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Spatial Analysis and Mapping of Soil Nutrient Levels in *Eucalyptus* Woodland: A Case Study of Pattoki, Kasur

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Abstract. The deficiency of micronutrients in soil caused by *Eucalyptus* has been investigated at three sampling sites in Pattoki, Punjab, Pakistan. *Eucalyptus* absorb more water and nutrients than the other trees usually absorb. One *Eucalyptus* tree absorbs the water of about 100 trees. *Eucalyptus* makes the soil nutrient deficit. The major problem is that *Eucalyptus* are affecting the soil moisture and the nutrients of the soil. The objectives of the study, a point-centered quarter sampling technique was used to collect the soil samples. Which were taken at the depth of 36. The main biological activity lies in these organic horizons (0-30 cm). Soil sample analysis demonstrated that the soil pH of the concerned study area was alkaline. The micronutrient contents (B, Zn, OM and P) were highly deficient in all selected sites. Moreover, significantly higher concentrations of Ca were identified in the study area. The linear regression model was applied to validate the relationship between variables. The study showed that sole cultivation of *Eucalyptus* tends to lower soil fertility and therefore, detailed investigation of nutrient dynamics and their effects on soil quality is a dire requirement. Cultivation of *Eucalyptus* only has a propensity to lower soil fertility by depletion of important soil nutrients (B, Zn and P). Based on results, it is recommended to interplant *Eucalyptus* with other leguminous plants and in addition to good agronomic practices such as the use of nitrogenous and phosphate fertilizers to replenish the nutrient availability and biological activity in the soil associated with *Eucalyptus* planting.

Keywords: deficiency, nutrient deficit, micro-nutrients, macro-nutrients, soil nutrients

Introduction

Trees are an essential component of the environment as, they regulate the temperature of the earth and provide oxygen, which is necessary for human beings and animal species' survival. They also provide food, shelter and habitat to the wildlife. Trees are beneficial but not all species of trees are profitable to the environment, some trees may also harm the environment with their damaging traits (Stone, 2017). Some trees have harmful characteristics that affect their surrounding atmosphere and other plant species as well (Viera *et al*., 2016). Typically, *Eucalyptus* trees are classified as Myrtaceae. There are more than 700 *Eucalyptus* species in the world. In many countries, *Eucalyptus* is found in enormous amounts but most species are found in larger quantities in Australia. There are more than 700 species of *Eucalyptus* in Australia and only small amounts of *Eucalyptus* are present in the outlying areas of New Guinea and Indonesia (Kaur *et al*., 2021). *Eucalyptus* is cultivated primarily in the World's tropical and temperate areas, such as America, Europe, Africa, the Mediterranean Basin and Asian regions such as China and Pakistan (Ali *et al.*, 2009; Baber *et al.*, 2006). Since *Eucalyptus* has been planted in many parts of the world as it supplies wood and pulp for various uses, apart from its benefits, it has more effects that are negative as it influences soil fertility and often subsides the water table. Sole plantation of *Eucalyptus* may slacken off the soil resources including the groundwater levels (Epeldel *et al.*, 2009; Davidson, 1993). Carbon stocks present in the soil may also fluctuate by 38 to 40% (Correia *et al.*, 2014) which affects the soil micro climate ultimately (Rizvi *et al.*, 2012).

As observed by Animon *et al*. (1999) that due to *Eucalyptus* small percentages of nitrogen (N) were found in low levels in the soil. Due to *Eucalyptus* mineral cations present in the soil are also decreased (Bueis, 2016; Jobbag and Jackson, 2003). Several studies have been carried out on *Eucalyptus*, which shows that it has an allelopathic effect on its surrounding species

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and the environment. Dellacassa *et al*. (1989). Carbon stocks present in the soil are also decreased by 40 and 38% respectively. Martín *et al*. (2016) demonstrated in his study that the biomass carbon (C) and nitrogen (N) were considerably decreased, which are low in quantity in *Eucalyptus* plantations. The area, where *Eucalyptus* is planted is areas having extreme weather conditions that include high acidic soil, intense weathering and great nutrient extraction from the soil (Guedes *et al*., 2016; Martin *et al*., 2016). *Eucalyptus* plantation has a great effect on carbon (C) pools and nutrient status mostly in tropical soils. According to (Imtiaz *et al*., 2010; Brown *et al*., 1990) many elements are affected in the soil, where *Eucalyptus* is planted, those include soil PH, organic carbon, total nitrogen and calcium and cations present in the soil are affected most probably. The plantation of *Eucalyptus* is contentious, as they are harming the environment by depleting the ground water, uplifting erosion, impairing the watershed, encouraging forest fires, intimidating the occurrence of native flora with allelopatahy and prodigious roots (Zerga *et al*., 2021; Mohsin *et al*., 2020).

