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Research article

Intrinsic restoration of a ferruginous ultisol using goosegrass obtained from different land use areas* **(Eleusine indica Unitalicize - L. [Gaertn.])*

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Abstract

Improving ferruginous utisols using *Eluesine indica*

The study is an attempt to predict land restoration through changes in plant-soil characteristics. The capacity of goosegrass (*Eleusine indica* L. [Gaertn]) obtained from different land use areas in the rehabilitation and restoration of ferruginous ultisol was investigated. Fresh healthy tillers of *E. indica* from ten built environments and ferruginous utisol with iron content of 298.10 mg/kg were used in the study. The plants were grown for seven weeks during which changes in the morphological characteristics of *E. indica* were assessed. Nitrogen, phosphorus, potassium and iron concentrations in the soil and plant parts were also determined. The morphological parameters revealed that there were no significant differences in the progression of plant height, spike length, number of primary roots. However, there was a significant decrease in the number of spikelets per plant, and root and shoot weight. Results suggest that rhizoacidity and phylloacidity of goosegrass roots and shoots result from the absorption and accumulation of iron from ferruginous utisols. *E. indica* shoots significantly accumulated more potassium compared to the roots. There were no significant differences in the residual iron content upon removal of *E. indica* from all locations, indicating that the introduction of the test plant did not significantly remove iron from the ferruginous soil. The concentration of nitrogen in the soil was not significantly impacted by the presence of *E. indica* as well as the root and shoot accumulation of nitrogen regardless of location. Overall, *E. indica* is capable of improving the fitness for agricultural use of ferruginous utisols.

Introduction

Humankind's fight to maintain the integrity of the ecosystem, especially soil quality, and sustain plant diversity is not novel, but the urgency has intensified in recent times (Osawaru and Ogwu, 2014; Ikhajiagbe et al. 2016; Ogwu, 2019). Crop production depends on the environmental carrying capacity of land, which is an estimation of the demand and supply of land required support human life and maintain ecological productivity. According to Pahulan et al. (2017) and Servidoni et al. (2017) understanding the biotic and environmental carrying capacity of land is vital to prevent misuse and degradation of the increasingly scarce resource. Land use is largely unsustainable especially in the global south where ecosystems and sociological systems are degrading beyond the capacity required to fight food insecurity and poverty (Geerling and de Bie, 1986; Sinaga and Dewata, 2020).

Degraded lands often hold soil with insufficient nutrients, discouraging plant growth and development and causing plants to become chlorotic and stunted. Nutrient deficiency is deleterious as well as the overabundance of some nutrients above threshold levels. A typical example is ferruginous utisols (red soil), which is characterized by excess oxides and hydroxides of iron and aluminum. This kind of soil is found in different parts of the world including Nigeria, India and Pacific Island countries (Buringh, 1970; Churchman and Lowe, 2012). Ikhile (2016) reported the presence and characteristics of ferruginous soil in Southern Nigeria particularly in Edo State. Ferruginous soils develop 200 - 400 years on average under humid tropical climate due to leaching of bases and release of iron and its coating on soil surfaces. Ferruginous soils of Benin City vary in their physical, chemical and mineralogical characteristics and are classified as ultisols, alfisols and even inceptisols (van Straaten, 2002; Jolloh et al., 2011). The ferruginous soils in general, are low in fertility status, but they may selectively support good vegetation (Ikhajiagbe et al., 2020; 2021). Ferruginous and aluminous clay soils are common products of weathering in tropical and subtropical latitudes (Huat and Toll, 2013; Pal et al. 2014). Vamaguche (2003) reported that the repeated leaching of rocks by percolating rainwater produce solutions of leached anions, which are carried to the surface by capillary action during the dry season. Ferruginous soils have red clay-like deposits that occur below a tough ferruginous hardpan. Alayaki et al. (2015) opined that these soils also contain low silica-sesquioxide ratio of clay-sand, which is soft when wet and considerably hard when dry.

Iron is an essential micronutrient for almost all living organisms, because it plays a critical role in metabolic processes, such as DNA synthesis, respiration, and photosynthesis. Many metabolic pathways are activated by iron, and it is a prosthetic group constituent of many enzymes. An imbalance between the solubility of iron in soil and the demand for iron by the plant are the primary causes of iron chlorosis. In plants, iron is involved in chlorophyll synthesis, and it is essential for the maintenance of chloroplast structure and function. Typically, approximately 80% of iron is found in photosynthetic cells, where it is essential for the biosynthesis of cytochromes and other heme molecules, including chlorophyll, the electron transport system, and the construction of Fe-S clusters (Briat et al., 2007). Iron toxicity is not common, but some plants do secrete acids from the roots, which lowers soil pH. These plants can take up too much iron, leading to toxicity. The symptoms of iron toxicity include bronzing and stippling of leaves. The leaf discoloration is caused by the plant creating enzymes to control free radicals that are present in high iron levels. Some plants that are prone to iron toxicity include tomatoes, basil, phlox and impatiens.

