Fertilization in *Eucalyptus urophylla* plantations in Guangxi, southern China

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Master Thesis no. 180
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Abstract

StoraEnso decided in year 2002 to build a pulp mill in the province of Guangxi, southern China, and also establish eucalyptus plantations to provide it with raw material. By 2010 StoraEnso controls about 90 000 of planned 120 000 ha, out of 75 000 ha is already planted with *Eucalyptus.*

By using better genetic material, improve the tending, selecting the sites more careful and by using a proper fertilization regime StoraEnso hopes to increase the mean annual increment from today's 25 m^3/ha, on bark, to 35 m^3/ha. This study is one part in this work to increase the mean annual increment in the plantation.

This master thesis is the forth in a series, that has followed up a fertilization trial that started in spring 2006 when the trial was laid out and treatments decided. The aim with the trial is to examine the production potential of *Eucalyptus urophylla* in Guangxi, southern China. In total there are seven different treatments, out of which one is the common practice for StoraEnso Guangxi, and one is an untreated control treatment. The three max-fertilized treatments have gotten the amounts of fertilizers decided after leaf-nutrient analysis. If the nutrient analysis revealed that the concentration of a specific nutrient was too low, extra amounts of that nutrient were included in the next fertilization.

The treatment with the highest total production and mean annual increment at a stand age of 68 months is the max-fertilized treatment: NPK-300-B with a total stem wood production of 208.10 m^3/ha and a MAI of 36.72 m^3/ha. NPK-300-B was also the only treatment that had a statistically significant higher total production and MAI than the Control treatment.

The mean basic density value was significantly lower in the wood harvested from treatment NPK-300-B (469 kg/m^3) compared to wood from the control (498 kg/m^3).

The leaf analysis showed that the concentrations of all nutrients have increased in both treatments since the last analysis in 2008 made by Rickard Carlsson and that the recommended ratios have been reached for all nutrients, except for phosphorous (P) in the control which was slightly under the recommended ratio.

Potential dry mass production/ ha/yr at the latitude of Guangxi is estimated to be around 30 tons, if water, nutrients and other biotic factors limiting the growth is satisfied. In treatment NPK-300-B the production reaches 14.095 tons/ha and year when the volume production peaked at a stand age of 68 months. So potentially the stem production is only 50% of the estimated potential.

Keywords: Eucalyptus, fertilization, southern China, Guangxi

摘要
StoraEnso在2002年决定建立一个在广西，中国南部省份纸浆厂，并建立桉树人工林提供原料的。到2010年StoraEnso已在其控制的约90万公顷，超过了75000公顷已与尾叶桉种植。

通过使用更好的遗传物质，改善抚育，选择使用适当的施肥制度的网站更仔细和StoraEnso希望树皮平均增加了今天的 25m³/ha/yr ▪ 年增加至 35m³/ha。

这是硕士论文中提出一个跟进一施肥试验，在2006年春季▪始审判时，布局和处理决定严重。与试验的目的是研究在广西的尾叶桉，南中国的生产潜力。总共有七个不同的受精卵，巫一OUT是StoraEnso广西普遍的做法，和一个控制治疗。这三个最大受精治疗后已得到叶营养缺乏养分分析其中已在下次施肥一次额外的金额决定给予化肥的数额。

最高的总产量和平均治疗在林龄的六十八个月每年增量最大受精治疗：氮磷钾-300，总茎 208.10 m³/ha 木材生产和 36.72 m³/ha 麦乙。氮磷钾- 300 -B是唯一的治疗方法也有显着较高，总产量比对照处理麦。

平均基本密度值也显着降低，在未来木材从治疗氮磷钾- 300-B 型（469 kg/m3的）相比，从控制木材（498 kg/m3的）。

叶分析表明，所有营养物质的浓度增加，两种处理自2008年上次里卡德卡尔松作出分析和建议的比例已经达到所有营养素的除外，磷的对照组（P），它是稍低于推荐的比例。

潜在的物质生产/公顷/在广西纬度年估计约为30吨，如果水，营养物和其他生物因素可以被排除在外。在治疗氮磷钾- 300 -B的产量达到十四点零九五吨/公顷，并在该六八个月立场岁。如此大的潜在干产量估计只有50%的潜力。

關鍵詞：▪樹，施肥，中國南部，廣西

Sammanfattning

StoraEnso beslutade år 2002 att man skulle bygga ett massabruk med tillhörande eukalyptus plantage i provinsen Guangxi, södra Kina. 2010 kontrollerar StoraEnso ca 90 av planerade 120 000 ha, varav ca 75 000 är planterade med eukalyptus.

Genom att förbättra det genetiska materialet, förbättra skötsel, välja plantageplatserna mer noggrant och genom att gödsla på ett bra sätt hoppas StoraEnso att medeltillväxten kommer öka, från nuvarande 25 m^3/ha, på bark, till 35 m^3/ha.

Detta examensarbete är det fjärde som följer upp utvecklingen av ett gödslingsförsök som startade våren 2006 när försöket lades ut och man beslutade om vilka behandlingar som skulle ingå. Målet med försöket är att undersökta produktionspotentialen på *Eucalyptus urophylla* i Guangxi. Totalt är det sju olika behandlingar, varav en är kutym i eukalyptus plantager i södra Kina, samt en kontroll. De tre maxgödslade ytorna har fått sina gödselgivor bestämda utifrån näringsanalyser utförda på bladen, de näringsämnen som funnits i för låg koncentration har givits i extra doser vid nästa gödslingstillfälle.

Behandlingen med högst volymtillväxt vid en beståndsålder av 68 månader var den maxgödslade; NPK-300-B, som hade en total stamvolym på 208.10 m^3/ha och en medeltillväxt på 36.72 m^3/ha. NPK-300-B var också den enda behandlingen som gav en statistiskt signifikant ökad total tillväxt och medeltillväxt jämfört med kontrollen.

Torrviktsdensiteten var signifikant lägre i veden som kom från behandling NPK-300B (469 kg/m3) jämfört med veden som kom från kontroll ytan (498 kg/m^3).

Näringsanalyserna som gjorts på bladen visade att koncentrationerna av alla näringsämnen ökat och att de rekommenderade kvoterna har uppnåtts för alla näringsämnen utom fosfor (P) i kontrollen som var alldeles under den rekommenderade kvoten.

Den potentiella stamtorrviktsproduktionen på Guangxis breddgrad är ca 30 ton/ha/år om alla begränsande faktorer som näring och vatten tillgodoses. I behandlingen med högst tillväxt, NPK-300-B, uppnåddes en årlig stamtorrviktsproduktion på 14.095 ton då tillväxten kulminerade vid en beståndsålder av 68 månader. Detta betyder att den uppnådda tillväxten i det här försöket inte ens var hälften mot den potentiella.

Nyckelord: Eukalyptus, gödsling, södra Kina, Guangxi

ABBREVATIONS

ADT= Air Dried Tons

BHKP= Bleached Hardwood Kraft Pulp

CNFPP= China Natural Forest Production Program

CAI= Current Annual Increment

CMP= Calcium Mono Phosphate

CTMP= Chemical Thermic Mechanical Pulp

FGHY = Fast-Growth High-Yield plantations

KCL= Potassium (K) Chloride (Cl)

NPK= Nitrogen (N) Phosphorous (P) Potassium (K)

MAI = Mean Annual Increment

SEGX= StoraEnso Guangxi

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1. Introduction

The global demand for forestry products is increasing quickly and in the world's second largest economy, China, (Wikberg 2010) the demand is growing fastest. The Chinese GDP has grown with almost 10% per year for decades and nothing indicates it will slow down (Placera.nu 2010). With a rapid growing economy the consumption of paper products is also growing quickly, North American and western European citizen's use about five times more paper per capita compared to the Chinese, which is corresponding to a difference of almost 200 kg paper/ capita and year *(fig 1)*.

The forecast in figure two predicts that the need of pulpwood will increase from today's ~25 million tons to ~38 million tons/yr in the coming 15 years and the absolute majority of this wood will be eucalyptus (Genfors unknown publication date) *(fig 2)*. In total China has about 88 million ha of forest that is managed for timber production containing a timber volume of around 7.57 billion m^3. Despite these enormous resources only 2/3 of the domestic timber demand could be produced within China in the late 1990´s and this share was decreasing quickly (Xiaoping unknown publication date). At the same time a large scale change driven by government orders was taking place when the pulp mill industry was forced to switch the raw material used, from agricultural residuals to wood fiber. In 1990 only ten percent of Chinas pulp was based on wood, compared to 50% in 2007 (Lang 2007).

The Chinese paper market has increased dramatically the last decades. Since 1990 more than 50% of the world's paper producing capacity has been installed in China. 20 years ago China produced 13.7 million tons paper, 2003 43.0 million tons (Barr et al 2004) and by 2007 73.50 million tons (China Paper 2009). The coming years a continued annual growth of around 10% is predicted (China Paper 2009) and the demand for bleached hardwood Kraft pulp is increasing fastest. Between 1990 and 2003 the annual demand increase was 21.4% meaning a yearly demand increase from 510 000 tons to 2.8 million tons, the main source for Bleached Hardwood Kraft Pulp is eucalyptus (Barr et al 2004).

All in all this means that new and expanded plantations are inevitable and research on how the production can increase is of outmost importance.

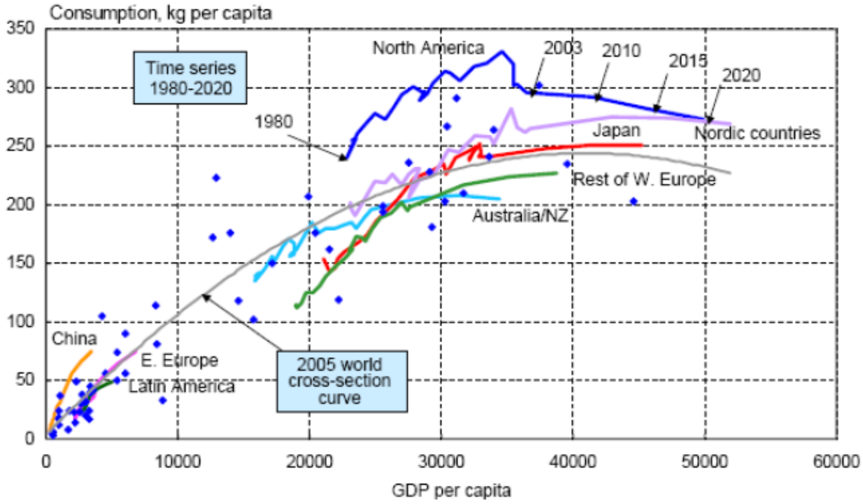

Figure 1: Paper consumption in kg per capita (Genfors unknown publication date)

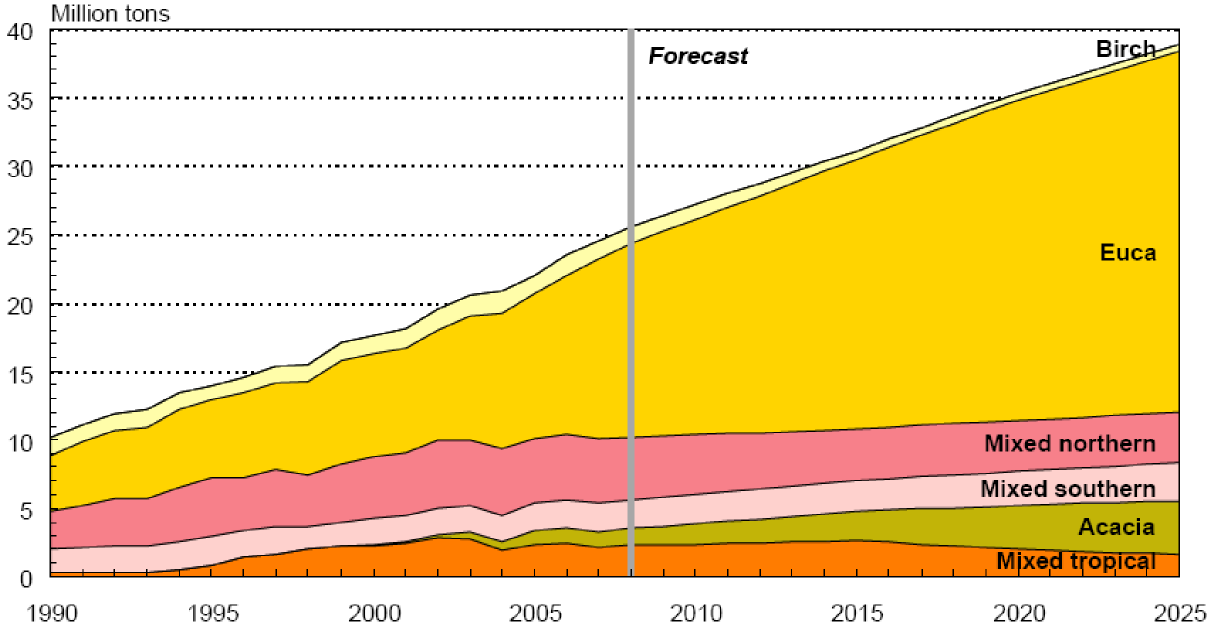

Figure 2: Pulp source forecast (Genfors unknown publication date)

1.1 Aims & hypothesis

The aim with this study was to examine the effect artificial fertilizers have on the growth and how the nutrients are allocated within the trees on eucalyptus trees in southern china. This thesis is the fourth being done in this trial following the stem volume growth and the leaf nutrient composition in eight different fertilization treatments in a *Eucalyptus urophylla* stand. The previous authors that have examined this trial are: Patrik Andersson (2007), Peter Genfors (2008) and Rickard Carlsson (2009).

The hypothesis examined were (i) that the mean basic density will be the same in the samples taken this year as those taken in year 2008 by Peter Genfors, (ii) that phosphorous (P) is crucial for the growth which has been indicated in several previous trials (Daping et al 2002, Goncalves et al 2004 and Xu et al 2005) and (iii) that the volume production is highest in the treatments that have been fertilized continuously.

The mean basic density calculated from my samples has been compared with the data from a stand age of 32 months that I have taken from P. Genfors (2008).

In the nutrient analysis the data from a stand age of 68 months has been compared with the data from 20, 32 and 44 months to see the development in the nutrient concentrations between the Control and the max-fertilized treatment; NPK-300-B. The data from 20 and 32 months has been taken from P. Genfors (2008) and the data from 44 months from R. Carlsson (2009); unfortunately Rickard Carlsson compared the Control treatment with NPK-150-B so I have no data for treatment NPK-300-B at a stand age of 44 months.