Serious environmental issues rises in areas, where *Eucalyptus* is grown, as they requirement for nutrients are excessive rather than other plant species, this excessive need of nutrients causes nutrient depletion in the soil that voluminously effect the biological condition of the soil. They causes problem in areas where they are planted in semi-arid water catchment areas as they reduce the total water yields in those areas and soon water table in those areas will be depleted (Syed *et al*., 2021; Jobbágy and Jackson, 2003).

López-Poma *et al.* (2020) demonstrated in their study that the biomass carbon (C) and nitrogen (N) were considerably decreased are low in quantity in *Eucalyptus* plantations. The area, where *Eucalyptus* is planted is described as the area having extreme weather conditions that include highly acidic soil (Rizvi *et al.*, 2012), intense weathering and excessive nutrient extraction from the soil (Martin *et al*., 2016; Davidson, 2006). *Eucalyptus* plantation has a great effect on C pools and nutrient status mostly in tropical soils. Many elements are affected in the soil, where *Eucalyptus* is planted, those include soil pH, organic carbon, total nitrogen and Ca and cations present in the soil are affected most probably (Leikam *et al*., 2003). The change in soil nutrient status and microclimate can change the biological activity and carbon storage (Korchagin *et al.*, 2019; Khattak and Hussain, 2007). *Eucalyptus* was introduced in Pakistan in 1843 but it was not planted until 1950. The *Eucalyptus* plantation started in Pakistan in 1981 in seven different districts. 3500 species of *Eucalyptus* have been planted in Pakistan till the year 1996 (Liang *et al.*, 2016; Ahmed *et al.*, 2008). As the *Eucalyptus* trees increased in Pakistan it is important to investigate, the impact of *Eucalyptus* on the soil conditions, especially the moisture contents. Therefore, the main objectives of this research are, to identify the spatial variations of *Eucalyptus* and analysis of the loss of micro-nutrients in *Eucalyptus* planted soils in Pattoki, Punjab, Pakistan.

Materials and Methods

Study area. The presented study was carried out in the tehsil Pattoki, Kasur district. The sampling sites were located at 73°43′′8′E longitude and 31°7′′20′N latitude, 73°50′′45′E longitude and 31°1′′8′N latitude, 73°46′′26′E longitude and 30°58′′23′N latitude. The soil of the study area is alkaline but some areas have fewer amounts of organic matter and phosphorus (Department of Agriculture, 2014). Due to this soil property, many plants species, including *Eucalyptus* are found in the study area. Figure 1(a, b and c) shows the location of the study area and sampling sites.

Soil sampling. Soil sampling was done by Point-centered quarter sampling method. For sampling, three sites were chosen. A total of 30 samples were taken from three sites, ten samples from each site. The soil samples were taken after every 6 trees and approximately at a depth of 36 cm near the active root was collected. The collected soil samples were analyzed in the laboratory for estimating the concentrations of calcium (Ca), zinc (Zn), iron (Fe), boron (B) and manganese (Mn), electrical conductivity (EC), pH, organic matter, available phosphorus, available potassium and saturation percentage (Fig. 2). The standard for pH and nutrients at the laboratory are mentioned in Tables (1 and 2).

GIS and statistical analysis. The inverse distance weighted (IDW) method is used to estimate the deficiency of nutrients in the soils. The linear regression model was applied to the deficiency of nutrients and their standards to test whether the hypothesis was accepted or rejected. The range of R^2 value is between -1 to +1 if the R^2 value is closer to +1 shows the positive strong relation between variables and if the value is near to 0 it shows a weak relationship between variables. The formula used for the regression model was:

