Production in a fertilization experiment with *Eucalyptus urophylla* in Guangxi, southern China

Tillväxt i ett gödslingsexperiment med *Eucalyptus urophylla* i Guangxi, södra Kina

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Foreword

This experiment is cooperation between the Swedish University of Agricultural Sciences (SLU) and StoraEnso Guangxi (SEGX). SEGX is responsible for the establishment of the trial and management cost. SEGX was established in 2002, aiming to establish Eucalyptus fiber production at low cost in southern Guangxi to develop a cost-efficient pulp and paper mill. SEGX has around 60000 ha of land, of that 35000 is Eucalyptus plantation. The goal is to achieve a production of 35-40 $m^3ha^{-1}yr^{-1}$. The current averages productivity is 14.9 $m^3ha^{-1}yr^{-1}$.

I would like to thank SLU and SEGX to have given me this opportunity to do this master thesis. Thanks to my supervisors Johan Bergh and Jonas Rönnberg at SLU, which has been always available for questions and discussion? Thanks to Anders Malmer SLU that read my thesis and made comments. Thanks to Urban Nilsson that help me with statistical analyses and Tove Vollbrecht for the illustration in figure 14. I would also like to thank all the staff of SEGX for the warm and welcome hospitality when I was in Hepu. Special thanks to Risto Vuokko for always being helpful, Helen Huang that made the Chinese version of the abstract and helped me around in Hepu and stand out with me for five weeks, Zhu Wei that helped me with measurements in field and also too the three Swedes at SEGX that took care of me Ulf Andersson, Bengt Lundholm and Tony Ohlsson. Also thanks to Lars Klint that collected material for me in Sweden.

Abstract

The high demand for forest products in southern Asia and also a high pressure on land for alternative use than forest makes Eucalyptus plantation forest useful to lower the pressure on natural forest in south-east Asia. One problem with Eucalyptus in Southern China is that the production is under its potential. A fertilization trial was established in spring 2006 to see the possible production capacity. This master thesis is the first measurement of this trial. Seven different treatments and one control were put out in four different blocks. The fertilizer that was used was NPK-fertilizers and NK-fertilizers. One of the treatments was the common practice for fertilization in Southern China. Three of the treatments had their fertilization levels based on nutrient analyses of leafs. The production differences between fertilization in strings and broadcast were also tested. In the comparison between string and broadcast fertilization the broadcast treatment (NPK-150-B) produced 7 m^3 ha^{-1} yr^{-1} more than the sting treatment (NPK-150-S). The treatment with the lowest growth had 25.7 m^3 ha^{-1} yr^{-1} (NPK-0) and the best treatment (NPK-300-B) had grown 34.4 m^3 ha^{-1} yr^{-1}. Eucalyptus stands in Southern China should at least be fertilized with 150 kg N, 115 kg P and 115 kg K ha^{-1} yr^{-1} broadcasted to achieve a high production according to the result in this thesis. The production was higher in the NPK fertilized treatments than the NK fertilized treatment. There were significant differences between fertilization once or twice a year. There was a higher amount of damaged trees in the higher fertilized treatments. The damages were mainly croakiness, double top and forking. There is no economical benefit so far of the fertilization. The untreated control had the highest economical profit. There was a higher amount of leaves on the ground in the fertilized plots compared with the untreated control. This could lead to an establishment of higher organic content of top soil or an organic layer which could lead to more stabile soil, more resistant to soil erosion.

Sammanfattning

Det höga trycket på skogliga råvaror i södra Asien och trycket på att använda marken för alternativa bruk än skogsmark gör Eukalyptus plantager användbara för att minska trycket på naturliga skogar i sydöstra Asien. Ett problem med Eukalyptus plantager i södra Kina är att tillväxten är under sin potential. Därför så anlades ett gödslingsförsök våren 2006 för att se den möjliga produktionen kapaciteten. Detta examensarbete är första mättningen av det försöket. Sju olika behandlingar och en kontroll lades ut i fyra olika block. Gödselmedlen som användes var NPK-gödsel och NK-gödsel. En av behandlingarna var standard sättet för gödsling i södra kina. Tre av behandlingarna hade sin gödselgiva baserad på näringsanalyser av bladen. Produktions skillnader mellan att gödsla i strängar och att sprida gödseln jämt över ytan testades också. I jämförelsen mellan strängar och sprida jämt över ytan så hade träden i behandlingen där gödselen spridits jämt över ytan (NPK-150-B) växt 7 m^3 ha^{-1} $år^{-1}$ mer än sträng behandlingen (NPK-150-S). Behandlingen som hade den lägsta tillväxten hade växt 25.7 m^3 ha^{-1} $år^{-1}$ (NPK-0) och den bästa tillväxten var 34.4 m^3 ha^{-1} $år^{-1}$ (NPK-300-B). Eukalyptus bestånd i södra Kina ska minst gödslas med 150 kg N, 115 kg P och 115 kg K ha^{-1} $år^{-1}$ enligt resultaten i detta examensarbete. Produktionen var högre i de behandlingar som hade NPK-gödsel jämfört med behandlingen som var NK-gödslad. Det var en signifikant skillnad mellan att gödsla en eller två gånger på ett år. Än så länge kan man inte se någon ekonomisk vinning av gödslingen. Det var en större mängd löv på marken i de gödslade ytorna jämfört med kontrollen. Detta kan leda till en höjd nivå av organiskt material i

toppskiktet eller etableringen av ett organiskt lager vilket kan leda till mer stabila jordar som är mer motståndskraftiga mot jorderosion.

在南亚对林产品大量需求及非林用土地与林用土地竞争紧张的形式下，桉树(人工)林的使用使东南亚对自然林的需求压力得以有效减轻。中国南部的桉树所面临的一个问题是其产量潜力未得到充分发挥。基于此，2006 年春建立了一个施肥试验以观察生长力可能存在的潜力。本硕士论文对这块试验地的首次测量进行了论证。试验设置了七个不同的处理方式及一个控制处理方式，分布在四个不同的小区中。试验用肥为 NPK 及 NK。其中, 有一种处理方式为中国南部常用的施肥方式；有三种处理方式的施肥水平是根据叶片营养分析结果来决定的。线性施肥方式与播洒式施肥方式的产量差异对比也是测定项目之一。经对比，播洒式(NPK-150-B)施肥比线性施肥(NPK-150-S)的产量高 7 m^3 ha^{-1} yr^{-1}。产量最低的施肥方式(NPK-0)产量为 25.7 m^3 ha^{-1} yr^{-1}，产量最高的施肥方式(NPK-300-B)产量为 34.4 m^3 ha^{-1} yr^{-1}。本论文的结论是，中国南部桉树应采用播洒式、最少施肥用量为 150 kg N, 115 kg P 及 115 kg K ha^{-1} yr^{-1} 施肥方式以便取得高产的效果。以叶片营养分析结果为基础的两种施肥方式取得了更为显著的生长量。使用 NPK 施肥的产量高于使用 NK 施肥的产量。而每年施肥一次与每年施肥两次的效果差异非常显著。施肥量较大的施肥方式树木的损害率较高，损害一般都集中表现为断顶、顶端分叉或树杆分叉。到目前为止，施肥未显示其经济效益；而不实施施肥处理的控制处理的经济效益最高。施肥小区的落叶比不施肥控制处理方式的更多，这种情况可能可以得到这样的推测：有机成分较高的表土，即富含有机质的土层，土壤较为牢固，更易于抵抗水土流失。

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1. Introduction

The amount of arable land per capita is decreasing in the tropics, caused by increasing population and a change in land use. In conditions when the amount of available land is insufficient for producing both forest fiber and other goods, every single hectare needs to be used more efficiently. The general trend in the tropics is that forestland is transformed to agricultural land but the rate is decreasing (FAO, 2005). The net forest area increased between 2000 and 2005 in East Asia (State of the world forest, 2007). Plantation forestry can compete with alternative use of land because of its high level of production, improved economy and efficient use of land. Land area used for plantation forestry is increasing in all regions of the world, where the largest increase is in Asia and especially in China (FAO, 2005). China is the country with largest area of productive forest plantations in the world 28.53 million ha, 26 % of Chinas total forest cover (FRA, 2005). In whole East Asia 30.01 million ha is productive forest plantation which is 12.3 % of the total forests cover (FRA, 2005).

A productive forest plantation is defined as forests plantation predominantly intended for producing wood, fiber and non-wood forest products. Further definitions of forest plantations are:

- Forest of introduced non native species and in some cases native species.
- The forest should be planted or saw using a few species.
- Even spacing and/or even-age stands (FRA, 2005).
- Plantations are normally rectangular shaped with clear borders and the area should be larger than 1 ha (Evans, 1982).
- The planted trees should be evenly distributed so most of the productive capacity is utilized (Evans, 1982).

The forest cover in China has increased during the past 20 years, after a long steady decline. In order to increase the forest cover, waste land has been planted (Rozelle et al., 2000). Large amount of the new forest is former wasteland and land susceptible to erosion. Another action taken, to improve the forest cover in China, has been logging bans in large areas (Rozelle et al., 2000). This has caused large social and economic costs, but was necessary to prevent erosion, flooding along rivers, save the natural forests and values for biodiversity and wildlife. China is one of the worlds largest forest countries with 159 million ha of forest, 113 000 million of standing volume and a forest cover of 16.55 % (Shengxian, Z. et al. 2000). China is consuming yearly 300 million m^3 and has a rapid economic growth (Rozelle et al., 2000). China is consuming 8 % (third larges) of all industrial roundwood and 13 % (second larges) of the pulp for paper in the world (FAO, 2003). The demand in the future will increase even more. To meet the increased demand, imports of forest products have increased drastically the past decade, while the export has been decreasing (Shengxian, Z. et al., 2000). Most of the timber- and pulpwood produced has been produced for the domestic market, only forest products for 8.01 million US dollar was exported 1999 (fig. 1). The total value of the import in 1999 was 1.25 billion US dollar (Shengxian, Z. et al., 2000). The export value is only 0.64 % of the import value. Paper is the major product of imported timber products 62.5 % of the total import value (Shengxian, Z. et al., 2000). In 2003 37.929 million ton paper and paperboard was produced in China (fig. 2) and 10.39 million ton paper and paperboard was imported (FAO, 2003). Consequently the inevitably increased import from other countries likely leads to a higher pressure on the remaining natural forests in China as well as in other Asian countries. One way to reduce the import and the pressure on natural forest is to increase the domestic production in the existing plantations and establish new plantations.

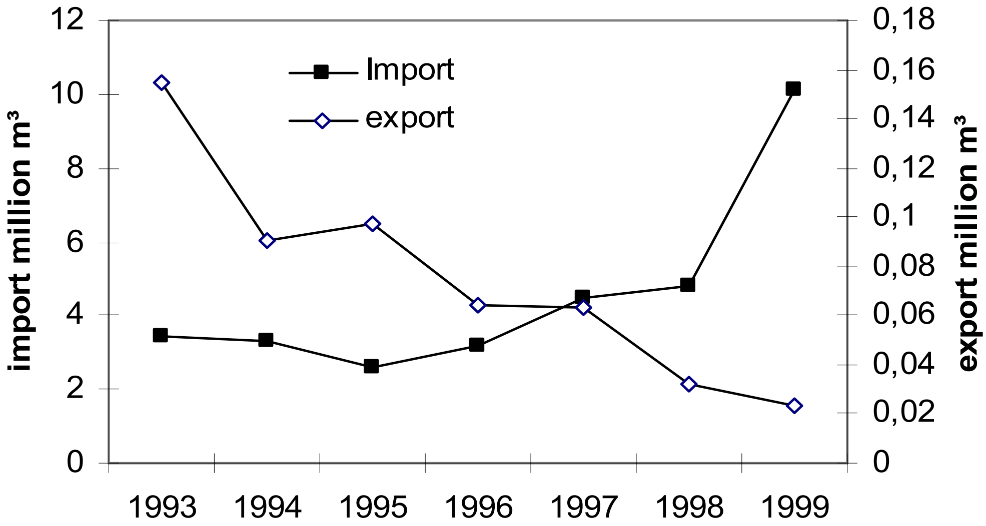


Figure 1 Stem volume (m³) of import and exported Major Forest Products 1993-1999. (China forestry Development Report, 2000)