2. Background

2.1 Chinas changing forestry policy

The Chinese forest policy has changed dramatically since the Peoples Republic of China was founded in 1949. At this time the forest cover was at all time low (8.6%) and the country was very poor and severely affected after the Second World War. The State Owned Enterprises (SOE) who was in charge of the harvesting operations were rewarded by higher profits but had no incentives of doing any kind of reforestation measures (Song et al unknown publication date).

Eucalyptus plantations were created over vast areas but the seed sources was unimproved and after planting weeding, tending or fertilization was very sparsely done. This resulted in very poor survival of the planted seedlings, often as low as 10% and sparsely stocked forests (Turnbull 2007).

In 1978 China began to open up to the outer world and started international cooperation's, particularly with Australia. The eucalyptus research focused on tree breeding, nursery techniques and plantation management. In 1985, seven years after the cooperation's began, the Chinese Ministry of Forestry coined the phrase "fast- growing high- yielding forest plantations". Before this date priority had been emphasized on "quantity, not on quality" when new plantations were created. The purpose with the new eucalyptus plantations was to increase the export of wood chips and provide planned future pulp and paper mills with raw material (Turnbull 2007).

2.2 Six key forestry program

In 1998 severe floods killed almost 4 000 people in the Yangtze valley, deforestation was said to be the cause and a wide logging ban called "China Natural Forest Production Program", CNFPP, was implemented (Jiang 2003). This program aimed at restoring ecosystems by initiating several vast forestry programs funded by the government (Wang et al 2007). In year 2000 the investments from CNFPP were specified in the "Six Key Forestry Program", SKFP, in total 85 billion USD was set aside for six different programs aiming at:

- Protecting the natural forests in the valleys of Yangtze and Yellow river
- Minimizing the soil erosion by converting cultivated hills and fragile farm land to forest or grass land.
- Stop the desertification by planting grass, shrubs and trees
- Expand already existing and create new shelterbelts of forests for weather protection
- Wildlife conservation and natural reserves development
- Create fast growing and high-yielding timber plantations (Wang et al 2007).

2.21 Fast growing high yield plantation (FGHY)

To balance the timber market and reduce the dependence on imported timber and market pulp the Chinese government initiated in 2002 another huge project called “China Fast-Growing and High-Yield Plantation Program”, FGHY (Jiang 2007). This project aimed at creating 13.33 million ha of fast-growing plantations during the period of 2001-2015. Out of this 5.8 million ha was planned to be dedicated to the pulp industry.

The program covers four main areas: Chinas south coastal region, the lower and middle reaches of the Yangtze River, the lower and middle reaches of the Yellow River, and Northeast China/ Inner Mongolia. The largest share is planned to be situated in Northeast China/ Inner Mongolia where in total 2.4 million ha of pulp wood plantations is supposed to be situated (Barr et al 2004). A World Bank project is also planned to create another 200 000 ha of “industrial tree plantations” in Guangxi (Lang 2007)

By 2020 the prognosis is that the FGHY plantations will produce 140 million m^3 of timber annually, which will be enough to produce 14 million Air dry tons, Adt of pulp, 21.50 million m^3 of wood panel and 16 million m^3 of construction timber coming from large diameter round wood (Jiang et al 2003).

In the tenth Five-Year Development plan, released in year 2000, the “National Development and Planning Commission” (NDPC) had made a list of totally 42 pulp and paper projects that was prioritized. To support these projects the governmental bank “China Development Bank” CDB, and the state owned bank “Agricultural Bank of China”, ABC, provided very favorable loans with interest rates up to 10% lower than the interest rate set by the Chinese Central Bank. These loans were often followed by a prolonged repayment period for up to 10-15 years. In total 8.65 billion USD was budgeted for the up starting of FGHY (Barr et al 2004).

In March 2002 NDPC specified the criteria’s the projects need to fulfill to get these financial privileges:

• The pulp and/ or paper mill needs to be based on wood fiber
• If it is a chemical pulp mill the minimum production should be 300 000 Adt/yr
• If it is a mechanical pulp mill (CTMP, BCTMP or APMP) the minimum capacity should be 100 000 Adt/yr
• The mill should produce high-grade paper and paperboard (except newsprint paper).

To further minimize bureaucracy, and to speed up the investment pace, for the foreign companies NDPC also took over the investment approval process for forestry and pulp-paper projects from the provincial governments. Previously, when the central government was evaluating new projects, long delays between the investment decision and project start was a major issue (Barr et al 2005).

2.3 The Chinese pulp production and timber market

Historically the Chinese pulp industry has consisted of a vast number of small-scale mechanical pulp mills using mainly non-wood fiber sources like bagasse, bamboo and wheat straw as raw material. To reduce the severe water pollution this production caused the Chinese government closed more than 4 000 of these mills between 1999 and 2004 (Barr et al 2004). In May 2007 Chinese officials announced that another "several thousands of small scale pulp mills" using wheat straw as raw material with a total production of 3 000 000 tons of pulp/ year will be closed during "the coming years" of the same reason (Lang 2007).

In the beginning of the new millennium the yearly paper consumption was growing with about seven million tons (China Paper 2009), at the same time the domestic paper production capacity was decreasing because of the closing of thousands of small non- wood pulp mills (Barr et al 2004) and the logging ban from 1998 (Jiang 2003) resulted in a timber harvesting decrease that reached 16 million m3/yr in 2003 (Zhang et al, Unknown publication date). This combined with a strong economical development (Wikipedia 2010) resulted in a dramatically increased import of timber products, between 1997- 2003 the market pulp import rose with 570% (38 million RWE m3), timber products with 420% (27.5 million RWE m3) (White et al 2004) and round wood with 1 500% (15 million RWE m3) (CIFOR 2004).

2.4 Development of pulp mill and pulp plantations in southern China

2.41 The eucalyptus history in Guangxi

In 1963 "Guinan Eucalypt Forest Farm" was created in Hepu County to produce *E. exserta* seedlings. These were then planted to create protection for rubber plantations and other agricultural crops against typhoons. In the beginning of the 1980s a program called "The China- Australia Dongmen Afforestation Project" was started and about 100 different eucalyptus species was planted in Guangxi to see which that was most suitable for the local climate and soil conditions (UNDP 2006). Most of the plantations created were placed on degraded land or replaced low-productive pine forests and fruit tree orchards (Kanninen et al 2010).

This program boomed the share of eucalyptus in southern Guangxi in the 1980`s, at the same time clone forestry developed, making intensively managed eucalyptus plantations common in the region. In 2002 there were totally 350 000 ha of eucalyptus plantations plus 100 000 ha with "four sided" plantings functioning as windbreak, soil stabilizing, typhoon protection etc. One of the goals for Guangxi in the tenth five year plan from 2000 was to expand the eucalyptus plantations up to 670 000 ha until 2005, all these plantations should be linked to different mills. The Guangxi Forest Inventory from 1999 classified 3.7 million ha in the province as suitable for fast growing tree plantations, the absolute majority of this land was identified as "shrub land" and "unstocked forest" (C. Cossalter et al 2005). In 2009 the total amount of eucalyptus plantations reached 1.6 million ha and by 2015 the provincial government's goal is three million ha (Nordlander 2010).

Like in all provinces in southern China most of the forests in Guangxi are under collective possession, about 90% of the commercial forests in Guangxi are on collective land and 92 % of the land suitable for plantations is owned by local societies, farmer cooperatives and/ or individual households (Kanninen et al 2010). 1.1 million ha of the provinces forest is state owned and managed by 150 different "Forest farms". The majority of the forests in Guangxi consist of conifers like Chinese fir and different pines but the area planted with eucalyptus is growing with 100- 150 000 ha/ year. The main species used in Guangxi and the neighboring provinces are: *Eucalyptus urophylla, E. tereticornis (clone: 12 ABL Congo), E.grandis x E. urophylla, E. urophylla x E. grandis* and *E. urophylla x E. tereticornis* (UNDP 2006).

2.5 Genetical improvement

FAO estimated the MAI in the present Chinese eucalyptus plantations to vary between 8 m^3/ha (min) to 21 m^3/ha (max) and the rotation length to 7-15 years (Del Lungo et al 2006). One of the biggest pulp producers in the world, the Brazilian company Aracruz, managed to increase the MAI in their plantations from 28 to 45 m^3/ha and the amount of wood needed to produce one Adt of bleached chemical pulp sank from 4.9 to 4.1 m^3. Combined this meant that the amount of pulp that could be produced/ ha almost doubled, from 5.9 to 10.9 Adt/ha/yr (Campinhos 1999). In southern China the Lezhou Forestry Bureau has managed to increase the MAI in their eucalyptus plantations from about 6 m^3/ha in the 1960's to more than 27 in 2005. This has been made possible by genetical improvement of the seedlings used, fertilization, improved silviculture and local adaption of the seedlings (UNDP 2006).

2.6 Pulp mills in the region

Since year 2000 when the Chinese government released the tenth five year plan and the adhesive forest industry campaign, four of the worlds paper and pulp giants Asia Pulp & Paper (APP), RGM International, StoraEnso and UPM Kymmene has started building pulp mills, announced that they are planning to build pulp mills or expanded already existing mills in the region. If all of these plans are realized the combined production will be 5.6 million Adt/yr (Barr et al 2004). APP is already having an existing pulp mill on Hainan with a planned future capacity of 2.4 million Adt/yr of BHKP (Barr et al 2005). The provincial plans are to increase the yearly pulp production from 400 000 to 2 000 000 Adt/yr between 2005 and 2010 and reach 4.2 million Adt/yr in 2015 (2.8 million Adt/yr of wood fiber based pulp and 1.4 million Adt/yr of bamboo pulp) (UNDP 2006).

All these projects are planned to have their own plantations to feed the mills with pulp wood. To prevent competition between StoraEnso and APP, which both are starting up plantations in southern Guangxi, the Guangxi government has divided the province between the two companies where they can acquire land for their plantations. APP has been assigned 23 counties in the south and StoraEnso 15 counties in the south east (Cossalter et al 2005).

2.7 The StoraEnso project

In 2002 StoraEnso announced that they wanted to start up eucalyptus plantations and later build a combined paper and pulp mill in the coast city of Beihai, in the province of Guangxi. Initially the aimed size of the plantation was 160 000 ha (StoraEnso 2005) ha but later this figure was revised to 120 000 ha (Nordlander 2010). To provide the mill with enough pulp wood StoraEnso is planning to create 20-30 000 ha of eucalyptus plantations in Laos and ship the wood to the mill in Beihai (Genfors, unknown publication date).

In 2005 StoraEnso handed in an application to start an integrated pulp mill that was planned to produce one million Adt/ yr of BHKP and CTMP and the same amount of paper and paperboard (StoraEnso 2005). This figure has changed over the years and the latest mill size I have heard is 700 000 Adt/yr of BHKP (Risto Vuokko, personal communication).

In 2007 StoraEnso bought 250 ha of industrial land suitable for a future pulp and paper mill from the government in Beihai City for 27 million Euros (StoraEnso 2007).

By 2010 StoraEnso had managed to lease 90 000 ha for their plantations out of which 75 000 ha are already planted with eucalyptus trees. The time schedule was revised in 2009 and the new plan implies that all land needed will be fixed by 2012 and the needed 120 000 ha will be controlled by StoraEnso and planted with eucalyptus. The delay was partly caused by a drastic pace decrease in the land acquisition process in 2009 when some of the 1 900 individual contracts turned out not to fulfill the requirements StoraEnso had which started a systematical control. This revision also resulted in a policy change, with the goal to reduce the dependence on collectively owned land. Now the ambition is that at least 60% of the plantation should be situated on state-owned forest farms and the rest on collectively owned land (Nordlander 2010).

The plantations will consist of blocks with a size of around 100 ha, within a radius of 75 km from the mill site and with a maximum slope of 15^o. The plantations will be concentrated to five regions; 66 667 ha in Beihai, 22 000 ha in Yulin, 12 000 ha in Nanning, 6 667 ha in Fengchenggang and 12 466 ha in the Dongmen region (UNDP 2006).
Site preparation will consist of ripping made with machines on the flat sites in straight rows with four meters apart. On the steeps sites the planting holes will be dug manually. 1 250 seedling will be planted/ ha which is coherent with the practice in Brazil, South Africa and Australia. To control weed, roundup will be used one-two times until the canopy has closed (UNDP 2006).

To maintain and improve the production StoraEnso will use in-organic fertilization. 150 g of CMP containing 18% phosphorous (P) and 100 g of NPK with the proportions: 16% nitrogen (N), 12% phosphorous (P) and 12% potassium (K) plus the needed trace elements will be given to each tree by the time of planting. Another 300 g of NPK will be spread after 1-2 months and the last fertilization will be made at an age of 8-10 months with 500 g NPK/ tree (UNDP 2006).

Average MAI on the sites that has been planted so far is around 25 m^3/ha over bark, but StoraEnso aims at reaching 35 m^3/ha by improving the genetic material, using proper fertilization, select the sites more strictly and improve the tending (Risto Vuokko, personal communication). These figures include all stem wood produced in the forest. The actual timber volume coming in to the mill is predicted to be 18-20% lower because of volume losses caused in harvesting, debarking and transportation (Kanninen et al 2010).

2.71 Threats and problems to the plantation

To be able to retain the production over the rotations it is crucial to maintain the soil fertility. To keep the soil fertility and production up StoraEnso plans to leave harvesting residues, debark the logs on site after harvesting and prolong the rotation length (five year rotation is normal practice compared to StoraEnso´s seven). This will reduce the amount of nutrients lost and enhance the nutrient cycle within the stand (UNDP 2006).

On the other hand locals are collecting harvesting residuals for fuel wood; the average amount in southern China reaches 3.3 tones/ha/ yr which in some parts is up to 55% of the annual litter and understory production. In a nutrient perspective this means a removal of 44-73% of the available nutrients that could have been a part in the nutrient cycle (Daping et al 2002). If this continues over a long time the soil will soon lack in both nutrients and organic material which will result in both a very poor soil structure making it very compact (Klevje 2008) and unproductive (Daping et al 2002).

Another problem for the region is the frequent typhoons; in average 1-2 typhoons hits the coast of Guangxi every year (UNDP 2006). But fortunately they are usually not as strong and severe as in the neighboring region; Guangdong has during the last 35 years been struck by six typhoons with wind forces so strong they have destroyed whole year classes of eucalyptus (Barr et al 2004). Eucalyptus is particularly sensitive for wind damages year two when the trees have developed large crowns and still has a rather small root system (UNDP 2006).