In developing countries like Nigeria, where farmers lack sufficient funds and experience of expensive high technology environmental management tools, a low-cost biological and technological approach devoid of any complications in application, is highly recommended for the decontamination of metal polluted lands. Assessment of indigenous metal tolerant plants becomes essential, especially in urban and industrial soils (Osawaru et al.,

2014a; Vwioko et al., 2018). Other researchers (Ikhajiagbe and Chijioke-Osuji 2012; Ikhajiagbe et al. 2016; Ikhajiagbe et al. 2017a,b; Ikhajiagbe and Osayamen, 2019; Ikhajiagbe and Ogwu, 2020) have reported the capacity of plants like Eleusine indica (L. [Gaertn]) in the reclamation of soils polluted with organic and inorganic contaminants. Since the potential of using phytoremediation to treat soils contaminated by organic pollutants is high for both ecological and economic reasons, an increasing number of researchers have focused on this area (Huang et al., 2004; Gerhardt et al. 2009). The findings from these researchers have also implicated the viability of the approach for treating, restoring and rehabilitation of soils with overabundance of certain nutrient elements. Moreover, vegetative uptake and degradation in the rhizosphere can play a major role in remediation at hazardous waste sites (Burken and Schnoor, 1997). Therefore, the main aim of this study is to investigate the land restoration and rehabilitation capacity of goosegrass (*E. indica*) through changes in plant-soil characteristics. Goosegrass is a common ruderal in Benin City that thrives in disturbed areas with compacted soils (Osawaru et al. 2014b; Ikhajiagbe and Ogwu, 2020) making it the ideal plant for this study. An additional objective of this study is to document alterations (if any) in *E. indica* plant characteristics like flowering and number of tillers, plant height, spike length and number of spikelets, leaf length and area as well as shoot and root weight in different built environment. Further, rhizoacidity test will be used to ascertain organic acid exudation by goosegrass as well as the iron, nitrogen and phosphorus, potassium accumulation by *E. indica* shoot and root. Put together, the work will report the capacity of *E. indica* to reduce iron levels in ferruginous utisols and contribute towards understanding the quality of ferruginous soils and sustainable land use.

Materials and Methods

Study area and sample collection. The study was conducted at the Botanic Garden of the Department of Plant Biology and Biotechnology, University of Benin, Nigeria.

The climatic and plant characteristics of the area are outlined in Ogwu et al. (2014) and Osawaru et al. (2013). In general, the area is characterized by diverse weed species, with Axonopus compressus being the dominant species. The study area was prepared by clearing the weeds and delimiting an experimental plot area of 2 x 3.5 m^2. Thereafter, experimental bowls were placed in the experimental plot in a completely randomized block design.

Sample collection. A total of 100 fresh healthy young *E. indica* with about seven to ten tillers were collected from ten different land use areas within Benin City, Nigeria with some particles of soil attached to their roots. The sample collection areas are built environments (i.e., human-altered environments). Control samples were taken from the periphery of a forest located next to the University of Benin near the Capitol back gate. This area is largely undisturbed and pristine. The descriptions of the various sampling locations are presented in the Table 1.

Table 1: Site description and GPS coordinates of sample collection points within Benin City

Sample location	Description	GPS coordinates
Hospital dumpsite	Health center/marriage registry Uhunmwode L.G.A	Lat 6º22'59"N Long 5 º42'42"E
Filling station	Urora NNPC Filling station Ikpoba-Okha L.G.A	Lat 6 º22'33"N Long 5 º41'48"E
Transformer	First bank plc King's square branch RingroadOredo L.G.A	Lat 6 º20'01"N Long 5 º37'24"E
Bakery periphery	Nadia bakery Ovia North-East	Lat 6 º23'58"N Long 5 º36'32"E
School hostel field	Tinubu female hostel (Hall 2) Ovia North-East L.G.A	Lat 6 º23'56"N Long 5 º38'03"E
Church main field	St. Andrew's Anglican church Uselu, Egor L.G.A	Lat 6 º22'30"N Long 5 º36'44"E
Airport field	Airport rd, Ogogugbo, Benin city Oredo L.G.A	Lat 6 º19'00"N Long5 º36'16"E
Hotel lawn	Ohonba royal Hotel & Suites Egor L.G.A	Lat 6 º22'49"N Long5 º36'40"E
Mechanic workshop	Mechanic workshop/welding shop Ovia North-East L.G.A	Lat 6 º25'21"N Long5 º36'07"E
Roadside	Sagamu – Benin Expressway Benin City Ovia North-East L.G.A.	Lat 6 º25'26"N Long5 º36'05"E
Capitol (Control)	Fringe of forest beside The Capitol, University of Benin, Benin City. Egor L.G.A	Lat 6 º24'02"N Long5 º38'03"E

The collected plants were kept in a nursery for acclimatization and stabilization for one month. After a month, freshly emerged tillers were harvested and used as transplants in the study. The ferruginous soils were obtained from an area measuring 50 x 50 m^2 marked near the Dentistry quarters, University of Benin, Benin City, Edo State. The iron content was determined and confirmed to be high enough for the experiment (>200 mg/kg). Iron content of the soil as pooled was 298.10 mg/kg. Thereafter, 5 kg sun-dried soil was transferred into the experimental bowls with height and diameter of 11 cm and 24 cm respectively with no perforations made at the bottom of each bowl to prevent leaching. Measured quantity of soil placed in each bowl occupied a dimension of 10 cm in depth and a radius of 21.50 cm.

Assessment of experimental parameters. The experimental set up, consisting of ferruginous soils and the transplanted test plants were maintained in a well-ventilated Screen House for seven week. During this period, morphological parameters were assessed including: plant height, leaf length, leaf width, leaf area, peduncle length, number of spikes, length of longest spike, root length and colour, number of tillers per plant, number of primary roots as well as number of branching roots.

