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Deforestation effects on soil physical and chemical properties, Lordegan, Iran

Mohammad A. Hajabbasi, Ahmad Jalalian and Hamid R. Karimzadeh
Isfahan University of Technology, Isfahan, Iran[*]

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Abstract

Quantification of soil quality changes following deforestation by measurable soil attributes is important to sustainable management of soil and water conservation. A study was initiated in 1994 to evaluate the effects of deforestation on physical and chemical properties of soils under oak (*Quercus brontii*) forests in Lordegan region of central Zagrous mountain, Iran. Nine profiles which were derived from Bakhtiari conglomerate from three sites were selected for this research. These sites were: i) a virgin forest; ii) a completely deforested and currently utilized as crop land; and iii) a forest which has been cultivated for cropping under the trees (a type of agroforestry). Soil (coarse-silty, carbonatic, calcixerollic xerocherpts) characteristics that were analyzed include: bulk density, mean weight diameter, aggregate uniformity coefficient, organic matter, nitrogen, potassium, phosphorous, pH, EC, soluble anions and cations, plasticity index, and tilth index. Deforestation and subsequently tillage practices resulted in almost a 20% increase in bulk density, 50% decrease in organic matter and total nitrogen, a 10 to 15% decrease in soluble ions comparing to the undisturbed forest soil. The tilth index coefficient (average of three depths) of the forest site was significantly higher (0.717) than the cultivated forest (0.633) and thc deforested (0.573) sites. Deforestation and clear cutting, of the forests in the central Zagrous mountain resulted in a lower soil quality and thus decreasing the productivity of the natural soil.

Abbreviations: OM – organic matter, BD – bulk density, EC – electrical conductivity, AUC – aggregate uniformity coefficient, PI – plasticity index, TI – tilth index, CF(x) – coefficient of soil parameters.

Introduction

Rapid population growth in the Zagrous area of Iran, requires additional farmlands for food production. One way to expand the croplands is clear cutting the forests. This results in destruction of natural ecosystems and consequently loss of soil quality for crop production. Monitoring of soil quality provides an opportunity to evaluate soil and land management systems.

The eastern slopes of Zagrous have been generally covered with open woodland vegetation dominated by oak (*Quercus brontii*) trees for thousands of years. Recently, due to rapid population growth, a large area of forests has been clear cut and converted to farmlands. This conversion could leave the land more susceptible to soil degradation including higher soil bulk density, lower hydraulic conductivity, and higher soil erosion (Spaans, 1989). A large body of information is now available that shows clearly severe damage to the soil quality and increased soil erosion caused by agricultural practices in the forest areas (Knuti et al., 1979). Likens et al. (1970) reported extensive nutrient losses (particularly NO_3-N and Ca) following deforestation. Boyle (1975) and Mroz et al. (1985) mentioned that total tree harvesting may have several effects on forest soils, including; nutrient removal in the harvested material, increased erosion rates and/or percolation losses of nutrients and, also soil compaction. Patrick and Smith (1975) also reported a three times greater removal of nutrients due to total tree harvesting of hardwoods as compared to conventional lodging. Many

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[*] FAX No.: +98318912254. E-mail: hajabbas@cc.iut.ac.ir

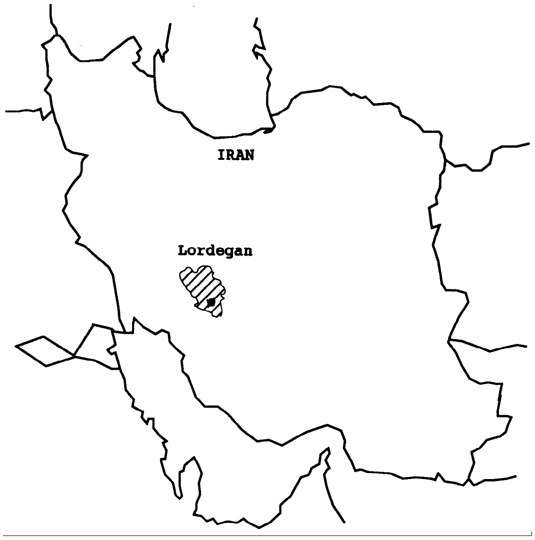

Figure 1. Location of the study sites in central Zagrous, Lordegan, Iran.