$$Y = a + bx$$

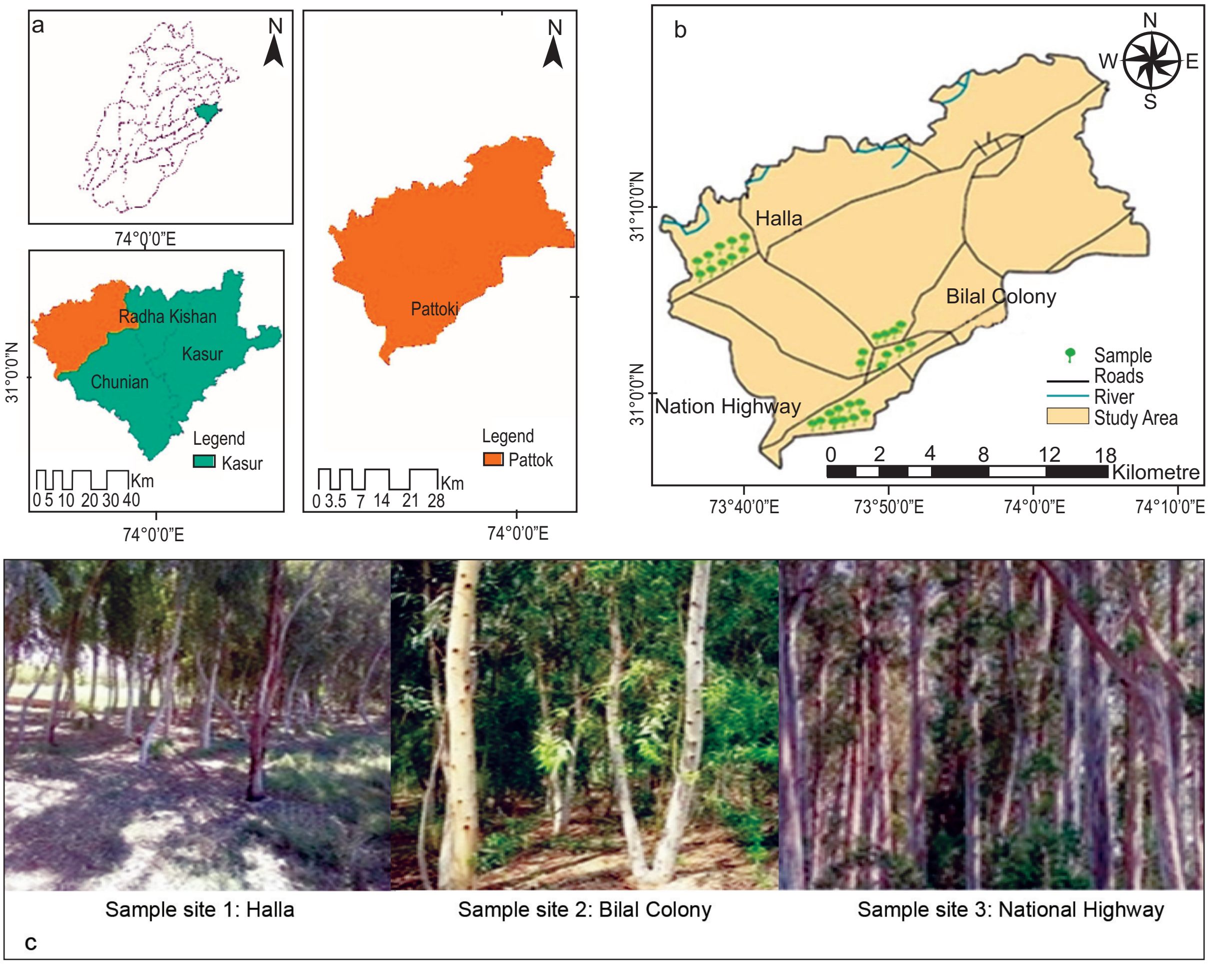

Fig. 1. (**a**) Shows the location of the study area and (**b** and **c**) sampling sites in Pattoki.

Fig. 2. Soil samples and testing laboratory.

Results and Discussion

Deficiency of nutrients in the soil. *Eucalyptus* has developed nutrient deficiency in the soil around the *Eucalyptus* plants. *Eucalyptus* influences the soil in two ways. Firstly, *Eucalyptus* reduced the micro-nutrient in the soil but find one nutrient excessively in the soil.

Table 1. pH standards for soil

Soil pH	Condition
7.0 -7.5	All nutrients present in the soil are easily available for plants.
7.6-8.0	All nutrients are available in the soil, but the availability of zinc, iron, manganese and boron is considerably low.
8.1-8.5	The availability of phosphorus becomes considerably low in the soil.
8.5 >	The amount of Borate is low in the soil which is necessary for agriculture.

Source: (Mohsin *et al*., 2020)

Table 2. Standards for nutrients

Nutrients	Poor	Medium	Fertile
Organic matter (%)	< 0.86	0.87-1.29	> 1.29
Phosphorus (mg/Kg)	< 7.0	7-21	> 21.0
Zinc (mg/Kg)	< 0.5	0.5-1.0	> 1.0
Potassium (mg/Kg)	< 80	80-180	> 180
Boron (mg/Kg)	< 0.2	0.2-0.5	0.5-1.0

Secondly, these plants also absorbed plenty of water and reduced the water level (Correia *et al*., 2014).

The boron deficiency (mg/Kg) caused by *Eucalyptus* is shown in Fig. 3. The highest B deficiency was observed in the southward side of the National Highway and Halla zone at a concentration of 0.01-0.02 (mg/Kg). In all three sampling areas of Bilal colony, Halla and National Highway, with a concentration of 0.13-0.14 (mg/Kg), the dark maroon color displays the high deficiency as B (see Table 3). Boron is one of the micro-nutrients present in the soil, but the lack of B influences vegetation and soil in different ways, it reduces the reproduction or reproductive growth of plants as well as the vegetative growth of plants and also decreases the fertility of plants.

