk density (1.33 Mg m^{-3}), indicating better soil structure and aeration. Dhab lands showed the lowest porosity (40.37%) and highest bulk density (1.62 Mg m^{-3}), reflecting compaction and poor aeration.

Soil Texture

The data related to soil sand particles is shown in Table 1 and depth wise distribution of different land patterns illustrated in Fig. 1. The sand particles of different land use patterns of Samastipur district range from 14.30 to 77.80 %. At the depth of 0-15 cm highest mean of sand particle were found in uncultivated land (77.80 %) followed by dhab land (67.30 %), sugarcane field (57.25 %) and forest land (39.90 %) while the lowest sand mean of were found in mango orchard (19.40 %). At the depth of 15-30 cm highest mean of sand particle were found in uncultivated land (76.60 %) followed by dhab land (64.75 %), sugarcane field (55.50 %) and forest land (37.7 %) while the lowest mean of sand were found in mango orchard (16.90 %). At the depth of 30-45 cm highest mean of sand particle were found in uncultivated land (75.80 %) followed by dhab land (64.00 %), sugarcane field (52.75 %) and forest land (36.80 %) while the lowest mean of sand were found in mango orchard (14.30 %). The depth wise distribution of soil silt particle in different land patterns illustrated in Fig. 1. The silt particle of different land use patterns of Samastipur district range from 13.40 to 74.6 %. At the depth of 0-15 cm highest mean of silt particle were found in mango orchard (72.30 %) followed by forest land (34.30 %), sugarcane field (19.50 %) and dhab land (17.70 %) while the lowest mean of sand were found in uncultivated land (13.40). At the depth of 15-30 cm highest mean of silt particle were found in mango orchard (73.50 %) followed by forest land (35.70 %), sugarcane field (19.75 %) and dhab land (18.60 %) while the lowest mean of sand were found in uncultivated land (14.10%). At the depth of 30-45 cm highest mean of silt particle were found in mango orchard (74.60 %) followed by forest land (36.00 %), sugarcane field (20.25 %) and dhab land (19.00 %) while the lowest mean of silt were found in uncultivated land (14.70 %). The clay particle of different land use patterns of Samastipur district range from 8.40 to 27.20 %. At the depth of 0-15 cm highest mean of clay particle were found in forest land (25.80 %)

followed by sugarcane field (23.25 %), dhab land (15.00 %) and uncultivated land (8.40 %) while the lowest mean of clay were found in Mango orchard (8.30 %). At the depth of 15-30 cm highest mean of clay particle were found in forest land (26.80 %) followed by sugarcane field (24.75 %), dhab land (16.65 %) and mango orchard (9.60 %) while the lowest mean of clay were found in uncultivated land (9.30 %). At the depth of 30-45 cm highest mean of clay particle were found in forest land (27.20 %) followed by sugarcane field (27.00 %), dhab land (17.00 %) and mango orchard (11.10 %) while the lowest mean of clay were found in uncultivated land (9.50 %).

Among the land use patterns, the sand particle content of soil was found to decrease with depth, likely because sand particles are more abundant near the surface due to the influence of wind and water, which deposit coarser particles in the upper layers. Uncultivated land exhibited the highest sand content among the land use patterns, possibly due to the lower amount of plant material, which leads to reduced organic matter content and, in turn, decreases the soil's ability to retain finer particles like silt and clay. Similar findings were reported by several scientists [55]. This can result in a higher proportion of sand, as finer particles are more susceptible to erosion or leaching. In contrast, silt and clay content increased with depth across the land use patterns, with the highest levels observed in forest land. This may be attributed to the greater addition of organic matter in the form of leaf litter and root exudates, which enhance the stability of soil aggregates, leading to higher clay content. The higher clay content in subsurface soil layers across all land use systems may also be due to a reduction in soil particle size as a result of compaction from overlying layers, in situ formation, and the residual accumulation of clays produced by the dissolution of coarser mineral grains. Similar results have been reported by [12, 15, 21].

Bulk Density (Mg m^{-3})

The data related to soil bulk density is shown in Fig. 2. The figure revealed that bulk density was significantly influenced by different land use patterns. The bulk density of different land use patterns of Samastipur district ranged from 1.33 to 1.62 Mg m^{-3} at all depths. Significantly highest bulk density (1.54, 1.58, and 1.62 Mg m^{-3}) was recorded in Dhab land at 0-15, 15-30 and 30-45 cm depth, respectively and it remained at par with uncultivated land and sugarcane field at all depths. Significantly lowest bulk density was observed in Mango orchard at all depths. The soil BD increases with depth across different land use patterns. This increase may be due to the deeper soil layers being more compacted from the weight of the overlying soil and having lower organic matter content compared to the surface layers. The similar result has been also reported by [56]. The highest BD was observed in Dhab land, may be due to the compacted soil, which is likely caused by lower organic matter content and higher soil compaction. In mango orchards and forest land were found lowest BD across the land use patterns, this could be attributed to the continuous leaf litter fall from trees, which contributes to higher organic matter content, improving soil physical conditions and making the soils more porous and well-structured, ultimately reducing BD values. The similar results have been reported by [57].

Total Porosity (%)

The data related to soil porosity is illustrated in Fig. 3. The total porosity of different land use patterns of Samastipur district was significantly influenced by different land use patterns. It ranged from 38.86% to 49.81% at all depths of the soil of different land use patterns. The significantly higher total porosity (49.81%, 49.38% and 49.05%) was found in mango orchard at 0-15 cm, 15-30 cm and 30-45 cm depth respectively and it remained at par with forest land (49.05%, 48.42% and 47.92%) at 0-15 cm, 15-30 cm and 30-45 cm depth respectively. Lowest total porosity was observed in dhab land (41.88%, 40.38% and 38.86%) at 0-15 cm, 15-30 cm and 30-45 cm depth.