investigators have speculated that potential impacts of intensive deforestation would be more severe on sites of poorer quality (Jurgensen et al., 1979). On the other hand, Rauscher (1980) reported that nutrient depletion might be greater in well rather than poor structured soils. To show the changes in soil quality, a tilth index was introduced by Singh et al. (1992). By definition tilth index (TI) is a tool to evaluate soil productivity which could affect crop yield, and includes the integration of several soil property coefficients, such as bulk density, organic matter, strength, aggregate uniformity, and plasticity index (Karlen et al., 1990). The objectives of this research were to: i) study the changes in the soil physico-chemical properties due to deforestation and cultivation of forest and, ii) express this quantitative changes in terms of tilth index.

Materials and methods

The research site was located in the Lordegan area within the northern Karoon watershed (49° N 31° W) of central Zagrous, Iran (Figure 1). The area has about 1800 m of elevation above the sea level in the central Zagrous mountain. The forest area is almost 340,000 hectare (24% of the total watershed area), and is totally covered with an average of 30 to 40 years age of oak trees (*Quercus brontii*). The average yearly temperature and rain fall are 14.9 °C and 500 mm, respectively (with warm summers, cold winters and semi humid climate). The Lordegan region is about 150,000 hectare, of which 55% is covered with forest, 35% is irrigated cropland and the rest is used for dry land farming. Three sites (about 3000 m apart from each other) were selected, consisting of an undisturbed forest, a completely deforested area which has been clear cut and cultivated for over 20 years and a cultivated forest (a stand forest which has been cultivated and cropped under the trees, a type of agroforestry). For both cultivated forest and deforested sites wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) were commonly cropped. Soil (coarse-silty, Carbonatic, calcixerollic xerocherpts) at these sites was developed on the Bakhtiari conglomerate and had almost similar profile combination (Table 1). Samples from nine profiles (three from each site) were collected for detailed analysis. Samples were taken from 0-30, 30-75, and 75-130 cm depth in each soil. The debris and the plant residues were included in the samples of the top soil (0-30 cm) in the forest site. Bulk density at air dried moisture content was measured by Plaster (1985) method (clod method). Clay content was found using the pipet method (Page, 1992). Mean weight diameters were determined using the wet sieving method expressed by van Bavel (1950). Aggregate size distribution was expressed in terms of the uniformity coefficient, which is the ratio of D_{60} to D_{10}, where D_{60} and D_{10}, are the diameters at which 60% and 10% of the soil mass is finer, respectively (Hillel, 1982; Wray, 1986). The organic matter content, total nitrogen, calcium carbonate and bicarbonate, chloride, sulfate, exchangeable cations, pH, and EC, were all determined according to Page (1992). Plasticity index was measured using the Casagrande technique (Casagrande, 1948). The tilth index was calculated using the equations and coefficients reported by Singh et al. (1992), cxcept for thc cone penetrometer measurement which was not used in this study. The analysis of variance of a randomized complete block design with three replications (profiles) and comparison of means by a Duncan multiple comparison test were all conducted using the SAS program (SAS, 1985).

Results and discussion

Analysis of variance (ANOVA) at the 0.05 level of probability showed no differences among the sites and depths for $CaCO_3$, EC, Na^+, pH, SO_4^{2-} and saturation percentage. Bulk density, clay content, mean weight diameter, organic matter, total nitrogen, cal-

Table 1. The general physiographic position, profile and soil structure descriptions for different depths of forest, cultivated forest and deforested sites

Site	Depth cm	Profile description[a]	Physiographic position	Structure[a]
Forest	0-30	A	Virgin forest located	m2gr
	30-75	Bk1	on an old river plain	c2abk
	75-130	Bk2		c2sbk
Cultivated	0-30	Ap	Non-irrigated wheat grown	m
forest	30-75	Bw	under open forest	m3abk
	75-130	Bk1		f2abk
Deforested	0-30	Ap	Wheat grown on completely	m
	30-75	Bk1	deforested land	m2abk
	75-130	Bk2		m2abk

[a] According to the USDA (1979).