Another problem that has already happened to the plantation is fire. In august 2007 a “medium scale” fire struck the trial site and damaged a large number of trees (Carlsson 2009).

2.8 Fertilization

Many of the soils that is planted with eucalyptus in southern China are acidic, severely weathered and leached, lacks commonly both macro and some micro nutrients and contains very little organic matter, which is important for the nutrient retention and soil water holding capacity (Turnbull 2007). Xu and Dell (2003) investigated the nutrient management in eucalyptus plantations in southern China and found that phosphorous (P) is the macronutrient limiting the growth in most cases. In fertilization trials the volume growth of eucalyptus has increased with 160-740% depending on phosphorous (P) dosage (Daping et al 2002).

In acidic soils phosphorous (P) ties to aluminum (Al) and iron (Fe) ions (Johnsson 1997). In these forms the plants are having big problems with the phosphorous (P) uptake and a shortage can appear although the soil is rich in phosphorous (P) (www.odla.nu).

3. Material and methods

3.2 Economical calculations

A rough estimation to calculate the cost for producing one extra cubic meter of round wood produced in the fertilized plots were made, the costs for fertilizers were taken from Patrik Andersons master thesis from 2007. The cost for the fertilizers used were in 2007 0.24 USD/kg, and the spreading cost was 18 USD/ha, no matter if they were broadcasted or if they were spread in strings (Andersson 2007).

3.3 Site description

The province of Guangxi covers a land area of 23.6 million ha, of which 13.6 million ha (57.5%) was classified as "forestry land" in a land inventory made 1999 (Cossalter et al 2005). In the last citizen count in 2004 49 million people were registered as citizens in the region, which makes the population density about nine times higher compared to Sweden (Wikipedia 2010).

The region has tropical/ subtropical monsoon climate. The temperature is fairly even with a maximum summer temperature of 23-29^{o}C in July and minimum winter temperature of 6-14^{o}C in January. The average annual rainfall is varying a lot in the region, from 1 100-1 200 mm/year in the western parts up to 2 780 mm in the south east (UNDP 2006). Rainfall is strongly depending on season which can be seen in figure 3; during October-April precipitation is so low that it is exceeded by evaporation (FAO 1987).

About 65% of the soils in Guangxi consist of either lateric or red soils; secondly most common is yellow earth, paddy purple and limestone soils. Almost 90% of the cultivated soils are lacking one or more of the six macro nutrients, with potassium (K), phosphorous (P) and nitrogen (N) as top three. About 2/3 of the soils are acidic whilst the rest is calcareous (IPNI 2009).

The experiment is located in Baisha, 90 km northeast from Beihai in the province of Guangxi. The vegetation has historically been dominated by tropical evergreen rain forest and subtropical deciduous forest but now most has been transformed to bush land, agricultural land and bamboo (Andersson 2007).

As can be seen in figure three drought can be a problem in the dry season ranging from October to April when the evaporation exceeds precipitation (FAO 1987).

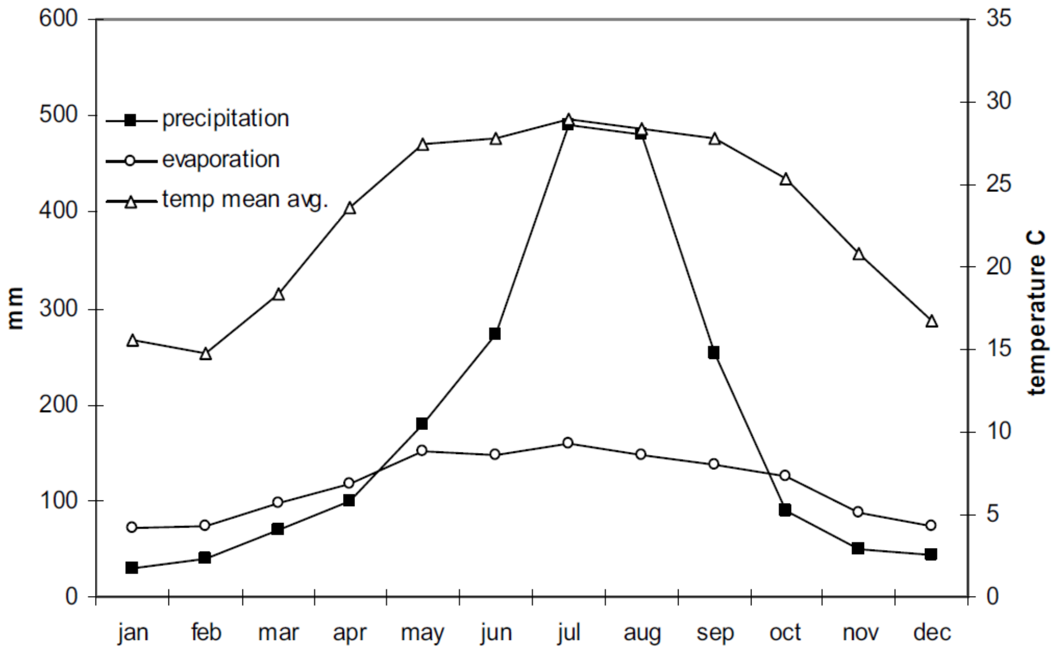

Figure 3: Climate data for Beihai. Mean temp, precipitation and potential evapotranspiration for the last climate period (FAO 1987)

3.4 Trial establishment and treatments

Before planting the site was prepared by a bulldozer in January 2005, the planting rows were 0.5 m deep, 0.6 m wide and with a distance of four meters between each other. In February planting holes were dug with a spacing of 2x4 meters and in March the site were base fertilized with 187.5 kg/ha CMP and 125 kg/ha of NPK and finally planted with 1 250 *Eucalyptus urophylla* seedlings/ ha from the clones DH 32-29 and GL-GU9. Three months later an herbicide treatment was done using Round-up and in August 2005 the stand was fertilized another time with 375 kg/ha of NPK with the proportions: 16% N, 12% P and 12% K (Andersson 2007).

The experiment was laid out, treatments decided and the stand was measured in March 2006, twelve months after planting. It was divided into four different blocks so that initial differences could be taken into account. Within the blocks the treatments were put out randomly and with a plot size of 32x32 m but the diameter and height are only measured in the inner plot that consists of four rows with ten trees in each. This is done to avoid any edge effects from neighboring plots (Andersson 2007)

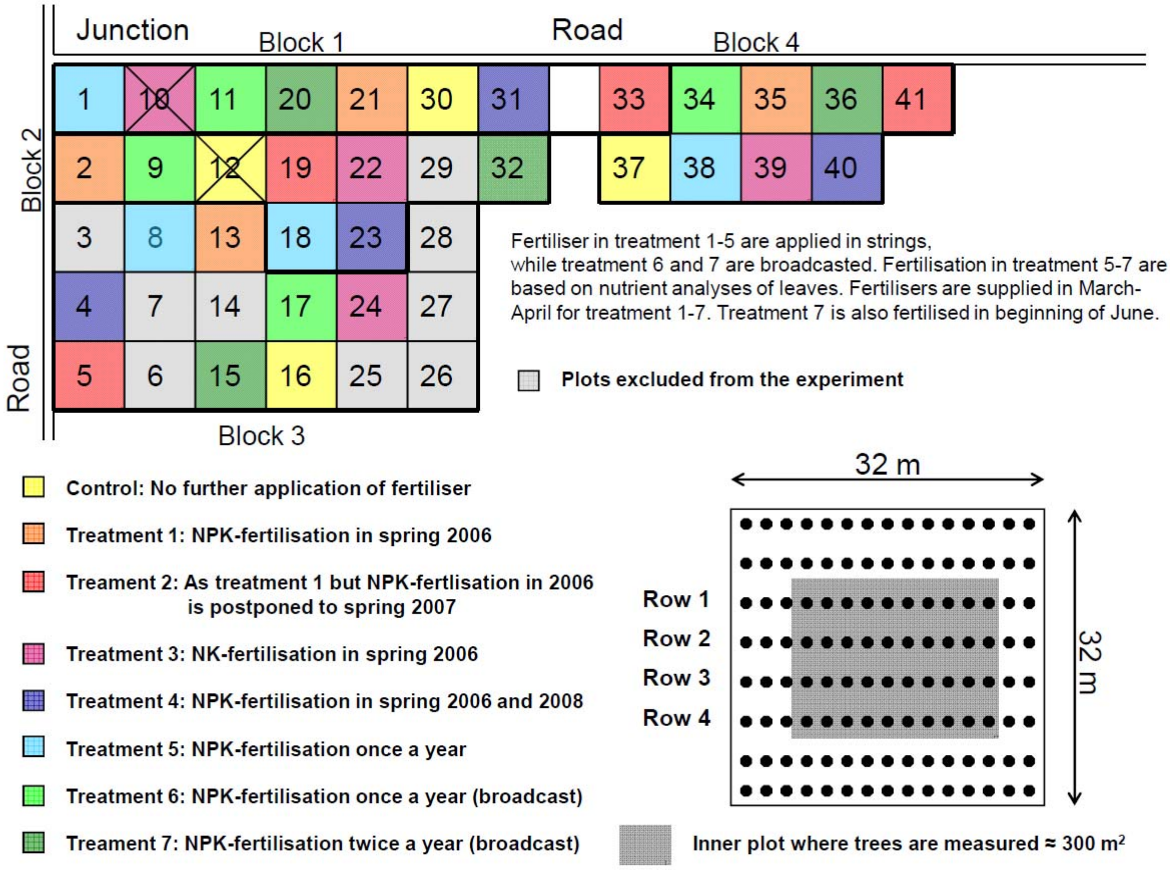

Figure 4: A map over Baisha trial 2008. The trial has eight treatments and repeated in four blocks. Total number from the start was 32plots but plot 10 and 12 was excluded in 2008 cause of the damages caused by first a typhoon and then a fire that struck the trial and damaged the plots so badly there were not enough trees to measure (R. Carlsson 2009). Control C is an untreated plot and is labeled 12, 16, 30 and 37. Treatment 1 (NPK-100) is labeled 2, 13, 21 and 35. Treatment 2 (NPK-100-0) is labeled 5, 19, 33 and 41. Treatment 3 (NK- 90) is labeled 22, 24 and 39. Treatment 4 (NPK-100-2) is labeled 4, 23, 31 and 40. Treatment 5 (NPK-150-S) is labeled (1, 8, 18 and 38). Treatment 6 (NPK -150-B) is labeled 9, 11, 17 and 34. And finally treatment 7 (NPK-300-B) is labeled 15, 20, 32 and 36 (Andersson 2007).

3.41 Description of treatments

There is in total eight different treatment plots in the trial according to previous authors in the topic Peter Genfors, Patrik Andersson and Rickard Carlsson:

Control: No fertilizers at all

NPK-100 or treatment 1: Was fertilized with 100 kg N, 75 kg P and 75 kg K/ha in the spring of 2006. In total 625 kg/ha of NPK (16-12-12) was spread out. This is the usual “standard fertilization treatment” made by StoraEnso in China.

NPK-100-0 or treatment 2: The same amounts of fertilization as NPK-100 but with the difference that the fertilizers where added one year later.

NK-90 or treatment 3: Was treated with 185 kg/ha of urea (containing 46% N) and 125 kg/ha of KCL (containing 60% K).

NPK-100-2 or treatment 4: Same as NPK-100-0 but with the difference that the fertilizers were applied in strings and not broadcasted and that another ration of fertilizers with the same proportions and content as the first ration was spread in 2008.

NPK-150-S or treatment 5: Fertilized in spring 2006 with NPK (16-12-12), the total amount was 150 kg N, 115 kg P and 115 kg K/ha. In 2008 another 120 kg phosphorous (P) where spread out per ha. The fertilizers were spread in strings

NPK-150-B or treatment 6: Treated exactly the same as NPK-150-S with the difference that the fertilizers where broadcasted

NPK-300-B or treatment 7: This plot has been treated the same way as NPK-150-S and NPK-150-B with the difference that the amounts of nutrients has been doubled and that they have been spread twice a year and not once a year. In year 2008 another 240 kg/ha of phosphorous (P) were spread out on the plot (Carlsson 2009) *(fig 4)*

String fertilization means that the fertilizers were put in holes with the dimension of 0,20x 0,20x 0,20m between every tree. After this was done the hole was covered with soil. The plots that were broadcasted got there fertilizers spread manually and even over the whole plot (Andersson 2007).

In the treatments NPK-150-S, NPK-150-B and NPK-300-B the amount of nitrogen (N) disseminated was determined from leaf N-concentration. The supply of the remaining macro and micro nutrients was adjusted to initial target ratios of each nutrient in relation to nitrogen (N). Leaf samples has been taken and sent to a lab each year to determine the nutrient content. Based on these data the amount and composition of fertilizers has been adjusted and extra amounts of the lacking nutrients has been given the following year (Andersson 2007).

The optimal nutrient ratios has been ascertained by Ericsson & Kähr (1993) who determined needed concentrations and proportions of the essential nutrients for maximized wood production in laboratories. These proportions were later confirmed in field tests reviewed by Stockfors et al., (1997).

Since the establishment the concentration of phosphorus has been insufficient in the trial. In autumn 2007 the fertilizer used (NPK-16-12-12) were sent for analyzing and they found out that it contained only 3.6% of phosphorous (P) instead of expected 12. This had the result that a new fertilizer (NPK-16-6-16+0.3B) has been used from spring 2008. CMP has been used for the additional phosphor fertilization in treatments NPK-150-S, NPK-150-B and NPK-300-B made in 2008 (Carlsson 2009).

3.5 Biomass measurement and nutrition analysis

To analyze the effects of the fertilization treatment destructive harvest of trees were done in the buffer-zone of the treatments NPK-300-B and the control. The reason why these two treatments were chosen was because the growth is as highest in treatment NPK-300-B and the Control was chosen as a comparison.

In total, eight trees were felled on a tarp in each treatment. The tarp collected all leaves and branches that fell off when the tree was felled. Leaves, fresh branches and dry branches where collected and weighed separately in the field with a "*Salter 235"* scale, sensitivity 0-25 kg, and an accuracy of 100 gr. The trunk were divided into 2.5 m pieces and weighed on an "*Alfa Laval"* scale, sensitivity 0-100 kg and accuracy of 250 gr. The diameter and bark thickness was measured at: stump height, 1.3 m (dbh), 2.0 m, 4.0 m, 6.0 m etc up to the absolute top of the tree. These measurements were made with a Haglöf caliper and a bark thickness measurer.

