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Eucalyptus plantations in the highlands of Ethiopia revisited: A comparison of soil nutrient status after the first coppicing

Master Thesis - Mountain Forestry program

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Acronyms

CEC	Cation exchangeable capacity
cm	Centimeter
FAO	Food and Agriculture Organization
ff	Form factor
GPS	Geographical positioning system
ha^{-1}	per hectare
LUS	Land use system
m.a.s.l	Meter above sea level
$mg.g^{-1}$	milligram per gram
$\mu g.g^{-1}$	Micro gram per gram
mm	millimeter
$t.ha^{-1}$	Tons per hectare
UNDP	United Nations Development Program

Zusammenfassung

Die steigende Nachfrage nach Brenn- und Bauholz hat in Äthiopien zu einer Ausweitung von Eucalyptus-Plantagen geführt, die raschwüchsig sind und daher im Kurzumtrieb bewirtschaftet werden. Die laufende Expansion dieser Plantagen hat zu einer kontroversen Diskussionen geführt: es wird auf mögliche Auswirkungen auf die Umwelt hingewiesen, denen wirtschaftliche Aspekte entgegenstehen. Eucalyptus wird als Ursache für Bodenversauerung, Nährstoffverarmung bei gleichzeitig hohem Wasserverbrauch gesehen, wobei die Biomassen-Produktion, Trockentoleranz und Verbissresistenz hoch ist. Tatsächlich wurden die nachhaltigen Aus-wirkungen von Eucalyptus-Plantagen bisher relativ selten längerfristig beobachtet und evaluiert. Diese Studie versucht die Auswirkungen einer *Eucalyptus camaldulensis* Plantage im Nordwesten Äthiopiens, in Jufi, auf Kohlenstoffgehalt, Bodennährstoffe und -pH-Werte zu untersuchen und diese Ergebnisse mit Daten von vor 10 Jahren zu vergleichen. Um die Kreisfläche und das Volumen pro ha zu be-stimmen wurde eine systematische Inventur der Plantage unter Anwendung von Kreisplots mit einem Radius von 5,64 m durchgeführt. Für die Bestimmung der Nährstoffgehalte wurden Boden- und Blattproben von drei nebeneinander liegenden Teilflächen des als Ausschlagwald bewirtschafteten Eucalyptus-Bestandes gesam-melt. Rund um jede Bodenprofilgrube (50 cm Tiefe) wurden je drei Stockausschläge für die Blattprobenwerbung ausgewählt, getrennt nach BHD-Klassen: < 5, 5,0-9,0, 9,1-14 und 14,1- 9,0 cm. Die Blattprobenwerbung wurde entweder durch Herab-biegen der Stockausschläge oder durch Baumsteiger durchgeführt. Auf jeder der Teilflächen erfolgte die Bodenprobennahme in 10 Profilgruben (5 Gruben bis 50 cm Tiefe und 5 Gruben bis 20 cm Tiefe) mittels Stechzylindern in 10 cm-Sektionen. Die Probenvorbereitung und chemische Analytik erfolgte gemäß der Standard-Methodik. Es wurden folgende chemischen Parameter bei Böden bestimmt: Gesamtgehalte von C, N, P, S, austauschbar gebundene Gehalte von Ca, K, Mg, Mn und Na; die Blattproben wurden untersucht auf: N, Ca, K, Mg, Mn, Na, P und S. Die Datenauswertung erfolgte durch deskriptive Statistik, sowie ANOVA und paarweisen Mittelwertvergleich (Scheffe-Test). Nach 10 Jahren wiesen die Böden des Ausschlagwaldes einen niedrigeren Gehalt an organischem Kohlenstoff, zuneh-mende Versauerung, geringere Gehalte an austauschbar gebundenen Kationen und eine niedrigere KAK auf; der N-Gehalt stieg an. Vor allem waren die Änderungen des organischen Boden-Kohlenstoffgehaltes, der austauschbar gebundenen Ca-, K- und Mg-Gehalte und der KAK in den oberen Bodenschichten bemerkenswert, während Änderungen der N-Gehalte und der pH-Werte (H_2O) in allen Bodentiefen zu beobachten waren. Die mittlere Kreisfläche lag bei 13,11 $m^2.ha^{-1}$, das Holzvolumen bei durchschnittlich 68,71 $m^3.ha^{-1}$. Außer für K, nahmen die Nährstoffgehalte der Blätter der Teilflächen 1 und 2 nach 10 Jahren deutliche zu, dagegen ist mit Ausnahme von Ca auf der Teilfläche 3 eine Abnahme der Blatt-Nährstoffgehalte zu beobachten. *E. camaldulensis* kann, ähnlich wie andere raschwüchsige Baumarten, den Boden-Nährstoffgehalt verringern und die Bodenversauerung verstärken. Aufgrund des raschen Wachstums, der hohen Biomasseproduktion, der vielfältigen Verwendbarkeit des Holzes, sowie der Trocken- und Verbissresistenz werden Eucalyptus-Plantagen in lokale Dorfgemeinschaften nicht zuletzt angeregt durch Förderungsmaßnahmen seitens der Regierung häufiger. Um die Standorte nachhaltig zu bewirtschaften und die ökologisch negativen Auswirkungen dieser Baumart zu minimieren sind angepasste Management-Methoden unumgänglich.

Abstract

In Ethiopia, the growing demand for fuel wood, construction wood, and other multiple forest uses, led to intensive expansion of fast growing and short rotation *E. camaldulensis* plantations. The ongoing expansion of these fast growing plantations triggers two debates, one on environmental impacts and another on economic roles. One debate connects with soil acidification, nutrient depletion and excessive water consumption, the second connects with the economic role of this fast growing species, its high biomass production, drought tolerance and browsing resistance. However, depletion of soil nutrients, lowering of ground water table and soil acidification are not yet evaluated from the sustainable utilization point of view. To address this knowledge gap, the present study tried to investigate the impact of an *E. camaldulensis* plantation after 10 years on soil nutrients and soil acidity at a plantation sites in the north western part of Ethiopia, in Jufi. To determine BA and volume.ha^{-1}, a systematic plantation inventory was done using circular plots with a radius of 5.64 m. For the nutrient content analysis, soil and leaf samples were collected from three consecutive blocks under *E. camaldulensis* coppice. Around each soil pit (50 cm deep), 3 coppices were selected for leaf samples from DBH classes of < 5, 5.0-9.0, 9.1-14.0 and 14.1-19.0 cm. The leaves were collected from the selected trees by bending and climbing. From each block, soil sampling was done in 10 soil sampling pits: 5 pits were 50 cm and the rest 20 cm deep. Sample collection was done in 10 cm subsections using a soil corer. Soil samples were treated according to the standard procedures and were analyzed for C and N contents, P, S and exchangeable base cations (Ca, K, Mg, Mn, and Na). Leaf samples were analyzed fo N, Ca, K, Mg, Mn, Na, S and P. Data were analyzed by using descriptive statistics, ANOVA and Pairwise comparisons of mean (Scheffe-Test). After 10 years, soils under *E. camaldulensis* plantation showed low level of SOC, increasing acidification, low level of base exchangeable cations and CEC and increased content of soil N. Under these plantation sites substantial changes in SOC, Ca, K, Mg and CEC occurred in the upper soil sections whereas N and pH (H_2O) changes occurred across all soil depths. Reduced contents of C: N was observed in lower soil sections. The average above ground wood stem of basal area (BA) and volume per hectare were estimated to be 13.11 m^2.ha^{-1} and 68.71 m^3.ha^{-1} respectively. Except for K, all nutrients in *E. camaldulensis* leaves indicated significant increases especially in blocks 1 and 2 after 10 years. But on the contrary except for Ca, all leaf nutrient contents decreased in block 3. Therefore, *E. camaldulensis,* like other fast growing trees, can reduce soil nutrients contents and increase soil acidity. On the other hand, due to its fast growing, high biomass production, multipurpose uses, drought and browsing resistance, *E. camaldulensis* has been expanded by local communities on differently used land and has been promoted by government. For the sustainable productivity of sites under *E. camaldulensis* forest and to reduce the environmental impacts of the species, there is a need for proper management activities.

Key words: *E. camaldulensis*, coppice, nutrient, leaf litter, biomass.

1 Introduction

Ethiopia has lost the majority of its forest resources especiallY during the 20th century. This forest depletion, together with the sharply increasing human population, has resulted in a severe shortage of wood products especially fuel wood and construction wood. This also has stemmed from the very strong dependence on wood products by the society as there is poor infrastructural development in the country (Duguma et. al., 2009). One of the measures taken by the government to minimize the problem of scarcity of wood products was to introduce fast growing exotic tree species (e.g. *Eucalyptus camaldulensis* and *Eucalyptus globulus*) and establish fuel wood projects near urban and per-urban areas. It is within this scheme that *Eucalyptus* species were introduced into Ethiopia by the government and were distributed to the farmers for planting at farm borders.

In northern Ethiopia, *Eucalyptus* is the most commonly grown tree species in community and household woodlots. This tree species grows well even on poor soils and grows faster compared to most indigenous tree species. Smallholders show a clear preference for *Eucalyptus* poles, which are useful for farm implements and constructing houses and fences. In addition, the sale of *Eucalyptus* poles and products has the potential to raise farm incomes, reduce poverty, increase food security and diversify smallholder farming systems in many areas of Amhara region (Zerfu, 2002). In addition to this, *Eucalyptus* plantations play a great role as a main source of fuel wood for both urban and rural inhabitants.

The ongoing expansion of *Eucalyptus* plantations by farmers have been the focus of two major debates on the environmental impact and the economic role of the species. The former debate is related to soil acidification, nutrient depletion, allelopathic effect and excessive water utilization of the species. The later debate focuses on the importance of the species because of its fast growth, high biomass production (Kidanu et. al., 2004) and browsing resistance. In Ethiopia, where there are huge gaps between demand and supply of wood as a result of escalating deforestation, the use of fast growing species which produce large amount of biomass like *Eucalyptus* is inevitable. Nonetheless, though this genus is very important and promising, the associated environmental concerns such as impoverishment of soil fertility, aggressiveness to ground water and soil acidification are not yet quantified and evaluated from the sustainable utilization point of view based on Ethiopian specific site conditions (Zerfu, 2002). This implicates the demand for further investigation regarding the environmental effects of this genus. To address this knowledge gap, this study tried to investigate the impacts of *Eucalyptus* species specifically after first coppicing on soil properties under Ethiopian ecological and socio-economic conditions.

The outputs of this study help us to know the possible impact of *Eucalyptus camaldulensis* on soil chemical properties. Besides, the results will also contribute to enhancing tree growing practices through improved management activities to fulfil the fuel wood and construction wood demands of the community while diversifying and increasing household income with minimal effect on the environment.

1.1 Objectives of the study

- Revisiting and evaluating soil chemical properties under *Eucalyptus camaldulensis* after the first coppicing in comparence to the findings of Zerfu (2002).

1.2 Research hypotheses

Depending on the objectives of the study the following hypotheses were formulated.

Hypothesis 1: Soil Carbon, Nitrogen and exchangeable cation stocks decrease as a result of growing *Eucalyptus* species.

Hypothesis 2: Soil pH decreases with time as a result of growing *Eucalyptus* species.

Hypothesis 3: Changes of soil nutrients and CEC due to growing of *Eucalyptus* species.

2 Literature review

2.1 The introduction of Eucalyptus tree species in to Ethiopia

Exotic species of *Eucalyptus* have firstly been introduced in to Ethiopia around the end of the 19^{th} century. As Zewdie (2008) indicated growing *Eucalyptus* began in Ethiopia around 1890, during the regime of Emperor Menelik II with the aim to minimize the shortage of wood. This effort mainly concentrated on the establishment of *Eucalyptus* plantations near the capital Addis Abeba and other towns by introducing seeds of 15 species of *Eucalyptus* from Australia (UNSO, 1991 cited in Zerfu, 2002). The species were grown in central plateaus of Ethiopia at altitudes ranging from 1400 to 3500 m.a.s.l and in rainfall zones of 700-2000 mm per year. Of the introduced species, *Eucalyptus globulus* performed well in terms of survival and fast growth. *E. camaldulensis* is the second most common *Eucalyptus* species often grown in lower altitudes (Zerfu, 2002).

As cited by Zerfu (2002), a study by Pohjonen and Pukkala (1991) indicated that during prolonged periods of private forestry initiation at the beginning of the 1900s which lasted until the revolution of 1974-1975, around 90,000 ha of *Eucalyptus* were planted in the surroundings of Addis Abeba and other cities. Up to the early 1990s, estimated areas of 35,000 ha of *Eucalyptus* plantations have been established in the country through different fuel-wood projects (Kinfe, 2000 unpublished cited in Zerfu, 2002). FAO (2000) showed that around 148,000 ha of *Eucalyptus* exist in Ethiopia in the year 2000 and the report also indicated an increasing trend of the plantation area. The country possesses around 20,000 ha of on farm *Eucalyptus* plantation.

In the Ethiopian highlands, where deforestation and woody biomass crisis are the major problems, *Eucalyptus* is the prominent tree species in government and community estate plantations. This dominance of *Eucalyptus* species is mostly due to their relatively easy and fast propagation by coppicing, high rate of biomass production and resistance to browsing which is one important attribute especially in the highlands where free grazing is dominantly practiced. According to Friis (1995) there are around 55 species of *Eucalyptus* in Ethiopia.

During the early 1980s, the government initiated *Eucalyptus* planting through state-owned plantation programmes and fuel wood plantation projects were part of the government decisions and led to *Eucalyptus* plantation establishment programs. One of the biggest of such plantations is the Addis Bah fuel wood project to which Jufi *Eucalyptus* plantation belongs (Zerfu, 2002). Besides such projects, recently planting of *Eucalyptus* species has expanded to community woodlots, farm boundaries, river banks and household compounds to provide households with wood and to generate income source by selling *Eucalyptus* poles and products and diversify smallholder farming systems in less-favored areas of northern Ethiopia.

2.2 Coppicing ability of Eucalyptus species

Many hard wood trees can coppice when cut near the ground. Coppice often describes many small stems which can be raised from dormant buds beneath the bark of tree stumps following harvesting (Robert, 2005). These new crops are known as coppice and they have more chance for fast growing and surviving than replanting. As described by Geary (1983) coppice crop often has a shorter rotation periods than those of seedling crops, because coppice stems grow faster than seedlings as they grow from large and well established root systems. It is obviously recognized that tree crops developing from coppice have higher yield compared with seedlings of the same age (Florence, 1996). *Eucalyptus* species have special characteristics to reproduce new coppices during hazardous environmental conditions.

Larger trees can produce high numbers of coppices from their stumps (Geary, 1983). To get high numbers of coppices from the stump of *Eucalyptus*, high cut is recommended rather than low cut, but due to the following reasons low cut (at the stump height of 10-12 cm above ground) is more preferably recommended than high cut: 1) when the trees are cut at higher levels in the beginning, the later cutting of coppice will increase in height which makes other coppice management interventions difficult. 2) Coppices originated from high stumps are sensitive to wind damage compared to coppices originating from short stamps. 3) Higher stumps may not allow easy mobility during various management operations in the stand especially for those using harvesting machineries (Geary, 1983).

Eucalyptus coppicing is also influenced by harvesting season. Harvesting during the summer season and freezing weather may lead to delay of sprouting and can result in increased chances of shoot decay. Robert (2005) indicated that summer felling may lead to separation of barks from the stumps. Areas with high rain fall may not be so critical for better coppice sprouting (Robert, 2005). But it is proved that in Israel, *Eucalyptus camaldulensis* harvested in winter cannot produce coppice until the coming spring season. Research findings indicated that spring harvesting is the best season for coppice regeneration (Heth et al., 1982, cited in Geary, 1983). During the establishment of seedlings, spacing should be considered for future coppice regeneration to allow machines to harvest without damaging the stamps. Usually at the final stage, only one coppice can dominate competition per stump (Robert, 2005).

As Munsinghe (2003) indicated *Eucalyptus* is widely distributed in tropical and subtropical environments as fast growing timber tree. To obtain more numbers of coppices per stump for intended uses short rotation period with less stem diameter is recommended (Robert, 2005). The rotation period of *Eucalyptus* species is not uniformly standardized due to different products and environmental conditions. For example, in China six years rotation is common for pulp production (White, 1987). In India, *Eucalyptus globulus* is managed for four rotation cycles and each rotation has been harvested between 10 to 15 years old (Doughty, 2000). In Ethiopia, most stands are usually harvested at the age of 5-7 years for pole and construction materials in some cases with maximum18 years (Zewdie, 2008). According to Wirtu and Gong (2000), in Ethiopia, maximum rotation period for *Eucalyptus* seedling originated rotation is between 5 and 11 years and 6 to 10 years of optimum rotation period for coppice plantation. As defined by Reed (2009) the rotation age of *Eucalyptus camaldulensis* on poor sites is estimated to be 15-20 years rather than 7-10 years.

2.3 Impact of Eucalyptus plantation on soil nutrients

In plants, growth is a function of soil nutrients, climate and neighborhood effects. This extraction and consumption of soil nutrients varies depending on the developmental stages of the plant and growing character of the species (fast growing or slow growing). The extraction of soil nutrients by plants is also influenced by the accessibility of the nutrients to the plant roots. Different tree species need different amounts of different nutrients (Cole and Rapp, 1981). Those fast growing and short rotation tree plantations such as *Eucalyptus* use high amounts of nutrients from the soil compared to slow growing species (Heilman and Norby, 1997). Various studies showed that soil physical properties are influenced by the species and age of the stands. For example, Chen et al. (2004) indicated that soil chemical properties, notably organic carbon, total nitrogen, phosphorus and potassium decreased as a result of reforestation with *Eucalyptus* and further decreased with increasing age. In general, monoculture forestry activities may affect soil chemical characteristics in different ways: 1) there is nutrient translocation from the soil to the plant compartments (leaves, twigs, branches and stem, roots), 2) when the organic litter raked continuously it could have significant effect on soil fertility by prohibiting nutrient recycling (Zewdie, 2008).

Despite its remarkable benefits, *Eucalyptus* is believed to have adverse effects on soil nutrients. This could be associated with the high rate of nutrient uptake as a result of its fast growing nature. A study in Ethiopia by Lemenih (2004) showed that sites where *Eucalyptus* was grown showed increased soil acidity while the base saturation declined compared to native vegetation sites and adjacent agricultural lands. Another study by Turner and Lambert (2000) in Brazil showed that the soil organic carbon content was less in *Eucalyptus* plantations compared to the adjacent native vegetation site.

Some management practices like clear felling and high intensity burning also had significant impacts on soil quality (Pennington et al., 2004). For example, in *Eucalyptus* plantations of Australia, the soil bulk density has increased from 0.58 $Mg.m^{-3}$ to 0.7 $Mg.m^{-3}$ after clear felling and high intensity burning. Ghosh et al. (1978) also showed that such activities contribute to a loss of 3850 kg C ha^{-1} and 107 kg N ha^{-1}.

2.4 Biomass production potential of Eucalyptus

At present, *Eucalyptus* is produced commercially as a commodity for multiple end uses. *Eucalyptus* is usually developed as a monoculture tree production with short rotation periods, usually twice or more compared with species for pulp and timber tree products (FAO, 1996). Cultivation of *Eucalyptus* in a large scale is no longer than 30-40 years and in this period it is used for specific end uses like fuel wood and other raw materials for rayon and pulp products (FAO, 1996). Expansion of *Eucalyptus* plantation was carried out on an area of 700,000-4,000,000 ha from 1955 to 1970 (Stevens, 1988) and the total area covered now may be about 13.4 million ha (Davidson, 1985). World wide area coverage of *Eucalyptus* plantation was estimated about 17.9 million hectares (FAO, 2000 cited in Myburg, et al. 2006).

Spacing plays an essential role for the biomass production of *Eucalyptus* plantations. In a general sense, the spacing of planting is chosen by considering the productivity of future intended final products (FAO, 1996). It is known that the spacing varies from place to place. Zohar (1989) reported that in a trial of 4 years old *E. camaldulensis* in Israel, under high soil water and temperature conditions, 1670 to 3,300 stocking per hectare did not affect biomass production. In Nepal, 1,000 to 1,667 stocking per hectare in dry monsoon climate did not affect biomass production (White, 1988). Mo Quiping and Mannion (1989) as cited in Ju (1996) also indicated that 1,000 to 2,000 trees per hectare is the optimum for biomass production of *E. camaldulensis* and *E. grandis* in China.

E. saligna plantation forest produces 185.8 $t.ha^{-1}$ on the dry basis at the age of 11 years with the density of 452 $trees.ha^{-1}$. From the total biomass of 185.8 $t.ha^{-1}$, 4.0 $t.ha^{-1}$were leaves, 13.8 $t.ha^{-1}$ were branches, 9.5 $t.ha^{-1}$ were bark and 158.5 $t.ha^{-1}$ were wood. When calculated in percentage it was 2.2% leaves, 7.4% branches, 5.1% bark and 85.3% wood (Poggiani, 1985, cited in Zerfu, 2002). Likewise, in Nigeria, the total above ground biomass production of a 25 years old *E camaldulensis* stand was 256 $t.ha^{-1}$. The total above ground mean biomass production per tree was 289.87 kg; of the total biomass in $t.ha^{-1}$ 153.08 kg were boles, 85.52 kg were branches, 29.82 kg were twigs and 21.46 kg were foliage and the proportionality was 52.82% in boles, 29.5% in branches, 10.28% in twigs and 7.4% in foliage (Akindele et al., 2010).

E. globulus on Ethiopian highland condition can convert more energy and water into biomass compared with exotic conifer species and it attains maximum wood production of 18 years (Pohjonen and Pukkala, 1990). In Ethiopian conditions the annual increment of *Eucalyptus* plantations at woodlots was found to be around 10 $m^3.ha^{-1}.yr^{-1}$ (Newcombe, 1989; Pohjonen and Pukkala, 1990) and according to Stiles et al. (1991) was 57 $m^3.ha^{-1}.yr^{-1}$. A study by

Kidanu et al. (2002) on *Eucalyptus* boundary plantation shows the tree densities in alley cropping system ranges from 100-110 trees.ha^{-1} and the annual wood production rate was between 168 kg.ha^{-1}.yr^{-1} for 4 years old trees to 2901 kg.ha^{-1}.yr^{-1} for 12 years old ones.

3 Materials and methods

3.1 Study area

3.1.1 Site selection and location of the study area

As the main aim of this study is to assess the soil macro-nutrient dynamics in the *Eucalyptus* plantation site, it was necessary to use the result of some previous researches. Hence, I used the study conducted by Zerfu (2002) as a reference and compared the status of the soil macronutrients by using the same study site (Fig 1). Nonetheless, as the previous study did not use specific geo-referencing materials like GPS, the sampling points were discussed with Dr. Zerfu Hailu and were approximately located so that it will be coherent with the former sampling points

Figure 1 Jufi *E. camaldulensis* coppice plantation.

Jufi *E. camaldulensis* plantation site is located in Achefer district, West Gojam administrative zone in Amhara national regional state, Ethiopia (Fig 3). Geographically, the study site is located between 36°57'8"- 36°57'45" longitude and 11°22'20"- 11°22'40" latitude and it is surrounded with different LUS (grazing, bush and farm lands) (Annex 1). The slope of the site is 3-4% inclined from southwest to northeast (Zerfu, 2002) and 4-6% is inclined from East to West.

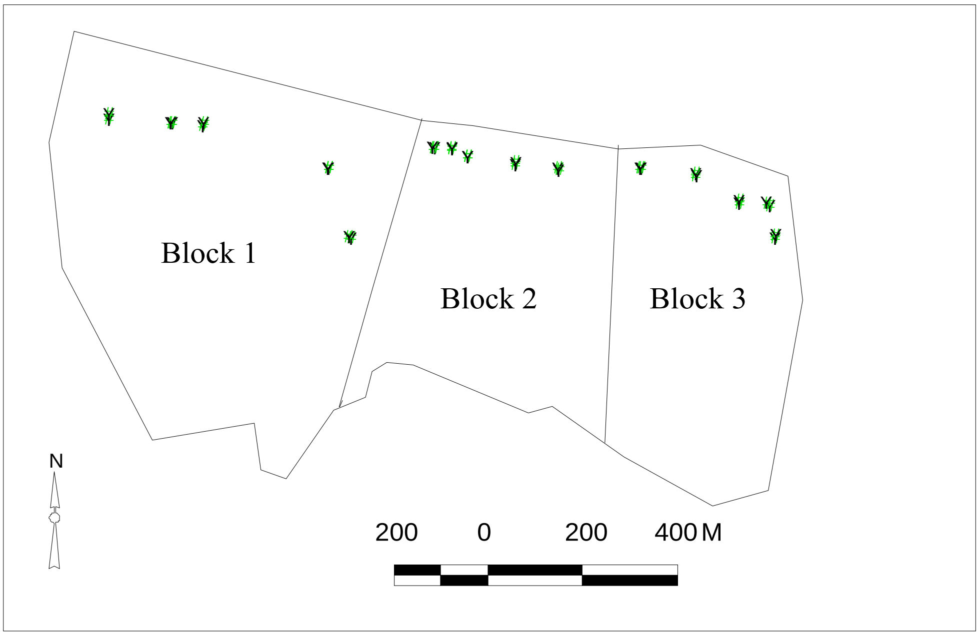


Figure 2 Sketch map of Jufi *E. camaldulensis* Plantation with soil pit locations.