Soil total porosity decreases with depth across different land use patterns it might be due to increased compaction at deeper layer, which reduces the space between soil particles. This compaction combined with lower organic matter content in deeper soil layers, results in fewer pore spaces and thus further reduces porosity. The similar result has been also reported by [57]. In Dhab land and uncultivated land the lowest total soil porosity were found among the land use patterns. This may be due to the lower organic matter content, which results in poor soil physical conditions and ultimately leads to higher soil bulk density, which is inversely related to total soil porosity. In mango orchards and forest land, the highest total soil porosity was found among the land use patterns, it might be due to the high amount of plant residue and leaf litter, which enhance organic matter in the soil. This increased organic matter improves soil structure and aeration, ultimately leading to higher total soil porosity. The similar results have been reported by [57, 18, 23].

Chemical Properties of Soil

Soil pH

The data related to soil pH illustrated in Fig. 4. The total soil pH of different land use patterns of Samastipur district was significantly influenced by different land use patterns. It ranged from 7.71 to 8.91 at all depths of soil of different land use patterns. Significantly highest soil pH (8.54 and 8.82) was found in dhab land at 0-15 and 15-30 cm depth, respectively and it remained at par to uncultivated land and sugarcane field but at 30-45 cm depth highest soil pH was recorded in uncultivated land (8.91) and remained at par with dhab land. Lowest soil pH was observed in mango orchard at 0-15, 15-30 but at 30-45 cm depth lowest soil pH was recorded in forest land. The Soil pH increases with depth across different land use patterns, it might be due to the continuous removal of bases from the surface layers to the lower layers through percolating water. Additionally, deeper soil layers often have less organic matter, which affects pH levels because organic matter produces organic acids in the soil. In dhab land, the highest soil pH was observed among the land use patterns, it might be due to more alkaline conditions, which can be attributed to lower organic matter content and potentially higher mineral content. In mango orchard and forest land were found lower soil pH due to the presence of tree continuous leaf litter fall contributes to higher organic matter content, which can lower soil pH. The similar trend of soil pH was observed by [51, 15, 55].

Electrical Conductivity (dS m^{-1})

The data related to soil EC is illustrated in Fig. 5. The electrical conductivity of soil was significantly affected by different land use patterns of Samastipur district and ranged from 0.24 to 1.10 dS m^{-1}. Significantly highest EC (0.85, 1.06 and 1.10 dS m^{-1}) was found in uncultivated land at 0-15, 15-30, and 30-45 cm, respectively. Significantly lowest electrical conductivity (0.24, 0.26 and 0.27 dS m^{-1}) was found in mango orchard at 0-15, 15-30 and 30-45 cm depth.

Across all land use patterns soil EC trends to increase with depth, it might be due to the accumulation of soluble salts in the lower soil layer, as water carrying dissolved ions percolates in downward. The similar result has been also reported by [54]. Uncultivated land was found highest EC across the land use patterns it might be due to salt accumulation due to lack of vegetation and poor soil management, leading to higher evaporation rates and salt concentration. In mango orchard was found lowest EC across the all depths it might be due to presence of organic matter content from leaf litter and better soil structure likely contributes to lower salt accumulation. The relevant results have been reported by [21, 15].

Soil Organic Carbon (%)

The data related to soil organic carbon of different land use patterns are illustrated in Fig. 6. The soil organic carbon of the different land use patterns of Samastipur district was significantly affected and ranged from 0.29 to 0.72 % at all depths of soil. The data showed that on an increase in depth, soil organic carbon decreased significantly. The highest soil organic carbon content (0.72, 0.65 and 0.57 %) was found in mango orchard at 0-15, 15-30 and 30-45 cm depth of soil, respectively. Lowest soil organic carbon content was found in uncultivated land at all depths of soil. Across the land use patterns SOC content decrease with increasing depth, this observation may be due to reduced recycling of organic residues in the lower layers and lower microbial activity as compare to the surface layer of the soil. In uncultivated land shows lowest SOC content among all land use patterns it might be due to the lesser accumulation of organic matter content in soils through increased soil disturbances along with poor vegetative cover and no crop growth. The similar result has been also reported by [24, 25]. In mango orchard and forest land were found that highest SOC among all the land use patterns may be due enrichment of organic matter in soils through its addition in form of leaf litter, root biomass, root exudates and lower rate of decomposition.

Available Nitrogen (kg ha^{-1})

The data related to soil available nitrogen of different land use patterns are illustrated in Fig. 7. The significant effect of different land use patterns was observed on soil available nitrogen at different depths of soil. Significantly highest available nitrogen (345.02, 327.63 and 304.08 kg ha^{-1}) was recorded in mango orchard at 0-15, 15-30 and 30-45 cm depth, respectively as compared to other land use patterns. Available nitrogen was highest at 0-15 cm depth than other depths of soil in all land use patterns. Significantly lowest available nitrogen was found in uncultivated land at all depths of soil than other land use patterns. Across all the land use patterns available nitrogen content tends to decrease with depth, it might be due to in surface layers generally having more organic matter content, root activity and microbial population which contribute to higher nitrogen content as compare to deeper layer of soil. Similar result were also obtained by [58]. In uncultivated land was found lowest available N content among all land use patterns due to lack of vegetation and organic matter input contributes to lower N levels. In mango orchard was highest available N content among all depths and land use patterns it might be due to continuous leaf litter decomposition, higher the organic matter content and microbial biomass that resulting enhance the N mineralization. And also mango orchard show maximum available N in deeper layer of the soil. The similar results were reported by [41, 44].