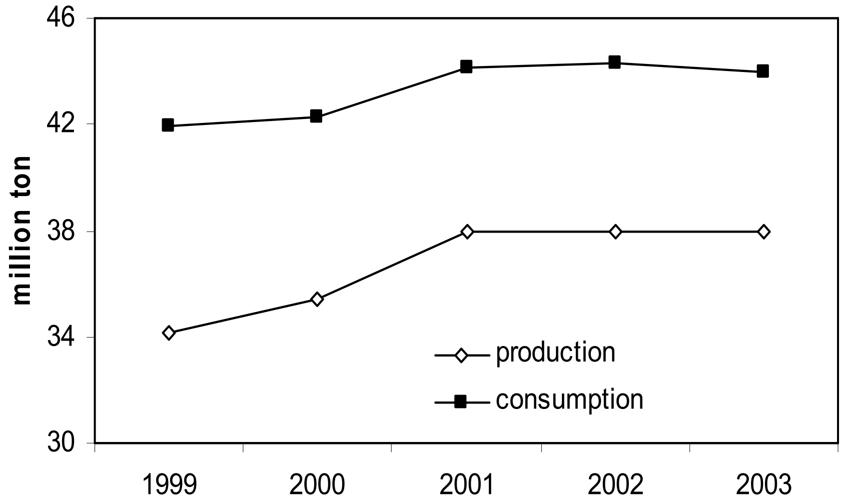


Figure 2. Paper and paperboard production and consumption (million tonnes) in China 1999-2003 (FAO Yearbook of Forest Products, 2003)

The production in existing plantations in China can probably increase significantly to the levels of the rest of the world (Xu & Dell, 2002). The increased production can only be achieved by adding nutrients, adapted silviculture and use of suitable genetic material. Such silvicultural activities might also increase the amount of high quality forest products produced in the plantations e.g. timber for veneer (Mery et al, 2005). This gives possibilities to meet the domestic demands for wood raw material (Rozelle et al., 2000). Highly productive forest plantations could therefore compete with alternative use of land.

Areas in southern China used for plantation forestry is mostly former agriculture land which has been degraded with extensive loss of organic layer (Xu & Dell, 2002). Tropical soils are in general sensitive to degradation and erosion (Lal 1997), problems which might decrease by planting trees and establishment of forest plantations. Soil degradation occurs because of deforestation, overgrazing, agriculture activities, over-exploitation and bio-industrial activities (Lal 1997). The tropics are adapted to be covered by forest so the risk of degradation is lower if land is forested (Lal, 1997). In temperate and boreal forest ecosystems nitrogen (N) is the main limiting nutrient (Berg, 1991 and Höberg, 1992), while in sub-tropical and tropical forest ecosystems other nutrients might strongly limit growth in plantations, like phosphorus (Barros 1992, Xu et al., 1999), potassium (Xu & Dell, 2002) and boron (Gonçalves et al., 2004).

In the tropical and subtropical China there are five regions of Eucalyptus plantations: South-eastern costal region; Guangdong and Guangxi Provinces; Leizhou Peninsula and Hainan Island; South-western Plateau and Hunan and Jiangxi Provences (Wang & Zhou, 1996). Eucalyptus was introduced to China in 1890 but large scale plantations of Eucalyptus were established first in the 1950's (Bai & Gan, 1996). Today it is approximately 1.500.000 ha of Eucalyptus plantations in China with an annual increase of 150.000 ha (Xu & Dell, 2002). *Eucalyptus urophylla* is most common in plantations, as an effect of the fast growth and the high yield. Guangxi region holds around 100.000 ha of Eucalyptus plantations. The most common species are *E. exserta, E. citiodora* and *E. urophylla* (Wang & Zhou, 1996). The areas which forest plantations have been established on are degraded soil with low production capacity, the areas are most suitable to use as forest. Eucalyptus plantations in this region, however, can increase the production rapidly and reduce the rotation length and this would lead to an improved economy. This could also lead to increasing employment due to new factories, improved infrastructure and welfare in the region. In south-western China Eucalyptus has usually a low production capacity 24 m^3 ha^{-1} yr^{-1} (Wang & Zhou, 1996). This is caused by poor soils with low amounts of nutrients. In these areas production could likely be increased by adding nutrients. Under given climatic conditions with a seasonal pattern of the precipitation it would be possible to increase the mean annual increment (MAI) in southern China to more than 40 m^3 ha^{-1} yr^{-1}, by adding nutrients throughout the rotation period (Pereira et al., 1994, Linder pers. comm.). The normal way to use fertilization in China is to put them in strings. The benefit of using strings according to Chinese forest practice is that nutrients will not be lost in same extent under heavy rainfall.

Two main problems in the tropics are soil degradation and soil erosion. Soil degradation occurs because of deforestation, overgrazing, agricultural activities, over-exploitation and bio-industrial activities. Soil degradation have caused serious problem for agriculture sustainability and environment quality in south-east Asia. Soil degradation depends on a lot of factors as climate, land use, and soil and vegetation management (Lal, 1997). The tropics are adapted to be covered by forest so the risk of degradation is lower in forest. Plantation forest can be made on degraded agricultural land and with fertilization still get a high growth. By planting high productive Eucalypt forest the degraded land is used in a better economical and sustainable way. The risk of erosion gets higher when deforested land but forested land is better than agriculture land in risk of erosion because the root system makes the soil more stabile. Heavy machines increase the risk of erosion (Lal, 1997). By using fertilization the trees grow faster and the time with bare land will be shorter and therefore the risk of soil erosion will be lower.

Compared with some other countries the productivity in China is low only 24 m^3 ha^{-1} yr^{-1} for eucalyptus (Wang & Zhou, 1996). In Brazil the productivity on the best location could be between 60–90 m^3 ha^{-1} yr^{-1} for eucalyptus (Christenson and Verma 2006). In Ethiopia some Eucalyptus plantation is established. There are big differences in annual increment 13-46 m^3 ha^{-1} yr^{-1} (Christenson and Verma 2006). In Congo the Eucalyptus plantations has an annual productivity of 20-25 m^3 ha^{-1} yr^{-1} (Bouillet et al., 1998). In South Africa the average production is at the same level as in China 21 m^3 ha^{-1} yr^{-1} (du Toit, 1998). In Sweden the maximum production for the most used tree for production, spruce is 7-10 m^3 ha^{-1} yr^{-1} (Berg et al. 2004).

Hypothesis in this thesis are:

1. Treatments with broadcasted fertilization will have higher production compared with string fertilized treatments.
2. Production will be higher in the treatments with NPK-fertilizer compared with NK-fertilized.
3. Fertilization twice a year will have the highest Current Annual Production (CAI).
4. Clear differences between treatments should be seen in the nutrient balance in leaves.

2. Material and Methods

2.1 Site description

The experiment is located in Baisha 90 km from Beihai in Guangxi province. The region for Eucalypt plantation is Leizhou Peninsula and Hainan Island. Leizhou Peninsula and Hainan Island region have a humid semi hot tropical climate with warm and humid ocean climate. Mean annual temperature (MAT) is ca. 23 °C, mean temperature in the coldest month´s 14.8 °C, and in the warmest month 28.9 °C. Average annual rainfall is ca. 2100 mm (FAO, 1987) and water could be a limiting factor for tree growth especially in October to April, when the evaporation exceeds the precipitation (fig. 3). Vegetation is tropical evergreen rain forest and subtropical deciduous forest. Historically the forest had a great number of different species but now it's mostly bushes and bamboo. Many different tropical and subtropical wood species can be found in the region (FAO 2007).

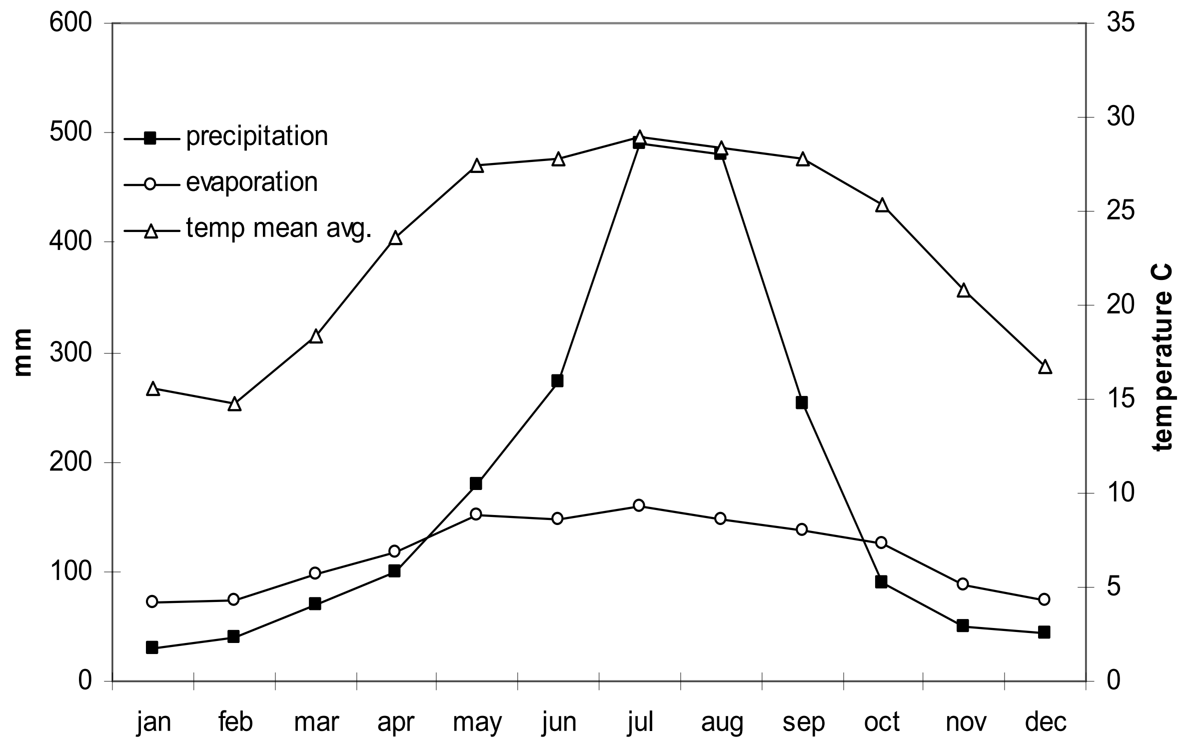


Figure 3. Climate data for Beihai. Mean temperature, precipitation and potential evapotranspiration during the last climate period. The precipitation is lower then than the evaporation during October to April (FAO 1987).

The soil is Ferric Acrisols and has a fine texture (FAO, 1978). Acrisols is most common in hilly or undulating topography in wet tropical and monsoonal climates. Tropical forest is the natural vegetation for acrisols (Driessen and Dudal, 1991). Ferric Acrisols are widely spread in Southeast Asia (FAO, 1978). Acrisols have medium to heavy textures and have a red color (table 2). Acrisols have a low pH. (table 1).

Table 1. Soil sample for the trial. The trial is divided in two different compartments 1-30 and 31-41. pH, organic material g/kg, total amount of N, P and K in g/kg and available nutrient for N, P and K in mg/kg.

	1-30		31-41	
subplot	0-20 cm	20-40 cm	0-20 cm	20-40 cm
pH	4.8	4.95	4.73	4.88
organic material	13.57	11.843	14.206	10.714
total amount of nutrion g/kg				
N	0.503	0.458	0.584	0.435
P	0.125	0.123	0.126	0.119
K	1.318	0.694	0.812	1.36
avalibal nutrition mg/kg				
N	39.87	31.85	32.85	31.52
P	0.81	0.52	1.02	0.91
K	12.33	14.24	16.69	8.06
Ca ² (mmol 1/2 Ca²+/kg)	3.451	1.498	1.135	2.124

Table 2. Soil fractions, in % of total amount, at different depth for the trial. The trial is divided in two different compartments 1-30 and 31-41. The soil fractions is from big fraction 2-1 mm down to fractions < 0,002. The soil fraction is measured in the upper soil layer 0-20 cm and deeper 20-40 cm.