Determination of physiochemical analysis of soil and plant parts

Determination of nitrogen content of soil. The soil sample was air-dried, and then oven dried at 105°C for five hours, then ground into powder. The nitrogen content was determined colorimetrically. About 1g of the soil was weighed into a boiling tube and 100 ml of sulphuric acid was measured and added. Two tablets of Kjedahl catalyst were added and heated slowly until the solution became clear. It was then filtered into a 100ml standard flask and made up to mark. 5ml of the digest was taken into a 25 ml flask. 2.50 ml of alkaline phenol was added and shaken thoroughly. 1.50 ml of sodium potassium Tartrate was added and shaken as well. 1 ml of sodium hypochlorite was added and shaken. The mixture was read colorimetrically using UV/VIS Spectrophotometer (Jenway 6715 model) at 630 nm wavelength, the standard N was also treated similarly.

The percentage of nitrogen was calculated thus:

$$\text{Percentage N} = \frac{\text{Instrument reading x Slope reciprocal x Color volume x Digest vol x } 10^{-6}}{\text{Weight of sample x Aliquat taken}}$$

Determination of phosphorus and potassium in soil. A mixture of acid (aqua ragia) HNO_2 and HCl, in the ratio of 3:1 was freshly prepared. First, 1g of the sample was weighed into digestion bottle. 10ml mixture of acid was measured into the bottle containing the sample. The mixture was then placed on a hot plate and heated slowly until the solution became clear. It was then cooled, diluted and filtered into a 100ml volumetric flask and made up to mark. Phosphorus was analyzed using ammonium molybdate method. 10ml of the digest was measured into a 100ml volumetric flask, 2ml mixture of ammonium molybdate ([NH4]6Mo7O24) and antimony metavanadate was added and read at 410nm, the standard was treated similarly. The formula below was used to determine the amount of K and P in the soil.

$$\text{P (mg/kg)} = \frac{\text{Instrument reading x Slope reciprocal x Colour volume x Extract volume}}{\text{Weight of sample x Aliquat}}$$

Flame Photometer (Model Sherwood 410) was used to analyze for Potassium. 1g of dry analar was accurately weighed quality KCl and dissolved in pure deionised water and then washed into a 100ml volumetric flask. The solution was filled to the mark using pure deionised water. The stock solution was then diluted 1 in 50 in order to prepare the standard solution for use with the flame photometer. The following formula was used to calculate the potassium content in the soil.

Atomic weight of K = 39.1
Molecular weight of KCl = 74.56
Therefore, 1 g KCl contains 39.1/74.56 = 0.52 g K
Thus in 100ml of solution there is 50mg K
Diluting one in fifty gives a standard of 1 mg K/100 ml = 10 ppm K.

Determination of iron in soil and plant parts. Measured 1g of the samples was weighed into a digestion bottle. 10ml mixture of acid was measured into the bottle containing the sample. The mixture was then placed on a hot plate and heated slowly until the solution became clear. It was then cooled, diluted and filtered into a 100ml volumetric flask and made up to mark. Atomic Absorption Spectroscopy (AAS Model BUCK Scientific VGA 210) was used to analyze for Fe. The formula was used to calculate the iron content in the soil and plant parts.

$$\text{Fe (mg/kg)} = \frac{\text{Weight percentage of iron x numerical value of iron expressed as oxide}}{10000}$$

Data analysis. The collected experimental data were analyzed to understand the capacity of *E. indica* to restore and rehabilitate ferruginous soil using Variance analysis, mean and standard error. The data analysis was carried out using SPSS-20 statistical software for Windows PC and the means were separated by using the Least Significant Difference.

Results

Morphological effects on *E. indica*

The changes in E. indica height after transplanting is presented in Figure 2. The plant height ranged from 6.30 cm to 27.40 cm in the first to seventh week respectively. In order to further assess the impact of the built environment on the average plant height of *E. indica* against that of the control site, we compared the mean height of all *E. indica* plants collected from the built environments for the entire seven weeks after transplanting (Figure 3). Result showed that there were no significant differences in the progression of plant height of *E. indica* collected from the built environment compared to those collected from Capitol. Plant height ranged from 6.40 – 7.30 cm at transplanting to 31.40 cm in the seventh week after planting (Figure 3).