Four samples with green branches, one with dry branches and two with leaves were taken from each tree, the samples was supposed to reflect the actual composition of branches in diameter. These samples were later weighed, dried and then weighed again so that a "*dry weight quota*" could be calculated. These quotas were then multiplied with the total biomass for the different assortments so that a dry weight/ ha could be presented *(tab 4)*.

When all weighing was done the samples were separated into the treatments and small samples were taken from the dried green/dry branches and leaves, samples were also taken from all discs. These samples were then sent to a Chinese lab to examine the nutrient content. These data was used to calculate the whole amount of nutrients the trees have taken up in the different treatments *(tab 5 and 7)*. A detailed description of the analyzing process can be found in (Anderson 2007).

The first step to determine which trees that were going to be harvested was to calculate the basal area for each treatment this was then divided by four. This figure was then used to create four classes with the same basal area in each *(tab 1)*. By using this method the sample rewarded the trees with higher diameter. Two trees were randomly selected from each diameter class and harvested.

Table 1: Diameter classes from which the sample trees were selected, the procedure on how these diameter classes was calculated can be read in the part just above.

Control		NPK 300-B	
Diameter class	Number of trees	Diameter class	Number of trees
4.65–13.10	45	9.00–14.55	50
13.10–14.35	32	14.55–15.70	37
14.35–15.60	27	15.70–17.25	31
15.60–18.10	23	17.25–19.60	24

3.51 Density measuring

Discs were taken every five meters on the trees that were harvested, at the stump (S1), five meters up (S2), ten meters (S3) and at 15 meters (S4). All discs were marked with plot number, tree number and which part of the tree it came from. Fresh weight was measured and after that they were soaked in water for five days and nights so that they would get the same moisture content. When the discs were taken up they were dried with a towel to remove superfluous water, bark taken off with a knife and then weighed to measure a "green weight".

To measure the volume of each disc, a bucket of water was weighed. Then a nail was attached to the disc and it was lowered into the water, now a water + disc weight could be registered. By taking this weight minus the water weight, the volume of each disc could be calculated. By taking the green weight of each disc and divide it with the volume a "Green basic density value" was calculated.

The discs were then put into a drying oven at 105 ^{o}C for five days and nights to assure they were completely dry, after these five days a dry weight could be measured. Now a "Mean basic density value" could be estimated by dividing the dry weight with the green volume. To assure that the discs would not add any weight from the moisture in the air only three discs were taken out from the oven to be weighed each time. All these weight measurements were done with an "Electronic Balance scale", with capacity 3 000g and sensivity 0.1g.

3.52 Tree measurements

The breast height diameters of all trees in the trial were measured for the first time, twelve months after planting, in March 2006 with a Haglöf caliper and the height of the trees were estimated with a Haglöf Vertex III hypsometer and a T3 transponder. To avoid errors the hypsometer were calibrated before measuring the first tree in every plot. In November 2007 six trees out of each plot were randomly chosen to have their height measured plus another two trees/ plot which had the greatest diameter; this was done to improve the volume estimations for the largest trees (Andersson 2007). Volume was calculated for the trees on which both diameter and height was measured. The used volume function was developed by Paula Susila at StoraEnso wood supply:

Volume over bark (m^3) = 0.038447 $*dbh^{2.058292}$ $*h^{0.933308}$

When the volume had been calculated for the trees on which height had been measured a function could be created by setting the DBH as the x-axis factor and the volume for each tree as the y-axis factor. A unique function was created for each treatment. By using this function the volume over bark could be estimated for all trees although height not had been measured. The tree volume from each treatment were summed up and divided with the plot area so that the volumes for each treatment could be presented in m^3/ha.

The amount of leaves, green branches and dry branches was calculated in a similar way. Functions were estimated by setting the leave, branch, etc weight in the y-axis and the DBH of the tree in the x-axis. These functions where then used in the same way as for the volume over bark. The bark weight was calculated in a little different way. The dried bark weight was divided with the dried disc weight the bark came from, then a mean could be calculated and I had a bark percentage for both treatments. This percentage was then multiplied with the total dry trunk weight to get a dry bark weight/ha. Total dry trunk weight under bark was calculated by multiplying the dry mass density for the specific tree with its volume under bark for each tree. Functions were the created in the same way as for the other parts of the tree and figures could be presented/ ha *(tab 4).*

The figures seen in table five are a comparison to the figures in table four. The data in table five has been calculated by using the dry mass percentage for the branches, and leaves which I multiplied with each total green weight. For example, the dry mass percentage for leaves in the control plot was 42.2%. By multiplying 0.422 with 5 626 kg/ha (which was the calculated total green weight/ha) the number 2 373 kg/ha was calculated.

The dry trunk weight was computed by first removing the bark weight. Because the bark density of the fresh bark was not measured, the dry bark mass percentage was removed from the volume on bark. Then the volume was multiplied with the dry mass density for each treatment. For the Control the calculations looked like this: 152.10 m^3/ha* 0.8878*501.65 kg/m^3 = 67 736 kg/ha *(tab 5).*

4. Results

4.1 Density

The mean value from the 2008 data of the mean basic density value differed 18 kg/m^3 between the treatments, from 433 kg/m^3 in the Control to 415 kg/m^3 in NPK-300-B. But with a standard deviation of 16 respectively 27 this difference was far from being statistically significant (P=0.4464). However, in the data from 2010 the mean basic density was 498 kg/m^3 for the Control treatment and 469 for NPK-300-B and standard deviations were 18 respectively 14, resulting in a statistically significant difference between treatments (P= 0.0422) (Genfors 2008).

To be statistically significant the P-value should be ≤ 0.05. This means that the outcome of the experiment is by ≤ 95% possibility the result of a relationship between the factors (in this case between fertilization and the amount of leaves, bark, etc.) and not by chance or coincidence (Gunsch 2011).
The basic density value, within the trees, from 2010 deviated very little from each other except for plot 15 which mean basic density ranged from 523 kg/m^3 in the root disc S1 to 459 kg/m^3 five meters up in the S2 disc. Between the plots the biggest difference was between the S2 discs in plot 15 and 20 that varied 43 kg/m^3 *(tab 2)*.

Table 2: The mean basic density (dry wood density) values at a stand age of 68 months for the control and treatment NPK 300-B. S1 stands for the disc taken at the base of the tree, S2 for samples taken 5 m up, S3 10 m up and S 4 for samples taken 15 m up.

Mean basic density value (kg/m^3)

Control	68 months			32 months		
Plot	16	30	37	16	30	37
S 1	523	512	507	436	457	444
S 2	459	492	502	444	417	429
S 3	481	496	500	413	431	401
S 4	478	502	523			
Overall mean value: 498				Overall mean value: 433		
Overall standard deviation: 18				Standard deviation: 16		

NPK-300-B	68 months				32 months			
Plot	15	20	32	36	15	20	32	36
S 1	450	492	479	464	427	407	409	405
S 2	440	483	459	467	424	430	434	422
S 3	455	475	480	486	413	445	424	337
S 4	459	472	473	477				
Overall mean value: 469					Overall mean value: 415			
Overall standard deviation: 14					Standard deviation: 27			

4.2 Tree weights

In 2009 the parameters that was statistically significant was: leaves (P= 0.0461), bark (P= 0.0071) and green branches (P=0.0291). Total biomass was very close of being significant (P=0.0616) while the trunk weight was more distant with (P=0.0865) *(fig 8)*.

In the data from 2010 the difference in trunk weight (P=0.0090), bark (P=0.0151), green branches (P=0.0392) and total biomass (P=0.0366) was the statistically significant parameters. The difference in leave weight was just outside of being significant (P=0.0513).

The growth between 56 and 68 months was almost the same for all parts of the tree except for the amount of wood which is almost doubled in the NPK-300-B treatment compared to the Control *(tab 3)*.

Table 3: The dried weights for all parts of the tree calculated in kg/ha and biomass increase between a stand age of 56-68 months for the Control plot and NPK 300-B. Dried weights in kg/ha. The data from 2009 is calculated by using the function from 2010 (described in "3.152 Tree measurements", and using them on the diameters from 2009.

Dry weights for all tree parts (kg/ha)

	68 months	56 months	Growth 56-68 months
Control			
Trunk	62 235	53 754	8 481
Leaves	2 317	1 951	366
Green branches	6 317	5 133	1 184
Bark	6 961	6 009	952
Tot. biomass	77 830	66 847	10 983
	68 months	56 months	Growth 56-68 months
NPK-300-B			
Trunk	79 875	64 058	15 817
Leaves	2 852	2 470	382
Green branches	8 255	7 233	1 022
Bark	6 242	5 220	1 022
Tot. Biomass	97 224	78 981	18 243

In the data calculated by using densities and the dry mass percentage the difference in trunk weight/ ha is not so dramatic between the Control and NPK-300-B. In table 4 the difference is 86% but here the difference is down to 57%.

The amounts of biomass are about the same except for the trunk weight which is higher compared to table four by using this way of calculating *(tab 4)*.

Table 4: The dried weights for all parts of the tree calculated in kg/ha. These figures have been calculated by using the dry mass percentage for the leaves, branches and bark and density for the wood.

Control	68 months	56 months	Growth 56-68 months
Trunk	67 736	57 759	9 977
Leaves	2 373	2 029	344
Green branches	6 135	5 008	1 127

NPK-300-B	68 months	56 months	Growth 56-68 months
Trunk	89 369	73 692	15 677
Leaves	2 849	2 504	345
Green branches	11 021	9 800	1 221

4.3 Results from the fertilization trial

4.31 The current annual increment (CAI), 68 months after planting

Treatment number five, NPK-150-S had the highest current annual increment after 68 months with 43.25 m^3/ha. The CAI for treatments NPK-150-S and NPK-150-B peaks at an age of 32 months and starts a negative trend, this turns positive however at a stand age of 56 months. The highest CAI is observed in treatment NPK-150-S. The lowest CAI is observed in treatment NK-90, where phosphorus (P) has been excluded in the fertilization mix, with only 16.06 m^3/ha *(fig 5 and tab 2 in appendix).*

At a stand age of 68 months the significant figures for current annual increment was: the CAI in treatment NPK-150-S was higher than treatments NPK-100, NK-90 and the control. And the CAI in treatments NPK-100-0, NPK-100-2, NPK-150-B and NPK-300-B was higher than in treatment NK-90.

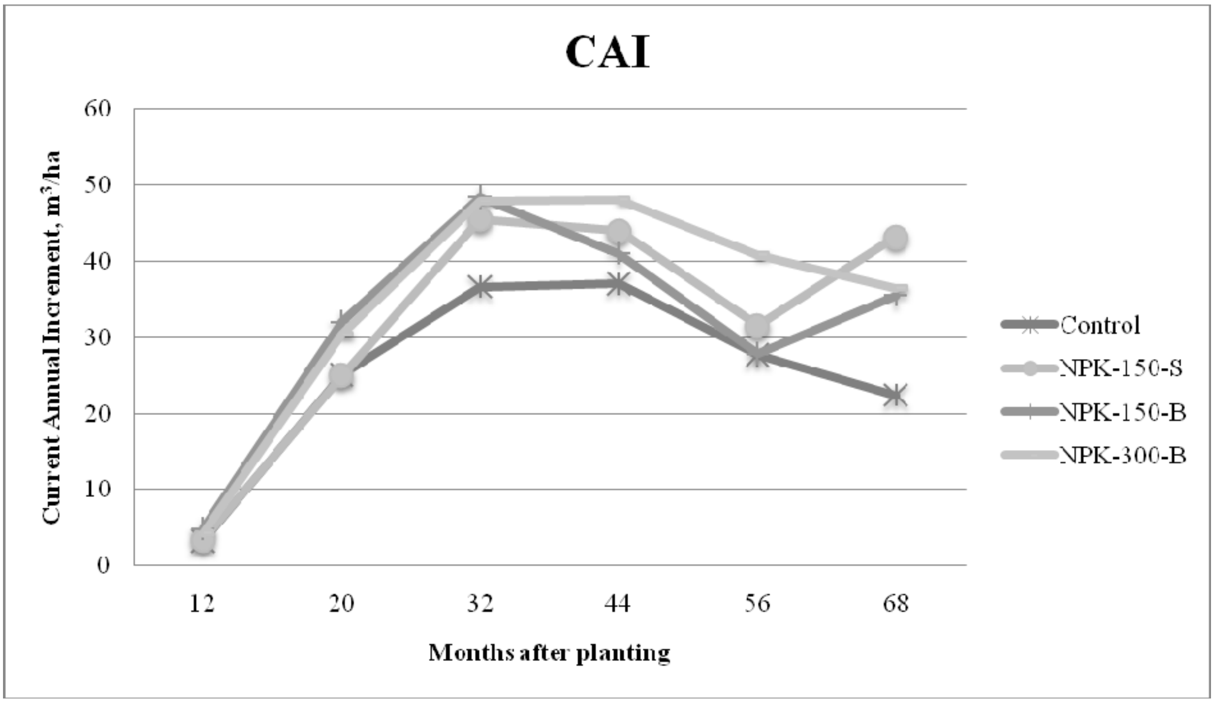

Figure 5: The current annual increment for the control and the three treatments that were continuously fertilized.

4.32 The mean annual increment (MAI), 68 months after planting

When the goal of the stand is to optimize the volume production the stand should be harvested when the current annual increment is crossing the mean annual increment (Albrektson et al 2008). This moment was reached for treatments NK-90, NPK-100-0, NPK-100 and Control after 56 months and at 68 months for the max fertilized treatment; NPK-300-B. The CAI curve for NPK-150-B and NPK-150-S crossed their MAI curve after 56 months but bounced then back up again and is at 68 months over their MAI curves. NPK-100-2 is the only treatment whose CAI curve never has been under its MAI curve, but the difference is only a couple of cubic meters *(fig 6 and fig 1-8 and tab 3 in the appendix)*.

The difference that was statistically significant was: NPK-300-B has a higher MAI than Control and NK-90 and the MAI in NPK-150-S is higher than NK-90.

