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FACULTEIT TOEGEPASTE BIO-INGENIEURSWETENSCHAPPEN

Academiejaar 2012 - 2013

Logistics of production and breeding of hardwood *Melia volkensii* in Kenya

Logistiek van productie en opkweek van hardhout *Melia volkensii* in Kenya

Masterproef voorgedragen door

Korneel Neysens

tot het bekomen van de titel en de graad van

Master in de biowetenschappen: land- en tuinbouwkunde
Afstudeerrichting tuinbouwkunde

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Ghent, July 2012

Promotor	Co-promotor	Author
Prof. Dr. Ir. Stefaan Werbrouck	Dr. Ir. Jan Vandenabeele	Korneel Neysens

Preface

At the beginning of this thesis, I would like to thank some people. Without their help, I could've never completed this piece of writing.
First of all a word of appreciation for the Better Globe Forestry Ltd. company to give me this chance and opportunity to gain field experience on the full package of a forestry project and for their financial support of this project. My thanks towards the people at the office in Nairobi but also towards the manager of the plantation at Kiambere, Mr. John Njeru, the local representative of BGF Ltd. Mr. Samuel Nakhone, the supervisor Mr. Bernard Mucune, Mr. Benson Matuku for the daily trip to the plantation and all the other collaborators at the plantation in Kiambere for their help, advice, support and understanding.

My special thanks goes to Ir. Jan Vandenabeele, the executive director at BGF Ltd. His managing skills, knowledge, experience and fresh-wind-blowing mentality have taught me a lot during my stay in Kenya. He supported me and stood with me the entire time, during my stay and the time beyond. Other logistic support came from the KenGen, Kenya Electricity Generating Company. They made it possible to stay at Kiambere, under very good conditions. Apart from that, they provided the daily transport to the plantation. Thank you.

This internship could only be made possible with the help and support of University/ College of Ghent, a special word of appreciation for the department of applied-bioscience to provide this opportunity. A huge word of thanks for Mrs. Nathalie De Bie, Mrs. Sofie Truwant, both of the service for international exchange, and Mr. Geert Baert. Their help and information to obtain a scholarship was a boost. The scholarship could not be provided without the help of VLIR-UOS (Vlaamse Interuniversitaire Raad – Universitaire Ontwikkelingssamenwerking) and without the scholarship, this journey would have never be possible.
Apart from the plantation, I also had the chance to use the laboratory facilities in Kabete. Mr. Titus Maghomere provided me with words of help, concerning the subject of writing, but also with a lot of tips, hints and other information concerning the use of the laboratory.

Apart from the Kenyan party, there is also a Belgian party worth mentioning.
First of all, I would like to thank Prof. Dr. Ir. Stefaan Werbrouck, the promotor of this thesis. He made it possible to start with this subject and to complete it. He is a driving force behind

the ideas and helped me as good as he could. He stood at the sideline for the complete run and supported me until the end.
A special word of thanks for saviour Soetkin, who was able to hand in this thesis in my place, because I could not deliver it personally.
To end this preface, I would like to thank everyone who helped me, in one way or another completing this four years of education and this piece of writing, who believed in me, 'till the end. Apart from this, also a special thanks to friends, relatives, family, who supported me during this three months by providing me with tons of e-mail.
Thank you.

Korneel Neysens
Ghent, August 2012

Abstract

This thesis gives an overview of the efficiency of the seedling production chain and plantation maintenance tasks of *Melia volkensii* on the Better Globe Forestry plantation at Lake Kiambere, Mbeere district, Kenya.
In-field observations were compared to the initial task rates and conclusions were based upon this. Observed tasks were: fruit sourcing, fruit depulping, cracking of the nuts, nipping of the seeds, slitting of the seeds, sowing of the seeds, transplanting of the seedlings, filling and arranging the polybags, marking the field for planting holes, digging of the actual planting holes, making a catchment dam, mulching around the seedlings, watering the seedlings in the field, pruning of the trees and weeding in the field. Moreover, the long term effect of an the fertiliser Mavuno (two trials) has been revised after three years. The first trial was to determine the effect of different quantities (0 g - 50 g - 100 g) of fertiliser. Results showed that the effect of applied fertiliser wore off, the third year of growth. The second trial was to determine the effect of two consecutive quantities (50 g - 100 g en 0 g - 100 g - 200 g - 300 g) of fertiliser. Results show that 100 g of fertilisation applied during planting, followed by 100 g 8 months after planting has the most beneficial impact of tree height and stem diameter. The flower biology of *M. volkensii* was studied, and finally, elite tree cuttings were initiated *in vitro* as a first step of a micropropagation program of elite *M. volkensii* trees.

KEY WORDS: *Melia volkensii,* task analysis, ergonomics, fertilisation, mature material micro-propagation.

Abstract

Deze scriptie geeft een overzicht van de efficientie van de productie, het kweken van en plantage onderhoudswerken van *Melia volkensii* op de Better Globe Forestry aanplanting aan Lake Kiambere, Mbeere district, Kenia.
Observaties in het veld werden getoetst aan de initiële task rate, waarop conclusies dan gebaseerd werden. Observaties van de taken waren: vruchten bekomen, ontpulpen van de vruchten, breken van de noten, zaden ontdoen van het uiteinde van de zaadhuid, aanbrengen van een snee in de zaadhuid, zaaien van de zaden, verplanten van de zaailingen, vullen en (ver)plaatsen van de plantzakjes, markeren van het veld voor plant gaten, graven van de plan gaten, maken van een opvang bassin voor water, *mulchen* rond de zaailingen, bewateren van de zaailingen in het veld, snoeien van de bomen en het onkruid wieden in het veld. Verder werden de langer termijn effecten van toegepaste Mavuno bemesting opgevolgd na drie jaar (twee proeven). Bij de eerste proef werd het effect van drie dosissen bemesting (0 g - 50 g - 100 g) getest. De resultaten tonen aan dat het effect na drie jaar geneutraliseerd is. Bij de tweede proef werd het effect van opeenvolgende dosissen (50 g - 100 g en 0 g - 100 g - 200 g - 300 g) bemesting getest. De resultaten tonen aan dat 100 g bemesting bij het planten van de zaailingen gevolgd door 100 g mest acht maanden na aanplanten de meest gunstige impact heeft op de hoogte en stamdiameter van de bomen. De bloembiologie van *M. volkensii* werd bestudeerd en ten slotte werden stekken van elite bomen geïnitieerd *in vitro* al eerste stap naar een microprropagatie programma van *M.volkensii* bomen.

KEY WORDS: *Melia volkensii*, taak analyse, ergonomie, bemesting, micropropagatie van matuur materiaal.

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List of abbreviations

2,4-D	2,4-Dichlorophenoxyacetic acid
ABA	Abscisic acid
BAP, BA	6-benzylaminopurine, 6-benzyladenine
BGF	Better Globe Forestry Ltd.
IAA	Indole-3-acetic acid
IBA	Indole-3-butyric acid
ISO	International organisation for standardisation
memTR	Meta-methoxy topolin
mTR	Meta-topoline riboside
NAA	Naphtalene acetic acid
NaFeEDTA	Sodium iron Ethylenediaminetetraacetic acid

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Introduction

Planting trees in Kenya is a rather hard business. The environment is very hostile and the economic status of the country is not ideal to start up a blooming and booming business. Since *Melia volkensii* is the ideal tree to be planted, because of its indigenousness, termite resistance and valuable hardwood, Better Globe Forestry Ltd. (BGF) started up a plantation in several parts of the country. The pilot plantation at Lake Kiambere is still the first and biggest one. The ambition of BGF is to become the largest tree planting company in the world within 20 years. This implies they need land to cultivate, employees to work with, enough planting stock, knowledge to be self-sustainable and money to buy their needs.

An important part of this thesis was the follow up of the production process from fruit to seedling and field maintenance tasks. It contains a lot of steps, and their efficiency could be improved by careful observations and timing. Mortality of the seedlings in the nursery, loss at each point in the production process, due to inefficiency or inaccuracy or simply because the shortage of tools and/or working space should be avoided. Factors such as working environment or ergonomic conditions for the employees are underestimated factors but nonetheless of great importance for the efficiency.

Elite *Melia volkensii* can be propagated vegetative by cuttings, grafting and micro-propagation. Cuttings of mature trees don't root very easily and grafting on seedlings has not been applied on a large scale ye. The plantations would suffer from heterogeneity induced by the rootstock. Micro-propagation could have potential for large scale production of full clones of elite plantlets. Up to now, most research has dealt with juvenile seedlings since all efforts to initiate mature elite trees failed due to problems with logistics. Therefore, a secondµ task was the initiation in vitro of a number of elite trees.

Finally, the long term effect of fertilisation experiment started in 2009 has been followed up, in order to complete the observations of previous students.

These chapters are meant to lead to the main hypothesis: *'Is it possible to optimise the production and breeding of hardwood in Kenya?'*

I Literature review

1 Melia volkensii

1.1 Introduction

Melia volkensii (Gurke) belongs to the family of the *Meliaceae*. Its area of natural distribution is the arid to semi-arid zone of Ethiopia, Somalia, Tanzania and Kenya, situated 400-1600 m above sea level (Juma, 2003).

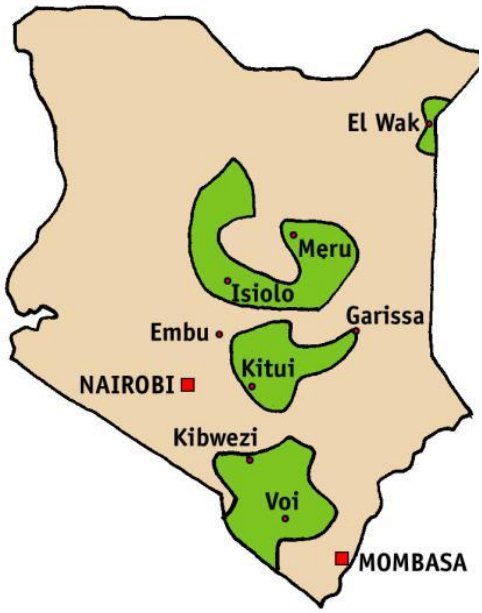

Figure 1: Distribution of *M. volkensii* in Kenya (Kwiga et al., 2009)

It is a drought resistant tree, which thrives on well-drained soils from sandy loam to sandy clay. It is naturally found along watercourses and in Acacia woodlands, but it certainly does not tolerate areas prone to water logging (Muok et al., 2010; Juma, 2003). It is a deciduous tree, with an open canopy, able to reach 20 m of height. Its bark is greyish, smooth and furrowing with age (Orwa et al. 2009). The hearth wood is pale red/brown and the timber is immune to termites (ICRAF, 2005).

1.2 Classification

Melia volkensii is classified as the following:

Domain	Eukaryota
Kingdom	Viridiplantae
Phylum	Spermatophyta
Subphylum	Angiospermae
Classis	Dicotyledonae
Ordo	Rutales
Familia	*Meliaceae*
Subfamilia	*Meliodeae*
Genus	*Melia*
Species	*Melia volkensii*

(ICRAF, 2005)

M. volkensii has a lot of local and/or native names:

Mukau (Kamba, Kikuyu), Bamba (Borana), melia (English), Baba (Somalia) (Juma, 2003).

1.3 Morphology

1.3.1 Flower

Very little is known about the flower biology of the *M. volkensii*. Although some studies on the flowers were done, information is contradictorily and not very clear.

Styles (1972) described the flowers of the *Meliaceae* are either female and male or hermaphrodite and male, but both perfect. The latter meaning both flowers contain both female and male parts (*i.e.* ovary/pistil and stamen/anthers). Male flowers are in general smaller than female/hermaphrodite flowers (Mabberley, 2011).

The genus *Melia* bears hermaphrodite and male flowers. Although it is very hard to distinguish the external difference between the functional and the not functional female flowers (*resp.* hermaphrodite and male), the internal differences are clear.

The ovary of both flowers may look normal in size and shape, the ovules of the male flowers are minute and rudimentary, brownish in colour and abortive. The ovules do not completely fill the loculi of the ovary as they do in functionally female flowers. Such a sterile ovary is known as a pistillode and is incapable of developing any further.

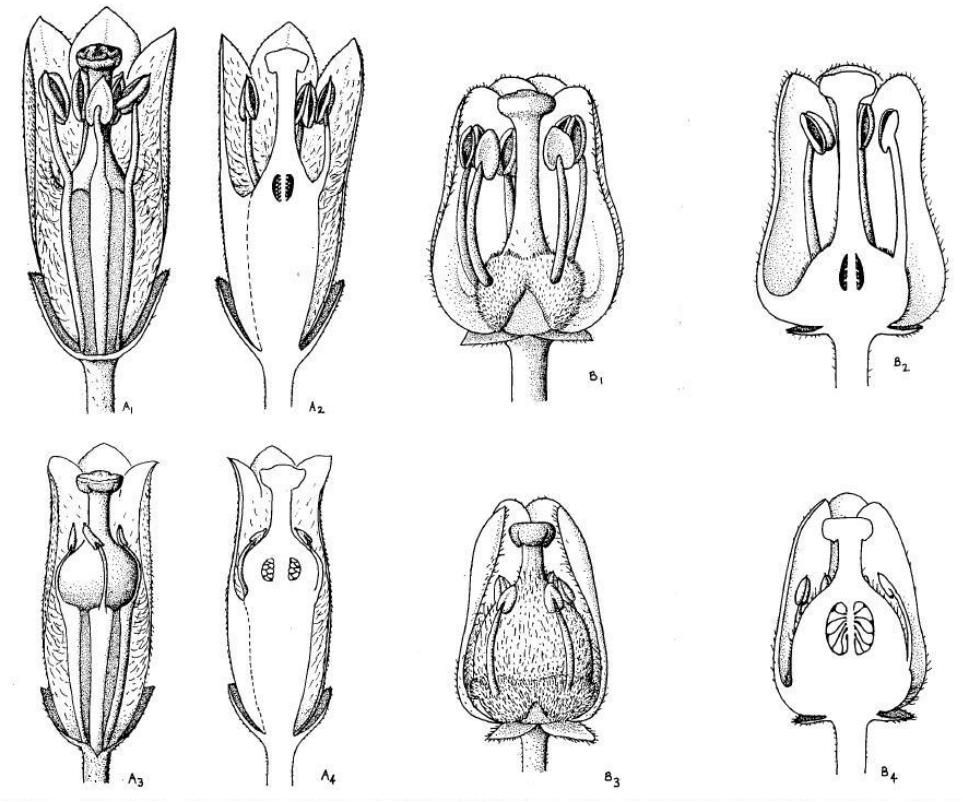

Figure 2: *Meliaceae* – (drawings) – (A1) Whole male flower of *Cedrela odorata* with 2 petals removed to show fertile anthers; (A2) semi section of same flower showing pistillode and abortive ovules; (A3) whole female flower with 2 petals removed to show antherodes; (A4) semi section of same flower to show ovary and ovules (all x6, from Pennington and Sarukhán 9650). – (B1) Whole male flower of *Toona ciliate* with 2 petals removed to show fertile anthers; (B2) semi section of same flower showing pistillode and abortive ovules; (B3) whole female flower with 2 petals removed to show antherodes; (B4) semi section of same flower to show ovary and ovules (all x6) (Styles, 1972)

The ovary in functional female flowers contains large, fleshy and translucent ovules. The ovary is surmounted by a short style and a thickened style-head.

Immediately after fertilisation, the ovary starts to develop and it appears to turn brown or black in colour. All genera in *Meliaceae* except *Cedrela* and *Toona* have flowers with the filaments of the androecium partially or completely joined to form a staminal tube (Styles, 1972).

On the tree, the flowers occur in large, much-branched and complex inflorescences, called panicle. Although a more correct term is thyrsi or thyrsoid (Mabberley, 2011).

The number of branches is variable and the central axis is indeterminate in growth, but each ultimate branchlet always ends in a cymule of 3 (or rarely 2) flowers, and thus a 2- or 3-flowered dichasium (Style, 1972).

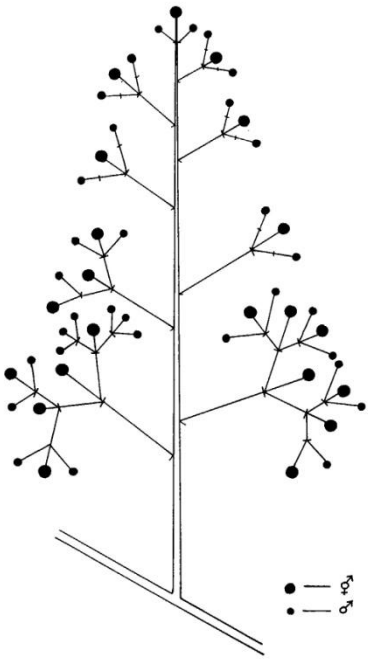

Figure 3: Diagram of thyrsi of genus *Melia*, showing positions of male and hermaphrodite flowers (Styles, 1972)

According to Juma, the flowers are small, white and fragrant. The inflorescence is up to 12 cm long and placed on older branches. It is pollinated by insects, but also self-pollinating (Juma, 2003). ICRAF (2005) mentioned *M. volkensii* has dense-head panicles bearing small white flowers. The inflorescence appears on older branches, is up to 12cm in length and axillary. The petals tetra- to pentamerous petals are 5mm to 7mm long, white, free and they might curl backwards. Apparently male and female flowers appear on the same tree. Further, ICRAF (2005) stated the amount of stamen is equal to the number of petals, and they are united in a tube. Orwa et al. stated the flowers as small, white and fragrant, occurring in loose sprays. The inflorescence is congested and up to 12 cm in length and axillary (Orwa et al., 2009).

1.3.2 Fruit

The fruits are large green oval droups. The endocarp is very thick and as hard as ebony. The fruits can be up to 4 cm long. It has a star-like 5-lobed apical depression and a rose-like 5 lobed basal depression. The occur in clusters onto an older branch on the tree (Juma, 2003). As the fruits age, they turn grey due to the deposit of cork in the exocarp (Jøker, 2003).

1.4 Phenology

1.4.1 Flower

Due to the lack of knowledge and insights into the flower biology of the M*eliaceae*, little is known about the pollination mechanism. It is reported, by Albrecht (Albrecht, 1993), that bees visit the flowers of the *M. volkensii*. Apart from bees, moths are very important pollinators of many trees, among which *Meliaceae* species (Finkeldey & Hattemer, 2007). Since nectary disks between ovary base and androecium are common in flowers of the genus *Melia* – although not every species – it can be assumed insects perform an important role in the pollination mechanism of the *Melia*. Even stronger: Mabberley (2011) stated most *Melia* species appear to be insect-pollinated, the agents possibly being bees, sting-less swatbees or syrphids. Other reports indicate *M. volkensii* as a self-pollinating species. (Milimo, 1994).

The monoecious nature of the flowers (Styles, 1972) can indicate that the male flowering period of a given tree can be shorter, so one of two synchronously flowering trees may fertilise the other but not vice versa. This translates in the fact that the number of near potential mates reduces – because of the asynchronous flowering – and the impact of far-distance pollen becoming more effective. This is very important, considering refining the *M. volkensii* for economical purpose. (Finkeldey & Hattemer, 2007).

1.4.2 Fruit

At first it was believed and proved that *M. volkensii* produces fruits twice a year, at the end of the dry season, when the leaves emerge. Later studies proved that fruits take 12 to 13 months to develop from onset of flowers to maturity. The development lacks seasonal patterns. This makes it possible to have a tree flowering and ripening fruits at the same time, even on the same branch. It also means that on the same site, trees can flowering or fruiting at different times (Kiduno, 1996).

1.5 Importance of *M. volkensii*

The *Melia* is one of the indigenous timber species in drylands. Although there are other dryland species, studies rate *Melia* as among the best (Wekesa et al., 2012).
The worthiness of *Melia* stems from its growth characteristics and uses. *Melia* has fast growth and exerts minimal competition to crops. Under good management, the tree could be harvested from as early as at 5 years of age as poles and fodder as well as firewood. From 10

years of age, its log can be sawn into high quality timber for quality furniture making as well as construction (Wekesa et al., 2012).

Melia volkensii is used for construction timber and fuelwood. In addition, the tree is used as fodder (fruit and leaves); medicine (bark), bee forage (beehives), mulch and green leaf manure (Omondi et al., 2004). It is also reported that some people use leave extracts of *M. volkensii* on the skin of goats to control ticks and fleas. The insecticidal properties of *M. volkensii* are widely documented, suggesting that the farmers' practices could be technically justified (Mwangi & Mukiama, 1988; Kimondo & Kiamba, 2004).

Mulatya and Misenya (2004) observed that the dark heartwood of *Melia* compares favourably with highly priced hardwood species as *Ocotea usambariensis* and *Vitex keniensis*. Its wood is durable and termites tolerant and resistant. It is thus suitable for making acoustic drums, containers, mortars, door and window frames and poles (Mulatya & Misenya, 2004).

Studies have shown that Melia is a fast growing species producing quality timber in 10 to 12 years. The growth is even faster of farm than in the wild, suggesting tremendous potential gains through domestication (Muchiri & Mulatya, 2004).

It is fast growing, tolerant to dry conditions and is compatible with most crops, though management through root and crown pruning is necessary and recommended to minimise competition, since studies have shown that there truly is a negative tree – crop interaction, when the soil moisture is limiting (Indieka & Odee, 2004).

2 Propagation of *M. volkensii*

2.1 Classical propagation of *Melia volkensii*

2.1.1 Generative propagation

A lot of research has been conducted towards the germination of *M. volkensii* through seeds, since this is a very difficult and a not-well understood mechanism due to dormancy of the seed coat (Omondi, 2004). Schmidt (2000) described the type of seed dormancy of the *Melia* as mechanical, whereas Indieka (2005) dedicated the problem of germination of seeds to both physical and physiological problems. The seed coat is able to inhibit the exchange of gas and water absorption. Even an embryonic development and growth is impossible (KEFRI, 2004). This mechanical restriction can be overcome: 1) to allow the embryo expansion by gradual softening of the seed coat, or 2) by extraction of the seeds from the restricting seed coat. The seed coat is not the only challenge. Seeds are enclosed by a stony endocarp, which are inside the fruit.

The fruit is the actual first obstacle for generative propagation. It is hard to distinguish mature (*i.e.* ripe) from immature fruits. Mature fruits can be distinguished by the soft mesocarp and the yellowish-green colour of their exocarp. The fruit maturity also depends on the amount of cork on the fruit. When deposition of cork is heavy, the fruit colour varies to grey, resulting in a very hard fruit to recognise when ripe (Milimo, 1986). Since immature fruits will give immature seeds, this is a first problem to counter when considering generative propagation of *M. volkensii*.

Milimo (1986) expounded a procedure, to extract the seed of *Melia volkensii* from its stony endocarp, involving a removal of the stones from the fruit, a horizontal crack of the stones with a knife (not to deep else the seeds can be damaged), a removal of the seeds and a subsequent soak in (warm) water.

Muok et al. (2002) gave an overview of the propagation of *Melia volkensii* through seeds. Germination rate of 80% within 5 to 7 days after planting was achieved when the following procedures were used:

- Collecting fresh mature fruits;
- Depulping them;
- Extracting the seeds from the nut without injuring the seed;

- Pre-treating the seeds through nipping, soaking overnight in cold water, slitting to break the inner and outer seed coat using a razor blade;
- Sowing the seeds in sterilised or fumigated medium.

Vandenabeele (2011) revised Muok et al.'s (2002) work instructions for *Melia volkensii* seedling production to apply it for seedling production for a vast plantation of *Melia volkensii* in Keyna, according to the following:

1 The propagation of *M. volkensii* starts with the collection of fresh and mature fruits. The best period to collect the fruits is April-August, with a peak in July, but the collection is possible year-round.
2 The fruits are depulped: they are being hit by a piece of wood, within a week after arrival at the plantation. The depulping leads to the extraction of the nut.
3 The extracted nut must first dry for 2 hours in the sun. Hereafter there is a selection phase: only brown nuts proceed in the process. Whitish or darkish nuts are removed.
4 The dried nuts are being cracked. This is done using a specific seed extractor or by hitting the nut with a panga. The panga is placed perpendicular on the long axis of the nut and is then hit by a piece of wood, causing it to crack so the seeds can be extracted.
5 The extracted seeds are subjected to a selection: only the dark brown seeds are used. They are deposited in a clean and disinfected container.
6 The seeds are nipped. This is breaking the seed exocarp at the small end. This will allow water to penetrate the seed coat from the inside.
7 After being nipped, the seeds are being soaked for 12 hours, in water mixed with bavistin (1 g/L).
8 The seeds are removed from the water and being slit over its entire length with a razor blade. The slit seeds are collected in a container with water mixed with bavistin (1 g/L), while accumulating a number big enough to bring to the propagator.
9 The seeds are then brought to the propagator, which is filled with a layer of coarse sand (1,5 inch thick). The seeds are sown and covered with a layer of coarse sand (0,5 cm thick).
10 Sown seeds are watered immediately with 6 L of water mixed with bavistin (1 g/L). After three days, the soil moisture must be checked and if necessary, a supplementary watering with 1 L water mixed with bavistin (1 g/L) is done. The ideal temperature for germination is 38-40 °C. The propagator must be kept closed, because the cold

air/wind will decrease the germination. The duration of germination is thus mostly dictated by the weather and after 7 days, the viable seeds will have germinated.

11 After germination, the seedlings are transplanted into polybags, filled with soil. The polybags with seedlings are being placed in a tunnel (tunnel structure, covered with plastic). Differentiation concerning length of the seedling is necessary: big seedlings are put together and small seedlings are put together. This to stimulate a homogeneity in growth and which translates itself in a lower mortality.
12 Watering is done using 18 ltr per 1000 seedlings every three days. Water is mixed with Bavistin (2 g/ltr).The seedlings stay in the tunnel for 7 days.
13 After 7 days, the seedlings are moved to nursery beds and are placed under plastic, to protect them from the rain.
14 Watering at 30 L for 1000 seedlings per day.
15 Weekly application of foliar fertiliser high in phosphorus (2 g/L of water).
16 Weekly application of copperoxychloride (2,5 g/L of water).
17 Selection of seedlings to discard inferior quality.
18 After 3 weeks, the plastic cover is removed.
19 Each 2 weeks foliar fertilisers are applied and the watering is done at 30 L for 1000 seedlings 3 times per week.
20 The seedlings remain in the nursery beds, without being covered by plastic, for 6 weeks.

2.1.2 Vegetative propagation

Vegetative propagation offer several advantages over generative propagation. Breeders can easily propagate selected elite plant clones, infertile hybrids and polyploidy can be induced. There are also several disadvantages. The propagator will face a variation in development response due different explant type and age and propagation conditions. Hence, Source material is very important for the rate of success for the (macro-)propagated trees. Concerning *M. volkensii,* source material collected at the beginning or during the dry season is generally of poor quality. The rate of rooting success depending on the season, as has been reported for other (tropical) tree species as well. Field collection of cuttings should thus be done during the rainy season (Indieka, 2005).

Macro-propagation is one type of vegetative propagation, where micro-propagation is the other type. Vegetative propagation through cuttings is considered the fastest and easiest way to produce seedlings, especially when the tree *species* forms roots easily. A cutting from the

stem, root or leaf is taken from parent material and induced to form shoots or roots (Indieka, 2005).

Studies concerning vegetative propagation pointed out it is very difficult to root mature stem cuttings of *Melia volkensii*. On the other hand does *M. volkensii* coppice well and it forms easily root suckers when roots are injured or damaged, thus the tree rejuvenates with ease via root suckers (Maundu & Tengnäs, 2005). Since vegetative propagation through stem and root cuttings have a very small rate of success (Muok et al., 2010), propagation through seed is still the most common process used to propagate *M. volkensii*.

2.2 Micro-propagation

2.2.1 introduction

The technique of plant tissue culture or plant micro-propagation (*in vitro*) is based on the totipotency of plant cells. This being the ability of single cells to divide, to differentiate into (every) complete plant organ and eventually to regenerate a whole complete plant. Isolated plant cells, tissues or other organs (callus, protoplast, anther, etc…) are used in sterile and controlled conditions to regenerate and propagate a complete plant (Davey & Anthony, 2010). Small pieces of plants – explants – are used as source material to establish tissues. All explants, cultures and recipients must be sterile and all operations must be executed in aseptic conditions. This to avoid any form of contamination. The micro-propagation of plants consists out of four stages: establishment of sterile cultures, *in vitro* multiplication, *in vitro* root formation and *ex vitro* acclimatisation. Mother plant selection can precede the four stages (George & Debergh, 2008).

This technique has lot of advantages over traditional propagation: the environment – light, temperature, relative humidity, gas exchange – is completely controlled, economical important species can be propagated and multiplied in a fast way (Davey & Anthony, 2010). Plant material is placed in closed containers – glass or plastic – filled with a culture medium providing with all essential elements for the growth of the plant. The media consist of salts of macro- and microelements, vitamins, organic components (including amino acids), energy source (mostly sucrose), plant growth regulators and a gelling agent (George, 2008).

Closed containers are placed in growth chambers, under special and controlled environmental conditions. The plantlets savour a higher air humidity and an irradiance lower than in conventional cultures. Closed containers limit the inflow of CO_2 and outlet of endogenous plant gasses (Pospisilova et al., 1999).

2.2.2 Micro-propagation of *Melia volkensii*

Melia volkensii is not easy to propagate, due to its low germination percentage caused by the seed coat and its dormancy. As stated above, by means of micro-propagation, farmers and companies can benefit of the mass production of superior planting material. The combination of *M. volkensii* and *in vitro* propagation resulting in a mass propagation and –production of the economical valuable wood. Apart from advantages, micro-propagation has also its disadvantages: an acclimatisation period, weaker and/or malfunctioning plants.
Van Acker (2012) summarised the different techniques of micro-propagation literature of *M. volkensii*.

2.2.2.1 Micro-propagation through seeds

Germination of sown *M. volkensii* seeds *in vitro* is no problem when the seed coat is removed. If not, the seeds cannot germinate. The embryo should be attached with the endosperm to result in a normal germination (VERMEIR, 2008).

2.2.2.2 Micro-propagation through somatic embryogenesis

Through the years, several somatic embryogenesis experiments were executed. Somatic embryogenesis is a process whereby somatic cells differentiate into somatic embryos. This method can be used as a large-scale vegetative propagation or as mean to rejuvenate an adult mother plant.
Indieka (2007) conducted experiments to study plant regeneration through direct somatic embryogenesis using mature zygotic embryo and cotyledonary explants from seeds of Melia volkensii stored for <3 and >12 months. Explants were cultured on Murashige and Skoog (MS) medium supplemented with BAP, NAA and 2,4-D (0.5, 1.0 and 2.0 mg l^{-1}) alone, and BAP (0.5, 1.0, 2.0 and 4.0 mg l^{-1}) in combination with 2,4-D or NAA (0.2 and 0.5 mg l^{-1}). After four weeks somatic embryos were developing onto 60 % of the cotyledonary explants from seed which were stored for three months. Only 20 % of the cotyledons of seeds stored for over 12 months iniated somatic embryos. Mature zygotic embryos failed to produce somatic embryos (Indieka, 2007). Verhaeghe's (2009) goal was to induce somatic embryos onto leaves, mature seeds and immature fruit. At first there was a callus formation on the explants, but after a couple of weeks – after transplantation – only mature cotyledons, longitudinally cut in half, produced somatic embryos. When the experiment was repeated with another seed lot, , no callus was formed and thus no somatic embryogenesis was possible. Verhaeghe also concluded that additions of NaFeEDTA – iron enhancer in the

medium (George & de Klerk, 2008) – and $AgNO_3$ – ethylene inhibitor (Chi et al, 1990) – to the media did not make any difference for somatic embryogenesis. In contrary to 2,4 –D – auxine hormone regulating plant embryogenesis (Von Arnold, 2008) – and 6-benzyladenine – a cytokinin eliciting plant growth and development response (Machakova et al., 2008) – which gave rise to most somatic embryos. Lamberigts (2010) used leaf explants from one parent tree to create somatic embryos. Callus was formed but no somatic embryos were formed after transplantation. Braem (2011) found that shoot induction onto leaves were possible, but the adventitious shoot did not develop into complete plants. Shoot induction on roots was possible. Treatments with 6-benzyladinin gave significantly more shoots.

2.2.2.3 *In vitro* multiplication

Multiplication of *M. volkensii* is possible with a wide range of cytokininns. The shoots of good quality and with highest multiplication rate were proven with the use of MemTR, a meta topolin cytokinin derivate. But this cytokinins still can inhibit the initiation of roots. A better alternative, root initiation bore in mind, is the use of phenyl-adenine, with less inhibition of subsequent root initiation but a growth delay of two weeks (Van Acker, 2012).

2.2.2.4 *In vitro* rooting

In vitro root initiation of *M. volkensii* is indeed very difficult. Van Acker (2012) found better results with the auxin indole-3-acetic acid (IAA) than with indole-3-butyric (IBA) acid. Both auxins inhibit root formation and growth, but since IAA is less stable than IBA, the inhibition is less profound and shorter in time. But more experiments are ought to be taken to draw conclusions. Also the combination of the used cytokinin and auxin must be monitored very closely: cytokinins of the phenyl-adenine family do not have an immediate inhibitory effect, because they are not recognised by the cytokinin plant receptors (resulting in a higher endogenous cytokinin/auxin ratio) (Motte et al., 2013).
Vanderhaeghe's (2009) trials showed that root development was also influenced by the amount of Murashig and Skoog macro salts in the rooting medium.

2.2.2.5 *Ex vitro* acclimatisation

The *in vitro* development of plantlets result in abnormal morphology, anatomy and physiology, due to the optimal and therefore special conditions. After *ex vitro* transfer, these plantlets can easily be damaged by environmental condition changes and thus a period of acclimatisation to correct these abnormalities is obliged (Pospisilova et al, 1999). In the field,

irradiance is significantly higher and air humidity is lower. Plantlets may wilt due to water loss through their leaves and in addition, water supply can be limited because of low hydraulic conductivity of roots and root-stem connections. This causes many plantlets to die in these acclimatisation period (Pospisilova et al., 1999).

Possibilities of improvement could be a hardening off period *in vitro*. The decrease of air humidity (*e.g.* by bottom cooling), increase of the irradiance or an increase of CO_2 concentration (*e.g.* by forced ventilation) can counter wilting of plants after transplantation. These measurements can, though, have pernicious consequences for the growth medium, due to a quickened drying out. Photoautotrophic growth of plantlets on medium without saccharides enables the development of fully functional photosynthetic apparatus. These plantlets usually need elevated CO_2 concentration and higher irradiance than conventionally used. Apparently addition of abscisic acid (ABA) softened the transplantation shock, because of the decrease of stomatal conductivity resulting is a reduced evaporation through the leaves (Pospisilova et al., 1999).

The most interesting short-term effect during transfer of plants to *ex vitro* conditions were the transient peaks in several characteristics immediately after transfer from *in vitro*, and more expressed after transfer from the greenhouse to open air. This is interpreted as stress reactions to the abrupt changes: the first transfer as the shock concerned with the removal of the root system from the agar medium and transplanting the plantlets into soil. The root hairs may be damaged during this procedure and the absorption of water and nutrients by the roots could be transiently impaired. The second transfer was a shock reaction mainly to the abrupt and considerable increase in irradiance (Kadlecek et al., 2001).

To protect the shoots from threats, the light composition must be kept the same prior and during acclimatisation. Otherwise the plantlets will be stressed. The shoots must also be treated with a systemic fungicide prior to the transplanting into a sterile or at least disinfected soil. The soil mixture must have a high water retention rate and the plantlets must be kept at high relative humidity and evaporation must be kept at minimum (Van Acker, 2012).

3 Introduction to quality assurance

3.1 International organisation for standardisation (ISO) (Hoyle, 2009)

3.1.1 Introduction

All organisations have their own way of operating, which is intrinsically a management system. There are no rights or wrongs in executing tasks or taking decisions, but it only matters if the organisations fares well with the decisions that is made. This is why certification ought never be a goal, but raising the effectiveness should be the main goal of the organisation.

ISO standards are voluntary and are based on international consensus among the experts in the field. ISO is a non-governmental organisation and it has no power to enforce implementation of their standards. Its aim is to facilitate the international coordination and unification of industrial standards.

ISO 9000 is a family of standards to define quality, but it also states why it is important for organisations to make it a high priority and what role the management has, in influencing the organisation's approach to achieve this quality. In a nutshell: the ISO 9000 family of standards will stop organisations from making false promises and will help to keep promises which are manageable. False promises will inevitably lead to conflict situations.

Although as mentioned before, ISO 9000 is voluntary, but ISO 9001 has become a market requirement. The primary purpose of this standards is to give confidence to the customers that the products and services meet the needs and expectations of the customers. It also points out the effort of the organisation to meet these needs of the customer.