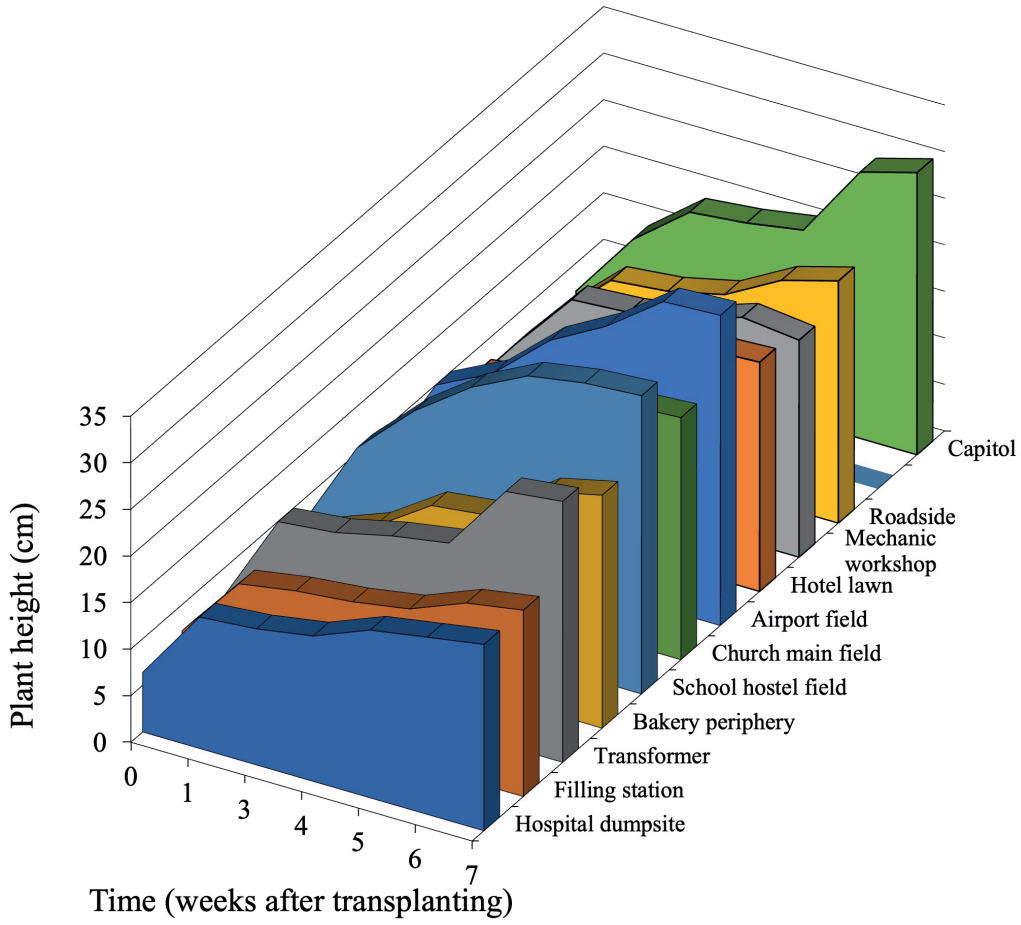

Figure 1: Plant height of *E. indica* collected from the various built environment and exposed to current experimental conditions for seven weeks.

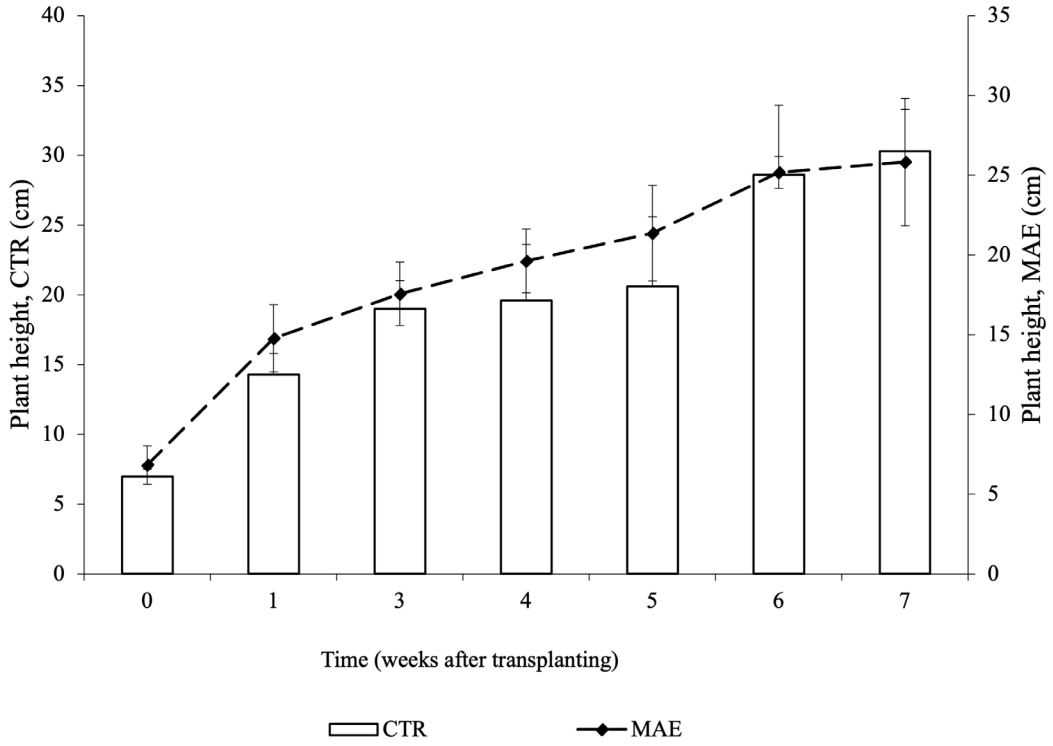

Figure 2: Mean height of test plant in the built environment (MAE) as a whole against those collected from the control site (CTR).

Table 2 shows the day of flowering of *E. indica* after transplanting and the number of tillers after 49 days of transplanting. The result given for the numbers of tillers are the mean values. The built environments started flowering between 8 – 29 days after transplanting compared to the control (8 days after transplanting). The built environments had a number of tillers ranging from 3 – 6 after 49 days of transplanting as compared to the control having 5 tillers after 49 days of transplanting.