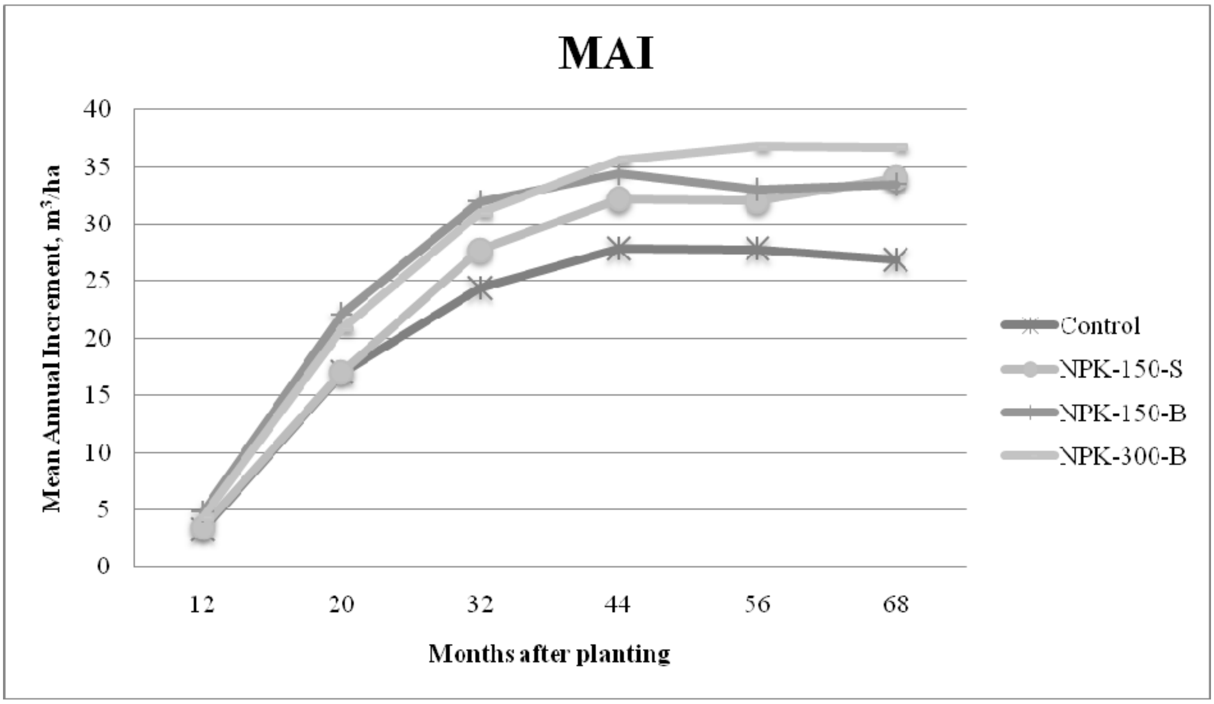

Figure 6: The mean annual increment for the control and the three different treatments that were continuously fertilized, highest MAI is recorded in the max fertilized treatment NPK-300-B.

4.33 The volume development on bark 68 months after planting

The treatment with the highest volume production was not so surprisingly the max-fertilized NPK-300-B with 208 m^3/ha closely followed by NPK-150-B and NPK-150-S on 190 respectively 193 m^3/ha. The treatment with the lowest production turned out to be NK-90 with only 140 m^3/ha which was even lower than the Control (152 m^3/ha). The other two treatments, NPK-100-2 and NPK-100-0 were in between with 181 respectively 163 m^3/ha *(fig 7 and fig 1-8 and tab 1 in the appendix).*

The statistically significant differences at a stand age of 68 months were: NPK-300-B has a higher volume production than Control and NK-90 and NPK-150-S has a higher production than NK-90.

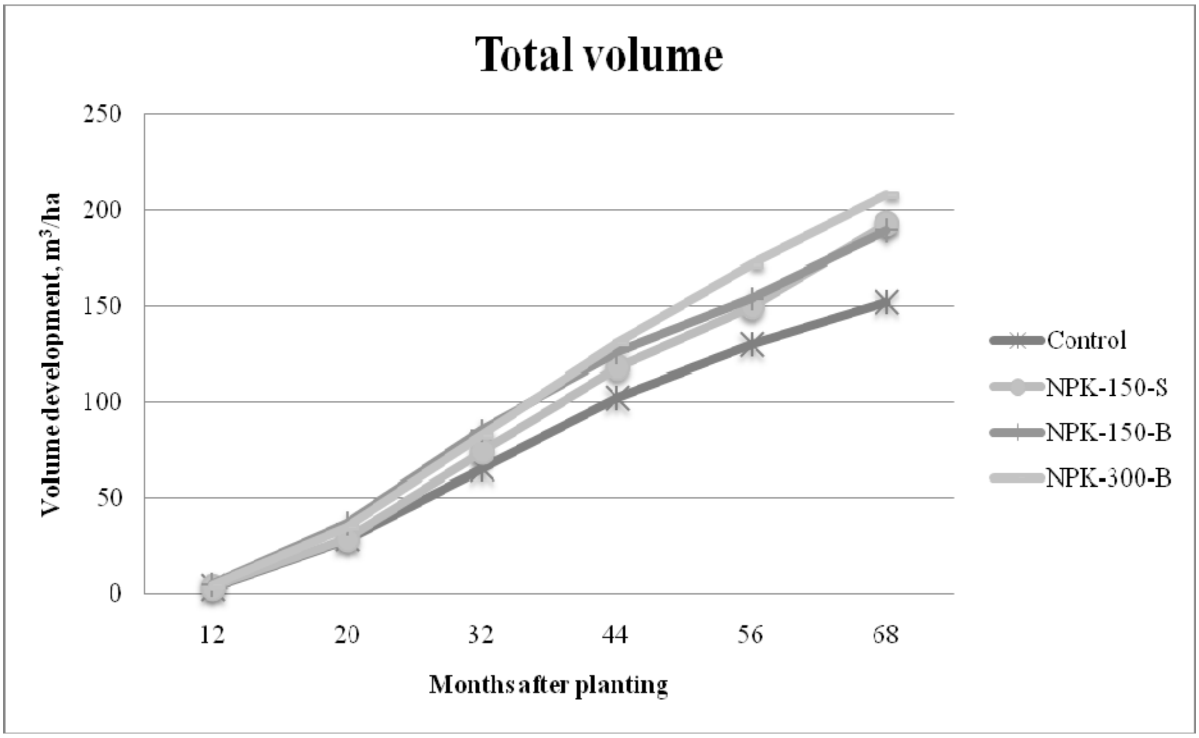

Figure 7: The volume production on bark for the control and the three treatments that were continuously fertilized the highest volume is recorded in the max fertilized treatment NPK-300-B.

4.4 Nutrient content

4.41 Leaf nutrient analysis after 68 months

The nutrient analysis shows that the concentration of macro nutrients has steadily increased, except for nitrogen (N) that has started to decrease in the Control treatment. The most dramatically difference among the macro nutrients is for phosphorus (P) that has almost doubled in the Control (from 0.81 to 1.40 g/kg) and more than doubled in NPK-300-B (from 0.96 to 2.14 g/kg) since the analysis in November 2006 *(tab 5)*.

Table 5: The nutrient content in the leaves from the two treatments in absolute values (g/ kg or Mg/kg) of dried mass.

Leaf nutrient content

Stand age (months)	N g/kg	P g/kg	K g/kg	Ca g/kg	Mg g/kg	Mn mg/kg	Cu mg/kg	Fe mg/kg	Zn mg/kg	B mg/kg
Control										
20	14.8	0.8	5.1	3.8	1.4	81	3	55	15	544
32	16.9	0.9	6.4	3.9	2.2	160	9	92	19	322
44	19.8	1.0	6.3	5.0	2.2	271	6	271	24	50
68	14.8	1.4	7.1	4.8	1.7	158	3	118	17	344
NPK-300-B										
Stand age (months)	N g/kg	P g/kg	K g/kg	Ca g/kg	Mg g/kg	Mn mg/kg	Cu mg/kg	Fe mg/kg	Zn mg/kg	B mg/kg
20	16.2	1.0	6.3	3.6	1.8	119	5	56	14	911
32	17.5	1.2	9.6	4.1	2.7	149	9	247	18	70
68	18.4	2.1	11.3	6.6	2.2	55	4	116	16	52

4.42 Recommended ratio

The recommended ratios between nitrogen (N) was reached for all analyzed macro and micro nutrients, except in the Control plot were the ratio between nitrogen (N) and phosphorus (P) was slightly under the recommended ratio with 9.43 *(tab 6)*.

Table 6: The recommended ratio between the nutrients in relation to nitrogen, the recommended values is in brackets.

Recommended ratio

Stand age (months)	P/N (10)	K/N (35)	Ca/N (2,50)	Mg/N (4,0)	Mn/N (0,05)	Cu/N (0,02)	Fe/N (0,20)	Zn/N (0,05)	B/N (0,05)
Control									
20	5.5	34.7	25.5	9,8	0.54	0.02	0.37	0.10	0.36
32	5.2	38.1	23.0	13.0	0.95	0.05	0.55	0.11	0.19
44	5.2	31.5	25.3	11.2	1.76	0.03	0.67	0.12	0.25
68	9.4	47.9	32.4	11.8	1.07	0.02	0.80	0.11	0.23
NPK-300-B									
Stand age (months)	N g/kg	P g/kg	K g/kg	Ca g/kg	Mg g/kg	Mn mg/kg	Cu mg/kg	Fe mg/kg	Zn mg/kg
20	5.9	38.8	56.4	11.1	0.73	0.01	0.35	0.08	0.56
32	6.7	54.7	20.3	15.6	0.85	0.05	1.41	0.10	0.40
68	11.6	61.0	35.9	11.9	0.30	0.02	0.63	0.086	0.28

4.43 Total nutrient content

In the comparison between the total nutrient content in kg/ha between the two treatments: Control and NPK-300-B, there was a statistically significant difference between all added macro nutrients. The total amount of nitrogen (N) was least significant (P=0.0152) compared to phosphorus (P) (P=0.0002), potassium (K) (P=0.011), calcium (Ca) (P=0.0007) and magnesium (Mg) (P=0.0004). The only added nutrient that had not a significant total weight difference was boron (B) (P=0.4897) and the only analyzed micro nutrient that had a significant difference was manganese (Mn) (P=0.0171).

The total nutrient content in the dried biomass was higher in treatment NPK-300-B for all macro nutrients plus the only micro nutrient that was included in the fertilization mix, boron (B). The nutrients with the biggest difference (between the Control and treatment NPK-300-B) were: phosphorus (P) 226% more, potassium (K) 64% more, calcium (Ca) 54% more and magnesium (Mg) 51% more *(tab 7).*

Table 7: The total nutrient content in the different parts of the tree showed as kg/ha or Mg/ha for the micro nutrients. These weights has been calculated by multiplying the nutrient concentration (that I got from the Chinese lab that analyzed the nutrient content) in the different tree parts with the total dry weight/ ha.

Total nutrient content (kg/ha)

Control	N	K	P	Ca	Mg	Cu	Fe	Zn	Mn	B
Trunk	66.11	25.52	4.36	46.74	3.88	74.47	451	316	746	278
Leaves	34.29	16.44	3.23	11.11	4.04	7.52	274	39.01	367	78.51
Green branches	20.96	20.30	4.45	15.89	4.99	16.42	388	52.62	674	38.15
Bark	23.76	16.67	3.57	47.35	9.59	20.28	600	82.20	1 119	63.36
Dry branches	0.52	0.18	0.04	0.49	0.09	0.56	16.82	2.95	13.50	1.38
Total	146	79.11	15.65	122	22.59	119	1 731	492	2 919	459
NPK-300-B	N	K	P	Ca	Mg	Cu	Fe	Zn	Mn	B
Trunk	79.50	40.79	8.23	64.78	6.26	72.95	712	370	451	224
Leaves	52.58	32.08	6.10	18.86	6.24	10.41	330	45.32	156	150
Green branches	22.89	32.28	7.23	29.13	7.10	12.00	502	52.69	376	50.93
Bark	28.88	24.53	13.69	72.73	14.37	8.30	731	50.73	731	75.26
Dry branches	1.15	0.38	0.17	1.15	0.21	0.60	15.87	4.32	12.09	2.34
Total	184	130	35.42	187	34.19	104	2 292	523	1 727	503

The total amount of fertilizers spread in the treatments differs from 687.50 kg/ha for the Control up to 11 464.50 kg/ha in NPK-300-B. NPK is the most frequently used fertilizer but CMP has been used in all treatments year one and as additional phosphorus (P) fertilization for treatments NPK-150-S, NPK-150-B and NPK-300-B. Treatment NK-90 has not been fertilized with either NPK or CMP but urea and potassium chloride, KCL. In treatment NPK-100, which is the normal fertilizations regime used by SEGX, a total amount of

1 312.50 kg/ha fertilizers is spread for each rotation *(tab 8)* (Carlsson 2009).

4.5 Amount of fertilizers spread

The total amount of fertilizers spread in the treatments differs from 687.50 kg/ha for the Control up to 11 464.50 kg/ha in NPK-300-B. NPK is the most frequently used fertilizer but CMP has been used in all treatments year one and as additional phosphorus fertilization for treatments NPK-150-S, NPK-150-B and NPK-300-B. Treatment NK-90 has not been fertilized with either NPK or CMP but urea and potassium chloride, KCL. In treatment NPK-100, which is the normal fertilizations regime used by SEGX a total of 1 312.50kg of fertilizers is spread/ha for each rotation *(tab 8)* (Carlsson 2009).

Table 8: The total amount of fertilizers spread for all treatments since the beginning of the trial start. 687.50 kg of fertilizers is the "base compound" being given to all plants at the moment of regenerating the new stand.

Total amount of fertilizers spread (kg/ha)

Control Year	Control	NPK-100	NPK-100-0	NK-90	NPK-100-2	NPK-150-S	NPK-150-B	NPK-300-B
2005	687.50	687.50	687.50	687.50	687.50	687.50	687.50	687.50
2006		625		310		938	938	1 875
2007			625		625	938	938	1 875
2008					625	1 639	1 639	3 277
2009						938	938	1 875
2010						938	938	1 875
Total	687.50	1 312.50	1 312.50	997.50	1 937.50	6 078.50	6 078.50	11 464.50

The amount of phosphorous (P) and potassium (K) spread is differing because the fertilizer used was changed in 2008, before that the NPK fertilizer used contained: 16% N, 3.6% P and 12% K from 2008 the composition has been: 16% N, 6% P and 16% K. In 2008 240 kg of extra phosphorous (P) were spread in NPK-300-B *(tab 9)* (Carlsson 2009).

Table 9: The total amount of pure nitrogen (N), phosphorous (P) and potassium (K) spread in the Control and NPK-300-B treatment. The data about amount of fertilizers spread and NPK concentration is coming from Rickard Carlsson (2009).