Available Phosphorus (kg ha^{-1})

The data related to soil available P of different land use patterns are illustrated in Fig. 8. The available P was significantly influenced by different land use patterns of Samastipur district and ranged from 9.71 to 23.81 kg ha^{-1}. Significantly highest available phosphorus (23.97, 18.70 and 14.57 kg ha^{-1}) was found in sugarcane field at 0-15, 15-30 and 30-45 cm depth, respectively and it was at par with forest land at 30-45 cm depth only. The lowest available phosphorus (11.48, 10.23 and 9.78 kg ha^{-1}) was found in uncultivated land at 0-15, 15-30 and 30-45 cm depth. Across all the land use patterns available P decrease with the increasing depths, it might be due to deeper soil less amount of organic matter and microbial activity resulting influencing P mineralization compare to the surface layer of soil. Similar result also obtained by [56]. In uncultivated land and dhab land the availability phosphorus content were found lowest among the all land use patterns it might be due to lack of organic matter and minimum biological activity, which are critical for P mineralization and availability. These is calcareous soils in this soil high accumulation of calcium carbonate that facilitate P sorption and this effect is more pronounced in case of coarse textured soils as compared to fine textured soils. In sugarcane field was found high availability of P content among all the land use patterns it might be due to the continuously applying of phosphorus fertilizers and organic amendments. The Similar result has been obtained by [39].

Available Potassium (kg ha^{-1})

The soil K content across different land use patterns was analyzed at three depth intervals as showed in Fig. 9. The results indicate significant variations in available K levels among the different land use patterns, with forest land exhibiting the highest K content at 0-15 and 30-45 cm depth but at 15-30 cm significantly highest available K was found in sugarcane field (194.4 kg ha^{-1}). Available K of forest land was at par with mango orchard and sugarcane field at all depth of soil. Lowest K content was recorded in uncultivated land at all depth of soil. Across all the land use patterns available K decreases with depth, it might be due to abundant plant residues, leaf litter and microbial activities in surface soils. Organic matter is essential for K retention through organic complexes and cation exchange. Primary mineral weathering releasing K is more active in topsoil aided by water, oxygen and organic acids from decaying plant material. In dhab land and uncultivated land available K were found low due to the lack of vegetation and organic matter content, which are crucial and retention of K in the soil. Available K in these areas is likely depleted due to minimum input from plant residues and reduced microbial activity. The relevant result has been also obtained by [15]. In forest land high available K content was found among the land use patterns it might be due to the continuous incorporation of organic matter from leaf litter and root turnover. The presence of mycorrhizal fungi in forest ecosystems can also enhance K availability by solubilizing K from mineral and organic sources [18, 19].

Available Sulphur (mg kg^{-1})

The data related to soil available sulphur of different land use pattern are illustrated in Fig. 10. The available sulphur of different land use patterns ranged from 7.57 to 23.36 mg kg^{-1}. The data indicates that the mango orchard has the significantly highest available sulphur content (23.37, 21.91 and 14.11 ppm) at 0-15, 15-30 and 30-45 cm depth of soil, respectively. Forest land also exhibited relatively high sulphur levels, particularly at shallower (0-15 and 15-30 cm) depth, while uncultivated land showed the significantly lowest sulphur at all depths of soil. Across all the land use patterns, available sulphur decreased with the increase depth, it might be due organic matter content and microbial activities are increased in surface layer of soil which is directly related with the available sulfur, hence the decreasing sulphur content with increasing depth. The similar results have been also reported by [24, 49]. In uncultivated land lowest available sulphur occurs due to low vegetation, directly expose to the sunlight hence easily oxidation of organic matter of soil and lack of microbial activity. In mango orchard highest available sulphur was found due to higher mineralization of organic S as the microbial activity is more pronounced owing to higher biomass addition. This also revealed that the mango orchard is more efficient in mineralizing the organic S to inorganic sulphate.

Free Calcium Carbonate (%)

The data of soil free calcium carbonate across different land use patterns is shown in Fig. 11. The free calcium carbonate of different land use patterns was significantly affected and ranged from 19.17 to 39.46%. The result indicated that dhab land significantly showed the highest levels of free $CaCO_3$ (36.55, 37.12 and 39.46 %) at 0-15, 15-30 and 30-45 cm depth, respectively. Free $CaCO_3$ of uncultivated land was at par with dhab land across all depths of soil. In contrast, both the mango orchard and forest land exhibited significantly lower $CaCO_3$ concentrations, particularly in the upper layers. Across all the land use patterns free $CaCO_3$ content tends to increase with the depth, it might be due to the leaching of soluble $CaCO_3$ from the surface to deeper layers of soil, where it precipitates and accumulates over time. In surface layer lowest $CaCO_3$ content was found due to more organic matter content and biological activities compared to the subsurface layers. The relevant result also obtained by [13]. In dhab land highest free $CaCO_3$ content was found among the all land use patterns, it might be due to the natural accumulation of $CaCO_3$ by limited disturbance and high evaporation rates which enhance the deposition of $CaCO_3$ from soil solutions. In mango orchard lowest free $CaCO_3$ content was found among all the land use patterns because of the organic acids produced by the decomposition of plant residues and root exudates, which promote the dissolution of $CaCO_3$.