Table 2: Plant parameters showing the day of flowering and number of tillers (results presented to the nearest whole number)

	Day of Flowering (after Transplanting)	Number of additional tillers
Hospital dumpsite	8^{d}	6^{a}
Filling station	21^{b}	5^{ab}
Transformer	29^{a}	5^{ab}
Bakery periphery	8^{d}	4^{ab}
School hostel field	16^{b}	4^{ab}
Church main field	21^{b}	6^{a}
Airport field	17^{bc}	5^{ab}
Hotel lawn	16^{bc}	4^{ab}
Mechanic workshop	15^{c}	4^{ab}
Roadside	21^{b}	3^{b}
Capitol (Control)	8^{d}	5^{ab}
Mean	15	5
P-value	<0.001	0.109

The morphological characteristics of *E. indica* after seven weeks of transplanting are presented in Table 3. There were no significant differences in spike length in *E. indica* collected throughout the built environment where in spike length ranged from 2.5 – 7.2cm compared to the control (8.90 cm). Number of spikes per plant in *E. indica* obtained from the built environment ranged from 3 – 8 per plant compared to 5 in the control. There was a significant decrease in the number of spikelets per plant. This parameter decreased from 95 per plant in the control sample to as low as 34 per plant in *E. indica* collected from the Hotel lawn, and 40 spikelets per plant in *E. indica* collected in the Mechanic workshop. Similarly, significant decreases in leaf area were reported from 12.42 cm² in the control to a range of 3.51 – 8.69 cm^2 in *E. indica* plants collected from the built environment. Although minimal differences in plant root weight occurred across the various sampling locations, significant decrease however in shoot weight was reported when shoot dry weight of *E. indica* collected from the control site (1.38 g) was compared to those collected from the built sites (1.15 g) (Table 3). The characteristics of roots of *E. indica* exposed to experimental soil for seven weeks upon transplanting from the various built environment and the control have been presented (Table 4). Results showed a significant decreases in main root length when *E. indica* collected from the control site (32.4cm) was compared with those collected from the built environment (16.4 – 29.0cm). However, there were no significant differences in the number of primary roots observed in the plants (8 – 13 primary roots per plants). In terms of prominent root color, results showed differences in the presentation of root color ranging from Peru to Chocolate. Both Peru and Chocolate were the most predominant brown color shades reported for *E. indica* roots.

Table 3: Plant parameters upon exposure for seven weeks to experimental conditions

	Plant height (cm)	Spike length (cm)	*Number of spike	*Number of spike-let	Leaf length (cm)	Leaf area (cm^2)	Weight (g)	
							Root	Shoot
Hospital dumpsite	20.0^{c}	2.5^{c}	4^{b}	62^{b}	17.5^{ab}	4.59^{b}	0.19^{c}	0.27^{c}
Filling station	20.0^{c}	$4.5b^{c}$	8^{a}	52^{b}	13.3^{b}	5.85^{b}	0.37^{bc}	0.99^{a}
Transformer	28.0^{ab}	3.4^{bc}	4^{b}	50^{b}	15.6^{ab}	4.05^{b}	0.32^{bc}	0.54^{bc}
Bakery periphery	25.0^{bc}	5.4^{bc}	5^{b}	46^{bc}	15.2^{ab}	4.05^{b}	0.22^{c}	0.69^{bc}
School hostel field	32.0^{a}	4.4^{bc}	4^{b}	47^{bc}	16.5^{ab}	5.94^{b}	0.24^{c}	0.88^{ab}
Church main field	26.0^{abc}	3.2^{bc}	4^{b}	42^{c}	12.4^{b}	4.32^{b}	0.43^{bc}	1.14^{a}
Airport field	33.3^{a}	4.6^{bc}	6^{ab}	56^{b}	14.7^{b}	5.04^{b}	0.31^{bc}	0.75^{b}
Hotel lawn	24.6^{bc}	4.1^{bc}	3^{b}	34^{c}	13.3^{b}	3.51^{b}	0.35^{bc}	0.54^{bc}
Mechanic workshop	23.3^{bc}	3.7^{bc}	5^{ab}	40^{c}	15.6^{ab}	5.48^{b}	0.17^{c}	0.67^{b}
Roadside	26.0^{abc}	7.2^{ab}	3^{b}	89^{a}	19.3^{ab}	8.69^{a}	0.56^{ab}	1.15^{a}
Capitol (Control)	30.3^{a}	8.9^{a}	5^{ab}	95^{a}	23.3^{a}	12.42^{a}	0.54^{a}	1.38^{a}
Mean	25.8	4.58	4.72	54.8	15.3	5.25	0.35	0.85
p-value	0.008	0.069	0.007	0.018	0.092	<0.001	0.051	0.001

Means on the same column with similar alphabetic superscripts do not differ from each other (P>0.05)

*Results presented to the nearest whole number

Rhizoacidicity of *E. indica* roots

A Rhizoacidity test was conducted to assess the capacity of *E. indica* to exude organic acids. The results presented in Table 4 show the capacity for the roots to exude acids. This was confirmed using a litmus test, which presented a color range of deep red (strongly acidic) to pink (slightly acidic). In the present study, rhizoacidity was positive indicating possibility for organic acid exudation by the root of *E. indica*. Although slight acid exudation was suspected in the control plant, it was however reported that the majority of the plants obtained from the built environment showed strong rhizoacidity (Figure 4).

Table 4: Plant root parameters upon exposure for seven weeks to experimental conditions

	Root length (cm)	No. of primary roots	No. of primary roots with sec. branches	Prominent root color	Rhizoacidity
Hospital dumpsite	18.2^{cd}	10^{a}	5^{b}	Peru	++
Filling station	16.4^{d}	11^{a}	6^{b}	Lemon chiffon	++
Transformer	20.2^{cd}	10^{a}	4^{b}	Pale goldenrod	+++
Bakery periphery	27.5^{bc}	11^{a}	5^{b}	Sandy brown	++
School hostel field	27.3^{bc}	13^{a}	9^{ab}	Chocolate	+
Church main field	18.7^{cd}	10^{a}	6^{b}	Sandy brown	++
Airport field	19.9^{cd}	8^{a}	6^{b}	Chocolate	++
Hotel lawn	15.5^{d}	10^{a}	5^{b}	Chocolate	+
Mechanic workshop	27.9^{bc}	10^{a}	8^{ab}	Peru	+++
Roadside	29.0^{b}	9^{a}	7^{ab}	Peru	+++
Capitol (Control)	32.4^{a}	11^{a}	12^{a}	Chocolate	+
Mean	22.6	10	6	**Peru	***+++
p-value	0.014	0.092	0.003		