[b] c-coarse, m-medium, f-fine 2 and 3, moderate and strong grades, respectively gr-granular, m-massive, abk-angular blocky, sbk-subangular blocky

cium, potassium, magnesium, chloride, bicarbonates (HCO_3^-), and phosphorous, were all significantly different (at the 0.05 level of probability) among either the sites and/or the depths. The calculated tilth index showed its higher and lower values for the forest and deforested sites, respectively.

Bulk density and clay content

There was a significant difference (at the 0.05 level of probability) for bulk density values among the depths of esch site. Organic matter lost by cultivation, caused a lower bulk density for the surface soil of the cultivated and deforested sites. Following deforestation and cultivation, due to the high temperature and humidity of the region the relatively small amount of organic matter decomposed, resulting in a decline in soil structural properties and thus increasing bulk density. This process could be enhanced by the use of machinery either for deforestation or cultivation (Lal, 1987). According to Seubert et al. (1977), and Allen (1985) soil compaction is commonly resulted in a decline in macroporosity, higher susceptibility to erosion, and decreased hydraulic conductivity (Spaans, 1989). The surface soil (0-30 cm) of the forest and deforested sites had the lowest (1.13 Mg m^{-3}) and the highest (1.28 Mg m^{-3}) bulk density values, respectively (Table 2). The bulk density ranged from 1.13 Mg m^{-3} for the forest top soil (0-30 cm) to 1.32 Mg m^{-3} for the deforested subsoil (30-75 cm). Although, neither of these values, according to Grosmman and Berdanier (1982), are limiting factors for plant root growth (Table 4), the statistically higher bulk density of the deforested site could result in a lower soil quality. Over all, reduced tillage and introduction of alley cropping and other forms of agroforestry which are now widely investigated as alternatives to the traditional slash-and-burn agriculture (Kang et al., 1990) would appear a useful method for the prevention and cure of soil compaction and high bulk density (Van Noordwijk et al., 1991) in this region.

Clay content of the sites range from 28.5 to 39.4 percent for the 0-30 cm depth of deforested and 75-130 cm of the cultivated sites, respectively (Table 2). There was more clay accumulation in the lower depths (30-130 cm) of the deforested and cultivated sites, whereas the top soil (0-30 cm) of the forest site had the greatest amount of clay. This may be the effect of tillage practices and cultivation which caused the organic matter content to be decreased. Loss of OM causes soil aggregates to be crashed and consequently the finer particles translocated to the lower depths, or moved to other areas via erosion and thus leaving the coarser particles in site. The erodability index of the sites (data not published) were 0.252, 0.283, and 0.360 for the forest, cultivsted forest, and deforested, respectively (Wischmeier et al., 1971).

Mean weight diameter and aggregate size distribution

Deforestation had a significant effect on the size of aggregates among the sites and/or depths of the study

Table 2. Mean values of three replications at three depths of soil bulk density, clay content, mean weight diameter, plasticity index, organic matter, and total nitrogen of the forest, cultivated forest, and deforested sites

Site	Depth	Bulk density	Clay Cont.	Mean weight diameter	Plasticity index	Organic matter	Total nitrogen
		(Mg m^{-3})	(%)	(mm)	(%)		
Forest	0–30	1.13b[z]	37.9a	7.43a	12.63a	2.50a	0.164a
	30–75	1.23ab	38.4a	7.13a	15.45a	0.41c	0.054c
	75–130	1.30a	29.5b	7.40a	21.81b	0.16c	0.033c
Cultivate forest	0–30	1.23ab	31.8b	6.13a	20.34b	1.20b	0.091b
	30–75	1.27a	35.3a	7.73a	25.71b	0.47c	0.044c
	75–130	1.29a	39.4a	4.97b	32.79c	0.36c	0.048c
Deforest	0–30	1.28a	28.6b	4.90b	29.43b	0.97b	0.091b
	30–75	1.32a	34.6ab	4.23b	36.81c	0.57cb	0.056c
	75–130	1.26a	37.1a	4.63b	47.25c	0.28c	0.038c

[z] Means in a column with the same letter are not significantly different at the 0.05 probability level.