Linear regression analysis shows the relationship between deficiency of B caused by *Eucalyptus* plant and standards of B for the fertile soil (Fig. 4) and Table 3 shows the mean values of pH boron deficiency and the standard value of boron. The mean pH value ranges from 7.6-7.9 marked as B is considerably low. The optimum B content for major plants is 20-100 ppm and the amount of B in any soil is about 1.1 Kg/ha but the above figure showed the less amount of B available in the soil to fulfill the needs. The R^2 values (0.999, 0.989 and 0.987) showed a positive relationship between deficiencies of B caused by the *Eucalyptus* growth.

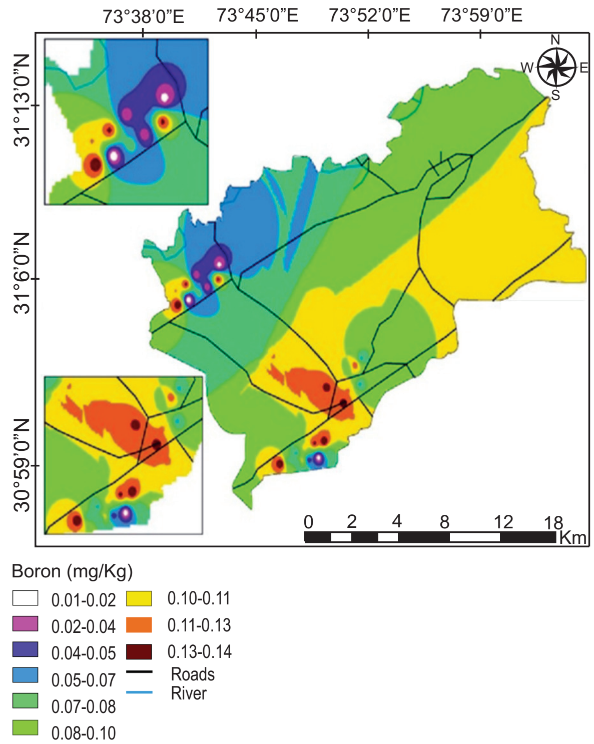

Fig. 3. Deficiency of Boron (mg/Kg) in sampling sites.

Table 3. Standards, deficiency of Boron (mg/Kg) and pH of soil

Sample sites	Mean deficiency	Standard	Mean pH
Halla	0.095	0.5	7.6
Bilal colony	0.16	0.5	7.8
National highway	0.08	0.5	7.9

Boron is reduced in the soil up to great extent mainly approximately 1/4 of the given standard. It is important to replace *Eucalyptus* with more beneficial trees like *Azadirachta indicia* (neem tree) and *Ficus riligiosa* (peepal tree) that will be beneficial for people and the surrounding plant species.

Figure 5, map illustrated the deficiency of Zn (mg/Kg) caused by the *Eucalyptus* in the three sampling sites, white colour shows the highest deficiency of Zn that was 0.01-0.06 (mg/Kg) found along the National Highway and the dark maroon colour showed the medium deficiency of Zn in sample sites ranging from 0.44-0.49 (mg/Kg) as fertile soil have Zn greater than 1 (mg/Kg) (Table 2). Zinc is important for the internode elongation of plants and growth hormone production.

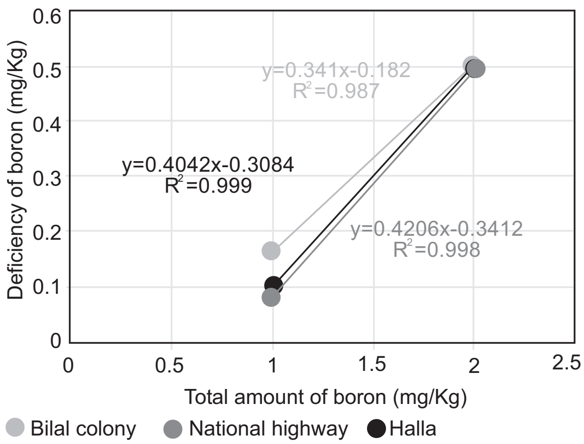

Fig. 4. Linear regression analysis on scarcity and the total amount of Boron in sampling sites.

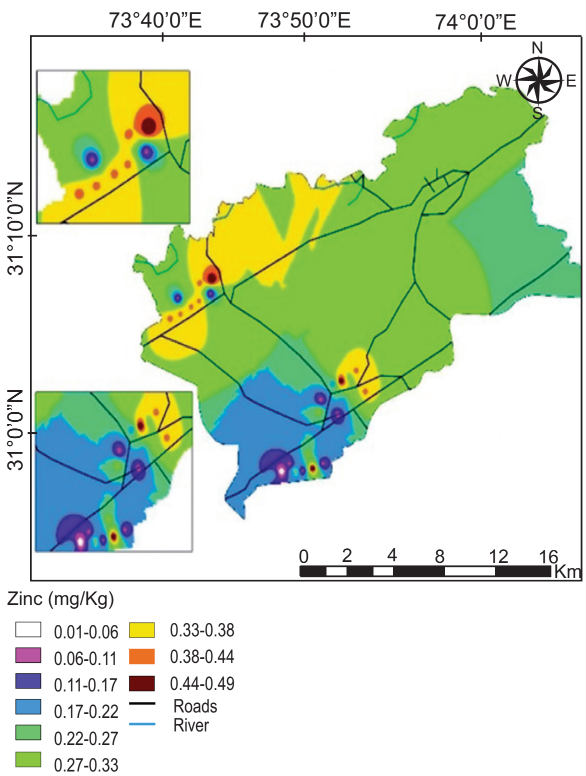

Fig. 5. Deficiency of zinc (mg/Kg) in sampled sites.