Jufi plantation site has an area of 35 hectare. It was formerly part of Addis Bah Fuel wood Project but later handed over to the local community. The plantation is divided into three blocks (Fig 2) depending on the plantation establishment years (block 1 planted in 1989 on the western side, block 2 planted in 1990 and block 3 planted in 1992 eastern side).

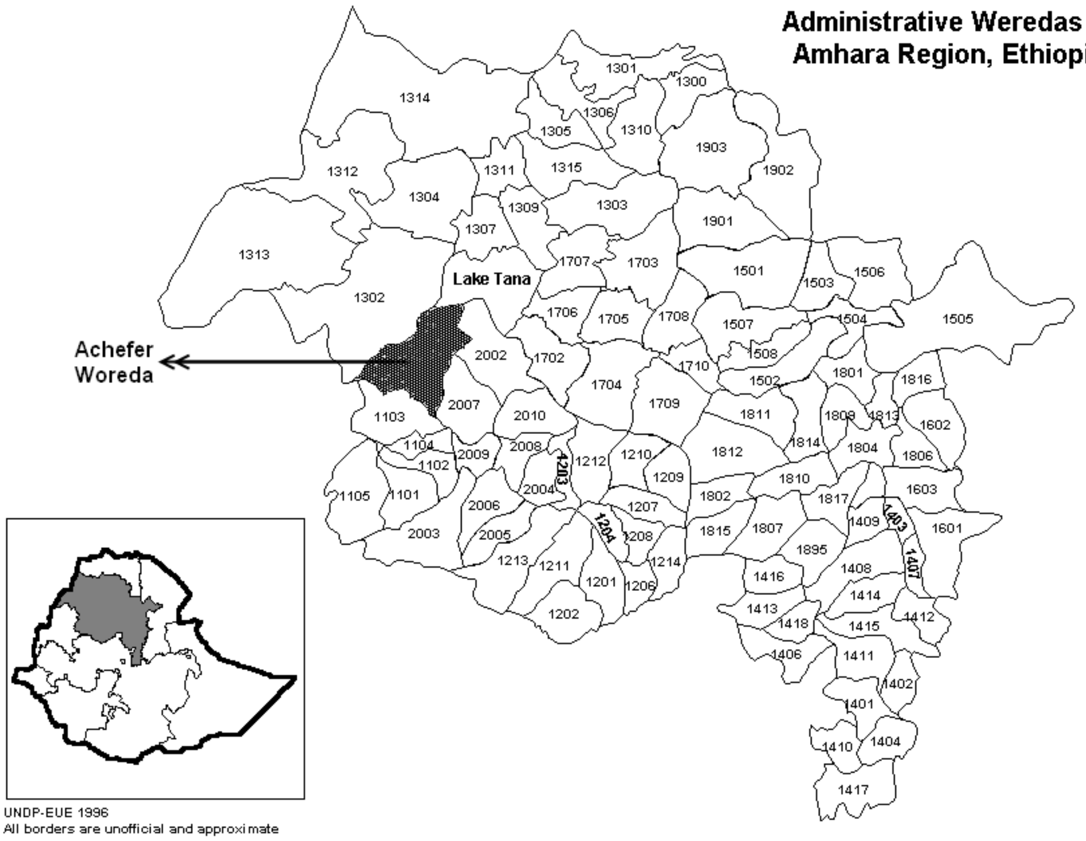


Figure 3 the location of the study district (Achefer Woreda) in Amhara region.

3.1.2 Agro-ecology of the study site

Jufi site lies in the tepid sub-humid plain sub agro-ecological zone. The topography of this area is an undulating plain with the altitude ranging from 1972 to 2021 m.a.s.l for the specific plantation site. The mean annual rain fall varies from 1200 mm to 1700 mm and its mean annual temperature ranges from 16 °C to 21 °C (Zerfu, 2002).

3.1.3 Major soil types in Jufi area

Two major soil types, namely Humic Alisol and Rhodic Nitisol, dominate the Jufi area (Fig 4). The Humic Alisols in the area are characterized as very deep, slightly to moderately eroded, slightly hard, and well drained and clay textured. Rhodic Nitisol is the other major soil type in Jufi area characterized as very deep, well drained, from none to severely eroded, slightly hard and clay textured (Zerfu, 2002). The whole area of block 1 and most parts of block 2 are dominated by Nitosols while block 3 is mainly dominated by Alisols with some parts having Nitisol soils.

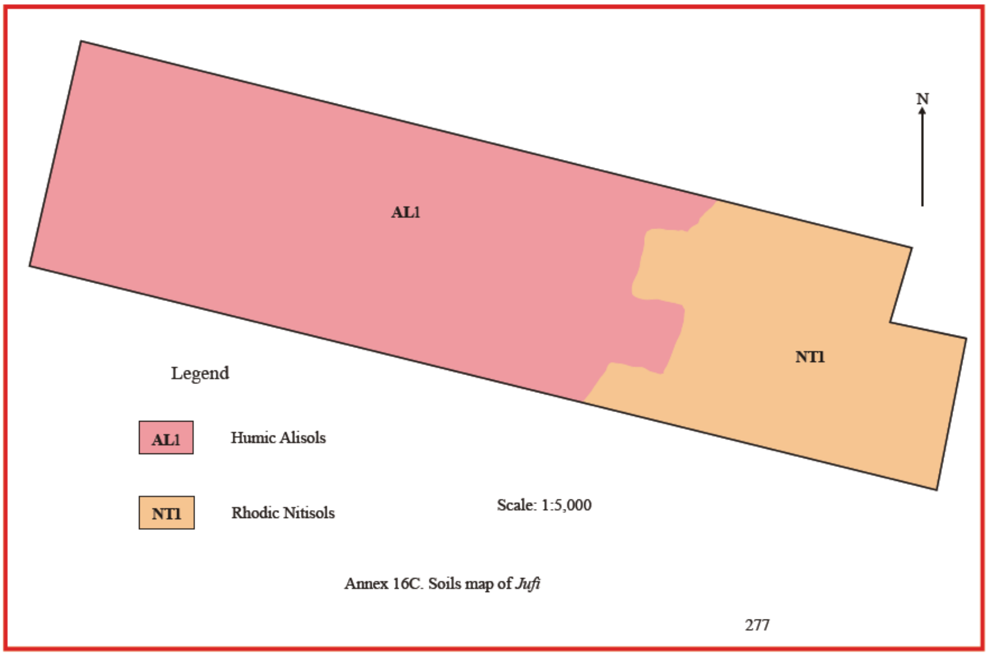


Figure 4 soil map of Jufi plantation site (Source: Zerfu, 2002).

3.2. The history of E. camaldulensis plantation establishment in Jufi site

As indicated earlier, *E. camaldulensis* plantations were established in Jufi site in 1989, 1990 and 1992 (Fig 2 and 3). The main objective of the plantation was to produce fuel-wood and construction poles to supply the communities in the nearby towns (e.g. Bahr Dar, Durbete, Dangla and Merawi) and rural communities. Before the plantation establishment, the land was used for growing agricultural crops and to some extent for grazing (Zerfu, 2002). The plantation was established with a 1m*1m spacing and stocking of 10,000 trees.ha^{-1} (Zerfu, 2002); Information from Achefer district agricultural office. First rotation cycle of the *E. camaldulensis* plantation was harvested in 1997 (block 1 and 2) and 1998 (block 3) with in consecutive years.

3.3 E. camaldulensis plantation coppice regeneration inventory

The *E. camaldulensis* plantation coppice regeneration inventory was conducted between July and September 2010. The aim of the inventory was to determine the total number of coppices greater than or equal to 5 cm DBH per stump and to determine the total aboveground biomass (stem wood) per hectare. The area delineation for the plantation site was done by using Garmin GPS 60 which also helped to construct the map of the plantation site. GPS readings are indicated in Annex 2.

Following the methods used by Zerfu (2002), a systematic sampling procedure was used to fit the sampling points with the ones used by previous author. Straight lines were laid across the blocks using Garmin GPS 60 on which at every 50 meter interval a circular sample plot with a radius of 5.64 m (area = 100 m^2) were established. In each of these plots, all coppices ≥ 5.0 cm DBH were counted and measured to the nearest one decimal place and one dominant tree per plot was measured for height. In addition, coppices < 5.0 cm DBH and dead stumps were also counted. Coppices ≥ 5.0 cm DBH were classified into 3 groups (5.0-9.0, 9.1-14.0, 14.1-19.0) based on 5.0 cm diameter class intervals. In general, the number of circular plots assessed for block 1, 2 and 3 were 71, 68 and 43 respectively. Inventory records are presented in Annex 8-a, 8-b and 8-c.

The tree basal area and volume were calculated only for trees ≥ 5.0 cm DBH by using the. following equations.

$$BA = \pi\left(\frac{DBH}{200}\right)^2 \quad \text{..Equation 1.}$$

Where BA – Tree basal area (m^2) and DBH – Diameter at Breast Height (cm).

$$V = \pi\left(\frac{DBH}{200}\right)^2 * H * ff \quad \text{..Equation 2.}$$

Where V – Tree volume (m^3); H – standing tree height (m).

Tree volume was calculated for each measured tree using DBH and the height of one dominant tree on each plot. In addition, a form factor of 0.4, developed by Wondo-Genet College of Forestry for *Eucalyptus* plantations, was used. The per hectare tree volume was computed from the plot volumes.

3.4 Leaf sample collection from the E. camaldulensis coppices

To investigate the nutrient contents of *E. camaldulensis* plantation after first coppicing leaf samples purpose fully and systematically were taken around each of the 15 soil pits (with 50 cm depth) (Fig 2 and 5). Around each soil pit, three coppices which are nearest to the pit were selected from each of the diameter classes (<5, 5.0-9.0, 9.1-14.0, 14.1-19.0). Then, all leaves from selected coppices were collected by bending and in the cases of strong coppices; climbers were hired to collect the leaves (Fig. 5). The total collected leaves were weighed using a graduated weight balance. Then 100 **g** fresh samples were taken from total weight and air-dried to avoid fungal decay. From each air-dried samples, 15 **g** subsamples were taken and were transported to Vienna for laboratory analysis.

Figure 5 Leaf samples collection in the field.

3.5 Soil sampling procedures

The soil sampling points were identified by consultation with Dr. Zerfu Hailu so that the points were nearly similar with the ones he used during his research. The soil sampling procedure was very similar to the ones used by Zerfu (2002) for the Jufi *E. camaldulensis* plantation site. For each block of the *E. camaldulensis* coppices, ten soil sampling pits were dug, five pits to the depth of 50 cm and the rest to the depth of 20 cm from the surface. The sampling depths used in the pits were 0-10 cm, 11-20 cm, 21-30 cm, 31-40 cm and 41-50 cm. Soil samples were collected by using a corer with a diameter of 67 mm. Soil samples were collected for each depth profile from three points (Fig. 6) and then hand mixed. From these composite samples, 300 **g** fresh subsamples were taken and air dried of which 150 **g** subsample was packed and brought to Vienna for laboratory analysis.

Figure 6 Soil samples collection procedures.

3.6 Laboratory analysis

3.6.1 Sample pre-treatment

The composite soil samples were sieved to a mesh < 2mm and air dried for further analytic procedures, a subsample was dried to constant mass at 105 °C for calculation of analytic results to oven dry basis and for C, N, P and S determination. The leaf-samples were oven dried at 80 °C to constant weight and grinded to a mesh < 0.5 mm.

3.6.2 Carbon and Nitrogen analysis

The total carbon and nitrogen contents of the soil and leaf samples were determined using an element analyzer (Truspec CN, LECO Corporation) according to ÖNORM 1080 (2009). Detailed laboratory results are available in Annex 6. The samples are combusted in a furnace in pure O_2-atmosphere at a temperature of 950 °C. The evolved CO_2 is measured by infrared absorption, NOx is converted into N_2 using a copper catalyst and measured using a thermal conductance detector.

The measurements are carried out after instrument calibration with different masses of $CaCO_3$ for C and of LECO soil standard 502.308 for N (N-content=3mg/g).

3.6.3 Soil pH measurement

Soil pH was determined in 1:3 soil suspensions in deionized water and 0,01 M $CaCl_2$ solution using a digital potentiometric pH-meter (CG840, Ag/AgCl electrode) according to Austrian Standard Procedure (ÖNORM L 1083, 2006).

3.6.4 Sample extraction and element analysis

Total P and S were extracted by using aqua regia according to the Austrian standard procedure (ÖNORM L1085, 2009). The exchangeable cations (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, Fe^{3+}, Mn^{2+} and Al^{3+}) were extracted from the air dried samples using 1M Ammonium acetate (NH_4OAc) buffered at pH 7.0 according to ÖNORM L1094-2 (1999), (results indicated in Annex 7).

Leaf samples were extracted in a mixture of HNO_3 and $HClO_4$ according to the Austrian standard procedure (ÖNORM L1085, 2009) (results indicated in annex 5).

The respective elements in all extracts were determined using a simultaneous ICP-AES with axial plasma (OPTIMA 3000 XL, Perkin Elmer). The instrument calibration was done matrix adapted.

3.6.5 Calculations

All elements were calculated on oven dry basis. The CEC was approximately calculated by summarizing the determined element-concentrations in the ammonium-acetate extract in relation to their atomic weight and charge as follows:

CEC mmol/100g: K ($\mu g.g^{-1}$)/390 + Ca ($\mu g.g^{-1}$)/200 + Mg C/120 + Na ($\mu g.g^{-1}$)/230 +Mn ($\mu g.g^{-1}$)/275. However in order to compare the results with (Zerfu 2002), we used Ca, K and Mg only to compute the CEC. Moreover, the cation of Na and Mn is almost negligible.

3.7 Data Analysis

The main data analysis procedures used were descriptive statistics (mean, standard deviation and standard error of the mean), analysis of variance (ANOVA) and pairwise mean comparison using the *Scheffe* test to solicit the significantly differing group means. The analysis outputs were displayed as text, tables and graphs.

4 Results

4.1 Plantation inventory

To ascertain the total number of trees per hectare and to classify in to different diameter classes for the estimation of basal area and volume, a systematic sample procedure was applied. In all *Eucalyptus* plantations a uniform inventory procedures were used. Tree thicknesses over bark were measured at 1.3 m (DBH) by using finish caliper and the height measurement also done from base of the tree up to the whole height (top) by using Silva hypsometer. Based on the forest inventory the results of the basal area and volume under different blocks are presented in Table 1, while trees with DBH classes and dominant height including stump numbers also presented in annex 8-a, 8-b and 8-c. The over bark wood stem volume in block 1, 2 and 3 was 85.7364 $m^3.ha^{-1}$,90.8417 $m^3.ha^{-1}$, and 29.558 $m^3.ha^{-1}$ and the respective over bark basal area was 14.8520 $m^2.ha^{-1}$, 17.6195 m^2 $.ha^{-1}$ and 6.8581 $m^2.ha^{-1}$ (Annex 9-a, 9-b and 9-c). These values were calculated based on Wondogenet College of Forestry work done on *Eucalyptus* plantations.

The estimated BA at block level indicates that block 2 has greater yield than block 1 and 3. The variability in BA among the blocks is mainly associated with number of trees per hectare. Thus, block 2 with higher tree number was ranked first followed by block 1 and 3 respectively. The total number of trees greater than or equal to 5 cm DBH were 5222, 7768 and 2744 ha^{-1} for Block 1, 2 and 3 respectively. The average number of coppices per stump was about two to three in most cases in all the blocks (Annex 8-a, 8-b and 8- c). The mean dead stump density was around 92 stumps per hectare for block 1 and for block 2 and 3 were 54 and 16 per hectare respectively (Annex 8-a, 8-b and 8- c). The average stump height in block 1 was 26 cm while for Block 2 and 3 it was 22 and 25 cm respectively (Annex 8-a, 8-b and 8-c).

Table 1: Estimated BA and V of *E. camaldulensis* at Jufi plantation sites.

Block	Stand age	Coppice age	Dead stump ($no.ha^{-1}$)	Alive stump ($no.ha^{-1}$)	Basal area ($m^2.ha^{-1}$)	Volume ($m^3.ha^{-1}$)
1	18	6	92	2618	14.8520	85.7364
2	17	6	53	3328	17.6195	90.8417
3	15	5	16	1172	6.8581	29.5580

4.2 Soil Organic Carbon

The soil organic carbon (SOC) did not show any considerable statistical difference among the *Eucalyptus* blocks which were established in different years (Table 2). But, soil samples from block 2 were observed to have higher SOC compared to the ones from block 1 and 3. Nonetheless, the comparison of the SOC across depth by aggregating the blocks together showed significant difference when assessed by using ANOVA ($F_{(4, 100)} = 19.48$, $p < 0.001$). It is also clearly visible that as the soil depth increases, the SOC content decreased continuously (Fig. 7).

Table 2 Soil organic carbon content ($mg.g^{-1}$) of the *E. camaldulensis* plantation sites.

	Establishment Year	Soil depth				
		0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm
Block 1	1989	26.9^{ab} (1.37)	25.50^{a} (1.49)	22.5^{a} (1.78)	18.9^{a} (1.02)	18.2^{a} (0.69)
Block 2	1990	31.4^{a} (1.31)	27.18^{a} (1.42)	24.3^{a} (1.29)	22.0^{a} (0.76)	20.3^{a} (0.97)
Block 3	1992	26.6^{b} (1.22)	22.97^{a} (0.97)	21.3^{a} (1.38)	20.1^{a} (1.36)	19.0^{a} (1.87)

N.B. Values followed by the same letter across a column are not significantly different using the *Scheffe* mean comparison test at p=0.05. Values in bracket indicate the standard error of the mean.

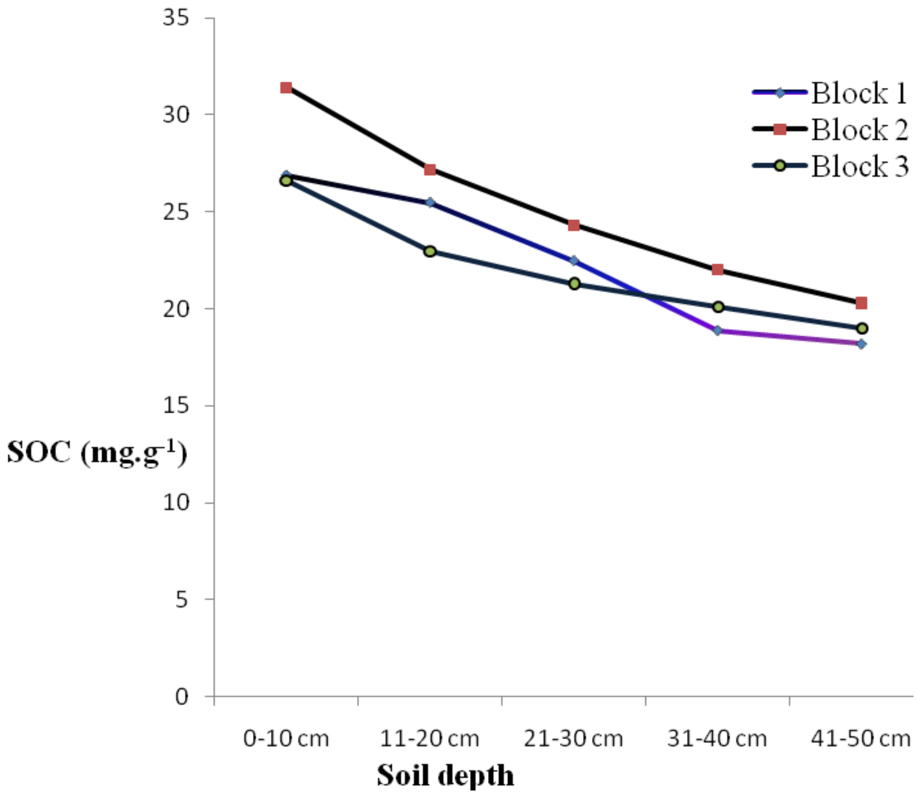


Figure 7 SOC (mg.g^{-1}) for the *E. camaldulensis* plantation sites.

4.3 Soil Nitrogen

No considerable statistical difference was observed in soil nitrogen (N) content among the *Eucalyptus* blocks which were established in different years (Table 3), though soil samples from block 2 were observed to have higher N content than other blocks. The comparison of the N across depth by aggregating the blocks together showed significant statistical difference when assessed by using ANOVA ($F_{(4, 100)} = 13.17$, $p < 0.001$). Like as the SOC, the N content of the soils decreased with increasing soil depth for all blocks (Fig. 8).

Table 3 Soil nitrogen content (mg.g^{-1}) of the *E. camaldulensis* plantation sites.

	Establishment Year	Soil depth				
		0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm
Block 1	1989	2.1^{ab} (0.12)	2.1^{a} (0.10)	1.9^{a} (0.14)	1.7^{a} (0.04)	1.6^{a} (0.08)
Block 2	1990	2.6^{a} (0.11)	2.2^{a} (0.09)	2.1^{a} (0.17)	1.9^{a} (0.15)	1.8^{a} (0.13)
Block 3	1992	2.3^{b} (0.11)	2.0^{a} (0.08)	1.9^{a} (0.09)	1.8^{a} (0.09)	1.8^{a} (0.10)

N.B. Values followed by the same letter across a column are not significantly different using the *Scheffe* mean comparison test at p=0.05. Values in bracket indicate the standard error of the mean.

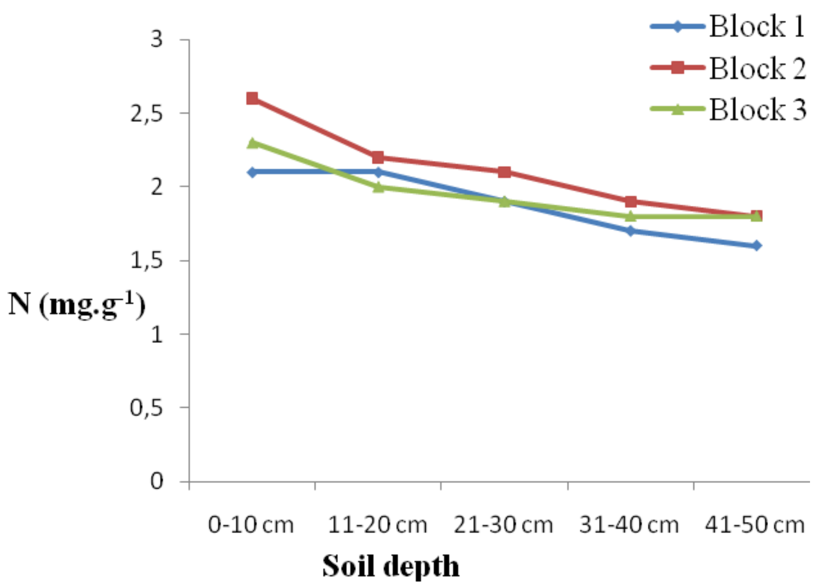


Figure 8 Soil N (mg.g^{-1}) for the *E. camaldulensis* sites.

4.4 Soil C:N (carbon nitrogen ratio)

The ratio of soil C and N (C: N) differed significantly between plantation blocks of the *E. camaldulensis* coppice regeneration (Table 4). The average value of soil C:N was nearly the same in all blocks: under block 1 it was observed as higher (11.84) than those of block 2 (11.80) and block 3 (11.22).

By avoiding the block separation and aggregating along the soil depths, ANOVA showed significant differences in the C: N across all soil depth sections. Significantly higher C:N ratios were found in the upper soil section and decreased smoothly with increasing soil depth (Fig 9).

Table 4 Soil C: N ratio of the *E. camaldulensis* plantation sites.

	0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm
Block 1	12,8	12,1	11,8	11,1	11,4
Block 2	12,1	12,4	11,6	11,6	11,3
Block 3	11,6	11,5	11,2	11,2	10,6

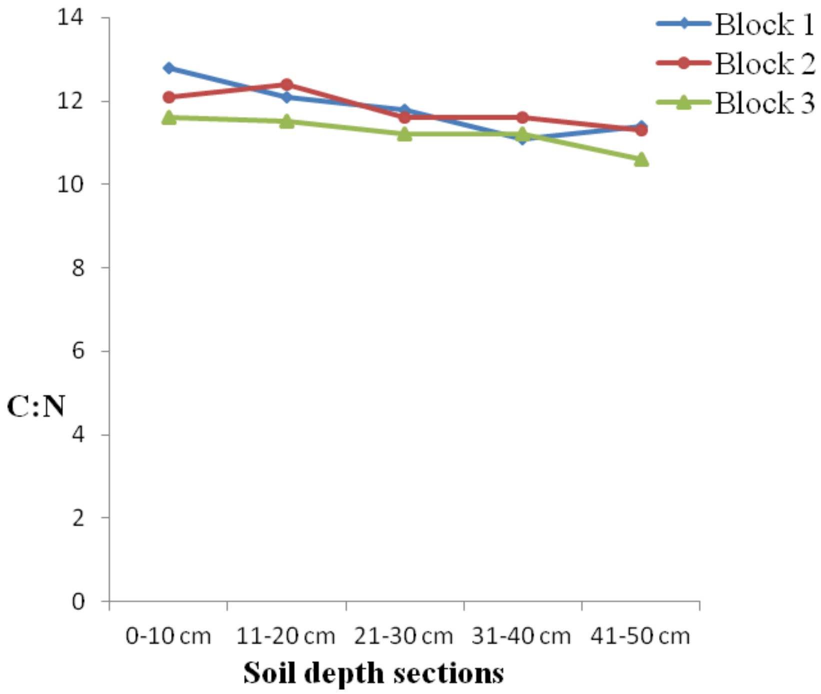


Figure 9 Soil C: N for the *E. camaldulensis* sites.