Table 3. Mean values of three replications at three depths of soluble ions and in soils of forest, cultivated forest, and deforested sites

Site	Depth	Ca^{2+}	K^{+}	Mg^{2+}	Cl^{-}	HCO_3^{-}	P
	(cm)	(meq L^{-1})					(mg kg^{-1})
Forest	0–30	3.61a[z]	0.25a	1.26b	1.9b	3.68a	35c
	30–75	1.76b	0.17ab	2.30a	3.1a	2.78ab	68b
	75–130	4.35a	0.19a	1.60ab	4.7a	1.91b	148a
Cultivate forest	0–30	4.45a	0.13b	1.35b	2.7ab	2.74ab	58b
	30–75	3.88a	0.15ab	0.45c	2.5ab	2.22ab	106a
	75–130	3.40a	0.11b	0.50c	2.7ab	2.27ab	127a
Deforest	0–30	3.43a	0.15ab	1.88a	1.8b	3.35a	67b
	30–75	2.26ab	0.10b	1.07b	1.7b	2.14b	92a
	75–130	1.33b	0.10b	1.01b	1.3b	1.68b	110a

[z] Means in a column with the same letter are not significantly different at the 0.05 probability level.

area. The largest and the smallest mean weight diameters (average of three depths) were observed for the forest soil (7.32 mm) and deforested site (4.61 mm), respectively (Table 2). The smaller aggregates in the deforested site perhaps is due to the cultivation through loss of organic matter and aggregate dispersion. Chaudhary and Sandhu (1983) reported that variation in aggregate size could occurred due to differences in texture and structure as naturally occurring or brought about by tillage, compaction, cropping, and other management events. Soil aggregate size distribution curves are shown in Figure 2. The forest soil had a more smooth curve and thus a well graded soil compared to the deforested site which had the most step-like curve and can therefore be grouped as a poorly graded soil (Marshal and Holmes, 1988). The surface soil aggregates of the forest were more uniformly distributed compared to the other sites (Figure 2). This is due to the aggregate stability enhanced by organic matter on the top soil (0-30 cm). The cultivated forest site has the lowest size uniformity in the top (0-30 cm) soil (Figure 2). The subsoil (75-130 cm) of all sites had almost the same aggregate size uniformity (Figure 2). According to Wray (1986), any soil with an aggre-

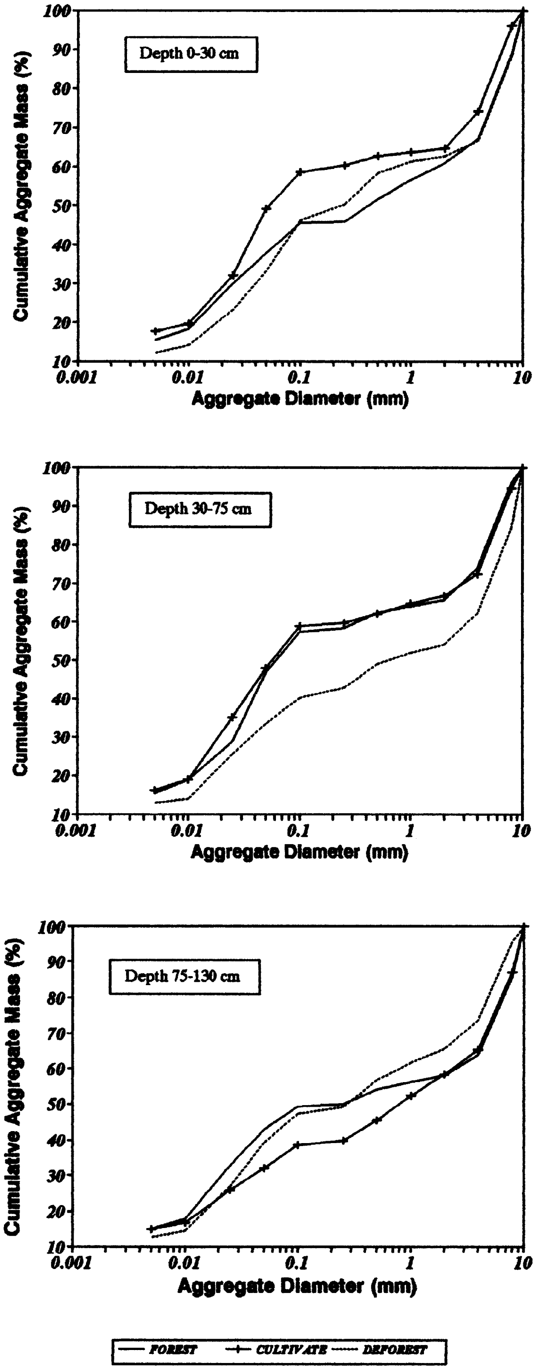

Figure 2. Aggregate size distribution curves of the forest, cultivated forest and deforested sites at three 0–30, 30–75, and 75–130 cm depths.