The deficiency of Zn results in a wide range of a substantial loss of crop yields (Imtiaz *et al*., 2010) and as well, as degrades the quality of the crop yield and the nourishing plants. Therefore, *Eucalyptus* is responsible for degrading the amount of Zn in soil that degrades the soil.

Figure 6, shows the linear regression analysis between the standard of Zn and scarcity of Zn (mg/Kg) caused by the *Eucalyptus*, and Table 4 showed the mean of Zn deficiency, the standard of Zn and mean of pH values of the soil. The mean pH value ranges from 7.6-7.9 illustrating that amount of Zn was not meet with standards. The Zn requirements of different plants vary but the optimum Zn content for plants ranges from 5-100 Kg/ha and the above figure shows less amount of Zn available in the soil to fulfill the needs. The R2 value showed a positive relationship between variables. *Eucalyptus* reduces the amount of Zn in soil up to a great extent approximately 1/3 of the given standard.

Figure 7, map shows the deficiency of P (mg/Kg) in the three sampling sites. The white colour shows the highest deficiency of phosphorus that was found at Halla and National Highway with the range of 0.46-0.85 (mg/Kg). The dark maroon colour shows the high deficiency ranging from 3.59-3.98 (mg/Kg) found in the soil of all three sampling sites. Probably all sample sites experience high deficiency as the fertile soil has phosphorus >21 (mg/Kg) (Table 2). Phosphorus plays many vital roles in the growth of plants including respiration, photosynthesis, cell enlargement, cell

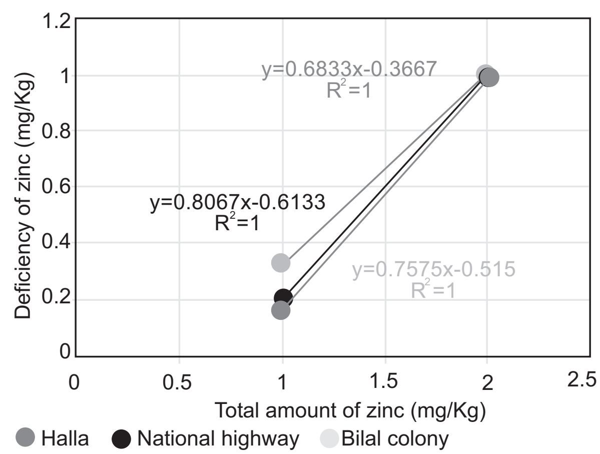

Fig. 6. Linear regression analysis on scarcity and the total amount of zinc in sampled sites.

Table 4. Standards, deficiency of zinc (mg/Kg) and pH of soil

Sample sites	Mean deficiency	Standard	Mean pH
Halla	0.31	1	7.9
Bilal colony	0.24	1	7.5
National highway	0.19	1	7.6

division, energy storage, transfer and many other processes. *Eucalyptus* makes the soil Phosphorus deficit and harms the plants and their growth structure.

The relationship between phosphorus deficiency (mg/Kg) and phosphorus levels for fertile soil and other plant species is shown by the linear regression analysis (Fig. 8) and Table 5 shows the mean pH value and mean soil deficiency. The pH value ranges from 7.6-7.7, showing that pH is slightly alkaline. The soil pH affects the supply of phosphorus for plants. The pH ranges from 6.0-7.0 indicating the appropriate amount of phosphorus available in the soil. However, the pH level (7.6-7.9) in sample locations was high, which means that the Phosphorus requirement is not met. 30-50 ppm should be the optimal level of phosphorus in the soil