4.5 Soil pH (H_2O)

No statistical difference was observed in soil pH among the *Eucalyptus* blocks due to its non normal distribution (Table 5 and Fig 10). Nonetheless, soil samples collected from block 1 had the lowest pH values compared to block 2 and 3 which might be associated to the difference in soil types among the blocks. One remarkable observation is that with increasing soil depth, the pH (H_2O) increases which also indicates the decreasing acidity of the soil with depth (Fig. 10).

Table 5 Soil pH (H_2O) of the *E. camaldulensis* plantation sites.

	Establishment Year	Soil depth				
		0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm
Block 1	1989	5.13 (0.11)	5.14 (0.1)	5.26 (0.22)	5.1 (0.27)	5.3 (0.21)
Block 2	1990	5.21 (0.03)	5.26 (0.03)	5.4 (0.04)	5.46 (0.04)	5.52 (0.05)
Block 3	1992	5.29 (0.07)	5.3 (0.04)	5.36 (0.05)	5.48 (0.04)	5.54 0.06)

Values in bracket indicate the standard error of the mean.

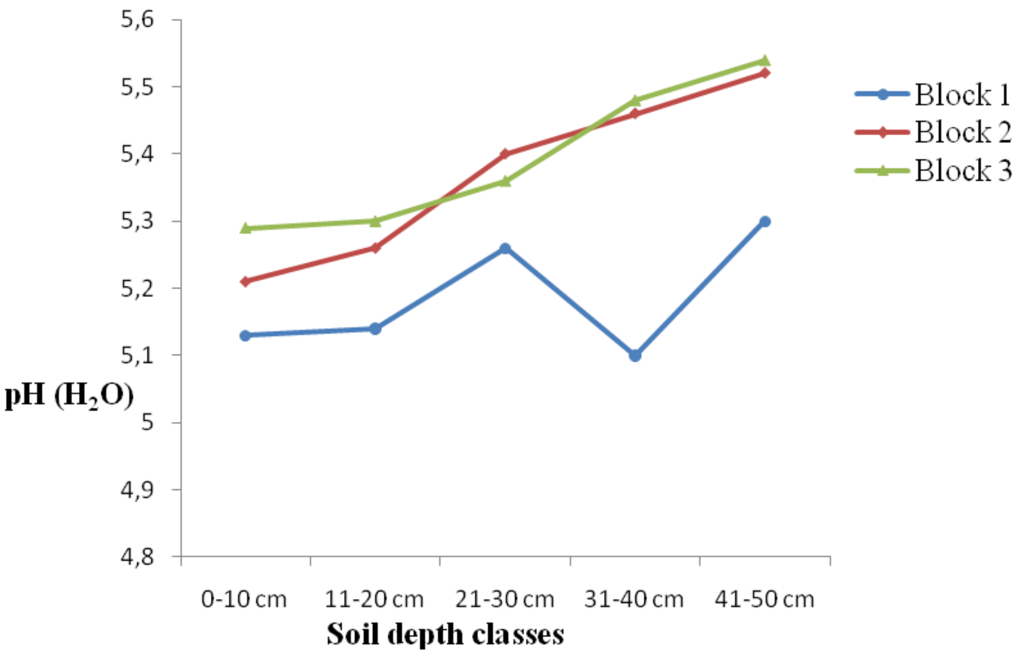


Figure 10 Soil pH (H_2O) of the *E. camaldulensis* plantation sites.

There were no observations of the statistically significant differences in soil pH ($CaCl_2$) between different plantation blocks (Table 6). Similarly there were no significant differences in the mean values of the soil pH ($CaCl_2$) along the soil depths of *E. camaldulensis* coppice regeneration. However, the lower soil pH values were observed in the upper soil sections whereas higher ones were observed in the lower soil sections, which means soil acidity decreased in the lower soil sections (Fig 11).

Table 6 Soil pH ($CaCl_2$) of the *E. camaldulensis* plantation sites.

	Establishment Year	Soil depth profiles				
		0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm
Block 1	1989	4.11 (0.16)	4.17 (0.17)	4.34 (0.90)	4.38 (0.13)	4.4 (0.20)
Block 2	1990	4.07 (0.10)	4.28 (0.08)	4.3 (.10)	4.3 (0.10)	4.18 (0.13)
Block 3	1992	4.14 (0.15)	4.13 (0.14)	4.26 (0.13)	4.34 (0.13)	4.38 (0.15)

Values in bracket indicate the standard error of the mean.

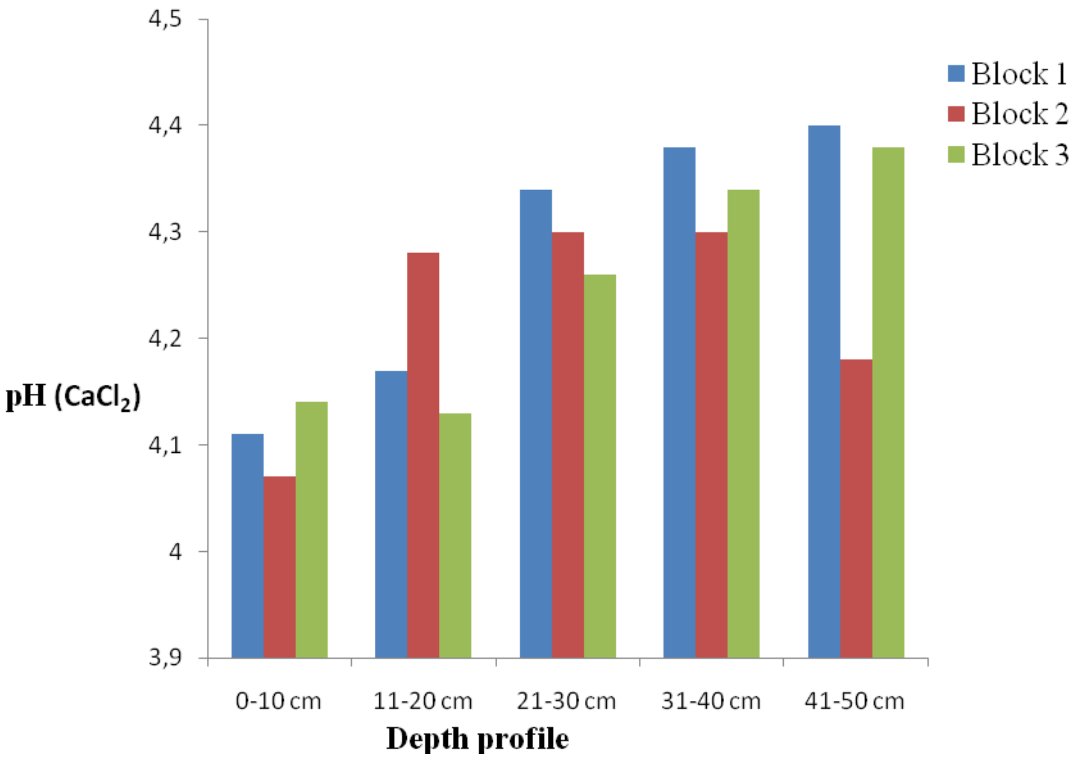


Figure 11 Soil pH ($CaCl_2$) of the *E. camaldulensis* plantation sites.

4.6 Exchangeable cations

Soils under different blocks of *E. camaldulensis* plantation at Jufi have different amount of exchangeable soil cations. In this study, some focused exchangeable cations were; Ca^{++}, K^{+}, Mg^{++}, Mn^{++} and Na^{+}.

Table 7 comparison of the content of exchangeable cations within different *E. camaldulensis* stand.

		Ca ($\mu g.g^{-1}$)	K ($\mu g.g^{-1}$)	Mg ($\mu g.g^{-1}$)	Mn ($\mu g.g^{-1}$)	Na ($\mu g.g^{-1}$)
Block 1	Mean	790.75[a]	145.55[a]	324.57[a]	18.00[a]	12.52[a]
	Std. Error	45.32	11.45	13.26	1.18	0.56
Block 2	Mean	629.60[ab]	203.93[b]	306.19[b]	14.85[a]	10,66[a]
	Std. Error	25.33	9.86	7.59	1.32	0.56
Block 3	Mean	532.42[b]	190.54[b]	234.37[b]	14.49[a]	11.15[a]
	Std. Error	64.45	14.52	9.14	.90	0.69
Total	Mean	650.92	180.00	288.37	15.78	11.44
	Std. Error	29.25	7.34	7.01	0.67	0.35

Note: Means followed by the same letter across a column are not significantly different at p=0.05 using the *Scheffe* mean comparison test.

Table 8 comparison of the exchangeable cations in different soil depths.

	0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm	Total
Ca ($\mu g.g^{-1}$)	640.41[a]	674.26[a]	646.31[a]	651.95[a]	628.88[a]	650.92
K ($\mu g.g^{-1}$)	215.96[a]	183.93[ab]	168.84[ab]	151.34[ab]	140.09[b]	180.01
Mg ($\mu g.g^{-1}$)	298.68[a]	293.12[a]	282.08[a]	275.12[a]	277.81[a]	288.38
Mn ($\mu g.g^{-1}$)	20.62[a]	17.53a[b]	13.09b[c]	10.80[c]	10.28[c]	15.78
Na ($\mu g.g^{-1}$)	12.02[ab]	13.12[b]	10.76[ab]	9.70[ab]	9.35[a]	11.44

Note: Means followed by the same letter across a row are not significantly different at p=0.05 using the *Scheffe* mean comparison test.

4.6.1 Calcium

At Jufi plantation site calcium is the most dominant cation in all three *Eucalyptus* blocks (Table 7). Block 1 has the highest exchangeable Ca^{++} (790.75 $\mu g.g^{-1}$) than block 2 (629.60 $\mu g.g^{-1}$) and 3 (532.42 $\mu g.g^{-1}$). The mean comparison of *Scheffe* test method showed statistically significant differences under block 1 when compared with block 2 and 3. However, variability of the exchangeable Ca^{++} across the soil depth profiles statistically it was not significant

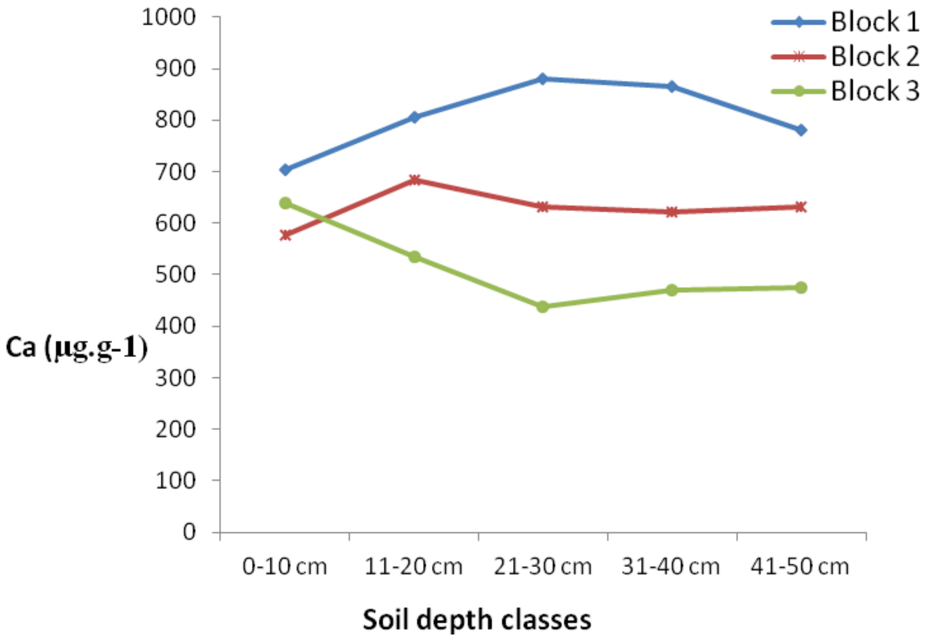


Figure 12 Calcium content across depth at Jufi *E. camaldulensis* plantation sites.

4.6.2 Potassium

Eucalyptus stand of block 1 contained the lowest exchangeable K^+ while compared with block 2 and 3 (Table 7). The highest K^+ content was observed in block 2 for all soil depth sections except for the soil depth of 0-10 cm where block 3 once exceeds. Block 1 showed statistically significant difference for the content of exchangeable K^+ while compared with block 2 and 3, but variability between block 2 and 3 was not showing statistically significant differences. Change in K^+ content under block 1 across the soil depth mostly showed regular reduction rate while compared to other blocks (Fig 13).

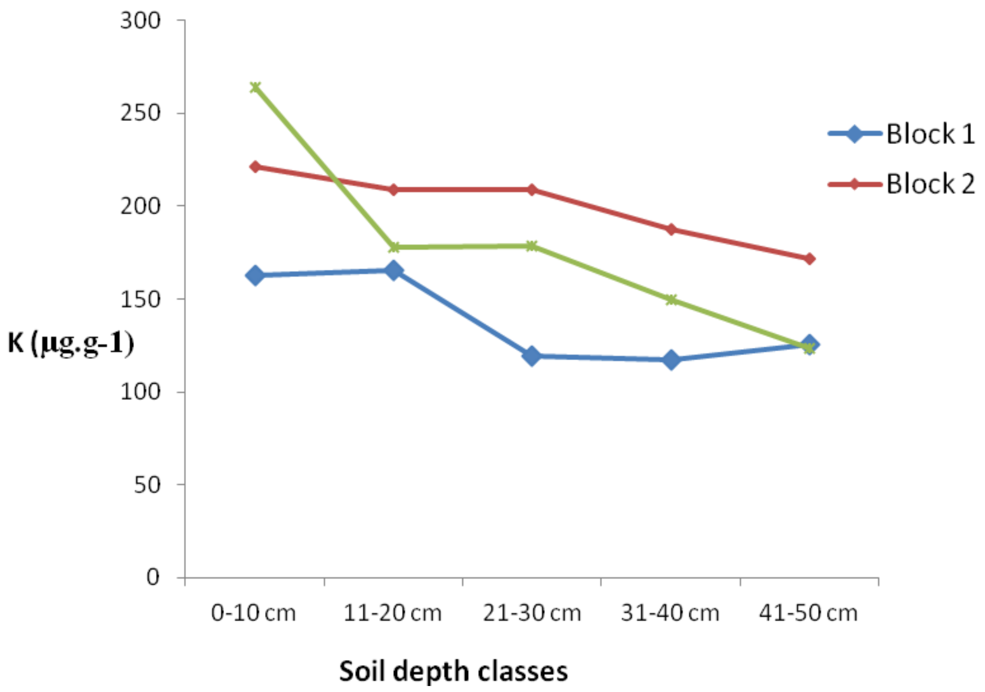


Figure 13 Potassium content across depth at Jufi *E. camaldulensis* plantation sites.

4.6.3 Magnesium

The average content of exchangeable Mg^{++} under block 1, 2 and 3 was 324.57 µg.g^{-1}, 306.19 µg.g^{-1} and 234.37 µg.g^{-1} respectively (Table 7). Statistically significant difference was observed among the blocks. Block 1 was significantly differed from block 2 and 3. The change in Mg^{++} concentration across soil depth sections showed almost negligible variation. However, the variability across depths was higher in block 2 (Table 8 and Fig 14).

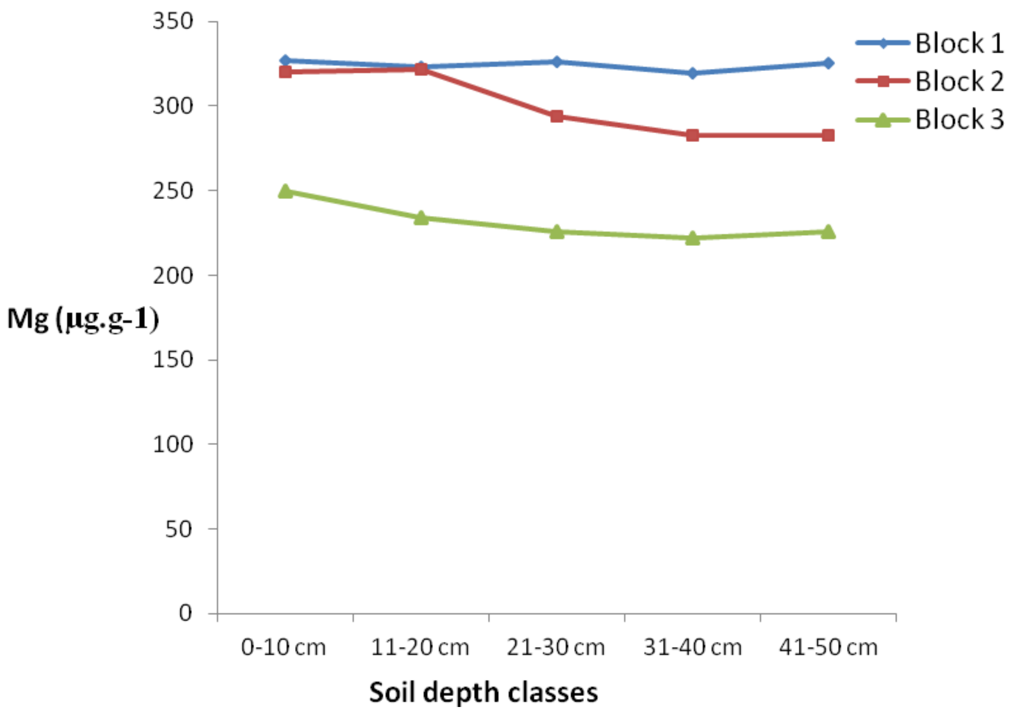


Figure 14 Magnesium content across depth at Jufi *E. camaldulensis* plantation sites.

4.6.4 Manganese

There is no statistically significant difference between the blocks concerning exchangeable Mn^{++} content (Table 7). However relatively higher content was recorded in block 1 (18.00 µg.g^{-1}) and lower content was recorded in block 3 (14.00 µg.g^{-1}). The Mn^{++} content sharply decreased as soil depth increased down ward for all blocks (Table 8). The highest and the lowest soil exchangeable Mn^{++} content was observed in 0-10 cm and 41-50 cm soil depths respectively for all blocks (Fig 15).

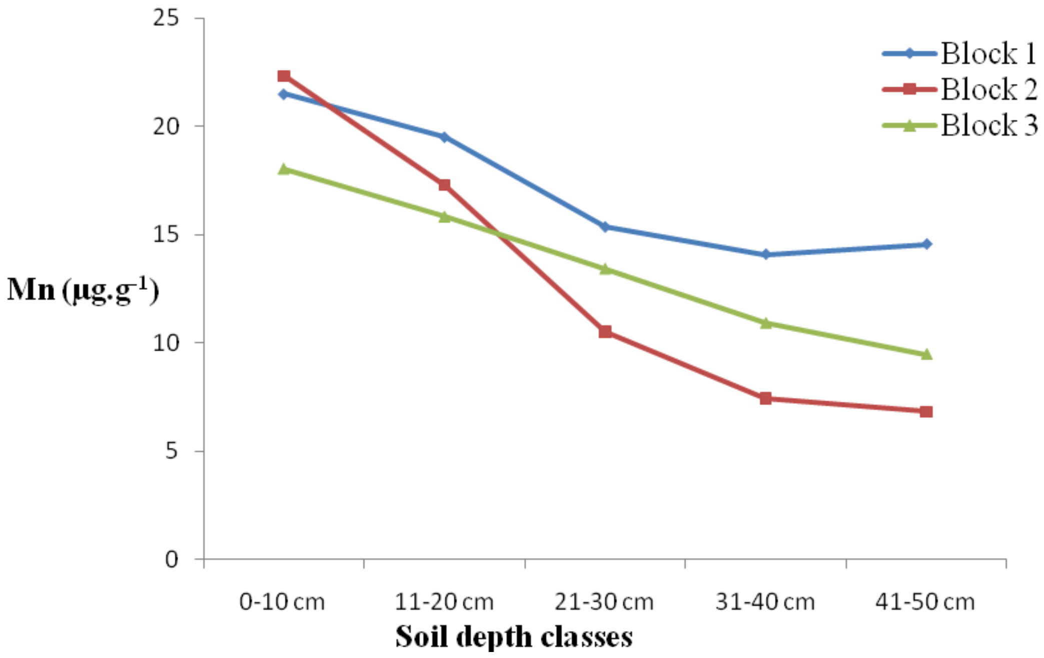


Figure 15 Manganese content across depth at Jufi *E. camaldulensis* plantation sites.

4.6.5 Sodium

As for Mn^{++}, the soil exchangeable Na^{+} also showed statistically insignificant variation between blocks (Table 7). However, block 1 has relatively higher soil exchangeable Na^{+} content (12.58 µg.g^{-1}) as compared to the rest. Mostly irregular patterns of variations were observed for all blocks. Irregular pattern of variation for the soil exchangeable Na^{+} also was observed among the soil depth sections for all blocks (Table 7 and Fig 16).

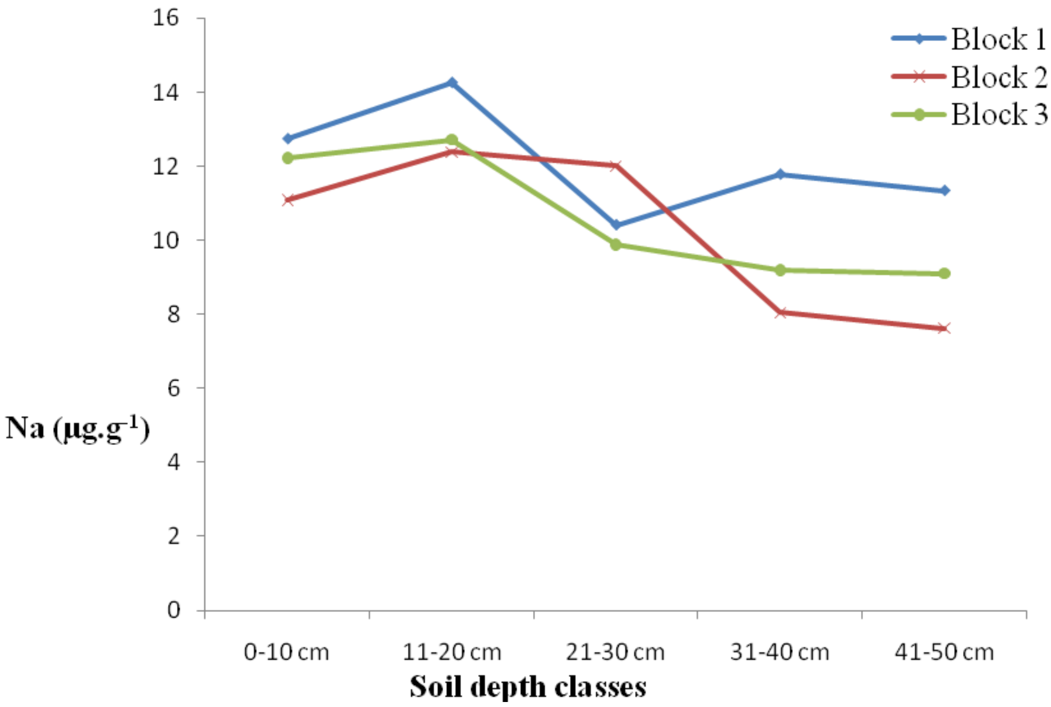


Figure 16 Sodium content cross depths at Jufi *E. camaldulensis* plantation sites.

4.7 Cation exchangeable capacity

The distributions of CEC were not showing uniform trends between blocks and across soil depth profiles under *Eucalyptus* plantation (Table 9 and Fig 17). Under block 1 the CEC was higher than in the other plantation blocks. In block 1 high CEC was observed in the 21-30 cm soil section while lower CEC was identified in the 0-10 cm soil section. In block 2, higher and lower CEC was observed in the 11-20 and 31-40 cm soil sections respectively. Under 5 years old *Eucalyptus* coppice plantation of block 3 higher and lower CEC were identified in the soil section of 0-10 and 21-30 cm respectively.

Table 9 CEC (μmolc.g^{-1}) of soils under *E. camaldulensis* plantation sites.