3.1.2 Definition of quality

Over the last 20 years, a number of principles have been developed upon which the achievement of quality is based:

1 Understanding customer's needs and expectations, *i.e.* customer focus;
2 Creating a unity of purpose and a quality culture, *i.e.* leadership;
3 Developing and motivating the people, *i.e.* involvement of people;
4 Managing processes effectively, *i.e.* the process approach;
5 Understanding interactions and interdependencies, *i.e.* the systems approach;
6 Continually seeking better ways of doing things, *i.e.* continual improvement;

7 Basing decisions on facts, *i.e.* the factual approach;

8 Realising that you need others to succeed, *i.e.* mutual beneficial relationships.

Next to the understanding how to achieve quality, it is also important to define quality. There are several definitions of quality among which the most important ones are:

- A degree/perception of excellence (OED) – the meaning used by the general public.
- Freedom from deficiencies or defects (Juran) – the meaning used by those making a product or delivering a service.
- Fitness for use (Juran) – the meaning used by those accepting a product or service.
- Conformity to requirements (Crosby) – the meaning used by those designing a product or a service or assessing conformity.
- Sustained satisfaction (Deming) – the meaning used by those in upper management, using quality for competitive advantage.

Through the years, several other definitions appeared, every time with a little tweak to improve it until this became the internationally agreed definition: *'Quality mean that all the principles, methodologies, tools and techniques in the field of quality management servo on purpose, that of enabling organisations to close the gap between the standard required and the standard reached and if desirable, exceed them.'*

3.1.3 Approaches to achieve, sustain and improve quality

As explained before, quality is the result produced when a need, expectation, requirement or demand is met or satisfied. ISO 9001 does not provide any information on this, so several approaches have been developed to achieve, sustain and improve quality.

3.1.3.1 A task based approach

A task based approach is defined as the approach to prescribe what has to happen and then supervise compliance to these procedures. This approach has a point of critic: it will lead to a separation between planners – the management – and the doers – the employees.

3.1.3.2 A risk based approach

A risk based approach depends on the identification of the risks to achieving quality and then manage these risks effectively. Basically this is a compilation of measurements to take, in order to prevent, detect and correct defects. This approach was the first step towards implementation of:

- End-process inspection;

- In-process inspection;
- Supplier appraisal;
- Hazard analysis;

An organisation can be exposed to several risks and so this approach can lead to a dependence on inspection to detect the problems in the process. Although seeking quality depends on the prevention of problems, by building in quality into the product in the first place.

3.1.3.3 Goal based approaches

Quality does not appear by chance or luck. The risk based approach depends on the ability to predict the effects of the organisation's decisions. It would be better to adopt practices that can enable the achievement of the objectives, whilst preventing failures. It is the opposite of the risk based approach: first the objectives need to be defined that match those of the organisation and then risks can be prevented.

3.2 Task analysis

3.2.1 Objective of task analysis

Task analysis yields data on the demands imposed on the worker by a given job. It enables the elements of a work system to be identified and compared with other work systems. It provides information on occurring situations and can eventually lead to job (re)design, if necessary (Landau et al., 2000).

The type of task analysis procedure used will depend on the aspect from which the task is defined and the terminology used.

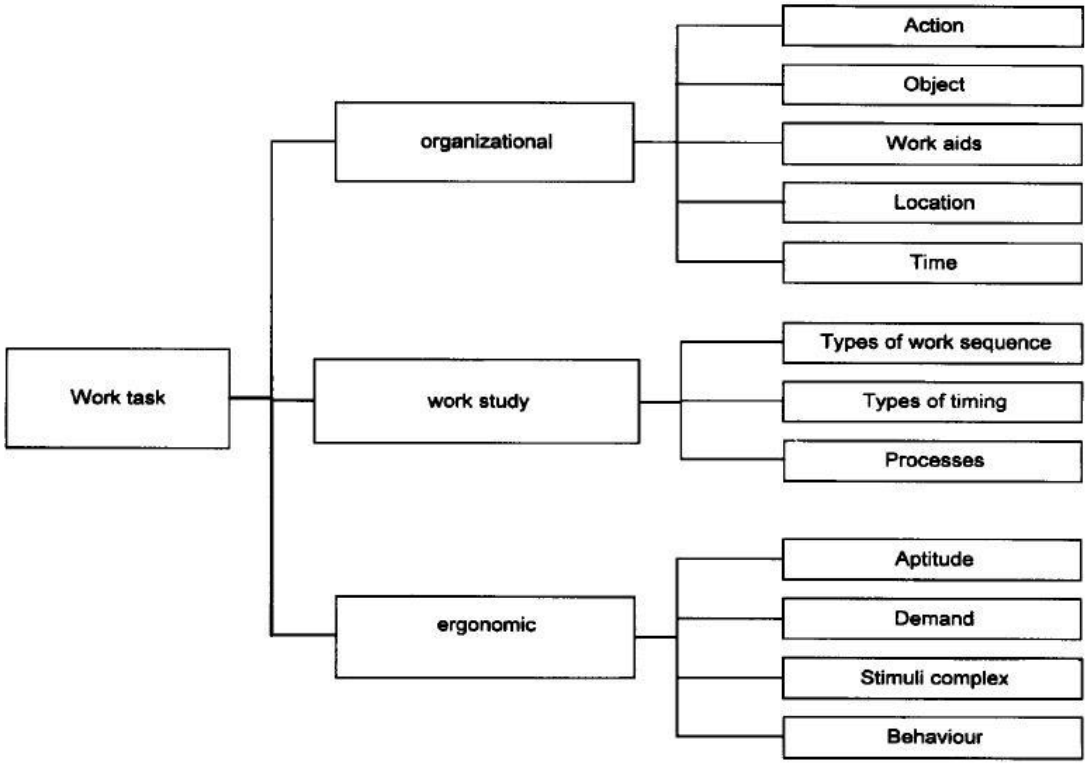

Figure 4: Terminology in task analysis (Landau et al., 2000)

Organisational definitions relate to the functional actions of the industrial worker: the task represents a set target that must be fulfilled. The intent of the organisational approach is a task analysis followed by a task synthesis: identified subtasks are bundled and can be delegated to specific persons or departments.
The work study approach can be organised into temporal and spatial consequences of interaction between man/machine and the work object in certain time frames. Next to these, the ergonomic area is also important. This is not about estimating the duration of specific work sequences, but improving the man-work interaction (Landau et al., 2000).

3.2.2 Task analysis methods and procedures

3.2.2.1 Review of existing procedures

Through the years, several analysis procedures, with their objectives, are documented already. Landau et al. (1990) summarised a lot of these procedures and their objectives into a table. Of course, more procedures can be added to the table.

3.2.3 Task analysis conclusion

Task analysis can be reduced to two fundamentally different types of procedure. The first one involving recording and classifying the main elements of the work system, the tasks involved and the demands imposed, based on the company's objectives. The second type evaluates the subjective perception of the work done by the practitioner (Brauchler & Landau, 2000). These two types are complementary: if one analysis leads to a 'bad' result, it will influence the other type and thus the total result. Concluded can be stated that a comprehensive task analysis system can provide information on the undesirable components of a given job, better appreciation of the psychological stresses arising in the job and a greater understanding of the tasks and requirements involved.

The main aim of applied ergonomics is the early identification of work-related relapse before serious health issues occur. Consequently, the main aim of task analysis should be to achieve a maximum cost-effectiveness by applying data obtained from observations(Brauchler & Landau, 2000).

Better Globe Forestry Ltd. has several work instructions for their employees. Combined with ergonomics prescriptions, these work instructions are the basic ideas to fulfil the several production processes at the plantation, they are the manual to deliver a high amount of qualitative products – qualitative hardwood *M. volkensii* trees. An analyse of these work instructions may help pointing out where stress points lie and where improvement is possible on labour as well as the ergonomics area.

3.3 Ergonomics on the shop floor

To convert input to output, the task need to be executed correctly. To obtain an output product of higher quality, several amelioration measurements can be taken. Improved ergonomics on the shop floor is one of them.

3.3.1 The scope of ergonomics

The work field seeks to optimise the relation between a human and a system, whether the system involves a complete production line or just a simple hand tool. Whenever one designs a more effective interface between a human and a tool or task, that is defined as ergonomics.

Every human interaction on a work process can be viewed from ergonomics point of view. *Fig. 5* gives a summarised overview of the scope of ergonomics.

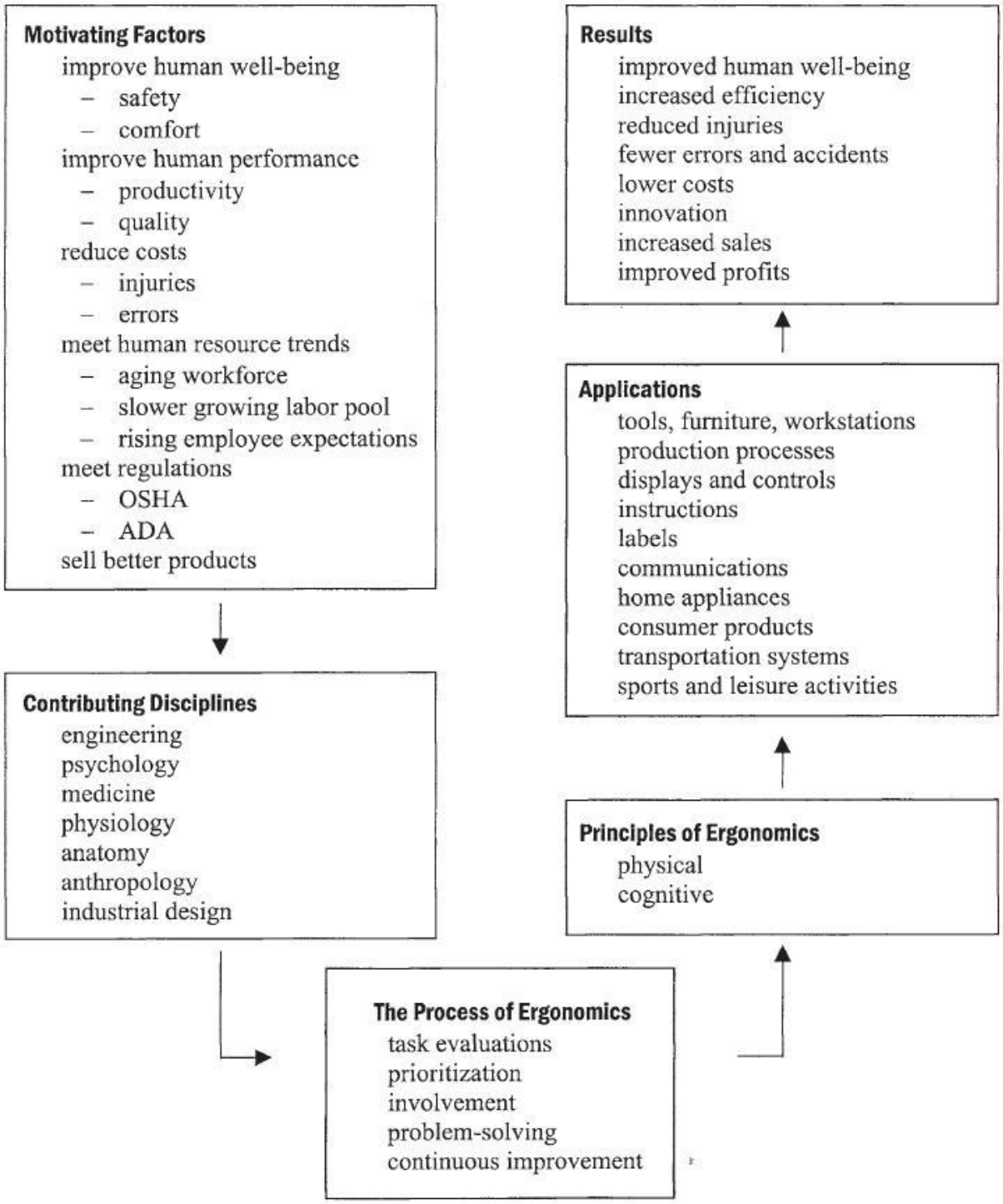

Figure 5: Scope of ergonomics (Macleod, 2000)

Macleod (2000) stated that the results on the shop floor are clearly influenced by the used application by the employees, whether it are tools to work with or using consumer products. An optimisation of the results starts with the amelioration of the motivating factors. A

motivated employee can and will perform better. Thereafter, processes must be evaluated, problems must be located and preferably solved, in order to have a continuous improvement of the operation(s). This combined with research for principles of ergonomics: cognitive (*i.e.* are the actions understandable for the practitioner) and physical (*i.e.* is the practitioner capable to execute the task), and eventually an implementation of the findings, may lead to an improved and optimised process.

3.3.2 Principles of ergonomics

Physical ergonomics can be itemised into ten interrelated principles (Macleod, 2000):

1. Work in neutral positions;
2. Reduce excessive force;
3. Keep everything in easy reach;
4. Work at proper height;
5. Reduce excessive motions;
6. Minimise fatigue and static load;
7. Minimise pressure points;
8. Provide clearance;
9. Move, exercise and stretch;
10. Maintain a comfortable environment.

Even though these principles appear simple and evident, they are routinely violated at the shop floor. Between these principles there is a considerable overlap, depending on the task and the issues at hand. Yet, each principle stands alone and serves to withhold knowledge in the field of ergonomics. It is crucial to understand the difference between these principles. The principles differ from task and situation and it is thus more important to learn and use these principles than to concentrate on the details (Macleod, 2000).

The basic principles of ergonomics can be applied in various 'settings'. Most applied at the Better Globe Forestry Ltd. plantation are the following: the sitting workstation and the standing tasks.

Most common issues when sitting to fulfil a task: the work surface not being at appropriate heights, a long reach for materials, the work surface with hard and/or sharp edges, inadequate clearance for thighs and knees, inadequate work area to perform all tasks and shadow or glare.

Performing standing tasks has its own common issues as: static load on legs, awkward back posture from too severe a sway in the lower back when standing straight up, awkward back

posture when bending over to perform the task and pressure points from hard floor (Macleod, 2000).

To expand human capability, humans did develop successive ways to organise chores and overcome human limitations. Work organisation is in this matter rather important and thus a good target for ergonomics. Human capability in relation to work can be organised in several ways. Task allocation, or how tasks should be divided and assigned to accomplish certain goals, is one of them. Is it better to have several employees doing the same tasks or is it better to have one highly qualified employee? Assembly-line or work cells or how the workplace should promote team activities, which can possibly lead to higher activity, is also an item to look at.

Another item to organise work is: shift work – should there be more than one shift in a given workplace? If so, should employees rotate between shifts every specific period of time? Ought there to be room for a reward system, as incentives for delivered effort? Work organisation is also about having an internal structure in the organisation and about making decisions on a certain level in the organisation.

The goal of the work organisation is to design systems that match organisational issues with human requirements and thereby increase overall efficiency of the system and increase personal fulfilment and well-being of people (Macleod, 2000).

All this principles should be applied at the Better Globe Forestry Ltd. plantation in order to have a maximum of performance through a minimum of labour. Only then the result can be influenced positively by raising the efficiency and decreasing the costs of labour for the company.

4 Better Globe Forestry Ltd.

4.1 Introduction

Better Globe Forestry Ltd. (BGF) is part of the Better Globe Group. The latter one's vision is to combine a commercial project with human and environmental activities. The Better Globe Group is presenting a vision wherein its goal is to ameliorate the African environment and to eliminate poverty in a sustainable manner. In order to create a greener and healthier environment in Africa, the Better Globe Group is developing profitable, commercial tree plantations, delivering human as well as environmental benefits. Better Globe Forestry Ltd. is providing services as taking on consultancy, training in different fields related to agro-forestry. A test and training centre is established in Kibwezi for modelling several farming techniques, with an emphasis on tree planting, water management and soil fertility. Other research is done to improve genetics of *M. volkensii* and other trees, to counter pests and diseases and to schedule an ideal silvicultural management for the trees at the plantation. By establishing the pilot plantations, BGF is providing local population employment in order to become self-sustainable in the specific area. BGF's vision is to become the largest tree planting company in the world – within 20 years, they are also looking into options for an efficient multiplication via *in vitro* applications.

4.2 Pilot plantation at Lake Kiambere, Kiambere, Kenya

4.2.1 Description and importance

In November 2006, BGF has started its first fieldwork in Kenya. The pilot plantation at Katithini, nearby Lake Kiambere, is a project of currently 300 ha. Lake Kiambere is an artificial lake created by damming the Tana River (for generating electricity). This pilot plantation is the first phase of a 5000 ha plantation around Lake Kiambere (Better Globe Forestry Ltd., 2009). A buffer zone is created around the pilot plantation, mainly for security and protection reasons. Local farmers have illegally been cultivating this buffer zone, since no activity is yet to be executed herein. The farmers have never invested in soil fertility management nor were anti-erosion measurements taken, as the farmers were aware they could be evicted any day (Vandenabeele, 2009). Due to strong soil erosion – caused by the illegal farmers and the natural erosion caused by meandering rivers after rainfall – tonnes of soil and nutrients are washed into Lake Kiambere. The nutrients have disastrous effects on

lifespan of power generation facilities in the dam. BGF has demonstrated that it is able to stop erosion on the lakesides, by planting trees and block erosion gullies with check dams (Vandenabeele, 2009). In most of the plantation area, soil erosion has been diminished by over 90 %, after barely two years of intervention (Vandenabeele, 2009).
Apart from erosion, poverty is a major concern in this area. 65 % of the population living below absolute poverty line (Vandenabeele, 2009). BGF can employ between 50 and 200 people in the pilot plantation, depending the season and thus the amount of work. Several tasks need to be executed: nursery activity, land preparation, tree planting, tree watering, weeding, etc. Apart from the plantation maintenance also security – by guards – to avoid theft and overall supervision are tasks with importance. BGF is thus the biggest employer in the area, with payment of salaries signifying an important injection of cash into the local economy. The money funding system is extraordinary, since BGF is depending on investors. This way, funds are acquired in parts and shares and not continuously (Better Globe Forestry Ltd., 2009).

4.3 Logistics of production and breeding of hardwood in Kenya

It is the objective of the producer is to maximise the gain or the profit. This being the basic assumption of producing a certain product. The gain (the profit) is the difference between the value of the produced products (product value) and the value of the factors of production (costs) used. Based on this assumption three issues can be identified (Rasmussen, 2011):

1 What to produce?
2 How much to produce?
3 How to produce?

The initial goal of BGF Ltd is to produce hardwood *M. volkensii*. These trees are sown, grown and eventually planted in the field. After a period of 20 years, the trees are harvested for its timber and other excellent qualities. The production processes to obtain seedlings and eventually trees, as well as the maintenance of the trees in the field are well known. Although there is room for improvement. Mortality in the nursery as losses through the production process of the seedlings as losses of trees in the field can/could be reduced. Growth rate can be improved, by using fertiliser. *Etcetera.* The only unknown is the amount to produce. This depending on the availability of money to purchase fruits. But the amount to produce depends also on the amount of employees available to do field and plantation maintenance and nursery work. But the production also depends on the money required to pay the employees, amongst other factors.

Logistics is a term used in the business field to refer to the means and methods related to the physical organisation of a company. This covering the flow of materials, before, during and after production. Logistics include supply chain management and include service activities (Langevin & Riopel, 2005). Logistics go hand in hand with the production performance of firms. The performance can be measured and ultimately be adjusted to optimise and complete the production process to obtain a better productivity and efficiency (Rasmussen, 2011). Production performance also comprises ergonomics. A major concern of ergonomics is to align humanity with economic efficiency. Absence due illness of staff members is connected to premium rates, breaking-in costs of new employees, increased costs for planning and controlling on the side of management. It is necessary to align ergonomic methods and findings for analysis and design of work systems with the established processes in companies for product development and production planning (Bruder et al., 2009).

It is the goal of Better Globe Forestry to become the largest tree breeding company in the world. This is achievable, but the existing bottlenecks should be determined by analysing the several processes at the plantation. When thoroughly analysed, the problems can be located. Thereafter measurements can be taken so the bottlenecks can be eliminated. Only then will the seedling production chain performance increase, but this may not be at the expense of the employees. The ergonomic conditions of the employees must be considered. Only with respected ergonomics and results from the analyses, the efficiency and thus the performance will be optimised.

4.4 Seedling production chain and plantation maintenance

BGF has created work instructions for all production processes to optimise the production chain. This is a work-in-progress. The production chain can roughly be divided into two large phases: every task concerning the propagation of *M. volkensii* and nursery related tasks. This is where seeds are extracted from the fruits and sown to finally harvest seedlings.
Next to that, there is every task concerning maintenance of the plantation. In-field tasks contain transporting the plantlets, planting the *M. volkensii* seedlings, eventually applying fertiliser, making a water catchment dam, mulching and watering the plantlets. But before these in-field activities can be done, the land must be prepared for planting. Land preparation starts by defining the piece of land with name and place/coordinates – on a map. Thereafter the land must be cleared of weeds or vigorously growing bushes. Gullies must be checked and if necessary a small dam must be build, to prevent water flowing down the hills and

erode the fertile soil away. Then the land can be marked. This action is followed by pitting. When the pits are made, the transported seedlings can finally be planted in the field.
Apart from nursery work and land preparation, plantation maintenance is also important. Operations such as removing the weeds, pruning the trees, pest and disease control are very important to deliver qualitative products. Next to the previously mentioned are tree counting, thinning and gapping – resp. removing trees and filling gaps in the plantation – and road maintenance. Plantation protection is highly underestimated, but very important. Every task is mentioned in detail in c*hapter 5*

II Experimental Part

5 Logistics of production and breeding of hardwood in Keyna at BGF Ltd.

5.1 General Purpose

This chapter covers the productivity and efficiency rates at the BGF Ltd. plantation in Kiambere. All the processes at the site have task rates that need to be achieved. Employees at the site were observed during a certain amount of time, to verify if the task rates were achieved in the first place. With this observation it was also possible to check the effort of the employees in achieving the task rate.

Next to the productivity and the efficiency, the ergonomics at the site were included in the report: improved ergonomic conditions may lead to a better economic efficiency (Bruder et al., 2009).

These figures together with the available funds, can lead to the formulation of a work schedule in order that future plans can be executed without having problems concerning available personnel. A proper future view is needed, *e.g.* '*x*' amount of trees need to be planted, therefor '*y*' amount of seeds is needed out of '*z*' amount of fruits. In order to obtain this, '*k*' people are needed in the nursery. This can be the ultimate optimisation of the seedling production process.

5.2 General material and methods

The report is based on personal observations of BGF Ltd. employees performing daily tasks concerning the production of *M. volkensii* hardwood. Better Globe Forestry Ltd. has developed work instruction for the employees concerning their tasks. These tasks can roughly be divided into two large phases, with nursery related tasks being the first. The sourced and foraged fruits are firstly depulped, to extract the nut. The nuts are then being cracked, to extract the seeds. These seeds are then subsequently being nipped, slit and eventually sowed. After 7 days, the seedlings are big enough for the first – out of three – transplantation step. After approximately 96 days, the seedlings are planted in the field. The second phase contains plantation maintenance tasks. This is everything from marking pits and making plantholes, to making catchment dams, mulching, watering and pruning the trees and preparing the field by removing weeds and grass. During a period of 2 months, these tasks were observed. The

observations were done as objective as possible. Apart from observations concerning the economical aspect, ergonomics concerning the production processes are noted down too.

5.3 Task analysis of nursery related processes

If statistical analysis shown in the results, p-values are based on a 95 % confidence interval.

5.3.1 Fruit sourcing

5.3.1.1 Introduction

The first step to the production chain is collecting fruits which contain the nuts with the seeds. Several '*Melia volkensii* plus trees' are catalogued and numbered by BGF. The plus trees suffice to certain conditions (Bedell, 2006) and only from these trees, fruits may be used for further purpose in the plantation. The plus trees are not per se situated in the plantation, they also occur on farmer's properties. The mature fruits were collected from the crown of the marked elite *M. volkensii* trees.

Harvesting fruits is fairly easy. Usage of physical force will release the ripe mature fruits, but immature fruits will remain on the branches (Jøker, 2003). Mature fruit differs from immature fruits by colour. Yellowish-green fruits with a soft pulp tend to be mature fruits. Although during development, cork deposits appear onto the fruit, which affects fruit colour (Jøker, 2003).

The work instruction to source fruit is according to the following (BGF, 2012 A):

1 There must be a need for seeds, according to the work plan;
2 Present the budget to the finance manager for approval;
3 The fruit sorcerer collects the fruits from the specific farmer. At each farm, the fruit sorcerer fills a seed collection form indicating how much has been collected (in kg), the name of the farmer, the ID number of the farmer, the phone number;
4 The farmers are currently paid in cash. In the future this will be via Mpesa;
5 The mode of transport used to ferry the fruits from the farmer's compound is donkey or a motorbike up to the collection point;
6 From the collection point the fruits are transported by pick-up vehicle;
7 Prices for donkey transport are not fix, they are negotiable and sometimes they vary with change in climate;
8 1600 kg collection in 5 days;

9 The forest technician then arranges a pick-up vehicle to collect the fruits at the drop point;
10 The transport form is filled by the forest technician. How fast the fruits are delivered indicating the mode of transport used, the name of the owner, the licence plate, phone number and the amount that has to be paid;
11 This form also shows the route used for the delivery of the fruits, the tree number;
12 At the forest station, the fruits are weighed in the presence of the forest technician and then inspected to ascertain their health;
13 Payment of the person who delivered the fruits to the forest station which is done by Mpesa by the finance director.

5.3.1.2 Results

The fruits were hand-picked from the branches or the branches were shaken until release of fruits. Ripe fruits out of reach were hit with a long stick. A specialist in recognition of mature, ripe fruits did climb the trees. After the fruits fell on the ground, they were collected from the soil into gunny bags.

The fruits were collected from the soil and put into gunny bags. This can induce the presence of soil fungi. It would be better to spread a net or a canvas under the crown area whereon fruits fall, are collected and put into the gunny bags. In the presence of a sufficient amount of people, the canvas should be correctly lifted until a certain height (maximum 70 inch (Macleod, 2000)) to fill the gunny bag.

The payment method via Mpesa will be safer for the fruit collector. He does not have to carry cash money. Mpesa is a money transfer service via a mobile phone, which only allows users with a passport to make money deposits, money withdrawals and to do other bank transfers, with their mobile phone. When one is paid via Mpesa, he will go to a money withdrawal centre and verifies the money deposit with his mobile phone number. Thereafter, he is able to withdraw the money he was paid.

5.3.2 Depulping and drying

5.3.2.1 Introduction

The fruits contain nuts. In order to extract the nuts from the fruits, the fruits are depulped and the nuts are left to dry. This to simplify subsequent steps: quality check and cracking of the nut. The depulping must be done within a week after arrival at the plantation, else the fruits start to rot. This affects the viability of the seeds, causing them not to germinate.

The work instruction for depulping the fruit and drying the nuts is the following (BGF, 2012 B):

1 Workers are obliged to put on overalls and gloves since the juice produced by the fruit can irritate the skin;
2 Gunny bugs are placed on the workers laps to prevent the fruit juice from sticking on and staining the overalls;
3 The task must be done under a shade to prevent direct exposure to the sun's rays both as an ergonomic measure and to prevent spoiling of the fruit;
4 The outer cover of the fruit is removed by hitting the fruit with a piece of wood while the fruit is lying on a stone (with little depression to fit the fruit), within a week of arrival of the fruits on site;
5 This is done till the outer succulent covering of the *M. volkensii* fruit splits;
6 The succulent coat must then completely be removed by hand, leaving a hard nut which contains the seeds;
7 The nuts must be washed and sun-dried for 2 hours;
8 Selection of nuts: only brown nuts are of decent quality, not whitish nor darkish nuts;
9 Task rates for depulping is 32-33 kg per day which is translated to 1 crate per day.

5.3.2.2 Results

The initial task rate concerning depulping the fruits is expressed in mass, not an amount of fruits. Due lack of that amount of scales and to have kept the depulping and drying process as fluent as possible, the depulped fruits are mentioned in units, not in mass. *Table 1* expresses the amount of fruits per 10 kg fruits.

Table 1: Amount of fruits per 10 kg

Repetitions	10
Average amount	569,95
Standard deviation	18,99
Minimal amount	520
Maximal amount	600

Table 2: Number of depulped fruits 7th of August per person per time interval

Time	Person 1	Person2	Person 3	Person 4	Person 5
7h30-9h	0	0	0	0	0
9h-10h	304	320	404	432	240
10h-11h	328	276	348	408	350
11h-12h	320	280	448	488	440
12h-12h30	117	122	120	160	166
13h15-14h	314	433	324	328	392
14h-15h	244	234	256	370	256
15h-16h	124	231	248	264	160
Total	1751	1896	2148	2450	2004
Average per hour	280,16	303,36	343,68	392	320,64
Standard deviation	92,73	94,80	109,78	110,69	109,80

Table 3: Amount of fruits depulped per person (in kg fruits) (7th of August)

	Person 1	Person2	Person 3	Person 4	Person 5
kg: start	40	44	46	43	48
kg: end	7	13	18	6	23
kg per day	33	31	28	37	25

Table 3 points out that the task rate of depulping 32 kg fruit was exceeded by person 4. Person 1 managed the task rate and person 2 managed the task rate, except for 1 kg. Person 3 and 5 did not manage to depulp enough fruits.

Out of *table 2*, it is clear that between 7h30 am and 9 am, the employees did not start their work yet. This implying out of 8 hours of work, they skipped 1,5 hours. Still, 3 out of 5 employees managed to fulfil the task rate, without problem. Given the fact there ought to be a supervisor – according to the work instructions (BGF, 2012 B) – he should've pointed out that the employees should start working according their contract with Better Globe Forestry Ltd.

It must be said that person 4 worked very hard, unlike person 5. The difference in working speed was remarkable. The average amount (kg) of fruits depulped was 30,8 kg (standard deviation = 4,60 kg). The performance of person 5 dropped the average below the task rate.

Although according to the average and standard deviation, 35,4 kg should be reachable to depulp.

Overall observation: in the afternoon the depulping speed is lower than before noon, for the 7th of August that is.

Table 2 also shows the difference in work efficiency. Person 5 did depulp 2004 fruits at the end of the day, but only managed to obtain 25 kg of depulped fruits. This implying a lot of nuts got lost during the depulping process. This is verified by employees who depulped less fruits, but obtained more depulped fruits (in kg) at the end of the day.

This process should be a process without any loss of output. Every fruit should provide a nut that needs to be dried.

Table 4: Number of depulped fruits 10th of August per person per time interval

time	Person 1	Person 2	Person 3
7h30-7h40	0	0	0
7h40-9h	334	353	200
9h-10h	292	322	318
10h-11h	228	300	356
11h-12h	298	244	333
12h-12h30	164	124	174
13h-14h	252	241	246
14h-15h	413	279	328
15h-16h	355	260	299
Total	2336	2123	2254
Average per hour	298,21	271,02	287,74
Deviation	82,13	63,98	63,01

Table 5: Amount of fruits depulped per person (in kg fruits) (10th of August)

	Person 1	Person 2	Person 3
kg: start	43	42	48
kg: end	13	9	15
Δkg per day	30	33	33

Table 5 shows that person 2 and 3 obtained the task rate. Although person 1 depulped the most fruits (hence *table 4*), he did not manage the task rate. This again connoting in inefficiency on the working spot.

Unlike to the 7th of August, it seems that the employees have depulped more fruits after the noon, the 10th of August.
An remarkable fact: unlike the 7th of August, the 10th of August counted 8 hours of labour. But this was not translated to the amount of fruits depulped. The employees seemed to work as hard as the 7th of August, but with 1,5 hours more time. The average amount of fruits depulped was 32 kg (standard deviation = 1,73 kg), which is in fact the task rate.
There is a hiatus from calculating the amount (kg) of fruits sourced and thus depulped towards the amounts further used. Provided 10 kg of fruits contain averagely 570 fruits (*table 1*), 1881 fruits are in 33 kg. These figures show every employee managed the task rate, apart from person 1, the 7th of August. But he in fact did manage the task rate.

Ergonomics

The work instruction (BGF, 2012 B) clearly stated that employees should wear protective clothing. Unfortunately this is not completely respected: none of the employees wore gloves. Gloves will protect employees from the harmful juice of the fruits.
If these gloves are not available, soap or an alternative should be available to clean hands after the process. Apart from that protective clothing is respected.
Depulping the fruits is done sitting. A sitting workstation has a lot of pitfalls, as mentioned in *chapter 3, section 3.*
As observed, the employees sat in very old chairs and performed their task onto two crates – used as table. These crates are seldom at good work height and have sharp edges, that can induce wounds to the limbs of the employees. Some employees even sat on the ground.
The soil is a little sloping, making it very hard to induce the ideal work conditions.
Surrounding trees block severe insolation and cast a shadow over the ‘shop floor’.

5.3.2.3 Conclusion

The observations proved that the task rate for depulping is easily manageable. The 7th of August, the employees did not start before 9 am, and still 3 out of 5 managed to depulp enough fruits according the work instructions. 1 employee performed really bad and 1 would have managed the task rate when starting earlier. These figures were confirmed the 10th of August, when every employee managed the task rate, although in 8 hours of time.
Based on the fact that the employee are able to depulp enough fruits in less than 8 hours, this can indicate, they are able to perform better than the initial task rate.

For work planning, the hiatus of the amount of fruits per weight unit should be solved or avoided. The end product is an amount of seedlings, so it would be useful to know 10 kg of fruits bear '*x'* extractable seeds.

$$y = x * (amount\ of\ seeds\ per\ nut * (1 - loss\ \%\ cracking) * (1 - loss\ \%\ nipping) * 1 - loss\%\ slitting * germination\ \% \quad (5.1)$$

With '*y'* amount of seedlings and '*x'* amount of fruits. This will make in convenient to plan. An overload of fruits to depulp will be avoided, preventing fruits from rotting.
The amount of employees – and their cost – needed, can be determined, as well as the time needed to process the fruits to seedlings, time needed in the nursery to harden the seedlings off, amount of people needed to plant the seedlings in the field and maintain a healthy status of these seedlings.
Supervision is needed to make sure none of the nuts are lost after their extraction from the fruits. Due to imprudence in the action, nuts can get lost. This most, by all means, be avoided. A supervisor can be an employee who is participating in the process, not an extra employee who is sitting and watching others work.

5.3.3 Cracking

5.3.3.1 Introduction

After a period of sun-drying, the nuts must be cracked to be able to remove the seed(s). The nuts are cracked with a developed device – a Melia seed extractor (*fig. 6*) – for this purpose only, or with a panga (*fig.8 and 9)*.

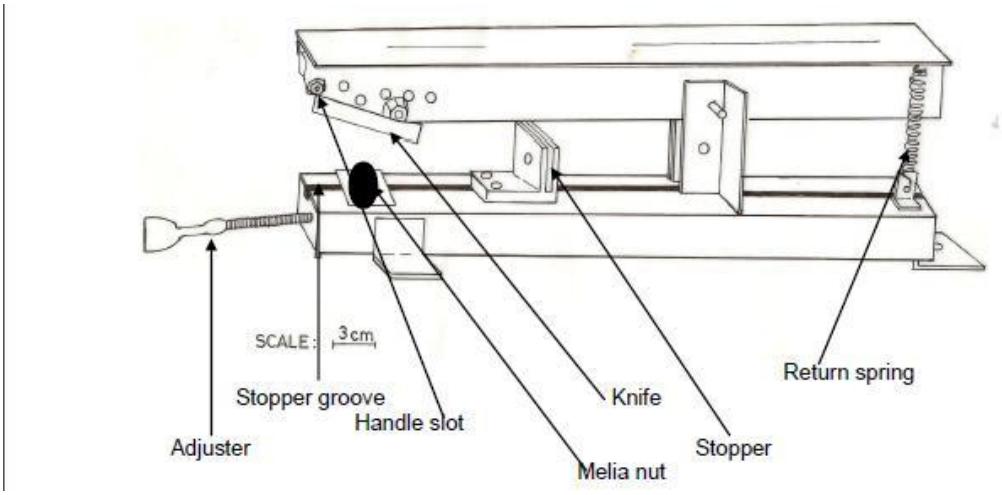

Figure 6: *Melia* seed extractor (Lugadiru, 2004).

All components are described in the manual. Also how to operate the device is clearly stated in manual (Lugadiru, 2004). At the BGF plantation in Katithini, the *Melia* seed extractor is

not used anymore. This because the rate of lost seeds is too high. At the plantation the people who crack the nuts, use a panga and pieces of wood. With this technique, strength is controllable and the rate of loss is lower (Vandenabeele, 2012).