Suitability of land management practices based on soil nutrient index approach

Table 1: Nutrient Index Value of soil organic carbon under different land use patterns

Different Land Use Patterns	No. of Sample	Category			Nutrient Index Value	Category of NIV
		Low	Medium	High		
Dhab Land	12	12	0	0	1.00	Low
Uncultivated Land	12	12	0	0	1.00	Low
Mango Orchard	12	0	11	1	2.08	Medium
Sugarcane field	12	10	2	0	1.17	Low
Forest Land	12	0	11	1	2.08	Medium

Soil management strategies for soil organic carbon based on NIV

Dhab Land (NIV 1.00): Enhance soil organic carbon by applying FYM @ 10 t ha^{-1}, crop residues and introducing crops like cowpea and green gram to enhance biomass and soil structure. Practice reduced tillage to limit disturbance and reduce carbon losses. Regularly monitor soil carbon to evaluate the effectiveness of these practices. *Uncultivated Land (NIV 1.00):* Restore soil health by incorporating compost and *Sesbania aculeata, S. rostrata* and *Crotolaria juncea*. Promote vegetation cover with reforestation or grass planting to stabilize soil and enhance organic carbon. Implement erosion control measures like contour ploughing or mulching. Regular soil testing is vital for monitoring and refining strategies. *Mango Orchard (NIV 2.08):* Enhance organic carbon by using organic mulches around trees and applying well-decomposed manure regularly. Employ green manures in off-season to add organic matter and protect the soil. For high carbon areas, focus on sustaining levels without over-applying inputs and monitor soil regularly. *Sugarcane Field (NIV 1.17):* Enhance soil organic carbon by returning crop residues to the soil post-harvest and applying compost or green manure. Minimize tillage to prevent carbon loss and improve soil structure. Use cowpea and green gram to protect and enrich organic matter of soil. Regularly test of SOC to track improvements. *Forest Land (NIV 2.08):* Increase soil organic carbon by incorporating plant residues back into the soil. Reduce tillage to minimize soil carbon loss and improve soil structure. Use cover crops to protect the soil and enhance organic matter content. Regularly test soil organic carbon levels.

Table 2: Nutrient Index Value of soil available nitrogen under different land use patterns

Different Land Use Patterns	No. of Sample	Category			Nutrient Index Value	Category of NIV
		Low	Medium	High		
Dhab Land	12	12	0	0	1.00	Low
Uncultivated Land	12	12	0	0	1.00	Low
Mango Orchard	12	0	12	0	2.00	Medium
Sugarcane field	12	12	0	0	1.00	Low
Forest Land	12	11	1	0	1.08	Low

Soil management strategies for available nitrogen based on NIV:

Dhab Land (NIV 1.00): Increasing soil nitrogen by using nitrogen-rich fertilizers @ 100% RDF like urea. Grow leguminous crops to fix atmospheric nitrogen and enhance soil fertility. Add compost or manure, to improve nitrogen availability and soil structure. Monitor nitrogen levels regularly to avoid leaching. *Uncultivated Land (NIV 1.00):* Restore soil nitrogen by planting nitrogen-fixing cover crops like clover or alfalfa. Use synthetic fertilizers @ 100% RDF and add organic materials @ 10-12 t ha^{-1} to boost soil structure and nitrogen retention. Practice soil conservation to avoid erosion and nutrient loss and test soil regularly to refine fertilization. *Mango Orchard (NIV 2.00):* Sustain nitrogen levels by applying fertilizers @ 50% RDF, avoiding excess. Use organic mulches like leaf litters and compost around trees to provide gradual nitrogen release and enhance soil health.

Plant cover crops like green gram and cowpea in off-seasons to add organic matter and nitrogen. Regular soil tests help monitor and adjust fertilization. *Sugarcane Field (NIV 1.00):* Enhance soil nitrogen by fertilizers @ 100% RDF. Add nitrogen-rich organic materials, such as green manures with *Sesbania aculata* or *S. rostrata*, to boost nitrogen levels. Rotate crops with legumes to naturally increase nitrogen. Regularly monitor soil to ensure adequate fertilization and prevent excess nitrogen loss. *Forest Land (NIV 1.08):* In low nitrogen areas, use organic fertilizers to enhance nitrogen levels. Encourage nitrogen-fixing legumes for natural nitrogen enrichment. For medium nitrogen areas, rely on natural nutrient cycling and apply chemical fertilizer @ 50% RDF only if soil tests show a decline. Adopt sustainable forest management to protect soil organic matter and keep nitrogen balanced.

Table 3: Nutrient Index Value of available phosphorus under different land use patterns

Different Land Use Patterns	No. of Sample	Category			Nutrient Index Value	Category of NIV
		Low	Medium	High		
Dhab Land	12	2	10	0	1.83	Medium
Uncultivated Land	12	5	7	0	1.58	Low
Mango Orchard	12	0	12	0	2.00	Medium
Sugarcane field	12	0	11	1	2.08	Medium
Forest Land	12	0	12	0	2.00	Medium

Soil management strategies for soil available phosphorus based on NIV

Dhab Land (NIV 1.83): To enhance soil phosphorus levels, it is essential to apply Di-Ammonium Phosphate (DAP) or Single Super Phosphate (SSP) at moderate doses, following 50% RDF. Incorporate compost or green manure crops like *Crotolaria juncea*, *Sesbania aculeata* and *S. rostrata* to further enhance phosphorus availability. Regular soil testing should be conducted to adjust phosphorus application rates accordingly. *Uncultivated Land (NIV 1.56):* The phosphorus NIV in uncultivated land is low, meaning there is a significant deficiency of phosphorus. In such cases, a higher dose of phosphorus fertilizers is necessary. Applying 60 kg ha^{-1} of P_2O_5 using DAP or SSP is recommended. Incorporating FYM @ 10-12 t ha^{-1} can improve soil structure and phosphorus availability over time. Phosphorus-solubilizing microbes can also mobilize phosphorus for plant uptake. *Mango Orchard (NIV 2.00):* Mango orchards exhibit a medium phosphorus level. To maintain healthy fruit production, the soil should be supplemented with **50 kg ha^{-1} of P_2O_5** using organic fertilizers (bone meal), or mineral fertilizers (DAP). Mulching with leaf litters and plant residues can retain soil moisture and improve phosphorus uptake. Regular soil testing should be conducted to prevent phosphorus build-up, which can lead to nutrient imbalances *Sugarcane Field (NIV 1.92):* The high phosphorus availability in sugarcane fields suggests that phosphorus levels are already sufficient. In this case, phosphorus fertilization can be reduced or even omitted for a season. However, to maintain nutrient balance, 20 kg ha^{-1} of P_2O_5 can be applied if necessary, especially if testing shows phosphorus depletion. Using organic matter to improve microbial activity and nutrient cycling is still beneficial for long term soil health. *Forest Field (NIV 2.00):* In forest land, the phosphorus level is high indicating minimum need for additional phosphorus. Maintaining natural nutrient cycling such as leaf litter decomposition and mycorrhizal associations can sustain phosphorus availability. No additional phosphorus be required unless there are signs of deficiency. If needed, a light application of 20 kg ha^{-1} of P_2O_5 can be used in disturbed areas to replenish phosphorus.