	0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm
Block 1	66.62	71.50	73.72	72.90	69.36
Block 2	61.24	66.34	61.45	59.45	59.52
Block 3	59.49	50.73	45.29	45.86	45.67

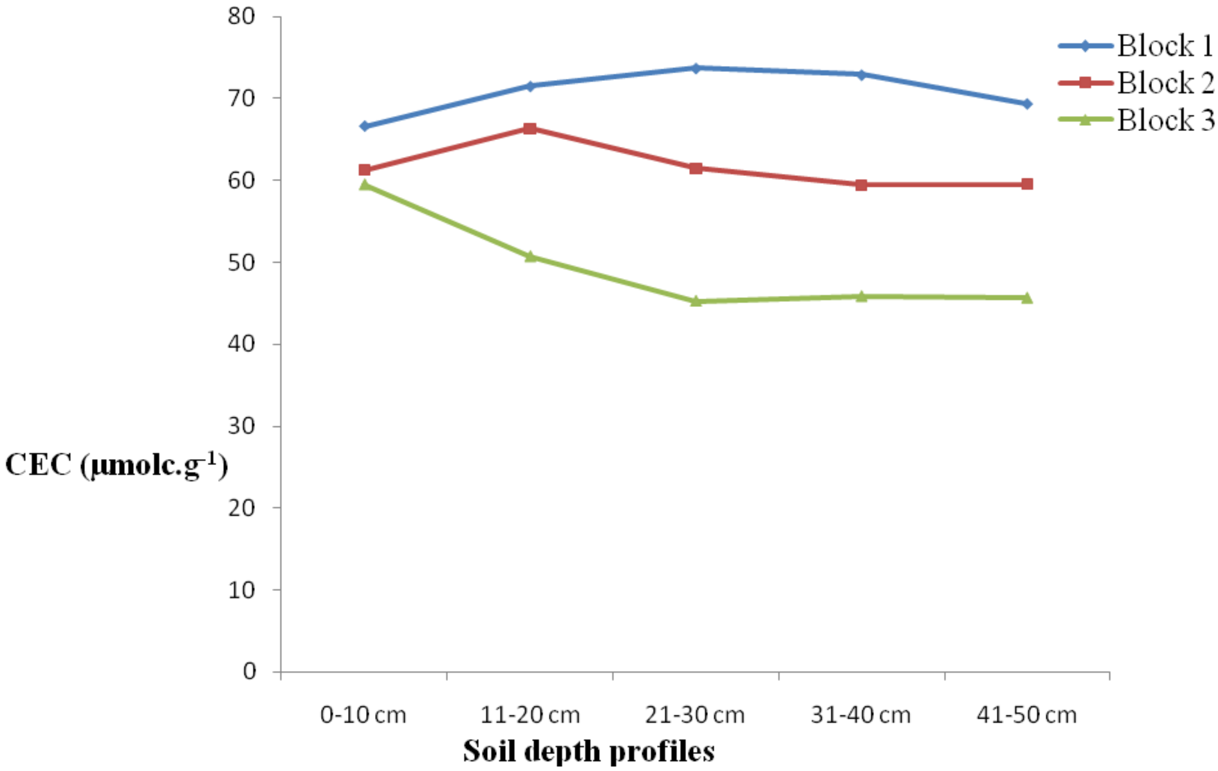


Figure 17 CEC potential cross depths at Jufi *E. camaldulensis* plantation sites.

4.8 Nutrient contents of E. camaldulensis coppices leaves

4.8.1. Nitrogen

The nitrogen mass in block 1 of 6 years old *E. camaldulensis* coppice growth leaves was found to be 103.42 kg N.ha^{-1}. Almost two-third of this nitrogen (60.93%) in this block is contributed by tree saplings' leaves. The rest, one-third (38.97%) is contributed by leaves of trees of DBH class of 5.0-9.0 cm. The contribution of trees in the DBH classes of 9.1-14.0 cm and 14.1-19.0 cm were relatively insignificant with respective numbers of 0.03 and 0.07% (Table 10 and Fig 18).

In block 2 of 6 years old *E. camaldulensis* coppice growth stand, the total nitrogen mass stored in leaves was found to be 131.99 kg N.ha^{-1} (Table 10). Out of these 35.59% of the nitrogen was originating from saplings' leaves. About 64.43% of the nitrogen derives from trees of DBH class of 5.0-9.0 cm. The contribution of trees in the DBH classes of 9.1-14.0 cm and 14.1-19.0 cm was very insignificant with respective contents of 0.04 and 0.05%.

In block 3 with age of 5 years old *E. camaldulensis*, the leaf nitrogen content was estimated to be 43.80 kg $N.ha^{-1}$, which was very low as compared to block 1 and 2. From the total content, 38.31% of the nitrogen was stored in tree saplings less than 5 cm DBH. About 61.44% was accumulated in trees with 5.0-9.1 cm DBH, while the rest 0.09 and 0.16% were accumulated in tree leaves with DBH classes of 9.1-14.0 and 14.1-19.0 cm, respectively (Table 12 and Fig 18).

When all sample-results for nitrogen are combined i.e. the block separation avoided, the mean nitrogen content of the coppice plantation according to DBH classes was estimated as: 17.63 $mg.g^{-1}$ for coppices with DBH less than 5 cm, 17.01 $mg.g^{-1}$ for those with DBH 5.0-9.0 cm, 16.20 $mg.g^{-1}$ in coppices with DBH 9.1-14.0 cm, and 16.90 $mg.g^{-1}$ for the ones with DBH 14.1-19.0 cm. This indicates that the leaf nitrogen content relatively decreased as the DBH of the coppices increased (Table 11).

Table 10 Nitrogen mass in leaves ($kg.ha^{-1}$) of different diameter classes of *E. camaldulensis* coppices in Jufi plantation sites.

Blocks	DBH classes (cm)				
	< 5	5.0 - 9.0	9.1 -14.0	14.1 - 19.0	Total
1	63.02	40.31	0.03	0.07	103.43
2	46.98	84.89	0.05	0.07	131.99
3	16.78	26.91	0.04	0.07	43.80

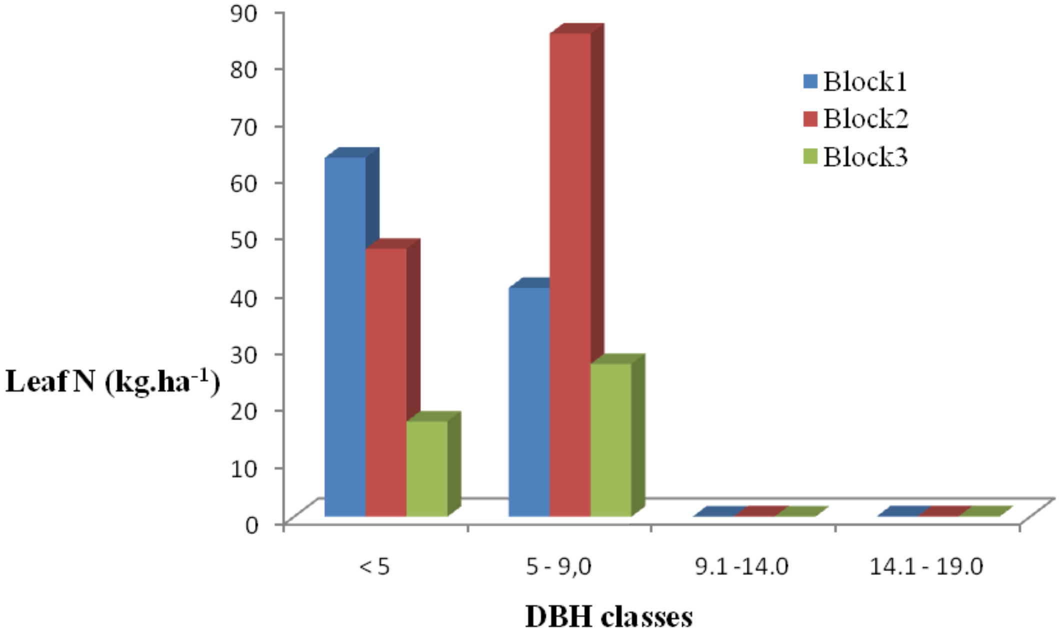


Figure 18 Leaf nitrogen in different blocks of the *E. camaldulensis* plantation sites.

4.8.2. Phosphorus

The total phosphorus content in leaf biomass of *E. camaldulensis* stand under block 1 of 6 years old was found to be 6.37 kg P. ha^{-1}. Out of this, 56.98% was contributed by coppices with less than 5 cm DBH, 35.48% by coppices with DBH class of 5.0-9.0 cm, 2.67% by trees with DBH classes of 9.1-14.0 cm and 4.87% by trees with DBH class 14.1-19.0 cm (Table 11).

In block 2 of 6 years old *E. camaldulensis* stand, the total phosphorus content in leaf biomass was 8.68 kg.ha^{-1}. About 34.45% derive from trees of DBH less than 5 cm. Trees in DBH class of 5.0-9.0 cm contribute about 56.22% to the stand leaf phosphorus content. The rest 3.80 and 5.53% were found in coppices within the DBH classes of 9.1-14.0 cm and 14.1-19.0 cm respectively.

In block 3 of 5 years old *E. camaldulensis* stand, the total leaf phosphorus content was around 2.77 kg P.ha^{-1}, which was lower as compared to the block 1 and 2. Out of this, 31.77% comes from coppices with DBH less than 5 cm, 49.10% from coppices with DBH 5.0-9.0 cm, 7.58 % from coppices with DBH 9.1-14.0 cm and 11.55% from the 14.1-19.0 cm DBH class.

When all samples were combined i.e. the block separation avoided, the mean phosphorus content of the coppices according to DBH classes was estimated as: 1.07 $mg.g^{-1}$ for coppices with DBH less than 5 cm, 0.94 $mg.g^{-1}$ for those with DBH 5.0-9.0 cm, 0.90 $mg.g^{-1}$ in coppices with DBH 9.1-14.0 cm, and 1.03 $mg.g^{-1}$ for the ones with DBH 14.1-19.0 cm.

4.8.3. Potassium

The potassium content of block 1 with 6 years age was estimated to be 40.72 $kg.ha^{-1}$ of which two-third (64.54%) was stored in tree saplings. The rest was stored in the trees with DBH class of 5.0-9.0, 9.1-14.0 and 14.1-19.0 cm, each with the potassium content of 34.87, 0.15 and 0.44% respectively (Table 12).

In block 2 with age of 6 years *E. camaldulensis* plantation stand, the total potassium content was observed to be 58.29 $kg.ha^{-1}$. Out of this 61.4% was stored in coppices with 5.0-9.0 cm DBH. About 38.14% of the potassium content was stored in saplings (with DBH < 5cm). The contributions of the rest of the DBH classes were very less (0.46%).

The per hectare potassium content of block 3 with age of 5 years *E. camaldulensis* was very small (18.87 $kg.ha^{-1}$) as compared to the other blocks. The leaves of the saplings in this stand contributed to around 37.26% of the potassium content of the stand. The major part (61.42%) of the leaf potassium content was stored in the coppices with the DBH class of 5.0-9.0 cm. Trees with DBH classes of 9.1-14.0 and 14.1-19.0 cm contained 0.47% and 0.85% respectively.

Without the block separation, the mean potassium content of the coppice according to DBH classes was: 7.64 $mg.g^{-1}$ for coppice with DBH less than 5 cm, 6.87 $mg.g^{-1}$ in DBH class 5.0-9.0 cm, 6.25 $mg.g^{-1}$ in DBH class 9.1-14.0 cm and 7.39 $mg.g^{-1}$ for coppices in DBH class

14.1-19.0 cm. The potassium content was relatively higher in lower and higher DBH classes than middle DBH classes of coppice trees (Table 11).

4.8.4. Sulfur

The per hectare sulfur content in the leaf of block 1 with age of 6 years old *E. camaldulensis* coppice plantation was 8.77 kg.ha^{-1}. The higher quantity was stored in the saplings (59.59%). Trees within the DBH class of 5.0-9.0 cm contained around 40% of sulfur in the leaves. The rest DBH classes were accumulating negligible quantity (Table 12).

In block 2 with age of 6 years old *E. camaldulensis*, the total sulfur content in *E. camaldulensis* leaf was estimated about 11.74 kg.ha^{-1}. The major part of the sulfur in the leaves (62.61%) was found in trees with DBH class of 5.0-9.0 cm. About 36.71% was found in the leaves of the saplings. Only 0.25% and 0.43% of the sulfur was contained in DBH classes of 9.1-14.0 and 14.1-19.0 cm.

The total calculated sulfur content in block 3 with age of 5 years old *E. camaldulensis* leaves was 3.75 kg.ha^{-1}. Out of this, 38.13% of the leaf sulfur content was accumulated in tree saplings. Trees in DBH class of 5.0-9.0 cm contained about 60% of the sulfur. Coppices in DBH classes of 9.1-14.0 cm and 14.1-19.0 cm contained about 0.54% and 1.33% respectively.

When all samples are combined i.e. the block separation avoided, the mean sulfur content of the coppice leaves according to DBH classes was: 1.54 mg.g^{-1} for saplings, 1.45 mg.g^{-1} for coppices in DBH class 5.0-9.0 cm, 1.45 mg.g^{-1} in DBH class 9.1-14.0 cm and 1.44 mg.g^{-1} for coppices within the DBH class 14.1-19.0 cm (Table 11).

4.8.5. Calcium

The total calcium content of block 1 with age of 6 years old *E. camaldulensis* was around 108.89 kg.ha^{-1} (Table 12). Two-third of this content was found in the sapling leaves. Trees within DBH class of 5.0-9.0 cm contained about 33.02%. The aggregate accumulation of the other DBH classes was estimated about 0.03%.

The per hectare calcium content of the *E. camaldulensis* leaves in block 2 with age of 6 years old *E. camaldulensis* was relatively high (145.38 kg.ha^{-1}). Sixty-two percent of this accumulation was found in DBH class of 5.0-9.0 cm. The accumulation of the Ca in the sapling leaves was estimated about 37.93. Trees with DBH classes of 9.1-14.0 and 14.1-19.0 cm contained similar proportions amounting to 0.01% each.

E. camaldulensis leaves under block 3 with age of 5 years old contained a small amount of Calcium as compared to block 1 and 2. Coppices in DBH classes of 5.0-9.0 cm and saplings contained 57.22% and 42.72% of Ca respectively. Those in DBH classes of 9.1-14.0 and 14.1-19.0 cm had smaller share equivalent to 0.02% and 0.04% respectively.

Avoiding the block effect, the mean calcium content in *E. camaldulensis* leaves according to DBH classes were: 20.62, 17.21, 24.16 and 21.67 mg.g^{-1} for saplings, 5.0-9.0, 9.1-14.0 and 14.1-19.0 cm, respectively (Table 11).

4.8.6 Magnesium

The total magnesium of coppices in block 1 with age of 6 years old *E. camaldulensis* was 13.80 kg.ha^{-1}. From this, tree saplings share the highest proportion (57.07%). Trees with DBH class 5.0-9.0 cm contained 39.59% whereas those with DBH classes 9.1-14.0 and 14.1-19.0 cm contained very low proportion equivalent to 0.87% and 2.47%, respectively.

In block 2 with age of 6 years old *E. camaldulensis* the magnesium content was around 16.43 $kg.ha^{-1}$ (Table 12). Saplings contributed about 38.18% and more than half (58.37%) of the magnesium accumulation was found in trees within DBH class of 5.0-9.0 cm. Trees with DBH classes ranging from 9.1-14.0 and 14.1-19.0 cm contained around 1.22% and 2.25%, respectively.

The magnesium content leaves of coppices in block 3 with age of 5 years old *E. camaldulensis* was about 5.29 $kg.ha^{-1}$. Out of this 35.16% was accumulated in saplings. Almost half (53.31%) of the magnesium content in the leaves was found in trees with DBH class 5.0-9.0 cm. Trees with DBH classes of 9.1-14.0 and 14.1-19.0 cm contained 3.97 and 7.69% respectively.

When all samples combined together, the Mg content across DBH classes was 2.12 $mg.g^{-1}$ for saplings, 1.98 $mg.g^{-1}$ for DBH class of 5.0-9.0 cm, 2.11 $mg.g^{-1}$ for DBH class of 9.1-14.0 cm and 2.02 $mg.g^{-1}$ for DBH class of 14.1-19.0 cm (Table 11).

Table 11 Nutrient contents of the leaves of coppices from different diameter classes in the three blocks of *E. camaldulensis* in Jufi site.

	Diameter classes				Overall mean
	< 5 cm	5.0 - 9.0 cm	9.1 - 14.0 cm	14.1- 19.0 cm	
Al ($mg.g^{-1}$)	0.42 (0.19)	0.45 (0.20)	0.39 (0.17)	0.35 (0.12)	0.40 (0.18)
Ca ($mg.g^{-1}$)	20.62 (7.53)	17.21 (3.92)	24.16 (9.59)	21.67 (7.44)	20.91 (7.64)
Fe ($\mu g.g^{-1}$)	343.17 (148.48)	383.92 (231.89)	317.83 183.83)	305.19 (146..22)	337.53 (178.89)
K ($mg.g^{-1}$)	7.64 (2.22)	6.87 (0.77)	6.25 (1.42)	7.39 (1.21)	7.04 (1.56)
Mg ($mg.g^{-1}$)	2.12 (0.81)	1.98 (0.38)	2.11 (0.59)	2.02 (0.85)	2.06 (0.67)
Mn ($\mu g.g^{-1}$)	2725.33 (1177.19)	2176.2 (530.14)	2275.87 (712.52)	2076.93 (707.59)	2313.58 (835.04)
Na ($\mu g.g^{-1}$)	1133.94 (317.27)	992.16 (213.61)	802.61 (335.02)	781.96 (433.44)	927.67 (356.61)
P ($mg.g^{-1}$)	1.07 (0.37)	0.94 (0.12)	0.90 (0.18)	1.03 (0.24)	0.98 (0.25)
S ($mg.g^{-1}$)	1.54 (0.33)	1.45 (0.08)	1.45 (0.11)	1.44 (0.12)	1.47 (0.19
N ($mg.g^{-1}$)	17.63(1.49)	17.01(1.77)	16.20 (2.2)	16.90 (1.61)	16.96 (1.81)

Table 12 Leaf nutrient contents (kg.ha^{-1}) of different diameter classes of *E. camaldulensis* coppices in Jufi site.

Blocks	DBH classes (cm)	Stems. ha^{-1}	Nutrients					
			N	P	K	S	Ca	Mg
	< 5	2400	63.02	3.63	26.28	5.22	72.91	7.87
	5.0-9.0	2161	40.31	2.26	14.20	3.47	35.95	5.45
1	9.1-14.0	596	0.03	0.17	0.06	0.02	0.01	0.12
	14.1-19.0	65	0.07	0.31	0.18	0.05	0.02	0.34
	Total	5222	103.43	6.37	40.72	8.77	108.89	13.80
	□ 5	4114	46.98	2.99	22.23	4.31	55.14	6.27
	5.0-9.0	3126	84.89	4.88	35.79	7.35	90.21	9.59
2	9.1-14.0	498	0.05	0.33	0.13	0.03	0.02	0.20
	14.1-19.0	30	0.07	0.48	0.14	0.05	0.02	0.37
	Total	7768	131.99	8.68	58.29	11.74	145.38	16.43
	□ 5	1326	16.78	0.88	7.03	1.43	21.50	1.86
	5.0-9.0	1190	26.91	1.36	11.59	2.25	28.80	2.82
3	9.1-14.0	225	0.04	0.21	0.09	0.03	0.01	0.21
	14.1-19.1	3	0.07	0.32	0.16	0.05	0.02	0.40
	total	2744	43.80	2.77	18.87	3.75	50.32	5.29

5 Discussion

5.1 Soil chemical properties under E. camaldulensis plantation

5.1.1 Soil organic carbon content

As indicated in the results section, soils from block 2 *E. camaldulensis* coppice regeneration have higher soil organic carbon content than in block 1 and 3. This could be because of the topography of the stand location. Block 2 is situated on gentle slope with less erosion impact and with better sediment deposition than block 1 and 3 which were located on sloppy positions susceptible to high surface erosion impact and thus, have less sediment deposition. Stocking density may also be another important factor for the difference in soil organic carbon content. Block 2 has the highest stocking density than block 1 and 3. For example, block 2 has 3654 trees per hectare while block 1 and 3 have 2822 and 1418 trees per hectare respectively. The more the number of trees, the more could be the contribution to soil organic matter which is an essential source of soil organic carbon.

Samples from block 1 contained the lowest amount of organic carbon relative to all other stands. This could be due to the proximity of the stand to roadside that exposes it to strong litter raking by humans and grazing of undergrowth by livestock. However, the intensity of litter raking is not very different among the blocks.

The SOC content decreased with increasing soil depth for all the Blocks. This could be due to the decrease in organic debris content of soil with increasing depth. For instance average higher 28.3 $mg.g^{-1}$ in upper soil sections and lower 19.17 $mg.g^{-1}$ in lower soil sections has been observed. The nearer the samples are to the top layer, the more is the input of different litter components to the soil. Zerfu (2002) also observed before 10 years, a similar trend of average soil organic carbon change across depth in his study at the same site, higher 33.9 $mg.g^{-1}$ in upper and lower 19.8 $mg.g^{-1}$ in lower soil sections. Binkley et al (2004) in their study on 8 years old *Eucalyptus* plantation in Hawaii also showed that the higher 10.5 kgm^{-2}

soil carbon content in the 0 to 15 cm depth and about 7.9 kgm^{-2} lower content was observed in the 30-45 soil horizon.

5.1.2 Soil Nitrogen content

The mean content of nitrogen in block 2 with age of 6 years old *E. camaldulensis* was higher compared to that in block 1 with age of 6 years and 3 with age of 5 years old *E. camaldulensis*. This may be because of the higher stalk density per hectare. Therefore, the high tree density in block 2 can reduce susceptibility of soil to water erosion by reducing surface run off and direct rain drop impact. Under non-nitrogen fixing *E. camaldulensis* plantation the averaged soil nitrogen content was higher (2.0 $mg.g^{-1}$) when compared to the averaged results reported by Zerfu (2002) for 10 years before(1.6 $mg.g^{-1}$). Probably, this may be because of the presence of free nitrogen fixing micro-organisms such as azotobacter, klebsiella and rhodospirillum around root zones of *E. camaldulensis*. The total averaged soil N, 2.3 high in upper and 1.7 less in lower soil sections was measured.

Bernhard-Reversat (1988) indicated that under *Eucalyptus* planted sites, the mineralization of soil nitrogen became 6.2 $\mu g.g^{-1}$ within 20 days. Kindu *et al.* (2006) also showed that *Eucalyptus* species have lower soil N contentment when compared to other some tree species. For instance under *E. camaldulensis* and *E. globulus* 21.31 and 17.14 $mg.g^{-1}$ soil N was reported respectively. Many studies indicate the nutrient depleting ability of *Eucalyptus* species. For example, Forrester (2006) reported that mixed plantations of *Eucalyptus* species with nitrogen fixing tree species have the ability to increase site productivity by maintaining the soil fertility as compared to monoculture plantations of *Eucalyptus*.

5.1.3 Soil C:N

The results showed that *E. camaldulensis* plantation management practices contribute markedly to the soil C: N changes through the time. The soil C: N levels among blocks and soil depth sections were lower compared to previous investigation which had been done by Dr. Zerfu on the same research site. For instance previous study before 10 years indicated that the mean values of C: N concentrations were 16.12 in block 1, 15.4 in block 2 and 15.3 in block 3 about with the stand age of 11, 10 and 8 years respectively. In this study the average values of C: N contents were 12.05 in block 1 with coppice stand of 6 years old, 11.91 in block 2 with coppice stand of 6 years old and 11.73 in block 3 with coppice stand of 5 years old. The lower content of soil C: N may be occurred due to continuous litter raking from the forest floor and increment of soil nitrogen through free nitrogen fixing micro-organisms.

A study by Nasabimana et al. (2008) in southern Rwanda indicates inverse relationship between C: N ratio and total nitrogen level. That was the larger C: N ratio under *Eucalyptus* resulted due to the low level of N content. For example under *E. grandis* 14.9 C:N had been indicated. Similarly, Wang et al. (1996) also indicated negative correlation between C: N ratio and total nitrogen content. Zerfu (2002) study also showed that, under *Eucalyptus* plantation C: N ratio content was lower (15.6) while compared to the adjacent grazing land (18.6).

5.1.4 Soil pH (H_2O)

The soil pH decreased in all blocks under *E. camaldulensis* plantation sites when compared with the results of Zerfu (2002). Soils in block 1 were more acidic than those in lock 2 and 3. The soil pH increased with increasing depth for all the blocks. The declining acidity with depth can be mainly attributed to un weathered coarse material, nutrient accumulation in stand biomass and irregular distribution of soil basic elements. In general averaged pH value of this study (5.3) was more acidic when compared to averaged value of Zerfu (2002) (5.8) before 10 years.

The decrease of pH is in congruence with results in the scientific literature: Berthrong et al. (2009) indicated that, afforestation with *Eucalyptus* tree species can acidify soil - decreasing pH from 6.0 to 5.3. Bohra and Lodhiyal (2010) also indicated that the soil pH value decreased with the increase in *Eucalyptus* plantation age. For instance 6.9 and 6.5 pH values were indicated under 4 and 8 years old plantations respectively. Results from Faria et al. (2009) on *Eucalyptus* stump also indicated that 4.95 and 4.66 pH values within 54 and 31 months old stamps were observed respectively. As Farely et al. (2008) indicated Eucalypts plantation had stronger effect on stream by lowering pH value by 0.6 units. Leite et al. (2010) showed that short-rotation Eucalypts caused a significant decrease in the pH in the different soil layers when compared with pasture land. At the present time in the highlands of Ethiopia, intensive removal of litter and harvesting the whole tree system are leading to further soil acidification, depletion and decreased future productivity of sites (Zerfu, 2002).