The work instruction to crack the nuts is the following:

1 It must be done under a shaded area to prevent direct exposure of the seeds to the sun;
2 Employees must put on an apron for this task. Putting on gloves is not desirable because it would slow the removal of the seeds from the nut;
3 The actual cracking of the nut is done by using a machete (in Kishwahili: panga) and a piece of wood (dimensions 4 by 2 inches by 1 foot) for hitting the panga/knife and another piece of wood with a depression to fit the nut;
4 The nut is placed on a piece of wood with a little depression to fit the nut. The long axis of the nut must be placed perpendicularly to the panga (*fig. 7*);
5 The tip of the panga is placed in the solid piece of wood. Doing so, the panga and the wood enclose the nut. The sharp edge of the panga will cut, crack and eventually split the nut;
6 The nut is hit with desired strength on its centre until it cracks. The seed, in its coat, has to be carefully removed from the cracked shell without damaging it. A seed with a slight crack on its coat is damaged and has to be discarded;

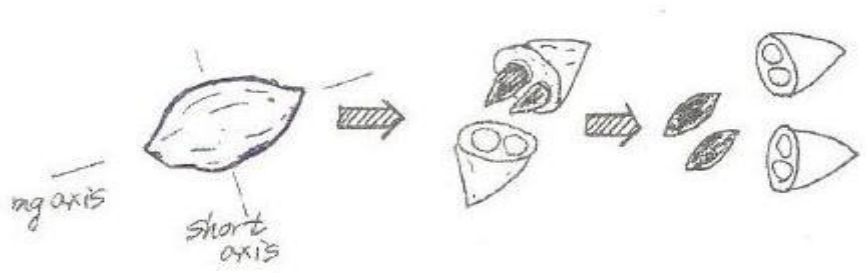

Figure 7: Example of *M. volkensii* seed extracting process (Lugadiru, 2004).

7 Immediate selection of seeds: dark brown seeds only suffice, not black coloured ones. Then they must be deposited in a clean and disinfected container;
8 The seed must be soaked overnight in cold salt-free water mixed with Bavistin (1 g/ltr);
9 The seeds must be counted;
10 Task rate for cracking is 2000 seeds at the end of the day;
11 Everything must be recorded in the nursery operations book.

The amount of seeds per nut must be taken into account as well as the rate of seeds that are lost. This is used to make proper task rates and can help in ameliorating the efficiency of the executed steps. The seeds lost through cracking is averagely 6 % per person of the total amount of seeds at the end of the day (BGF, 2012 C).

Table 6: Overview of amount of seeds per nut (Vandenabeele, 2010).

nuts	seeds/nut	total seeds
52	1	52
36	2	72
4	3	12
2	4	8
6	0	0
100		144
average seeds/nut		1.44

5.3.3.2 Results

Initial task rate: 2000 nuts cracked per employee per day. This translates itself into an average of 250 cracked nuts per hour.

For work planning purpose, it is important to determine the amount of seeds extracted from the nuts. As stated in *table 6,* not every nut gives a seed. In 2010 the average amount of seeds per nut was 1,44. In July 2012, the average amount of seeds per nut was 1,46 (*appendix 1, p145*). Next to this, seeds can be damaged by cracking the nuts and thus lost. Observation led to a loss of 8,29 % of the seeds. This figure must be taken into account when a certain amount of seeds is needed, in order to estimate the needed nuts and fruits.

Table 7 shows the amount of cracked nuts the 8th of August. It is clear that every employee managed the task rate, apart from person 3, who failed for 59 nuts. Based on the average this is approximately only a quarter of an hour work.

Striking numbers from person 1, 10 minutes before lunch break. Compared to the average, person 1 did 26 minutes of work in 10 minutes.

Even the 80 minutes after lunch, person 1 cracked 480 nuts. According to the average, this should be 311,41 nuts. Even now, person 1 did work a lot faster than average. Person 2 and 3 also worked faster compared to the average, but the difference is less profound than with person 1. This is clearly visible in *fig. 10.*

Remarkable is that the employees did not work the first 50 minutes of the day, but still managed their task rate. Again this should be noticed by the supervisor.

Statistical analysis made clear the employees did not work faster than their task rate (p-values for person 1, 2 and 3 *resp. p = 0,745, p = 0,646 and p = 0,451.* All p-values > 0,05) and the

amount of cracked nuts did not differ between the employees (p-values for person 1-2, 1-3 and 2-3 *resp. p = 0,741, p = 0,231 and p = 0,517.* All p-values > 0,05). Although in the end on the shop floor, the differences are remarkable.

Table 7: Amount of nuts cracked per person per time interval (8th of August)

Time	Person 1	Person 2	Person 3
7h30-8h20	0	0	0
8h20-9h20	249	274	291
9h20-10h20	342	285	318
10h20-11h20	282	371	274
11h20-12h20	288	265	295
12h20-12h30	104	42	67
13h00-14h20	480	390	372
14h20-15h20	267	325	234
15h20-16h00	90	90	90
Total	2102	2042	1941
Average per hour	233,56	226,89	215,67
Standard deviation	146,25	145,11	129,92

Table 8: Amount of nuts cracked per person per time interval (9th of August)

Time	Person 1	Person 2
7h30-8h20	0	0
8h20-9h	270	263
9h-10h	289	233
10h-11h	291	207
11h-12h	276	261
12h-12h30	200	99
13h-14h	432	279
14h-15h	267	217
15h-16h	296	240
Total	2321	1799
Average per hour	257,89	199,89
Standard deviation	114,15	91,62

Table 8 states person 1 managed the task rate with ease and person 2 did not. Out of the observations was clear that person 2 worked slower than person 1, cause unknown. Overall, person 2 was slow and never intended to manage the task rate. Although out of statistics it seems both employees work according to the task rate (p-values *resp. $p = 0,441$*and *$p = 0,139$*. Both p-values > 0,05). Although as mentioned before, the difference on the shop floor is certainly noteworthy.

Also remarkable: the employees did not work for the first 50 minutes, resulting in an inadequate performance of the supervisor. Still, person 1 managed to exceed the task rate, by 321 nuts, in 50 minutes less time.

The first hour after lunch, person 1 managed to crack 432 nuts in 1 hour. Compared to the average, the employee did the work for 100 minutes into 60 minutes. The half an hour before lunch, employee 1 cracked 200 nuts, resulting in 46 minutes of work, jammed into a half an hour. These remarks are made visible in *fig. 11*.

Statistical analysis pointed out though person 1worked significantly faster compared to person 2 (*$p = 0,012 < 0,05$)*.

Table 9: Amount of nuts cracked per person per time interval (10th of August)

Time	Person 1	Person 2
7h30-7h40	0	0
7h40-9h	349	456
9h-10h	269	272
10h-11h	332	304
11h-12h	336	336
12h-12h30	87	90
13h-14h	252	238
14h-15h	202	206
15h-16h	242	200
Total	2069	2102
Average	229,89	233,56
Deviation	118,37	133,92

Table 9 shows both employees managed the task rate. Unlike the other days of cracking nuts, the employees started only 10 minutes late. A general observation: the work tempo was slower than the previous days of the same action.

Remarkable are the first 80 minutes of the day. Compared to the average, both employees worked faster. Person 2 nearly worked 1,5 times faster than average. This is made visible in *fig. 12*.

Seen from a totally objective point of view, this is an ordinary day on the shop floor. Statistical analysis showed no difference between the amount of nuts cracked by the employees and the task rate (person 1 and person 2 have *resp. p = 0,624* and *p = 0,722*. Both p-values >0,05). There wasn't even a significant difference in amount of nuts cracked across the employees (*p = 0,800 > 0,05)*.

Ergonomics

The cracking work instructions (BGF, 2012 C) recommends employees to wear aprons. Gloves are not desirable, since they can slow down the removal of the seeds out of the nut. The panga, used to crack the nuts, should be sharp at all times. This will obviously raise the efficiency.

As well as the depulping process, this is an action done sitting. The same recommendations are at hand:

- A flat terrain;
- A decent workstation: table and chair at ideal height;
- A continuously shaded workstation;
- All tools and objects (nuts to crack) should be within reach;

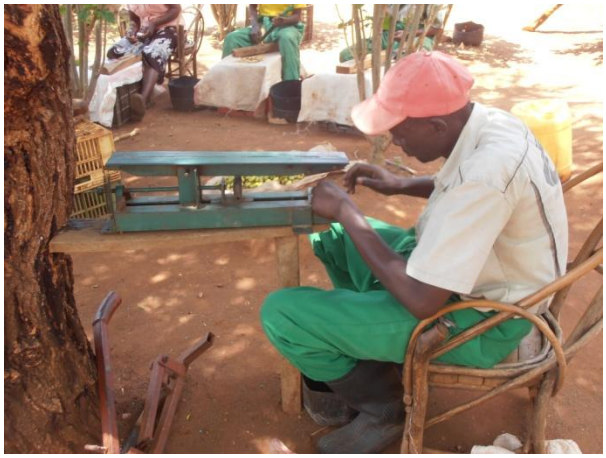

Figure 8: Cracking a nut by use of the cracking device

Figure 9: Cracking a nut by use of panga

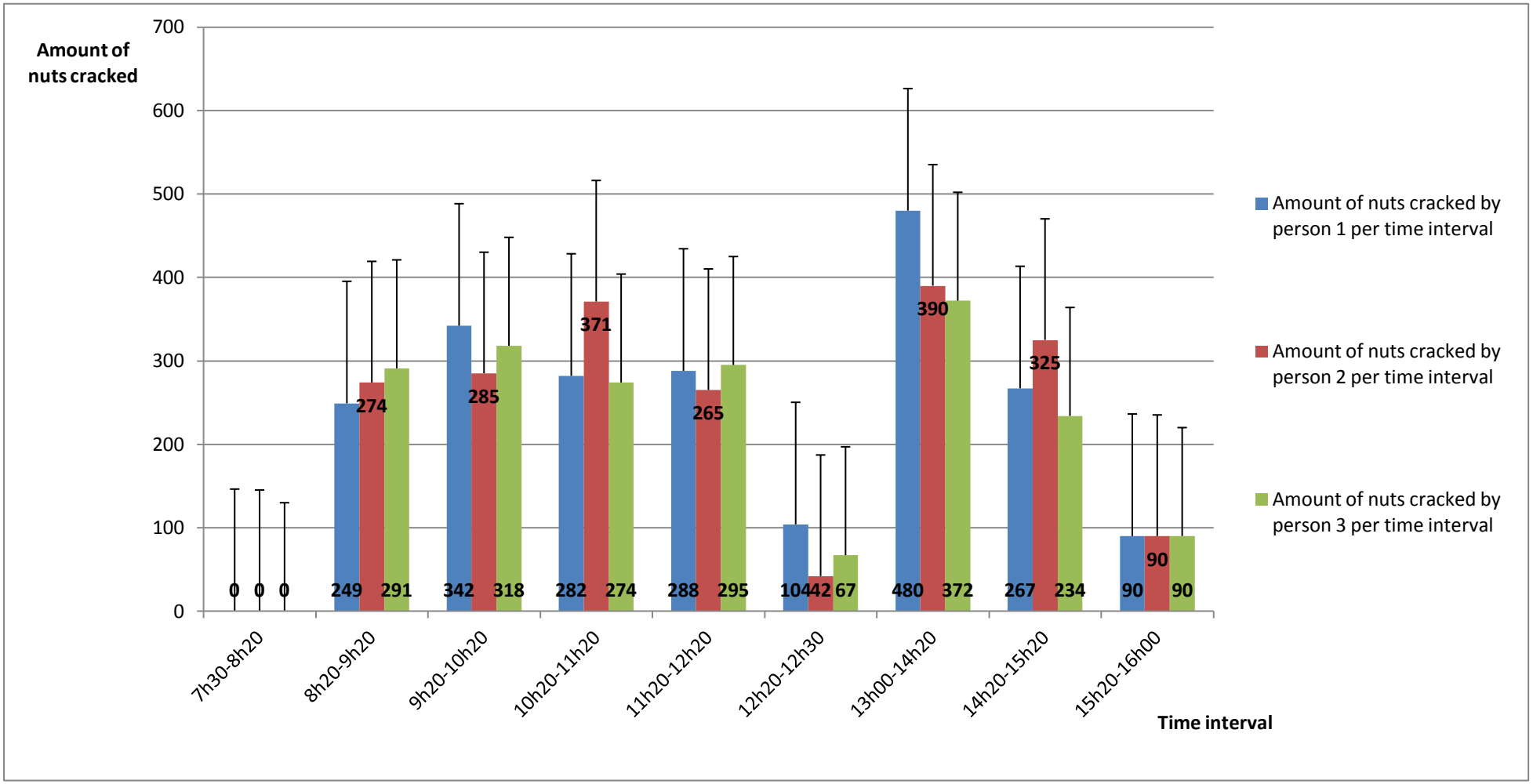

Figure 10: Amount of nuts cracked per time interval per person (8th of August)

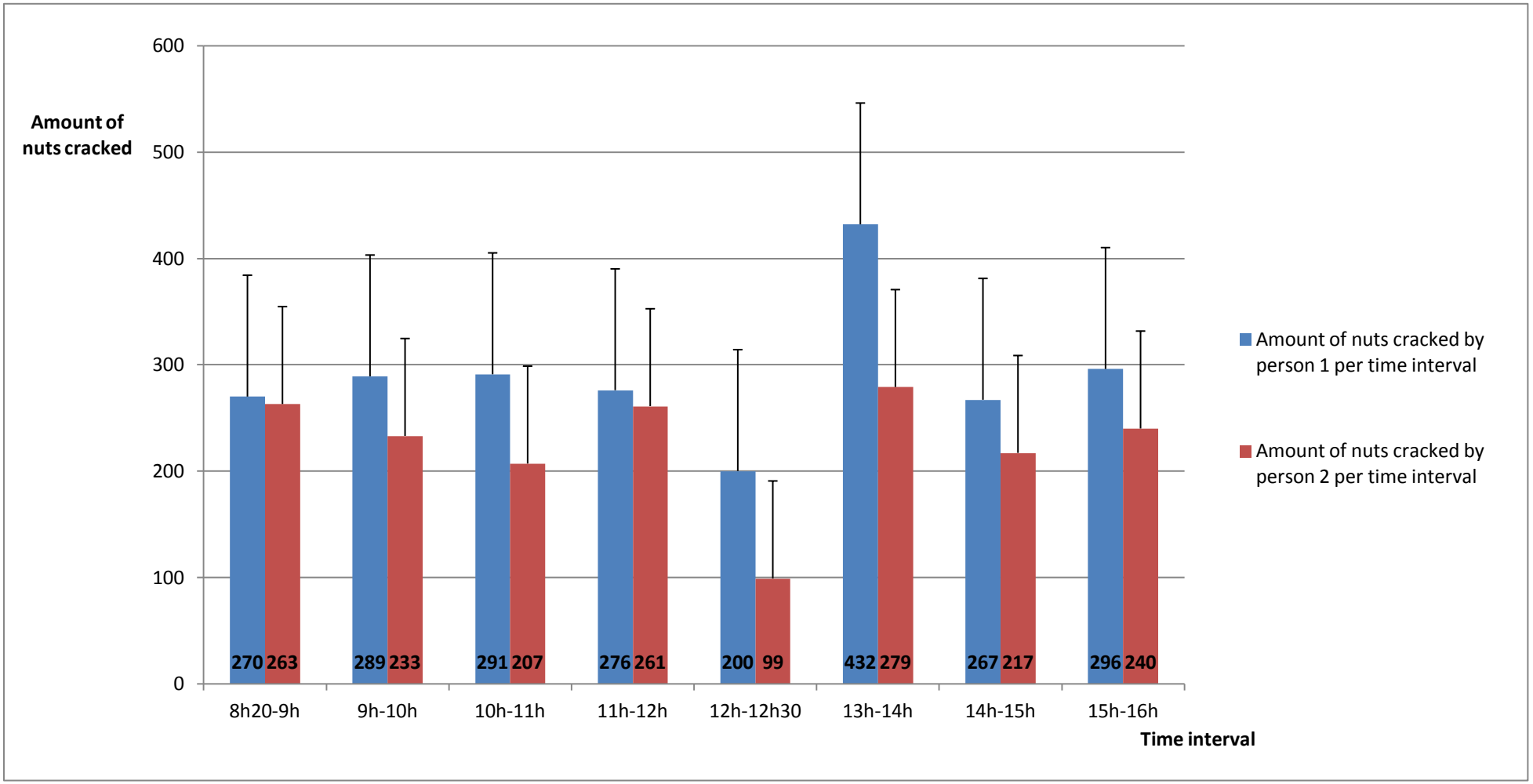

Figure 11: Amount of nuts cracked per time interval per person (9th of August)

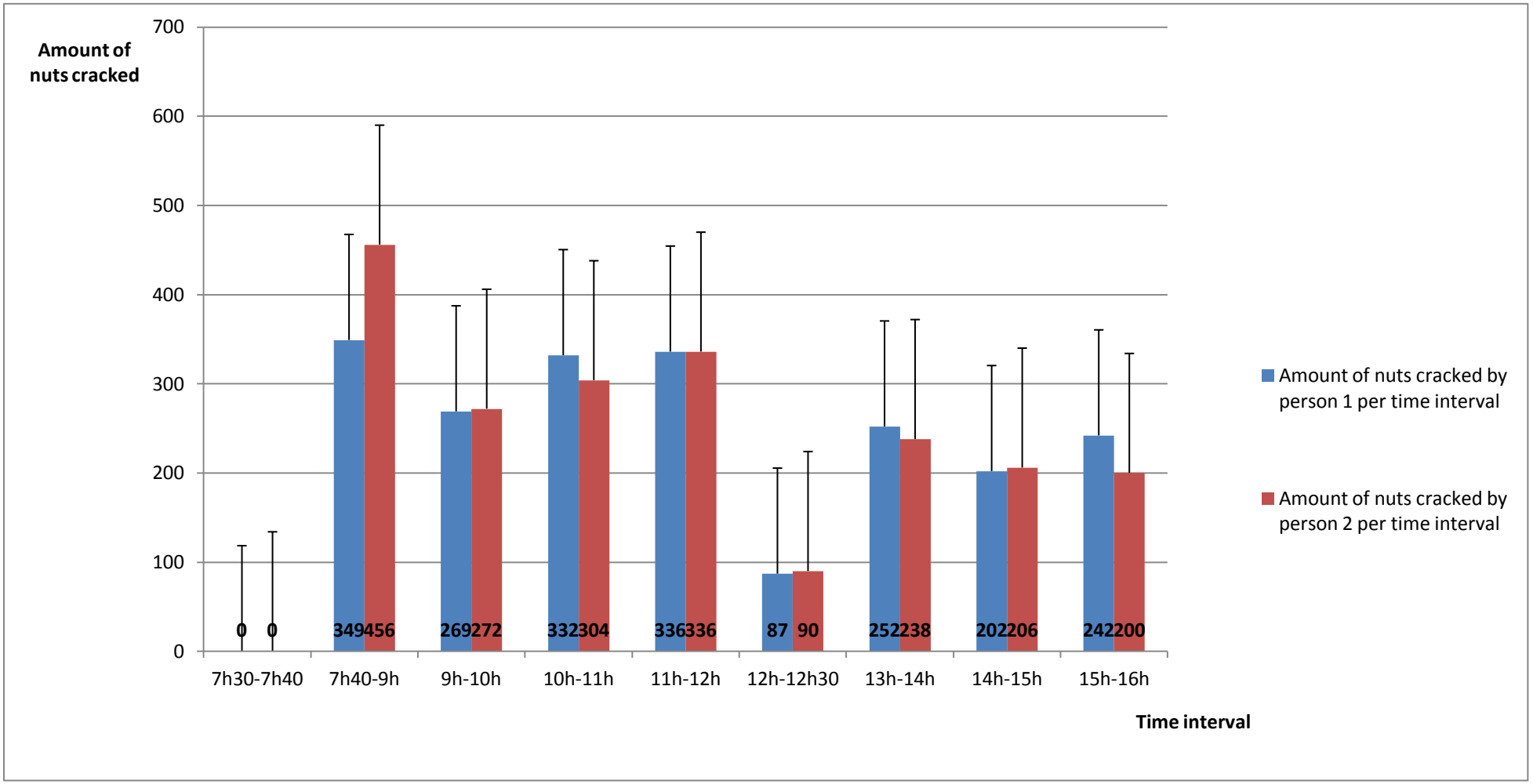

Figure 12: Amount of nuts cracked per time interval per person (10th of August)

5.3.3.3 Conclusion

In the first place, the observation pointed out the cracking task rate is also easily manageable. 2 out of 3 days of observation, the employee started 50 minutes late, but still cracked the amount of nuts provided by the work instruction. This implying the employees know exactly what they are doing, also proven the third day (10th of August), when the employees only started 10 minutes late. Although statistical analysis proved that the average amount of cracked nuts compared to the actual average amount of cracked nuts (derived from the task rate) does not differ, the actual amount of cracked nuts on the shop floor is a huge difference. Given these figures, the employees can be able to perform better than the initial task rate.
Cracking is a very underestimated process. The hit of the panga in the nut must be hard, though not too hard, otherwise the seeds are broken. Therefor the knife must be sharp at all time and the employees must know what to do, *i.e.* how to hit the nut. Training a new employee will be very hard. The rookie will work slow and will have a high loss percentage of seeds, so patience in the learning process is needed.
The loss percentage of seeds is 8,29 %, which is too high. Earlier observations gave 6 % loss percentage. Lugadiru (2004) described the use of the seed extractor from the nuts, but due a too high loss of seeds, this device is not operative anymore.
Cracking will be a compromise between working fast (er) and perhaps obtaining a higher loss percentage or working at a good pace to suppress a high loss percentage.

5.3.4 Nipping

5.3.4.1 Introduction

The nipping of the seeds is an artificial action to make the subsequent step, the slitting of the seed exocarp, more easy. This step is created by the manager of the plantation at Lake Kiambere, due to his field experience. The seeds that are nipped can be penetrated by water. This action will allow water to penetrate and soften the strong exocarp from the inside, which is not water repellent in contraire with the outside of the seed coat.
The work instruction to nip and soak the seeds is the following (BGF, 2012 D):

1 After cracking the nuts and removing the seeds from the nut, an immediate selection of seeds takes place: dark brown seeds suffice. Black or other coloured seeds are discarded. Thereafter the seeds must be deposited in a, clean disinfected container;
2 Nipping of seed (at its small end) with finger nail (holding the seed between the thumb and the pointing finger);

3 Recording of the number of nipped seeds in the nursery activity book. This must later on be transferred into the daily nursery operations form.

Figure 13: To nip seeds

Figure 14: Nipped seeds

4 Collecting the seeds after the nipping, the exact amount of seeds must be known, hence step 3;
5 Soaking the seeds – mostly – overnight for 12 hours in a clean disinfected container, which is then filled with water and bavistin (at 1 g/L).
6 Initial task rate: 3000 seeds nipped per employee per day, translated to an average of 375 per hour.

5.3.4.2 Results

Table 10 gives an partial overview of the amount of seeds nipped.
The average is slightly higher than the average based on the task rate, although not significantly higher ($p = 0{,}638 > 0{,}05$). So this will not make a significant difference in the total nipped seeds at the end of the day.
As it seems out of *fig. 15*, this is an ordinary day. When these figures would be extrapolated, the task rate would be easily managed. 3000 seeds would be nipped in 466,69 minutes (1 day of work contains 480 minutes).

$$nipped\ seeds = 6{,}4282\ seeds * time\ (minutes) \quad (5.2)$$
$$\Leftrightarrow 3000 = 6{,}4282 * time\ (minutes)$$
$$\Leftrightarrow time = 466{,}69\ minutes$$

Although the work instruction (BGF, 2012 D) mentioned a colour selection of the seeds, this was not done at the time of observation.

Table 10: Amount of seeds nipped per 10 minutes

Time	Nipped seeds
10h30-10h40	67
10h40-10h50	52
10h50-11h00	31
11h00-11h10	80
11h10-11h20	65
11h20-11h30	69
11h30-11h40	66
11h40-11h50	76
11h50-12h00	61
12h00-12h10	85
12h10-12h20	95
12h20-12h30	41
14h00-14h10	55
Total	843
Average	65,67
Deviation	18,03

Ergonomics

Nipping is also done sitting. The same observations can be added as for depulping and cracking. Next to this, the seed coat will be destroyed. This implying seeds will be vulnerable for threats and infections. Nipping is not recommended with gloves, so the hands of the employees should be disinfected before nipping. There should also be soap or another disinfectant available after nipping the seeds.

5.3.4.3 Conclusion

The nipping task rate was managed without a problem. The employee did it slightly faster – and at a good pace – than the task rate, but the difference was not significantly higher. Therefore the initial task rate can be maintained. The amount of seeds lost due nipping, wasn't monitored, but must be taken into account.

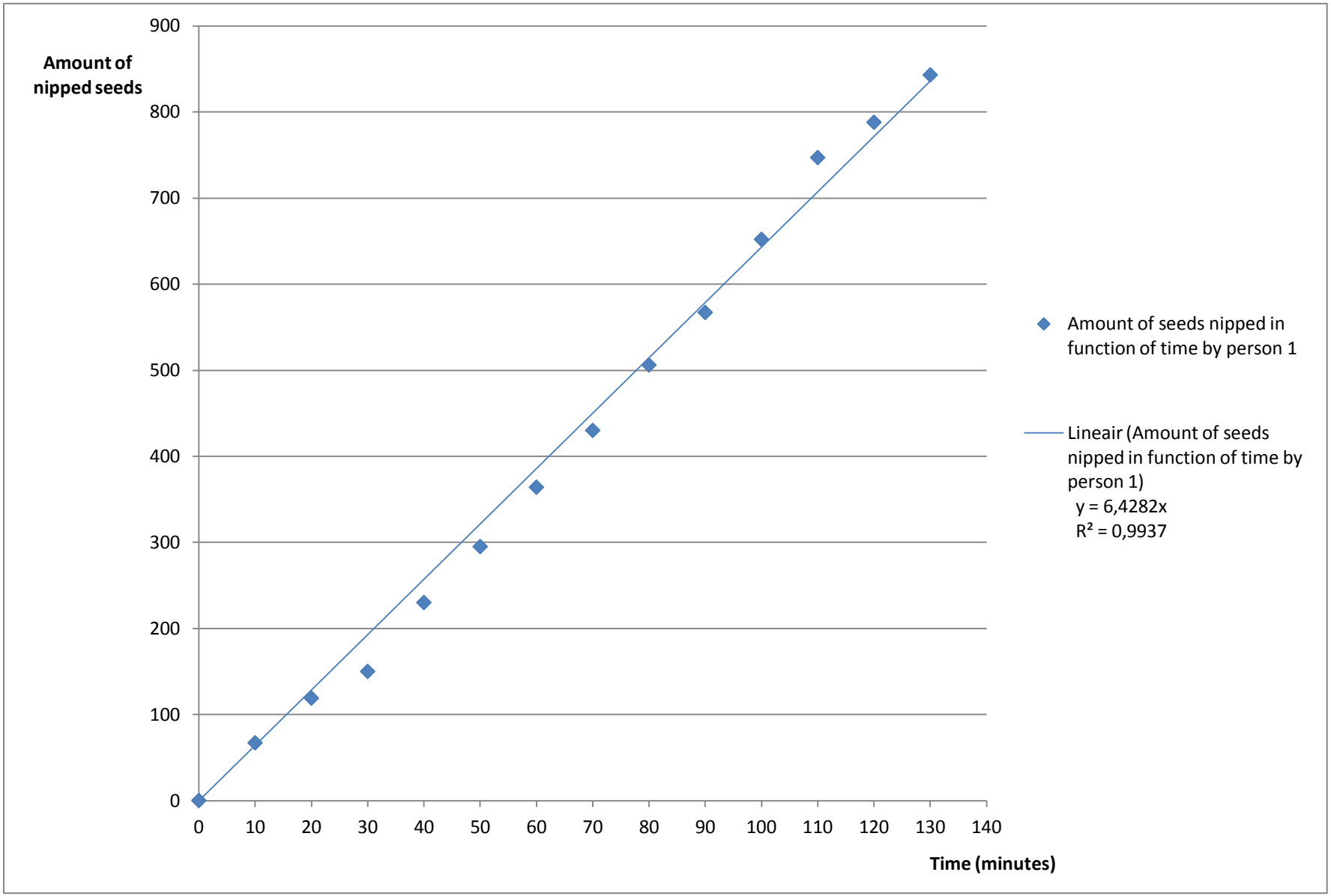

Figure 15: Amount of seeds nipped in function of time by, 1 person

5.3.5 Slitting

5.3.5.1 Introduction

Slitting the seeds points out the importance of the seed coat and the dormancy of the seeds. The seeds are viable, but fail to germinate under favourable conditions – as they are left in the state as they are. The seeds do germinate normally when the seed coat is (partially) removed. The dormancy in intact seeds is caused by the integuments, the perisperm or/and the endosperm. The integuments prevent germination, partly, by not allowing water to penetrate the seed, thus the embryo cannot absorb a sufficient amount for water to its cell division. When integuments, perisperm and endosperm are cut longitudinally at the micropylar end of the seed, normal germination can occur. But employees who slit the seeds, must be cautious to cut the seed coat well. A horizontal cut in the centre or a longitudinal cut at the chalazal end induce abnormal germination. The radical elongates, but is unable to shed the integuments, which halts the germination (Milimo, 1986).

The specific instruction for slitting the seed coat is as following (BGF, 2012 E):

1 Seeds are removed from the water, wherein they have soaked for 12 hours, and slit over its entire length with a razorblade;
2 Two slits are made on the opposite sides of the seed;
3 Slit seeds are put in a container with water (and bavistin: 1 g/L) while accumulating a number big enough to bring to the propagator;
4 The task rate for slitting seeds is2000 seeds to slit per day. Note that this must be done in 6 hours;
5 After slitting at least 2000 seeds in 6 hours, the following 2 hours must be used to sow the slit seeds.

5.3.5.2 Results

Initial task rate: 2000 seeds slit per employee per 6 hours, translated to an average of 333,33… per hour. Only 6 hours of slitting is done, to immediately sow the slit seeds in the propagator.

Table 11: Amount of seeds slit per 10 minutes (13th of August)

Time	Person 1	Person 2
10h30-10h40	46	57
10h40-10h50	26	65
10h50-11h00	52	58
11h00-11h10	59	72
11h10-11h20	74	19
11h20-11h30	52	50
11h30-11h40	40	44
11h40-11h50	42	49
11h50-12h00	40	37
12h00-12h10	40	38
12h10-12h20	38	43
12h20-12h30	24	25
14h00-14h10	66	71
14h10-14h15	44	59
Total	643	687
Average per 10 minutes	45,93	49,07
Standard deviation	13,87	15,97

Table 11 together with *fig. 16* (after extrapolation) point out the employees will not reach the task rate of 2000 slit seeds. If the average amount of slit seeds should be 333,33.. per hour, person 1 as well as person 2 do not suffice. Person 1 and person 2 managed to slit the first hour respectively 309 and 321 seeds and the second hour only 224 and 236, these values being even lower than the first hour of observation.

Some figures are extremely and inexplicably low. Person 2 only slit 19 seeds in 10 minutes (11h10 – 11h20). There was no break observed.

This is also proven by statistical analysis of the mean values. The mean value per 10 minutes according to the task rate is 55,555… slit seeds. The amount of seeds slit by person 1 differs significantly from this value ($p = 0,035 < 0,05$). Person 2 did not differ significantly from the mean value ($p = 0,136 > 0,05$).

This inefficiency should be countered by a supervisor who will need to point out, the work tempo needs to raise.

Table 12: Amount of seeds slit per 10 minutes (15th of August)

Time	Person 1
09h30-09h40	75
09h40-09h50	81
09h50-10h00	72
10h00-10h10	79
10h10-10h20	49
10h20-10h30	82
10h30-10h40	68
10h40-10h50	71
10h50-11h00	16
11h00-11h10	66
11h10-11h20	75
11h20-11h30	66
11h30-11h40	64
11h40-11h50	73
11h50-12h00	65
12h00-12h10	53
12h10-12h20	53
12h20-12h30	53
Total	1161
Average per 10 minutes	64,50
Deviation	15,69

Unlike the 13th of August, the amount of slit seeds on the 15th of August did suffice (*table 12*). The extrapolation of *fig. 17* points out that the task rate can be managed with ease. At this work tempo, the task rate is met at 300,30 minutes – where the task rate of 2000 slit seeds should be managed within 360 minutes (or 6 hours). This can give employee 1 an extra hour to slit seeds. Even statistically, the mean values differ significantly (*$p = 0{,}012 > 0{,}05$)* but on the shop floor, this extra hour can make a huge difference.

$$slit\ seeds = 6{,}66\ seeds * time\ (minutes) \quad (5.3)$$

$$\Leftrightarrow 2000 = 6{,}66 * time\ (minutes)$$

$$\Leftrightarrow time = 300{,}30\ minutes$$

Given this average of slit seeds, it is obvious the employees did not work fast enough the 13th of August. The lowest value in *table 12* is due a toilet visit of the employee. It is clear that even with breaks, the task rates are manageable.

Ergonomics

Slitting is also done sitting. The same observations can be added as for depulping, cracking and nipping.

Slitting is done using a sharp razor blade. Employees must be aware of the dangers of these razors.