Pure, N, P and K spread (kg/ha)

Treatment	Year	N	P	K
Control	2005, March	20	136	15
	2005, August	60	14	45
	2006			
	2007			
	2008			
	2009			
	2010			
	Total	80	150	60
NPK-300-B	2005, March	20	136	15
	2005, August	60	14	45
	2006	300	68	225
	2007	300	68	225
	2008	300	353	300
	2009	300	113	300
	2010	300	113	300
	Total	1 580	862	1 410

4.51 Amount of nutrients taken up

The concentration of nitrogen (N) was almost the same for both the Control treatment and NPK-300-B with 0.999 respectively 0.971 kg N/m^3. Nitrogen (N) was the only analyzed nutrient that had a lower concentration /m^3 in the NPK-300-B treatment compared to the Control. The phosphorous (P) and potassium (K) concentration was 78 respectively 30% higher in the parts coming from NPK-300-B *(tab 10)*.

Table 10: The total amount of nutrients that the trees has taken up in the Control and NPK-300-B treatment. And the amount of N, P and K/ m^3 of fresh wood, OB. At a stand age of 68 months there was 152.10 m^3/ha in the Control and 208.07 m^3/ha in treatment NPK-300-B.

Total uptake N, P and K

Control	N	P	K
Whole tree (limbs, bark, etc) (kg/ ha)	152	16.0	81.76
Nutrient content/ m^3 wood	0.999	0.105	0.538
NPK-300-B	N	P	K
Whole tree (limbs, bark, etc) (kg/ ha)	202	38.82	146
Nutrient content/ m^3 wood	0.971	0.187	0.702

4.6 Economical calculations

The cost for producing one extra m^3 of wood, compared to the Control treatment is differing from 11.59 USD up to 47.79 depending on treatment. The most expensive wood is produced in the max-fertilized treatment, NPK-300-B and the cheapest comes from treatment NPK-100-2. Wood coming from the fertilization regime used by SEGX costs 15.27 USD/m^3. The cost for NK-90 is zero because the volume production in this treatment was lower than in the Control plot *(tab 11).* In dry wood mass the difference between the control and the NPK-300-B is different because both the amount of bark (8.0 respectively 11.2%) and the mean basic density (469 respectively 498 kg/m^3) was lower in treatment NPK-300-B compared to the control. This means that the growth difference of dry wood mass between treatment NPK-300-B and the control is even smaller than seen in table 11.

Table 11: An economical calculation showing the fertilization cost for producing one m^3 of wood more than the Control. The figures for fertilization cost have been taken from Patrik Anderson's master thesis from 2007.The cost for fertilizers is fluctuating greatly, therefore the data from 2007 is used as a mean value. In this example the cost for fertilizers has been set to 0.24 USD/kg and 18 USD/ha for spreading them (Andersson 2007).

Cost for the fertilizers spread

Year	Control	NPK-100	NPK-100-0	NK-90	NPK-100-2	NPK-150-S	NPK-150-B	NPK-300-B
2006		168		92.4		243	243	468
2007			168		168	243	243	468
2008					168	411	411	804
2009						243	243	468
2010						243	243	468
Total cost (USD/ha)	0	168	168	92.40	336	1 383	1 383	2 676
Excess volume produced, compared to Control	0	11	11	0	29	41	38	56
Cost (USD/m^3)	0	15.27	15.27	0	11.59	33.73	36.39	47.79

5. Discussion

The potential growth is always limited by how much light the plant can absorb and how efficient the photosynthesis works. The faster the canopy closes in a stand, the faster can it fully utilizing the potential growth. The potential growth is only reached in a small number of cases, because lack of resources limits the amount of leaves or needles that the trees can produce (Linder et al 1996).

In this trial all macro and micro nutrients needed has been supplied in the stand to see which potential growth can be reached. The potential dry mass production/ ha and year at the latitude of Guangxi has been estimated to ca 30 tons, if water, nutrients and other biotic factors limiting the growth could be removed. In the max fertilized plot in this trial the production reaches 14.095 tons/ha and year at a stand age of 68 months *(tab 4)*. So potentially the stem production is only 50% of the estimated potential. My theory is that water is the main limiting resource here, as seen in figure 3 the evaporation exceeds the precipitation from October to April. Meaning that half of the year drought can be a problem. And the other half of the year it rains so much that I believe erosion and nutrient leakage can be a problem *(fig 3)* (FAO 1987).

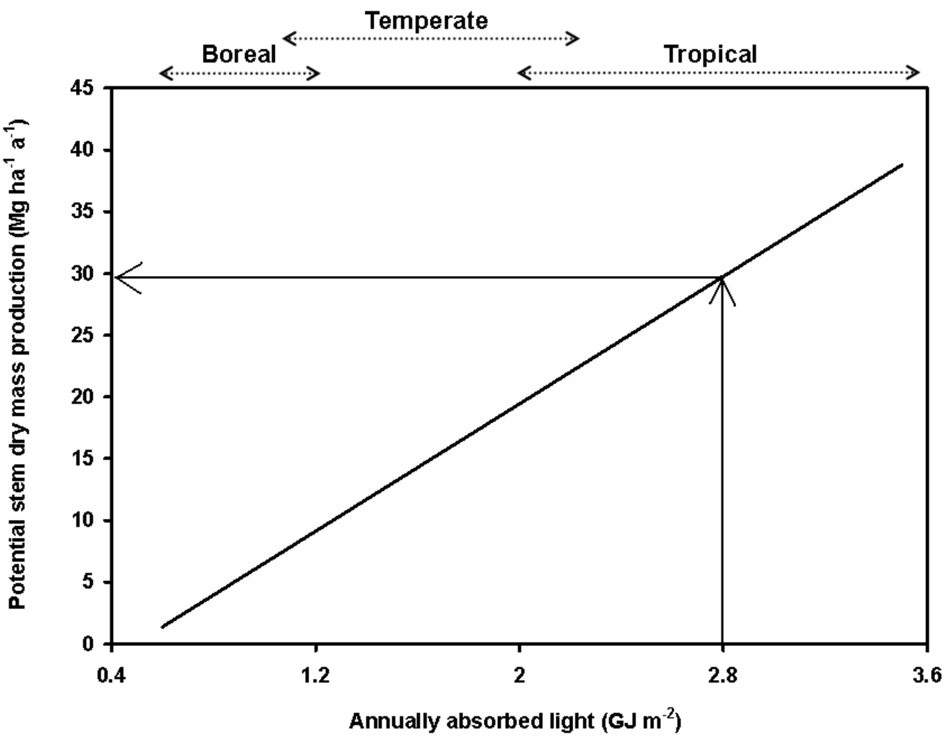

Figure 8: The potential dry stem production (ton/ha) at the latitude of Guangxi (Johan Bergh, personal communication)

Nutrient analysis shows also that it is hard to correct phosphorous (P) defiance's in this trial since the recommended P/N ratio was not reached until a stand age of 68 months in the max fertilized treatment, NPK-300-B *(tab 6).* Factors like low pH in the soil and lack of organic layer in the soil might influence on the phosphorous (P) availability. But genetical improvement for future generations of Eucalyptus stands might move the actual stem production closer to the estimated potential for this area.

In fertilization trials made in Flakaliden (64°07′N, 19°27′E, 310–320 m a.s.l), northern Sweden, the MAI for Norway spruce *(Picea abies)* increased with more than 350% in the stands that were fertilized with a "complete nutrient mixture" that was spread once a year compared to the control plots which was unfertilized (Bergh et al 2005). In fertilization trials made in eucalyptus plantations in Southern China the stem volume growth has increased with 160-740% depending on phosphorous (P) dosage (Daping et al 2002).

A possible reason for why the max fertilized treatment, NPK-300-B, has not responded heavier towards the intensive fertilization regimes is that the trial has been struck by a numerous of disturbances. In 2007 the trial was struck by a fire that damaged many trees and in 2008 it was hit by a typhoon that felled and damaged many trees and also caused a flooding that killed numerous trees. Plots number 10 and 12 were so severely damaged that they were excluded from the trial (Carlsson 2009). These occurrences have probably caused significant growth losses which are impossible to estimate and have therefore influenced the stand development negatively.

An interesting thing to notice is the bark weight. Although the trunk weight/ha is almost 22% lower in the Control the bark weight/ha is eleven percent higher, compared to the NPK-300-B treatment. The difference in both bark and trunk weight is statistically significant with a P-value of 0.0151 respectively 0.0090. Over bark the volume production difference is 56 m^3/ha after 68 months, but the difference is bigger if the under bark volume is compared because the fertilized trees are obviously having thinner bark also this volume difference was statistically significant.

The data in table four and five from 2009 was calculated by using the functions from 2010 on the DBH diameters from 2009. This assumed that the proportions between diameters and amount of leaves, branches and bark were the same in 2009 as it was in 2010.

The current annual increment is steadily decreasing in all treatments, except for treatments NPK-150-B and NPK-150-S who's CAI-curves started going up again in 2009. This sudden growth increase might be a result of the extra phosphorus (P) fertilization being made in 2008. The max fertilized treatment also got extra phosphorus (P) in 2008 but the growth in this plot continued to decrease in contrast to treatments NPK-150-B and NPK-150-S.

The only treatment who's CAI and MAI curves has never crossed (and therefore has not reached its optimal harvesting age) at the current stand age of 68 months is treatment NPK-100-2 *(see appendix fig 4)*. The stand growth increased after the additional fertilization that was spread in spring 2008 and the CAI that started to go down at a stand age of 32 months got slightly positive and increased from 33.65 m^3/ha to 35.16 m^3/ha *(see appendix fig 10)*.

By comparing the two treatments that got exactly the same amount of fertilizers an interesting tendency can be seen. NPK-150-B and NPK-150-S has been treated in exactly the same way, except for that that the fertilizers have been spread in strings in NPK-150-S and broadcasted in NPK-150-B, but reacted very differently after the additional phosphorus (P) fertilizers that was spread in the spring of 2008. The volume production at a stand age of 68 months is pretty much the same but the CAI is differing dramatically. NPK-150-S responded massively on the extra phosphorous being spread in 2008 and the CAI increased from 31.55 m^3/ha to 43.25 m^3/ha between 2009 and 2010, the same figures for treatment NPK-150-B is 27.81 respectively 35.53 m^3/ha *(see appendix fig 2 and 3 and table 2)*. If this trend will continue the total volume production will be considerably higher in treatment NPK-150-S compared to NPK-150-B. This could mean that the production gets more perseverant and higher if the fertilizers are spread in strings instead of being broadcasted although the differencies at an stand age of 68 months where not statistically significant. A possible reasion for this is that grass, shrubs, herbs and other competing vegetation is taking up a higher share of the added nutrients if they are broadcasted and spread evenly over the whole area instead of concentrated to each tree *(fig 9)*.

The treatment with the lowest total production is treatment NK-90 that consistenly has produced less or just slightly more than Control. Why this has happened is hard to understand as although no phosphourus (P) has been added the nitrogen (N) and potassium (K) should not decrease the production atleast. None of the differences mentioned above is significant and is probably only the result of aleatorical differencies in productivity between the parcells.

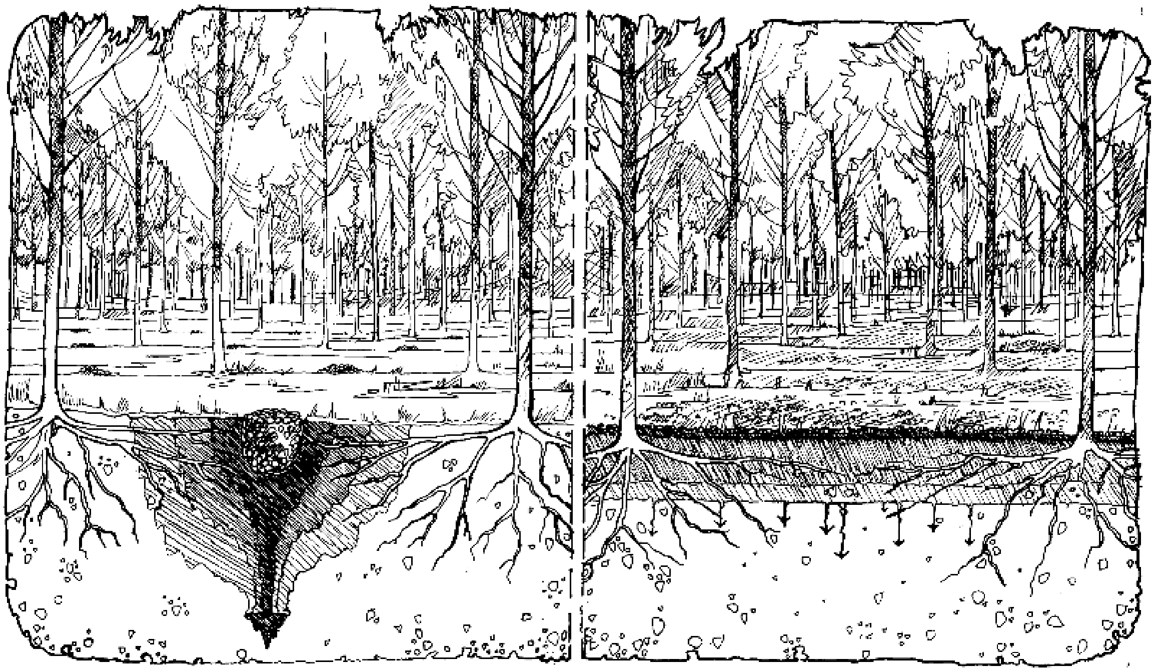

Figure 9: An illustration how the nutrients are distributed and how the roots can react to this depending of if they are spread in strings (left) or broadcasted (right) (drawing by Tove Vollbrecht) (Andersson 2007)

The phosphourus (P) concentration increased with 81% (from 1.18 to 2.14 g/kg dried leaves) in the leaves from treatment NPK-300-B from the analysis made at an stand age of 32 months compared to 68 months. This increase was expected because large amounts of phosphorous (P) that has been added to the plot. What was not expected was the concentration increase in the Control which went up with 59% (from 0.88 to 1.40 g/kg dried leaves). This is harder to explain, especially since the concentration increased with almost 40% between 44 and 68 months, unfortunately I have no leave nutrient analysis data from 56 months. This sudden and drastic increse might mean that a mistake has been done when the fertilizers has been spread and that the Control treatment has been fertilized by mistake *(tab 5).*

There was three hypotheses for this study: (i) that the mean basic density will be the same in the samples taken this year as those taken in year 2008 by Peter Genfors, (ii) that phosphorous (P) is crucial for the growth which has been indicated in several previous trials (Daping et al 2002 and Goncalves et al 2004). And (iii) the volume production is highest in the treatments that have been fertilized continuously.