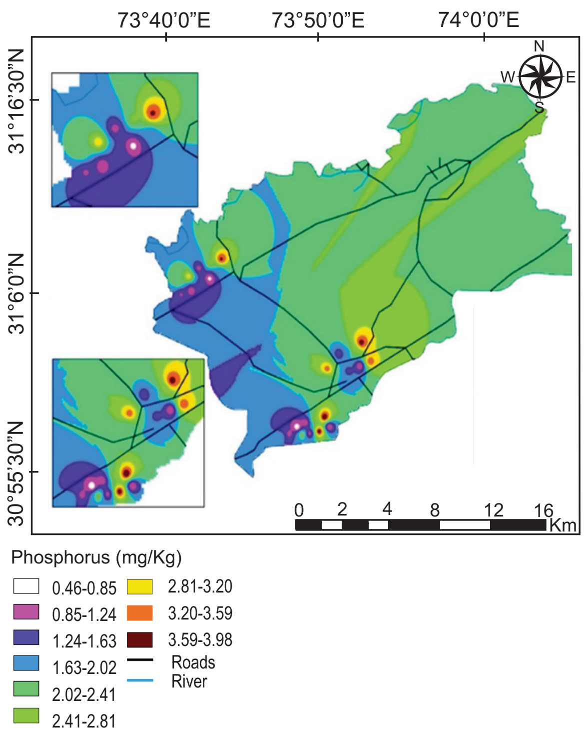

Fig. 7. Deficiency of phosphorus (mg/Kg) in sampled sites.

Table 5. Standard, mean deficiency of phosphorus (mg/Kg) and mean pH of soil

Sample sites	Mean deficiency	Standard	Mean pH
Halla	1.45	7	7.7
Bilal colony	2.35	7	7.6
National highway	2.09	7	7.7

(Leikam *et al*., 2003). *Eucalyptus* makes the soil pH alkaline due to which plants become unable to obtain the required significant amounts of nutrients. R^2 values 0.998, 0.999 and 1.0 marked as *Eucalyptus* is the source of soil deficits.

The organic matter (%) deficiency caused by *Eucalyptus* in the three sampling sites is shown in Fig. 9. The large amount of organic matter deficiency ranging from 0.76 to 0.77 (%) is seen in the white colour and it is mainly seen in all three sampling sites, including Halla, Bilal Colony and National Highway. The dark maroon colour indicates the less amount of deficiency ranging from 0.84-0.85 (%) in all three sampling sites. The light blue, jade and green colour demonstrate a mild deficiency range from 0.79 to 0.822%. Organic matter of the soil ameliorates the composition of the soil (Rizvi *et al*., 2012), the biodiversity of the soil (Rizvi *et al*., 2014) and also improves water retention and pollutant absorption and retention. *Eucalyptus* disturbed the soil organic matter of the soil because soil organic matter is maintained through decomposition and *Eucalyptus* leaves and their remaining parts do not decompose easily (Table 6).

The linear regression analysis indicates a relationship between the organic matter deficiencies (%) caused by *Eucalyptus* and the organic matter requirements for other plant species and fertile soil in Fig. 10. The soil becomes basic and often neutral when the organic matter of the soil decreases. Therefore, the range of soil organic matter 0.81-0.85 (%) was lower than their normal, so

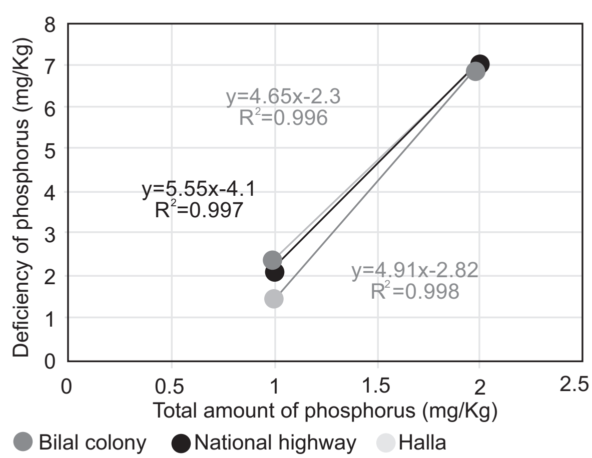

Fig. 8. Linear regression analysis on scarcity and the total amount of phosphorus in sample sites.

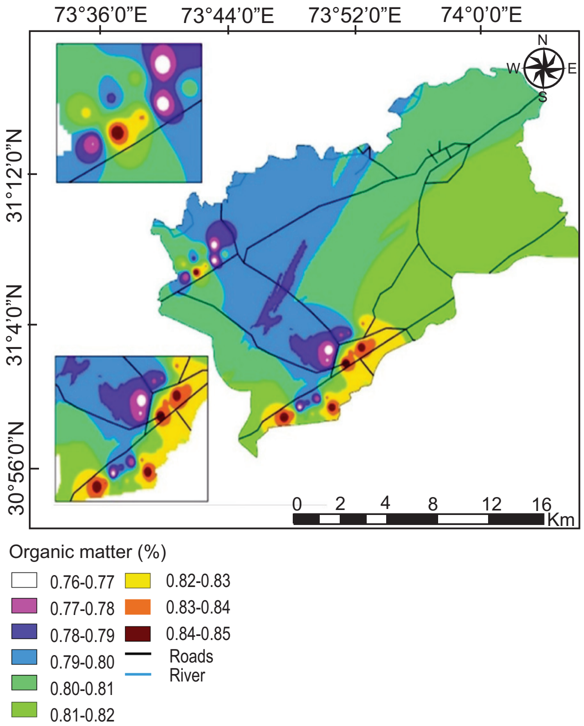

Fig. 9. Deficiency of organic matter (%) in sample sites.