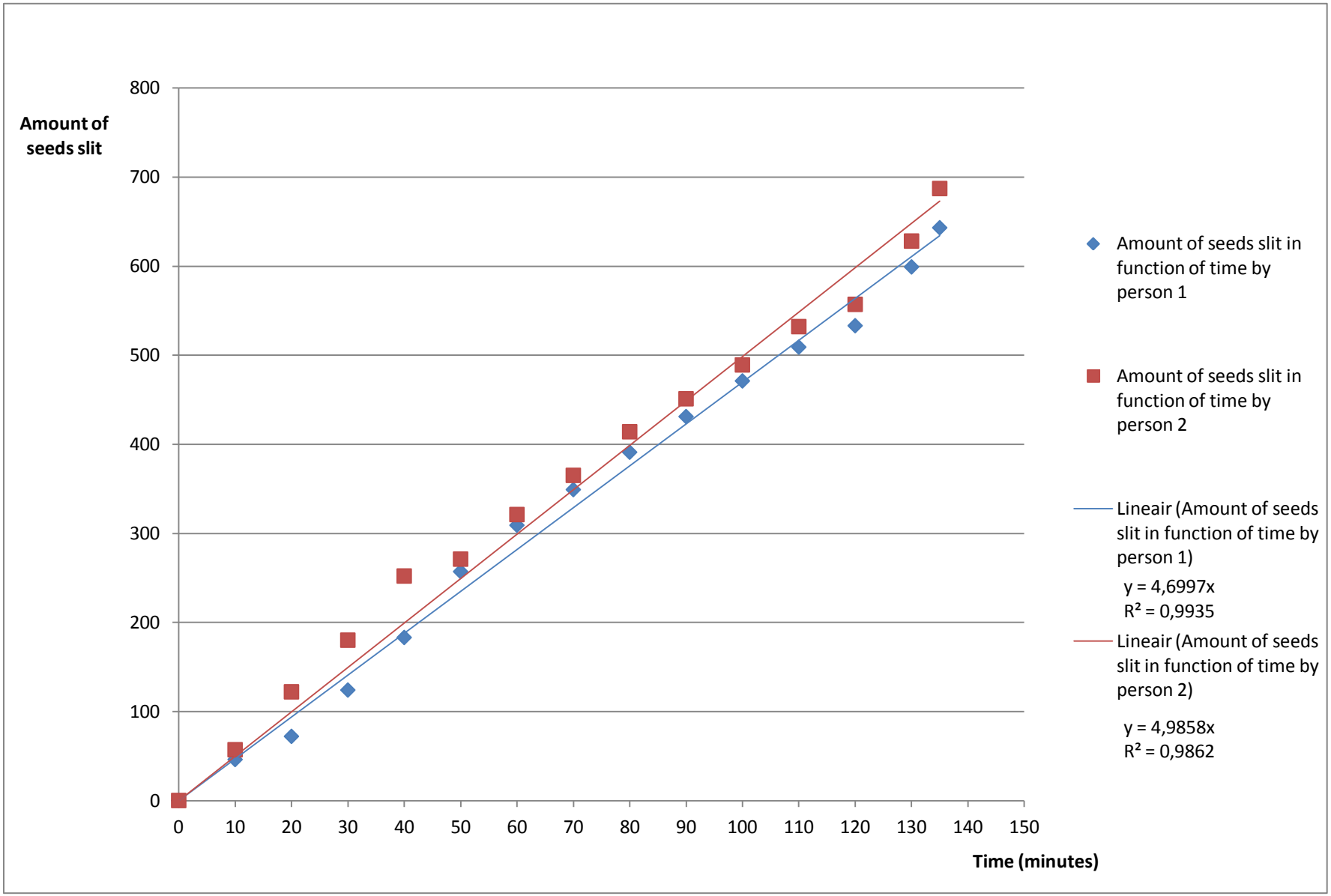

Figure 16: Amount of seeds slit by person 1 and 2, in function of time (13th of August)

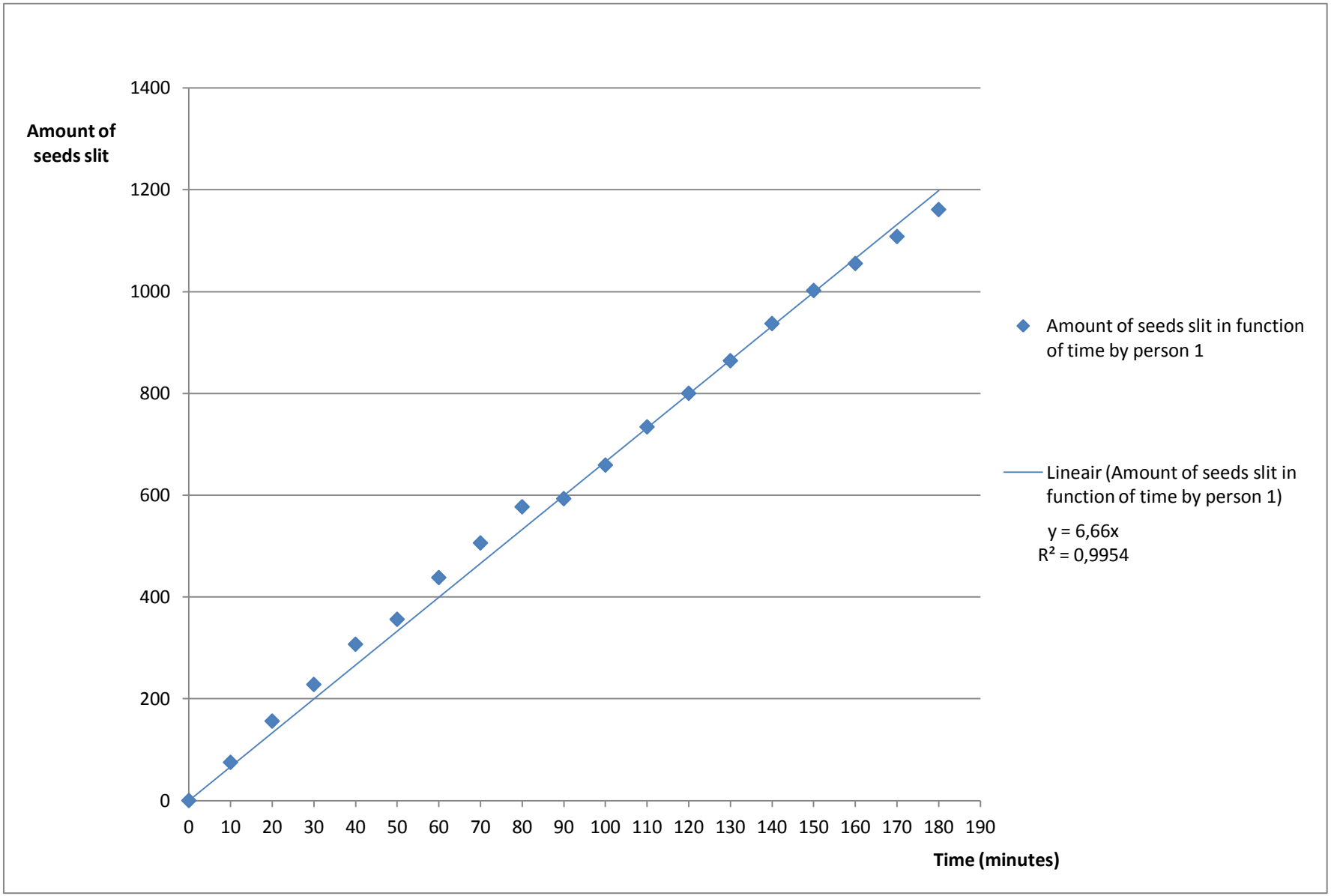

Figure 17: Amount of seeds slit by person 1 in function of time (15th of August)

5.3.5.3 Conclusion

The first day of slitting was a bad day. The task rate was not managed at all. Both employees worked at a slow pace, but it did not seem as if it was deliberately. Perhaps because of the social setting, the employees were distracted, although was never a problem with the other tasks.

The second day, the employee worked fast and good and managed the task rate with ease. Although there wasn't a statistical difference between the mean values, the employee would have 1 extra hour (after extrapolation) when the task rate was managed. This implying in the first place that it is plausible to manage the task rate, opposed to the first day of observing slitting. And secondly, the initial task rate can be adjusted. The employee would have done the task in 5/6 of the time. In an extreme point of view based on the average of the task rate, this means time to slit 333,33… more seeds.

The amount of seeds lost due slitting, wasn't monitored, but must be taken into account.

5.3.6 Sowing of the seeds

5.3.6.1 Introduction

After the seeds being slit, they are immediately being sown in the propagator. At this stage, seeds and seedlings are very susceptible for fungal attack, situated in – nutrient-wise – poor soil, are subjected to unfavourable weather conditions, *etc*. This is an important step in the production chain. It is crucial for producing good seedlings, that can be used for further hardwood production in the field. Due to unfavourable conditions, the germination percentage is rarely 100 %.

The sowing of the seeds is done in a propagator. It is a structure (180 cm long, 60 cm wide, 20 cm high at front and 25,4 cm high at the back) made out of decay resistant wood, with a capacity of 1500 seeds. The wooden structure is covered with a double layer of transparent polyethylene, except for the bottom, where the layer is single and perforated allowing water to percolate into the soil.

Figure 18: Seed propagator

The instruction on sowing the seeds is the following (BGF, 2012 F):

1 Coarse, sterilised sand is spread in the propagator. The layer of sand should have a maximum height of 3,80 cm (1,5 inch);
2 The seeds are sown in rows. Interrow distance of the seeds should be 1 cm and the distance between the rows should be 2,5 cm;
3 After sowing, the seeds are covered with 1 cm coarse sand or 0,5 cm fine sand;
4 Bavistin/benlate/rootgard are used to control fungal infection inside the propagator. The fungicides are used interchangeably to avoid build-up of resistance by the fungi. Mark that rootgard is a biological fungicide. This cannot be mixed with other chemical products, since those can affect the biological fungicide;
5 At the day of sowing, the seeds are watered. Using 6 L of water mixed with bavistin (1g/L).
6 After three days, the propagator must be checked for moisture conditions. Ideally the moisture must be
7 A secondary watering can be done, according to the conditions;
8 The propagators must be labelled. This to indicate the date of sowing, the person who has sown the seeds, how many seeds were sown;
9 The propagator must be kept closed by all means. Cold air can decrease the germination rate of the seeds;

10 The temperature must be checked on a daily basis (ideal temperature = 38 – 40°C);
11 The temperature in the propagators must be regulated. This is done by adjusting the shades on the roof of the propagator shed;
12 The duration of the germination is dictated by the weather conditions. This will affect the temperature, insolation and moisture content inside the propagator;
13 The germination is uneven: a mixture of early and late germinated seeds. All will be used for the subsequent transplanting step;
14 After a complete germination cycle, the propagator must be cleaned with an agent containing hypochlorite, mixed with a sticking agent. Thereafter the propagator should be dried in the sun for 2 days.

The coarse sand to apply, is considered sterile when washed with water mixed with a fungicide, before application. This sand may be used only once.

5.3.6.2 Results

Sowing the seeds must be done in the remaining 2 hours of the same day when the seeds were slit. Sowing the seeds imply the preparation of the propagators wherein the seeds will be sown. The amount of seeds slit must be sown, implying enough propagators should be ready. When observed, the amount of total seeds was too little to view a complete operational production chain: only 3 propagators were filled with seeds.

Sowing the seeds is a process executed in several steps. The first step is to prepare the propagator. This exists out of taking coarse sand, transport it to the clean and disinfected propagator, fill it according to the sowing work instructions and sprinkle it with a mix of water and fungicide (BGF, 2012 F). As *table 13* points out, the preparation of the propagators took some time.

Table 13: Elapsed time for preparing the propagator

Preparing the propagator	Elapsed time
1	38 minutes
2	14 minutes
3	20 minutes

After the preparation, the slit seeds can be sown into rows in the propagator. Then the seeds are covered with a thin layer of sand and watered with a water/fungicide mix (BGF, 2012 F). Thereafter, the propagator most be labelled, to indicate person, date and amount of seeds sown. Then the cycle of sowing seeds is completed.

Table 14: Elapsed time for sowing seeds into the propagator

Sowing the seeds	Elapsed time
1	28 minutes
2	28 minutes
3	30 minutes

First 1500 seeds were sown, thereafter 1480 and 1552. The average time of these actions is 52 minutes, with standard deviation of 12 minutes. This is only based on 3 determinations, so this is only useful to give a general idea.
After the seeds being slit, they are put into a container filled with water mixed with a fungicide (bavistin at 1 g/L). Thereafter they are being sown. This implying seeds slit at 8 am are soaked for nearly 6 hours, where seeds slit at 1 pm are soaked for only 1 hour. This is very important concerning mortality of the seedlings in the propagator.

Ergonomics

Preparing of the propagator is done by transporting coarse sand by wheelbarrow to the propagator. When sowing the seeds, employees are forced to sit on their knees, to sow the seeds at normal pace. Thereafter, the propagator is rinsed with water mixed with a fungicide. Due to the fact the propagator are located onto the soil, the employees must bend forward to properly water the propagator.

5.3.6.3 Conclusion

All seeds were sown after being slit, propagators were clean and the action of preparing the propagator, sowing and watering was fluent. Although it would be more efficient to have the propagators already prepared and ready, so the seeds can be sown immediately. For example, an employee who is appointed to water the seedlings in the nursery, can prepare a propagator at the beginning of the day, provided it is the day the seeds are sown. Or the guard patrolling at the office can do this too. This can eventually lead to more time for slitting seeds or sowing seeds.
The variation of mortality in the propagators is very high. A lot of seeds do not germinate due rot or fungal attack. Perhaps this is caused by the soaking of the seeds after being slit. If the slitting starts at 7:30 am, some seeds will be soaked for 6 hours, which can induce rotting of the seeds under favourable conditions in the propagator.

A solution could be to put the seeds into a container with high moisture content, but not into water (mixed with a fungicide) as it is now. Make sure to keep the moisture content up, especially for the harsh conditions at the plantation.

5.3.7 Transplanting the seedlings

5.3.7.1 Introduction

After germination the seedlings develop first the cotyledons and thereafter their real leaves. The coarse sand, in the propagator, lacks nutrients for further development. When the seedlings stay too long in the propagator, they will suffer from nutrient deficiencies which will eventually lead to growth stop. But after the germination, seedlings are too small and weak to be immediately planted out in the field. They first need to be transplanted, followed by several stages of hardening off. The latter being the acclimatisation of young plantlets to temperatures out of the propagators. This period may not be rushed because the natural waxes coating the leaves must undergo changes in form and thickness to reduce the water loss. Stomatal pores also need to adapt to the less favourable conditions (The Royal Horticulture Society, 2006).

First stage of hardening off contains the removal of the seedlings out of the propagator, place them into polybags – small polyethylene containers/bags filled with sterilised soil. Seedlings are very susceptible to pathogens, mostly hosted by the soil. Soil sterilisation is necessary. The soil can be sterilised by sun drying, *i.e.* laying a thin layer of soil onto a sterile polyethylene sheet and let it heathen up by the sun. The soil can also be sterilised by steaming it. Pathogens are killed by the high temperature of the steam. Steaming is more thorough than sun drying, but also more expensive.

Once filled, the polybags are then arranged in beds of 1000 units placed in a tunnel section – a half-circular wooden construction, which is covered with a polyethylene sheet (Vandenabeele, 2011). Once the polybags are filled and arranged in the tunnels, the seedlings can be transplanted from the propagator to the tunnels.

Filling the polybags, as well as transplanting the seedlings have their own specific work instructions:

The working instructions on filling the polybags (BGF, 2012 G):

1 Potting soil should be forest soil, rich in organic matter. The area where the soil will be mined must be located and must be cleared from grass and leaves;
2 The soil shall be mined 3 to 4 inches deep, using a digging hoe;

3 Transport of the soil by wheelbarrow to the nursery and heaped under a shade;
4 The soil is mixed with sand in a 5 to 1 ratio (soil:sand) and sprinkled with water if too dry;
5 Filling the polybags is done using a scooping spoon, for improvement of efficiency and prevention of injuries;
6 The filled polybags are arranged in a tunnel;
7 The polybags are watered with 54 L water per tunnel;
8 The task rate to arrange polybags in the tunnel: one employee must arrange 3000 polybags per day;
9 The task rate to fill the polybags: per day one employee must fill 700 polybags.

The instruction on transplanting the seedlings from the propagator into the polybags (BGF, 2012 H):

1 Everything must be done in sterile conditions: the seedlings will be taken out of the propagator with bare hands. Hands must first be disinfected with a H_2O_2 solution;
2 The removal of the seedlings out of the propagator is done best when the seedlings have developed their first true leaves. They must be handled with care, a minimal physical handling;
3 The seedlings are taken out by loosening the soil around the roots, to reduce damage done to roots, stem and leaves when taken out of the propagator;
4 The seedlings should be grouped per length. Due to uneven germination, seedling size/length will differ. Seedlings should be grouped according size/length and planted in different nurseries – using the same criteria – to obtain homogeneity;
5 The seedlings which are removed from the propagator, are put into a container containing water mixed with fungicide. The water prevents roots drying out;
6 The filled polybags are sprinkled with water mixed with fungicide (2g/L bavistine);
7 The transplanting of the seedlings into the polybags is done by creating a hole in the soil with a dibble. The seedling is placed into the hole and the root is covered with soil. This must be done with care;
8 Excessively long or damaged taproots are cut short before the seedling is being transplanted. This to prevent coiling or rotting of the roots;
9 Every transplanted seedling must be watered carefully, with a cup;
10 The covering of this section, in the nursery, is done after watering the polybags. When covering, a narrow space is left between the ground and the polyethylene sheet for ventilation purpose and prevention of occurrence of fungi;

11 Every three days, the seedlings are watered with 18 L water (mixed with 2 g/L fungicide: bavistin) per 1000 seedlings;
12 The task rate for transplanting is 2000 seedlings per day;
13 Whilst transplanting, the germination rate must be calculated;
14 The seedlings remain in the tunnel section for 7 days.

The following step in the hardening off process entails transport, after 7 days, of the seedlings from tunnels to nursery beds. Per day, an employee must transport 1000 polybags from the tunnel to the nursery beds. At first, the nursery bed are still covered with a polyethylene sheet, to protect the seedlings from the rain and severe insolation. A specific watering protocol must be followed:

1 One nursery bed equals 1000 seedlings and must be watered 36 L of water per day;
2 There must be a weekly addition of phosphorus, as foliar fertiliser. Addition of 2 g/L water;
3 There must be a weekly addition of copper-oxy-chloride, as nutrient supplement or fungicide. Addition of 2,5 g/L water.

After a period of six weeks, the seedlings are selected for quality: the seedlings of inferior quality are being disposed (Vandenabeele, 2011).

The next step in the hardening off process, is hardening off without plastic. The polyethylene cover is removed and the plantlets remain in the nursery beds for six weeks. The seedlings get 45 L (36 L in the rainy season) water per nursery bed per day. It is important to water the polybags evenly, to maintain the homogeneity of growth. Too much water, as well as too little, will lead to mortality of the seedlings. The water used for the seedling around the plantation, is being pumped out of Lake Kiambere and stored in large tanks. Since the water is too alkaline to apply – it can inhibit uptake of several minerals (Mengel & Kirkby, 2006) – it has to be made acidic. This is done by adding nitric acid in sufficient amount to drop the pH_{H2O} of the water between 5,7 and 6,5.

After six weeks in the nursery, the plantlets are sorted out (selected on quality) and are ready to be transported into the field. The polybags are put into a crate, which is carried through the field to where the plantlets need to be planted. Per day, an employee should be able to take 150 polybags to the field. Eventually, the *M. volkensii* are being planted in the field.

Table 15 shows the amount of time needed for a seedling to complete the nursery cycle.

Table 15: Overview of elapsed time, amount, concentration and frequency of used water and fungicide

Phase	Duration	watering		fungicide		
		Amounts	frequency	type	concentration	frequency
Propagator	12 days	6 L	once	Bavistin/Benlate	1 g/L	once
Tunnel	7 days	18 L/1000 seedlings	twice	Bavistin/Benlate	1 g/L	twice
Hardening-off with plastic	21 days	30 L/1000 seedlings	daily	Copper oxychloride, Bavistin/Bayleton	*resp* 2.5 and 1 g/L	Weekly, more when it rains
Hardening-off without plastic	56 days	30 L/1000 seedlings	3 times/ week	Copper oxychloride, Bavistin/Bayleton	*resp* 2.5 and 1 g/L e	Weekly, more when it rains
TOTAL	96 days					

5.3.7.2 Results

First stage of transplanting the seedlings contains the removal of the seedlings out of the propagator into polybags. The polybags are arranged in beds per 1000, in a tunnel section. *Table 16* gives an overview how fast the employee worked to fill the polybags. The initial task rate is set at one person filling 700 polybags per day. Brought back this ought to be 15 per 10 minutes. The first 10 minutes the employee worked as a hurricane and filled 23 polybags. From then on, the tempo slowed down and with great effort, the employee managed to keep up with 18 polybags per 10 minutes. Seeing this effort for only 50 minutes, it is clear this pace cannot be kept up the complete day. After filling the polybags, they are arranged in the tunnels.

Table 17 clearly points out that arranging polybags is an easy task, executed with little effort. An extrapolation (*fig. 20*)shows that at this pace, the task rate of arranging 3000 polybags can be managed easily.

Table 16: Time elapsed filling polybags per time interval of 1 and 10 minute(s)

Time interval	1 minute	10 minutes
1	3	23
2	2,5	18
3	2	15
4	2	18
5	2	18
Average	2,3	18,4
Standard deviation	0,45	2,88
Min	2	15
Max	3	23

Table 17: Time elapsed (mm:ss) arranging the polybags in the tunnels

Amount of polybags	Elapsed time (mm:ss)
10	01:07
10	01:02
10	01:17
10	01:01
10	01:15
10	01:43
10	00:48
10	01:11
10	00:37
10	00:48
Total	10:49
Average	01:05
Standard deviation	00:03

When every previous step is done, the seedlings are taken out of the propagator and put into the filled polybags. This was very hard to observe because several other side chores had to be done too. The employee had to go forth and back from transplantation spot to the propagator, after several polybags were filled with a seedling, the employee had to rinse them with water mixed with a fungicide. Therefore, the mix of water with a fungicide had to be prepared in a watering can.

The initial task rate: an employee should be able to transplant 2000 seedlings per day. Because of the very slow pace of the employee – notable in *table 18*, the task rate was not managed at all. It was as if the employee was uninterested and did not want to cooperate.

Table 18: Time elapsed transplanting seedlings per time interval

Time	Amount of seedlings transplanted
10h – 11h	199
11h – 12h	175
12h – 12h30	64
14h – 15h	179
15h – 16h	93
Total	710
Average	158
Standard deviation	59,56

Ergonomics

Filling the polybags is done sitting on the soil. The continuous bending over to grab an empty polybag, bend to the heap of soil, fill the polybag, bend over to place it elsewhere, is very demanding for the back. After a while, it is aggravating for all the limbs.

Figure 19: 2 employees sitting on the floor, filling polybags

Arranging the polybags is done using crates to transport the polybags from the filling spot to the tunnels. Lifting is done wrong, *i.e.* in a way it is very unhealthy for the back. The crates are transported and put down wrong again. Sometimes the transport of the crates with polybags is done with two employees. This is positive, dividing the mass of the crate, but even then, lifting and putting down the crate is done wrong.

Transplanting the seedlings is also a task where bending over is prominent. Bending over to 'prick out' the seedlings out of the propagator, bend over or kneel to transplant them into the polybags.

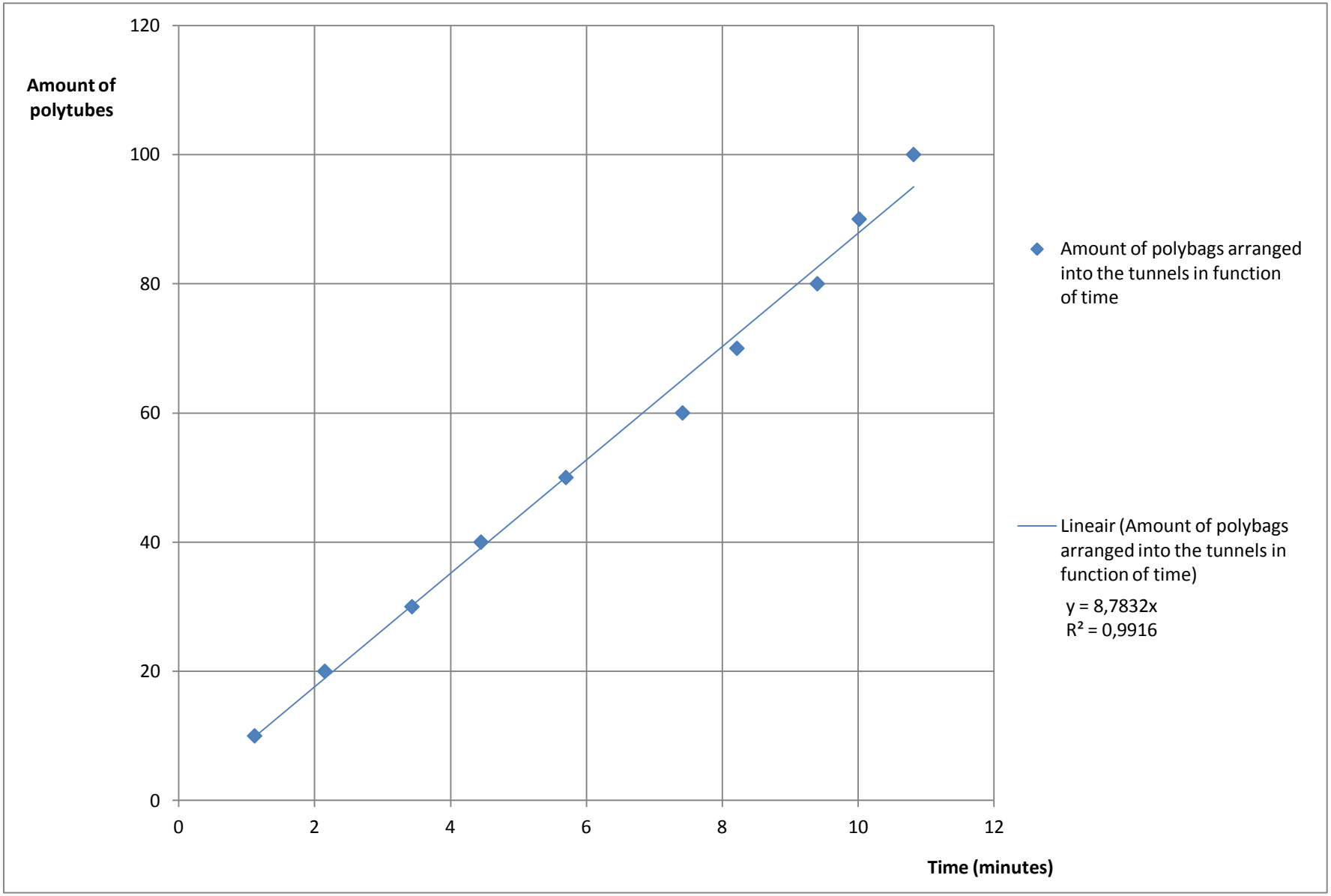

Figure 20: Amount of polybags arranged in the tunnels in function of time

5.3.7.3 Conclusion

Observing the filling of the polybags lead to the conclusion there must be another, faster, more accurate way of doing this. The task rate would have been managed, but the number of bags filled in 1 day is very little. *E.g.* when there is enough fruits to process 10.000 seedlings, 1 person will need 14,29 days to fill all polybags. This is an insanely high cost for the company, for an action like this. This is 1 employee that will not be available for 14,29 days to do another – more important – chore on the plantation.
The soil to fill the polybags as well as the employee filling the polybags were located on the ground.

A few ideas to solve, improve, make the filling of the polybags faster: a potting table.
A table with a hole in the middle, few millimetres smaller than the diameter of the polybag. At the bottom of the table, at the hole, extensions are made – a tube, to easily fit the polybag. The surface of the table has a little slope towards the hole. The employee opens the polybag, fits it underneath the hole – the extensions fitting in the polybag, keeping it open. The employee then collects soil and swipes it towards the hole, into the polybag, until it is filled. Repeat action. This task can be done sitting, this to make it easier to refill the soil onto the table. The soil now is being foraged in the forest and brought in by wheelbarrow. Thus the table must be strong enough to contain a wheelbarrow and several kilogram of soil.

The idea of a potting machine, based on gravity.
A box with a hole in the middle, few millimetres smaller than the diameter of the polybag. At the bottom, at the hole, extensions are made – at tube, to easily fit the polybag. The bottom surface of the box is very steep towards the hole, and the material has preferably as less friction as possible. This way, the soil will shove towards the filling hole of the polybag. Once the polybag is put over the tube, a shutter – perpendicular to the tube, is opened (manually) to allow soil into the polybag. Once filled, the shutter closes and another empty polybag is placed underneath the hole.
Observation of arrangement of the polybags lead to the conclusion that the task rate is easily manageable. The employees will even have time left after arranging the 3000 polybags.
No conclusion can be drawn out of the actual transplantation of the seedlings. The employee failed to manage the task rate, there was no intention at all to work at a decent pace: the movement forth and back from the propagator to the tunnels could be done much faster, the

planting of the seedlings was done with care, but very slow and the preparation of the watering cans with water and the fungicide took very long too.
It would be more efficient if the watering cans were already prepared before use. This to prevent seedlings being soaked for 10 minutes while an employee is preparing the watering can.

5.4 Task analysis of plantation maintenance

5.4.1 Marking the field

5.4.1.1 Introduction

Marking is done to point out where the trees will eventually be planted. Shallow pits of 1 or 2 hits with a digging hoe in the soil are made along a marking rope, to indicate where the permanent pits will be. This is where the *M. volkensii* trees will be planted. Planting distance for *M. volkensii* is 4 m, thus 625 tree per hectare.
This action goes with a specific instruction sheet:

1 The marking is done using a steel cable. The cable is marked every 4 m;
2 The steel cable is or is not tied at both ends to a peg. Four people do the marking;
3 The marking of the pits is done using a digging hoe. Shallow pits (1 or 2 firm hits with the digging hoe) are dug along the cable, every 4 m. These marks indicate where eventually the pitting has to be done;
4 The task rate for marking is 800 marks per day, per cable.

5.4.1.2 Results

The initial task rate for marking an area is 800 mark per day. This translates itself to 100 marks per hour. Four people do the marking, 2 at each end of the rope/cable and 2 employees who mark the field alongside the rope/cable.
The work instructions (BGF, 2012 J) date from when marking was done with a sisal rope. This has been replaced with a steel cable, because the sisal rope would stretch and thus the demarcated area would be incorrect. The total action entails:

1 placing the rope correctly, to create a rectangular area to plant the trees.
2 When both ends of the cable are at place, the employees start making holes – one or two hits with the digging hoe – in the soil every 4 m, starting from the end until they meet each other half way.

3 The next challenge is to move the cable parallel with the earlier line, so the rectangle can be created. This action is repeated until the complete area is demarcated.

Table 19: Time elapsed placing the rope and marking the field. Time between end of marking and placing the next rope is referred to as time loss

Nr row	amount of marks	(re)placing rope(*i.e.* mark 1 line) (mm:ss)	Digging marking pits per line(mm:ss)	Moving to next line (mm:ss)
1	17	02:00	02:29	00:08
2	16	02:03	01:30	00:10
3	15	01:06	01:43	00:10
4	16	00:47	02:51	01:21
5	18	02:37	01:55	00:03
6	17	03:16	01:44	00:10
7	15	01:51	01:16	00:03
8	13	02:07	01:17	10:18
9	12	01:20	01:24	00:08
10	9	01:04	01:14	02:51
11	8	01:43	01:22	00:02
12	4	01:22	01:00	06:58
13	6	01:30	01:05	00:21
14	6	00:55	00:21	00:10
15	6	01:03	01:41	00:02
16	6	02:01	00:57	00:02
17	6	01:49	00:39	00:16
18	7	02:42	00:46	00:13
19	8	01:19	00:56	00:14
20	8	01:17	02:09	00:11
21	9	01:20	01:13	00:03
22	9	01:17	01:01	00:02
23	11	04:47	01:20	00:10
24	12	02:47	01:13	
Total	254	44:03	33:06	24:06
Average	10,58	01:50	01:23	01:03
Standard deviation	4,34	00:54	00:34	02:31

Table 19 points out the time elapsed to place the cable in the correct position, the time elapsed to actually dig the shallow marking pits and time ‘lost’ moving on to the next line, parallel to the previous.

The first notable figure is the time lost between row 8 and row 9. The four employees spent 10 minutes determining where the next cable should be laid. With a proper preparation, this should be avoided. Losing 10 minutes time is a lot, considering the average time loss was

1,02 minutes and the complete action averagely took 4,26 minutes. This determination cost, based on average values, 2 complete row of marks.
The total time spent marking the field was 1 hour, 40 min and 44 s and a total of 254 pits were marked. This means 2,52 pits per minute. A t-test pointed out the marking was done significantly faster than the task rate ($p < 0{,}0005$). If a day counts 480 working minutes and approximately 100 minutes were needed for 254 marks, a simple calculation of 254 * 4,8 would lead to a total of 1219,2 marks that day.
Remarkable as well: *fig. 21* is an extrapolation of only the time spent digging the marks. Simple calculation according to the slope of the extrapolation curve gives the following:

$$marked\ units = 7{,}8189\ marks * time\ (minutes) \quad (5.3)$$
$$\Leftrightarrow marked\ units = 7{,}8189\ marks * 480\ (minutes)$$
$$\Leftrightarrow marked\ units = 3753{,}072$$

The notable difference between 3753,072 and 1219,2 is because of the time needed to move from one line to the next – and determining that line, parallel to the previous – and time needed to place the rope. This took a lot of time because the field was not prepared optimally. It was roughly grown with shrubs and small weeds. Moreover, due to the length of the steel cable, it was hard to transport it, because of the catenary of the cable.
The observation led to the remark that the coordination was rigid but done with routine, without spending too much words on actually planning the action. Because of their competence in the tasks, the employees do not fail their task, even more, they exceeded the task rate.
The work instruction dictates four employees. The task is done very fluently.

Ergonomics

This task is done standing, moving and is located in the field. In the field the employees were victim of the insolation of the sun, rough soil, thorny shrubs. They did wear protective clothing (*i.e.* the overall and rubber boots) and even a cap or other head gear.
Because the marking of the pits was done using a digging hoe, the employees had to bend over to mark the field. Some employees bend over the entire time, until the line of marking was finished.
It was very hard for the employees to hold the steel cable. It had the tendency to slip out of their hands.

5.4.1.3 Conclusion

The observations proved that the task rate of marking is easily manageable.
Because of the experience of the employees, they could fulfil the task without a lot of preparation or communication. It is so that time can be won, when a task is well prepared, when everyone knows his/her job. Perhaps with more structure and coordination, the task could be fulfilled even faster.
The length of the cable is inconvenient. It hauls on the ground or is stuck in shrubs. But a shorter cable implies more replacements and eventually more ‘loss’ of time. But as the task is performed now, the length of the cable is the best compromise. To have a better grip, handles can be adjusted to the cable.
The extrapolation leads to an unreal figure of amount of marks. Due to too less data, extrapolations require a great leeway when interpreted. An amount of 3753,07 marks is undoable, although it helps indicating the task rate must take time ‘loss’ due replacement in account. To reduce time ‘loss’, preparation of the field must be done and the task must be well coordinated. Nonetheless, there is room for increasing the task rate without overdemanding the employees.

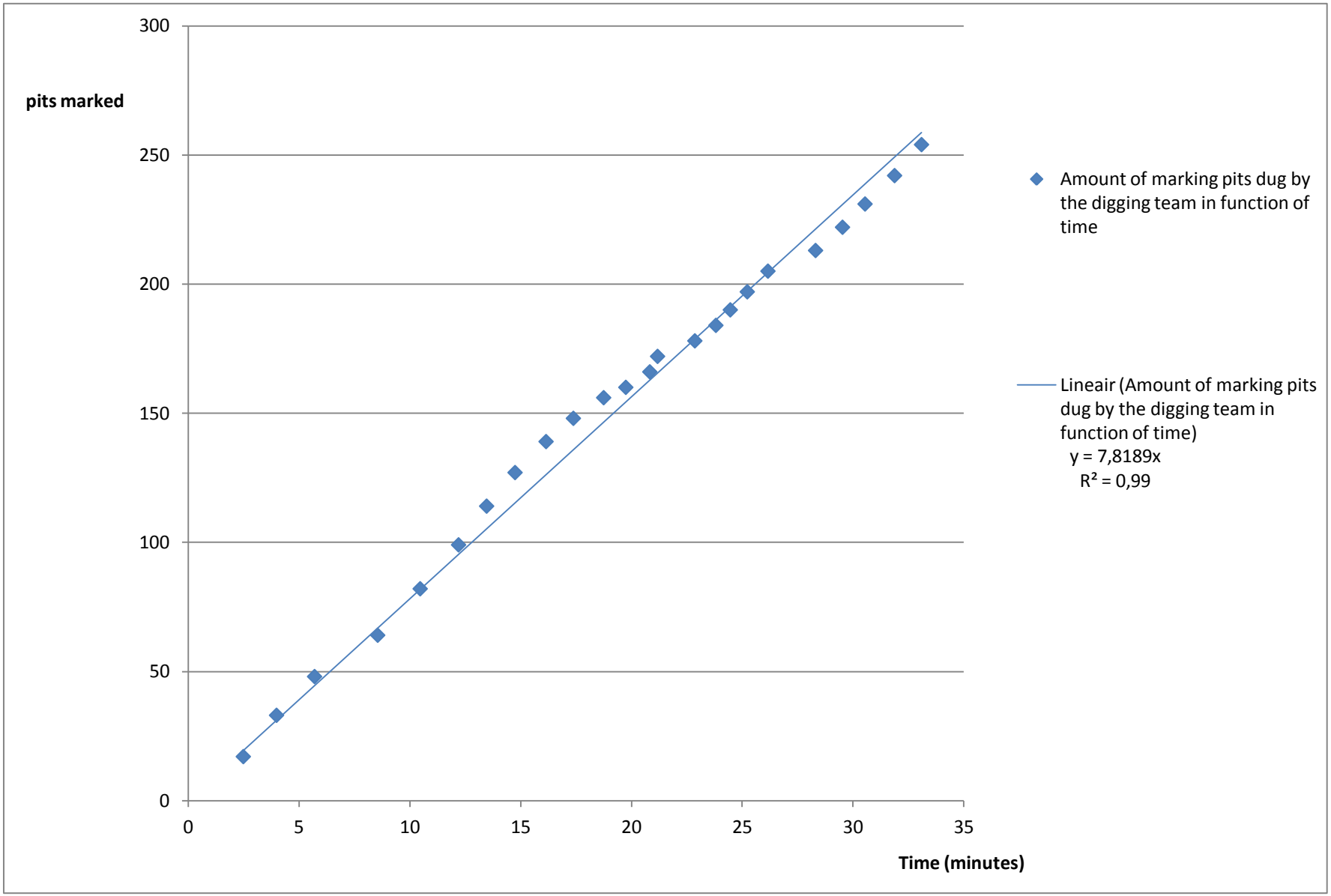

Figure 21: Amount of marking pits dug in function of time, by 1 marking team. Replacement and time loss was not applied in this figure.

5.4.2 Making pits

5.4.2.1 Introduction

Making pits must be done before planting, and is only done in a field block intended for planting – this according to the yearly work plan. First of all the field ought be cleared of bushes, grass and weeds. This must not be done, but it ameliorates the conditions for marking the field, the subsequent step. If the previous steps are done, the plant holes can be made. Employees' main tools are digging hoes. The amount of employees depends on the number of seedlings assigned in the yearly work plan. After preparation of the land, the seedlings can be transported from the nursery to the area of planting. Depending on the accessibility, seedlings can be transported by a donkey cart or by employees, in crates. Once in the field, the seedlings are being planted.

Work instructions for making pits are the following (BGF, 2012 K):

1 The pits are dug at an interval of 4 m, according to the marking;
2 The dimensions of the pits: 45 cm by 45 cm and 30 cm deep;
3 The task rates for digging:
    - During the rainy season: 60 pits per man per day;
    - During the dry season: 35 pits per man per day.
4 If the land is ploughed, 60 pits per man per day can be dug.