*Rhizoacidity was determined by simple litmus test. +++ Deep Red (strong acid), ++ orange (acidic exudation), +pink (slight acidic exudation), **most prominent root colour, *** most prominent rhizoacidity status, Means on the same column with similar alphabetic superscripts do not differ from each other (P>0.05)

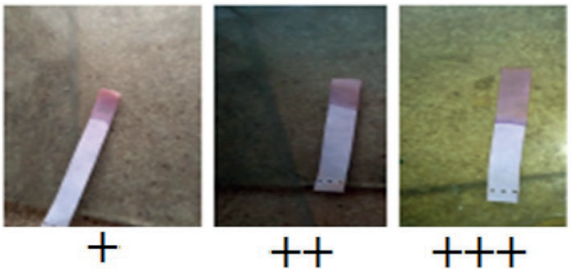

Figure 3: Rhizoacidity test. (+++ Deep red showing strong acid, ++ Orange showing medium acidic exudation, and + Pink showing slight acidic exudation)

Accumulation of iron, phosphorus and potassium by *E. indica*

Table 5 shows the Potassium content of soil as well as accumulation by plants at seven weeks after transplanting. Residual K content in the soil ranged from 3.20 – 8.10 mg/kg, ($P<0.05$). Plant shoots significantly accumulated K compared to the roots; K content in plant roots ranged from 13.2 – 30.2 mg/kg compared to rhizoaccumulation of the element (2.10 – 6.80 mg/kg). Although there were minimal differences in K accumulation in the built environment compared to the control, this was not significant. Results showed that K content in the shoot of *E. indica* collected from the control site was significantly lower when compared with the shoot of those collected from the built environment.

Table 5: Potassium content of soil and accumulation by plant shoot and roots at seven weeks after transplanting

	Soil (Residual) (mg/kg)	Shoot (mg/kg)	Root (mg/kg)
	Initial soil conc. - 0.89mg/kg		
Hospital dumpsite	8.1^{a}	25.5^{abc}	2.3^{a}
Filling station	4.1^{a}	16.3^{cd}	3.8^{a}
Transformer	6.2^{a}	13.2^{d}	4.2^{a}
Bakery periphery	7.1^{a}	30.1^{a}	3.6^{a}
School hostel field	8.1^{a}	28.7^{ab}	2.6^{a}
Church main field	3.3^{a}	18.7^{bcd}	3.5^{a}
Airport field	5.8^{a}	20.4^{abcd}	2.1^{a}
Hotel lawn	6.5^{a}	15.2^{cd}	2.9^{a}
Mechanic workshop	3.2^{a}	30.2^{a}	3.8^{a}
Roadside	7.1^{a}	23.2^{abcd}	2.3^{a}
Capitol (Control)	6.3^{a}	13.5^{d}	6.8^{a}
p-value	0.212	0.006	0.621

Means on the same column with similar alphabetic superscripts do not differ from each other ($P>0.05$)

Iron content of the soil as well as accumulation by the root and shoots of the test plants after seven weeks have been presented (Table 6). Results however showed that there were no significant differences in the residual Fe content in soil upon removal of *E. indica* (120 – 171 mg/kg). Therefore, this indicated that the location from which *E. indica* was collected may not necessarily affect its capacity of Fe removal in the soil. Furthermore, the concentration of Fe in the shoots of *E. indica* collected from the control site minimally differed from those obtained in the control plants apart from those from the hospital dumpsite (8.20 mg/kg), filling station (6.90 mg/kg), transformer (4.90 mg/kg), hotel lawn (5.40 mg/kg) as well as mechanic workshop (8.80 mg/kg) when compared with the control (17.70 mg/kg).

Table 6: Iron content of soil and accumulation by plant shoot and roots at seven weeks after transplanting

	Soil (Residual) (mg/kg)	Shoot (mg/kg)	Root (mg/kg)
	Initial soil conc. - 298.1mg/kg		
Hospital dumpsite	131^{a}	8.2^{bc}	11.3^{ab}
Filling station	121^{a}	6.9^{bc}	13.2^{ab}
Transformer	155^{a}	4.9^{c}	16.9^{a}
Bakery periphery	153^{a}	11.3^{ac}	16.8^{a}
School hostel field	157^{a}	13.8^{ab}	14.2^{ab}
Church main field	171^{a}	10.5^{abc}	18.6^{a}
Airport field	120^{a}	10.1^{abc}	15.5^{a}
Hotel lawn	126^{a}	5.4^{bbc}	16.5^{a}
Mechanic workshop	149^{a}	8.8^{bc}	16.3^{a}
Roadside	126^{a}	15.8^{a}	11.9^{ab}
Capitol (Control)	155^{a}	17.7^{a}	6.9b
p-value	0.388	0.027	0.049

Means on the same column with similar alphabetic superscripts do not differ from each other (P>0.05)

The concentration of total Nitrogen in the soil was not significantly impacted by the presence of *E. indica* irrespective of the location from which the plant was collected. Total N content from the built environment ranged from 0.28 – 0.892 mg/kg compared with 1.578 mg/kg in the control ($p<0.05$). Similarly shoot and root accumulations of N were not significantly impaired due to differences in location from which *E. indica* was collected (Table 7). Table 8 shows total P content of soil as well as accumulation patterns by plant shoot and roots at seven weeks after transplanting. There were no significant differences in residual P content of soil when sown with plants obtained from the built environment (0.109 – 0.166 mg/kg) compared to 0.131 which was obtained in the control site. Similarly, there were no significant differences in shoot accumulation (0.111 – 0.204) and root accumulations (0.106 – 0.339 mg/kg). This implies that the shoots accumulated as much as the roots ($p>0.05$). The background concentration of P as reported was 0.138 mg/kg. The fact that there was no significant reduction in P in the soil after the removal of plants but minimal increase underscores the importance of E. indica in enhancing soil phosphate content (Table 8).