	1-30		31-41	
subplot	0-20 cm	20-40 cm	0-20 cm	20-40 cm
mm				
2-1	5.82	5.25	3.61	4.36
1- 0,5	5.62	5.43	4.24	5.85
0,5-0,25	14.06	12.83	12.31	14.33
0,25-0,05	45.01	42.78	46.16	41.68
0,05-0,02	6.1	6.13	7.14	6.14
0,02-0,002	6.1	6.13	7.14	6.14
< 0,002	17.29	21.45	19.39	21.49

2.2 Trial establishment and treatments

Soil preparation was made by bulldozer in the experimental area in January 2005. The prepared planting rows were 0.5 m deep, 0.6 m wide and the distance between the rows was 4 m. In the end of February 2005 the area was prepared for planting by making planting holes with spacing 2 x 4m. In the beginning of March 2005 the area was base fertilized used in practical forestry with CMP 187.5 kg ha^{-1} and NPK 125 kg ha^{-1}. In the middle of March 2005 the area was planted with two *Eucalyptus urophylla* clones DH32-29 and GL-GU9, with a plant density of 1250 plants ha^{-1}. In mid-July 2005 an herbicide treatment was made using

Round-up. In August 2005 a follow-up fertilization was done using NPK-fertilization 375 kg ha^{-1} with proportions 16 % (N)-12% (P)-12% (K).

In March 2006, 12 month after planting the experiment was establish when all plots were laid out, measured and treatments were decided. The experiment consists of eight different treatments divided into four blocks to take initial differences within the experiment into account, which in total means 32 plots (fig 4). Within each block the treatments were randomized. The plot size is 32 x 32 m but only diameter and height is measured in the inner plot is measured; 4 rows with ca. 10 trees row^{-1} gives an inner area of 300 m^2. The plot set up was chosen to avoid edge effects from the neighboring plots. Treatments 1-5 are applied in strings and 6-7 are broadcasted. To apply fertilizers in strings, a hole was dug between every tree with the dimensions 0.2 x 0.2 x 0.2 m and the fertilizer was put in the hole. After that the hole was covered by soil. In broadcasted treatments the fertilizer was spread evenly by hand over the whole plot. The different treatments in the experiment were:

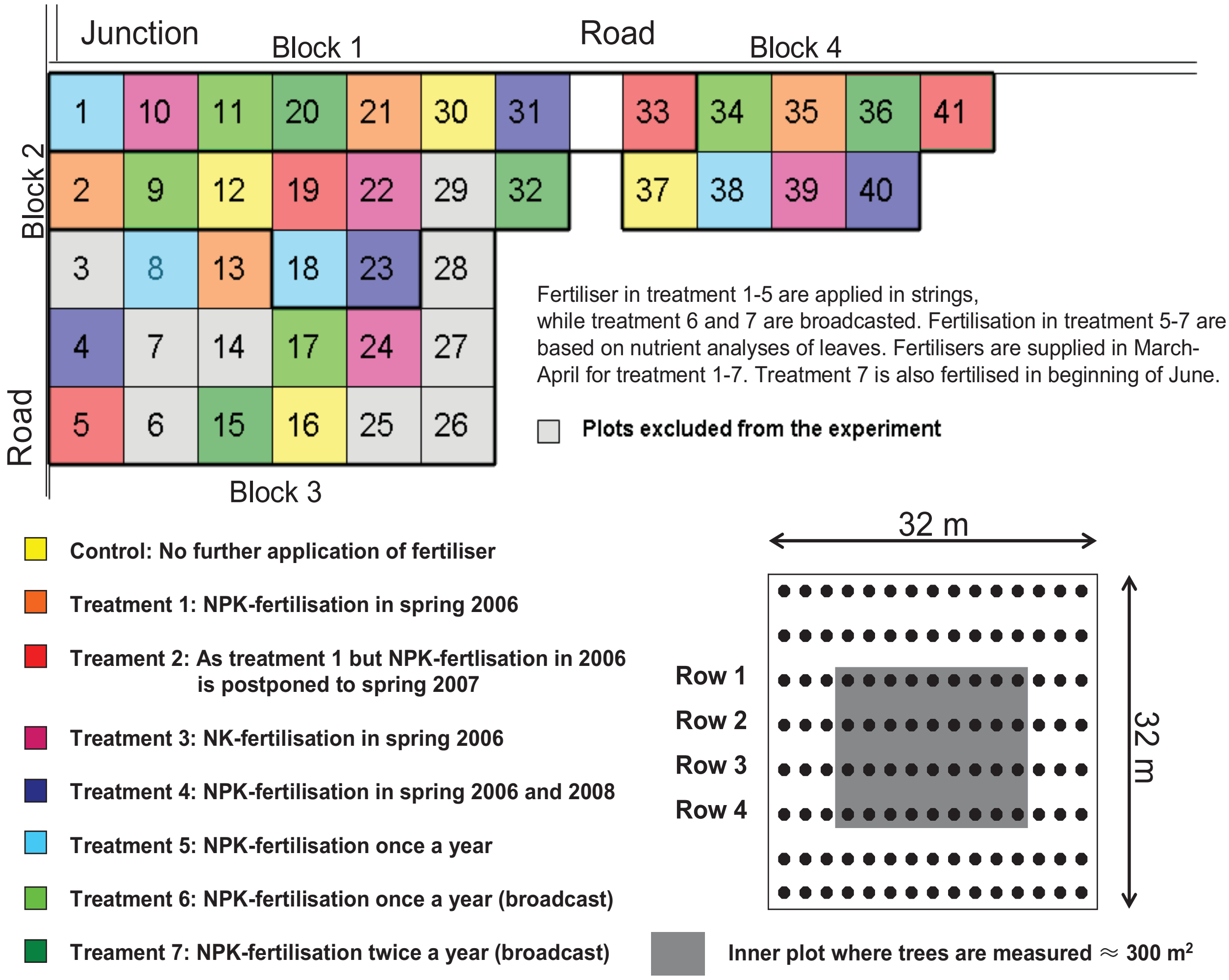


Figure 4. Map over the experiment in Baisha. There are eight different treatments repeated in four blocks and the total number of measured plots are 32. The plots size is 32 x 32 m but only the inner plot is measured in the experiment. Untreated control C is plot 12, 16, 30 and 37. Treatment 1 (NPK-100) are plot 2, 13, 21 and 35. The plots for treatment 2 (NPK-0) are 5, 19, 33 and 41. Treatment 3 (NK-90) are plots 10, 22, 24 and 39. Treatment 4 (NPK-100-2) are 4, 23, 31, and 40. Treatment 5 (NPK-150-S) are 1, 8, 18 and 38. Treatment 6 (NPK-150-B) are 9, 11, 17 and 34. Treatment 7 (NPK-300-B) are 15, 20, 32 and 36.

- Treatment 1 (NPK-100) was 100 kg ha^{-1} N, 75 kg ha^{-1} P and 75 kg ha^{-1} K supplied in strings March 2006 and represent common practice for fertilization in plantations in southern China (table 3). The fertilizer NPK 16-12-12 contains 16% of nitrogen (N), 12% of phosphorous (P) and 12% of potassium (K) of the total dry weight. The name is the fertilizer type NPK and the amount kg N.
- Treatment 2 (NPK-0) the same amount of fertilizers should be applied as in NPK-100 but the fertilization was postponed until spring 2007 instead therefore the name.
- Treatment 3 (NK-90) was NK fertilization, 185 kg ha^{-1} urea (46% N) and 125 kg ha^{-1} KCL (60 % K_2O) applied per plot in strings in March 2006.
- Treatment 4 (NPK-100-2) was 625 kg ha^{-1} of NPK 16-12-12 supplied in strings in March 2006. Treatment 4 will be fertilized an additional time in spring 2008. This far in the experiment NPK-100 and NPK-100-2 has received the same amount of fertilizers.
- Treatment 5 (NPK-150-S) 150 kg ha^{-1} N, 115 kg ha^{-1} P and 115 kg ha^{-1} K in NPK fertilizers proportion 16-12-12 was added in strings and fertilization will be supplied in March every year. The name is the fertilizer type, the amount of N and the fertilization method.
- Treatment 6 (NPK-150-B) is identical as NPK-150-S but the fertilizers was broadcasted instead.
- Treatment 7 (NPK-300-B) will be fertilized twice a year once in March and once in June. In both occasions the same amount of fertilizers as NPK-150-B and broadcasted.

The amount of N supplied in treatment NPK-150-S, NPK-150-B and NPK-300-B were determined from leaf N-concentration. The supply of other macro- and micronutrients was adjusted to initial target ratios of each element to N (Linder, 1995). If the ratio of a nutrient element to N is below its target value, an extra amount will be added at next occasion. Threshold leaf concentrations and proportions of the essential nutrient elements for the attainment of unlimited growth have been determined in earlier laboratory (Ericsson & Kähr, 1993) and field experiments (Stockfors et al., 1997). These proportions correspond with recommendations given by Braekke (1994). Leaf analysis will be made every year to decide the amount and composition of fertilizer the following year.

Table 3. The different treatments with the type of fertilization, amount of fertilization, how the fertilizers is spread and times per year in 2006. For amount of fertilizers it is Kg for the N,P and K. For the NPK fertilizers the proportion is 16-12-12 and for the NK fertilizers 46-60.

Treatment	**C**	**NPK 100**	**NPK 0**	**NK 90**	**NPK 100-2**	**NPK 150-S**	**NPK 150-B**	**NPK 300-B**
Type of fertilization	None	NPK	None	NK	NPK	NPK	NPK	NPK
Amount Kg/ha								
N		100		187.5	100	150	150	150
P		75			75	115	115	115
K		75		125	75	115	115	115
Spread		String		String	String	String	Broadcast	Broadcast
Time per year		Once		Once	Once	Once	Once	Twice

2.3 Measurements, growth estimates, leaf analysis and statistical analysis

Diameter was measured in cm at 1.3 m height (diameter at breast height, DBH) for all trees with a calliper. Height was measured in m with a Haglöf Vertex III hypsometer and a transponder T3. The hypsometer was calibrated before measuring the first tree in every plot to avoided errors. In March was height measured for all trees, while in November was height measured for six trees per plot and the two trees with largest diameter were selected for every plot in order to get better volume estimates of large trees. Volume was calculated for those trees where both diameter and height was measured and a relationship (2^{nd} grade polynomial function) between diameter and volume was established. The relationship between diameter and volume was made separately for each treatment. This secondary volume function was used to assign the rest of the tress a volume. When diameter and height were measured was also dead and visible damages of trees noted.

The volume function used for calculations of those trees where both diameter and height was measured was originally developed by Paula Susila StoraEnso Wood Supply. Height and diameter is required to estimate the growth and unit for the volume is m^3.

$$V \text{ (over bark)} = 0.038447 * dbh^{2.058292} * h^{0.933308}$$

Leaves were collected in late February 2006 in the Baisha experiment to see differences in nutrient composition for different blocks. Ten shoots from each block were taken from upper third of the canopy and samples were dried at 85 ºC for 48 hour before they were sent to laboratory for nutrient analysis. At laboratory needles were dried (at 70 ºC in 48 h) and ground in a cyclone mill (Cyclotec 1093 sample mill, Tecator, Sweden). Sub-samples were then dried under vacuum (70 ºC, 24 h). For element analysis a part of each sub-sample was wet-digested in nitric and perchloric acid in an open digestion system, and then analyzed on ICP/MS (Elan 6100, PerkinElmer, Norwalk, CT, USA). Between 4 and 7 mg of each sub-sample was weighed into tin capsules. These samples were analysed for percent N (%) and C (%) in a continuous flow isotope ratio mass spectrometer (model 20-20 Stable Isotope Analyzer, Europa Scientific Ltd, Crewe, UK) interfaced with an elemental analyser unit (ANCA-NT solid/liquid preparation module, Europa Scientific Ltd). Four leaves from every plot were collected so it was 16 leaves per treatment in November. The leaves were dried at 85 °C for 48 h and sent to a laboratory for nutrient analysis. In March leaves were sent to one laboratory in Sweden and one in China, to see the difference between the laboratories. In November was only the laboratory in China used.

The standing volume and the volume growth for all different treatments were analysed by ANOVA to calculate the statistical differences between the treatments. Block, treatment and initial stem volume were used as variables.

2.4 Stand description 12 months after planting

In March 2006 when the stand was 12 months old the experiment was measured for the first time. DBH varied between 4.2 cm for C to 3.6 cm for NPK-100 a difference of 0.6 cm (table 4). The two plots which were broadcasted had the second (NPK-150-B) and the third (NPK-300-B) highest diameter 12 month after planting. NPK-100, NPK-0 and NPK-100-2 had similar DBH and differed only 0.1 cm in the start of the experiment.