5.4.2.2 Results

The initial task rate for making pits depends on the soil. If the land is ploughed, it is easier to dig, so more pits can be dug. This brings the task rate to 60 pits per man per day.

Pitting also depends on the season, in rainy season 60 pits can be dug per man, but in the dry season, only 35 pits can be dug. This observation took place in the dry season.

Table 20: Time elapsed digging pits per person

Number pit	Time elapsed per pit (mm:ss)		
	person 1	person 2	person 3
1	10:13	11:34	11:24
2	16:36	12:31	17:43
3	03:16	09:22	09:58
4	03:54	07:12	03:06
5	08:06	04:50	10:48

Table 21: *Table* 20 continued: Time elapsed digging pits per person

Number pit	Time elapsed per pit (mm:ss)		
	person 1	person 2	person 3
6	07:41	08:07	08:35
7	05:51	09:06	05:58
8	06:38	07:49	07:03
9	15:27	10:38	09:27
Average per person	08:38	09:01	09:20
Standard deviation	04:42	02:22	04:05
Min	03:16	04:50	03:06
Max	16:36	12:31	17:43

Table 20-21 have a small number of observations, due to the fact pits have already been made in advance in this area, because of the work planning. At this point the cooperation with the employees was a little rigid because they would do double work.
Verified by a t-test for person 1 and 2, and a sign rank test for person 3 (due non normal distribution), *table 20-21* points out that the employees work faster than the task rate of 35 pits per day per man (person 1, 2 and 3 with *resp.* p-values: $p = 0{,}011 < 0{,}05$; $p = 0{,}004 < 0{,}05$; $p = 0{,}015 < 0{,}05$). Via the extrapolation in *fig. 22*, employee 1 would be able to make 56,88 pits in 8 hours. Employee 2 and 3 would have made *resp.* 53,28 and 49,10 pits.

Ergonomics

Making pits is very aggravating for the back, under every circumstances. But using a digging hoe obliged the employees to bend over, from the beginning until the pit is made.
This action took place in the field. As well as with marking, employees are victim of the sun and every other condition in the field. Again, employees wore protective clothing.

5.4.2.3 Conclusion

Statistical analysis pointed out that all three employees worked significantly faster than the task rate. This indicates the task rate is manageable, even in these rough conditions (stony soil, warm weather, …). Although very few data was available (it is hard to persuade people in doing double work), it may be said the employees worked well.
As well with marking the field, the extrapolation must be taken with a great leeway. It helps indicating the task rate is manageable and could be reformulated.

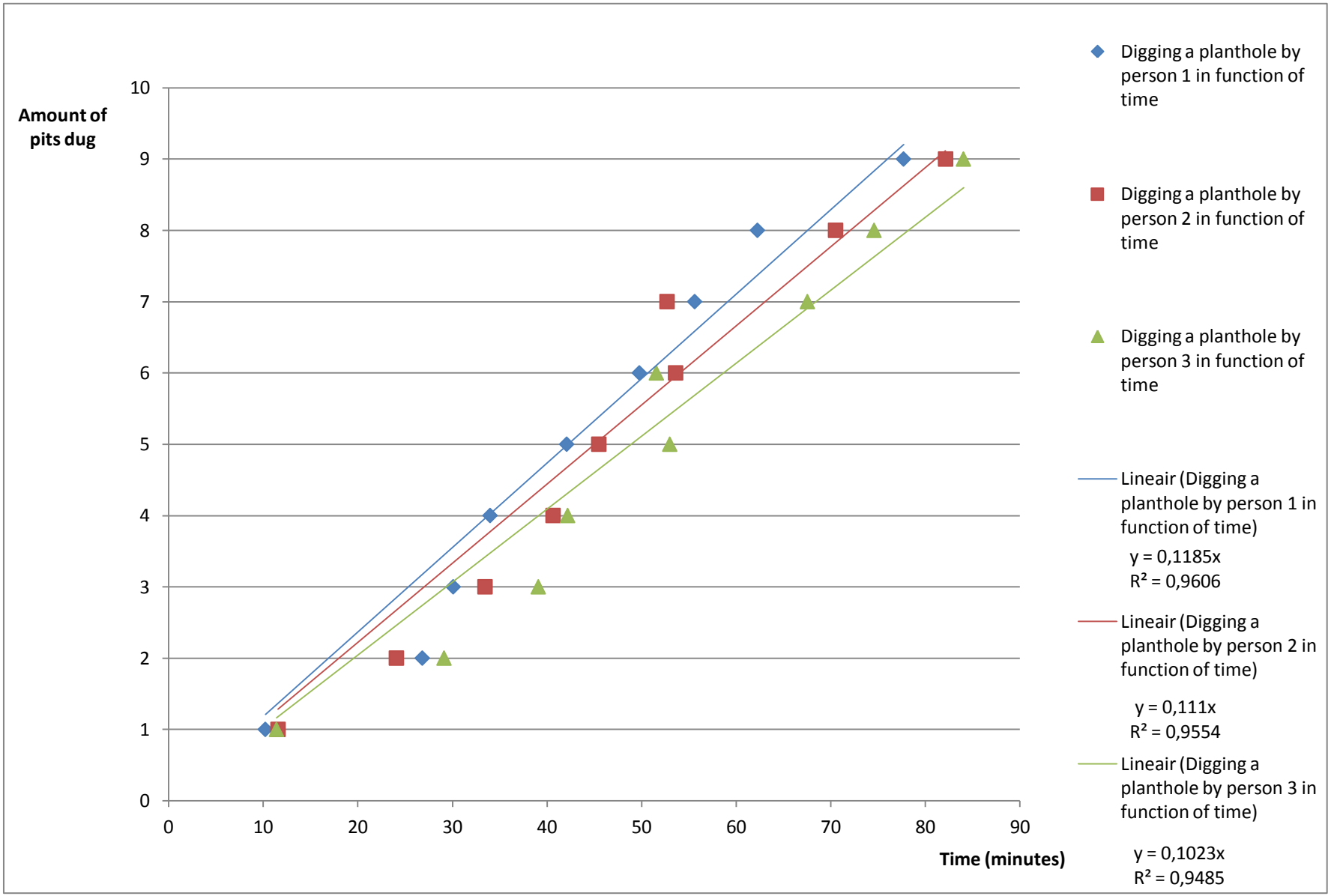

Figure 22: Amount of plant holes dug in function of time, by 3 persons

5.4.3 Making catchment dams

5.4.3.1 Introduction

When the seedlings are planted, they are watered. To keep the water from draining off and to gather water from rainfall, catchment dams are made around the newly planted trees. Several types of catchment dams exist. Better Globe Forestry choose to work with half-moon catchment dams.

Half-moon catchment dams are mostly used in areas where soils are poor and where it inhibits infiltration, increases leaching or draining off of the water. Half-moon catchment dams are semi-circular shaped, and special attention should be given to the slope of the land. The opening of the half-moon should face the slope of the field, to prevent water flowing out of it. Theoretically, it has a 1:1 ratio of cultivated and not cultivated area (Desta et al., 2005).

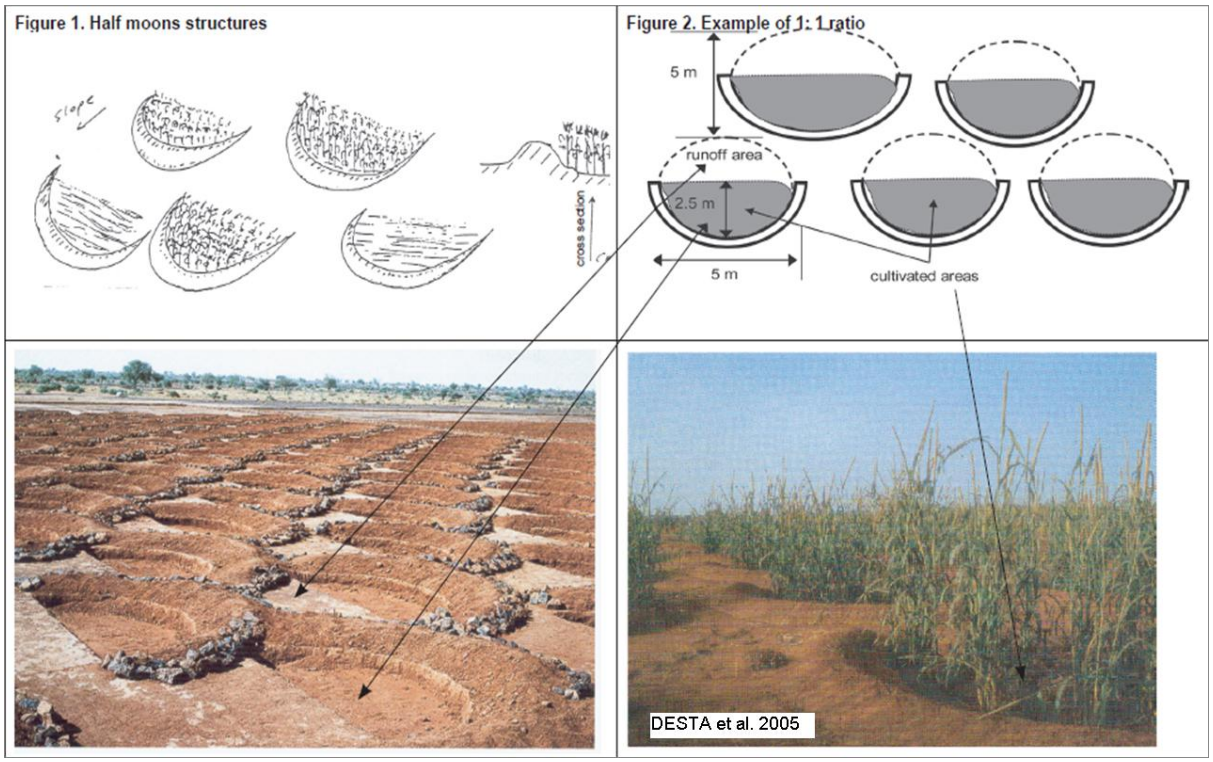

Figure 23: Theoretical approach of making halfmoon catchment dams (Desta et al., 2005)

Catchment dams are made after the seedling has been planted. In order to make this action clear, a work instruction has been made. Work instruction on making a half-moon (BGF, 2012 L):

1 Before the build-up of the catchment dam, one should pay attention to the slope of the land: the opening of the half-moon must face the slope;

2 The half-moon should be 1,5 m long and at least 20 cm high in the centre. This implying a distance from the seedling of approximately 50 cm (150/π);

3 The task rate to make half-moons: per day, one employee should be able to make 150 half-moons, using a digging hoe.

Figure 24: A halfmoon catchment dam built around a newly planted seedling

5.4.3.2 Results

The concept of a catchment dam is very useful in (semi-)dry area, but requires a lot of work. Depending of the conditions of the soil, the task can be executed fast - when the soil is soft, with less stones and rocks – or at a slower pace – when the soil contains a lot of rocks and is hard to penetrate with a digging hoe. Both hard (Korogocho) and soft soil (Katithini West) were observed concerning making a halfmoon catchment dam. Depending on the condition of the soil, there is, though, only 1 task rate: an employee should be able to make 150 halfmoon catchment dams per day.

It is important to note that the catchment dams are slowly demolished by the water used for watering the trees, but also by rain or physical damage (animals or people). It is necessary to control (within certain time intervals) whether the catchment dams are still operational. If not, they should be repaired.

The observations in Korogocho led to *table 22* and the observations in Katithini-West led to *table 23*.

Table 22: Total amounts of catchment dams and required time per person, before and after noon in Korogocho (hard soil)

		Total time (h:mm:ss)	Total amount of catchment dams
Person 1	before noon	2:26:07	61
	after noon	2:00:09	55
Person 2	before noon	2:25:21	44
	after noon	2:01:06	55

Table 23: Total amounts of catchment dams and required time per person, before and after noon in Katithini-West (soft soil)

		Total time (h:mm:ss)	Total amount of catchment dams
Person 1	before noon	2:44:08	137
	after noon	1:17:09	68
Person 2	before noon	2:44:12	148
	after noon	1:17:33	67

Table 24: *p-values* compared to the task rate for making catchment dams per region

Employee		Place	*p-value*
Person 1	before noon	Korogocho	< 0,0005
	after noon	Korogocho	< 0,0005
Person 2	before noon	Korogocho	0,021
	after noon	Korogocho	< 0,0005
Person 1	before noon	Katithini West	< 0,0005
	after noon	Katithini West	< 0,0005
Person 2	before noon	Katithini West	< 0,0005
	after noon	Katithini West	< 0,0005

A sign rank test on the data of making a catchment dam in Korogocho and Katithini West resulted in the fact person 1 and person 2 worked faster than the task rate before noon as well as after noon. *Table 24* gives the p-values of the observation compared to the task rate. Statistical analysis also resulted in the fact that the average observed speed is significantly different (*p < 0,0005)* between making a halfmoon catchment dam in soft soil (*i.e.* Katithini West) and hard soil (*i.e.* Korogocho) – after the noon as well as before noon. This is also demonstrated in *fig. 25-28*: the slope of *fig. 27 and 28* is remarkably higher than the one in *fig. 25 and 26.*

Ergonomics

Making halfmoon catchment dams is also done with a digging hoe, implying employees had to bend over to perform well. It seems the handle is rather short. Notable is that sometimes the head of the digging hoe got loose from the handle. This is very dangerous, given when the digging hoe is swung around, the head can hit somebody else.
Other ergonomically aspect are the same as all other in-field plantation maintenance tasks. The employees are:

- Victim of the sun's insolation;
- Victim of the severe surroundings (soil, flora, fauna, …).

5.4.3.3 Conclusion

The initial task rate of 150 catchment dams per man per day was clearly exceeded when observed. Not only did the employees manage the task rate, they exceeded it with flair. When confronted with soft soil, the task rate was managed after nearly 3 hours of work. Making catchment dams in hard soil was different. It is also statistically proven that both employees worked slower in hard soil than on soft soil. This indicating it would be useful to make two task rates, considering the roughness of the soil.
Catchment dams should be checked very often. It prevents water from percolating, away from the tree (root system). When broken, it should be fixed as fast as possible.
No research has been done to verify until what age of the tree such a catchment dam is useful.

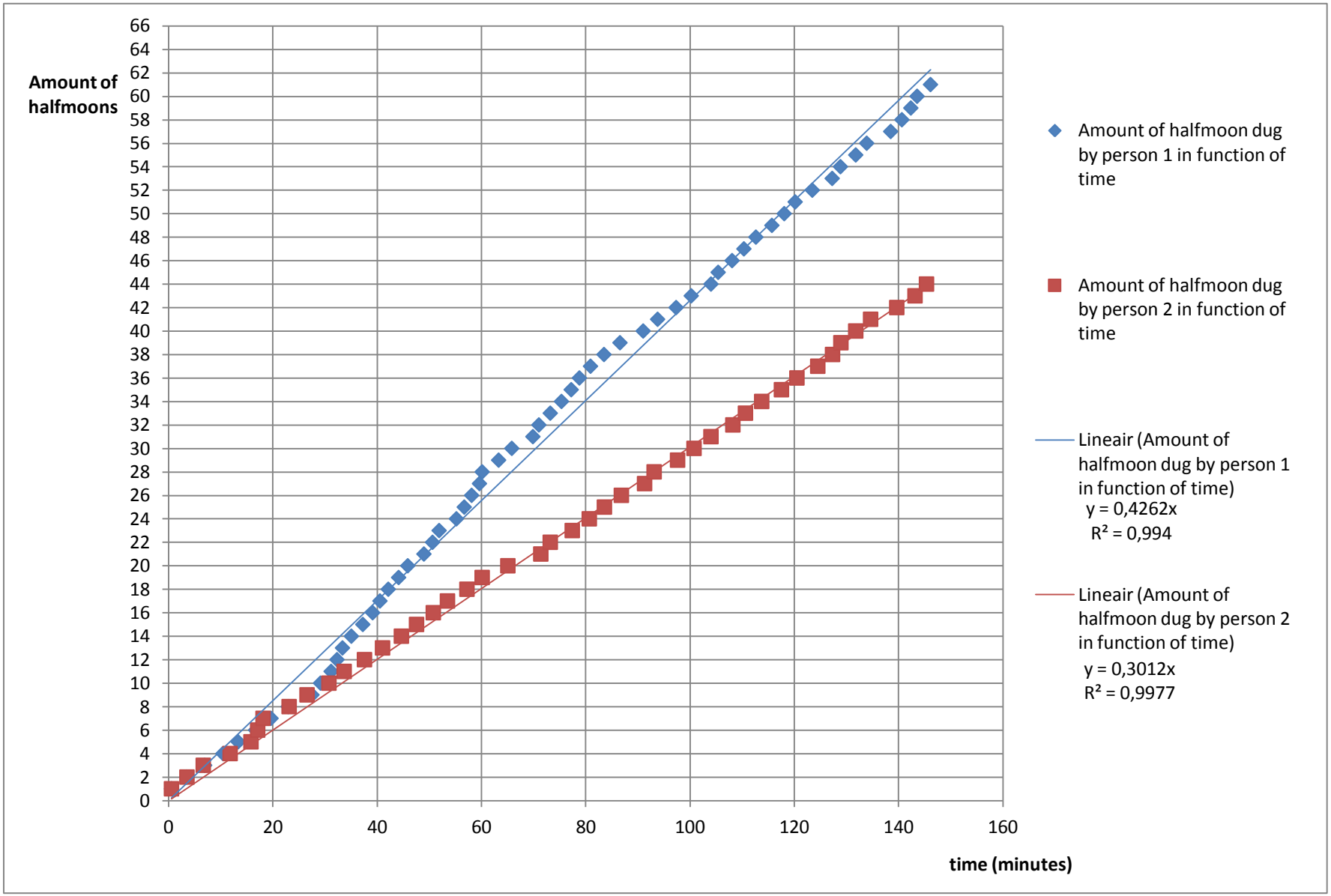

Figure 25: Amount of halfmoon catchment dams dug in function of time by person 1 and 2 in hard soil before noon

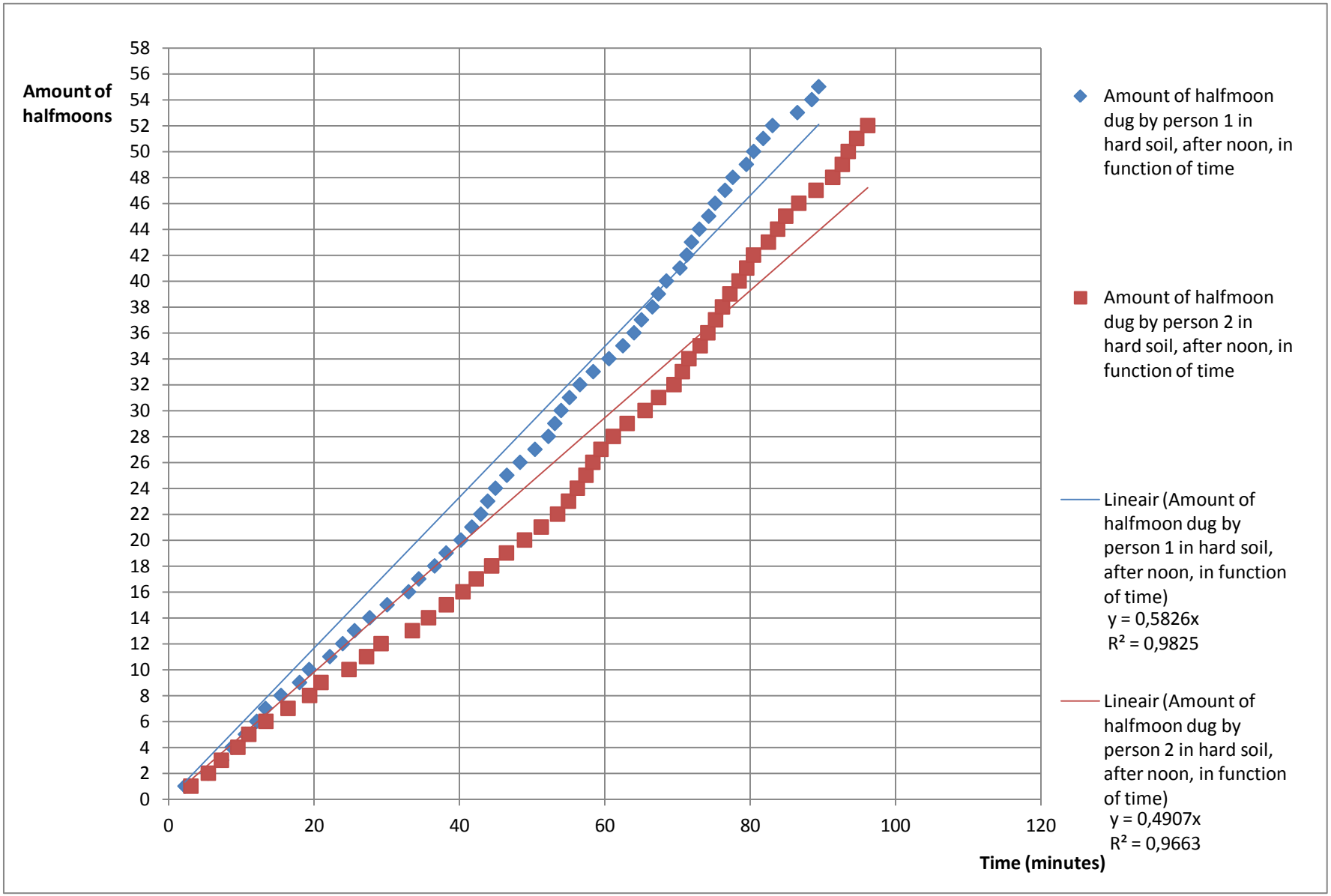

Figure 26: Amount of halfmoon catchment dams dug in function of time by person 1 and 2 in hard soil, after noon

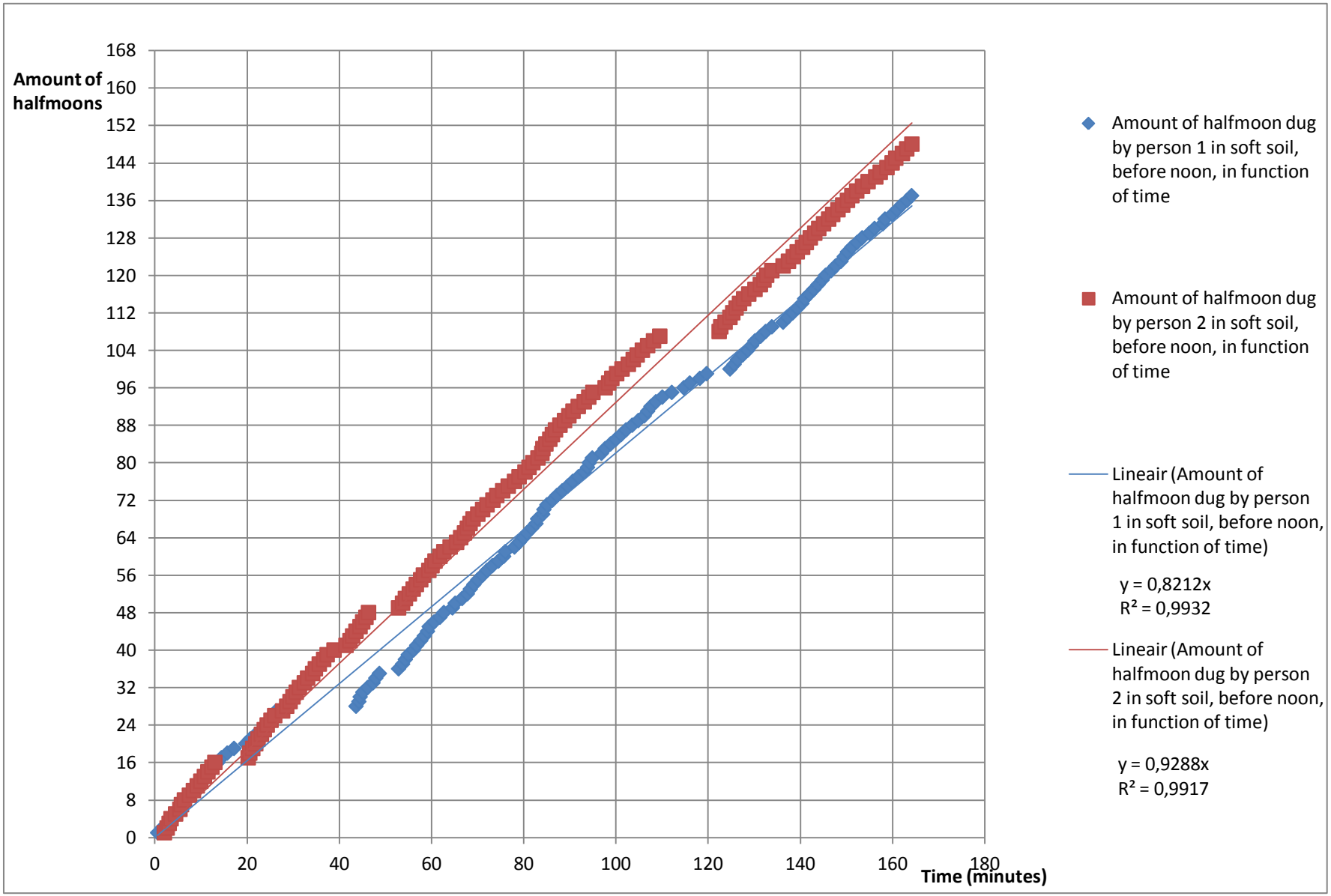

Figure 27: Amount of halfmoon catchment dams dug in function of time by person 1 and 2 in soft soil, before noon

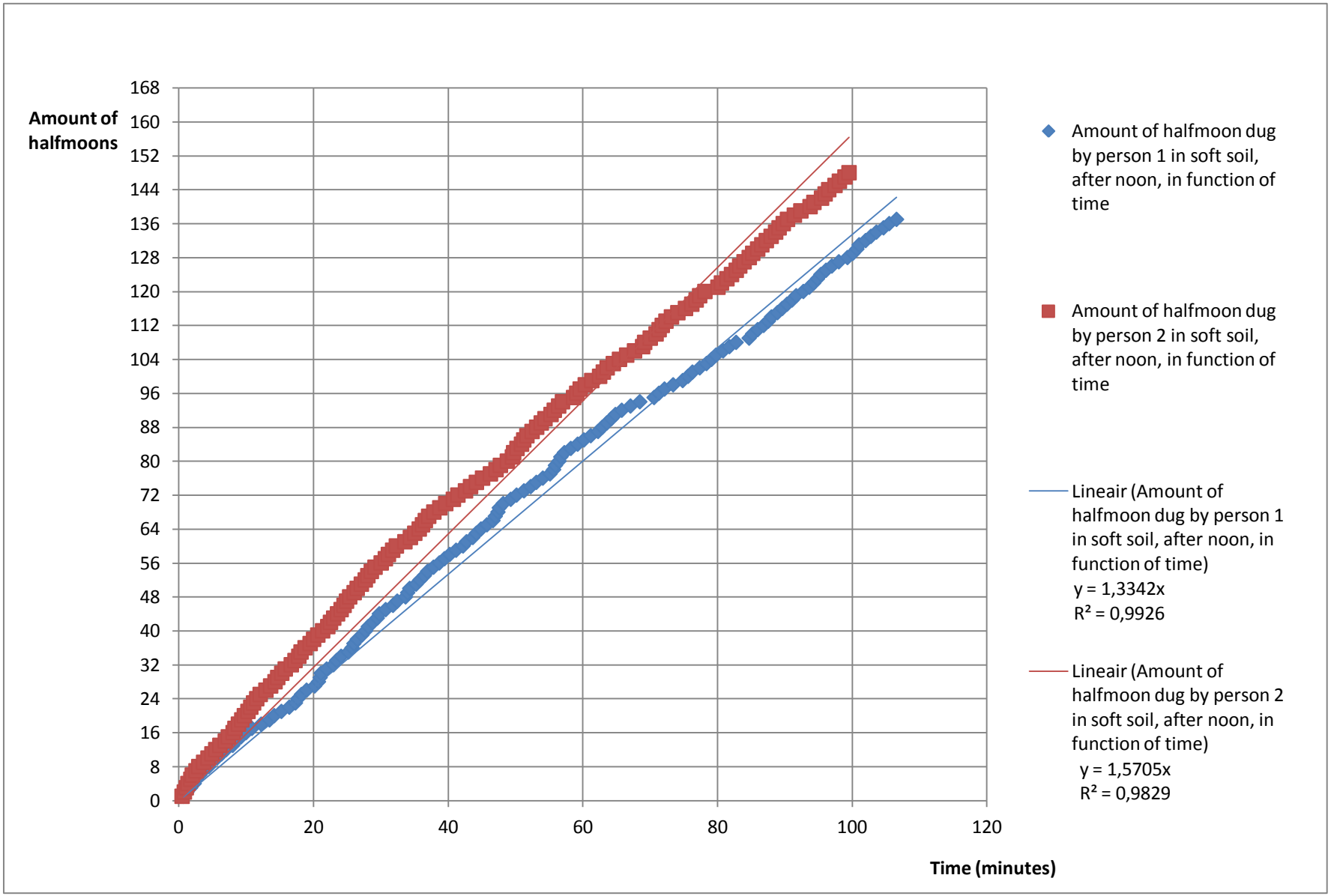

Figure 28: Amount of halfmoon catchment dams dug in function of time by person 1 and 2 in soft soil, after noon

5.4.4 Mulching

5.4.4.1 Introduction

One day after planting and making the half-moon catchment dam and the first watering, mulch is applied. Mulch is organic matter, added around the crop – here *M. volkensii* seedling – to ameliorate topsoil physical conditions. Especially with respect to temperature, evaporation and water content. According to Lai (1976) application of straw as mulch was effective in improving soil physical conditions in tropical environments. If the temperature of the topsoil is too high, mulch can buffer this for better germination and root development. Apart from that, soil surface evaporation may be reduced (Bussiere, 1994).
Wheat straw application progressively ameliorated topsoil water content: water intercepted by the mulch served as a temporarily water reservoir, though the water will evaporate eventually (Cook et al., 2005).
The mulch around the seedlings comes from surrounding grasses in the field. For this task also, there is a work instruction.
Work instruction for mulching (BGF, 2012 M):

1 Application of mulch is done a day after planting;
2 The mulch is collected from surrounding grasses and is placed around the seedling;
3 The mulch should be put in the half-moon;
4 The mulch must be renewed each four months;
5 The mulch must not be placed too close to the seedling, else heat will accumulate and might burn the stem;
6 The task rate for mulching: 180/250 seedlings ought to be mulched, depending on the availability of the grass.

5.4.4.2 Results

The concept of mulching is also very useful. The initial task rate takes the availability of grass into account concerning the ability to mulch an amount of seedlings. The mulch used at the plantation, were cut grass. No shrubs or bushes or weeds were used. The work instruction (BGF, 2012 M) prescribed the amount of seedlings mulched to be 180-250. Assuming in densely grown areas, the task rate is 250 and in sparsely grown areas it is 180 seedlings per man per day.

Table 25: Total amount of mulched seedlings and required time per person per different area (densely grown opposed to sparsely grown areas)

		Total time (h:mm:ss)	Total amount of seedlings mulched
Person 1	densely grown area	1:52:24	50
	sparsely grown area	2:38:53	26
Person 2	densely grown area	1:53:24	56
	sparsely grown area	2:38:46	25

Statistical analysis from the data collected concerning mulching points out that person 1 did mulching according to the task rate ($p = 0{,}904 > 0{,}05$), but person 2 did it significantly faster than the task rate ($p < 0{,}0005$). This counts for the densely grown area. Statistical analysis on the sparsely grown area pointed out that person 1 as well as person 2 worked slower than the task rate (p-values for person 1 and 2 *resp.* being $p = 0{,}001 < 0{,}05$ and $p = 0{,}002 < 0{,}05$). Thereafter, there is a significant difference in speed of mulching seedlings in a densely grown area compared to a sparsely grown area (person 1 and 2 with *resp.* $p = 0{,}001 < 0{,}05$ and $p < 0{,}0005$). This is made visible in *fig. 29 and 30*. The slope in *fig. 28* is approximately twice the slope as in *fig. 30*. The form of the graphic in *fig. 30* points out the time keeps increasing, but the amount of seedlings mulched is not increasing.

A remark concerning mulching, the exquisite usage of grass. As observed, the height of the mulch layer was sometimes higher than the seedling.

Ergonomics

Mulching is done using a panga to cut the grass. This is done bending over, which is demanding for the back.

The vegetation can be very thorny, protective clothing was worn. Although none of the employees had protective hand gear.

Other ergonomically aspect are the same as all other in-field plantation maintenance tasks.

- Victim of the sun's insolation;
- Victim of the severe surroundings (soil, flora, fauna, …).

5.4.4.3 Conclusion

Mulching is performed into two regions, regions with densely grown and with sparsely grown grass. Where a lot of grass is available, the employees manage the task rate. One of them works according to it, the other significantly faster.

In areas where grass grows sparsely, both employees work significantly slower than the task rate. Even stronger, the time to mulch a seedling increases in time. This is because of the availability of the grass. Employees must go further and further to find enough grass to mulch a seedling. This causes time to mulch a seedling to increase.
A solution could be to slash grass in the plantation and use that grass to mulch the trees in areas where grass is rare.