Table 7: Total Nitrogen content of soil and accumulation by plant shoot and roots at seven weeks after transplanting

	Soil (Residual) (mg/kg)	Shoot (mg/kg)	Root (mg/kg)
	Initial soil conc. - 0.101mg/kg		
Hospital dumpsite	0.396[b]	0.219[a]	0.512[a]
Filling station	0.287[b]	0.127[a]	0.233[a]
Transformer	0.351[b]	0.136[a]	0.244[a]
Bakery periphery	0.819a[b]	0.314[a]	0.667[a]
School hostel field	0.228[b]	0.202[a]	0.154[a]
Church main field	0.329[b]	0.093[a]	2.487[a]
Airport field	0.709[b]	0.128[a]	0.365[a]
Hotel lawn	0.246[b]	0.141[a]	0.252[a]
Mechanic workshop	0.892[ab]	0.289[a]	0.283[a]
Roadside	0.783[a]	0.212[a]	0.203[a]
Capitol (Control)	1.578[a]	0.306[a]	0.183[a]
p-value	0.069	0.247	0.325

Means on the same column with similar alphabetic superscripts do not differ from each other (P>0.05)

Table 8: Phosphorus content of soil and accumulation by plant shoot and roots at seven weeks after transplanting

	Soil (Residual) (mg/kg)	Shoot (mg/kg)	Root (mg/kg)
	Initial soil conc. - 0.138mg/kg		
Hospital dumpsite	0.171[a]	0.204[a]	0.109[a]
Filling station	0.122[a]	0.125[a]	0.113[a]
Transformer	0.135[a]	0.125[a]	0.106[a]
Bakery periphery	0.114[a]	0.146[a]	0.127[a]
School hostel field	0.118[a]	0.142[a]	0.143[a]
Church main field	0.118[a]	0.113[a]	0.339[a]
Airport field	0.166[a]	0.111[a]	0.115[a]
Hotel lawn	0.109[a]	0.118[a]	0.114[a]
Mechanic workshop	0.117[a]	0.149[a]	0.137[a]
Roadside	0.122[a]	0.114[a]	0.101[a]
Capitol (Control)	0.131[a]	0.123[a]	0.112[a]
p-value	0.142	0.135	0.103

Means on the same column with similar alphabetic superscripts do not differ from each other (P>0.05)

Discussion

Ferruginous soil affects growth and development of ruderals such as *E. indica* because of the poor soil organic matter, organic carbon, available phosphorus, and cation exchange capacity, which is required by plant and soil biota (Ibrahim and Ikhajiagbe, 2020). In this study, the plant height of *E. indica* collected from various sites in Benin City varied significantly from that of the control (Figure 2). The control (Capitol) showed the highest growth of 35cm while the plants collected from the hospital had the least growth of about 15.60 cm. This is probably due to medical wastes released from hospitals into dumpsites around, these wastes include infectious wastes, hazardous wastes, radioactive wastes and general municipal solid wastes (Malsparo, 2016). These wastes may contain chemicals that accumulate in the tissues of plants.

Heavy metal presence in soils would adversely impact all living things; these metals such as arsenic, cadmium, lead, and mercury can accumulate in food chains that humans and animals consume (Malsparo, 2016). Plants collected near the transformer (Table 2) showed the longest flowering time (29 days after transplanting). This observation may not be directly linked to the amount of iron in the soil, even though the E. indica collected near the transformer showed a significant accumulation of Fe. The previous study has stated that iron deficiency induces abnormal flowering in plants while an ample amount of Fe improves flower formation (Smith et al., 1957). Fe plays a role in improving meristematic cell division (Hilo et al., 2017). This may significantly enhance tillering in the weed. This was reported in plants collected around the built environment than from the control site. Upon exposure for seven weeks to experimental conditions, various plant parameters were determined (Table 3). The length of spikes showed no significant difference on the filling station, transformer, bakery periphery, school hostel field, main church field, airport field, hotel lawn and mechanic workshop. However, there was a significant difference between the control, roadside and hospital dumpsite. The plants collected from the roadside had a spike length of 7.20 cm lower than the control (8.90 cm). This may be due to exposure of the plants to fumes and motor vehicle gases. Fumes have been reported to have an inhibitory effect on the growth of plants, especially NO(x), which is the key phytotoxic component of exhaust emissions (Bell et al., 2011). However, the hospital dumpsite showed the least spike length (2.50 cm). Put together, the changes in *E. indica* morphology might be expressive of their tolerant capacity to the ferruginous soil and stress from the built environment.