Height measured in March varied between 4.4 m NPK-150-S to 5.06 m for NPK-150-B, a difference of 0.66 m. The three tallest treatments were NPK-150-B, C and NPK-300-B (fig. 5). The same three treatments were largest both in diameter and height. NPK-100 and NPK-150-S was little smaller then the rest of the treatments both in diameter and height.

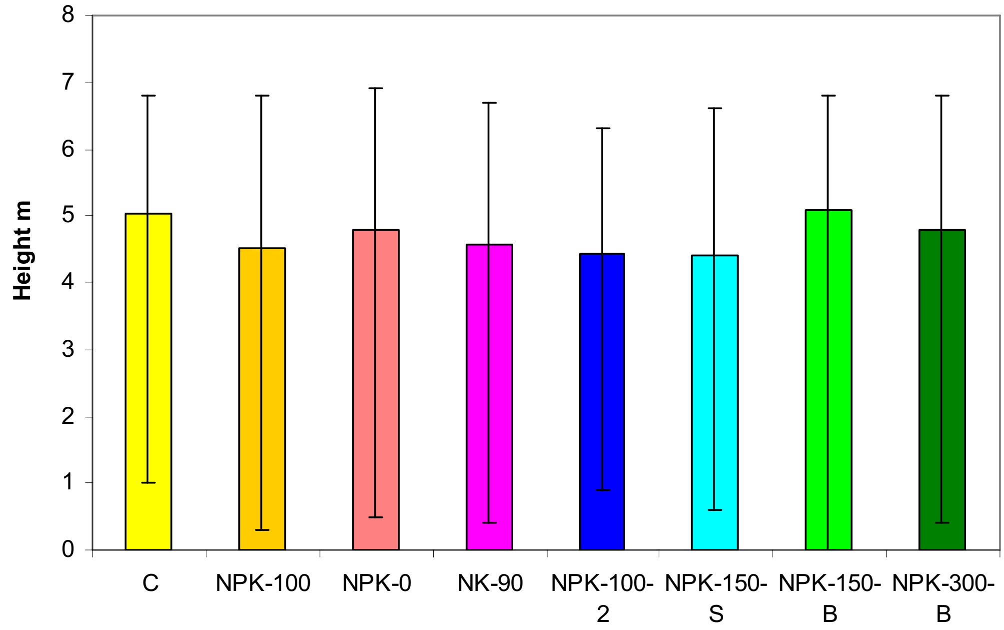


Figure 5. Mean height in m for the different treatments in March 12 month after planting. The line is the variation of height in the treatment, the both ends is the highest and lowest value.

Control had the largest basal area ha^{-1} in Mach 2.04 m^2 and the smallest was NPK-100 with 1.56 m^2, a difference of 0.48 m^2. The treatment with the largest standing stem volume in the start of the experiment was NPK-150-B by 5.26 m^3 and the smallest NPK-150-S with 3.79 m^3, a difference of 1.47 m^3 (fig.6). NPK-300-B had a volume which was 0.62 m^3 less than NPK-150-B. C and NPK-150-B were 0.5 m^3 bigger then the rest of the treatments. NPK-100, NPK-100-2 and NPK-150-S had grown 0.5 m^3 less then all the other treatments.

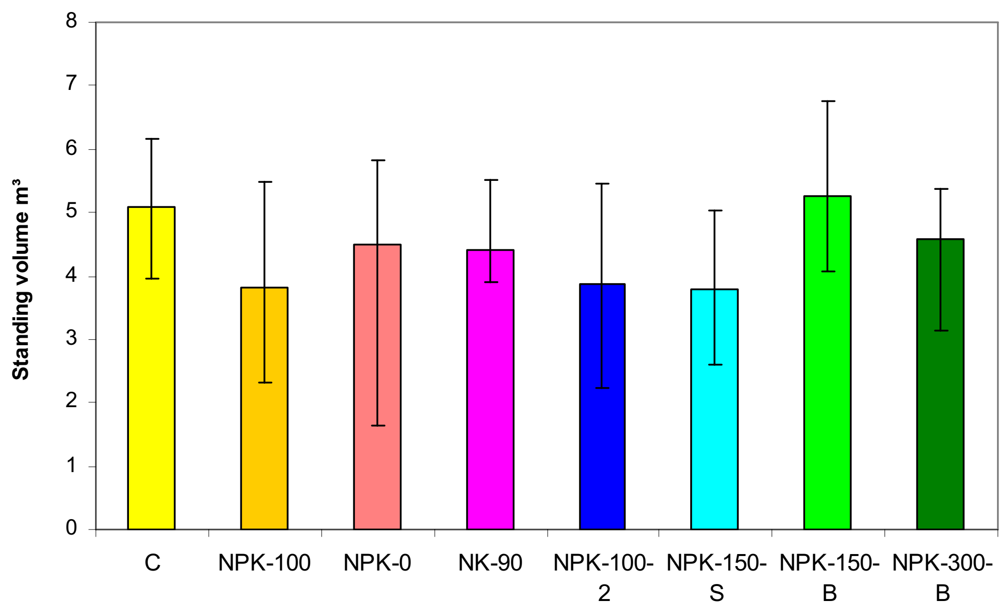


Figure 6. Standing stem volume m^3 ha^{-1} (on bark) for the different treatments 12 months after planting. The line is the variation between the plots in the treatments.

2.5 Dead and damaged trees 12 months after planting

If all measured trees were alive it should have been 40 trees per plot and 160 trees for each treatment. All treatments had dead trees when the experiment was established. NPK-100-2 had the lowest number of dead trees 12 month after planting, and C, NPK-150-S, NPK-300-B had largest amount (table 4). Treatment damages were recorded before the experiment was started. NPK-150-S had the largest number of trees with damages (table 4). For NPK-100, NK-90, NPK-100-2 and NPK-300-B there were now visible damages one year after planting. The damages were mostly forking, double stems and diseased trees. NPK-150-S had the larges amount of both dead and damaged trees.

Table 4. Values 12 month after planting when the experiment was establish in spring 2006. Mean DBH in cm, mean height in m, standing stem volume in m^3 ha^{-1}, total number of trees for treatments, total number of trees below 1.3 m, total number of dead trees in the treatments, percents dead trees, total damages in the treatments and total damages in percents living trees.

Treatment	C	NPK 100	NPK 0	NK 90	NPK 100-2	NPK 150-S	NPK 150-B	NPK 300-B
Diameter (cm)	4.3	3.6	3.9	3.9	3.8	3.7	4.2	4.1
Height (m)	5.0	4.5	4.8	4.6	4.4	4.4	5.1	4.8
Volume (m^3/ha)	5.1	3.8	4.5	4.4	3.9	3.8	5.3	4.6
Basal area (m^2/ha)	2.0	1.6	1.7	1.8	1.7	1.6	2.0	1.9
Number of trees	153	157	157	158	159	153	157	154
Trees below 1.3 m	2	6	5	9	1	5	4	2
Number of dead trees	7	3	3	2	1	7	3	6
Dead %	4.4	1.9	1.9	1.3	0.6	4.4	1.9	3.8
Total damaged trees	2	0	4	0	0	7	3	0
Total damages %	1.3	0	2.6	0	0	4.6	1.9	0

2.7 Leaf analysis 12 month after planting

Leaves analyzed in March 2006 for all blocks, showed differences between the Swedish and Chinese laboratories (table 5). It was not large differences in percentage of nitrogen in leafs, where the level of nitrogen was around 2% for all blocks analyzed both in the Chinese and the Swedish lab (table 5). For phosphorous was the P/N-ratio considerable lower than the desired target value (10% of N-content) and P limits likely the potential production. Potassium had also a lower K/N-ration than the desired target value of 35%, where different blocks ranged between 21 – 24%. Leaf samples taken from the different blocks showed a very high amount of calcium, ca. 8 times higher than the desired target value. The level of magnesium (Mg) was above the target value in all blocks but there were some differences between them. According to the leaf analysis conducted at the Swedish laboratory, block 2 and 4 had 2 % higher ratio of magnesium compared with the Chinese laboratory. According to the Chinese analysis the lowest level of magnesium was in block 4. The Swedish laboratory showed a high ration of sulphur (S). Analysis showed a high Fe/N-ratio of iron (Fe) in all blocks, ca. two times the required ration. The Mn/N-ratio of manganese (Mn) was much higher than needed. According to the Chinese laboratory it was ca. 6 times higher than the target value for all blocks, while it was 12 times higher according to the Swedish laboratory. The Cu/N-ratio of copper (Cu) was only half of the target value for all blocks. Zinc (Zn) had a slightly higher ratio than needed for all blocks. The ratio of boron (B) varied between the laboratories, where the Chinese laboratory had a level twice as high as the Swedish laboratory.

Table 5. Leaf analysis from the Chinese (upper) and Swedish (lower) laboratory. Sulphur (S) was only measured at the Swedish laboratory. The values are presented both in absolute concentration of dry weight of leaves and in relation to nitrogen. The relative values within bracket are recommended target value of different nutrients to nitrogen.

Sample	Block 1	Block 2	Block 3	Block 4
N (g/kg)	19.059	17.634	18.813	18.854
P (g/kg)	0.864	0.829	0.984	0.807
K (g/kg)	4.481	4.137	4.5	3.962
Ca (g/kg)	5.082	5.15	3.319	5.278
Mg (g/kg)	1.441	1.234	1.425	1.123
Fe (mg/kg)	72.698	91.36	84.147	68.172
Mn (mg/kg)	59.085	58.241	52.548	58.576
Cu (mg/kg)	1.8278	1.7486	1.9871	2.3857
Zn (mg/kg)	11.741	13.077	11.463	11.378
B (mg/kg)	19.138	25.131	17.417	16.148

N (%)	1.9059	1.7634	1.8813	1.8854
P/N-ratio (10 %)	4.53	4.70	5.23	4.28
K/N-ratio (35 %)	23.51	23.46	23.92	21.01
Ca/N-ratio (2.5 %)	26.66	29.20	17.64	27.99
Mg/N-ratio (4 %)	7.56	7.0	7.57	5.96
Fe/N-ratio (0.2 %)	0.38	0.52	0.45	0.36
Mn/N-ratio (0.05 %)	0.31	0.33	0.28	0.31
Cu/N-ratio (0.02 %)	0.0095	0.0099	0.0106	0.0127
Zn/N-ratio (0.05 %)	0.062	0.07	0.061	0.060
B/N-ratio (0.05 %)	0.100	0.143	0.093	0.086

Sample	Block 1	Block 2	Block 3	Block 4
N (g/kg)	20.1	18.8	20.4	20.8
P (g/kg)	0.89	1.05	0.99	1.26
K (g/kg)	4.32	4.88	5.38	6.02
Ca (g/kg)	5.11	4.55	4.57	3.6
Mg (g/kg)	1.06	1.62	1.35	1.79
S (g/kg)	2.95	2.32	2.63	2.55
Fe (mg/kg)	123	149	158	135
Mn (mg/kg)	169	120	130	133
Cu (mg/kg)	2.4	1.4	1.6	2
Zn (mg/kg)	17.9	10.9	11.2	11.7
B (mg/kg)	19	11.6	21.4	13.8

N (%)	2.01	1.88	2.04	2.08
P/N-ratio (10 %)	4.43	5.59	4.85	6.06
K/N-ratio (35 %)	21.49	25.96	26.37	28.94
Ca/N-ratio (2.5 %)	25.42	24.20	22.40	17.31
Mg/N-ratio (4 %)	5.27	8.62	6.62	8.61
S/N-ratio (5 %)	14.68	12.34	12.89	12.26
Fe/N-ratio (0.2 %)	0.61	0.79	0.77	0.65
Mn/N-ratio (0.05 %)	0.841	0.638	0.637	0.639
Cu/N-ratio (0.02 %)	0.012	0.007	0.008	0.010
Zn/N-ratio (0.05 %)	0.089	0.058	0.054	0.056
B/N-ratio (0.05 %)	0.09	0.06	0.10	0.07

2.8. Economic calculation

Basic economic calculations were made. The calculations cover only the growth for the studied period of 12-20 months after planting. The cost of fertilization and the income of roundwood per m^3 were relevant figures received from StoraEnso. The currency were first in RMB but were transformed to $ at the 24^{th} of January, 2007 by using the Swedish bank SEB currency changer. 1 RMB = 0.12 $.The cost for NPK-fertilization was 0.24 $ kg^{-1} and cost for applying fertilization in strings or broadcast was equal 18 $ ha^{-1}. The estimation was made so that the stand was cut down today and how much money that would provide.