The second and the third hypothesis proved to be correct in this study, the treatments that has gotten the most phosphorous (P) also have the highest growth. The volume production is highest in treatments NPK-150-S, NPK-150-B and NPK-300-B that has been continuously fertilized *(appendix, tab 1).* The mean basic density is, however, considerably higher compared to 2008, 15% and 13% respectively for the Control and NPK-300-B treatment *(tab 3).* The CAI sank from 37.05 to 22.40 m^3/ha in the Control treatment and from 48.12 to 36.50

m^3/ha in the NPK-300-B treatment between a stand age of 44-68 months. This production decrease was partly compensated by the increased mean basic density.

The density difference between the two treatments were far from being significant in 2008 (P=0.4464) but in 2010 the difference was significant (P=0.0422). This surprised me cause Swedish broad leaves, like *Populus tremula, Betula pendula/ pubescens, Alnus incana/ gluttinosa etc,* has the same density no matter of how fast they grow. And some broadleaves, like *Quercus robur/ petrea, Ulmus glabra, Fraxinus excelsior, etc,* even gets higher mean basic density the faster they grow (Fahlvik et al 2009).

Table 12: The nutrient concentration, in percent, in the different parts of the tree for the Control treatment

Nutrient concentration (%)

Part of the tree	N	K	P	Ca	Mg
Trunk	0.11	0.04	0.01	0.08	0.01
Leaves	1.48	0.71	0.14	0.48	0.17
Green branches	0.33	0.32	0.07	0.25	0.08
Bark	0.34	0.24	0.05	0.68	0.14

Table 13: This data is coming from a study made in 1983 by John Turner and Marcia J. Lambert in a “Eucalyptus grandis” stand in New South Wales, Australia (Turner et al 1983)

Nutrient concentration (%)

Part of the tree	N	K	P	Ca	Mg
Sapwood	0.08	0.08	0.01	0.06	0.02
Heartwood	0.05	0.01	0.00	0.04	0.01
Leaves	1.47	0.65	0.09	0.48	0.27
Green branches	0.32	0.32	0.03	0.22	0.20
Bark	0.22	0.25	0.02	1.94	0.16

Although the trees have been grown thousands of km apart, the Control treatment in southern China and the comparison in southern Australia, the nutrient concentrations are similar although they probably have grown under very different conditions. The nitrogen (N) concentration is almost identical in the leaves and green branches, only differing 0.01%. The situation is the same for potassium (K) in green branches and bark, for magnesium (Mg) in the wood and bark and for phosphorous (P) in the wood. The biggest nutrient concentration differences can be seen in calcium (Ca), the bark from the Control treatment contains less than half as much as in the stand studied by John Turner, also the concentrations of phosphorous (P) deviates about 50% up or down for leaves, green branches and bark *(tab 12 and 13).*

5.1 Conclusions

The production of nitrogen (N) is extremely energy demanding and an absolute majority is produced with fossil fuels as energy sources, mainly natural gas or oil (Cavallius 2006). In 2009 the International Energy Association, IEA, warned that the world is facing "a global energy crisis" following the depletion of oil and gas resources (Ohlsson 2009). It is very hard to estimate how this will influence the price of nitrogen (N), but will most likely increase in the same pace as the cost for oil and gas, if it cannot be fueled in another way.

Phosphorous (P) is mined as phosphate rock and is an in commutable and crucial part in all kinds of artificial fertilizers produced for the agriculture. It is thanks to mined phosphor the "green revolution" has been possible, making the world's population increase to the number we are today (Färnbo 2010).

2/3 of the worlds known resources of phosphate rock are situated in China, Morocco and West Sahara (which is occupied by Morocco) (www. sweden.gov.se). In late 2006 China suddenly raised the export taxes with 135% on phosphate rock to discourage export. The coming 14 months the price for phosphate ore rose with more than 700%. The price has gone down since this peak but is still more than three times as high as it was before Chinas sudden tax increase (Falklöf 2009).

"The Global Phosphorous Research Initiative" is an international cooperation between five different institutes around the world: "University of Technology in Sidney Australia, Civil Engineering Department, University of British Columbia, Vancouver Canada and Stockholm Environment Institute, Sweden. This team has estimated when the breaking speed cannot increase and the production of phosphorous (P) starts declining, the curve is simply called "Peak Phosphorous". According to this prognosis the phosphorous production will start declining around 2030 *(fig 10)* (Sustainable Phosph, 2011).

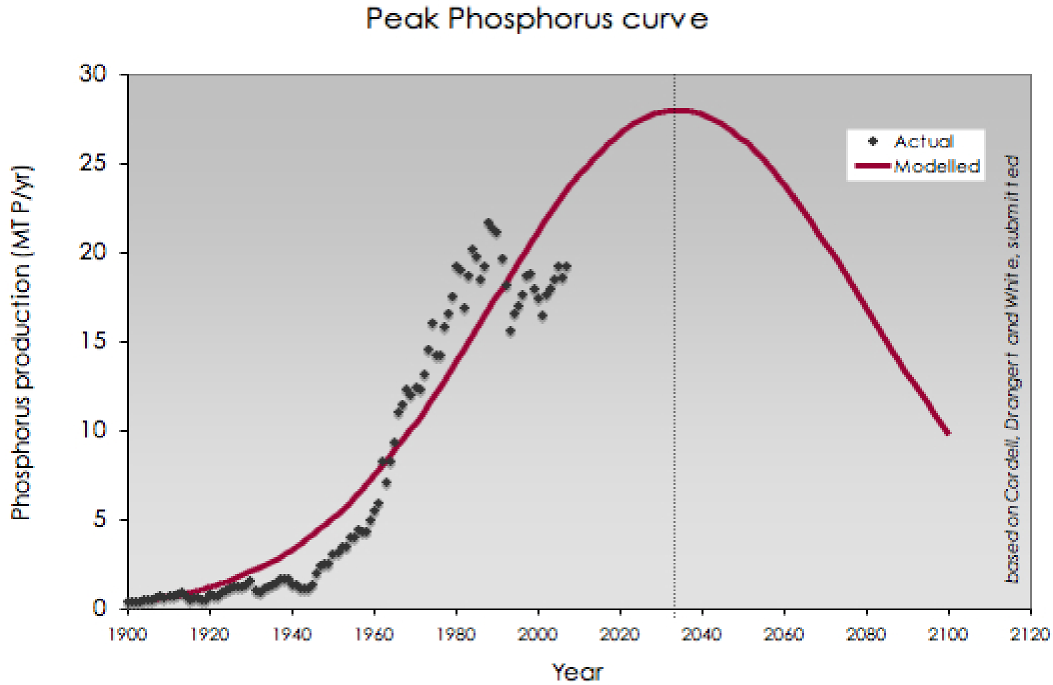

Fig 10: The prognosis over the phosphorous (P) production the coming decade made by the organization “The global phosphorous research initiative” (Cordell 2010).

If the future mill will produce 700 000 Adt of BHKP the annually needed amount of wood to the mill will be around 3 430 000 m^3 (4.9 m^3/ Adt BHKP * 700 000 Adt BHKP). This means that if StoraEnso will not be able to get more land than the planned 120 000 ha the MAI needs to be at least 28.60 m^3/ha (this is the total stem wood production; some losses will be made in the harvesting and transportation so this figure needs to be higher in a realistic prognosis). Meaning the growth in the Control treatment is simply not high enough to provide a mill of this size with enough pulp wood, simply because the MAI reaches only 27.79 m^3/ha when the growth peaks at 56 months *(appendix fig 7)*. Since the only treatment that gives a statistically significant increased wood volume production, compared to the Control, is the max-fertilized treatment: NPK-300-B this is the only alternative if StoraEnso is not able to get more land, can increase the growth by improving the genetical material planted or improving the production in any other way

The U.S Geological Survey wrote in a report called: “Summary of phosphates”:
“The agriculture is addicted to mined phosphates, because there are no substitutes for phosphorous in agriculture” (Déry et al 2007).

This makes me believe that the prices for especially phosphorous (P) (since it’s a resource capable of being depleted) but also nitrogen (N) (since the production is very energy intensive) will increase rapidly, or at least fluctuate strongly, in the coming decades. And I think that it would be very hazardous for the future pulp mill to get dependent on wood produced with fertilizers that can get very expensive in the future.

But it is important to remember that these conclusions are based on only one trial and that a serious of trials on different soils is needed to be able to make secure implications.

In the parts of the StoraEnso plantations I visited the local inhabitants took all available branches and bark and used it for fire wood. In the long run this is dangerous since this will lead to soils that is lacking in both nutrients and organic material which will result in both a very poor soil structure making it very compact (Klevje 2008) and unproductive (Daping 2002). In some cases the villagers has even harvested the stumps (Tony Ohlsson, personal communication) which will cause or worsen already existing erosion problems. Therefore I would recommend StoraEnso to provide the local villagers with wood, or find some other solution to the problem.

One thing that can be further examined is whether the “base compound” being spread at planting time and six months after planting (Andersson 2007) gives a statistically significant stem growth increase. In the only treatment that gives a statistically significant growth increase, NPK-300-B, an annual ration of 1 875 kg/ha fertilizers is spread compared to the 687.50 kg/ha every seventh year that is spread as a “base compound” *(tab 8)*. This makes me think that a trial comparing stands fertilized with “base compound” and a totally non-fertilized would be of interest.