5.1.5 Differences between soil pH in H_2O and $CaCl_2$

The values of pH ($CaCl_2$) are lower than the values of pH (H_2O) under all plantation blocks and along the soil depth sections. As indicated by Lake (2000) in the study of understanding of soil pH, the values of pH ($CaCl_2$) are lower than pH (H_2O) by 0.5 to 0.9. In general in this study the values of pH ($CaCl_2$) ranged from 4.07 to 4.4 (Table 6) and values of pH (H_2O) also ranged from 5.1 to 5.5 (Table 5).

The differences in the values of soil pH measured in $CaCl_2$ and H_2O suspensions showed stable state in block 2 and 3 and instable variation under block 1 across the soil layers (Table 13 and Fig 19). The difference in resulting values of soil pH measured in $CaCl_2$ and H_2O suspension approximately ranged above 1.0 and below 1.2 for block 2 and 3 and for block 1 ranges above 0.6 and below 1.0 along the soil depth sections. The higher difference between pH in (H2O) and in $CaCl_2$ depicts the acidification of soils and the high H^+ saturation of cation-exchange complex (Brady & Weil 2002).

Table 13 Soil pH differences of *E. camaldulensis* coppices in Jufi sites.

	0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm
Block 1	1	1	0,96	0,72	0,9
Block 2	1,13	1,02	1,1	1,2	1,32
Block 3	1,16	1,17	1,14	1,16	1,12

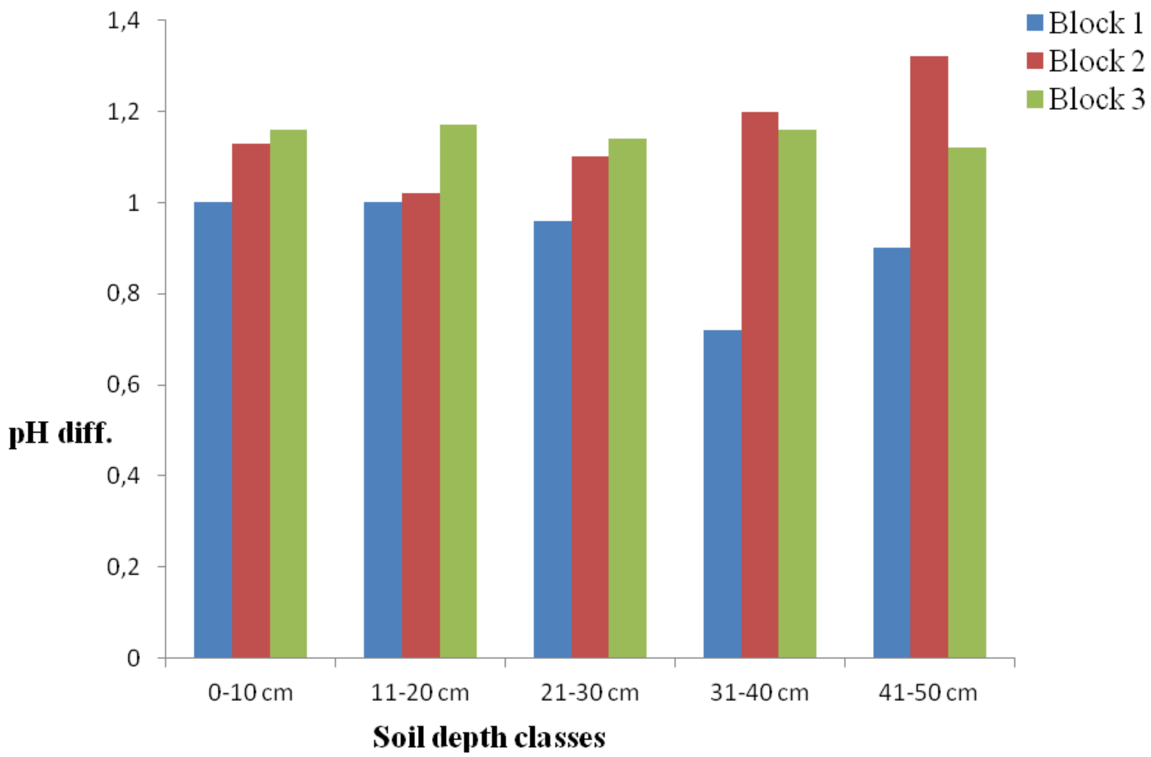


Figure 19 Soil pH (H_2O- $CaCl_2$) differences of the *E. camaldulensis* plantation sites.

5.2 Soil exchangeable cations

In order to ascertain changes in soil exchangeable cations under *E. camaldulensis* plantation sites, this study used also the results of Zerfu (2002) for comparison. Mostly after 10 years revisiting the site major soil exchangeable cations (Ca, K and Mg) showed decreased level at all plantation blocks.

5.2.1 Calcium

Block 1 with age of 6 years old *E. camaldulensis* stand contained the highest amount of calcium as compared to block 2 with 6 and 3 with 5 years old *E. camaldulensis*. Across soil depths the relative highest quantity of Ca^{++} was found in the 11-20 cm soil section and the lowest was found in 41-50 cm. The reduction of exchangeable Ca^{++} content across soil layers under *E. camaldulensis* coppice plantation at Jufi site as compared to the former study may be due to: 1) intensive litter raking; 2) above ground biomass harvest; 3) immobilization of Ca^{++}

in the existing stand. The mean Ca content of this study (648.36 $\mu g.g^{-1}$) was lower than former 10 years study (1340 $\mu g.g^{-1}$) on the same site. As Farely et al. (2008) indicated, soils under *Eucalyptus* plantation reduce Ca^{++} content by 30% compared to grassland soils. Aweto and Moleele (2004) also as they observed that, Ca^{++} was considerably lower in the immediate 0-20 cm top layer of soil under 8 years old *E. camaldulensis* plantation site. The decreasing of exchangeable Ca^{++} under *E. camaldulensis* was also reported by Berthrong et al (2009).

5.2.2 Potassium

10 years after revisiting the site, low exchangeable K^{+} content were observed for the entire plantation blocks. In the current study, the highest concentration of K^{+} was observed in the upper soil horizon of 0-10 cm while the lowest was found in 41-50 cm. The mean content of K^{+} in this study was estimated to 180.01 $\mu g.g^{-1}$ which was lower than the mean content of Zerfu (2002) 4820 $\mu g.g^{-1}$ before 10 years study.

The implication of the reduced exchangeable K^{+} in the soil after revisiting could be because of the litter raking, biomass harvest and nutrient immobilization in the standing biomass. As Leite et al. (2010) indicated, due to the large amount of nutrients depleted with *Eucalyptus* harvest, K^{+} content could decline (16.9 $mg.dm^{-3}$) when compared to native forest sites (23.3 $mg.dm^{-3}$). The immobilization of soil nutrients by *Eucalyptus* species in their standing biomass is mentioned by many authors as a reason for the gradual decline in exchangeable cations. For instance, Guo et al. (2002) study on 3 short rotation *Eucalyptus* tree species of 3 years old indicates that the highest accumulation of nutrients in its biomass.

5.2.3 Magnesium

Like other exchangeable cations, Mg also decreased when revisiting the site after 10 years. In the current study relatively higher quantity of Mg was found in block 1 compared to others blocks. Across soil depth, Mg^{++} content was high in 0-10 and 41-50 cm. In general 288.38 $\mu g.g^{-1}$ mean content of Mg was measured in this study.

The reduction of exchangeable Mg^{++} content under the *E. camaldulensis* plantation soils could be due to the similar factors mentioned for exchangeable Ca^{++}. Farey et al. (2008) observed 30% lower exchangeable Mg^{++} content in the soil under *Eucalyptus* plantation compared to grasslands. Leite et al. (2010) described reduced amount of the exchangeable Mg^{++} under *Eucalyptus* plantation due to the negative balance between input and output of nutrients exported through timber harvest and reduced import by litter decomposition or weathering. Jobba and Jackson (2004) also observed lower soil exchangeable Mg^{++} under *Eucalyptus* plantations compared to grasslands.

5.3 Cation exchange capacity

Across different *Eucalyptus* blocks at Jufi plantation site, this study observed decreased soil nutrient CEC (Ca, K and Mg) after 10 year revisiting. Block 1 with the age of 6 years *Eucalyptus* coppice regeneration showed better decreased CEC than block 2 and 3 with the age of 6 and 5 years coppice regenerations respectively while compared with the study of Dr. Zerfu Hailu from the same study sites.

Three factors may define the decreased levels of CEC in soils from both *E. camaldulensis* coppice regenerations. First, *Eucalyptus* could have higher nutrient uptake and accumulate in its compartments. Second, higher litter raking might have prohibited natural nutrient recycling. Third, removing whole nutrient rich harvest residues from plantation sites has affected the nutrient contents. After the study of soil carbon and nutrient accumulation under forest plantations in southern Rwanda, Nsabimana et al. (2008) reported lower level of CEC under *Eucalyptus* than most native and exotic tree species. For instance, under *E. grandis* plantation site 7.0 cmol kg^{-1} has been observed.

5.4 Changes in soil properties 10 years after of E. camaldulensis coppice growth

This assessment was conducted mainly by comparing the results of the current study with that of Zerfu (2002). The relative change (%) was calculated by subtracting the result of the current study from that of Zerfu (2002) and then dividing the quotient by the results of Zerfu (2002).

5.4.1 Change in soil organic carbon

After 10 years, the SOC decreased in the 0-10 cm and 11-20 cm soil depths though no considerable change has been observed for the other depth classes (Fig. 20). For example, the average relative changes in SOC in 0-10 cm and 11-20 cm were -15.77 and -5.73% respectively when compared to the time 10 years before (Fig. 21). Hence, the assumed hypothesis that says growing *E. camaldulensis* decreases the SOC is proved to true as the results of this study show declining SOC content in most cases and no change in some cases. But as ANOVA indicated there were no significantly observed differences between these studies. Reduced SOC was also observed by Zinn et al. (2002) in the sandy soils in Cerrado region of Brazil where variations were compared under different land uses. For instance, in the 0-60 cm soil profile, total SOC losses were 9 and 11 $Mg.ha^{-1}$ under *Eucalyptus* and *Pinus* respectively. Perez (2008) also reported that monoculture *Eucalyptus* plantation can cause significant losses in SOC by altering physiochemical soil properties. Furthermore Perez (2008) indicated that, monoculture fast growing plantations will release reserved SOC through trees felled, used and frequently burned resulting CO_2 in to the atmosphere.

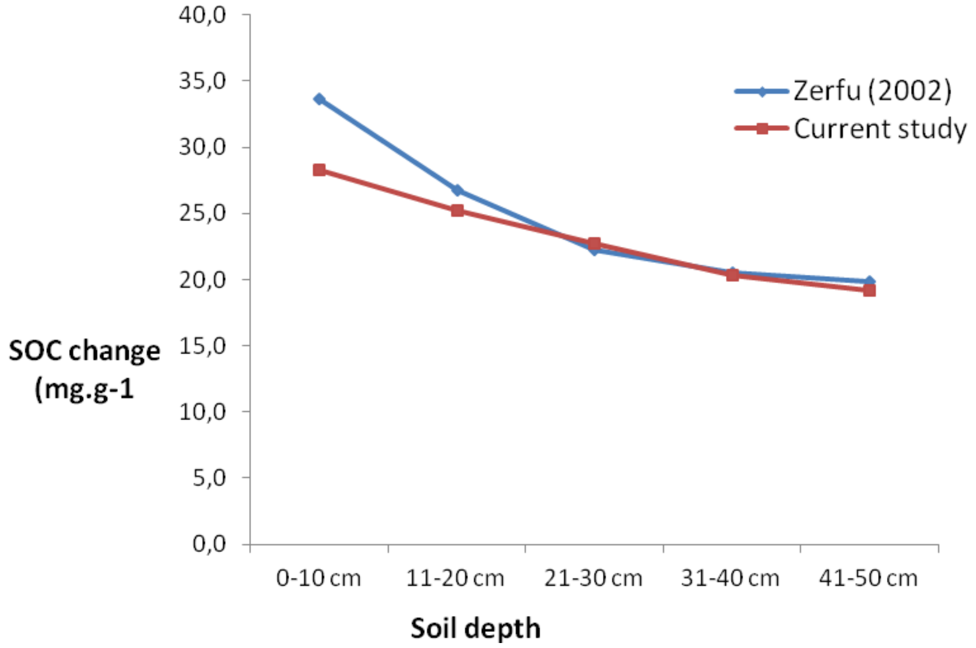


Figure 20 Trends of SOC across depth in 2000 and 2010.

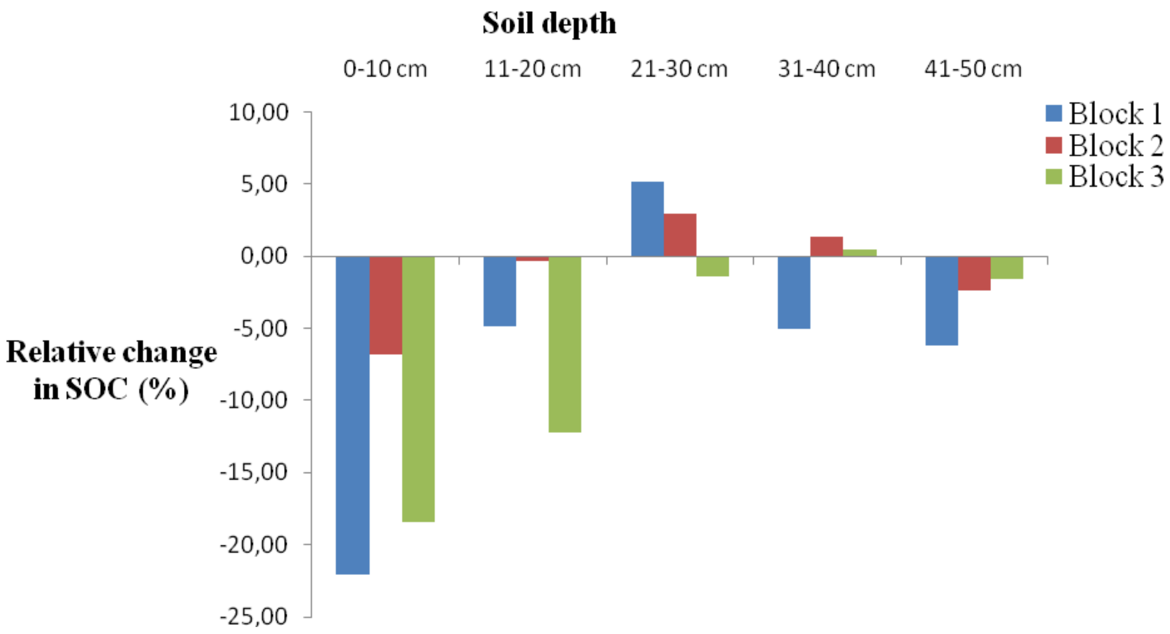


Figure 21 Relative changes (%) of SOC across soil depth and the *Eucalyptus* blocks.

5.4.2 Change in soil nitrogen

A remarkable increase in soil nitrogen was observed across all depth classes in the study site after 10 years of *E. camaldulensis* growing. The difference between the current result and that before 10 years showed no difference for the 0-10 cm soil depth though the increase in soil N contents were observed for the rest of the soil depth classes, but not statistically significant (Fig. 22). The relative increment was higher in block 2 soils compared to the rest blocks (Fig. 23). When all the blocks are aggregated, the mean relative change (%) increases with increasing soil depth with 41-50 cm soils having the highest increase of around 44%. Hence, unlike for the SOC, the assumed (hypothesis) of this study that says growing *E. camaldulensis* increases the nitrogen content of the soil is not falsified as the results of this study also show increasing N contents in the soil after 10 years of growing *E. camaldulensis*. As Bernhard-Reversat (1988) stated that soil nitrogen mineralization could be increased under *Eucalyptus* forests by 11-14 ppm per year. John et al. (2005) also indicated that, soils under *Eucalyptus* forests had showed increased quantity of soil nitrogen through the long period of time.

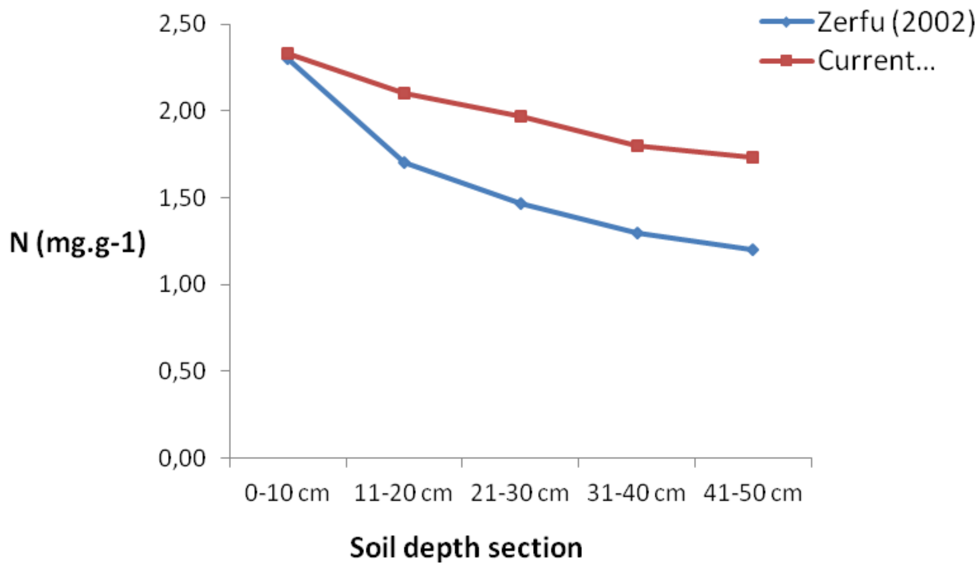


Figure 22 Trends of soil N across depth in 2000 and 2010.

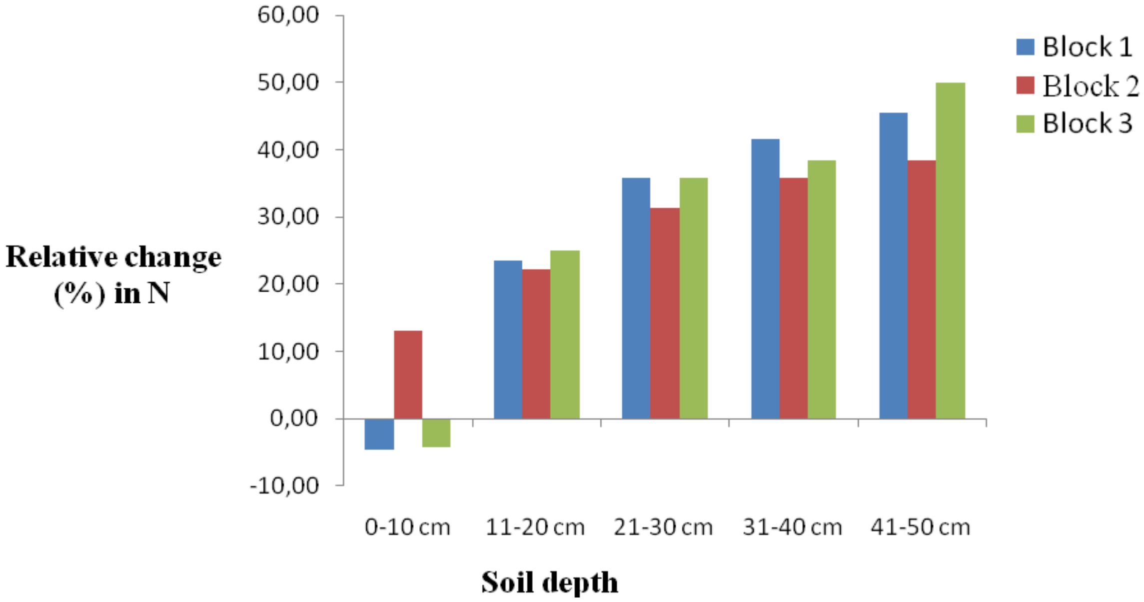


Figure 23 Relative changes (%) of soil N across soil depth and the *Eucalyptus* blocks.

5.4.3 Change in soil C:N

The soil C:N contents were decreased among blocks and soil depth sections after 10 years revising of *E. camaldulensis* coppice growth (Fig 24). Situations of C:N changes were not show similar trends throughout all blocks. For instance under block 1 with age of 6 years old coppice plantation C: N was decreased by 4.07 and under 6 years old coppice plantation of block 2 also 3.53 reduced. Block 3 with 5 years old was decreased by 3.57. Hence management practice of *E. camaldulensis* can affect soil C:N through the time. Dora et al. (2001) they have reported lower C: N ratio 8.85 under older *E. citriodora* plantation trial plots than younger ones with 16.84.

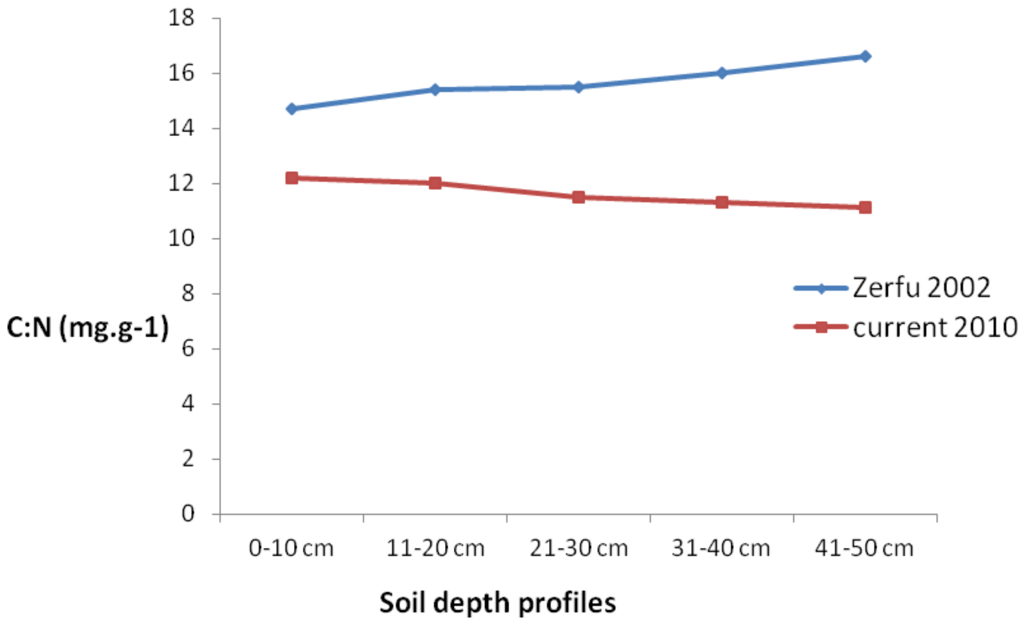


Figure 24 changes of soil C: N across soil depth of the *Eucalyptus* plantations.

5.4.4 Change in soil pH

The soil pH (H_2O) decreased after 10 years of *E. camaldulensis* coppicing management (Fig. 25). The trends of changes are almost similar across all depth profiles. However, strong changes were observed in block 1 *E. camaldulensis* coppice plantation. The relative change (%) in soil pH after 10 years ranged from -7.39 to -9.77% (Fig 26). This, therefore, confirms that growing *E. camaldulensis* plantations increases the level of soil acidity. As to the pre-formulated hypothesis, the results of this study con not falsify it because soil pH was found to be lower after 10 years of growing *E. camaldulensis* plantations.

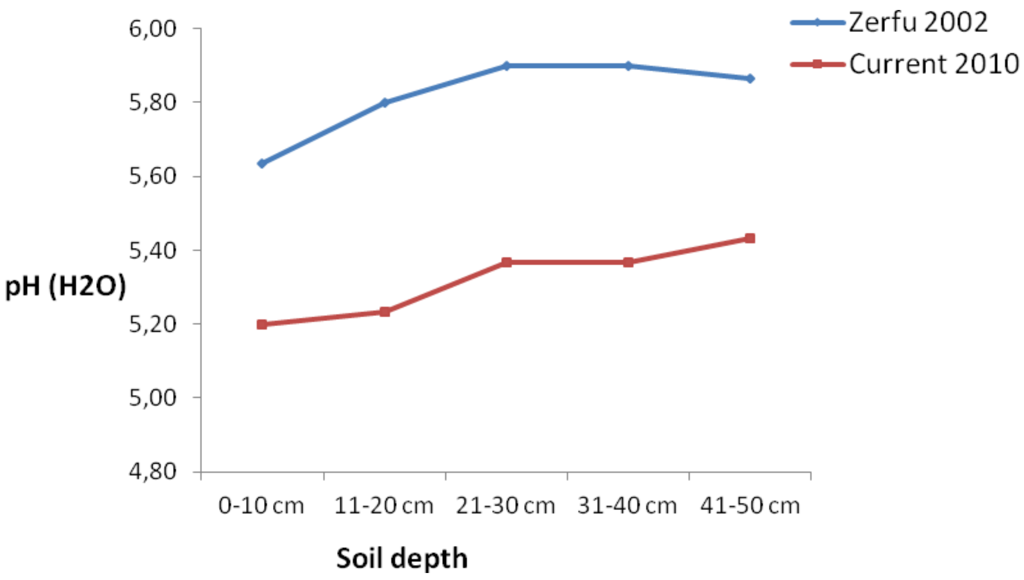


Figure 25 Trends of soil pH across depth in 2000 and 2010.