3. Result

3.1 Stand data 20 months after planting

Largest mean diameter, 20 months after planting, ranged from 7.98 in NPK-300-B and 7.05 in NPK-0 (table 6). There was a difference of 9 mm between NPK-300-B and NPK-0. NPK-150-B had the second largest mean diameter by 7.93 cm (fig. 7). The three largest in terms of mean diameter was the same 20 months after planting as after 12 months, NPK-300-B, NPK-150-B and C. The average tree height 20 months after planting ranged from 12.2 m in NPK-

150-B to 10.7 m in NPK-100, a difference of 1.5 m. In resemblance with mean diameter had NPK-150-B, NPK-300-B and C the three largest tree heights 20 months after planting as after 12 months.

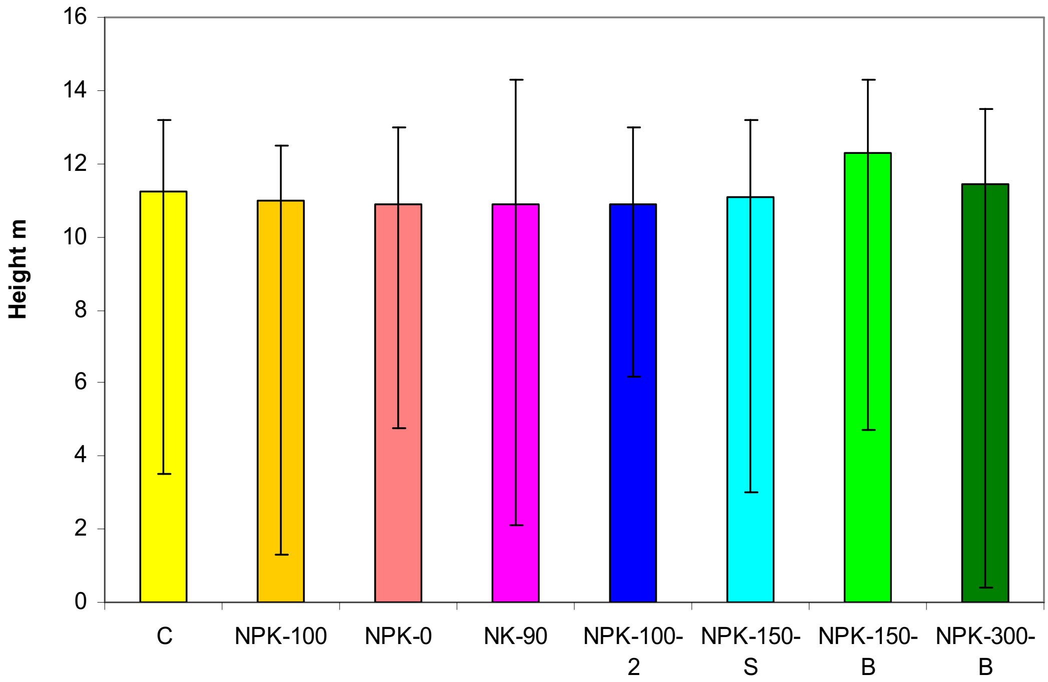


Figure 7. Mean diameter in cm 20 months after planting. The line is variation of diameter in the treatment the highest and the lowest value.

In November the basal area ha^{-1} ranged from 6.68 m^2 in NPK-150-B and 5.31 m^2 in NPK-0. The three largest treatments in terms of basal area ha^{-1} were NPK-150-B, NPK-300-B and NPK-150-S (table 6).

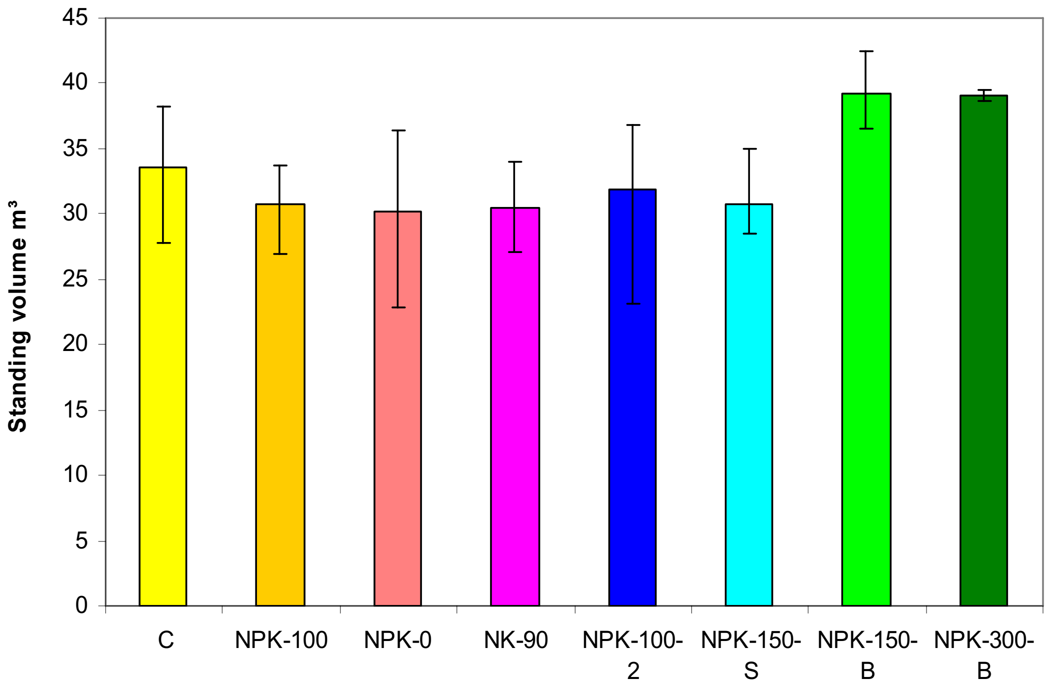


Figure 8. Standing stem volume m^3 on bark ha^{-1} for the different treatments 20 months after planting. The line is variation between the highest and lowest standing volume.

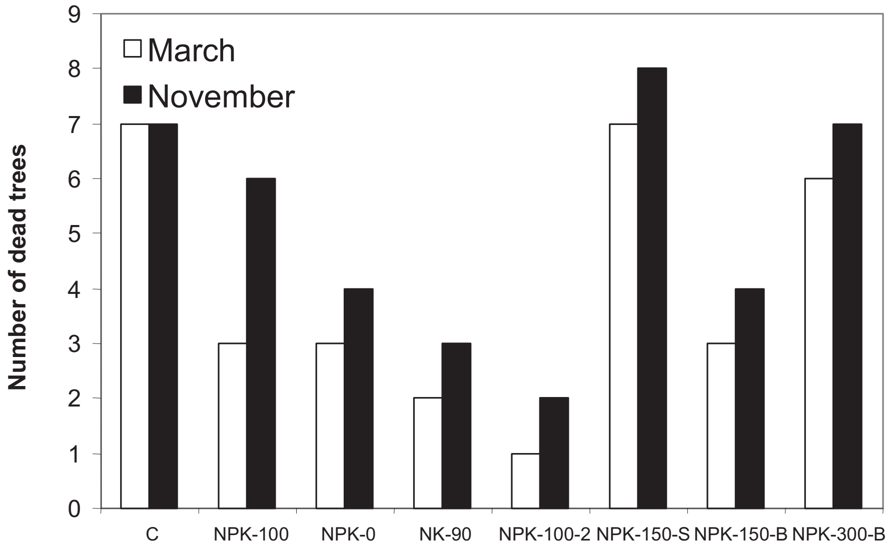
The standing stem volume 20 month after planting varied from 39.2 m^3 on bark in NPK-150-B to 30.2 m^3 in NPK-0, a difference of almost 9 m^3 (fig. 8). NPK-150-B had also the largest stem volume in March but NPK-0 was the fourth largest in standing stem volume (fig. 8). It was no significant different between NPK-150-B and NPK-300-B. Between NPK-100, NPK-0, NK-90 and NPK-150-S were no significant difference (table 6). Between C and NPK-100-2 were no significant differences. The three treatments with largest standing stem volume in November were NPK-150-B, NPK-300-B and C. The same treatments where biggest in DBH, height and standing stem volume.

Table 6. Values in November 20 month after planting. Mean DBH in cm, mean height in m, stem volume in m^3 ha^{-1}, total number of trees for the treatments, total number of trees below 1.3 m, total number of dead trees in the treatments, percents dead trees, total damages in the treatments and total damages in percent of living trees. The treatment with the same letters for stem volume has no significant differences in terms of standing volume.

Treatment	C	NPK 100	NPK 0	NK 90	NPK 100-2	NPK 150-S	NPK 150-B	NPK 300-B
Diameter (cm)	7.5	7.2	7.1	7.2	7.3	7.4	7.9	8.0
Height (m)	11.3	10.7	10.8	10.8	10.8	11.0	12.2	11.4
Volume (m³/ha)	33.6 AB	30.8 B	30.2 B	30.5 B	31.9 AB	30.8 B	39.2 A	39.0 A
Basal area (m²/ha)	5.7	5.6	5.3	5.5	5.7	5.7	6.7	6.6
Number of trees	153	154	156	157	158	152	156	153
Trees below 1.3 m	0	0	0	0	0	0	0	1
Number of dead trees	7	6	4	3	2	8	4	7
Dead %	4.4	3.8	2.5	1.9	1.3	5	2.5	4.4
Total damaged trees	3	4	5	1	0	11	5	8
Total damages %	2.0	2.6	3.2	0.6	0	7.2	3.2	5.2

3.2 Tree survival and damages 20 month after planting

In all treatments, except the untreated control (C), 1-3 trees died between the revisions in March and November (table 6). NPK-150-S had still the largest number of dead trees in total (fig. 9). NPK-100 had the largest increase of dead trees with 3 new dead trees. NPK-100-2 had the lowest number of dead trees. Almost all the additional dead trees for the different treatments were from trees that had some damages noted at the revision 12 months after planting.



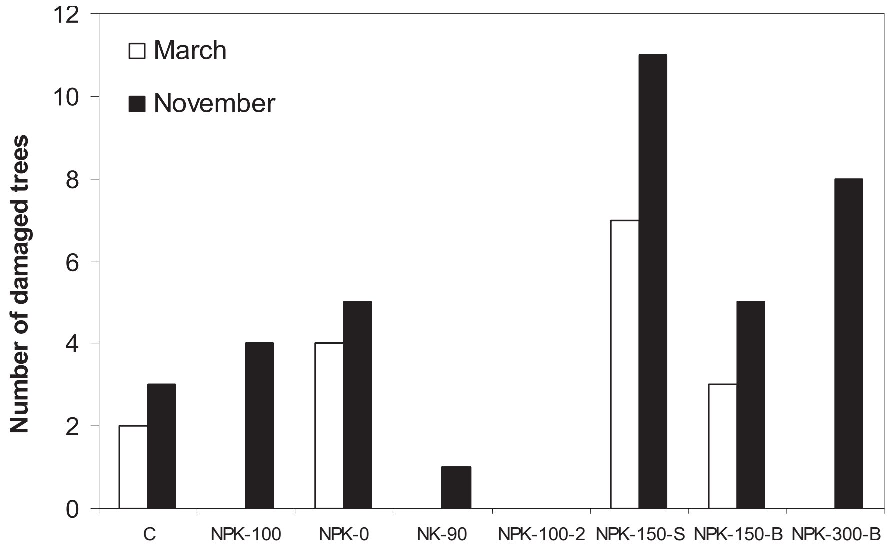


Figure 9. The upper figure: Number of dead trees in the different treatments, 12 and 20 months after planting. The lower figure: Total number of damaged trees in the different treatments 12 and 20 months after planting.