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7. Appendix

7.1 CAI/ MAI curves for all treatments

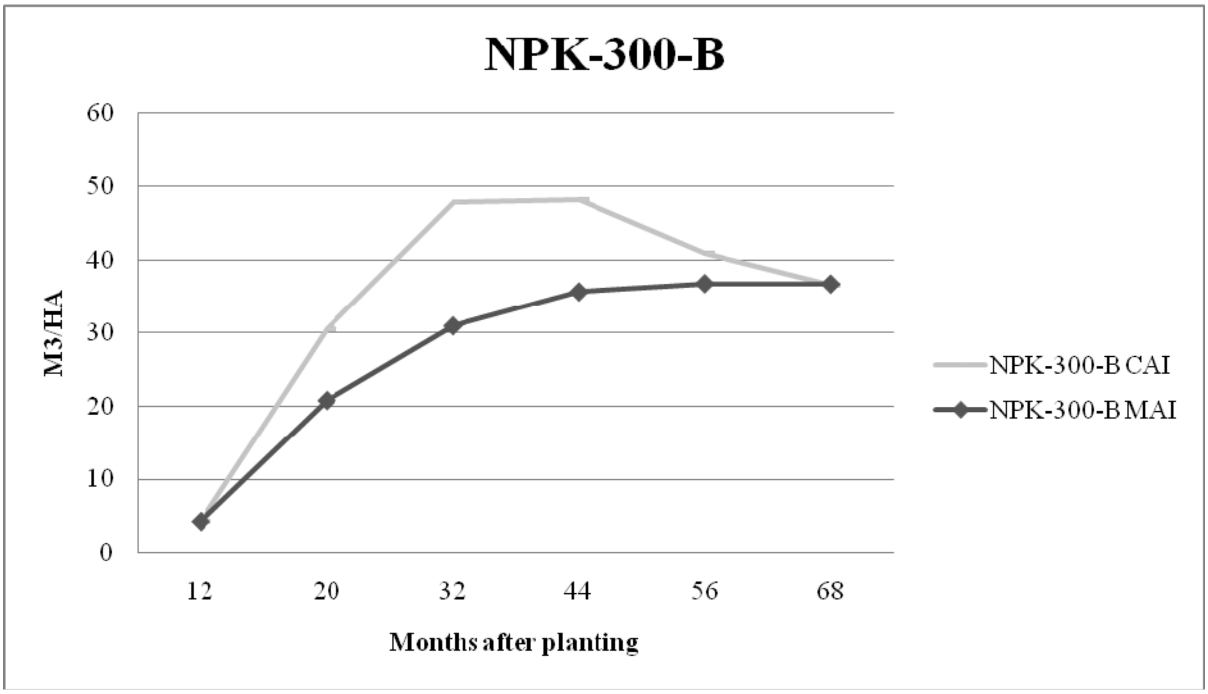

Figure 1: the CAI respectively MAI curves for treatment NPK-300-B

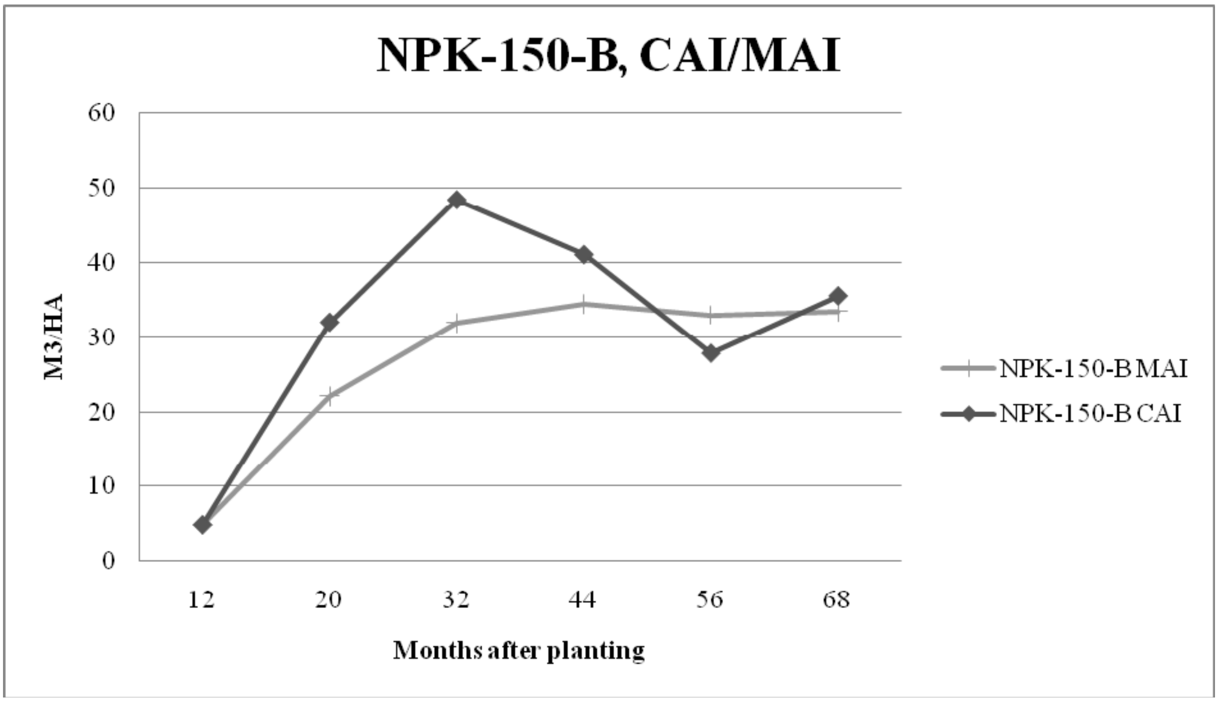

Figure 2: the CAI respectively MAI curves for treatment NPK-150-B

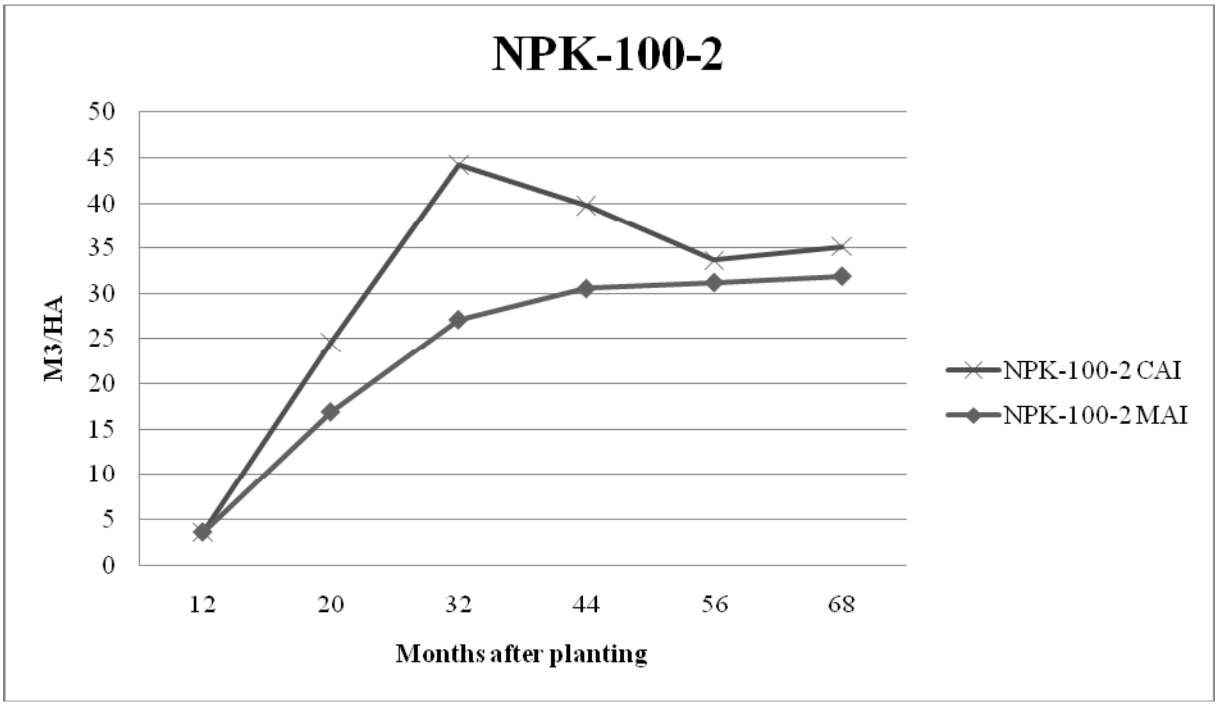

Figure 3: the CAI respectively MAI curves for treatment NPK-100-2

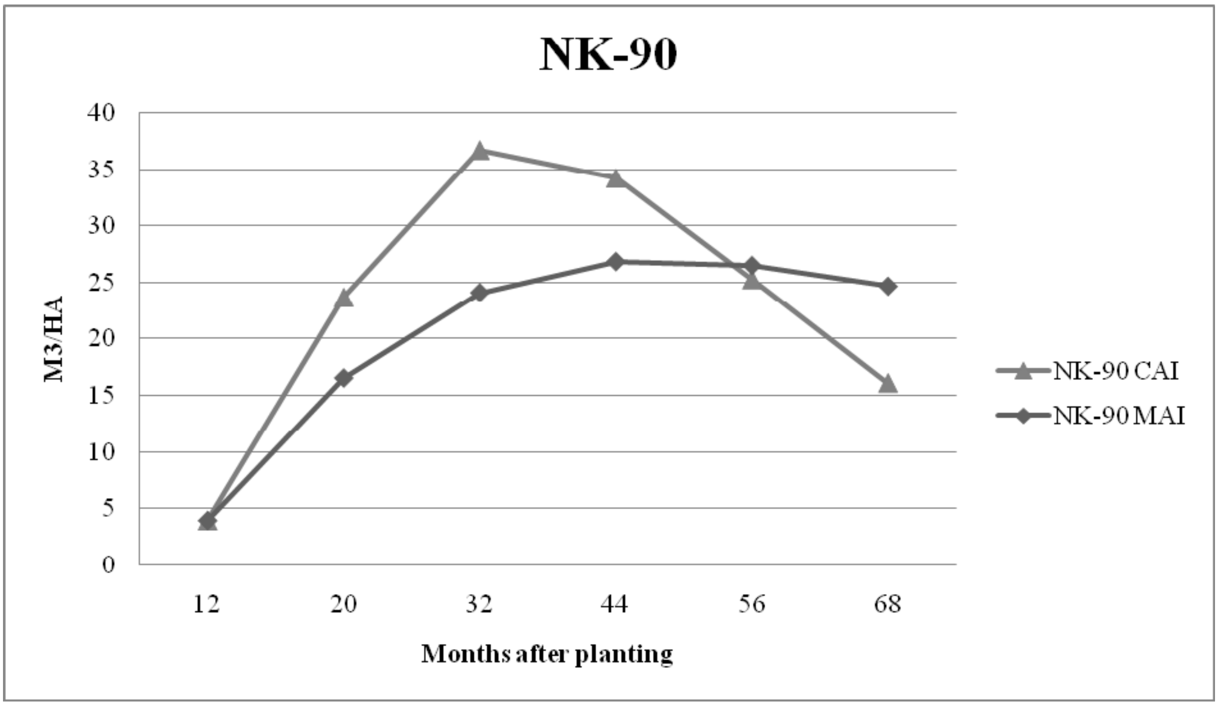

Figure 4: the CAI respectively MAI curves for treatment NK-90

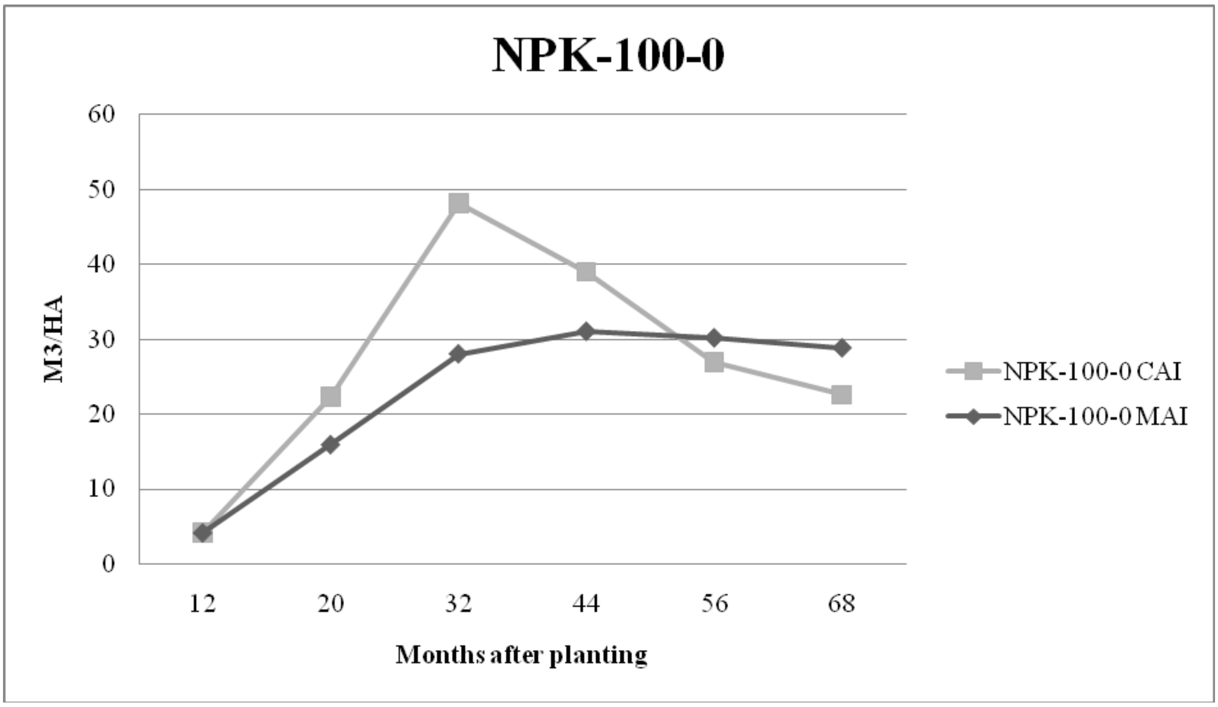

Figure 5: the CAI respectively MAI curves for treatment NPK-100-0

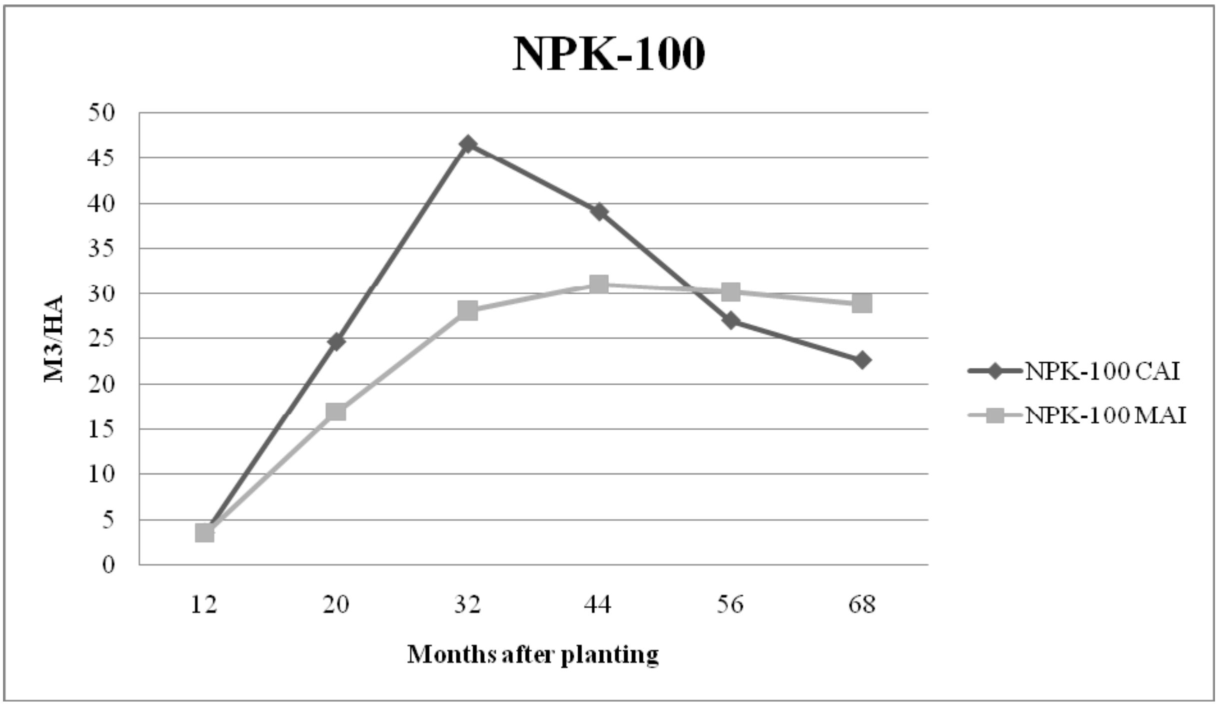

Figure 6: the CAI respectively MAI curves for treatment NPK-100

Figure 8: the CAI respectively MAI curves for the Control treatment

7.2 Volume, CAI and MAI tables for all treatments

Table 1: The total volume production for all treatments, OB (m^3/ha)

Volume, OB, (m^3/ha)

	Stand age					
Treatment	12	20	32	44	56	68
Control	3.21	28.33	64.96	102.02	129.69	152.10
NPK 100	3.57	28.21	74.79	113.82	140.80	163.43
NPK 100-0	4.23	26.58	74.70	113.67	123.68	163.22
NK-90	3.88	27.53	64.24	98.44	123.68	139.75
NPK 100-2	3.59	28.16	72.35	112.06	145.70	180.86
NPK 150-S	3.45	28.48	74.05	118.08	149.64	192.89
NPK 150-B	4.83	36.82	85.21	126.24	154.04	189.58
NPK 300-B	4.33	34.73	82.58	130.70	171.57	208.07

Table 2: The current annual increment for all treatments in m^3/ha

Current annual increment, CAI, (m^3/ha)

	Stand age					
Treatment	12	20	32	44	56	68
Control	3.21	25.11	36.64	37.05	27.68	22.40
NPK 100	3.57	24.63	46.59	39.02	26.98	22.64
NPK 100-0	4.23	22.34	48.12	38.97	26.95	22.61
NK-90	3.88	23.65	36.71	34.20	25.25	16.06
NPK 100-2	3.59	24.58	44.19	39.70	33.65	35.16
NPK 150-S	3.45	25.03	45.57	44.03	31.55	43.25
NPK 150-B	4.83	31.99	48.39	41.03	27.88	35.53
NPK 300-B	4.33	30.40	47.85	48.12	40.88	36.50

Table 3: The mean annual increment for all treatments in m^3/ha

Mean annual increment, MAI, (m^3/ha)

	Stand age					
Treatment	12	20	32	44	56	68
Control	3.21	17.00	24.36	27.82	27.79	26.84
NPK 100	3.57	16.92	28.05	31.04	30.17	28.84
NPK 100-0	4.23	15.95	28.01	31.00	30.13	28.80
NK-90	3.88	16.52	24.09	26.85	26.50	24.66
NPK 100-2	3.59	16.90	27.13	30.56	31.22	31.92
NPK 150-S	3.45	17.09	27.77	32.20	32.07	34.04
NPK 150-B	4.83	22.09	31.95	34.43	33.01	33.45
NPK 300-B	4.33	20.84	30.97	35.64	36.77	36.72