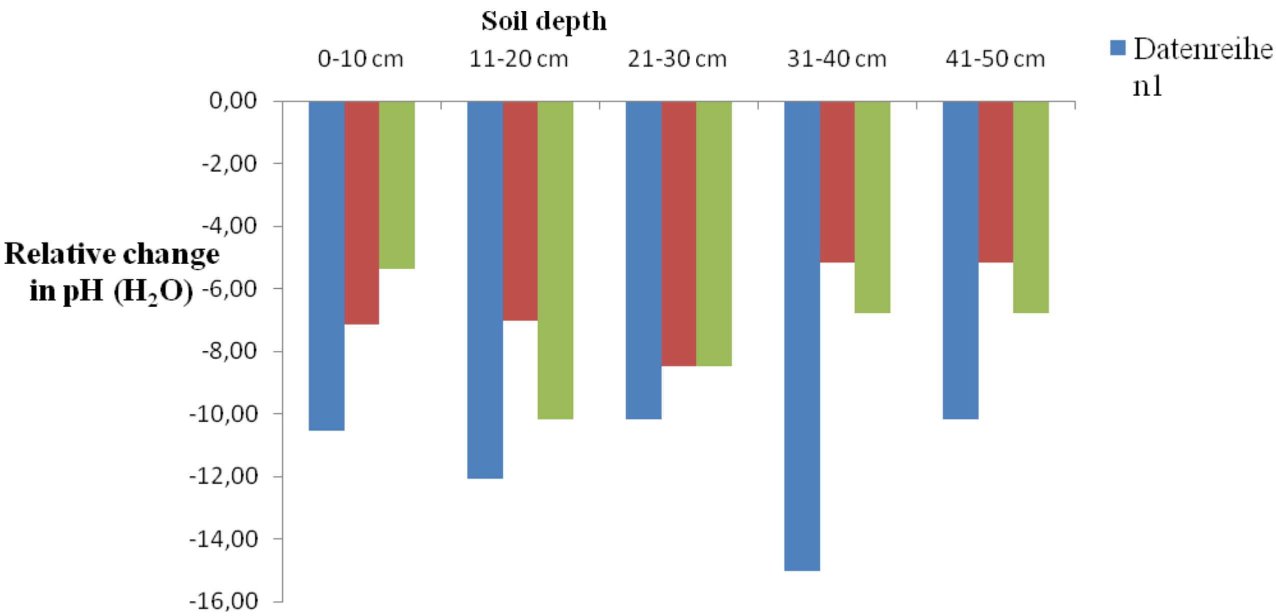


Figure 26 Relative change (%) of soil pH across soil depth and the *Eucalyptus* blocks

Like as pH (H_2O), pH ($CaCl_2$) also showed decreased level after 10 years revisiting of *E. camaldulensis* coppice regeneration at Jufi plantation sites. Under block 1 with 6 years old coppice regeneration higher pH change (-0.43) was observed in the 11-20 cm and lower (-0.2) change in the 41-50 cm soil sections. There are also pH ($CaCl_2$) differences with the respect of soil depth sections in block 2 with the age of 6 years of *E. camaldulensis* coppice. Thus for this block, higher change (-0.32) in the 41-50 and lower change (-0.12) in the 11-20 cm soil sections were observed. Block 3 with 5 years old coppice, has higher (-0.47) pH ($CaCl_2$) change in the 11-20 and lower (-0.22) change in the 41-50 cm soil sections. In general this study proved that, *E. camaldulensis* plantation management practices can increase soil acidity through the time.

5.4.5 Changes in some soil exchangeable cations

After 10 years, the soil exchangeable Ca^{++} concentration has decreased considerably. The highest declines were observed in block 1 and 3 while declines in block 2 are relatively smaller (Table 14). Therefore, it is clear that growing *Eucalyptus* can reduce the concentration of exchangeable calcium in the soil. Like for the Calcium, the potassium content also declined considerably. Strong declines were recorded in the block 3 stand while block 1 had the lowest changes in potassium concentration. The same is also true for magnesium though in this case there is an increase in deeper soil horizons, for example in block 2. For all these three exchangeable cations there is no consistent pattern of change across depth. However, in general, growing *E. camaldulensis* decreases the soil exchangeable cations pool mainly as growth also requires the extraction of the elements in order to be facilitated. This could also indicate that the management practices applied in *Eucalyptus* plantations caused significant alteration in soil chemical properties.

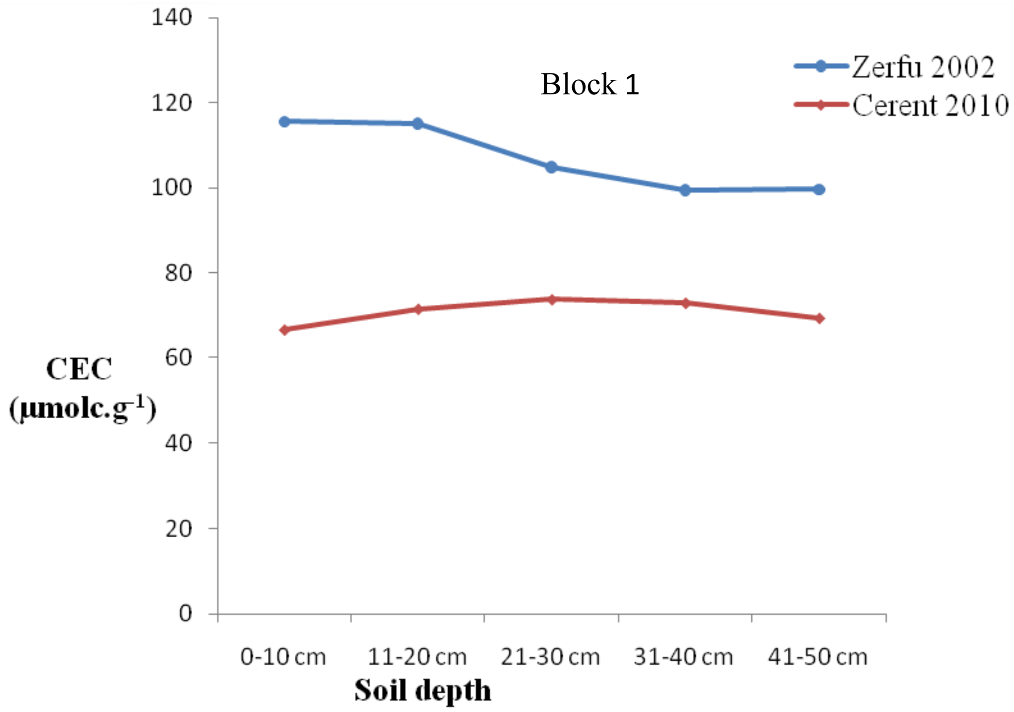
Table 14 Changes of some exchangeable cations in reference to the results of Zerfu (2002).

		Soil depth classes				
		0-10 cm	11-20 cm	21-30 cm	31-40 cm	41-50 cm
Calcium ($\mu g.g^{-1}$)	Block 1	-572.87	-540.14	-357.82	-307.04	-421.76
	Block 2	-117.01	-62.22	-97.10	-28.46	24.42
	Block 3	-33.80	-212.07	-872.16	-570.64	-594.72
Potassium ($\mu g.g^{-1}$)	Block 1	-100.53	-30.46	-37.73	-14.11	11.78
	Block 2	-93.50	-94.47	-98.88	-72.56	-30.24
	Block 3	-107.39	-206.77	-183.89	-165.41	-135.37
Magnesium ($\mu g.g^{-1}$)	Block 1	-159.03	-146.95	-116.80	-103.92	-89.42
	Block 2	-30.02	-12.45	-10.86	22.04	32.30
	Block 3	-92.30	-72.53	-47.80	-47.56	-49.74

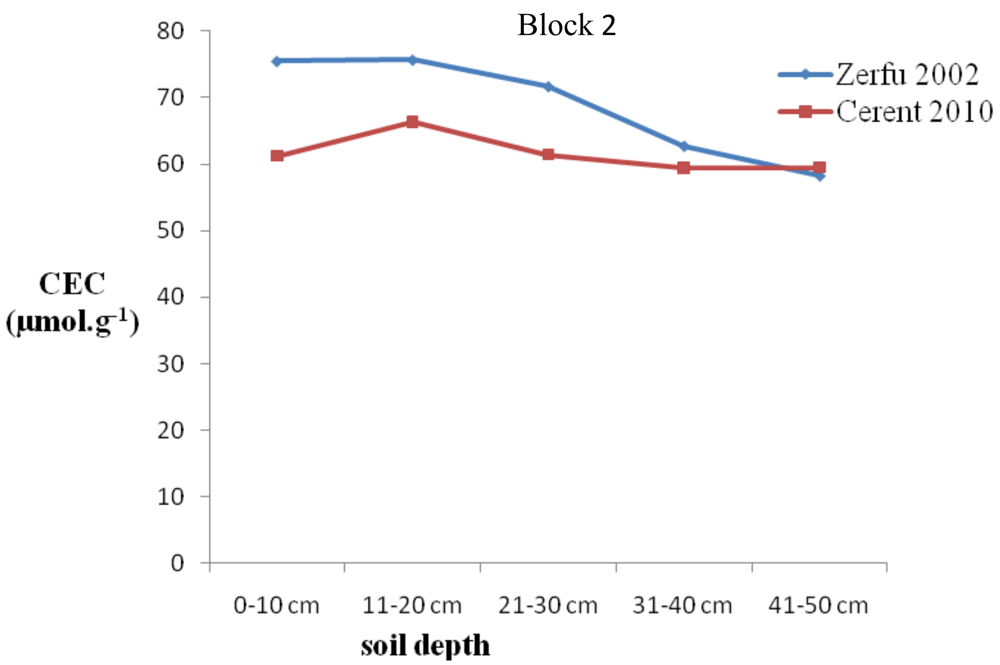
Note: The values indicate the difference of the cations concentrations results in the current study subtracted from the results obtained by Zerfu (2002).

5.4.6 Change in cation exchangeable capacity

After 10 years revisiting of *E. camaldulensis* coppice regeneration the soil CEC content had decreased in all plantation blocks (Fig 27). Higher declines were most notable under block 1 and 2 with 6 years old coppice regenerations in the upper soil sections (0-10, 11-20 and 21-30 cm), but for block 3 with 5 years old, notable declines were observed in all soil sections (11-20,21-30, 31-40 and 41-50) except first part (0-10 cm).



Block 1
Zerfu 2002
Cerent 2010
CEC
(µmolc.g-1)
140
120
100
80
60
40
20
0
0-10 cm
11-20 cm
21-30 cm
31-40 cm
41-50 cm
Soil depth



Block 2
Zerfu 2002
Cerent 2010
CEC
(µmol.g-1)
80
70
60
50
40
30
20
10
0
0-10 cm
11-20 cm
21-30 cm
31-40 cm
41-50 cm
soil depth

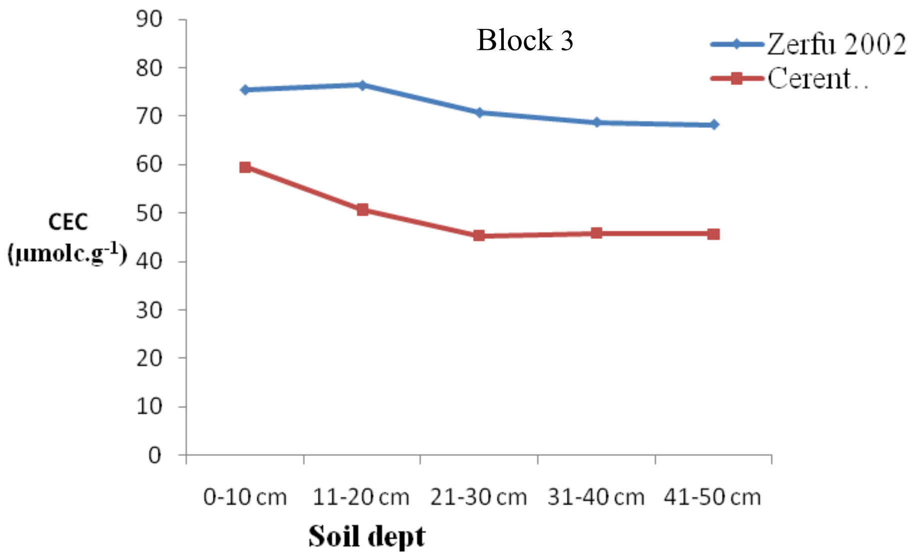


Figure 27 Changes of soil CEC across soil depth in 2000 and 2010.

5.5 Nutrient content in E. camaldulensis coppice leaves

5.5.1 Nitrogen

Trees in lower DBH classes have higher nitrogen content than trees with higher DBH classes in *E. camaldulensis* leaves for both blocks (Table 12). For instance the mean nitrogen content in leaves from trees (2400) 5 cm was 42.26 kg $N.ha^{-1}$ and in DBH of 5.0-9.0 cm trees (2161) 50.7 kg $N.ha^{-1}$. Trees (596) with DBH classes of 9.1-14.0 and trees (65) with 14.1-19.0 cm DBH contained 0.04 and 0.07 kg $N.ha^{-1}$ respectively. This may be because of the high density of trees in lower DBH classes per hectare. The higher the number of trees, the higher the leaf nitrogen content.

The mean *E. camaldulensis* leaf nitrogen content of trees varied with the DBH classes of the plants. This can be mainly attributed by the age of leaves. Trees in lower DBH classes have relatively younger leaves than trees with higher DBH classes. Fife et al. (2008) indicated that the nitrogen content was lower in mature leaves than in young ones for the same tree species of *A. mearnsii, Eucalyptus . globulus, E. fraxinoides E. grandis and Pinus. radiata*. Nuno and Manuel (1996) also reported that the nitrogen content foliage of decreased from the top to the bottom of the canopy in leaves of the *Eucalyptus* species.

5.5.2 Phosphorus

The phosphorus content in *E. camaldulensis* leaves mostly revealed consistent reduction pattern from lower to the higher DBH classes (Table 12). Unlike the nitrogen content, the phosphorus content of the leaves did not show a strong variation according to the DBH classes. This could be because of the presence of higher number of trees in lower DBH classes in all the blocks. The higher number of trees in lower DBH classes could lead to have higher phosphorus content than lower number of trees in higher DBH classes. In Zerfu (2002) report, block 3 (with less number of trees per hectare) has low quantity (3.60 $kg.ha^{-1}$) of phosphorus, compared to block 2 (with higher number of trees per hectare) with the phosphorus amount of 4.10 kg $P.ha^{-1}$.

The relative variation of the phosphorus content in the *E. camaldulensis* leaves among the DBH classes may be also because of the age of the leaves. The younger leaves can accumulate higher amount of the phosphorus than aged leaves. Fife et al. (2008) also found that the phosphorus content was lower in mature leaves than young ones for tree species of *A. mearnsii, E. globulus, E. fraxinoides E. grandis and P. radiata*. Nuno and Manuel (1996) also reported that the phosphorus accumulation in foliage decreased from the top to the bottom of the canopy in leaves of the *Eucalyptus* species. The accumulation of phosphorus in *Eucalyptus* plantation leaves increased up to 3.5 years as reported by Goncalves et al. (2004).

5.5.3 Potassium

The potassium content in *E. camaldulensis* coppice regeneration leaves at Jufi plantation site also showed a declining trend from lower to higher DBH classes in all blocks. Like in the case of nitrogen and phosphorus content, this decline could also be because of the higher number of trees in lower DBH classes. Zerfu (2002) study also indicted similar trend of potassium content. The possible reason for the change across DBH classes could be due to the age of the leaves. Nuno and Manuel (1996) also reported that the potassium content in foliage decreased from the top to the bottom of the canopy in leaves of the *Eucalyptus* species and the net reduction in nutrient content reflects nutrient retranslocation from green leaves. As Sanchez et al. (2010) reported, the rapid decrease of K^+ with increasing age is attributed to leaching rather than to residue decomposition.

5.5.4 Sulfur

Similar to other nutrients, the sulfur content of *E. camaldulensis* leaves also shows decreasing rate in block 1 with age of 6 years from lower to higher DBH classes, whereas, for block 2 with 6 years old and 3 with 5 years old, it was showing changing irregularly (Table 12). The total sulfur content in the leaf biomass of *E. camaldulensis* in each block was 8.77 kg $S.ha^{-1}$ in block 1, 11.74 kg $S.ha^{-1}$ in block 2 and 3.75 kg $S.ha^{-1}$ in block 3. This variation could be because of the variability in number of trees per hectare. Large number of trees per hectare could have high amount of sulfur in their leaves. Ribeiro et al. (2002) after *Eucalyptus globulus* Labill leaf litter decomposition analysis on different litter layers in the Furadouro area in Portugal they reported 0.57-0.82 $mg.g^{-1}$ of sulfur content from different trial sites.

5.5.5 Calcium

Higher difference of calcium content in *E. camaldulensis* leaves was observed in different blocks. The highest amount was observed in block 2 of 6 years age (145.38 kg $Ca.ha^{-1}$) and the lowest (50.32 kg $Ca.ha^{-1}$) in block 3 of 5 years age (Table 12). As for other nutrients, number of trees per hectare could be the reason for the variability in Calcium concentration. A study by Zerfu (2002) before 10 years indicated Ca content of 62.9 $kg.ha^{-1}$, 50.8 $kg.ha^{-1}$ and 41.3 $kg.ha^{-1}$ for block 1 (n=5820 trees/ha), block 2 (n=6211 trees/ha) and block 3 (n=2813 trees/ha) respectively. Thus, it is possible to see the sharp increase in Ca concentration in the *Eucalyptus* leaves. Laclau et al. (2003) reported that the annual requirements of calcium for biomass production of *Eucalyptus* plantation leaves was 14 $kg.ha^{-1}year^{-1}$. Fife et al. (2008) observed the continuous increase in Ca content in *Eucalyptus* stands.

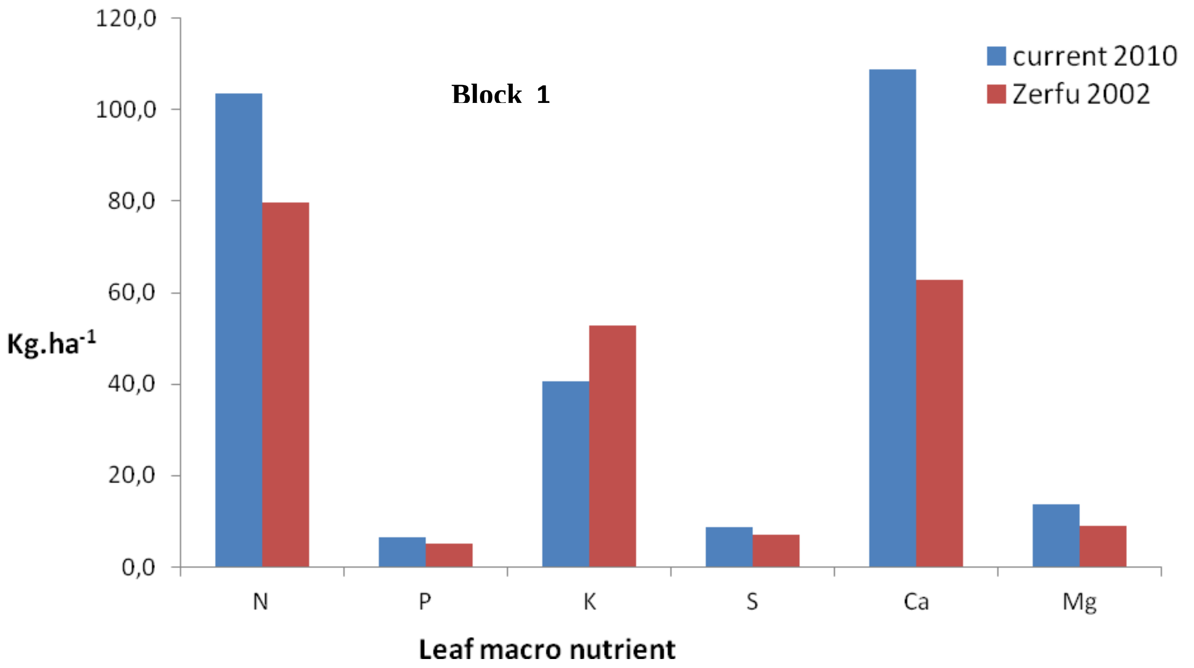
5.5.6 Magnesium

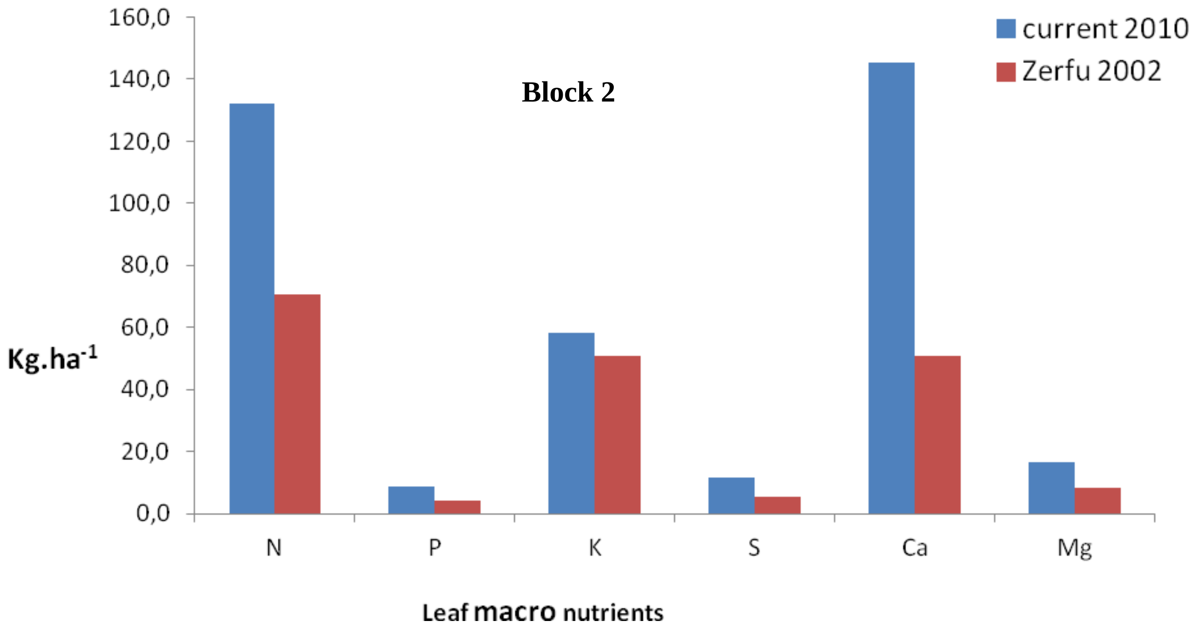
The highest Mg^{++} content for all compartments was observed in lower DBH classes (Table 12). Across blocks, 6 years coppice plantations, blocks 1 and 2 with large number of trees per hectare contained 13.8 kg $Mg.ha^{-1}$ and 16.43 kg $Mg.ha^{-1}$ respectively, whereas 5 years coppice growth, block 3 with lower number of trees per hectare contained 5.29 $kg.ha^{-1}$. Therefore, these differences could be due to the differences in number of trees per hectare. Zerfu (2002) also reported similar differences in Mg^{++} content mainly depending on number of trees per hectare. A study in Congo on Eucalyptus clones also showed a per hectare content of 13.2 kg (Laclau et al., 2003).

5.6 Changes in nutrient content in E. camaldulensis leaves after 10 years

After 10 years, changes of nutrient contents were observed in *E. camaldulensis* leaves in all blocks. For example, in block 1 coppice regeneration of 6 years old, N, P, Ca, Mg and S concentrations were higher than they were before 10 years of 11 years old while the K accumulation decreased. In block 2 with age of 6 years *E. camaldulensis* showed an increasing trend for the all the analyzed nutrients when compared with the leaf nutrient contents before 10 years of 10 years old. In block 3 with 5 years old coppice plantation N, P, K, Mg and S contents decreased while Ca content increased compared to the earlier study by Zerfu (2002) at the age of 8 years old.

The relative change (%), which is the percentage of the difference of the concentration of nutrients after 10 years divided by the results before 10 years, indicated that there is a higher increase in nutrient concentrations in the leaves after 10 years especially in block 1 and 2 (Fig 28 and 29). In contrary, the concentrations of nutrients (except calcium) in the leaves decreased in block 3. Nonetheless, the changes are very small in block 1 and 3 while they are so high in block 2. Recher (1996) indicated that the younger leaves of *Eucalyptus* tree species had greater nutrient levels than older leaves and subcanopy had lower than canopy foliar nutrient levels.