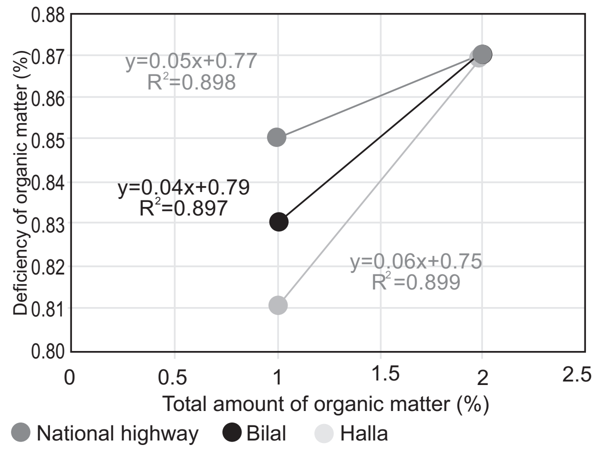

Fig. 10. Linear regression analysis on scarcity and the total amount of organic matter in sampled sites.

Table 6. Standard, deficiency of organic matter (%) and pH of soil

Sample sites	Mean deficiency	Standard	Mean pH
Halla	0.81	0.87	7.7
Bilal colony	0.83	0.87	7.9
National highway	0.85	0.87	7.8

it affects the quality of the soil. As the nutrient cycle is disrupted due to less decomposition of *Eucalyptus* leaves, the amount of soil organic matter is not up to the standards and because of this pH is also not preserved and affects the fertility of the soil and causes deficiency of certain major and minor nutrients in the soil. Consequently, the deficiency in *Eucalyptus* soil is thus directly related to the organic matter and the pH of the soil (Glaser *et al.*, 2002). The R^2 value showed that the soil organic matter is decreased in the soil as *Eucalyptus* growth upturns.

Surplus amount of nutrients present in the *Eucalyptus* soil. *Eucalyptus* induces soil inadequacies of various nutrients but alternatively, the volume of certain nutrients in the soil was increased by *Eucalyptus*. As with nutrient deficiency, these excess nutrients also affect soil fertility. Calcium is found in a surplus amount in the soil (Rizvi *et al*., 2014).

Figure 11, the map indicated the surplus amount of Ca (mg/Kg) caused by *Eucalyptus* in the three sampling sites. The white colour shows the less amount of concentration of Ca ranges 9.3-10.9 (mg/Kg) in the sampling sites including Halla and National Highway. The dark maroon colour shows the high concentration of Ca ranges from 21.4-22.9 (mg/Kg) in the sampling sites including the west side of Halla and the whole Bilal Colony. The sky blue, jade and green colour shows the moderate amount of Ca ranges 13.9-18.4 (mg/Kg) in all three sampling sites. As Ca is one of the macronutrients in the soil, it is very important as it helps to maintain the chemical balance in the soil and it improves the water penetration and reduces the salinity level if available in moderate amount in the soil. Excessive Ca in the soil destroys a plant uptake system. Due to excess Ca uptake by a plant, it cannot uptake other nutrients such as P, Zn, B, magnesium (Mg), potassium (K), copper (Cu) and iron (Fe) that are necessary for plant growth and produce a deficiency of nutrients in the soil.

A relationship between the surplus quantities of Ca (mg/Kg) caused by *Eucalyptus* and the Ca standard for fertile soil and other plant species are shown in Fig. 12. The standard of Ca is given above in Table 7 and the amount found in the *Eucalyptus* soil was 16-18 (mg/Kg). The R2 value indicates a relationship between variables and the comparison of the excess amount of Ca present in the sampled sites is shown in the bar chart. At Halla, Bilal Colony and National Highway, R^2 values of 0.987, 0.879 and 0.988 respectively suggested that *Eucalyptus* growth increases the Ca level in the surrounding area.

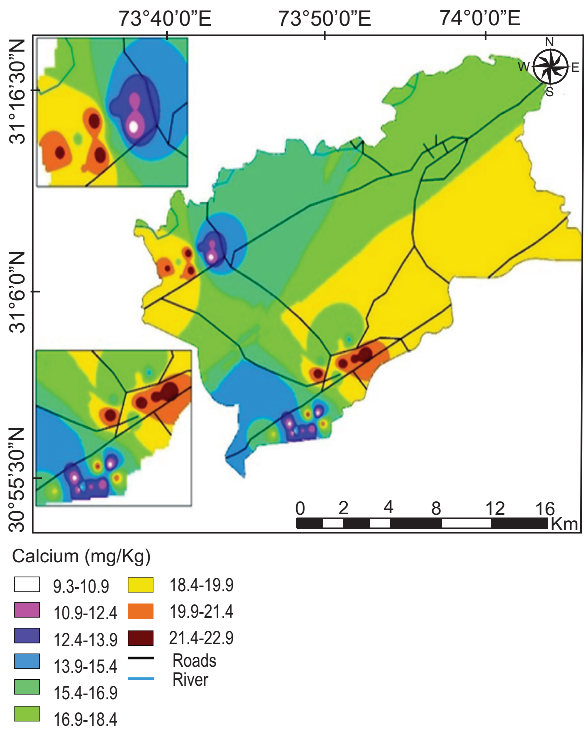

Fig. 11. High concentration of calcium (mg/Kg) in sampled sites.