NPK-150-S had the highest number of damaged trees 20 month after planting (table 6) and NPK-300-B had the second highest number of damaged trees. It was a large increase of damages for NPK-300-B during the summer (fig. 9). The observed damages for NPK-300-B were three double tops, two trees were damaged by soil erosion, one was crooked, one deceased and one forking. The three treatments with highest increase of tree damages were NPK-300-B, NPK-150-S and NPK-100. The highest number of damaged trees was in treatments with heaviest fertilization.

3.3 Current annual increment in 2006

The largest increase in diameter growth was in the treatment which had received highest amount of N, P and K, NPK-300-B. The diameter growth was ca 1 mm bigger in NPK-150-B compared with NPK-150-S (table 7), which had been fertilized with same amount of N, P and K, but NPK-150-B was broadcasted instead of fertilized in strings. NPK-100-2 and NPK-100 has been fertilized this far in the experiment the same way, but the diameter growth was 1 mm larger in NPK-100 compared with NPK-100-2 (fig. 10). The highest growth increment in mean height was in NPK-150-B and the second highest was in NPK-300-B. NPK-300-B has been fertilized twice and NPK-150-B once but the height growth was higher in NPK-150-B (fig. 11). Height growth was 0.17 m higher in NPK-100-2 compared with NPK-100. Height growth was 0.16 m higher in C, compared with NPK-0. The largest difference in height growth was 1.09 m between NPK-150-B and NPK-0.

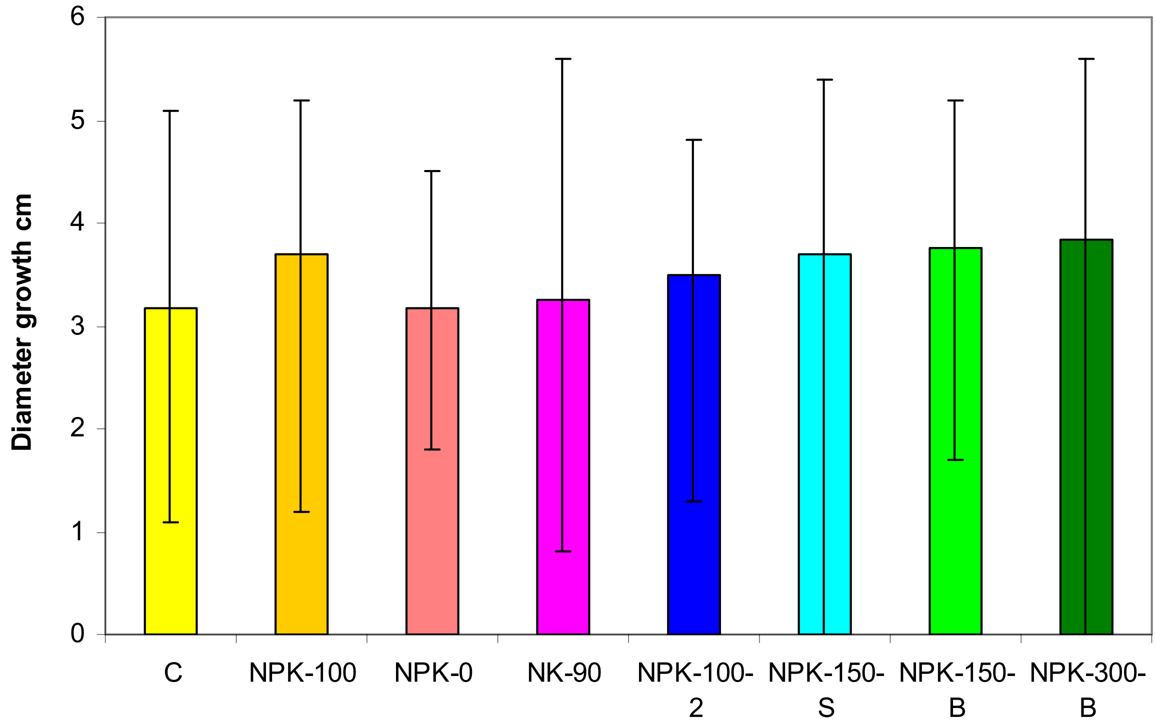


Figure 10. Increment of mean diameter in cm in 2006 for the different treatments. The line is variation of diameter in the treatments.

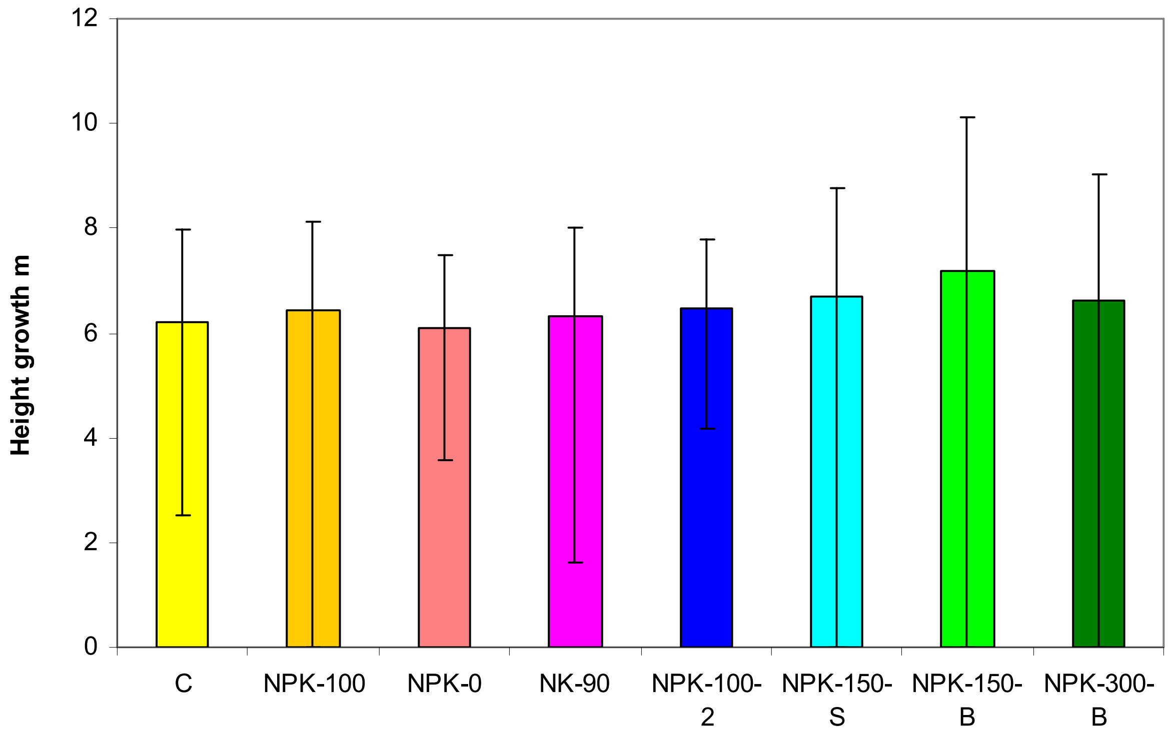


Figure 11. Increment of mean height in m in 2006 for the different treatments. The line is variation of height in the treatments.

The largest increase in basal area ha^{-1} during this period was in NPK-300-B. There was no effect on basal area growth between fertilize twice or just once per year. The growth of basal area was higher in NPK-150-B compared with NPK-150-S, where the difference was 0.57 m^2. NPK-100-2 had almost the same growth of basal area as NPK-100. NK-90 that was fertilized with NK had lower growth of basal area compared with the treatments fertilized with NPK. The basal area growth in NK-90 was approx. 0.30 m^2 smaller than NPK-100 and NPK-100-2. Untreated control (C) had higher growth in basal area by 0.10 m^2 compared with NPK-0.

The trees in the treatment which had received the largest amount of nutrients (NPK-300-B) had also the highest volume growth (fig. 12). There was a significant difference between NPK-300-B and NPK-150-B. NPK-150-B had a volume growth that was 7 m^3 higher than NPK-150-S. NPK-100-2 and NPK-100 were fertilized in the same way in 2006 but the volume growth was 1 m^3 ha^{-1} higher for NPK-100-2, that was a significant difference. The NK-fertilized treatment had a volume growth 1 m^3 ha^{-1} less then NPK-100 and 2 m^3 ha^{-1} less than NPK-100-2, which both has been fertilized with NPK. C has grown 2.84 m^3 more than NPK-0 in terms of volume growth. There was no significant difference between NPK-0 and NK-90. There were some differences in growth between the different blocks. Between the smallest and the largest block it was 3.5 m^3 ha^{-1}.

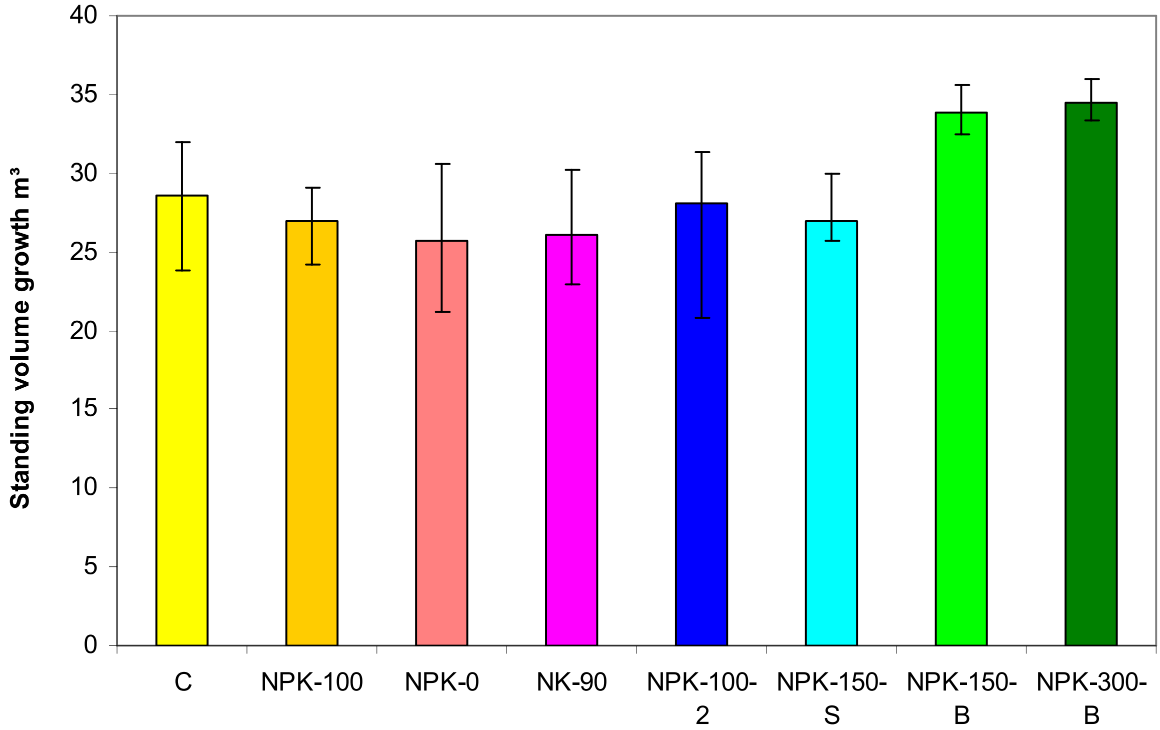


Figure 12. Volume growth in m3 on bark ha^{-1} in 2006 for the different treatments. The line is variation of standing volume growth in the treatments.

Table 7. Growth in height, diameter, basal area and volume in 2006. Growth in mean DBH in cm, mean height in m, basal area m^2 ha^{-1} and stem volume in m^3 ha^{-1}, difference in total amount of trees in the treatments, increase in total number of dead trees in the treatments and increase of total damages in the treatments. The treatment with the same letters for stem volume has no significant differences in terms of stem volume growth.