Table 4: NIV of soil available potassium under different land use patterns

Different Land Use Patterns	No. of Sample	Category			Nutrient Index Value	Category of NIV
		Low	Medium	High		
Dhab Land	12	4	8	0	1.67	Medium
Uncultivated Land	12	7	5	0	1.42	Low
Mango Orchard	12	1	11	0	1.92	Medium
Sugarcane field	12	0	12	0	2.00	Medium
Forest Land	12	0	12	0	2.00	Medium

Soil management strategies for soil available potassium based on NIV

Dhab Land (NIV 1.67): Dhab Land has a medium Nutrient Index Value for available potassium, indicating that potassium is moderately present but may require supplementation to support optimal plant growth. To maintain adequate potassium levels, it is recommended to apply 40-60 kg ha^{-1} of Muriate of Potash (MoP) or potassium sulphate, particularly during planting or when deficiency symptoms are observed. In addition, practices such as the incorporation of crop residues and organic matter can help maintain potassium levels and enhance soil structure. *Uncultivated Land (NIV 1.42):* To restore potassium levels before cultivation, it is recommended to apply 60-80 kg ha^{-1} of MoP or potassium sulphate. Organic amendments such as compost or green manure should also be added to improve potassium retention and overall soil fertility. Apply soil conservation techniques like mulching to reduce potassium leaching and erosion. Plant cover crops to protect the soil and gradually increase potassium levels. *Mango Orchard (NIV 1.92):* Mango orchards exhibit a medium level of potassium availability with an NIV of 1.89. While not critically deficient, regular potassium applications are necessary to sustain fruit production and overall tree health. A recommended dose of 50 $kgha^{-1}$ of potassium sulphate should be applied during key growth stages, such as flowering and fruit development. Organic mulching around the trees can also help in maintaining potassium levels by preventing nutrient loss through erosion or leaching. *Sugarcane field (NIV 2.00):* Sugarcane fields have a medium potassium level indicating sufficient availability but requiring periodic replenishment to support the high nutrient demands of sugarcane. Applying 40 kg ha^{-1} of K_2SO_4, at the time of planting, is recommended. Crop residue management is critical in sugarcane fields, as the large biomass recycle potassium and other nutrients. Regular soil testing can ensure the maintenance of optimal potassium levels. *Forest Land (NIV 2.00):* Forest land has a medium potassium level maintained naturally through organic matter and leaf litter. No external potassium fertilization is required in forest ecosystems, as the natural processes of decomposition and nutrient cycling are typically sufficient.

The primary management strategy is to conserve the forest biodiversity and maintain organic matter levels to ensure continued potassium availability. Regular monitoring of soil health will help track nutrient dynamics and ensure long-term sustainability.

Table 5: Nutrient Index Value of soil available sulphur under different land use patterns

Different Land Use Patterns	No. of Sample	Category			Nutrient Index Value	Category of NIV
		Low	Medium	High		
Dhab Land	12	8	4	0	1.33	Low
Uncultivated Land	12	10	2	0	1.17	Medium
Mango Orchard	12	0	5	7	2.58	High
Sugarcane field	12	3	9	0	1.75	Medium
Forest Land	12	0	11	1	2.08	Medium

Soil management strategies for soil available sulfur based on NIV

Dhab Land (NIV 1.33): Apply sulphur-rich fertilizers like ammonium sulphate or gypsum @ 30-40 kg ha^{-1}. Incorporate organic matter such as compost, to improve soil fertility. Regularly monitor soil sulphur levels to prevent deficiencies. *Uncultivated Land (NIV 1.17):* Increase sulphur inputs using sulphur-containing fertilizers with 35-45 kg ha^{-1} of elemental sulphur or ammonium sulphate. Implement soil conservation practices to reduce erosion and maintain sulphur levels. Encourage vegetation growth to enhance organic matter content in the soil. *Mango Orchard (NIV 2.58):* Minimize additional sulphur fertilization to avoid excess accumulation. Focus on maintaining healthy soil organic matter through mulching with organic materials like leaves or grass clippings. Mulching helps with moisture retention and the gradual release of sulphur. Regular soil testing will ensure that sulphur levels stay balanced with other essential nutrients. *Sugarcane field (NIV 1.75):* Applying 20-30 kg ha^{-1} of gypsum or ammonium sulphate will sustain sulphur levels. Managing crop residues is important in sugarcane fields, as these residues can help recycle sulphur and other nutrients. Adding organic matter and maintaining soil moisture is also crucial for improving sulphur availability. *Forest Land (NIV 2.08):* Forest Land has a medium sulphur level which is largely maintained by the natural cycling of organic matter from fallen leaves and plant residues. No additional sulphur fertilizer is required, as the ecosystem natural processes are sufficient to maintain nutrient balance. The key soil management strategy is to protect the forest biodiversity and prevent over-harvesting of organic material to maintain natural sulphur cycling and soil health over time. Regular monitoring of soil fertility will help track nutrient dynamics.