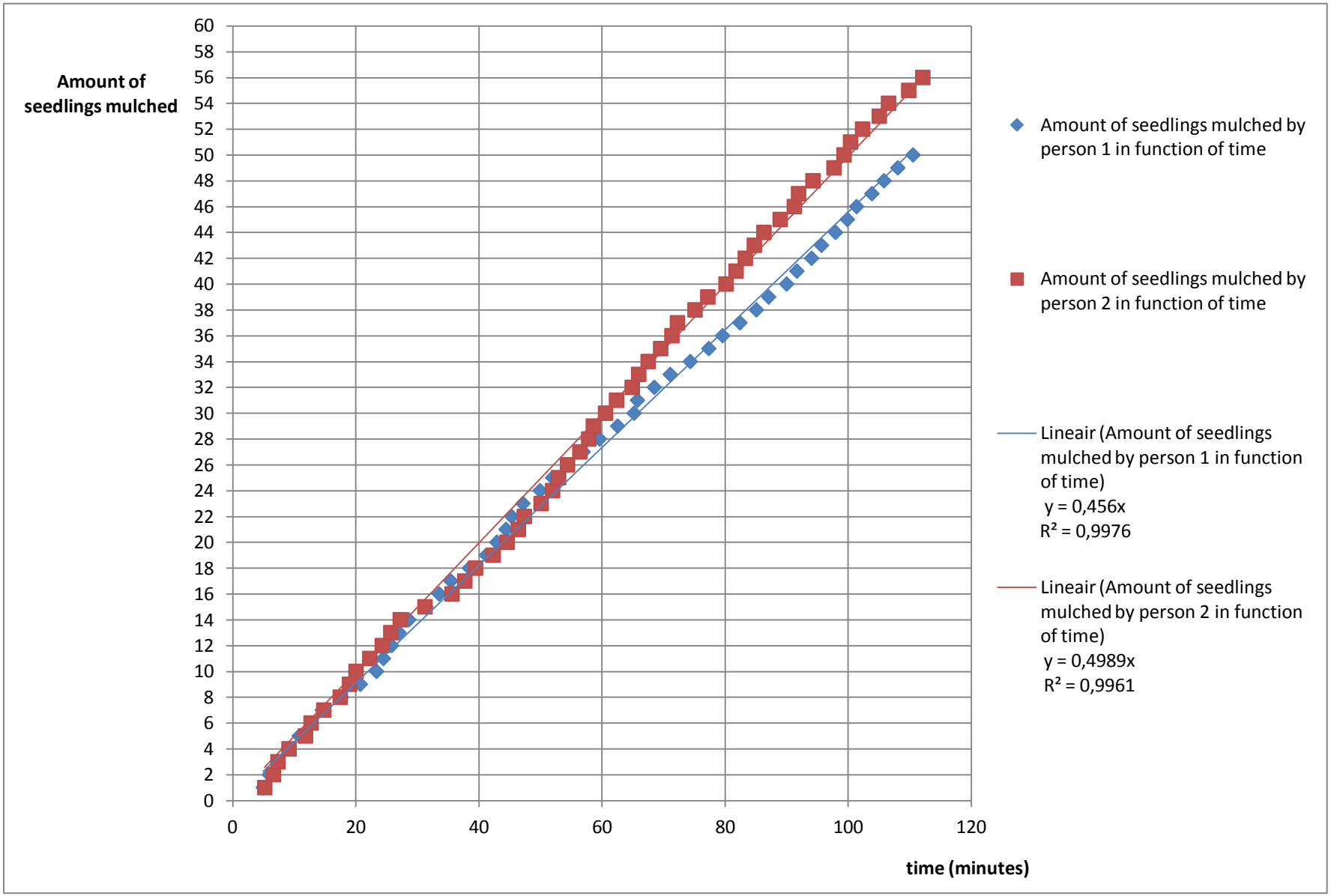

Figure 29: Amount of seedling mulched by person 1 and 2 in function of time, in an area with densely growing grass

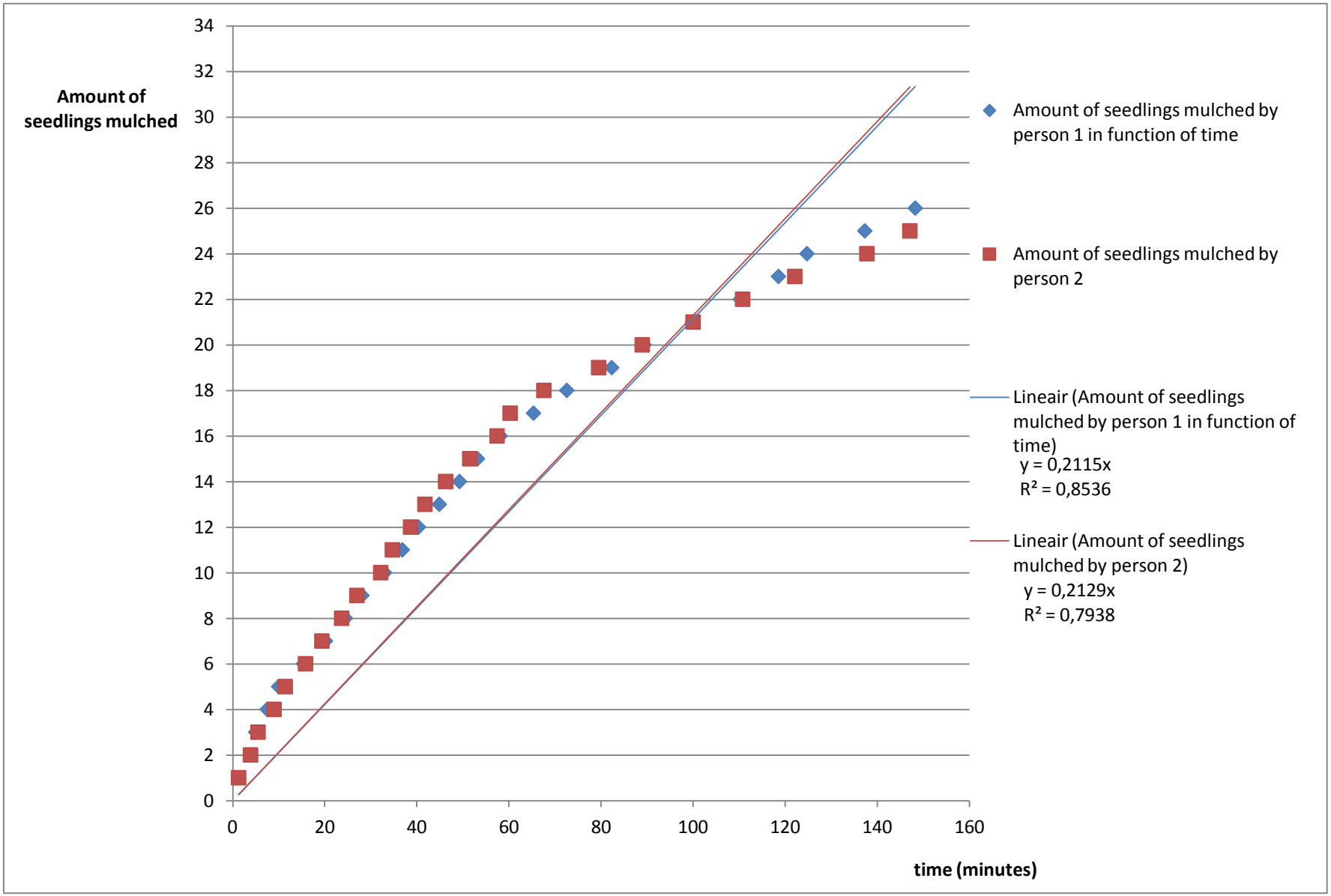

Figure 30: Amount of seedlings mulched by person 1 and 2 in function of time, in an area with sparsely growing grass

5.4.5 Watering trees in the field

5.4.5.1 Introduction

During planting, the seedlings are given 10 L of water. After that, the seedlings are watered with 5 L per week. And this for the first 3 months. To make this action fluent, a determination of the area, *ergo* the amount of trees to be watered, has to be made.
Water is being fetched, out of Lake Kiambere, at the nearest point from the area with the trees. A crocodile cage must be placed in the water, before fetching water, for the safety of the people. Transport of the water and watering in the field is done completely manually. This involves fetching water by immersing a jerrycan in the lake, carrying it on the back to the field and watering the seedlings in the field. One jerrycan contains 20 L of water, *ergo* water for four seedlings or two seedlings if the watering is done immediately after planting. The number of trips made by an employee will depend on the distance between the dam and the field. For areas within a distance of 1 km, an employee must be able to water 60 to 80 seedlings per day. Another option to transport water is by a donkey cart. This is a cart, pulled by donkeys, to transport several jerrycans at once. Unfortunately, not every area is accessible for the cart, so it cannot be used as often as wanted.
It is very important that watering is done with care. First of all to protect the seedlings and to maintain the shape of the half-moon catchment dam (BGF, 2012 N).
A new watering method is being tested at this moment. The country near Lake Kiambere is very hilly. At the top of a hill, a large basin with a volume of 50.000 L is build. The large basin is filled by pumping up water out of the lake, with a fuel powered water pump. This is not evident, due the slope of the land. The pump must generate enough power to pump up the water into the basin. With a network of pipes through the fields, all the surrounding areas can be provided with water out of the basin. Because of gravity and gradient of pressure, water flows out of the pipes at a high discharge. A lot seedlings can be watered in a short period of time. Do note, the pressure fades when the basin empties.

Figure 31: Network of pipes for water division

Figure 32: Water basin (50.000 L)

5.4.5.2 Results

Manual water transport

Watering, as it is done now, is a heavy duty task in the field. Employees fill the jerry cans at the lake, then walk to the area of watering and water a certain amount of seedlings, according to the work instructions. The task rate to water seedlings is 60-80 seedlings per man per day. In order to improve this rate, the idea came forth to use the donkeys to carry the jerry cans. A donkey can carry up to 4 jerry cans. As observed, 6 donkeys went forth and back to the lake, led by 4 employees. This equals 80 L of water per donkey. With this amount 16 or 8 seedlings can be watered, depending the moment of planting.

Table 26: Total elapsed time per trip, to water 48 seedlings with the help of donkeys

Trip	Amount of seedlings watered	Total time elapsed (h:mm:ss)
1	48	1:11:33
2	48	1:05:26
3	48	0:42:55
4	48	0:50:20
Total	192 (newly planted seedlings) 384 (older seedlings)	3:50:14

Table 26 gives the information that with 4 trips, 192 seedlings were watered – or 384 seedlings, if watered with 5 L – in a total time of 3 hours 50 minutes and 14 seconds.
As observed, every employee had an equivalent of 80 seedlings per day. Since 4 employees led the donkeys, they were equivalent to 320 seedlings per 8 hours. The 6 donkeys would've transported in 1 day at least the same amount of water as the 4 employees would've done, in best scenario more.

Watering system

The new watering system, has been tested and observed. The largest water tank contains 50.000 L. There hasn't been a task rate set yet, for the amount of seedlings that can be watered with this method.

Fig. 33 and 34 give the amount of seedlings watered in 10 minutes on 2 different days. The 20th of September, the tank was completely filled and it is clear watering by using this system is faster than fetching water and carrying it all the way to the field.

The first day of testing 269 seedlings were watered, only in 90 minutes. This is incredibly fast, although the pressure of the water coming out of the hose pipe was already fading.

The 21st were significantly less seedlings watered compared to the 20th of September ($p = 0,029 < 0,05$).

The initial incompetence of the employees was visible as this system is not easy to apply. A lot of water was wasted, going from one seedling to another. In ideal occasions, the tank should be able to water 10.000 seedlings, but it was very hard to measure 5 L of water when it burst out of the hose as it did.

Ergonomics

As for fetching water and carrying a 20 kg jerry can for a few kilometres, this is very aggravating for the back, for the muscles, for the complete body. The task rate prescribes 20 trips (BGF, 2012 N).

This task is executed in the field, where the sun's insolation and the temperatures can decrease the work efficiency. Not only the temperature can be a problem, the rocky soil may cause sprained ankles or another event, the shrubs and weeds carry thorns and the insects, millipede or other fauna can react aggressive. The employees carried their uniform all day, but the thorns of the weeds can penetrate the overalls easily. Rubber boots are protective, but not against rocks or a rocky soil.

When fetching water the crocodile cage was not used. The intention to use it was present, but it was not used.

5.4.5.3 Conclusion

Watering trees by manually carrying jerry cans from the water fetching point to the seedlings is not efficient. It causes fatigue and perhaps health issues among the employees. The usage of the donkeys results in the same amount of seedlings watered – perhaps more – for the

same cost. And this method allows the employees to stay healthy, so they can be used somewhere else in the field or in the nursery.

The new water system is very promising, a lot of seedlings can be watered at a time. There are still several flaws: how to dose 5 L of water, to avoid the waste of water when walking from one seedling to another, to avoid the fading of water pressure resulting into a significant lower amount of seedlings that can receive water. This can be solved by a faucet at the end of the hose, that can be closed when walking from a seedling to another.

Some points of interest should be considered:

- At the end of the day, the main faucet must be closed;
- Release air from inside the pipes;
- Pipes and hoses should not be bend. This causes tears and a decrease of pressure and a loss of water;

It became clear that 3 employees are needed to operate the hose pipe system. One at the end, to water the trees. One in the middle of the smaller pipe, to help translocate the pipe. And one holding the bigger, stiffer pipe, also to ease the replacing of the pipe.

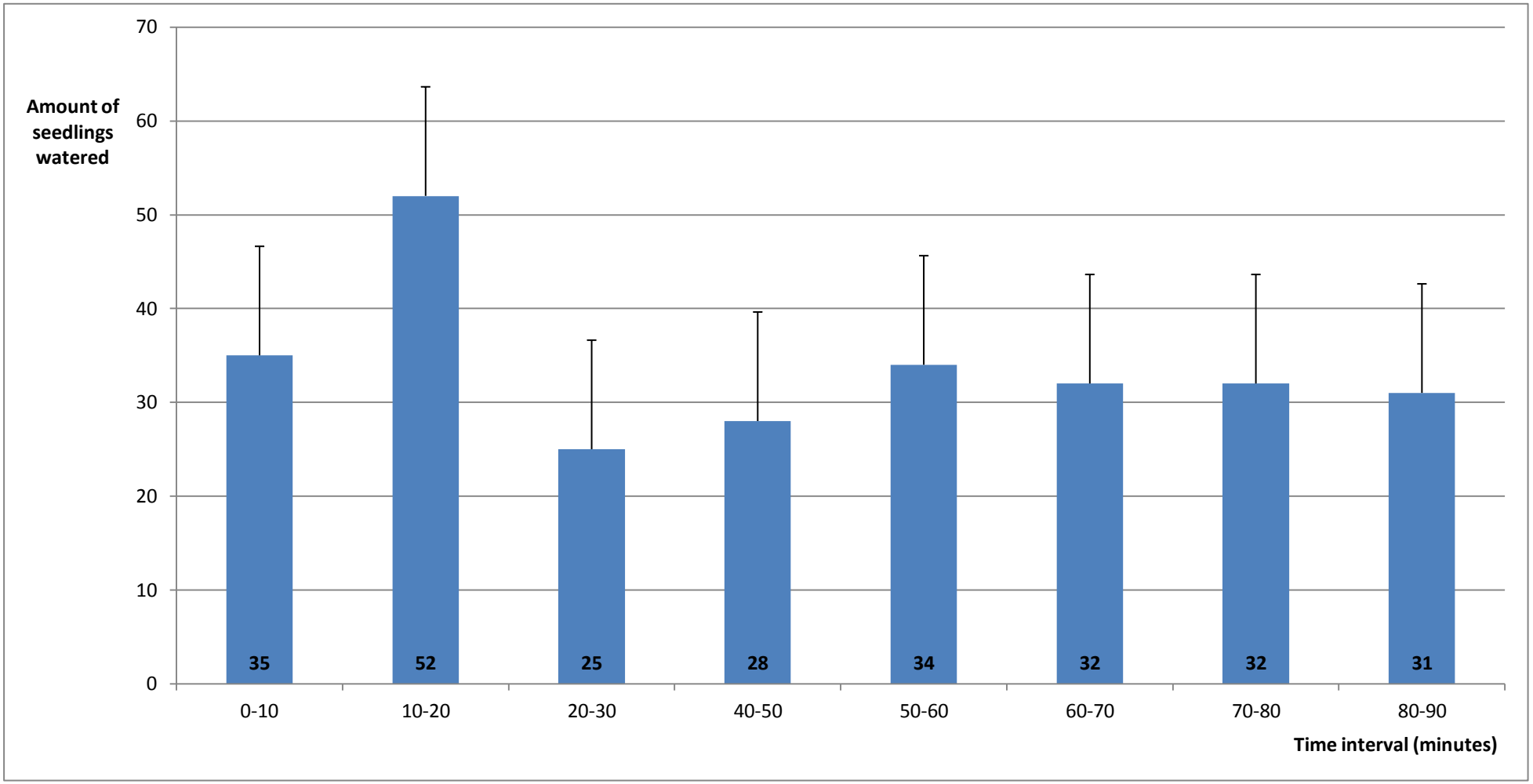

Figure 33: Amount of seedlings watered with the waterhose per time interval of 10 minutes by 1 employee (20th of September)

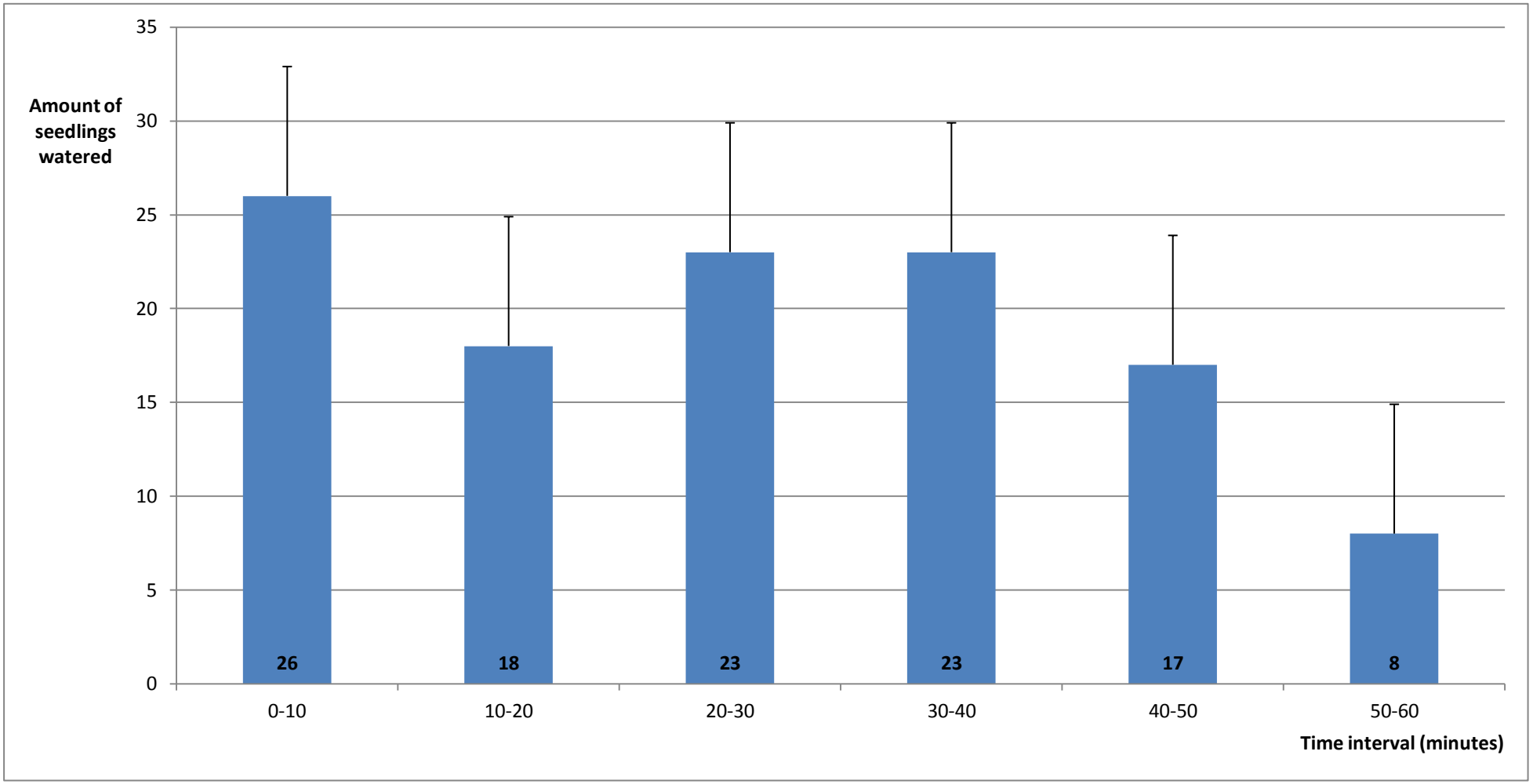

Figure 34: Amount of seedlings watered with the waterhose per time interval of 10 minutes by 1 employee (21st of September)

5.4.6 Pruning of the trees

5.4.6.1 Introduction

The pruning of trees in the early years is very important. The canopy represents the *'powerhouse'* of the tree providing carbon, via photosynthesis for growth and wood production. The size of the canopy determines the growth and thus the volume of wood produced (Montagu et al., 2002). The most important factors determining timber quality are: straightness, length of a single trunk and clear wood timber (*i.e.* the amount of knot- and defect-free timber the trunk can produce).

Pruning systems consist of form, pre-emptive pruning activities, bud pruning and long-term or clear wood pruning (Sheperd, 1986). Form pruning produces a good stem, by removing any branch that causes an unhealthy stem. An early start of form pruning and so clearing defects shall give healthier and stronger trees. The process is simple and little time consuming. Form pruning involves:

- The removal of multi-stems: to create a straight stem;
- The removal of damaged or diseased branches;
- The removal of branches which can harm the main stem, when breaking caused by (fierce) gusts.

When branches develop to such a size they can harm the form, health, quality and quantity of timber, they ought to be removed preventative. This is pre-emptive pruning. The removal of foliage is limited to a maximum of 30 %, else the growth and development can be slowed down. Bud pruning is the removal of buds from axis of the main stem, before development of woody tissue. Buds can be pinched out with the fingers or cut out with a knife. Bud pruning is a very fast procedure. By removing the buds, more intensive pruning later on is avoided. Thus bud pruning is a cost-saving procedure (Windel, 1996).

Clear wood pruning is the action producing a stem clear of branches: the bole length. Branches and knots cause defects to the wood and decrease the value of the timber. This is a process over several periods of time: pruning to a specific height on the bole of the tree, to create a product free of knots. A common recommendation is to prune trees to 6 m bole height (DNR, undated). Time schedule for pruning to produce quality timber:

- Bud pruning is done from age six months to three years, as required.
- Pre-emptive pruning is done when the trees reach two meters in height or at age of one year.

- Clear wood pruning is done in intervals, onwards from two years until the desired bole length is obtained.

Better Globe Forestry developed a work instruction, based on common silvicultural actions, to produce value timber of high quality. The four earlier mentioned pruning activities are applied. The pruning program is based on the compartments of planting. The employees must move from sub-compartment to another.

Work instruction on pruning *M. volkensii* (BGF, 2012 O):

1 The first pruning must be done within a time spun of the fourth to sixth month after planting. Bud pruning and removing bigger branches, with a secateurs, up to 1,5 to 1,7 m height. This is done in four passages during age three to twelve months.
2 When pruning a young tree shorter than 4 m, double leaders (*fig. 35*) must be eliminated.
3 Branches should be removed by secateurs if the diameter is less than 2 cm. A pruning saw is used when the branches are bigger, although the maximal diameter is 3 cm;
4 The tools for pruning must be sterilised with H_2O_2 (3 % w/w) before use. The tools must be sterilised after pruning every tree;
5 Some branches must be left alone along the stem. This can increase diameter growth. This is to make the stem stronger in case of strong winds;
6 Always remain at least two third of the total tree height in living branches. Excessive removal will reduce foliage hence growth rate;
7 For trees taller than 2 m, an aluminium ladder is used to access the branches;
8 Pruning with a pruning saw must be done with care, to prevent damaging the branch collar or the bark;
9 Depending on the weight of the branch, pruning shall be done in several steps (*fig. 36*):

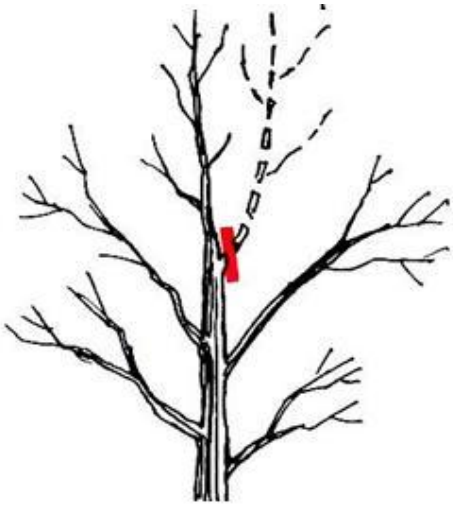

Figure 35: Double leaders

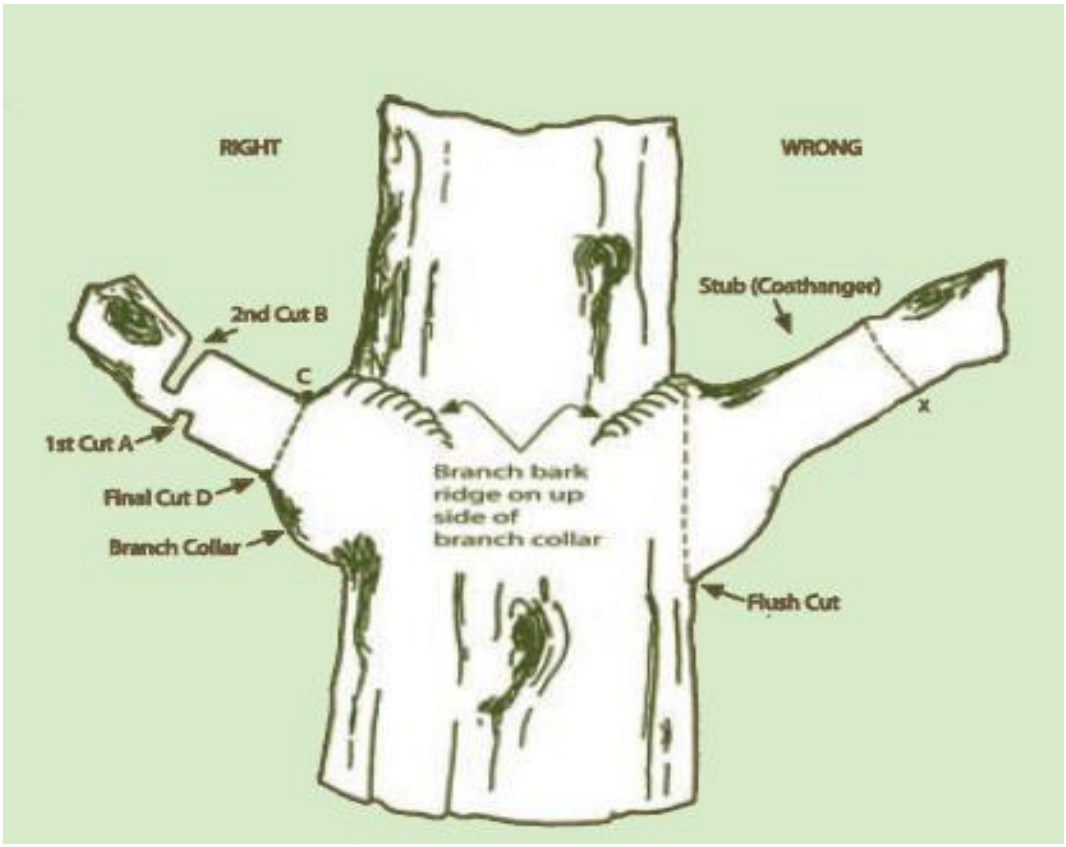

Figure 36: Proper (left) and improper (right) pruning (Treeby, 1994)

Step 1: Cut the branch at point A (up cut) and point B (down cut). B is located about half the branch thickness from A

Step 2: Locate points C and D, where the branch meet the branch collar. Cut from C to D with care as close to the branch collar as possible. Never injure the branch collar.

(Treeby, 1994)

10 Avoid the formation of whorls of branches, by eliminating them in 2-3 times;

11 After two years, the stem diameter is thick enough to allow complete pruning up to 4 m. After 3 to 4 years, clear wood pruning up to 6 m is allowed – according to the site of planting;

5.4.6.2 Results

The pruning of the *M. volkensii* is divided into two parts, with their own task rate:

Pruning without ladder:	300 trees per day with secateurs 150 trees per day with pruning saw
Pruning with ladder:	40 trees per day

Concerning pruning without a ladder, it is rather hard to distinguish between the usage of secateurs and a pruning saw. Mostly the pruning is done with secateurs, but when the pruning saw is used, it is in combination with the secateurs.

Table 27: Time spent on pruning trees per person without ladder

	Amount of trees pruned	Time elapsed pruning (mm:ss)
Person 1	70	56:57
Person 2	70	48:14

Statistical analysis made clear that both employees pruning without ladder worked significantly faster than the task rate of 300 trees per day per man (person 1 and 2 with *resp.* p-values: $p < 0{,}0005$ and $p < 0{,}0005$). The task rate would translate itself to 37,5 trees per hour, which is easily exceeded by both employees, hence *table 27*.
Remark on the method of pruning: branches with a diameter larger than 2 cm should be removed with the pruning saw and not with the secateurs. Both employees used secateurs on branches larger than 2 cm. Occasionally even branches with a diameter larger than 3 cm were removed by secateurs.
Ideally, the tools ought to be sterilised before and after every cut, this is not respected.

Gathered data pointed out the task rate of 40 trees, for pruning with the ladder, will easily be managed. After already 3 hours 30 minutes and 9 seconds, the employees have pruned 39 trees. The 39 observations led to an average of 5 minutes and 23 seconds, with deviation of 2 minutes and 8 seconds.
The pruning method by pruning saw is not always applied well by the employees. According to *fig. 36*, the pruning is done using 3 cuts: A, B and then a clean cut from C to D. The employees only applied cut A – at the downside of the branch, very close to the branch collar, approximately one third through the branch. Then cut from above, to meet the earlier made cut. According to the pruners, this is done to win time.
Ideally, the tools ought to be sterilised before and after every cut, this is not respected.

Ergonomics

Pruning without ladder is a fluent action, moving from one tree to another. Pre-emptive pruning starts when a tree has a two metres in height. No unnecessary bending over has to be done, when pruning trees. Because the trees are small and do not have a closed canopy yet,

the employees are subjected to high temperatures and an insolation of the sun. Apart from that, the trees can host several insects or other fauna that can harm the employee who is pruning the trees. The employees wore the overall for the complete action, protecting them from threats as thorns, stinging or biting fauna, etc...
Pruning with ladder requires more prudence. The employee's health be protected at all cost. Using a ladder is done with 2 employees, but none of them wore protective headgear. None of the employees wore goggles, as protection to saw-dust.

5.4.6.3 Conclusion

Pruning without ladder was done significantly faster than the task rate. Also pruning using a ladder was done faster than the task rate.
As already mentioned in the result part, it is important to make sure that the pruning saw and secateurs are used properly. It is also very essential to sterilise the tools before and after every action. In this way, disease spread is prevented.
The pre-emptive pruning as it is mostly applied now can be avoided by applying the budding technique. Budding is even less time consuming and prevents loss of time – because of pre-emptive pruning – in the future.

5.4.7 Weeding

5.4.7.1 Introduction

Weeding is an important measurement. Weeds and grasses can compete with the newly planted *M. volkensii* seedlings in the field for nutrients, water and daylight. The weeds growing in the field are very vicious. After planting the seedlings, the seedlings must adapt to the conditions of the field: a higher rate of insolation, less water and less nutrients are available compared to the nursery. This implying in a short moment of growth rest, to continue growing and developing when adapted. In this period of rest ,weeds and grasses can get a head start, overgrowing the seedling and it will be nearly impossible for the seedling to recover from this situation. To avoid seedling mortality in the field, it is necessary to remove all weeds, grasses, bushes and other competitive vegetation before planting the seedlings. After planting the seedling, the weeds will return. This leading to the same consequences as before planting, especially in the first years.
A trial at Katithini showed a visual difference in this purpose: the trees in the field where the weeding was done, shed their leaves later compared to the trees where weeding wasn't done. Both fields were of the same age, this as example how important weeding is. Weeding in the

plantation is done using glyphosate. Glyphosate [N- (phosphonomethyl)glycine] is a non-selective, broad spectrum, systemic, post-emergence herbicide. It inhibits the biosynthesis of aromatic amino acids, which leads to several metabolic failures: the deregulation of the shikimate pathway, inhibition of protein and secondary product biosynthesis (Nandula et al., 2005). Glyphosate is a systemic herbicide thus absorbed through leaves and transported to the root system. This implying non-target plants can be severely damaged by a residual amount of glyphosate in the soil (due to wash off from leaves, root exudation of treated weeds and drift caused by wind) (Eker et al., 2006). This is important to know when applying glyphosate in the field, near small seedlings. The application of glyphosate in the field comes with general instructions and a specific procedure.

General instructions:

- Weeding is done twice a year, in April and November;
- Spraying needs to be done with flat nozzles on the spray lances, directing the spray to the ground and avoid drift;
- The people handling chemicals must al all time wear protective clothing (*i.e.* overalls, goggles, heavy rubber gloves, gumboots and maks);
- The people handling chemicals are provided with 0,5 L milk at the end of each working day.

Specific working procedure concerning weeding:

- Weeding consist out of two different methods: application of glyphosate by using knapsack sprayers or weeding around the stem, with a panga;
- Glyphosate is a systemic herbicide. Around the seedlings, weeds have to be removed manually – by hand or with a panga, not with a digging hoe – nor with a knapsack. Glyphosate can harm the seedling and can only be used as the stem is completely woody;
- Weeding around the stem is done by a pack of workers going ahead of the sprayers, pulling the weeds with their hands. Gloves are recommended since the weeds can be thorny;
- Glyphosate is mixed with vegetable oil. This to make the penetration through the cuticule of the grass easier;
- Grass and other weeds should be maximum 20-30 cm high. Weeding must be done in time. Repeated showers can cause fast growth of earlier exterminated vegetation;
- 4 L of glyphosate is applied on 250 L of water per hectare;
- The people who the spraying must move in pack, along the rows of trees/seedlings;

- Young seedlings are shielded from the glyphosate by a metal sheet or a flexible piece of plastic;
- The knapsack sprayers have a capacity of 16 L and one sprayer is filled with chemical 13 times a day;
- Weeding is done at a rate of 60 seedlings per knapsack sprayer when the weeds are maximal 20-30 cm high. When the weeds are taller, the rate drops to 30-35 seedlings per knapsack sprayer.

Tables 28, 29 and *30* give overviews of the requirements in order to eradicate the weeds from the plantation fields in Kiambere. Based on these tables, the costs of personnel and materials can be estimated and calculated for weeding.

Weeding is a money consuming action, but it is not yet known for what period the area around the trees need to be weeded – *i.e.* it is not yet known until what age of the tree the competition with the weeds for uptake of nutrients, daylight, water, etc… will have a significant influence on the growth rate of *M. volkensii*. It is necessary to comprehend this completely in order to know when to stop weeding, and to save money for other processes in the plantation.

Table 28: Requirements for weeding in April and November

Item	amount
glyphosate	4 L/ha
vegetable oil	1promille
labour for spraying	0.83ha/manday
labour for shielding	Depends with number of pumps
water needed	16 L/pump
	250 L/ha
nr of donkey carts	400 L/cart
labour for supplying water	4 men and 2 carts
labour for manual weeding	1ft around the seedlings

Table 29: Weeding with 10 pumps with current amount of seedlings (2012)

Amount of seedlings to weed	221.274
Amount of knapsack sprayers	10
Amount of fillings of a knapsack sprayer	13
Amount of seedlings sprayed per filling	40
Amount of seedlings sprayed per day	5.200
Amount of days to finish weeding	43

Table 30: Labour requirements

Task	Amount of employees needed
Protecting seedling stems with plastic	10
Weeding around stem	10
Mixing chemical	1
Handling pumps	10
Transporting of water	10
Supervisor	1
Total	42

(BGF, 2012 P)

5.4.7.2 Results

Weeding around the stem as well as weeding with a knapsack sprayer were observed. The latter being a flop, due to lack of care of the employees.

- First of all too much glyphosate solution was used per seedling. In normal conditions, 1 knapsack sprayer can cover 60 or 30 seedlings – depending on the height of the weeds. Out of 8 observations came clear that the employees only managed to weed averagely around 27,5 seedlings (with standard deviation = 6,41 seedlings) per knapsack. This was done in an average of 14 minutes and 34 seconds (with standard deviation =2 minutes 35 seconds).
- In normal circumstances, the employees can fill the knapsack sprayer 13 times a day. At time of the observation, the knapsack sprayer was filled 8 times in a period of 1 hour 56 minutes and 34 seconds, which is remarkably fast.
- Second remark was the fact the employees sprayed a too large perimeter around the seedling, thus wasting more glyphosate solution.
- And as third remark: the employees held their nozzles too high.

Unfortunately, this observation was not repeated. Weeding is very important, concerning growth of the trees and must be taken into account.

Manual weeding was observed as well. There is no task rate set for this procedure, although this is also important. These weeds are too close to the stem of the tree, where the glyphosate solution could harm it, so the weeds must be removed manually. *Table 31* points out, the manual weeding was rather fast.

Table 31: Amount of seedlings cleared of weeds, by hand, per time, per person

	Weeded around amount of seedlings		
Time	Person 1	Person 2	Person 3
10h20-11h	74	72	65
11h-12h	106	100	117
12h-12h30	56	51	54
13h-14h	120	112	108
Total	356	335	344
Average	79,11	74,44	76,44
Standard deviation	29,23	27,52	31,14

As *table 31* points out, the manual weeding was rather fast. A lot of weeds can be removed from around the stem of seedlings, where glyphosate cannot be applied, otherwise the seedlings may be die due affecting of the chemical component.

Slashing

Another important aspect is slashing. This is a massive removal of grass growing between tall trees, with a slasher. In fact, this action is not quite necessary, but can come in useful. The initial task rate for slashing is set at a slashed area of 764 m² per person per day. Via *table 32*, statistical analysis concluded that all three employees worked significantly faster than the task rate (*resp.* p-values of person 1, 2 and 3 being $p < 0,0005$; $p < 0,0005$ and $p < 0,0005$). *Fig. 37* shows what the employees are capable of doing in 6 hours of time. The total slashed area at the end of the day is a high number. This slashed grass has no function anymore. A suggestion is to use it in areas where the grass grows very sparsely, to use as mulch around the seedlings.

Table 32: Slashed area (m²) per elapsed hour for 3 persons

	Slashed area (m²)		
Time	Person 1	Person 2	Person 3
9h-10h	196	192	168
10h-11h	116	120	128
11h-12h	228	224	224
12h-12h30	52	56	44
13h30-14h	136	136	140
14h-15h	208	208	216
15h-16h	312	312	312
Total	1248	1248	1232
Average	208	208	205,3333
Standard deviation	84,82	82,84	85,14

Ergonomics

Benachour and Séralini (2008) mentioned that the adjuvants in Roundup® formulations are not inert. Moreover, the proprietary mixtures available on the market could be toxic cause cell damage. For this reason, it is necessary for the employees who work with and in the presence of glyphosate wear protective clothing. Employees using a knapsack sprayer must use the safety goggles as gloves as mouthpiece to protect themselves. As proven by the observations, all employees wore safety clothing.

The mixing of water with the glyphosate is done using a stick and may not be done by hand.

Employees walked slightly bend over, to spray around the seedlings.

Employees weeding manually with a panga had to continuously bend over, nearly crawl, to execute their task well. This is posture is very aggravating for the back.

The employees did not wear protective clothing – as gloves.