Table 4. Mean values of three replications at three depths of soil property coefficients, CF(X) used to find tilth index TI, for the forest, cultivated forest and deforested sites in the Lordegan region

Depth (cm)	Forest	Cultivated forest	Deforested
Coefficients of bulk density CF(BD)			
0–30	1a[z]	1a	1a
30–75	1a	1a	0.995a
75–130	1a	1a	1a
Coefficients of organic matter CF(OM)			
0–30	0.845a	0.720b	0.700b
30–75	0.700b	0.700b	0.700b
75–130	0.700b	0.700b	0.700b
Coefficients of aggregate uniformity CF(AU)			
0-30	1a	1a	1a
30–75	1a	1a	1a
75–130	1a	1a	1a
Coefficients of plasticity index CF(PI)			
0–30	1a	0.972a	0.908b
30–75	0.996a	0.937a	0.836b
75–130	0.964a	0.877b	0.800b
Tilth index (TI)			
0–30	0.845a	0.697b	0.627b
30–75	0.677b	0.626b	0.557c
75-130	0.628b	0.576c	0.543c
Average			
0–130	0.717a[y]	0.633b	0.573b

[z] Means in a column with the same letter are not significantly different at the 0.05 probability level.
[y] Means in this row with the same letter are not significantly different at the 0.05 probability level.

gate uniformity coefficient greater than or equal to five is considered non-limiting, and one with a value less than or equal to two is considered to be not suitable for plant growth. All of the sites and depths in this study had aggregate uniformity coefficients greater than five suggesting that as it stands, those soils did not pose problems for plant growth when the tilth index is considered (Table 4).

Plasticity index

The plasticity index ranged from 12.63 for the forest top soil (0-30 cm) to 47.25 for the deforested subsoil (75-130 cm) (Table 2). Aggregate breakdown enhanced by deforestation and cultivation resulted in the movement of finer particles by water transport to the lower depths (75-130 cm). So, larger amounts of fine particles and lack of organic matter resulted in a higher plasticity index in the lower layers (Table 2). Except for the forest top soil (0-30 cm), plasticity index was limiting factor for all other treatments as far as tilth index is concerned (Table 4). The average value for plasticity index of three depths in each site was 16.63, 26.28, and 37.83 for the forest, cultivated forest and deforested sites, respectively (Table 2).

Organic matter and total nitrogen

The surface soil (0-30 cm) at all sites had the greatest amount of organic matter. The forest top soil (0-30 cm) had the highest amount of OM (2.5%) compare to the deforested site at the same depth (0.97%) (Table 2). Organic matter (OM) in the lower layers (30-75 and 75-130 cm) were basically similar for all sites (Table 2). Cultivation brought significant changes to total nitrogen (TN). The loss of nitrogen from deforestation sites appear to be particularly important. The deforested and cultivated forest sites at surface (0-30 cm) had at least half as much as TN than forest soil (Table 2). The largest amount of total nitrogen (same as OM) was observed for the forest top soil (0-30 cm). Patrick and Smith (1975) reported that total tree harvesting caused the nutrient, including nitrogen, to be removed up to three times compared to conventional lodging. In addition to losses from biomass removal, nutrient can be lost from deforested sites by increased soil nutrient mobilization and leaching, when little vegetation is present to take up (Mroz et al., 1985).