Table 6: Nutrient Index Value of soil available boron under different land use patterns

Different Land Use Pattern	No. of Sample	Category			Nutrient Index Value	Category of NIV
		Low	Medium	High		
Dhab Land	12	11	1	0	1.08	Low
Uncultivated Land	12	12	0	0	1.00	Low
Mango Orchard	12	3	9	0	1.75	Medium
Sugarcane field	12	8	4	0	1.33	Low
Forest Land	12	3	9	0	1.75	Medium

Soil management strategies for soil available boron based on NIV

Dhab Land (NIV 1.08): Apply boron-containing fertilizers such as borax @ 1-2 kg ha^{-1} to address boron deficiency. Incorporate organic matter to improve soil fertility and boron retention. Regularly test the soil to monitor boron levels and adjust applications as needed to avoid toxicity.

Uncultivated land (NIV 1.00): Apply boron-containing fertilizers such as borax @ 2-3 kg ha^{-1} to correct deficiency and support vegetation growth. Incorporating organic matter, such as compost or well-rotted manure, improves soil structure and microbial activity to enhance boron availability. Implement soil conservation practices to prevent erosion and nutrient loss.

Mango Orchard (NIV 1.75): Apply boron fertilizers such as borax @ 0.5-1 kg ha^{-1} without causing toxicity. Focus on improving soil organic matter to aid in boron retention. Conduct regular soil testing to monitor boron levels and ensure balanced nutrient management.

Sugarcane Field (NIV 1.33): Use boron fertilizers such as borax @ 1-2 kg ha^{-1} to address the deficiency. Incorporate crop residues and organic matter to enhance soil fertility and boron availability. Monitor soil boron levels regularly to guide future fertilization.

Forest Land (NIV 1.75): Maintain boron levels by applying fertilizers such as borax @ 0.5-1 kg ha^{-1}. Enhance soil organic matter through natural processes like leaf litter decomposition to support boron availability. Regular soil monitoring is advised to maintain balanced nutrient levels.

Conclusions

The study highlights the significant role of Nutrient Index Value (NIV) in assessing soil fertility across diverse agroecosystems in Bihar. The findings reveal that land-use patterns exert a substantial influence on soil organic carbon content, nitrogen availability, and microbial activity. Mango orchards and forest lands demonstrated superior soil health, characterized by higher organic carbon levels, microbial biomass and improved nutrient retention. In contrast, uncultivated and dhab lands exhibited poor soil quality, with lower nutrient indices and higher soil compaction, underscoring the need for targeted soil management strategies. The observed variations in soil fertility underscore the importance of site-specific soil management practices to enhance land productivity and sustainability. Adoption of organic amendments, reduced tillage and cover cropping in low-fertility areas can improve soil structure and nutrient availability. Furthermore, maintaining balanced fertilization in high-NIV areas will ensure long-term soil health and prevent nutrient depletion. The study reinforces NIV as a pragmatic and effective tool for guiding land management decisions.

By integrating NIV-based recommendations into agricultural planning, policymakers and farmers can develop sustainable land-use strategies that promote soil conservation, enhance crop productivity and ensure long-term agricultural sustainability in the Indo-Gangetic Plains.

Recommendation

Based on the findings of this study on soil fertility assessment using the Nutrient Index Value (NIV) in diverse agroecosystems, the following recommendations are proposed:

1. Land-Specific Soil Management Strategies

Mango Orchard & Forest Land **(Medium to high NIV):** Maintain soil fertility through organic amendments such as compost, farmyard manure (FYM), and mulching. Avoid excessive fertilization to prevent nutrient imbalances. Encourage agroforestry practices to sustain organic carbon levels and microbial diversity.

Sugarcane Fields **(Low to medium NIV):** Implement integrated nutrient management by combining organic matter with balanced chemical fertilizers. Promote residue retention and green manuring to enhance organic matter. Adopt reduced tillage to minimize soil compaction and carbon loss.

Dhab & Uncultivated Land **(Low NIV):** Implement rehabilitation strategies such as afforestation and cover cropping to restore soil fertility. Apply organic matter (FYM @ 10-12 t/ha) and nitrogen-fixing crops to improve nutrient content. Improve soil aeration and water retention through soil conservation practices like contour plowing and mulching.

2. Nutrient-Specific Recommendations

Organic Carbon Management: Encourage organic residue incorporation to maintain soil carbon levels. Reduce excessive tillage to minimize soil organic matter depletion. Introduce crop rotations with legumes to improve carbon sequestration.

Nitrogen Management: Apply nitrogen fertilizers based on site-specific requirements (e.g., 50% RDF for mango orchards, 100% RDF for sugarcane fields and dhab land). Promote biological nitrogen fixation using leguminous cover crops. Avoid excessive nitrogen applications to minimize leaching and groundwater contamination.

Phosphorus Management: In low-phosphorus areas (uncultivated and dhab land), apply phosphorus fertilizers (DAP @ 60 kg P_2O_5/ha). Encourage the use of phosphorus solubilizing bacteria to improve phosphorus availability. Reduce soil erosion to prevent phosphorus loss.

Potassium Management: Maintain potassium levels through organic mulching and crop residue management. Apply potassium fertilizers (MoP @ 40 kg K_2O/ha) in deficient areas. Adopt controlled irrigation practices to reduce potassium leaching.

Sulphur & Micronutrient Management: Apply gypsum in sulfur deficient areas (uncultivated and dhab land). Use boron fertilizers (borax @ 2 kg/ha) to improve soil boron levels. Promote microbial inoculants to enhance nutrient cycling.