Slashing is done using a slasher. Slashing implying cutting the grass above the soil, meaning the employees were bending over all the time. This is a very aggravating position.

Other ergonomically aspect are the same as all other in-field plantation maintenance tasks:

- Victim of the sun's insolation;
- Victim of the severe surroundings (soil, flora, fauna, …);

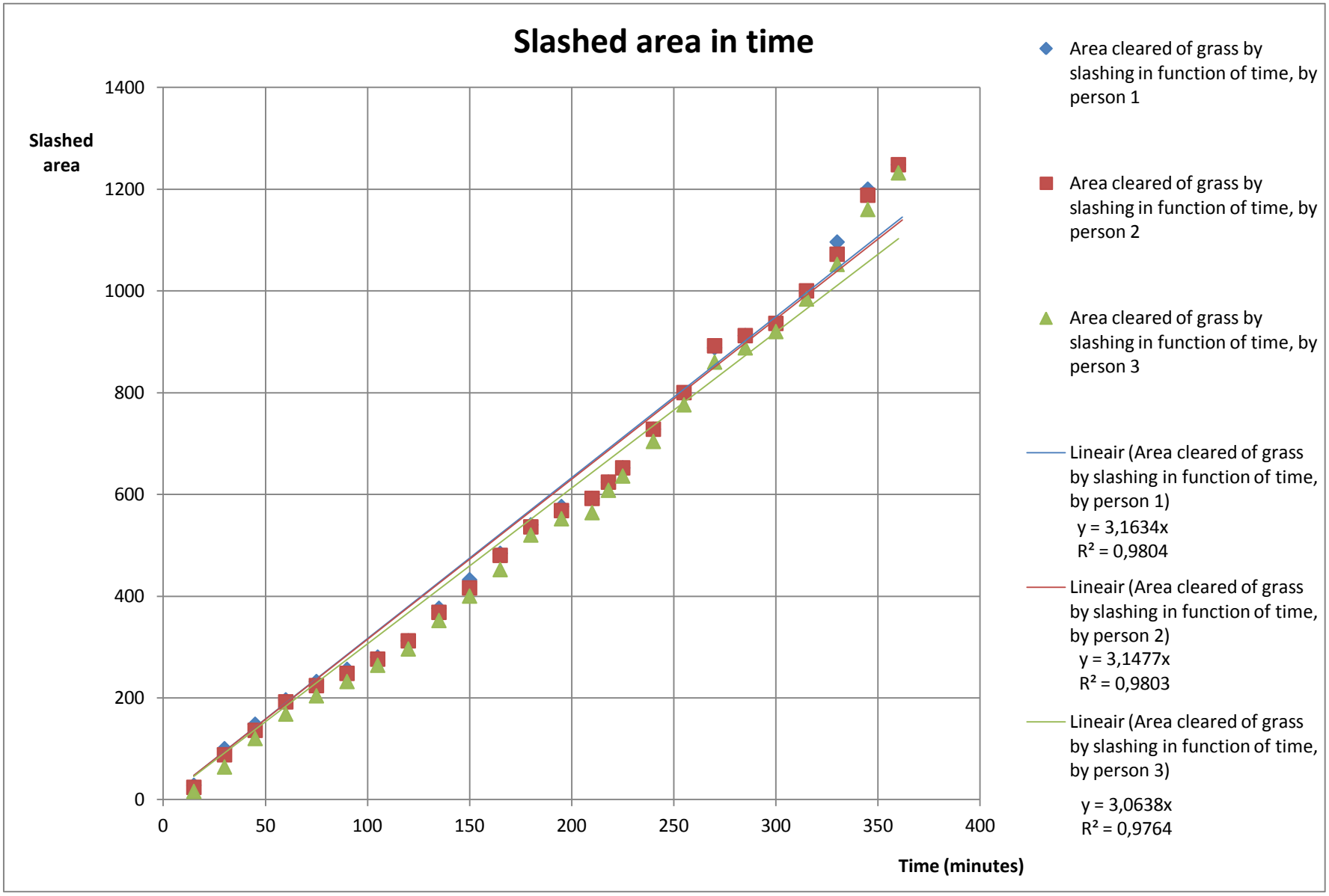

Figure 37: Area of grass slashed in function of time by 3 employees

5.4.7.3 Conclusion

There are several manuals to plan, test and form good task rates for weeding. Since this is a very expensive measurement, there may not be any waste of chemicals, neither may there be waste of human energy. When weeding is done in an efficient way, this will benefit employees and trees. If weeding is well done, trees can grow better – perhaps faster – and the chance they overgrow the weeds is plausible. So efficiency is the key in this task.
Weeding by hand is done very fast, but, and it is still necessary. When the stem of the trees is not entirely woody, glyphosate can penetrate the stem and destroy the seedling. It is possible to combine manual weeding with weeding with glyphosate, if manual weeding has an advantage over chemical weeding. If this is applied, the weeding should be done in one direction, else the manual weeders must wear protective gear (*i.e.* mouth mask, protective goggles, gloves, etc..). This will only hinder the manual weeders, so should be avoided.
Slashing is done significantly faster than the task rate.
The slashed grass could be used to mulch seedlings in area where grass is sparsely growing. Slashing is also the most useless of all previous actions and tasks. Its use hasn't been proven yet. Although the trees tend to shed their leaves earlier if the grass is not put down yet.

5.5 General conclusion concerning ergonomics at the plantation

5.5.1 Overall observations concerning nursery related processes

For a sitting workstation, it is nearly impossible to make every 'workstation' as adequate as possible due the inadaptable table and/or chair position. However, an addition of a support cushion or a flat terrain could help to improve the position of the employees. For the employees sake, it should be forbidden to sit on the soil and perform their task. This costs too much effort for the employee, the sitting position is unhealthy for the back and uncomfortable for other limbs. It is also proven that continuous sitting in the same position leads to fatigue.
Due the movement of the sun, the employees need to replace themselves continuously through the day, in order to remain in the shades. This leads to a reduced efficiency. Anyhow, high temperatures in the sun, when the employees should not replace themselves, has to be avoided.
Summarised some additions could be:

- A flat terrain;
- A decent workstation: table and chair at ideal height;
- A continuously shaded workstation;

- All objects (tools, fruits, nuts, seeds, etc…) should be easily reachable.

Some actions could be done standing, because a sitting position can create a load on the back that is 50 % higher than when standing, due to flattening of the natural S-curve of the back. With standing tasks, it is important to maintain this natural S-curve of the back. But standing tasks will increase the static load on the legs and can induce an awkward back posture due to bending forward or standing up straight for too long. To prevent this, a foot rest and leaning stands can be built near the work bench.

To work in an efficient manner, every task should be done at the optimal elbow height.

Every task from depulping, cracking, nipping, slitting and sowing can be done whilst standing.

For several tasks, lifting is required. A decent lifting guide would be very useful at the plantation. The National Institute for Occupational Safety and Health (NIOSH) published a guideline which provides an useful approach based on crucial variables while lifting objects. For the complete background, refer to the NIOSH documentation (NIOSH, 1994).

Mixing water with a fungicide should be done with a mixing spoon and not with bare hands.

5.5.2 Overall observations concerning plantation maintenance

All plantation maintenance tasks are out in the field, where employees are being exposed to severe insolation of the sun and high temperatures, rough terrain, thorny shrubs and weeds, insects, *etc*…It is important for the employees to protect them as good as possible against these threats. A cap or other headgear is perhaps the most important one. The rubber boots are protective, but not against everything. It would be more useful to have boots – rubber or not – with hard soil, unlike what the employees have now. That way thorns, branches or other things won't sting through the boots.

Revision of the tools is a must. Digging hoes with loose heads are dangerous in the field. The sharpness of the panga and slashers is also very important.

When working in the field, it should be considered to make a source of water available for the employees.

5.5.3 Observation per task

Most protective conditions are mentioned in the work instructions.

Although for slitting: single edge razors would be of much use. To prevent employees from cutting themselves.

Sowing is now done kneeling down at the propagator. It would be much more useful to put the propagators onto tables, so the sowing can be done whilst standing. The bottom of the propagator should be at elbow height. This way the employees sowing the seeds as well as the employees transplanting the seedlings to the polybags benefit this improvement. The tables can also prevent the infection of soil-borne fungi of the propagator. Water discharge out of the propagator, is a point of interest in the design.
Employees transplanting the seedling must kneel down, in order to reach the polybags in the tunnels. For these people, a polystyrene kneeler pad would be very useful.
Considering marking the field: a peg at both ends of the steel cable would be of much use. In this way, the cable won't slip out of the employee's hands anymore. Perhaps also recommend the use of gloves when holding the steel cable.
Making pits with a digging hoe is very demanding for the back, due to short handles. Maybe consider using a spade, to spare the back. When used, make sure employees have boots with hard soil.
From an ergonomic point of view, fetching water using a donkey is much better than carrying a jerry can for kilometres. This option should be considered over the manual carrying.
When pruning with a ladder, one should at least wear a helmet to protect him/herself from falling branches. Goggles to counter saw-dust could be useful too. Much prudence is needed when using a ladder, always go out in couple when using a ladder.
Employees doing weeding with chemical components, should at all time wear protective clothing, consisting of: protective goggles, a face mask, heavy duty gloves, full uniform, rubber boots and trousers out of the boots.
Slashing is done using slashers. This is though demanding for the back, due to a continuous bending posture. Perhaps using a scythe would be much more interesting than the slashers. Due to the great range of the scythe, the efficiency of the task will increase.

6 Propagation experiments concerning *M. volkensii*

6.1 Initiation of elite tree cuttings

6.1.1 Introduction

Elite *M. volkensii* are trees selected, based on specific parameters, that are superior to the common *M. volkensii* trees. These trees can be used in micro-propagation to preserve and maintain this genetic quality. In the long run, micro-propagated elite trees may be used for (mass)production of *M. volkensii*. This trial was executed at the university of Nairobi (UON), in Kabete as well as in college/university Ghent.

6.1.2 Material and methods

The elite trees have an age of approximately 6 years and are found at the BGF plantation in Kiambere, situated at Area 1. 6 trees were used, with 5 vigorous cuttings per tree. All cuttings were approximately 10 cm in length. The cuttings were taken all over the tree, from the top of the canopy to branches at the bottom of the tree. After being cut, the cuttings were put into a plastic bag, which was put into a cooler. The cuttings stayed in this conditions for 24 h.

The obtained elite cuttings were subjected to a standard sterilisation protocol:

- The upper part (3 to 5 cm) was used
- Sterilising the cuttings by rinsing them with 70% ethanol for a few seconds.
- followed by soaking the cuttings into a 0,5% $HgCl_2$ solution for 5 minutes.
- A subsequent rinsing, with sterile water, of the cuttings is obliged.
- Thereafter sterilising the surface of the cuttings with 7,7% NaOCl (containing 77 mL JIC per 1000 mL) for 12 minutes.
- Finally a three-time rinsing with sterile water is obliged before they were being cut into smaller pieces.

Every explant had one to two buds. They were inoculated on a Murashige and Skoog medium (1962) with 20 g/l sucrose and 7 g/l agar-agar, with addition of 2µM BA.
The recipient were glass jars, containing 50mL of the medium. One to four explants were inoculated into the glass jars. The cultures were incubated at the growth chambers of UON, which were illuminated with fluorescent lamps. The provided temperature fluctuated between 23 and 26 °C, with photoperiods of 18 h of light and 6 h darkness.

This trial was repeated in Ghent. The cuttings from the elite trees were obtained, at the plantation in Kiambere, 2 days before flight and transported to Ghent from Nairobi. The cuttings were preserved fresh and were initiated 2 days after arrival in Ghent. The sterilisation protocol was identical as well as the initiation medium to those used in Nairobi. The recipients of the explants were glass tubes and one tube contained one initiated cutting. The cultures were incubated at the growth chamber at 23 °C, 16 h light/8h night regime.

6.1.3 Results

The cuttings were successfully sterilised and initiated onto the initiation medium in Nairobi as well as in Ghent. Due to field-work at Lake Kiambere, the initiated cuttings stood in the growth chambers at UON for 74 days. After 60 days, all initiated cuttings died. They were brown coloured and seemed to have dried out. When opening the jars under laminar flow, an ethanol scent rose from the glass jars.

Figure 38: successful initiated elite tree cutting at UON, Nairobi after 40 days

Figure 39: Failed initiated elite tree cuttings at UON, Nairobi after 74 days (34 days after fig 34)

The initiation in Ghent was more successful, more initiated elite cuttings did survive. Not all cuttings survived, but those who did are now being subcultured.

Figure 40: successful initiation of elite tree cutting at College/University Ghent, after 20 days

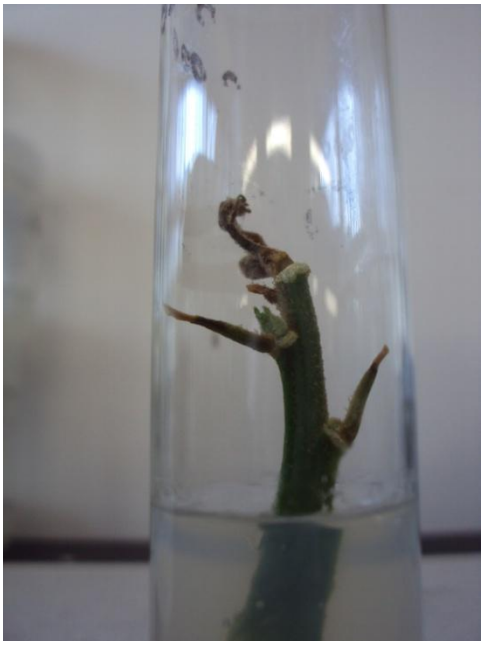

Figure 41: Less successful initiation of elite tree cutting at College/University Ghent, after 20 days

6.1.4 Discussion and conclusion

The death of the initiated cutting at the university of Nairobi could be due the method of cleaning in the growth chamber. The glass jars stood on wooden shelves. Every day, the growth chamber is cleaned and disinfected with ethanol (70 % solution), the shelves are sprayed with it. Perhaps the jars were not removed before applying the ethanol or perhaps the lids of the jars were not completely closed and ethanol could enter it. All plants died, without any fungal or bacterial growth on/in the medium. This raises a lot of questions.

6.2 Subculturing elite tree cuttings

6.2.1 Purpose

There is a difference between growth rate of mature plant material versus juvenile material. This must be bore in mind, when planning to use juvenile or mature material for *in vitro* purpose. This trial was set up to verify whether this is the case or not. This was a trial on very small scale, so the conclusion will only give a general view on the difference.

6.2.2 Material and methods

Mature material was derived from the elite trees from the plantation at Lake Kiambere, Kenya. The elite trees that were successfully initiated – from section 6.1, were subcultured and were used for this trial. Juvenile material was derived from *in vitro* sown seeds, that were successfully subcultured at the laboratory in Ghent. Notice that these trees do not have the

same genotype. Shoots from subcultured elite cuttings and juvenile shoots were subcultured on Murashige and Skoog medium (1962) with 20 g/l sucrose and 5 g/l plant agar, with addition of 10 µM meta-topolin riboside (mTR) as cytokinin. mTR is a naturally occurring aromatic cytokinin (Tarkowská et al., 2003). The shoots had 2 buds and were 10 – 20 mm in length (depending on the amount of buds).
After 40 days, the length of the plantlets was measured and evaluated.

6.2.3 results

Table 33 gives an overview of the length of the shoots after a subculture of 40 days. Tree lines 69106 (1) and 69100 (2) are elite tree line, tree lines 3, 4 and 5 are juvenile material. 8 plant lengths were measured per tree line.

Table 33: Length of plants per initiated tree line after 40 days

Tree Line	Average plant length (cm)	
69106 (1)	4,84 ± 2,26	a
69100 (2)	5,13 ± 1,64	a
69001 (3)	8,00 ± 1,93	b
69008 (4)	8,56 ± 1,97	b
69073 (5)	8,06 ± 1,45	b

Mean shoot length of adult (1,2) and juvenile (3,4,5) *M. volkensii* after a subculture of 40 days. Means followed by the same letter are not significantly different from each other (Tukey 95%).

Length of tree line 1 and 2 does not differs significantly ($p > 0,05$) nor did the length of tree line 3, 4 and 5 ($p > 0,05$). The length of the shoots from tree line 1 is significantly smaller than the length of the shoots from tree line 3, 4 and 5 ($p < 0,05$). The same results for the shoots from tree line 2. They were significantly shorter than those of tree line 3, 4 and 5 ($p < 0,05$).
Fig 42 proves the results of the difference in growth rate between mature and juvenile material *in vitro*.

Figure 42: Difference **in** growth rate between mature (left) and juvenile (right) shoots *in vitro*

6.2.4 Discussion and conclusion

This trial is only orientating because there was only a limited number of available shoots. Moreover the adult and juvenile lines did not have the same genotype. The result suggests that in vitro, adult elite trees not necessarily grow as good as the best seedlings. Performance in the field is not the same as performance in the test tube. The question could be adequately answered by future research, when more shoots will become available and when the adult lines will be rejuvenated by means of somatic embryogenesis.

7 Impact of fertilisation on *M. volkensii*

7.1 Purpose

The purpose of these trials was to determine the optimal quantity of fertiliser for the *M.volkensii* seedlings. Based on growth parameters, stem diameter and height of the tree, the effect of different quantities of used fertiliser can become clear through the years. These trials, 1 and 2, are follow-up studies of respectively Silke Nowak from 2009 (Nowak, 2010) and Pieter De Catelle (De Catelle, 2012) from 2011. De Catelle (2012) also made a report on the fertiliser trial of Nowak (2010).

7.2 Material and methods

The used fertiliser in the trails, was Mavuno. It is a local fertiliser containing 10 % ammonical N, 26 % available P2O5, 10 % K2O, 10 % CaO, 4 % MgO, 4 % S and the meso- and micro elements B, Mn, Cu, Mo and Zn. Two different trails were conducted to determine the effect of:

- different quantities of the fertiliser;
- the time of addition/treatment with the fertiliser.

7.2.1 Fertiliser trial 1

The first fertiliser trial contains *M volkensii* trees that are treated with three different quantities of Mavuno fertiliser: 0 g, 50 g and 100 g. These trees were planted in the summer of 2009, the month of July, and were one year old when treated with the fertiliser. Every treatment was repeated 4 times and the fertiliser was added near the seedling. The trees in this trial area were planted in 12 blocks, every block containing 49 (7 by 7) seedlings. The total amount of *M.volkensii* trees in this trial area is thus 588. The setup of this first trial, is given in *table 34*, *table 35* and *table 36*

Table 34: Numeration of the blocks

1	2	3	4
5	6	7	8
9	10	11	12

Table 35: Different quantity of fertiliser per block

0 g	100 g	50 g	100 g
50 g	0 g	0 g	100 g
50 g	0 g	100 g	50 g

Table 36: Orientation of the *M. volkensii* trees in one block

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

The height of the trees was measured. This was done from the soil level to the apical growing point of the tree. The diameter of the stem was measured with a calliper, approximately 150 cm above the soil level.

Dead trees and trees with length beneath 150 cm were not included in the analysis of the gained parameters out of the trial. The obtained data was statistically tested with Statistical Package for the Social Science (SPSS). The evolution of mortality was verified with a Tuckey-Kramer test. The output was added in *appendix 12*.

7.2.2 Fertiliser trial 2

The second fertiliser trial contains *M. volkensii* trees that were planted in October 2009. The trees are treated with the Mavuno fertiliser in two phases. The first phase took place in October 2009, after the planting of the *M. volkensii* in the field. Two different quantities of Mavuno fertiliser were given to the trees: 50 g and 100 g. *Table 39* displays the first phase of distribution of the fertiliser. After this treatment, no measurements were carried out to determine the effect of these quantities (De Catelle, 2012).
Phase two of this trial took place in June 2010. Four different quantities of Mavuno fertiliser were applied to the trees: 0 g, 100 g, 200 g and 300 g. These quantities are additional to the first phase, equalling a total of eight different applied quantities of the fertiliser: 50 g - 0 g, 50 g - 100 g, 50 g - 200 g, 50 g - 300 g, 100 g - 0 g, 100 g - 100 g, 100 g - 200 g, 100 g - 300 g. *Table 40* displays the second phase of distribution of these quantities. Every treatment was

repeated four times and the fertiliser was added circular around the seedling. The trees in this area were planted in 16 blocks, every block containing 24 (6 by 4) seedlings, making the total amount of *M. volkensii* in this second area thus 384. The setup of this second trial is given in *table 37, table 38.* Phase one and two of donation of fertiliser are given respectively in *table 39* and *table 40.*

Table 37: Numeration of the blocks

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

Table 38: Orientation of the *M. volkensii* trees in one block

1	2	3	4	5	6
12	11	10	9	8	7
13	14	15	16	17	18
24	23	22	21	20	19

Table 39: Different quantity of fertiliser per block, phase 1, October 2009

100 g	100 g	50 g	50 g
100 g	100 g	50 g	50 g
100 g	100 g	50 g	50 g
100 g	100 g	50 g	50 g

Table 40: Different quantity of fertiliser per block, phase 2, June 2010

0 g	200 g	100 g	100 g
300 g	300 g	0 g	0 g
200 g	0 g	300 g	200 g
100 g	200 g	300 g	100 g

The height of the trees was measured. This was done from the soil level to the apical growing point of the tree. The diameter of the stem was measured with a calliper, approximately 150 cm above the soil level. Dead trees and trees with length beneath 150 cm were not included in the analysis of the gained parameters out of the second trial.

De Catelle (2012) also stumbled upon a problem in the setup of the second trial. The amount of trees fertilised with 50 g - 100 g differ from 100 g - 100 g. The same problem appeared

with the amount of trees fertilised with 50 g - 200 g and 100 g - 200 g. To solve this problem, the median of tree height and stem diameter of the control treatments (all trees whom received 0 g fertiliser in second phase) was measured (De Catelle, 2012). The obtained data from this trial was statistically tested with SPSS. The results of this trial were obtained by using an analysis of variance. Because of this setup (the donation of fertiliser in two phases) it is impossible to draw conclusion out of a one way ANOVA, since the first phase can influence the second one. A two way ANOVA will be able to clarify whether phase one, two or the combination (i.e. interaction) of both phases gives best results for tree height and stem diameter. In case of interaction between phase one and two, a Tukey-Kramer test will be used to determine the difference between the treatments. In absence of a normal distribution, a Friedman test will be applied, where after a Wilcoxon sign rank test, with pairwise comparison, will make the result clear. This test is based on the mean ranks, so the earlier token measurements of De Catelle (2012) can be avoided. The output of the second fertiliser trial is added in *appendix 13*.

7.3 Results

7.3.1 Fertiliser trial 1

The evolution of height and stem diameter are *resp.* given in *fig. 43* and *44*.

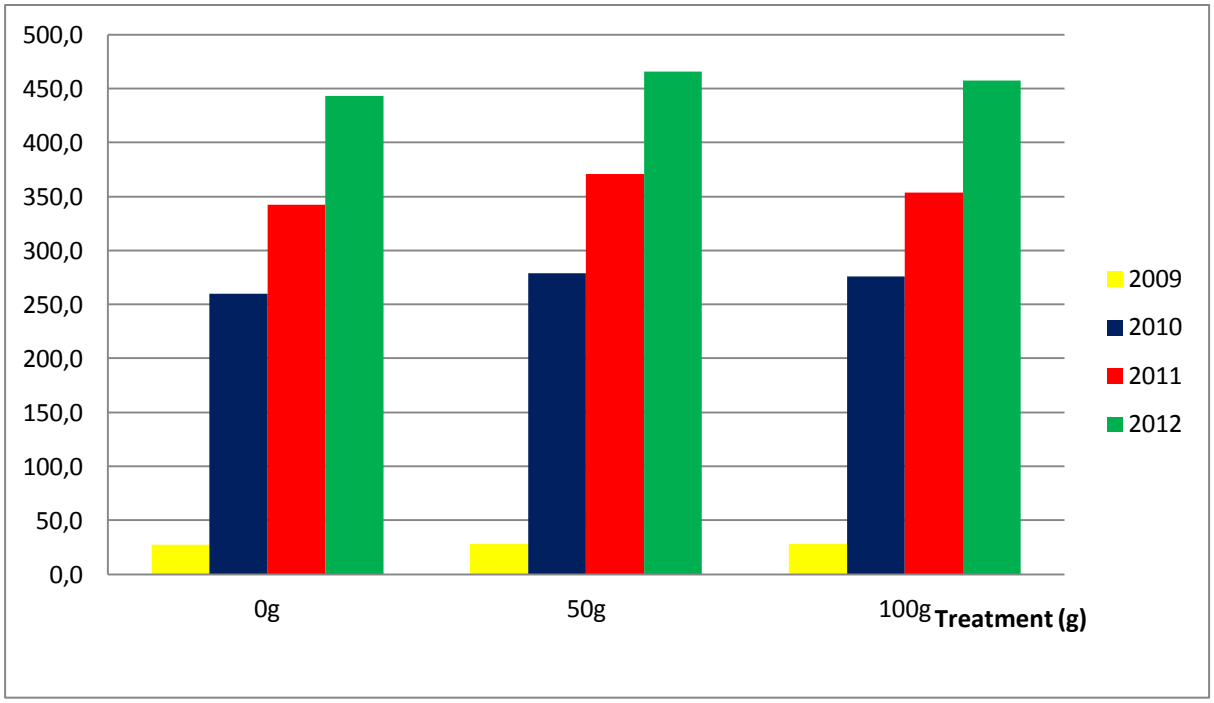

Figure 43: Evolution of height of *M. volkensii*

The average height of *M. volkensii* in 2012 of the 0 g, 50 g and 100 g treatments are *resp.* 443,2 cm, 466,0 cm and 457,3 cm.

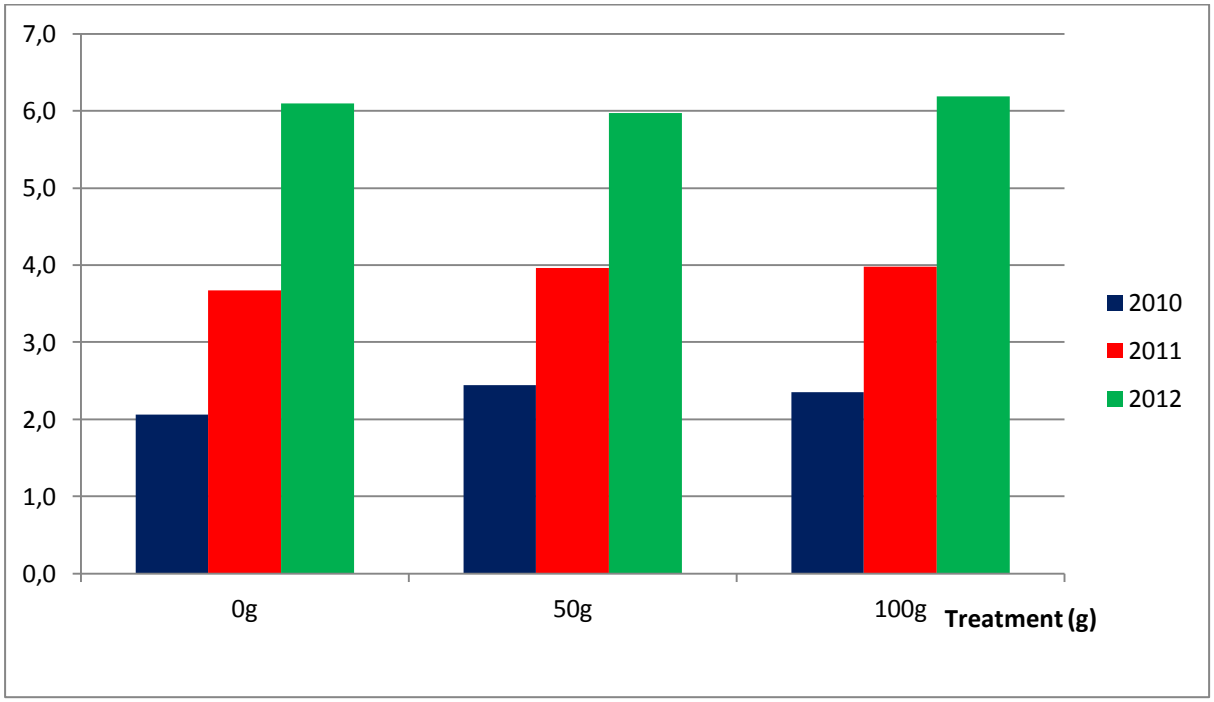

Figure 44: Evolution of stem diameter of *M. volkensii*

The average stem diameter of *M. volkensii* in 2012 of the 0 g, 50 g and 100 g treatments are *resp.* 6,1 cm, 6,0 cm and 6,2 cm.

Statistical analysis made clear for the year 2012 that the distribution of height ($p = 0,066 > 0,05$) as well as the distribution of stem diameter ($p = 0,532 > 0,05$) is the same across categories of treatment. This has been verified with a Kruskal-Wallis test, since the data had no normal distribution.

There is a significant linear correlation between the factors height and stem diameter ($r^2 = 0,792$). This implying the conclusion based on one of the factors must be the same – in 80 % of the cases –as conclusions based on the other factor.

Fig. 45 shows the average mortality percentages per treatment. The 0 g, 50 g and 100 g treatment have *resp.* a 8,16 %, 9,18 % and 15,31 % mortality in 2012. Out of *fig. 45* is clear the mortality in the blocks with the 100 g fertiliser addition is the highest of all. The mortality in the block with the 100 g treatment differs significantly from the mortality in the 0 g treatment ($p = 0,044 < 0,05$), but it is equal to the 50 g treatment ($p = 0,108 > 0,05$). The 0 g treatment and the 50 g treatment do not differ on factor mortality per treatment ($p = 0,837 > 0,05$).

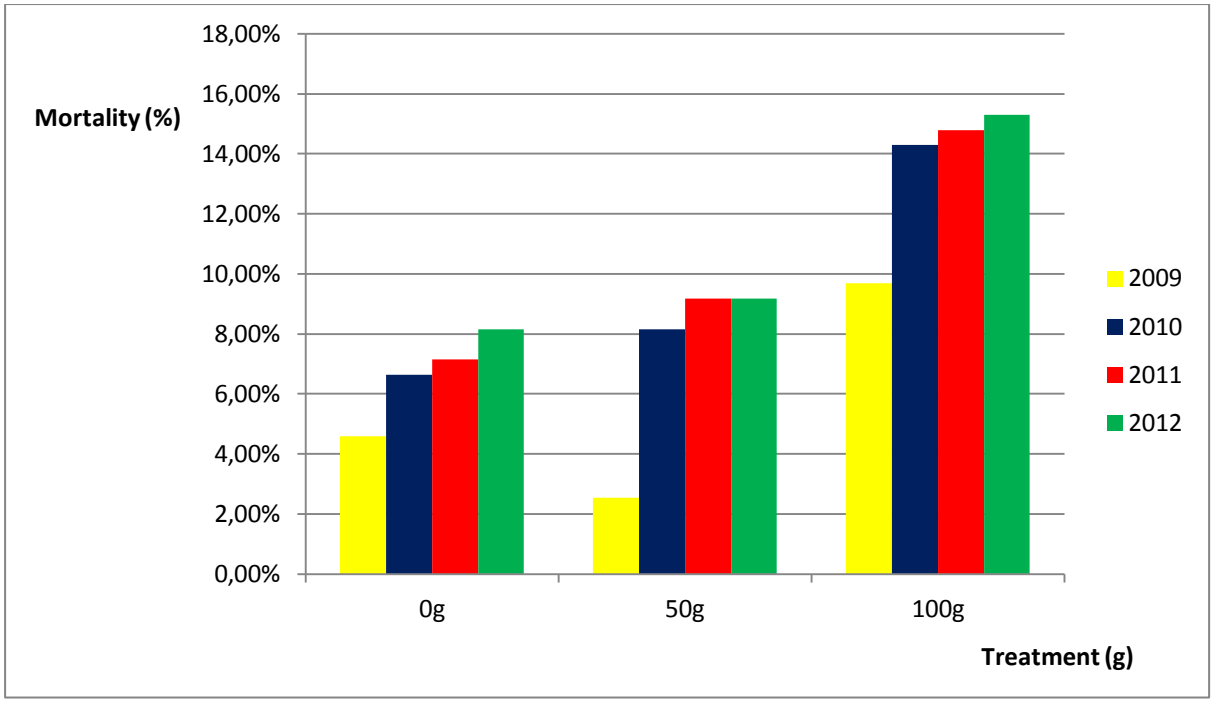

Figure 45: Evolution of mortality of *M. volkensii* per treatment

7.3.2 Fertiliser trial 2

The evolution of height and stem diameter are *resp.* given in *fig. 46* and *47*.

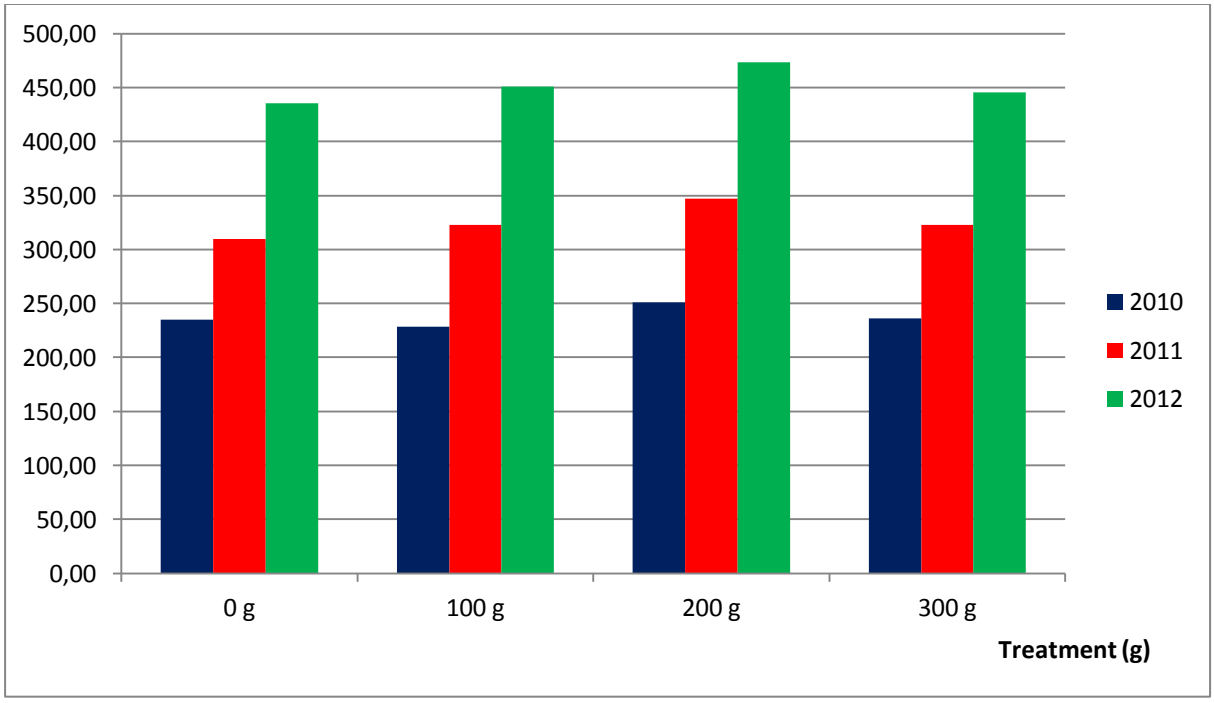

Figure 46: Evolution of height of *M. volkensii*

The average height of *M. volkensii* in 2012 of the 0 g, 100 g, 200 g and 300 g treatments (second treatment) are *resp.* 435,27 cm, 451,11 cm, 473,58 and 445,37 cm.