Treatment	C	NPK 100	NPK 0	NK 90	NPK 100-2	NPK 150-S	NPK 150-B	NPK 300-B
Diameter (cm)	3.2	3.6	3.1	3.2	3.5	3.7	3.7	3.8
Height (m)	6.2	6.2	6.1	6.3	6.4	6.6	7.2	6.6
Volume (m³/ha)	28.5 ABC	26.9 BC	25.7 C	26.1 C	28.1 ABC	27.0 BC	33.9 AB	34.4 A
Basal area (m²/ha)	3.7	4.1	3.6	3.8	4.0	4.1	4.7	4.8
Number of trees	0	-3	-1	-1	-1	-1	-1	-1
Number of dead trees	0	3	1	1	1	1	1	1
Total damaged trees	1	4	1	1	0	4	2	8

3.4 Leaf analysis in November

Leaf analysis from samples taken 20 months after planting showed that the nitrogen concentration was highest in NPK-150-S. All the NPK-fertilized treatments had almost the same N-concentration (table 8). The lowest levels of nitrogen were found in the treatments without fertilization, C and NPK-0. No treatment reached above a P/N-ratio of 5% (table 8) despite the supply of NPK-fertilizer in 2006. There were no differences between the treatments in levels of phosphorous. For potassium the trees in NPK-300-B had slightly above the target value, while C was just below. For the rest of the treatments the K/N-ratio ranged between 28-35%. All treatments had an Mg/N-ratio almost twice the target level. The only thing that could be seen was that Mg/N-ratio for NK-90 was lower then the rest of the treatments. NPK-300-B had the highest Mg/N-ratio and was almost 1.5-3.5 % higher than the other treatments.

Table. 8. Leaf analysis from the Chinese laboratory 20 months after planting. The values are presented both in absolute concentration of dry weight of leaves (upper) and in relation to nitrogen (lower). The relative values within bracket are recommended target value of different nutrients to nitrogen.

plot	C	NPK 100	NPK 0	NK 90	NPK 100-2	NPK 150-S	NPK 150-B	NPK 300-B
g/kg								
N	14.778	16.011	14.032	15.785	16.229	17.068	16.187	16.18
P	0.806	0.833	0.751	0.781	0.909	0.93	0.893	0.961
K	5.121	5.073	4.61	5.002	5.509	4.778	5.353	6.284
Ca	3.773	3.585	3.784	3.108	2.803	3.579	3.838	4.104
Mg	1.443	1.318	1.253	1.219	1.466	1.434	1.432	1.795
mg/kg								
Fe	55.07	135.78	48.7	48.62	65.61	75.35	91.14	56.32
Mn	80.45	45.08	35.73	37.45	129.11	61.87	77.73	118.48
Cu	3.29	21.77	2.83	2.99	2.48	4.82	6.78	1.54
Zn	14.89	14.92	14.58	13.02	12.03	13.14	14.57	13.63
B	53.74	60.31	57.64	50.63	51	60.68	74.4	90.8

plot	C	NPK 100	NPK 0	NK 90	NPK 100-2	NPK 150-S	NPK 150-B	NPK 300-B
N (%)	1.48	1.60	1.40	1.58	1.62	1.71	1.62	1.62
P/N-ration (10%)	5.45	5.20	5.35	4.95	5.60	5.45	5.52	5.94
K/N-ration (35 %)	34.65	31.68	32.85	31.69	33.95	27.99	33.07	38.84
Ca/N-ration (2.5 %)	25.53	22.39	26.97	19.69	17.27	20.97	23.71	25.36
Mg/N-ration (4 %)	9.76	8.23	8.93	7.72	9.03	8.40	8.85	11.09
Fe/N-ration (0.20 %	0.37	0.85	0.35	0.31	0.40	0.44	0.56	0.35
Mn/N-ration (0.05 %	0.54	0.28	0.25	0.24	0.80	0.36	0.48	0.73
Cu/N-ration (0.02 %	0.02	0.14	0.02	0.02	0.02	0.03	0.04	0.01
Zn/N-ration (0.05 %	0.10	0.09	0.10	0.08	0.07	0.08	0.09	0.08
B/N-ration (0.05 %)	0.36	0.38	0.41	0.32	0.31	0.36	0.46	0.56

Table 9. The composition of different nutrients changes in leafs during 2006. All the shaded values are values that were lower after 20 month compared with 12 month. N to mg is in g/kg and Fe to B is in mg/kg.

plot	C	NPK 100	NPK 0	NK 90	NPK 100-2	NPK 150-S	NPK 150-B	NPK 300-B
g/kg								
N	-3.81	-2.579	-4.558	-2.805	-2.361	-1.522	-2.403	-2.41
P	0.77	-0.038	-0.12	-0.09	0.038	0.059	0.022	0.09
K	0.85	0.803	0.34	0.732	1.239	0.508	1.083	2.014
Ca	-0.93	-1.12	-0.92	-1.60	-1.90	-1.13	-0.87	-0.60
Mg	0.14	0.0122	-0.0528	-0.0867	0.160	0.128	0.126	0.489
mg/kg								
Fe	-24.02	56.69	-30.39	-30.47	-13.48	-3.74	12.046	-22.77
Mn	23.34	-12.03	-21.38	-19.66	71.0	4.76	20.62	61.37
Cu	1.303	19.78	0.84	1.002	0.49	2.83	4.79	-0.45
Zn	2.98	3.01	2.67	1.11	0.12	1.23	2.66	1.72
B	34.28	40.85	38.18	31.17	31.54	41.22	54.94	71.34

plot	C	NPK 100	NPK 0	NK 90	NPK 100-2	NPK 150-S	NPK 150-B	NPK 300-B
N %	-0.38	-0.26	-0.46	-0.28	-0.24	-0.15	-0.24	-0.24
P/N-ratio %	0.77	0.52	0.67	0.26	0.91	0.76	0.83	1.25
K/N-ratio %	11.68	8.71	9.88	8.71	10.97	5.02	10.09	15.86
Ca/N-ratio %	0.15	-2.99	1.59	-5.69	-8.105	-4.41	-1.67	-0.012
Mg/N-ratio %	2.74	1.21	1.91	0.70	2.01	1.38	1.82	4.07
Fe/N-ratio %	-0.05	0.42	-0.08	-0.12	-0.023	0.014	0.136	-0.079
Mn/N-ratio %	0.24	-0.03	-0.05	-0.07	0.49	0.06	0.17	0.42
Cu/N-ratio %	0.012	0.13	0.009	0.008	0.005	0.018	0.031	-0.001
Zn/N-ratio %	0.036	0.0289	0.0396	0.018	0.0098	0.0127	0.0257	0.0199
B/N-ratio %	0.26	0.27	0.31	0.22	0.21	0.25	0.35	0.46

3.6 Economic calculation of fertilization

No treatment had better economic then the untreated control. The treatment with the second best profit was NPK-150-B (table 10). The lowest profit was in NPK-300-B. NK-90 had higher profit compared with NPK-100 and NPK-100-2.

Table 10. Cost and income from fertilization of the different treatments. Calculating the net income ha^{-1} and the difference for all treatments compared with unfertilized (C), where positive values denote economical benefit compared with C.

Treatment	C	NPK 100	NPK 0	NK 90	NPK 100-2	NPK 150-S	NPK 150-B	NPK 300-B
Amount of fertilization kg/ha	0	625	0	313	625	938	938	1875
Cost fertilization $/ha	0	150	0	68	150	225	225	450
Cost fertilization method $/h	0	18	0	18	18	18	18	36
Total cost $/ha	0	168	0	86	168	243	243	486
Growth m³	28.54	26.93	25.70	26.10	28.08	26.98	33.90	34.42
Income $/ha	890	840	802	814	876	842	1058	1074
Net $/ha	890	672	802	729	708	599	815	588
Benefit compared with C	0	-218	-89	-161	-182	-292	-76	-302

4. Discussion

Since sunlight is the energy source and amount of light absorbed by foliage determines the photosynthetic production, the favorable light conditions in southern China will likely allow high yields in plantations of Eucalyptus. Different environmental constraints like water- and nutrients availability, however is normally limiting the amount of the light-absorbing foliage and have therefore a direct effect on the growth and trees (Linder, 1985). It is therefore important to keep the light-absorbing foliage at a high level as possible which is possible through improved silviculture and by adding nutrients. Adding water is normally not an option in plantations by economical and environmental reasons and plantation forestry should be oriented in regions where precipitation exceeds 1500 mm per year (fig. 13).

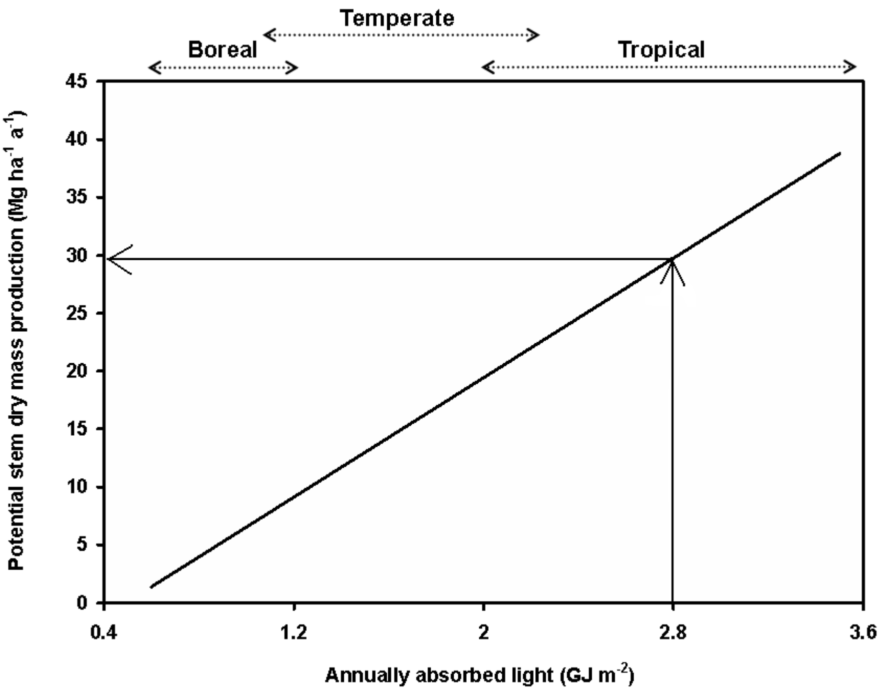


Figure 13 The possible dry mass production depending on annually absorbing light. The arrow shows the possible dry mass production in Baisha (Bergh pers. comm.).

Since some treatments are postponed in time it is difficult to compare and evaluate these first results. NPK-0 has not been fertilized yet so the production should not differ from C, while NPK-100 and NPK-100-2 have received the same amount of fertilizer this far in the experiment. There was a significant difference between NPK-0 and C both in terms of standing volume and in stem volume growth. Between NPK-100 and NPK-100-2 there was also a significant difference both for standing volume and volume growth. The reason for that it was a significant difference between NPK-0 and C was probably because of that C hade higher volume when the experiment started. The reason for the differences between NPK-100 and NPK-100-2 is not so simple but one explanation could be that a higher amount of trees have died in NPK-100. The problem of dying trees is not unique for this experiment. In Brazil large amount of trees can die during a rotation period (Gonçalves et al., 2004). The significant difference between NPK-100 and NPK-100-2 shows that the growth is not only determined of the amount of fertilizers but also local differences in soil conditions.

To broadcast the fertilizer instead of supply it in strings, significantly increased the stem volume production by 7 m^3 on bark after only 7 month. The growth in the broadcasted plot NPK-150-B was probably better because of several reasons. If the fertilization is put in a small hole only a small part of the root system will be exposed to improved nutritional status in the soil. When fertilizer is supplied in strings could also mean that the root system is exposed to supra-optimal concentration of nutrients (fig. 14) and affect the dose response of the fertilizer. Therefore will likely maximum fertilization effect, in terms of production, be reached at a considerably lower supply of fertilizer compared when fertilizer is broadcasted. Since the whole root system is exposed to improved nutrient availability when the fertilizer is broadcasted, a larger amount of fertilizer can be taken up by roots (fig. 14) and maximum fertilization effect is likely considerably higher. NPK-150-S could also have received too much nutrients in the strings and even become toxic for the roots and decreased the uptake of nutrients by roots (fig. 14). It’s also likely that a considerable part of the supplied nutrients in NPK-150-S has leached through the soil profile compared with NPK-150-B.