3. Sustainable Agricultural Practices

Implement precision farming techniques (GIS mapping, remote sensing) to optimize fertilizer application. Promote conservation agriculture, including minimum tillage and residue retention, to maintain soil health. Encourage farmer training programs on soil fertility management and sustainable land-use practices. Develop policy frameworks supporting balanced fertilization and sustainable soil conservation efforts. By adopting these recommendations, soil fertility can be improved, ensuring long-term agricultural productivity and environmental sustainability in the Indo-Gangetic Plains.

Future Scope of Studies:

Future research should focus on the long-term impacts of land use changes on soil fertility, the integration of remote sensing and GIS for spatial mapping of soil properties, and the role of microbial diversity in enhancing nutrient cycling. These approaches will further refine soil fertility assessment methods and contribute to improved agricultural productivity and environmental sustainability.

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Table 1: Effect of different land use patterns on soil texture at different soil depth

Soil Depth	Value of Soil Texture under Different Land Use Patterns														
	Dhab Land			Uncultivated land			Mango orchard			Sugarcane field			Forest land		
	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
0-15 cm	67.30	17.70	15.00	77.80	13.40	8.40	19.40	72.30	8.30	57.25	19.50	23.25	39.9	34.3	25.8
15-30 cm	64.75	18.60	16.65	76.60	14.10	9.30	16.90	73.50	9.60	55.50	19.75	24.75	37.7	35.7	26.8
30-45 cm	64.00	19.00	17.00	75.80	14.70	9.50	14.30	74.60	11.10	52.75	20.25	27.00	36.8	36	27.2
Mean	65.35	18.43	16.22	76.73	14.07	9.07	16.87	73.47	9.67	55.17	19.83	25.00	38.13	35.33	26.60
SD	1.41	0.54	0.87	0.82	0.53	0.48	2.08	0.94	1.14	1.85	0.31	1.54	1.30	0.74	0.59
CV	2.16	2.95	5.38	1.07	3.78	5.28	12.35	1.28	10.31	3.36	1.57	6.16	3.41	2.10	2.21