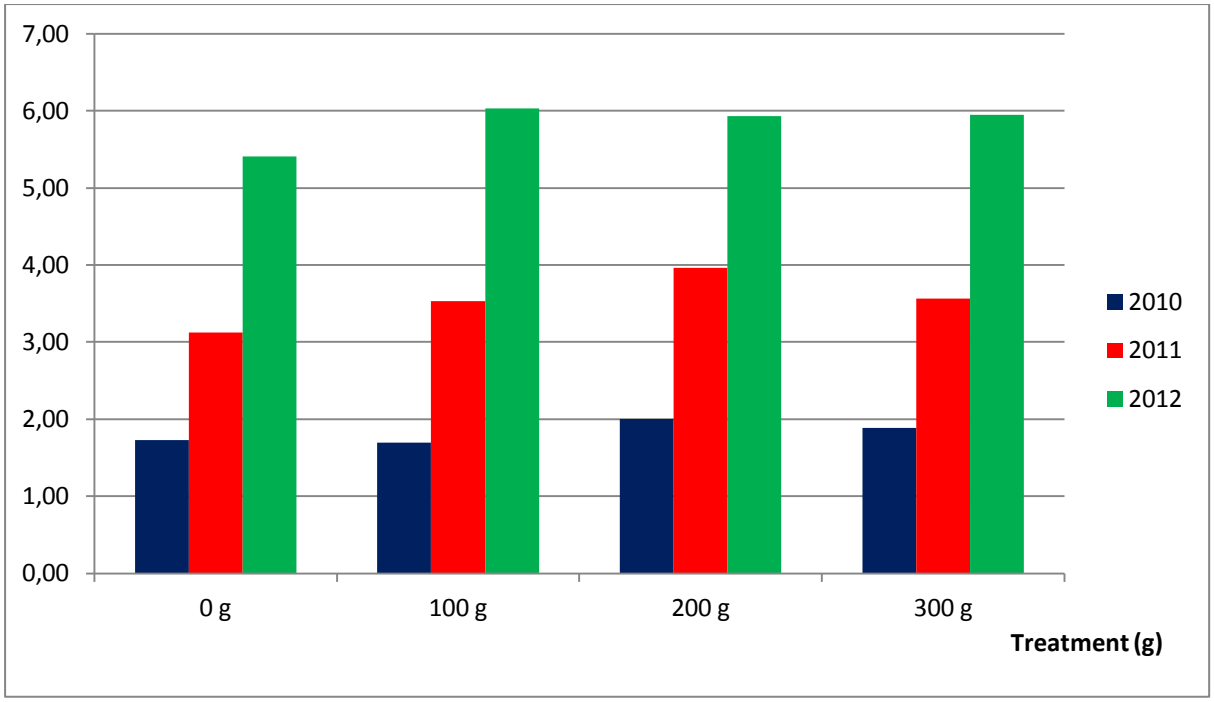

Figure 47: Evolution of stem diameter of *M. volkensii*

The average stem diameter of *M. volkensii* in 2012 of the 0 g, 100 g, 200 g and 300 g treatments are *resp.* 5,41 cm, 6,03 cm, 5,93 and 5,95 cm.

There is a significant correlation between height and stem diameter ($r^2 = 0,875$), implying conclusion based on one of the factors must be the same as conclusions based on the other factor. Pairwise comparison considering height and both treatments provided useful information. When first applied 50 g of fertiliser and second treatment being 0 g, 100 g, 200 g or 300 g, there was no significant difference between 0 g and 100 g nor between the 0 g and 300 g (*resp.* p-values: $p = 0,062 > 0,05$ and $p = 0,373 > 0,05$). But there was a significant difference when 200 g of the fertiliser was applied, compared to the 0 g as second ($p = 0,024 < 0,05$). The combination of 200 g fertiliser after 50 g gave the best results considering tree height. When first applied 100 g fertiliser and thereafter 0 g, 100 g, 200 g or 300 g, it was remarkable that there was no significant difference between 0 g and 300 g as second application ($p = 0,571 > 0,05$). Both secondly applied 100 g and 200 g fertiliser differed significantly with the 0 g (0 – 100 and 0 – 200, second treatment, with *resp.* p values: $p = 0,040 < 0,05$ and $p = 0,028 < 0,05$). The difference between 100 g and 200 g as second application was also significant: as second treatment, 100 g applied fertiliser gave the highest trees ($p = 0,040 < 0,05$). Out of both combinations of fertiliser giving the best results in height: 50 g – 200 g and 100 g – 100 g combinations, 100 g – 100 g was significantly better than 50 g – 200 g ($p = 0,012 < 0,05$).

Pairwise comparison between both treatments also provided useful information considering stem diameter. When first applied 50 g of fertiliser and second treatment being 0 g, 100 g, 200 g or 300 g, there was no significant difference between 0 g and 100 g nor between the 0 g and 300 g (*resp.* p-values: $p = 0,317 > 0,05$ and $p = 0,080 > 0,05$). But there was a significant difference when 200 g of the fertiliser was applied, compared to the 0 g as second ($p = 0,027 < 0,05$). The combination of 200 g fertiliser after 50 g gave the best results considering stem diameter.

When first applied 100 g fertiliser and thereafter 0 g, 100 g, 200 g or 300 g, there was no significant difference between 0 g and 100 g as nor between 0 g and 300 g second application (*resp.* p-values: $p = 0,067 > 0,05$ and $p = 0,287 > 0,05$). There was a significant difference between 0 g and 200 g applied as second treatment ($p < 0,0005$). Although remarkably there was no significant difference between the 100 g and 200 g second treatment ($p = 0,116 > 0,05$). Out of both combinations of fertiliser giving the best results in stem diameter: 50 g – 200 g and 100 g – 200 g combinations, there was no significant difference ($p = 0,205 > 0,05$).

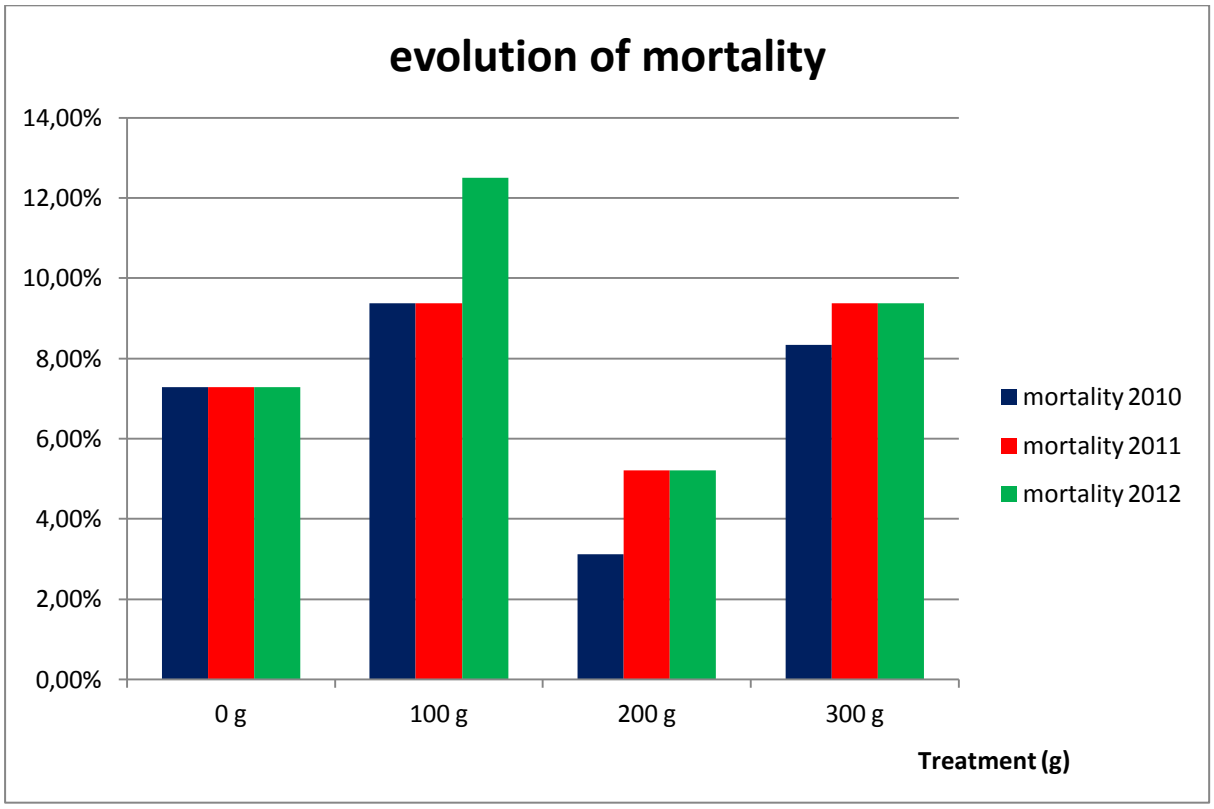

Figure 48: Evolution of mortality of *M. volkensii* per treatment

Fig. 48 shows the average mortality percentages per treatment. The 0 g, 100 g, 200 g and 300 g treatment have *resp.* a 7,29 %, 12,50 % and 5,21 % and 9,38 % mortality in 2012.

Fig. 48 shows the highest mortality percentage in blocks with the 100 g treatment (second treatment). Although there is no significant difference between these mortality percentages.

7.4 Discussion and conclusion

7.4.1 Fertiliser trial 1

De Catelle (2012) mentioned the impact of the fertiliser in 2010 had a significant influence on the two growth parameters (height and stem diameter) of the *M. volkensii*.
Next to that the overall conclusion was that 50 g and 100 g of Mavuno fertiliser seem to have the most beneficial impact on the growth parameters, with a small benefit for 50 g. This shows that 50 g of fertiliser applied during the first year of growth is the optimal amount for tree height and stem diameter. Mark that the growth parameters are linear correlated to each other. 2 years later, it is clear that as for the stem diameter as well as the height of the *M. volkensii* trees, the treatments do not differ significantly anymore. This can point out the effect of the fertiliser wore off and the trees managed to catch up with each other in height and stem diameter.
As general conclusion can be stated that the addition of fertiliser is very effective in the first years of growth, but that is wore off after a couple of years – here 3 years after planting The mortality among the trees still raised for the 0 g and the 100 g treatment. In block 4 and 10 a tree died, reason unknown.

7.4.2 Fertiliser trial 2

Considering height of the trees, the best combination of fertiliser applied is 100 g at the first phase, combined with 100 g at the second phase. This combination gives the best results considering height, after 3 years of growth. Considering stem diameter, the best combination is in the first phase 50 g, followed by 200 g in the second phase or 100 g in the first phase, followed by 200 g in the second phase. Note that there was no significant difference in stem diameter between trees when 100 g fertiliser was applied in the first phase and 100 g in the second phase. From an economical point of view, considering stem diameter, the application of 50 g followed by 200 g in the second phase will be more opportune. For the optimal combination considering height and stem diameter, the 100 g – 100 g treatment should be considered.
As well as in the first fertiliser trial, there is a significant linear correlation between height and stem diameter of the trees in the second trial.

The mortality is the highest among the trees where 100 g fertiliser was applied, though this is not significantly different with the other mortality percentages. The evolution of the mortality among the 100 g treatment is remarkable, although unexplainable. In block 16, the number of dead trees went from 1 to 3.

7.4.3 Overall

In general, the trees grow very fast. The fact that the data for both trials has no normal distributions per treatment or per block, makes it difficult to make hard conclusions concerning the optimal fertilisation.

III GENERAL CONCLUSION

For over 2 months, the tasks on the plantation at Lake Kiambere were analysed. It was not easy to gain the confidence of the employees whilst only carrying a chronometer and a notebook, to watch them doing their job. It was concluded that the efficiency on the shop floor could be improved.

Concerning the nursery production processes, the depulping of the fruits was easy manageable for the employees. The same goes for cracking the nuts. Nipping the seeds had a high task rate, which was achieved by the employees and therefore it will not slow down the production chain. The task rate for slitting was easily manageable, but we noticed that the employees were not always interested in achieving the task rate. The sharp razor blade was an obvious psychological factor in this process. Passing from slitting to sowing was not efficient. It would be more fluent if the propagators were already prepared at the beginning of the day. There is also more room for improvement concerning transplanting the seedlings and filling the polybags with soil (*e.g.* a potting table or potting 'machine' based on gravity).

Plantation maintenance tasks were overall performed faster than the initial task rate. Placing planting marks on the field would be more efficient if the land was cleared of shrubs, weeds or other vegetation before the plant holes are marked. Making plant holes is done faster than the task rate, even in rough conditions. Making catchment dams needs a different task rate for soft soil and hard soil, nonetheless the employees achieved the initial one with ease. The mulching of the seedlings was done according to the task rate in densely –with grass – grown areas. Unlike to the areas where grass is sparse. Perhaps a combination with slashing – which went very fast – is possible. Mulching, as well as a catchment dam, have proven their importance in these semi-arid areas.

As for watering the seedlings in the field, the use of donkeys is recommended. It is at least as fast as employees carrying jerry cans, but ergonomically better. The new watering system, with the reservoir, looks very promising, a lot of seedlings can be watered. Chemical weeding in the field must be revised. Pruning the trees was done faster than the task rate, but the task was not always executed well (*e.g.* too big branches pruned with secateurs). Overall, the employees did their job in an acceptable way, with obvious and visible ease, but there is room for improvement.

From an ergonomic point of view, there are several improvements possible. Amelioration of the sitting work place by flattening the terrain, having continuous shade and adjusting the work spot to the worker. Perhaps a switch from sitting to standing would be interesting,

following the recommendations for a standing work place. Protective clothing must be recommended at all times and a revision of the tools after a certain amount of time, might be useful.
Perhaps it is possible to raise the motivation of the employees by using incentives. This might be a donation of food, a day off, extra salary or any other form of motivation.
Perhaps a variation in performed task might be a source of new energy for the employees.
The initiation on a culture medium of cuttings of elite trees (mature material) out of the plantation at Lake Kiambere illustrated the difference in accommodation between the Laboratory of applied *in vitro* biotechnology at the University College Gent And the laboratory of tissue culture at the University of Nairobi in Kabete, Nairobi. The initial survival rate at UON was very high, but after 70 days, the initiated cuttings died due to unknown circumstances – possibly caused by method of cleaning in the growth chambers. The initiations at the college/university in Ghent had a survival rate of 70 %. This with cuttings that were preserved for 4 days. This initiated cuttings were then successfully subcultured and compared to *in vitro* seedlings. This trial was too small to draw specific conclusions, but suggested that mature plant material grows slower *in vitro* than seedlings.

The first fertiliser trial showed that Mavuno, applied when planting trees, had an effect in the first two years of growth. However, three years after start-up, the fertiliser effect wore off. It is clear that height and stem diameter did not differ anymore. The second fertiliser trial showed that Mavuno divided over 2 phases still had an effect. After three years, 100 g Mavuno, applied in the first year of growth, combined with 100 g Mavuno in the second year of growth gave the highest trees. However, the largest diameter was obtained with the combination of 50 g – 200 g and 100 g – 200 g (*resp.* first – second application). For economic purpose, the combination of 50 g- 200 g should be considered. The optimal combination Mavuno for both growth parameters can be 100 g in first year of growth and 100 g in the second year of growth.

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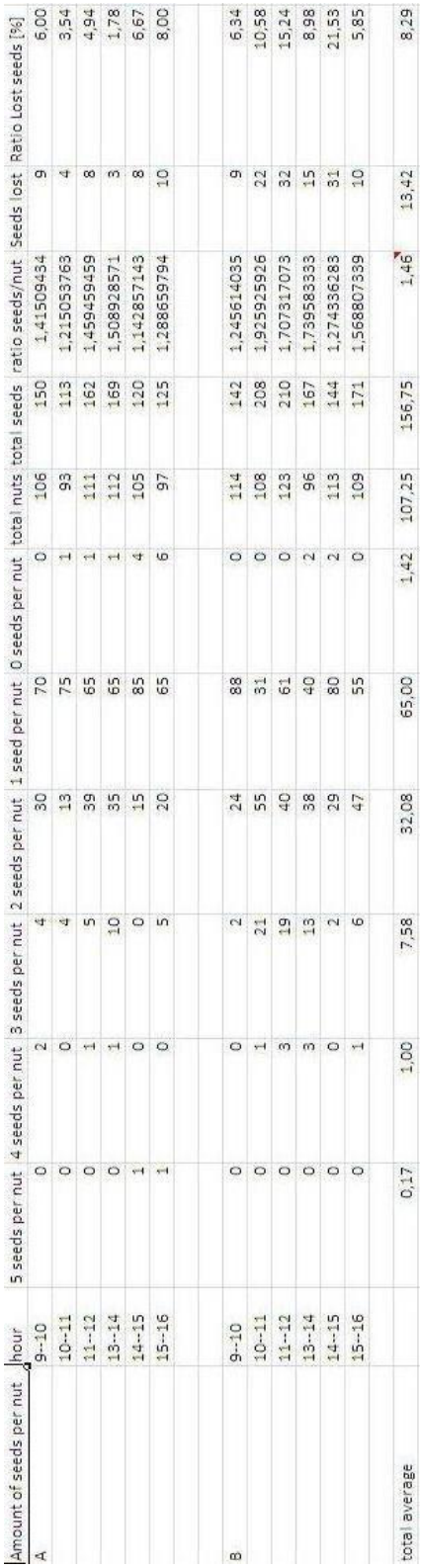
Appendices

Appendix 1: Cracking table, with indication of lost seeds



Amount of seeds per nut	hour	5 seeds per nut	4 seeds per nut	3 seeds per nut	2 seeds per nut	1 seed per nut	0 seeds per nut	total nuts	total seeds	ratio seeds/nut	Seeds lost	Ratio Lost seeds [%]
A	9--10	0	2	4	30	70	0	106	150	1,41509434	9	6,00
	10--11	0	0	4	13	75	1	93	113	1,215053763	4	3,54
	11--12	0	1	5	39	65	1	111	162	1,459459459	8	4,94
	13--14	0	1	10	35	65	1	112	169	1,508928571	3	1,78
	14--15	1	0	0	15	85	4	105	120	1,142857143	8	6,67
	15--16	1	0	5	20	65	6	97	125	1,288659794	10	8,00
B	9--10	0	0	2	24	88	0	114	142	1,245614035	9	6,34
	10--11	0	1	21	55	31	0	108	208	1,925925926	22	10,58
	11--12	0	3	19	40	61	0	123	210	1,707317073	32	15,24
	13--14	0	3	13	38	40	2	96	167	1,739583333	15	8,98
	14--15	0	0	2	29	80	2	113	144	1,274336283	31	21,53
	15--16	0	1	6	47	55	0	109	171	1,568807339	10	5,85
total average		0,17	1,00	7,58	32,08	65,00	1,42	107,25	156,75	1,46	13,42	8,29

Appendix 2: SPSS output t-test marking the field

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
VAR00001	24	96,0%	1	4,0%	25	100,0%

Descriptives

			Statistic	Std. Error
VAR00001	Mean		2,8363	,24946
	95% Confidence Interval for Mean	Lower Bound	2,3202	
		Upper Bound	3,3523	
	5% Trimmed Mean		2,8265	
	Median		2,9500	
	Variance		1,494	
	Std. Deviation		1,22211	
	Minimum		,63	
	Maximum		5,29	
	Range		4,66	
	Interquartile Range		1,94	
	Skewness		,061	,472
	Kurtosis		-,715	,918

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00001	,092	24	,200*	,980	24	,895

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
VAR00001	24	2,8363	1,22211	,24946

One-Sample Test

	Test Value = 1.6666666666666					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
VAR00001	4,688	23	,000	1,16958	,6535	1,6856

Appendix 3: SPSS output t-test and sign rank test for making pits

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00001	,184	9	,200*	,908	9	,300
VAR00003	,193	9	,200*	,858	9	,092
VAR00004	,247	9	,120	,770	9	,009

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

T-Test

[DataSet0]

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
VAR00001	9	2,2678000	1,24675437	,41558479
VAR00003	9	1,7899411	,57270544	,19090181

One-Sample Test

	Test Value = 1.09375					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
VAR00001	2,825	8	,022	1,17405000	,2157098	2,1323902
VAR00003	3,647	8	,007	,69619111	,2559707	1,1364115

Nonparametric Tests

[DataSet0]

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of VAR00004 equals 1,09.	One-Sample Wilcoxon Signed Rank Test	,015	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Appendix 4: SPSS output t-test and sign rank test for making halfmoon catchment dams in hard soil (A) and soft soil (B).

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
pers1_AM	,225	67	,000	,727	67	,000
pers2_AM	,137	67	,003	,887	67	,000
pers1_PM	,079	67	,200*	,969	67	,090
pers2_PM	,137	67	,003	,942	67	,003

A

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
pers1_AM	,099	44	,200*	,922	44	,005
pers2_AM	,227	44	,000	,800	44	,000
pers1_PM	,144	44	,022	,918	44	,004
pers2_PM	,164	44	,004	,915	44	,003

B

* This is a lower bound of the true significance

Nonparametric Tests

[DataSet0]

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of HM_AM1 equals 4,69.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.
2	The median of HM_AM2 equals 4,69.	One-Sample Wilcoxon Signed Rank Test	,021	Reject the null hypothesis.
3	The median of HM_PM1 equals 4,69.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.
4	The median of HM_PM2 equals 4,69.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

A

Nonparametric Tests

[DataSet0]

B

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of HM_AM1 equals 4,69.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.
2	The median of HM_AM2 equals 4,69.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.
3	The median of HM_PM1 equals 4,69.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.
4	The median of HM_PM2 equals 4,69.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Appendix 5: SPSS output sign rank test for mulching around a seedling in densely (A) and sparsely grown area (B).

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mulch_Dense1	,175	25	,046	,895	25	,014
Mulch_dense2	,253	25	,000	,845	25	,001
Mulch_sparse1	,221	25	,003	,797	25	,000
Mulch_sparse2	,130	25	,200*	,895	25	,014

*. This is a lower bound of the true significance.

Nonparametric Tests

[DataSet0]

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Mulch_Dense1 equals 7,81.	One-Sample Wilcoxon Signed Rank Test	,904	Retain the null hypothesis.
2	The median of Mulch_dense2 equals 7,81.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

A

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Mulch_sparse1 equals 5,62.	One-Sample Wilcoxon Signed Rank Test	,001	Reject the null hypothesis.
2	The median of Mulch_sparse2 equals 5,62.	One-Sample Wilcoxon Signed Rank Test	,002	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

B

Appendix 6 and 7: Resp. SPSS output sign rank test for pruning the trees without ladder

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pruning_NoLadder1	,244	39	,000	,770	39	,000
Pruning_NoLadder2	,304	39	,000	,507	39	,000
Pruning_Ladder1	,124	39	,135	,955	39	,123

a. Lilliefors Significance Correction

Nonparametric Tests

[DataSet0]

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Pruning_NoLadder2 equals 0,62.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.
2	The median of Pruning_NoLadder1 equals 0,62.	One-Sample Wilcoxon Signed Rank Test	,000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Appendix 7: SPSS output t-test for for slashing

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pers1	,124	23	,200*	,937	23	,156
Pers2	,135	23	,200*	,924	23	,081
Pers3	,135	23	,200*	,961	23	,488

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

T-Test

[DataSet0]

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Pers1	23	51,6522	25,26695	5,26852
Pers2	23	51,6522	24,71402	5,15323
Pers3	23	50,4348	23,15918	4,82902

One-Sample Test

	Test Value = 23.875					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Pers1	5,272	22	,000	27,77717	16,8509	38,7034
Pers2	5,390	22	,000	27,77717	17,0900	38,4643
Pers3	5,500	22	,000	26,55978	16,5450	36,5746

Appendix 8: SPSS output of the t-test for cracking the nuts, 8th (A), 9th (B) and 10th (C) of August

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Crack1	,209	9	,200*	,953	9	,727
Crack2	,270	9	,057	,879	9	,152
Crack3	,229	9	,192	,889	9	,194

A

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Crack1	,310	9	,013	,818	9	,033
Crack2	,309	9	,013	,790	9	,016

B

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Crack1	,207	9	,200*	,883	9	,167
Crack2	,179	9	,200*	,981	9	,967

C

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

T-Test

[DataSet0]

One-Sample Statistics

A

	N	Mean	Std. Deviation	Std. Error Mean
Crack3	9	215,666667	129,9163192	43,3054397
Crack1	9	233,555556	146,2464624	48,7488208
Crack2	9	226,888889	145,1072400	48,3690800

One-Sample Test

	Test Value = 250					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Crack3	-,793	8	,451	-34,3333333	-134,195856	65,529190
Crack1	-,337	8	,745	-16,4444444	-128,859427	95,970538
Crack2	-,478	8	,646	-23,1111111	-134,650410	88,428187

Nonparametric Tests

[DataSet0]

B

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Crack1 equals 250,00.	One-Sample Wilcoxon Signed Rank Test	,441	Retain the null hypothesis.
2	The median of Crack2 equals 250,00.	One-Sample Wilcoxon Signed Rank Test	,139	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

T-Test

[DataSet0]

One-Sample Statistics

C

	N	Mean	Std. Deviation	Std. Error Mean
Crack1	9	229,888889	118,3653712	39,4551237
Crack2	9	233,555556	133,9207892	44,6402631

One-Sample Test

	Test Value = 250					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Crack1	-,510	8	,624	-20,1111111	-111,094790	70,872567
Crack2	-,368	8	,722	-16,4444444	-119,385076	86,496187

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
		Std. Error Mean	95% Confidence Interval of the Difference				
Mean	Std. Deviation		Lower	Upper			
6,6666667	58,3438086	19,4479362	-38,1803546	51,5136880	,343	8	,741
17,8888889	41,3746433	13,7915478	-13,9144773	49,6922551	1,297	8	,231
11,2222222	49,7287085	16,5762362	-27,0026469	49,4470913	,677	8	,517

Crack2 - Crack1
-2.524[b]

s Te

s.

From top to bottom: A, B and C

Paired Samples Test

Paired Differences					t	df	Sig. (2-tailed)
		Std. Error Mean	95% Confidence Interval of the Difference				
Mean	Std. Deviation		Lower	Upper			
3,6666667	41,9910705	13,9970235	-35,9438607	28,6105274	-,262	8	,800

Appendix 9: SPSS output t-test for nipping

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Nipped	,119	13	,200*	,985	13	,996

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

T-Test

[DataSet0]

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Nipped	13	64,85	17,521	4,859

One-Sample Test

	Test Value = 62.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Nipped	,483	12	,638	2,346	-8,24	12,93

Appendix 10: SPSS output t-test for slitting

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Slit1	,150	13	,200*	,956	13	,687
Slit2	,091	13	,200*	,967	13	,859

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

A

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Slit1	,210	18	,036	,837	18	,005

a. Lilliefors Significance Correction

B

T-Test

```
[DataSet0]
```

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Slit1	13	46,076923	14,4248717	4,0007396
Slit2	13	48,307692	16,3573868	4,5367228

A

One-Sample Test

	Test Value = 55.5555555555555555					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Slit1	-2,369	12	,035	-9,4786325	-18,195495	-,761770
Slit2	-1,598	12	,136	-7,2478632	-17,132533	2,636807

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Slit1 equals 55,56.	One-Sample Wilcoxon Signed Rank Test	,012	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

B

Appendix 11: SPSS output for micro-propagation test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
length	,136	40	,058	,937	40	,028

a. Lilliefors Significance Correction

Mann-Whitney Test

Ranks

	VAR00001	N	Mean Rank	Sum of Ranks
VAR00003	1	8	7,88	63,00
	2	8	9,13	73,00
	Total	16		

Test Statistics[a]

	VAR00003
Mann-Whitney U	27,000
Wilcoxon W	63,000
Z	-,528
Asymp. Sig. (2-tailed)	,598
Exact Sig. [2*(1-tailed Sig.)]	,645[b]

a. Grouping Variable: VAR00001

b. Not corrected for ties.

Ranks

	VAR00001	N	Mean Rank	Sum of Ranks
VAR00003	1	8	6,38	51,00
	3	8	10,63	85,00
	Total	16		

Test Statistics[a]

	VAR00003
Mann-Whitney U	15,000
Wilcoxon W	51,000
Z	-1,795
Asymp. Sig. (2-tailed)	,073
Exact Sig. [2*(1-tailed Sig.)]	,083[b]

a. Grouping Variable: VAR00001

b. Not corrected for ties.

Mann-Whitney Test

Ranks

	VAR00001	N	Mean Rank	Sum of Ranks
VAR00003	1	8	5,75	46,00
	4	8	11,25	90,00
	Total	16		

Test Statistics[a]

	VAR00003
Mann-Whitney U	10,000
Wilcoxon W	46,000
Z	-2,329
Asymp. Sig. (2-tailed)	,020
Exact Sig. [2*(1-tailed Sig.)]	,021[b]

a. Grouping Variable: VAR00001

b. Not corrected for ties.

Ranks

	VAR00001	N	Mean Rank	Sum of Ranks
VAR00003	1	8	5,75	46,00
	5	8	11,25	90,00
	Total	16		

Test Statistics[a]

	VAR00003
Mann-Whitney U	10,000
Wilcoxon W	46,000
Z	-2,329
Asymp. Sig. (2-tailed)	,020
Exact Sig. [2*(1-tailed Sig.)]	,021[b]

a. Grouping Variable: VAR00001

b. Not corrected for ties.

Mann-Whitney Test

Ranks

	VAR00001	N	Mean Rank	Sum of Ranks
VAR00003	2	8	5,38	43,00
	5	8	11,63	93,00
	Total	16		

Test Statistics[a]

	VAR00003
Mann-Whitney U	7,000
Wilcoxon W	43,000
Z	-2,637
Asymp. Sig. (2-tailed)	,008
Exact Sig. [2*(1-tailed Sig.)]	,007[b]

a. Grouping Variable: VAR00001

b. Not corrected for ties.

Ranks

	VAR00001	N	Mean Rank	Sum of Ranks
VAR00003	2	8	5,38	43,00
	4	8	11,63	93,00
	Total	16		

Test Statistics[a]

	VAR00003
Mann-Whitney U	7,000
Wilcoxon W	43,000
Z	-2,637
Asymp. Sig. (2-tailed)	,008
Exact Sig. [2*(1-tailed Sig.)]	,007[b]

a. Grouping Variable: VAR00001

b. Not corrected for ties.

Ranks

	VAR00001	N	Mean Rank	Sum of Ranks
VAR00003	2	8	5,63	45,00
	3	8	11,38	91,00
	Total	16		

Test Statistics[a]

	VAR00003
Mann-Whitney U	9,000
Wilcoxon W	45,000
Z	-2,424
Asymp. Sig. (2-tailed)	,015
Exact Sig. [2*(1-tailed Sig.)]	,015[b]

a. Grouping Variable: VAR00001

b. Not corrected for ties.

Appendix 12: SPSS output for fertiliser trial 1

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
height	,209	588	,000	,778	588	,000

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
diam	,126	588	,000	,885	588	,000

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
mortality	,200	12	,198	,946	12	,574

a. Lilliefors Significance Correction

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of height is the same across categories of treatement.	Independent-Samples Kruskal-Wallis Test	,066	Retain the null hypothesis.
2	The distribution of diam is the same across categories of treatement.	Independent-Samples Kruskal-Wallis Test	,532	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,890[a]	,792	,792	72,454

a. Predictors: (Constant), diam

Oneway

[DataSet0]

Test of Homogeneity of Variances

mortality

Levene Statistic	df1	df2	Sig.
2,374	2	9	,149

ANOVA

mortality

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	31,500	2	15,750	4,610	,042
Within Groups	30,750	9	3,417		
Total	62,250	11			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: mortality

	(I) treatment2	(J) treatment2	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	0	50	-,75000	1,30703	,837	-4,3992	2,8992
		100	-3,75000*	1,30703	,044	-7,3992	-,1008
	50	0	,75000	1,30703	,837	-2,8992	4,3992
		100	-3,00000	1,30703	,108	-6,6492	,6492
	100	0	3,75000*	1,30703	,044	,1008	7,3992
		50	3,00000	1,30703	,108	-,6492	6,6492

Appendix 13: SPSS output for fertiliser trial 2

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
height	,168	384	,000	,844	384	,000
diameter	,138	384	,000	,890	384	,000

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
mortality	,181	16	,172	,903	16	,088

a. Lilliefors Significance Correction

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,935[a]	,875	,875	54,460

a. Predictors: (Constant), diameter

Post Hoc Tests

Multiple Comparisons

Dependent Variable: mortality

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	0	100	-1,25000	1,00519	,613	-4,2343	1,7343
		200	,50000	1,00519	,958	-2,4843	3,4843
		300	-,50000	1,00519	,958	-3,4843	2,4843
	100	0	1,25000	1,00519	,613	-1,7343	4,2343
		200	1,75000	1,00519	,346	-1,2343	4,7343
		300	,75000	1,00519	,877	-2,2343	3,7343
	200	0	-,50000	1,00519	,958	-3,4843	2,4843
		100	-1,75000	1,00519	,346	-4,7343	1,2343
		300	-1,00000	1,00519	,755	-3,9843	1,9843
	300	0	,50000	1,00519	,958	-2,4843	3,4843
		100	-,75000	1,00519	,877	-3,7343	2,2343
		200	1,00000	1,00519	,755	-1,9843	3,9843

NPar Tests Friedman Test

Wilcoxon signed rank test for stem diameter

Test Statistics[a]

N	384
Chi-Square	439,616
df	2
Asymp. Sig.	,000

Test Statistics[a]

	TR100_200 - TR100_0	TR_50_100 - TR100_0	TR100_300 - TR100_0	TR50_0 - TR100_0	TR50_300 - TR100_0	TR50_200 - TR100_0	TR100_100 - TR100_0
Z	-3,492[b]	-1,667[c]	-1,065[b]	-,513[c]	-,533[b]	-1,621[b]	-1,829[b]
Asymp. Sig. (2-tailed)	,000	,096	,287	,608	,594	,105	,067

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.

Test Statistics[a]

	TR_50_100 - TR100_200	TR100_300 - TR100_200	TR50_0 - TR100_200	TR50_300 - TR100_200	TR50_200 - TR100_200	TR100_100 - TR100_200
Z	-5,359[b]	-2,267[b]	-3,595[b]	-3,257[b]	-1,267[b]	-1,572[c]
Asymp. Sig. (2-tailed)	,000	,023	,000	,001	,205	,116

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

c. Based on negative ranks.

Test Statistics[a]

	TR100_300 - TR_50_100	TR50_0 - TR_50_100	TR50_300 - TR_50_100	TR50_200 - TR_50_100	TR100_100 - TR_50_100
Z	-2,148[b]	-1,000[b]	-2,939[b]	-3,467[b]	-2,629[b]
Asymp. Sig. (2-tailed)	,032	,317	,003	,001	,009

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Test Statistics[a]

	TR50_0 - TR100_300	TR50_300 - TR100_300	TR50_200 - TR100_300	TR100_100 - TR100_300
Z	-1,344[b]	-,437[b]	-,913[c]	-2,342[c]
Asymp. Sig. (2-tailed)	,179	,662	,361	,019

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

c. Based on negative ranks.

Test Statistics[a]

	TR50_300 - TR50_0	TR50_200 - TR50_0	TR100_100 - TR50_0
Z	-1,749[b]	-2,210[b]	-2,312[b]
Asymp. Sig. (2-tailed)	,080	,027	,021

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Test Statistics[a]

	TR50_200 - TR50_300	TR100_100 - TR50_300
Z	-1,741[b]	-2,000[b]
Asymp. Sig. (2-tailed)	,082	,046

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

NPar Tests Friedman Test

Wilcoxon signed rank test for tree height

Test Statistics[a]

N	384
Chi-Square	439,616
df	2
Asymp. Sig.	,000

Test Statistics[a]

	TR100_200 - TR100_0	TR_50_100 - TR100_0	TR100_300 - TR100_0	TR50_0 - TR100_0	TR50_300 - TR100_0	TR50_200 - TR100_0	TR100_100 - TR100_0
Z	-2,200[b]	-3,005[c]	-,566[c]	-1,149[c]	-,292[c]	-2,500[c]	-2,057[b]
Asymp. Sig. (2-tailed)	,028	,003	,571	,251	,770	,012	,040

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.

Test Statistics[a]

	TR_50_100 - TR100_200	TR100_300 - TR100_200	TR50_0 - TR100_200	TR50_300 - TR100_200	TR50_200 - TR100_200	TR100_100 - TR100_200
Z	-5,449[b]	-2,072[b]	-2,339[b]	-2,549[b]	-,414[b]	-2,057[c]
Asymp. Sig. (2-tailed)	,000	,038	,019	,011	,679	,040

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

c. Based on negative ranks.

Test Statistics[a]

	TR100_300 - TR_50_100	TR50_0 - TR_50_100	TR50_300 - TR_50_100	TR50_200 - TR_50_100	TR100_100 - TR_50_100
Z	-1,958[b]	-1,867[b]	-3,134[b]	-2,200[b]	-2,886[b]
Asymp. Sig. (2-tailed)	,050	,062	,002	,028	,004

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Test Statistics[a]

	TR50_0 - TR100_300	TR50_300 - TR100_300	TR50_200 - TR100_300	TR100_100 - TR100_300
Z	-,082[b]	-,418[c]	-1,314[b]	-2,312[c]
Asymp. Sig. (2-tailed)	,935	,676	,189	,021

Test Statistics[a]

	TR50_300 - TR50_0	TR50_200 - TR50_0	TR100_100 - TR50_0
Z	-,890[b]	-2,258[c]	-2,220[b]
Asymp. Sig. (2-tailed)	,373	,024	,026

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.

Test Statistics[a]

	TR50_200 - TR50_300	TR100_100 - TR50_300
Z	-,227[b]	-2,514[c]
Asymp. Sig. (2-tailed)	,820	,012

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

c. Based on negative ranks.