The leaf length of *E. indica* was also measured (Table 3) after seven weeks. There was a significant difference between the control and all other treatments. The roadside did not differ from the mechanic workshop, hostel school field, bakery periphery, transformer, and hospital dumpsite. The filling station, main church field, airport field, and hotel lawn showed no significant difference. It has been reported that air pollutants cause damage to leaves by damaging their cuticles and stomatal conductance; they can also affect photosynthetic systems, leaf longevity and patterns of carbon allocation within plants (Winner and Atkinson, 1986). As for the leaf area, there was a significant difference between the control and all locations except roadside. The lowest value was given in hotel lawn, 3.51cm^2 as opposed to the control 12.42cm^2. Studies have shown that high amount of iron in the soil increase leaf area of W. murcott (Citrus x Nobilis), this may be because low iron negatively affects chlorophyll content and other components of chloroplast which reduces growth capacity (Incesu et al., 2015). The number of spikes on the test plants were observed. There was no significant difference between the control, mechanic workshop and airport field. There was no significant difference between the hospital dumpsite, transformer, bakery periphery, school hostel field, church main field, hotel lawn and roadside. The lowest recorded values were from the roadside and hotel lawn (3) while the highest values were from the filling station (8). Regarding plant root parameters upon exposure for seven weeks to experimental conditions, the control site had the highest root length (32.40 cm) as compared to other sites (16.40 – 29.00 cm). This difference in primary root length may be a result

of excess iron in the roots of *E. indica*. Primary root growth inhibition has been reported to be as a result of high concentrations of Fe in roots (Ward et al., 2008). The roots of the *E. indica* collected from the built environments may have taken up more Fe than the *E. indica* collected from the control, this may have resulted in their root length being shorter than that of the control plants. Similarly, the control plants showed slight acidic exudation, this is in accordance with studies conducted by Chen et al. (2018). They state that grasses utilize the chelation strategy for iron accumulation; this strategy involves the exudation of acidic chelating phytosiderophores like mugineic acid. The rhizoacidity of *E. indica* collected from the built environments were significantly higher than those from the control sites indicating that more phytosiderophores were exuded from the roots. Although the control site had the highest number of primary roots with secondary branching (12) compared to the built environments (4 – 9) with the highest being the school hostel field. These results may be connected to the amount of Fe absorbed by the roots of *E. indica*. Previous studies have revealed that iron can be directly linked to the formation of adventitious roots, plants in iron deficient soil showed a lesser number of secondary roots according to the study conducted by Hilo et al. (2017). It has been reported that the amount of Potassium a plant absorbs is dependent on species, concentration of K in soil and relative amounts of Ca^{2+} and Mg^{2+}. A high amount of Ca^{2+} and Mg^{2+} decreases the accumulation of K. In soybeans, Ca^{2+} decreases the velocity of the metabolic phase of K uptake. However, it increases the affinity of K and its carrier (Chen et al., 2018). Studies have shown that transpiration affects the amount of P in shoots and roots. Accelerated flow of water promotes uptake and xylem transport of K to the shoot significantly decreasing K content in roots (Kahn and Hanson, 1957).

Factors like light intensity, pH availability and other nutrients affect the distribution and accumulation of iron in plant shoots and roots. High pH (8.5) has been reported to decrease the uptake and specific activity of iron in soybeans (Wallace et al., 2008). The results from Table 6 show that *E. indica* has the ability to rehabilitate ferruginous soils. In a previous study, Ikhajiagbe et al. (2019) explained that the ability of *E. indica* to alter cation exchange capacity and other soil properties may be linked to their ferruginous soil remediation and rehabilitation capacity. This ability may stem from its innate capacity to absorb and accumulate iron. Gramineous plants utilize chelating strategy for iron accumulation where phytosiderophores such as mugineic acid (MA) are released into the rhizosphere to chelate Fe^{3+} directly. The resulting Fe(III) – PS complexes are absorbed by root cells via proteins (Chen et al., 2018). This may also account for the acidity of *E. indica* roots represented in Table 5.

Nitrogen accumulation in plant shoots and roots are dependent on amount of light and on other nutrients. High light intensity reduces accumulation of N. Although P has no effect on N accumulation, K affects N accumulation with direct proportionality (Canliffe, 1973). Light also affects the amount of N in shoots as reported by (Agren and Franklin, 2018), high light intensity increases number of leaves in shoot and high leaf number increases N in shoot. Excess iron has been reported to decrease the uptake of N in grasses leading to deficiency of N to plants. Both nutrients acting in opposition to each other as N has also been reported to interfere with Fe nutrition by raising soil pH leading to chlorosis. The residual Nitrogen content of the soil (between 0.228 – 1.578 mg/kg) was observed to be higher than the initial concentration (0.101 mg/kg). This may result from interactions between N and Fe in soil (excess iron decreases N) (Fageria, 2008). However, *E. indica* has shown that it has the ability to remove Fe from the soil (Table 7). This removal may have led to the increase of N in soil after seven weeks since the total iron in the soils have been reduced. Crops typically obtain Phosphate from weathered minerals and dissolved fertilizers. Plants absorb P in the inorganic form. It has been reported that P availability in soil depends on how much it is adsorbed or desorbed by iron oxides (Fink et al., 2016). This may be responsible for the minimal increase in P in soil after seven weeks (Table 8), *E. indica* absorbed Fe giving rise to more P in soil.

Conclusion

The results obtained from this study indicated that *E. indica* was capable of restoring the nutrient balance of ferruginous ultisols. The ferruginous utisol restoration capacity of *E. indica* is not dependent on the collection site as all *E. indica* plants were able to reclaim the soil. Ferruginous soils are predominant in Benin City and, due to their low fertility status, reduce the region's agricultural productivity. It is therefore important that efforts should be made for the restoration of these soils using *E. indica*, this method is of great importance as it is economical, environmentally friendly and easy to carry out.

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