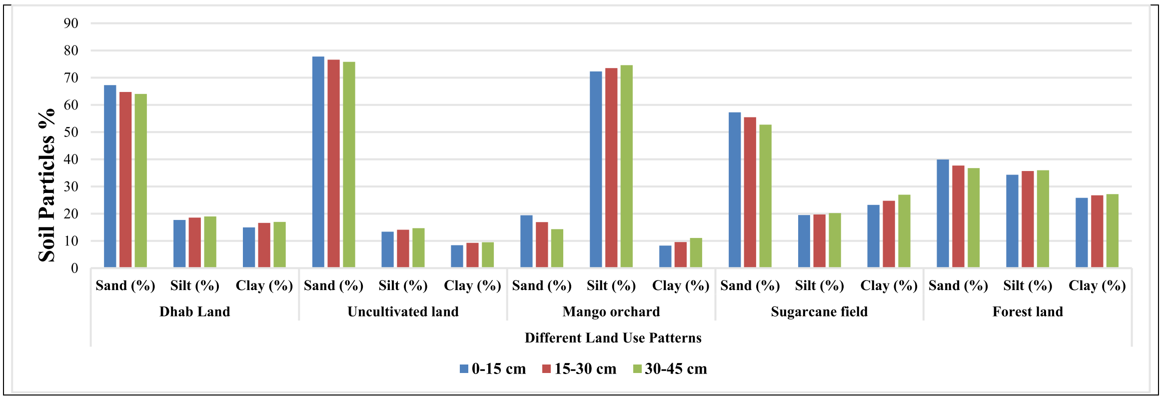

Fig 1: Effect of different LUP on soil texture at different soil depth

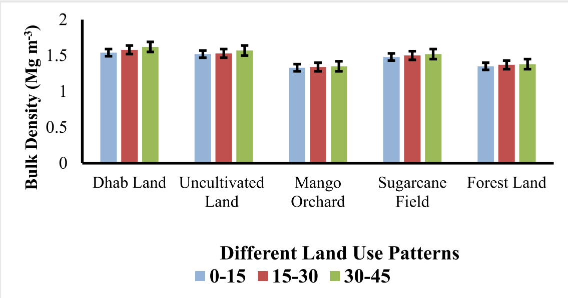

Fig 2: Effect of different LUP on bulk density at different depth

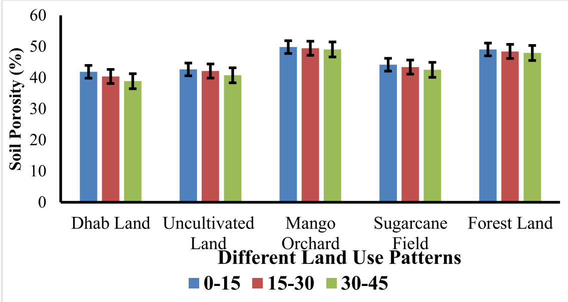

Fig 3: Effect of different LUP on total porosity at different depth

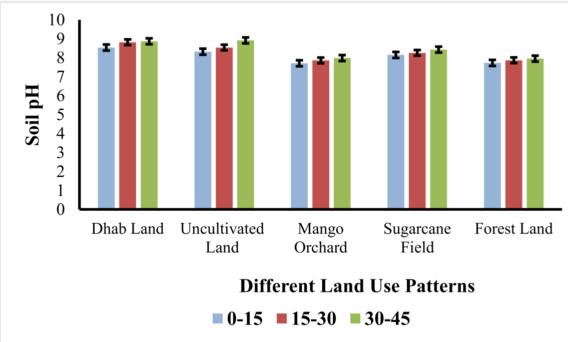

Fig 4: Effect of different LUP on soil pH at different soil depth

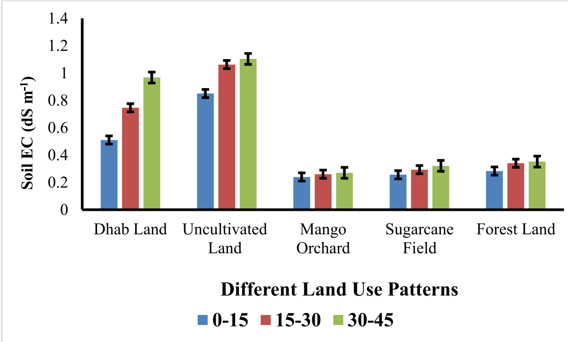

Fig 5: Effect of different LUP on EC at different soil depth

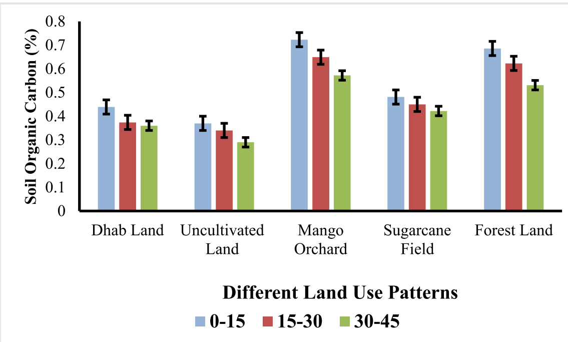

Fig 4: Effect of different LUP on soil pH at different soil depth

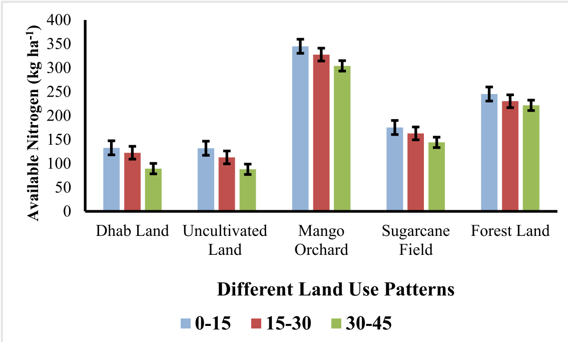

Fig 5: Effect of different LUP on EC at different soil depth

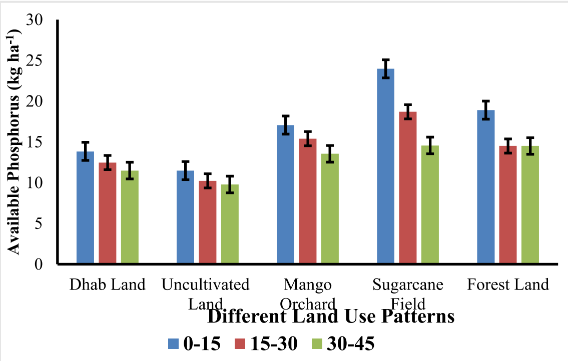

Fig 4: Effect of different LUP on soil pH at different soil depth

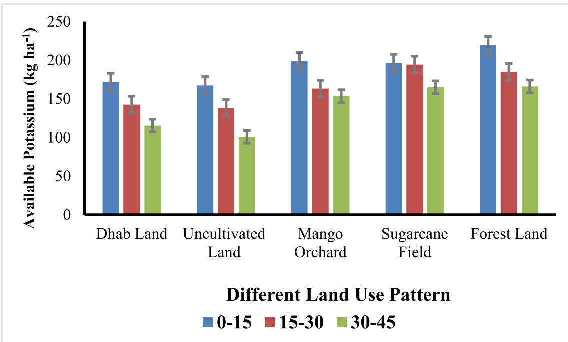

Fig 5: Effect of different LUP on EC at different soil depth

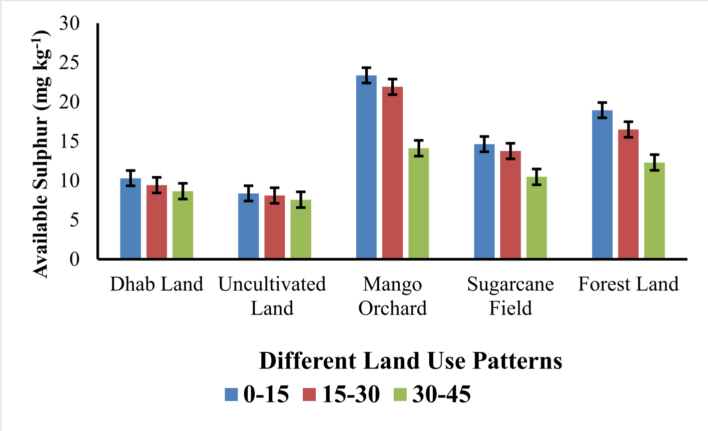

Fig 10: Effect of different LUP on available S at different depth

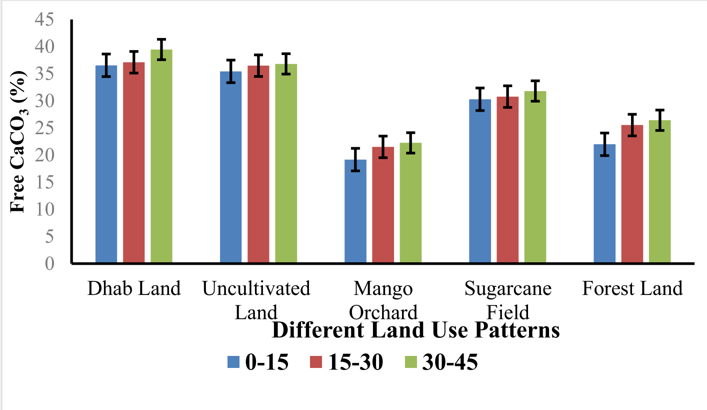

Fig 11: Effect of different LUP on free CaCO3 at different soil depth

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