Soluble cations and anions

The input of soluble cations and anions from decomposing surface organic matter influences the base status of the solum, and the changes in soils under forest were dynamic (Adams and Boyle, 1982). Calcium contents of the surface soil (0-30 cm) at all three sites were found to be significantly similar (3.61, 4.45, and 3.43 meq L^{-1} for the forest, cultivated forest and deforested sites, respectively) (Table 3). The forest site at 30-75 cm and the deforested site at 75-130 cm had the lowest amount of Ca, but the cultivated forest had the same amount of Ca in all three depths. The forest and deforested sites at the 0-30 cm depth had significantly similar and the highest amount of potassium (Table 3). The average K content (three depths) of the forest site was significantly higher than the other sites (0.21, 0.13, and 0.11 meq L^{-1} for the forest, cultivated forest, and deforested sites, respectively) (Table 3). Adams and Boyle (1982) reported a more rapid increase in K relative to Ca immediately after clearcutting. They suggested that initially, Ca, Mg, and K are released from surface organic matter by mineralization then these nutrients are taken up by plants and, therefore, reduction in plant uptake in the mid or end of the season (Adams and Boyle, 1982). Magnesium content of the surface soil (0-30 cm) for the deforested site was significantly higher than the other sites (1.26, 1.35, and 1.88 meq L^{-1} for the forest, cultivated forest, and deforested sites, respectively) (Table 3). This probably is due to the organic matter mineralization after clear cutting (Adams and Boyle, 1982). The highest amount of Mg (average of three depths) was found in the forest site (1.72 meq L^{-1}), but the lowest in the cultivsted forest (0.765 meq L^{-1}) site (Table 3). Upon initial mineralization, enhanced by cultivation Ca, K, and Mg probably move through the soil with counter ions, thus having little interaction with the soil exchange complex (Adams and Boyle, 1982). These events are suggested by the rapid ion concentration and ion pair formation (Snyder and Harter, 1984) and/or rapid nutrient uptake by crops in the cultivated sites.

Organic matter mineralization may also release anions such as nitrate, chloride, sulfate and a variety of organic acids (McColl and Grigal, 1979). There were no differences among the sites and depths for sulfates but the sites had different amounts of chloride (Table 3). Comparing to the surface soil (0-30 cm) in the forest site, the lower depths (30-75 and 75-130 cm) had higher chloride content (1.9, 3.1, and 4.7 meq L^{-1}, respectively). There were no significant differences of chloride content among other sites and/or depths (Table 3). The forest and deforested sites at the surface soil (0-30 cm) had the highest bicarbonate content (3.68, 3.35 meq L^{-1}, respectively), and the forest at 75-130 cm, and the deforested at 30-75 and 75-130 cm had the lowest amount of bicarbonates (1.91, 2.14, and 1.68 meq L^{-1}, respectively). The average soil phosphorous content (of three depths) were found to be 84, 97 and 90 mg kg^{-1}, for the forest, cultivated forest, and deforested sites respectively. Basically, a higher P content was found for the lower depths (30-75 and 75-130) whereas the top soil (0-30 cm) of all sites had relatively lower amount of phosphorous.

Tilth index

A summary of the coefficients needed for calculating tilth index are brought together in Table 4. There was a significant decrease in the average tilth index after cultivation and/or deforestation. Among the sites the forest profiles had larger average (three depths) values of tilth index (0.717) while the cultivated forest and deforested sites had a significantly smaller tilth index (0.633, and 0.573, respectively) (Table 4). Tilth indices of individual site and depth ranged from 0.845 for the forest top soil (0-30 cm) to 0.543 for the deforested site and depth of 75-130 cm. The average tilth index for the forest site in all depths was 12 and 24 percent higher than for the cultivated forest and deforested sites, respectively. The higher value for the forest soil was mostly due to the higher amount of organic matter and lower plasticity index compared to the other sites. Tilth coefficients for bulk density and aggregate uniformity were similar among the sites and depths, all indicating that in this region, these are not the limiting factors for the plant growth.

Conclusion

High population growth rate and consequent needs for food and fiber requires more land to farm, therefore, each year hundreds of hectare of the forest in northern and central Zagrous of Iran are deforested and converted to the croplands. Deforestation brought a lower soil quality in the sites under the study. Soil quality was examined through determination and comparing of some soil physical and chemical properties. Decreasing soil organic matter and aggregate size, increasing soil bulk density, and plasticity index, and changing the base status of the soil were few outcomes of the deforestation. Cultivating and cropping in the stand forest (a type of agroforestry) is another practice of crop production in the region which also decreased the soil quality in some extent, but not as much as the completely deforested method. Therefore cropping in between the forest trees may be the most feasible and recommending way of crop production, by which the relatively high populated region will be nourished, while, the natural resources like forest trees and soil will relatively remain conserved.

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