Block 1
current 2010
Zerfu 2002
Kg.ha-1
120,0
100,0
80,0
60,0
40,0
20,0
0,0
N
P
K
S
Ca
Mg
Leaf macro nutrient


Block 2
current 2010
Zerfu 2002
Kg.ha-1
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
N
P
K
S
Ca
Mg
Leaf macro nutrients

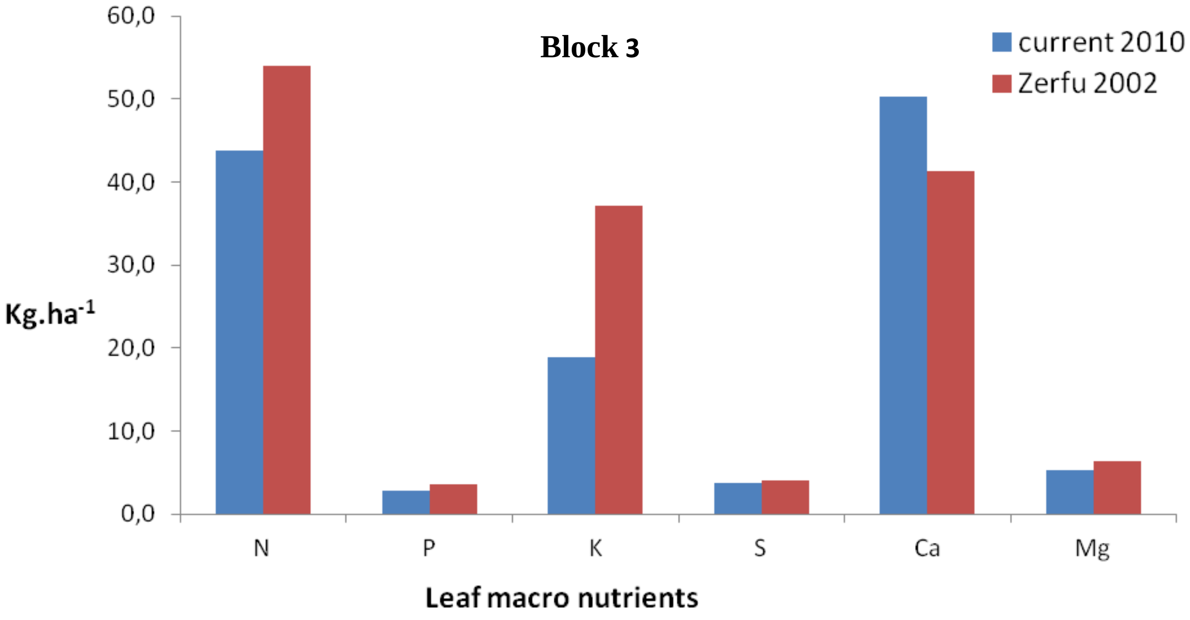


Figure 28 Leaf nutrient contents of *E. camaldulensis* coppice stand in Jufi site as compared to results before 10 years.

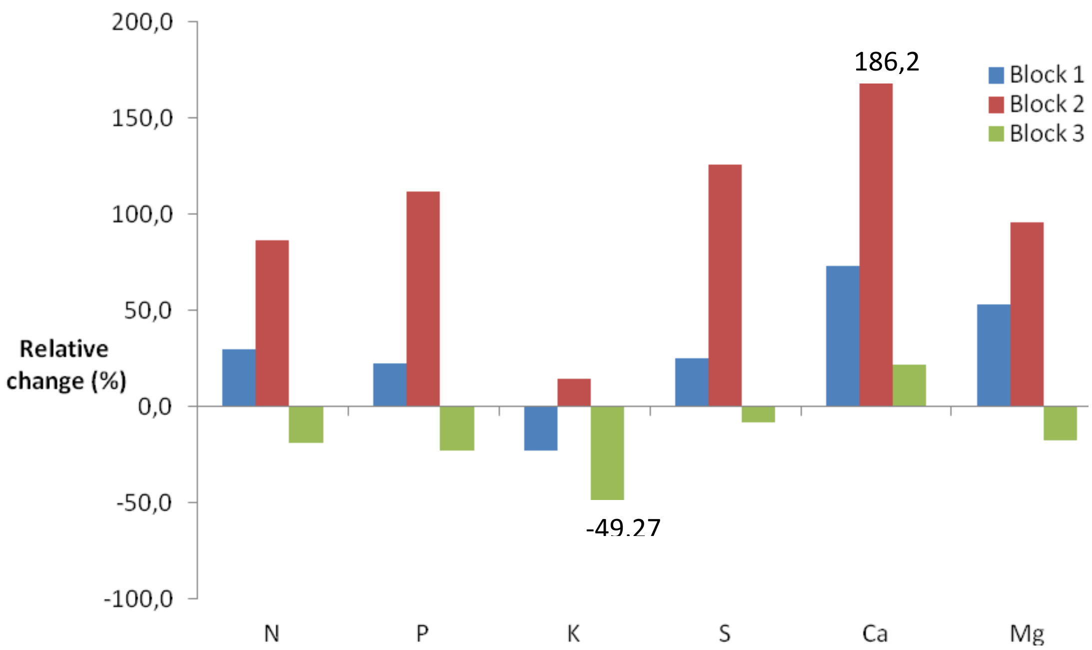


Figure 29 Relative changes (%) in leaf nutrient contents in Jufi *E. camaldulensis* plantation sites.

6 Conclusion and Recommendation

6.1 Conclusion

The nutrient content analysis of the soil and leaf biomass in *E. camaldulensis* plantation is essential for comparison of changes in nutrient concentration. This study aimed at assessing the changes in nutrient concentrations in the soil and leaf biomass after 10 years in an *E. camaldulensis* plantation established in Northern Ethiopia. Besides the nutrient content analysis, the volume of coppice stand was also measured to estimate the above ground wood productivity of the site.

Under the *E. camaldulensis* of first coppice regeneration at Jufi plantation site after 10 years revisiting, all soil nutrients except N decreased. In the current assessment, the SOC change was very strong in the upper soil horizons compared to the deeper ones. After 10 years revisiting, it has been observed that the *E. camaldulensis* plantation management practices have significantly decreased the amount of soil exchangeable base cations (Ca^{++}, Mg^{++} and K^{+}). The soil pH was found to be lower than it was 10 years before at all soil depths under all *E. camaldulensis* plantation. Across depth the soil pH increased with increasing soil depth for all the *E. camaldulensis* blocks.

In Jufi plantation site higher level of Ca, K and N nutrients were accumulated in the *E. camaldulensis* leaves as compared to P, S and Mg. N, S, P, Na, Mn and K were found to be higher in lower DBH classes. Based on the DBH classes, this study revealed that the higher contents of most nutrients were found in the leaves of the low DBH classes. This could be mainly because of the large number of plants in the lower DBH classes. However the accumulation of Ca showed irregular pattern over all the DBH classes depending on the increased Ca-uptake into higher DBH classes with more woody elements.

The average basal area and wood volume of the stands were estimated to be 13.110 $m^2.ha^{-1}$ and 68.712 $m^3.ha^{-1}$ respectively. It was also observed that the BA and volume were strongly related with the DBH and number of trees per hectare.

Afforestation with *E. camaldulensis*, like most other fast growing plantations, can deplete soil nutrients which may lead to soil acidity and nutrient deficiency in the soil complex. This is mainly because growth is a function of nutrients extracted from the soil and absorbed from the atmosphere. In order to maintain or minimize soil acidity and nutrient deficiency under *E. camaldulensis* plantation forests, nutrient balance should be controlled mainly through avoiding litter raking and keeping nutrient rich harvest residues such as bark, leaves and small branches in the stands.

6.2 Recommendations

- The establishment of fast growing *E. camaldulensis* for longer periods of time can lead the soil into insufficient nutrient content and more acidic character. Such consequences should be acknowledged at the local and national level when dealing with *Eucalyptus* species. Therefore, it is recommended to maintain site productivity for long production periods under *E. camaldulensis* plantation by avoiding litter raking, keeping harvest residues on site and replenishing nutrients through liming.
- Due to its multipurpose use, browsing resistance, drought tolerance, higher biomass production and fast growing character, *E. camaldulensis* plantation is expanding extensively in different LUS of north western part of Ethiopia. Hence, it is important to assess the impact of the expansion on the soil nutrient status by considering the rotation cycles and the long term effects of the species on soil characters.
- Further investigation is necessary to observe the consequences of successive *E. camaldulensis* coppice regeneration on different soil nutrients across stand ages.
- It is also very important to investigate the impact of the successive *E. camaldulensis* plantations management practices on the different soil types.
- Up to now it is not clear what has caused the increase in the level of N in the soil.

7 Limitations of the study

The outputs reported in this study are only limited to the site conditions and plantation characteristics like in the current study area Jufi. Even, the appropriate representativeness of the sampling may not be really sufficient because only 30 soil pits were used to represent the 35 ha plantation and the biomass assessment only covered the leaf samples i.e. does not include root, bark, stem and branch.

Available budget for the field work and allotted time were also some important limitations to be mentioned. For example this study only covered sampling during three months of the year which may not be really representative in case of leaf samples.

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Annexes

Annex 1: Map of the Jufi plantation site and its surrounding (source: Zerfu, 200)

Annex 2: GPS readings (coordinates) of Jufi Plantation area

Point Id	North	East	Height	Point Code
22	1257500	276191	2001	Jufi
23	1257871	276001	2011	Jufi
24	1258143	275974	2021	Jufi
25	1258385	276027	2019	Jufi
26	1258193	276764	2006	Jufi
27	1258180	276871	1999	Jufi
28	1258129	277178	1991	Jufi
29	1258138	277351	1982	Jufi
30	1258072	277538	1972	Jufi
31	1257801	277567	1979	Jufi
32	1257389	277496	1977	Jufi
33	1257357	277377	1979	Jufi
34	1257462	277189	1984	Jufi
35	1257573	277037	1990	Jufi
36	1257558	276988	1990	Jufi
37	1257662	276743	1992	Jufi
38	1257667	276687	1991	Jufi
39	1257647	276658	1990	Jufi
40	1257591	276642	1985	Jufi
41	1257562	276575	1986	Jufi
42	1257415	276475	1987	Jufi
43	1257434	276422	1989	Jufi
44	1257534	276407	1996	Jufi
86	1257492	277151	1986	B
87	1258136	277180	1988	B

Annex 3: Geographical locations of 0-20 cm depth soil sample pits at Jufi plantation site

Point Id	Block code	x-coordinate	y-coordinate
123	$B_1 P_1$	276102	1258210
121	$B_1 P_2$	276235	1258192
119	$B_1 P_3$	276304	1258190
117	$B_1 P_4$	276609	1257944
115	$B_1 P_5$	276568	1258093
113	$B_2 P_1$	276789	1258139
111	$B_2 P_2$	276827	1258138
108	$B_2 P_3$	276861	1258118
105	$B_2 P_4$	276962	1258108
107	$B_2 P_5$	277055	1258091
103	$B_3 P_1$	277512	1257947
101	$B_3 P_2$	277496	1258019
099	$B_3 P_3$	277437	1258024
095	$B_3 P_4$	277227	1258094
097	$B_3 P_5$	277343	1258076

Annex 4: Geographical locations of 0-50 cm depth soil sample pits at Jufi plantation site

Point Id	Block code	x-coordinate	y-coordinate
122	$B_1 P_1$	276104	1258199
120	$B_1 P_2$	276235	1258190
118	$B_1 P_3$	276300	1258186
116	$B_1 P_4$	276614	1257943
114	$B_1 P_5$	276569	1258093
112	$B_2 P_1$	276792	1258138
110	$B_2 P_2$	276827	1258135
109	$B_2 P_3$	276861	1258118
104	$B_2 P_4$	276963	1258103

106	$B_2 P_5$	277052	1258092
102	$B_3 P_1$	277511	1257942
100	$B_3 P_2$	277500	1258013
098	$B_3 P_3$	277435	1258019
094	$B_3 P_4$	277229	1258092
096	$B_3 P_5$	277343	1258081

Annex 5: Leaf nutrients (acid) extraction of Jufi *E. camaldulensis* coppice plantation sites

Sample ID	ODW (g)	Al $Mg.g^{-1}$	Ca $Mg.g^{-1}$	Fe $\mu g.g^{-1}$	K $Mg.g^{-1}$	Mg $Mg.g^{-1}$	Mn $\mu g.g^{-1}$	Na $\mu g.g^{-1}$	P $Mg.g^{-1}$	S $Mg.g^{-1}$	N $Mg.g^{-1}$
10-67-01	19.11	0.452	26.07	342.4	7.442	2.205	3122	889.5	1.005	1.543	17.96
10-67-02	17.27	0.585	24.87	454.9	7.557	2.413	2787	6252	0.899	1.543	17.15
10-67-03	17.80	0.801	14.28	782.8	9.166	0.903	1337	444.3	0.759	1.438	18.97
10-67-04	16.27	0.422	12.64	373	9.634	1.301	1645	461.4	0.818	1.162	13.99
10-67-05	18.93	0.367	20.93	290.6	8.542	1.917	3049	1047	0.833	1.448	17.25
10-67-06	15.75	0.322	18.18	267.8	7.547	1.719	1804	1006	0.684	1.301	15.20
10-67-07	18.37	0.325	26.35	233.2	7.536	2.128	3066	750.2	1.098	1.394	14.92
10-67-08	18.46	0.619	10.68	557.6	6.957	1.636	1730	515.2	1.045	1.358	16.69
10-67-09	19.07	0.378	25.83	291	7.437	1.918	2302	1364	0.77	1.336	14.39
10-67-10	15.63	0.360	22.99	255.9	7.672	1.909	2626	890.8	0.872	1.337	14.42
10-67-11	15.84	0.271	15.16	172.7	7.483	1.479	1901	1027	0.708	1.197	13.13
10-67-12	15.92	0.274	24.52	173.9	7.563	1.824	2173	678.8	1.081	1.439	16.34
10-67-13	17.11	0.17	17.03	138.9	6.029	1.494	1405	1093	0.991	1.485	17.97
10-67-14	13.44	0.174	11.24	144.2	7.74	1.358	1376	1325	1.087	1.601	21.40
10-67-15	18.74	0.263	32.71	198.8	6.574	1.809	2985	1009	0.762	1.627	17.15
10-67-16	17.4	0.284	13.3	222.1	7.112	0.903	1015	727.9	0.812	1.339	15.51
10-67-17	19.1	0.289	16.85	253.5	5.982	1.732	1433	1152	0.856	1.438	1784
10-67-18	15.2	0.594	13.18	554.4	6.783	1.494	1276	1038	0.837	1.445	18.80
10-67-19	15.24	0.216	30.24	175.6	6.663	1.409	1406	403.9	0.827	1.482	15.91
10-67-20	11.41	0.204	24.33	199.1	7.866	2.369	2341	803.2	1.010	1.639	18.54
10-68-01	15.99	0.469	17.24	390.6	8.205	1.533	2734	1353	1.032	1.496	18.57
10-68-02	16.24	0.344	17.65	289.5	6.105	1.707	1836	915.5	0.836	1.494	17.07
10-68-03	13.73	0.239	48.54	195	5.596	2.787	1100	719.3	0.760	1.463	13.89
10-68-04	14.9	0.38	30.03	329	7.348	2.001	1452	2170	1.322	1.604	19.62
10-68-05	15.24	0.978	44.8	760.9	14.93	4.929	6113	1821	2.156	2.672	15.94
10-68-06	14.85	0.491	21.3	418.3	6.959	2.238	3112	555.6	1.016	1.48	16.27
10-68-07	15.38	0.317	32.3	220	4.124	2.818	3370	475.2	0.841	1.351	12.09
10-68-08	21.47	0.306	22.41	262.4	9.079	2.327	1516	436.3	1.066	1.333	18.10
10-68-09	15.58	0.501	15.44	445.1	6.272	1.872	2723	1090	1.042	1.44	17.06

10-68-10	17.68	0.55	18.03	478	6.928	2.005	2816	1172	1.011	1.408	16.31
10-68-11	17.2	0.459	27.6	407.2	7.407	1.643	2663	1629	1.044	1.422	17.12
10-68-12	15.5	0.372	21.23	332.1	5.434	1.398	3030	6583	0.833	1.407	15.63
10-68-13	17.54	0.349	14.79	322.7	6.332	2.024	1445	657.7	0.689	1.214	18.18
10-68-14	17.3	0.457	14.73	362.7	7.707	1.73	1986	984.4	0.986	1.369	16.81
10-68-15	13.79	0.681	24.97	617.6	7..98	2.638	2842	964.6	0.916	1.629	19.39
10-68-16	14.12	0.302	36.24	213.8	7.955	3.331	2458	1018	1.476	1.431	15.52
10-68-17	17.89	0.607	17.2	525.5	7.455	1.973	2198	1653	0.9	1.430	16.16
10-68-18	16.86	1.170	17.34	113	7.338	1.781	2129	1088	0.943	1.416	15.98
10-68-19	20.06	0.55	22.86	412.9	5.729	2.11	2274	948.5	0.778	1.440	14.97
10-68-20	17.18	0.358	14.56	315.6	7.829	1.194	1562	882.4	0.92	1.448	18.23
10-69-01	15.87	0.246	21.36	203.9	7.545	2.285	3948	769.2	0.966	1.443	17.34
10-69-02	20.22	0.291	16.17	259.3	6.526	1.911	2213	1060	0.866	1.472	17.33
10-69-03	16.75	0.399	25.26	419.8	5.642	2.541	2657	462	0.832	1.360	15.78
10-69-04	20.01	0.56	23.85	677.7	6.272	2.622	3419	496.9	0.832	1.444	15.87
10-69-05	16.41	0.399	19.98	322	7.556	1.839	2504	1019	0.917	1.517	18.89
10-69-06	16.33	0.298	19.32	291.5	6.745	2.365	2518	1161	1.181	1.453	17.02
10-69-07	16.31	0.353	13.15	304.2	6.684	1.852	2021	1034	1.248	1.510	17.61
10-69-08	15.88	0.24	20.2	167.1	6.748	2.614	1797	471.6	0.967	1.433	16.80
10-69-09	16.65	0.422	15.96	327	8.596	1.811	2012	1281	1.567	1.538	20.96
10-69-10	17.73	0.37	17.65	272.5	6.514	2.09	1721	1235	0.897	1.559	19.38
10-69-11	16.31	0.321	16.83	283.2	5.084	2.174	2300	962.9	1.092	1.509	17.54
10-69-12	15.08	0.253	29.36	184.7	6.999	1.862	1559	1098	0.764	1.444	15.53
10-69-13	17.15	0.342	16.54	246.9	6.011	2.197	2981	926.2	1.251	1.406	18.57
10-69-14	17.05	0.403	12.04	314.3	5.846	2.17	2195	1051	1.012	1.412	15.14
10-69-15	15.9	0.277	13.51	237.5	4.939	2.725	1443	791.8	1.129	1.529	19.13
10-69-16	16.18	0.278	27.38	211.1	5.328	3.927	2241	709.2	1.559	1.500	18.85
10-69-17	14.87	0.36	19.30	286.5	6.228	2.083	2911	893.5	1.006	1.638	17.30
10-69-18	20.92	0.328	13.51	265.5	5.075	2.828	2248	774.9	0.905	1.459	16.92
10-69-19	15.72	0.313	18.64	106.9	3.943	2.686	2773	417.5	0.688	1.354	15.47
10-69-20	16,64	0.392	14.27	358.6	8.674	1.072	3216	602.2	0.985	1.567	18.28

Annex 6: Soil N and C content ($mg.g^{-1}$) in Jufi *E. camaldulensis* coppice plantation sites

Sample ID	N	Org.C	Sample ID	N	Org. C
10-75-01	2.31	26.13	10-77-14	1.671	21.24
10-75-02	2.277	20.78	10-77-15	1.612	19.43
10-75-03	3.213	33.78	10-77-16	2.880	36.28
10-75-04	2.294	30.77	10-77-17	2.509	31.9
10-75-05	2.656	35.06	10-77-18	2.077	25.86
10-75-06	2.117	27.44	10-77-19	1.723	21.3
10-75-07	2.176	26.8	10-77-20	1.69	20.88
10-75-08	2.359	31.9	10-78-01	2.158	24.9
10-75-09	2.369	30.32	10-78-02	1.744	20.6
10-75-10	1.84	23.02	10-78-03	1.708	20.62
10-75-11	1.609	22.04	10-78-04	1.53	20.45
10-75-12	1.786	4.4	10-78-05	1.387	16.95
10-75-13	2.343	30.52	10-78-06	2.735	35.18
10-75-14	2.23	26.8	10-78-07	2.244	27.92
10-75-15	2.346	32	10-78-08	1.894	23.75
10-75-16	2.118	28.39	10-78-09	1.956	21.69
10-75-17	1.793	23.84	10-78-10	1.761	20.32
10-75-18	1.515	18.31	10-78-11	2.76	32.9
10-75-19	2.165	26.44	10-78-12	2.063	25.76
10-75-20	2.364	32.83	10-78-13	2.151	23.22
10-76-01	2.649	32.64	10-78-14	1.964	21.64
10-76-02	2.140	25.1	10-78-15	1.916	20.27
10-76-03	2.208	29.06	10-78-16	2.806	33.01
10-76-04	1.95	24.48	10-78-17	2.727	31.73
10-76-05	1.974	24.62	10-78-18	2.738	28.27
10-76-06	1.825	22.31	10-78-19	2.436	24.91
10-76-07	1.814	23.45	10-78-20	2.188	22.99
10-76-08	1.658	19.5	10-79-01	2.989	32.74
10-76-09	2.174	25.91	10-79-02	2.551	29.85
10-76-10	1.894	23.63	10-79-03	2.262	25.56
10-76-11	1.675	21.17	10-79-04	2.029	23.38
10-76-12	2.015	21.01	10-79-05	1.732	20.37
10-76-13	1.489	19.34	10-79-06	2.589	28.22
10-76-14	1.69	17.1	10-79-07	2.031	22.26
10-76-15	1.354	17.9	10-79-08	1.942	20.39
10-76-16	2.42	28.97	10-79-09	1.796	19.70
10-76-17	2.305	28.03	10-79-10	1.746	18.19
10-76-18	2.008	23.28	10-79-11	1.981	21.71
10-76-19	1.663	17.58	10-79-12	2.185	20.24
10-76-20	1.853	20.14	10-79-13	1.810	19.92
10-77-01	2.392	28.71	10-79-14	1.705	19.66

10-77-02	2.457	28.82	10-79-15	1.759	18.52
10-77-03	2.145	26.84	10-79-16	2.207	24.00
10-77-04	1.89	21.43	10-79-17	1.895	20.07
10-77-05	1.71	16.65	10-79-18	1.707	17.58
10-77-06	1.936	22.43	10-79-19	1.613	15.51
10-77-07	1.753	19.08	10-79-20	1.504	13.10
10-77-08	1.587	17.42	10-80-01	2.255	24.06
10-77-09	1.66	16.9	10-80-02	2.030	22.25
10-77-10	1.479	16.9	10-80-03	1.986	23.16
10-77-11	2.688	32.96	10-80-04	2.049	22.25
10-77-12	2.282	26.35	10-80-05	2.149	24.66
10-77-13	2.126	25.38			

Annex 7: Soil nutrients contents ($\mu g.g^{-1}$) in Jufi *E. camaldulensis* coppice plantation sites

Sample ID	Al	Ca	K	Mg	Mn	Na
10-75-01	nd	616.5	205.8	310.9	18.04	11.02
10-75-02	nd	664.1	175.8	273.5	12.6	12.16
10-75-03	nd	687.4	252.2	348.7	21.34	13.52
10-75-04	nd	1046	218.7	367.1	16.33	12.35
10-75-05	nd	712.4	302.8	351.9	22.2	14.07
10-75-06	nd	1013	212.8	389.6	18.85	17.87
10-75-07	nd	768.6	94.01	327.4	21.27	11.4
10-75-08	nd	439.2	209.9	305.7	23.14	12.15
10-75-09	nd	536.4	216.7	265.7	16.13	11.86
10-75-10	nd	651	169.9	253.3	9.91	15.65
10-75-11	nd	593	145.9	225.4	7.54	14.67
10-75-12	nd	407.7	217.1	221.4	15.4	15.68
10-75-13	nd	723.6	196.7	348	17.99	14.35
10-75-14	nd	898.4	122.6	361	24.08	14.87
10-75-15	nd	1056	175.6	408.8	20.37	16.08
10-75-16	nd	1563	151.1	455.3	23.62	15.69
10-75-17	nd	379.2	151.6	289.3	19.07	12.46
10-75-18	nd	396.5	68.31	259.4	18.42	10.57
10-75-19	nd	1179	187.1	381.8	19.45	12.23
10-75-20	nd	1011	208.6	389.1	20.9	16.14
10-76-01	nd	722.9	324.6	294.8	17.97	10.81
10-76-02	nd	1149	126.2	382.3	19.59	9.54
10-76-03	nd	483.4	151.3	229.7	17.92	12.97
10-76-04	nd	721.7	131.2	229.3	10.91	9.82
10-76-05	nd	587.9	297.4	245.9	12.65	10.69
10-76-06	nd	511.6	172.4	212.3	10.73	9.95