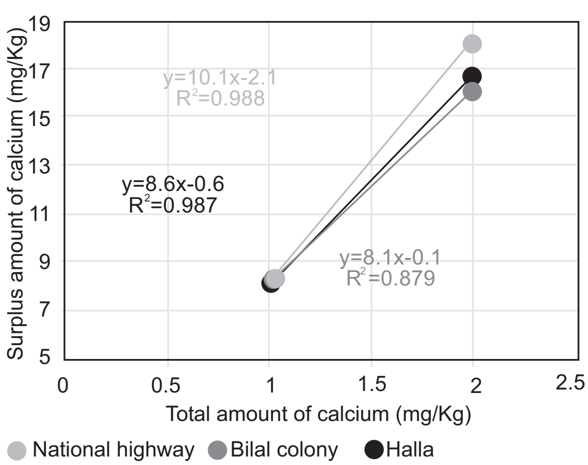

Fig. 12. Linear regression analysis on the high concentration of calcium and growth of *Eucalyptus*.

Table 7. Standard, mean surplus of calcium (mg/Kg) and soil mean pH

Sample sites	Mean deficiency	Standard	Mean pH
Halla	16.6	8	7.6
Bilal colony	18.1	8	7.9
National highway	16.1	8	7.7

The results provide valid reasoning that *Eucalyptus* has affected the soil nutrients badly. *Eucalyptus* has been in discussion for a long time in terms of its effects on soil nutrients. Due to the *Eucalyptus* plantation, there is an imminent change in the exchangeable magnesium, calcium and potassium, as the concentration of these cations is visibly low which contributes to increased soil acidity and other soil factors and elements are also affected (Epelde *et al*., 2009). The *Eucalyptus* plant also decreases the concentrations of nitrogen and phosphorous. Hence, *Eucalyptus* are advised to grow in areas where other beneficial plant species are not found. *Eucalyptus* should be grown in areas, where no or less plantation is found so it cannot affect the water table and other plant species (Fialho and Zinn, 2014). The current study has been connected with different articles to provide validation. *Eucalyptus* don't affect all physico-chemical properties of the soil, it affects some of the micro and macro nutrients but a little effect on the soil properties can affect the nutrient cycle which is important for the ecosystem and other Biodiversity (Kaur *et al*., 2021). Rather than effecting soil fertility and soil nutrient contents, it has impacts on topsoil retention, the topsoil of the areas where *Eucalyptus* is planted is very dry and has very less nutrients in it (0-6 cm) soil of *Eucalyptus* is hard and dry and lack water and moisture content (Teketay, 2000). Hence, *Eucalyptus* are advised to grow in areas where other beneficial plant species are not found. *Eucalyptus* should be grown in areas where no or less plantation is found so it cannot effect the water table and other plant species (Temesgen *et al*., 2016).

Conclusion

The soils of the study sites (Pattoki) containing the *Eucalyptus* plantation, found nutrient deficit. These soils were found deficient in B, Zn and P while the concentration of organic matter and Ca were found enhanced due to the *Eucalyptus* plantation. The soil and its underlying vegetation are harmed by the change in nutrient concentrations (deficiency/surplus). The pH of the soil is also nearly alkaline causing the deficiency of these nutrients. The high deficiency of B (0.07 mg/Kg) and Zn (0.19 mg/Kg) was mainly found in the Bilal Colony, the deficiency of organic matter (0.81%) and P (1.45 mg/Kg) were found in the sampling site of Halla and the surplus amount of Ca (18.1 mg/Kg) was found in the sampling site of National Highway. These deficiencies were mainly found due to the growth of *Eucalyptus* as the *Eucalyptus* grows, they require more nutrients and this causes deficiencies of nutrients in the soil. Therefore, *Eucalyptus* badly affects the soil nutrient status, also affects the fertility of the soil and disrupts the nutrient cycle due to which the other vegetation surrounding *Eucalyptus* is seriously affected and does not grow properly due to lack of soil nutrient uptake. Ultimately, this work has acted as a revelation to some hidden facts about the deficiencies found in the soil of *Eucalyptus*. The results of this study could help the decision-maker and planners to formulate the information accordingly. Especially on how to retain the lost nutrients again in soil and how to improve the fertility of the soil for the better growth of surrounding plants.

Conflict of Interest. The authors declare no conflict of interest.

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