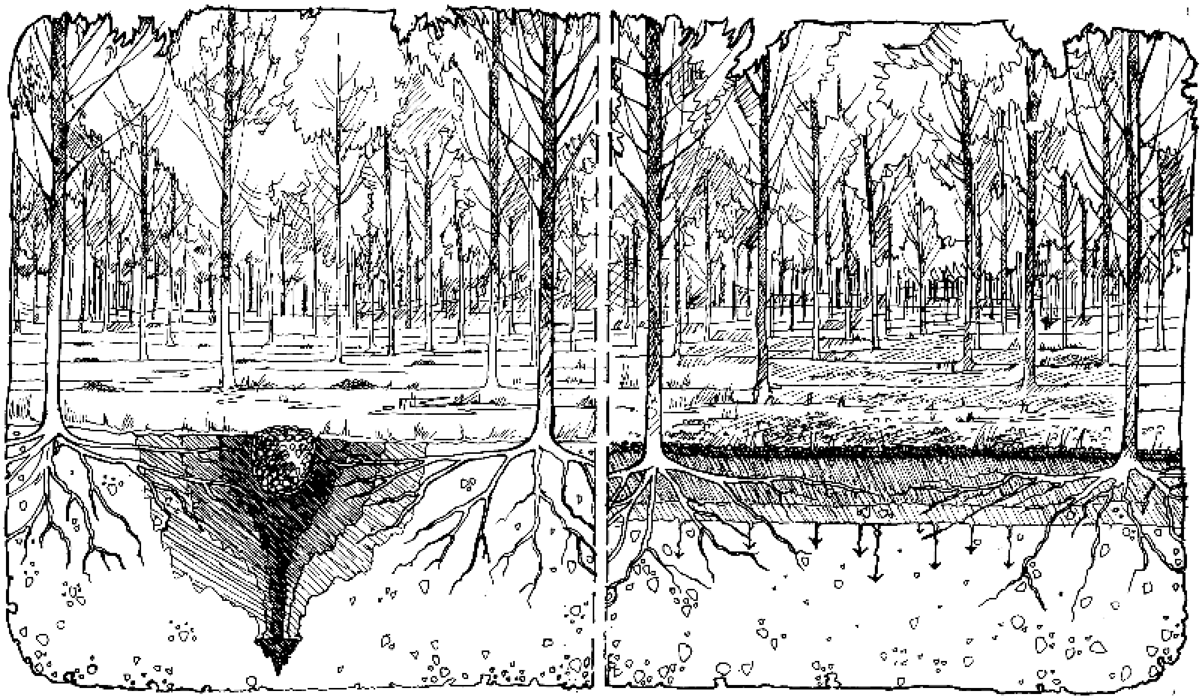


Figure 14. Schematic figure how fertilization in strings (left hand side) and when broadcasted (right hand side) might affect the soil nutrient concentration and leakage of nutrients (drawing by Tove Vollbrecht).

In steep terrain string fertilization could be better due to the risk of surface runoff of water will flush the fertilizer to lower parts when broadcasted. A practical problem is that local people come and collect the fertilizer and the problem is probably bigger when fertilized is applied in strings, because it is more effective to collect the fertilizer when it is concentrated in holes. The granules of the fertilizer could also be made smaller and make it even harder to collect the fertilizer from broadcasted areas. It is very hard to hide the hole in string fertilization.

The production was significantly higher in NPK-300-B compared with NPK-150-B. In terms of cubic meter the difference was rater small only 0.5 m^3. The probably reason might be that 300 kg of N and 230 kg of P and 230 K ha^{-1}, is more than the stand need at the current age. According to nutrient analysis of leaves taken in November 2006 NPK-300-B showed slightly better ratios of P, K and Mg to N compared with NPK-150-B and this might effect the production in 2007. Later in the rotation period a double amount of nutrient could be utilized to a larger extent and increase the stem volume production drastically. A practical recommendation might be that in this stage in the rotation period, when the stand is 12-20 month old, an amount of fertilizer equal to NPK-150-B should be used, because of the low difference in growth and the much higher cost for fertilize twice. One other reason for the low difference could be that there were three more dead trees in NPK-300-B 20 months after planting compared with NPK-150-B.

The treatments where fertilization was based on nutrient analysis had the highest volume increment and will likely have the highest stem wood production during the whole rotation period. Nutrient analysis and an adapted fertilization program, which follow the potential nutrient requirement of Eucalyptus stands in southern China, might avoid nutrient leakage to groundwater and maximize the production, and therefore be important tool for sustainable forest plantations in economical, social and environmental point of view. Trials in Sweden shows that the risk of phosphorous leakages is very low and also that it is possible to apply large amounts of nitrogen every year on normal forest land before leakage appear (Grip 2006). Even if there are large differences between Swedish and Chinese conditions, it is likely possible to fertilize 300 kg N ha^{-1} every year. Concern how heavy rain in summer (fig. 3) affects the leakage of nutrients must be taken into account. There was lower variation between the plots of same treatments after the experiment was established concerning standing volume. The lowest variation was in the treatments, where fertilization was based on nutrient analysis (fig. 8 and 12). More fertilizers make the variation, due to the local condition, less important. Therefore was variation larger in C and NPK-0. Higher amount of fertilizers lead to smaller variation in volume and therefore easier to estimate the volume growth in the stands.

There is an indication in the experiment that heavy fertilization might cause damages on trees. NPK-300-B had the highest number of damaged trees and NPK-150-S the second highest. This could be an effect of increased leaf area and more susceptible to wind and/or increased competition between trees. Dieback can also be a result of boron deficiency (Gonçalves et al., 2004**).** In spruce and pine stands in Sweden fertilization of nitrogen can lead to increased deficiency of other nutrients (Tamm et al., 1999). Zinc and/or boron deficiency could lead to double tops (Pettersson and Samuelsson, 1995), but leaf analysis of samples taken from the different treatments didn't show any limitations of neither zinc nor boron. More testing is needed in this matter. Studies of Eucalyptus in South America showed that boron is the micronutrient, which limits production the most (Gonçalves et al., 2004 & Barros et al., 1991). Phosphorous limits likely the production (Barros et al, 1991, Xu et al. 1999 and

Gonçalves et al., 2004), since levels of P and ratios to N was considerably below the target values for all treatments, 20 months after planting (table 7). The level of phosphorous could probably be corrected/increased by the fertilization in April 2007. The level of potassium in leaves should also be increased by the fertilization in 2007. Both NPK-150-S and NPK-300-B had two trees damaged from soil erosion and NPK-150-B one tree which are probably not affected by a larger dose of fertilizer. Maybe the below-ground biomass in relation to the above-ground biomass is smaller for the heavy fertilized treatments compared with control and this could maybe lead to higher risk of damages from soil erosion. The measurement of visible damages was not performed in a perfectly objective way; some trees with damages could be missed. Every tree needs to be searched more carefully to detect damages the next time the trial will be measured.

It has only been seven months between the measurements and probably would maximum annual increment of 34 m^3 ha^{-1} and $year^{-1}$ for NPK-300-B, be slightly larger if the total growth for 2006 had been measured. It is likely that the annual production would exceed over 40 m^3 ha^{-1} and $year^{-1}$ in 2007. The yield is considerably lower in December and March because of lower precipitation (fig. 3) but there is still some growth during this period as well. Current annual increment (CAI) is closely related to mean annual increment (MAI) for a whole rotation period. In order to get a rough estimation of MAI, maximum CAI has to be multiplied with 0.65 (Eriksson, 1976; Elfving pers. comm.). To achieve a MAI of 40 m^3 ha^{-1} and $year^{-1}$, for a whole rotation period, means that CAI must reach 60 m^3 ha^{-1} and $year^{-1}$ for a single year the next three years to come.

The annual growth for NPK-150-S was even lower than untreated control (C). It was only NPK-150-B and NPK-300-B that had a higher volume growth than C and NPK-100-2 had no significant difference with C. These inconsistencies might be an effect of the differences in initial conditions in terms of standing volume, water and nutritional conditions of the randomized selected plots. The production for the different fertilization treatments will probably surpass the production of C the next years. In the next years the fertilized plots will take even more advantage of the fertilization and have a higher growth then the untreated plot. In April 2007 NPK-0 will be fertilized the first time and it will be interesting to see how the trees respond to the fertilizers compared how NPK-100 responded to the fertilizers during the first year of the experiment. It will also be interesting to see how NPK-0 will grow compared with the untreated control.

One explanation why NPK-150-B had the largest height growth of all treatments could be that two of the plots for NPK-150-B were situated in a slope. No other treatments had more than one plot in this slope. The slope is not steep, but an interesting observation was that trees at the lower part of the slope had the tree tops at same level as the trees in the upper part of the slope. This is probably due to the competition from the tree higher up in the slop that makes the tree in the lower part equal in height. The reason could also be higher amount of water and nutrient but I think that the most important reason is competition from surrounding trees. A tree with relatively small diameter could still be tall and the relationship between diameter and height was to some extent different. For all treatment except NPK-150-B there was a good correlation between diameter and height. For the rest of the treatments the r^2 values were 0.65 or higher, while it was below 0.45 for NPK-150-B. During revisions of diameter and height, only one person was measuring height and one DBH and a systematic error might have been introduced.

When the experiment was measured in November an increased amount of leaves on the ground was observed (fig. 15). This might lead to an establishment of an organic layer. If an organic layer develops more nutrients can be stored in the soil and recycled in the plantation. If an organic layer is developed more organisms in the soil will occur and increase the decomposition of organic material. This might lead to increased mineralization cycle and increased production. An organic layer might also improve water holding capacity and water availability for roots and make the soil more stable and decrease the risk of soil erosion.

In Southern China the local people commonly collects the branches and leaves in Eucalyptus stand for firewood. More than the stems is therefore taken out from the stands and also more of the nutrients stored in branches and leaves. Production will be higher in next rotation if the slash is left in the stand (Xu et al., 1998 & Xu et al. 2003). The highest volume production was when all slash was left on the plot, plus added slash from another treatment and stem and bark harvest plus intercropping with *Acacia holosericea* (Xu et al., 2003). The available P in the soil was highest in the treatment with double amount of slash (Xu et al., 1998). It is impossible for the landowner to control so the local people not is collecting any branches and leaves from the stand. Even if it would be good silviculture to leave branches and leaves to maintain and/or improved the productivity in the stand, it might lead to disappointed local people. Compensation by supplying the local community with firewood might be an option and/or fertilize the plantation and extra time to compensate for the losses from removal of branches and leaves.

Figure 15. Increased amount of leaves on the ground was observed in the experiment. Photo: Patrik Andersson

If the experiment was cut down today the best economy would be in the untreated control. This is due to the high initial standing volume for the untreated plots. In the future the growth in the other treatments will probably be higher and it will be less in the control. In the whole rotation period there will probably be an economical benefit of fertilization. The prize for timber was if the timber was sold to a mill not processing by the own organization. In StoraEnsos case they will use the timber for own industry and sell a full develop product. In this scenario the prize per m^3 could be considerable higher. The treatment that had best economical benefits except C was NPK-150-B. NPK-150-B had the second highest cost for fertilization but had still the second best profit. NPK-300-B had the worse economy due to that it had twice as high cost as the rest as the treatments. The income was much higher in NPK-150-B and NPK-300-B, approx. 150 $/ha more then C but the cost was also much higher, therefore the lower profit. There was so small effect in stem volume growth between NPK-150-B and NPK-300-B so in economical terms it was better to fertilize only once. It would be interesting to have one treatment that received the amount of fertilizers that NPK-300-B at once instead of twice. This could lead to a chock for the trees that could lower the growth and the leakages would probably also increase. If the same growth could be received for this treatment as for NPK-300-B the economical advantages would be large due to half cost as NPK-300-B. The environmental disadvantages must be studied and taken in consideration if this new treatment would be added as one option.

5. Conclusion

Broadcast fertilization increased the growth more than fertilization in strings. With the same amount of supplied nutrients, broadcasted treatments had grown 7 m^3 ha^{-1} on bark more than the treatment fertilized in strings. Eucalyptus plantations in southern China should be fertilized at least with 150 kg N, 115 kg P and 115 kg K ha^{-1} and $year^{-1}$ broadcasted to achieve highest stem volume production. There was a significant difference between fertilization once with twice per year with 150 kg N, 115 kg P and 115 kg K ha^{-1} and $year^{-1}$. The highest stem volume growth was when fertilize twice, 34.4 m^3. NK-fertilization gave a significant lower volume production than NPK-fertilization in the first year of the experiment. There were significant differences between the treatments that had received the same amount of fertilizers, so not only fertilizers determents the growth of eucalyptus. It is too early to see any economical benefits of the fertilization in the experiment. The best economic profit was in the untreated plots.

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