10-76-07	nd	649.3	304	243.2	14.52	10.96
10-76-08	nd	185.8	91.19	118	9.19	7.43
10-76-09	nd	2315	415.2	302.8	14.71	13.03
10-76-10	nd	892.7	303.5	282.7	23.8	13.93
10-76-11	nd	258.5	94.24	199	17.91	10.73
10-76-12	nd	623.9	92.12	208.5	9.8	11.47
10-76-13	nd	729	85.32	219.5	10.58	11.69
10-76-14	nd	715.8	76.15	206.7	11.72	9.92
10-76-15	nd	695.8	84.27	203.3	10.31	12.82
10-76-16	nd	788.3	179.3	311.8	18.68	11.99
10-76-17	nd	1101	139.5	342	18.63	25.21
10-76-18	nd	1129	119.4	339.9	13.77	10.66
10-76-19	nd	1063	136.5	328	17.77	13.58
10-76-20	1.5	569	188	339.7	22.29	10.08
10-77-01	1.56	918	214.9	423	33.71	12.94
10-77-02	1.55	613.2	388.1	294.2	21	14.53
10-77-03	1.56	1043	108.2	419.2	25.07	13.59
10-77-04	1.55	1036	86.59	416.9	14.42	15.99
10-77-05	1.52	1046	81.7	422.6	10.18	12.16
10-77-06	1.52	508.3	96.76	286.8	25.11	12.1
10-77-07	1.51	637.8	80.95	288.6	15.1	10.18
10-77-08	1.48	662.3	68.34	261	7.69	8.12
10-77-09	1.47	717	68.41	259	6.78	11.02
10-77-10	1.47	757.4	70.54	261.3	8.01	8.55
10-77-11	1.56	639.9	185.6	392.8	35.18	9.88
10-77-12	1.53	806.1	188	416	28.1	8.3
10-77-13	1.51	784.6	214.6	391.4	19.64	7.97
10-77-14	1.51	790.5	219.3	389.3	19.75	8.86
10-77-15	1.53	835	202.9	400	22.01	13.1
10-77-16	1.55	513.8	300.7	377.2	32.45	10.68
10-77-17	1.52	762.7	294.4	383.9	22.8	10.98
10-77-18	1.53	804.5	306.3	354.5	13.15	22.55
10-77-19	1.53	745.7	264.5	332.3	7.76	7.85
10-77-20	1.49	743.9	239.1	328.6	6.45	7.02
10-78-01	1.49	417	191.5	259.4	12.02	8.52
10-78-02	1.46	561.2	261.2	279.3	13.94	12.41
10-78-03	1.46	596	210.5	262.1	6.42	10.22
10-78-04	1.49	621.7	184.6	267.3	7.56	7.74
10-78-05	1.48	595	169.5	269	6.01	5.61
10-78-06	1.61	510,3	248.3	326.4	34.16	9.15
10-78-07	1.51	582.4	213.6	319.5	15.34	8.35
10-78-08	1.49	561.7	219	273.8	8.14	8.23
10-78-09	1.47	565.6	218.7	259	5.65	7.28
10-78-10	1.47	655	214.4	273	4.8	9.48
10-78-11	1.56	500.8	233.7	315.1	19.46	10.25

10-78-12	1.47	418.8	220.7	29	14.98	9.23
10-78-13	1.58	456.2	200.1	233.1	7.57	9.35
10-78-14	1.56	441.2	168	231.9	6.16	8.86
10-78-15	1.52	459.7	136.9	236.8	7.83	7.83
10-78-16	1.57	516.7	167.3	317.1	26.16	10.39
10-78-17	1.52	695.4	108.3	356.6	24.87	12.66
0-78-18	1.54	739.6	109.7	346.7	17.26	9.64
10-78-19	1.53	732.5	100.4	324.7	10.02	8.46
10-78-20	1.53	704	97.4	305.6	9.08	8.15
10-79-01	0.75	39	246.6	255	26.91	14.91
10-79-02	0.64	623.2	249.3	274	23.06	29.43
10-79-03	0.61	681.7	244.1	326.9	17.32	10.01
10-79-04	0.61	609.7	191.3	290.3	9.65	8.78
10-79-05	0.61	585.3	149.9	293.9	6.86	12.11
10-79-06	0.76	176.8	164.9	228.1	25.02	15.4
10-79-07	0.64	277.5	124.4	211.2	20.39	17.03
10-79-08	0.6	339.7	105.3	203.9	12.66	7.55
10-79-09	0.62	358.9	76.12	211.3	10.44	6.71
10-79-10	0.58	424.1	69.07	230.5	9.14	9.98
10-79-11	0.57	255.9	262.6	213	12.48	14.51
10-79-12	0.59	296.9	290.3	191.5	7.75	11.64
10-79-12	0.65	289.4	286.3	160.2	7.68	12.59
10-79-14	0.65	294.1	235.7	151.1	10.15	13.17
10-79-15	0.64	307.1	185.3	149.4	5.97	8.57
10-79-16	0.6	272.1	237.5	224.9	20.01	9.90
10-79-17	0.73	97.96	116.5	189.2	16.57	10.37
10-79-18	0.63	256.6	93.07	185.3	13.44	11.7
10-79-19	0.54	444.7	93.04	201	12.51	10.39
10-79-20	0.5	364.6	68.27	181.8	11.2	8.31
10-80-01	0.56	534.7	234	256.6	18.07	9.05
10-80-02	0.55	578.9	171.3	249.2	16.12	8.04
10-80-03	0.56	621.3	162.3	253.7	15.96	7.54
10-80-04	0.55	642.9	150.8	258	11.73	6.92
10-80-05	0.55	691.3	144.1	271.7	14.13	6.51

Annex 8-a: Tree number per DBH classes under block 1

Plot	DBH (cm)				Tree number	Tree H (m)	Alive Stump	Stump dia.(cm)	Stump H (cm)	Dead stump
	5<	5.0-9.0	9.1-14.0	14.1-19.0						
1	16	26	19		45	14	26	25	34	2
2	20	29	14	1	44	15	24			
3	11	8	5		13	15	11			
4	10	8	4		12	15	10	22	30	
5										
6	5	2	2		4	11	4			
7										
8	2	1	2		3	11.5	2			
9	58	39	1		40	10.5	37	21	39	
10	60	38			38	10	36			
11	80	37	1		38	11	55			
12	62	38			38	10	43	22	35	
13	21	38	10		48	11.5	30			
14	24	36	17		53	11	31			
15	33	40	6		46	11	42	17	32	
16	30	38	6		44	11	41			
17	29	43	4		47	11	42			
18	27	40	4		44	11	38	17	25	
19	18	24	20	3	47	11	40	17		2
20	20	23	21	4	48	11	23	17		
21	35	38	2		40	11	41	16	24	
22	37	35	2		37	11	42			
23	46	37	3		40	11	52	19	15c	1
24	41	35	3		38	11	48			
25										
26	62	27	2		29	9	52			4
27	65	23	4		27	11	53	18	49	

28	37	35			35	10	42			2
29	35	29	2		31	10.5	40			1
30										
31	3	1	3		4	11.5	3	20	25	
32	4	6	8	6	20	21	7			
33	3		7	7	14	22	7			
34	12	13	14	3	30	19	20	20	25	1
35	10	15	14	2	31	20	20			
36	20	20	10	1	31	17	26			
37	22	20	11	1	32	17.5	27	16	24	
38										
39										
40	7	22	10		32	15	18			1
41	10	13	12	2	27	17	21			
42	16	1	2		3	11	2	18	24	
43	5	5	1		6	9	4			
44										
45	8	2	2		4	10.5	3			
46	37	34			34	10	37	19	11	
47	34	23	5		28	11	33			
48	40	45	3		48	13.5	50	16	25	4
49	45	38	6		44	14	52			
50	39	47	3		50	12	49			3
51	36	34	8		42	13.5	49	19	32	
52	17	19	14		33	15	23			2
53	22	17	12		29	17	25			
54	40	33	7		40	14	38	18	10	
55	38	30	4		34	16	35			
56	28	38	8		46	14.5	22			4
57	30	28	10		38	16	24	18	26	

58	7	14	12	3	29	18.5	15			4
59	9	13	12	5	30	18	17			
60										
61	10	4	3	1	8	13		18	24	
62	27	27	12	3	42	16	36			6
63	25	25	10	4	39	17	33			
64	28	22	7		29	16	37	17	32	7
65	29	19	6		25	16.5	36			
66	37	35			35	11	36			5
67	35	29	3		32	12	34	21.5	24	
68	30	24	10		34	14	33			5
69	28	23	8		31	15	31			
70	14	18	5		23	12	25	22	35	11
71	15	10	7		17	13	26			

Annex 8-b: Tree number per DBH classes under block 2

Plot	DBH(cm)				Tree number	Tree height(m)	Alive Stump	Stump dia.(cm)	Stump H. (cm)	Dead stump
	<5	5.0-9.0	9.1-14.9.0	14.1-19.0						
1	25	38	7	1	46	13.5	28	16	22	1
2	30	36	9	1	46	14.5	29			
3	24	33	1		34	9.5	17			
4	20	29	4		33	10	15	30	25	
5	32	31	1		32	12	23			
6	35	30	2		32	12.5	25			
7	80	32			32	10	48	23	18	
8	65	30	2		32	11	36			
9	60	44	3		47	10.5	43			
10	71	40	5		45	11	68	27	19	
11	65	41	10		51	13	37			
12	51	40	9		49	13.5	36			
13	33	31	5		36	12	30	23	19	

14	35	26	7		33	13	35			
15	39	28	12	1	41	12	38			
16	32	31	5	2	38	12	34	28	22	
17	63	37	2		39	11	45			
18	71	35	3		38	10	47			
19	56	32			32	10.5	41	26	22	
20	59	30	1		31	11	43			
21	48	41	1		42	10	30			
22	49	24			24	11	42	23	21	
23	86	12	1		13	8	47			
24	44	51	4		55	13	40			
25	19	55	4		59	13	43	30	19	2
26	26	15	17	2	34	13	23			
27	2	19	18	5	42	13	16			
28	33	41			41	13	36	28	20	2
29	20	24	10		34	13	24			
30	36	20			20	13	34			2
31	105	4			4	13	38	18	23	
32	47	30	5		35	13	38			
33	38	41	3		44	13	33			
34	45	43	10		53	13	44	24	31	
35	33	37	10		47	13	31			3
36	51	28	1		29	13	37			
37	45	41			41	13	38	19	23	
38	25	28	6		34	13	29			1
39	24	23	9		32	13	18			1
40										
41	4	12	14	1	27	20	11	22	29	5
42	25	45	2		47	12	34			6
43	18	36	11		47	18	27			

Annex 8-c: Tree number per DBH classes under block 3

Plot	DBH(cm) <5	5.0-9.0	9.1-14.0	14.1-19.0	Tree No.	Tree height (m)	Alive Stump	Stamp dia.(cm)	Stump H. (cm)	Dead stump
1	3	5	2		7	10	4			
2	2	5	2		7	10.5	3			
3	5	8	2		10	11	5	30	28	
4	7	7	4		11	10	4			
5	2	1	1		2	9	1			
6	3		1		1	11.5		27	30	
7	2	1		1		8	1			
8	1	2			2	7	1			
9	8	4	4		8	12	3	29	27	
10	10	3	5		8	12.5	4			
11										
12	3	2	1		3	9.5	2	25	31	
13	5	12	6		18	11	7			
14	4	10	6		16	11.5	6			
15										
16										
17	3	4	2		6	10	4	21	26	
18	4	4	2		6	10.5	3			
19	2	3	2		5	10	2			
20	4	1	4		5	9.5	3	27	24	
21	4	8	3		11	12	4			
22	2	7	4		11	12	3			
23										
24	1	4	2		6	9.5	3	28	27	
25	15	34			34	9	21			

26	14	26	3		29	9.5	18			
27	18	25	2		27	10	22	25	32	
28	21	18	5		23	11.5	20			
29	19	10	2		12	10	21			
30	20	10			10	8.5	19	22	28	
31	14	11	2		13	12	12			
32	16	7	3		10	12.5	11			
33	2	1			1	9	1			
34	10	3	1		4	12	5	26	27	
35										
36	11	6			6	8	7			
37										
38	2	1	1		2	11.5	2	28	28	
39	12	11	7		18	12m	9			
40	7	7	7		14	12.5	7			
41	10	16	4		20	12	9	24	33	
42	7	14	1		15	12	8			
43	2	9	6		15	13	7			
44	8	7	6		13	12	11	27	26	
45	6	2	6		8	13	5			
46	4	2	6		8	13	4			
47	7	12			12	12	11	18	22	2
48		8	3		11					
49										
50	8	5	7	2	14	11	15			
51	30	19	2		21	9	22	25	16	
52	25	16	1		17	9	18			
53	26	30			30	10	26			
54	56	32	1		33	9	18	15	20	
55	36	12			12	8.5	33			

56	24	25			25	10	15			
57	20	21	1		22	10	27			
58	22	38	2		40	12	24	18	11	
59	47	16			16	9	33			
60	24	35			35	10	27			
61	18	25	7		32	14	26	28	14	1
62	33	38	4		42	12	32			
63	18	21	1		22	10	25			
64	50	21			21	10	28	21	28	
65	50	18			18	10.5	37			
66	50	39	1		40	10.5	37			
67	36	35			35	11	32	19	24	
68	29	32	8		40	12	29			

Annex 9-a: volume and basal area of *E. camaldulensis* under block 1

plot	Basal area in DBH Classes				Dominant tree H	Volume
	5.0-9.0	9.1-14.0	14.1-19.0	Total		
1	0.092830353	0.161632		0.254462353	14	1.424989177
2	0.111351656	0.136551	0.002269806	0.250172462	15	1.501034772
3	0.03057248	0.034415		0.06498748	10	0.25994992
4	0.032838359	0.032014		0.064852359	11	0.28535038
5	-					
6	0.007786456	0.017117		0.024903456	11	0.109575206
7						
8	0.00636174	0.018853		0.02521474	11.5	0.115987804
9	0.122988928	0.007854		0.130842928	10.5	0.549540298
10	0.141358648			0.141358648	10	0.565434592
11	0.116084476	0.006793		0.122877476	11	0.540660894
12	0.137069579			0.137069579	10	0.548278316

13	0.131841171	0.090387		0.222228171	11.5	1.022249587
14	0.138399261	0.147333		0.285732261	11	1.257221948
15	0.138064681	0.049578		0.187642681	11	0.825627796
16	0.165024321	0.055552		0.220576321	12	1.058766341
17	0.134530381	0.006648		0.141178381	11	0.621184876
18	0.145192186	0.02807		0.173262186	10	0.693048744
19	0.103459171	0.220298	0.056257417	0.380014588	18	2.736105034
20	0.100960814	0.223669	0.077714545	0.402344359	19	3.057817128
21	0.119551232	0.013586		0.133137232	10	0.532548928
22	0.122569524	0.014476		0.137045524	11	0.603000306
23	0.105267162	0.022356		0.127623162	10	0.510492648
24	0.108800677	0.02935		0.138150677	11	0.607862979
25						
26	0,079696894	0.014502		0.094198894	9	0.339116018
27	0.078202278	0.035668		0.113870278	11	0.501029223
28	0.111998825			0.111998825	10	0.4479953
29	0.111684665	0.017675		0.129359665	10.5	0.543310593
30						
31	0.005808818	0.028974		0.034782818	11.5	0.160000963
32	0.027456799	0.090725	0.144734297	0.262916096	21	2.208495206
33		0.074092	0.163449594	0.237541594	22	2.090366027
34	0.05118766	0.138115	0.05382896	0.24313162	19	1.847800312
35	0.064538674	0.133831	0.044115918	0.242485592	20	1.939884736
36	0.078933485	0.094258	0.016971709	0.190163194	17	1.293109719
37	0.080675503	0.118335	0.016513035	0.215523538	17.5	1.508664766
38						
39						
40	0.086576213	0.108121		0.194697213	15	1.168183278
41	0.060587327	0.121234	0.033254621	0.215075948	17	1.462516446
42	0.003019078	002272		0.025739078	11	0.113251943
43	0.017025901	0.12469		0.141715901	9	0.510177244

44						
45	0.009804934	0.014183		0.023987934	10.5	0.100749323
46	0.122402234			0.122402234	10	0.489608936
47	0.096118823	0.039938		0.136056823	11	0.598650021
48	0.152932303	0.024533		0.177465303	13.3	0.944115412
49	0.147260929	0.057583		0.204843929	14	1.147126002
50	0.169497174	0.018241		0.187738174	12	0.901143235
51	0.137470918	0.065981		0.203451918	13.5	1.098640357
52	0.080124152	0.121422		0.201546152	15	1.209276912
53	0.085288942	0.119886		0.205174942	17	1.395189606
54	0.123260676	0.054482		0.177742676	14	0.995358986
55	0.143692857	0.041705		0.185397857	16	1.186546285
56	0.145158413	0.074743		0.219901413	14.5	1.275428195
57	0.127519115	0.074981		0.202500115	16	1.296000736
58	0.045719705	0.142324	0.078161437	0.266205142	18.5	1.969918051
59	0.053013715			0.053013715	18	0.381698748
60						
61	0.017232461	0.036468		0.053700461	13	0.279242397
62	0.104846188	0.111974	0.064295986	0.281116174	16	1.799143514
63	0.107145839	0.103945	0.083400841	0.29449168	17	2.002543424
64	0.072746104	0.056233		0.128979104	16	0.825466266
65	0.076119397	0.053315		0.129434397	16.5	0.85426702
66	0.119741299			0.119741299	11	0.526861716
67	0.107949303	0.022081		0.130030303	12	0.624145454
68	0.090549551	0.086959	0.018145882	0.195654433	14	1.095664825
69	0.101831822	0.086898		0.188729822	15	1.132378932
70	0.073050054	0.046814		0.119864054	12	0.575347459
71	0.040571408	0.076295		0.116866408	13	0.607705322

Annex 9-b: volume and basal area of *E. camaldulensis* under block 2.

Plot	Basal area in DBH Classes				Dominant tree H	volume
	5.0-9.0	9.1-14.0	14.1-19.0	Total		
1	0.147872758	0.072965231	0.02216713	0.243005119	13.5	1.312227643
2	0.133076605	0.081356444	0.02269806	0.237131109	14.5	1.375360432
3	0.123605467	0.008332309		0.131937776	9.5	0.501363549
4	0.119779783	0.032942818		0.152722601	10	0.610890404
5	0.09423779	0.006792925		0.101030715	12	0.484947432
6	0.097519191	0.017146853		0.114666044	12.5	0.57333022
7	0.101815329			0.101815329	10	0.407261316
8	0.102222952	0.15306661		0.255289562	11	1.123274073
9	0.149709806	0.02265879		0.172368596	10	0.689474384
10	0.143828731	0.038666027		0.182494758	11	0.802976935
11	0.152370742	0.085809662		0.238180404	13	1.238538101
12	0.157087069	0.081650184		0.238737253	13.5	1.289181166
13	0.121722863	0.041268058		0.162990921	12	0.782356421
14	0.102980077	0.059599294		0.162579371	13	0.845412729
15	0.112521116	0.112726891		0.225248007	12	1.081190434
16	0.140568536	0.062249233	0.039439646	0.242257415	12	1.162835592
17	0.121861879	0.015420544		0.137282423	11	0.604042661
18	0.116781126	0.020236616		0.137017742	10	0.548070968
19	0.094302193			0.094302193	10.5	0.396069211
20	0.101450118	0.006503897		0.107954015	11	0.474997666
21	0.130373258	0.006792925		0.137166183	10	0.548664732
22	0.072518338			0.072518338	11	0.319080687
23	0.035472591	0.007238248		0.042710839	8	0.136674685
24	0.195809645	0.3188648		0.514674445	13	2.676307114
25	0.203959741	0.31686963		0.520829371	13	2.708312729
26	0.051105978	0.181749414	0.037781667	0.270637059	15	1.623822354
27	0.076852175	0.173833367	0.104585435	0.355270977	20	2.842167816

28	0.135606379			0.135606379	11	0.596668068
29	0.086602916	0.098275531		0.184878447	17	1.25717344
30	0.05119787			005119787	8	0.163833184
31	0.011078067			0.011078067	10	0.044312268
32	0.106193149	0.04850866		0.154701809	10	0.618807236
33	0.135689631	0.023562		0.159251631	11.5	0.732557503
34	0.15081565	0.078640561	0.016513035	0.245969246	12	1.180652381
35	0.125843857	0.099797636		0.225641493	11	0.992822569
36	0.044270642	0.006503897		0.050774539	11	0.223407972
37	0.101128889			0.101128889	12	0.485418667
38	0.096033214	0.050377127		0.146410341	12	0.702769637
39	0.08557954	0.075401542		0.160981082	13	0.837101626
40						
41	0.04627891	0.140023468	0.016060645	0.202363023	20	1.618904184
42	0.145227529	0.014979934		0.160207463	12	0.768995822
43	0.139501177	0.09384888		0.233350057	18	1.68012041

Annex 9-c: Volume and basal area of *E. camaldulensis* under block 3.

Plot	Basal area by DBH classes				Dominant tree h	Volume
	5.0-9.0	9.1-14.0	14.1-19.0	Total		
1	0.02248208	0.016513		0.03899508	10	0.15598032
2	0.02146106	0.018664		0.04012506	10.5	0.168525252
3	0.04030202	0.017998		0.05830002	11	0.256520088
4	0.03294753	0.033382		0.06632953	10	0.26531812
5	0.00567452	0.006793		0.01246752	9	0.044883072
6		0.010387		0.010387	11.5	0.0477802
7	0.00636174			0.00636174	8	0.020357568
8	0.1183127			0.1183127	7	0.33127556
9	0.01939938	0.038288		0.05768738	12	0.276899424
10	0.137767	0.045513		0.18328	12.5	0.9164

11						
12	0.0909807	0.007854		0.0988347	9.5	0.37557186
13	0.06129183	0.050306		0.11159783	11.5	0.513350018
14	0.05009674	0.046449		0.09654574	10	0.38618296
15						
16						
17	0.01441209	0.015708		0.03012009	9.5	0.114456342
18	0.01351045	0.018495		0.03200545	12	0.15362616
19	0.01272348	0.07357		0.08629348	12	0.414208704
20	0.00502656	0.030718		0.03574456	9.5	0.135829328
21	0.0420534	0.02946		0.0715134	9	0.25744824
22	0.03428428	0.039007		0.07329128	12	0.351798144
23						
24	0.01517157	0.017706		0.03287757	9	0.118359252
25	0.12188151			0.12188151	9.5	0.463149738
26	0.09624763	0.022195		0.11844263	10	0.47377052
27	0.08734748	0.014202		0.10154948	11.5	0.467127608
28	0.07697862	0.035762		0.11274062	10	0.45096248
29	0.02470397	0.017357		0.04206097	8.5	0.143007298
30	0.03783979			0.03783979	12	0.181630992
31	0.04171888	0.014047		0.05576588	12.5	0.2788294
32	0.03273547	0.021571		0.05430647	9	0.195503292
33	0.00636174			0.00636174	10	0.02544696
34	0.0019635			0.0019635	12	0.0094248
35						
36	0.02243574			0.02243574	11.5	0.103204404
37						
38	0.00636174	0.007088		0.01344974	12	0.064558752
39	0.04373657	0.069429		0.11316557	12	0.543194736
40	0.02739083	0.063864		0.09125483	12.5	0.45627415
41	0.06552357	0.030396		0.09591957	12	0.460413936
42	0.06247464	0.009852		0.07232664	12	0.347167872

43	0.0298342	0.047414		0.0772482	13	0.40169064
44	0.02441416	0.048358		0.07277216	12	0.349306368
45	0.00803386	0.051043		0.05907686	13	0.307199672
46	0.00815716	0.052429		0.06058616	11	0.266579104
47	0.0555427			0.0555427	12	0.26660496
48	0.03234906	0.021885		0.05423406	11	0.238629864
49						
50	0.02378427	0.06071	0.039604	0.12409827	13	0.645311004
51	0.06713992	0.018398		0.08553792	11	0.376366848
52	0.05632889	0.007854		0.06418289	9	0.231058404
53	0.10614288			0.10614288	9	0.382114368
54	0.10658978	0.006793		0.11338278	10	0.45353112
55	0.03076883			0.03076883	9	0.110767788
56	0.0679803			0.0679803	8.5	0.23113302
57	0.07486197	0.006793		0.08165497	10	0.32661988
58	0.14399916	0.016025		0.16002416	10	0.64009664
59	0.04322292			0.04322292	12	0.207470016
60	0.13050285			0.13050285	9	0.46981026
61	0.10490509	0.070281		0.17518609	12	0.840893232
62	0.13308682	0.030355		0.16344182	10.5	0.686455644
63	0.05811018	0.00694		0.06505018	10	0.26020072
64	0.05567308			0.05567308	10	0.22269232
65	0.05165654			0.05165654	10.5	0.216957468
66	0.13209407	0.006504		0.13859807	10.5	0.582111894
67	0.10965284			0.10965284	11	0.482472496
68	0.12636458	0.068412		0.19477658	12	0.934927584