Influence of mulch and green manure from multi-purpose trees on soil conditions

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Submitted in partial fulfilment of the requirements of the degree

M. Sc. (Agric) - Pasture Science

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Supervisor: Prof. N.F.G. Rethman

I declare that the dissertation, which I hereby submit for the degree M. Sc. (Agric.)-Pasture Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at another university.

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J. I. Cronjé Date

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ABSTRACT

Influence of mulch and green manure from multi-purpose trees on soil conditions

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Mulching and green manuring are two soil improvement practices commonly found in agroforestry systems, especially in alley-cropping systems and variations thereof. To quantify the effect that a mulch or green manure can have on an agroforestry system research must be orientated to a mechanistic understanding of the influence a mulch or green manure can have on the soil environment and how factors such as the application rate and species (from which plant material are accumulated for a mulch or green manure) influences the suitability of a mulch or green manure.

Plant material from *Sesbania sesban* (sesban) and *Morus alba* (mulberry) were assessed, in terms of the influence on soil characteristics in small plot and green house trials. Both of these tree species are well adapted to a range of environments in South Africa and can produce material for fuel, fodder or soil amelioration purposes. This

study has indicated that mulches from these trees can influence the soil nutrient status significantly over the short term (ten weeks), and that the tree species will influence the type and amount of nutrients released from leaf material. Both mulches decreased the maximum soil temperature, while the mulberry mulch also increased the minimum soil temperature (in the top 200mm of the soil profile).There were, however, no significant interactions between temperatures at different soil depths and mulch treatment. While the mulch, therefore, influenced the soil temperature in the surface layer; the energy transfer to and from greater depths was not influenced by the mulch. The mulches had only a temporary effect on the microbial activity in the soil, suggesting that the mulch could not change the specific capacity of the soil to sustain microbial biomass after only one application of a mulch. Repeated applications of mulch might, however, have such an effect. Green manure, or mulch, of sesbania and mulberry increased water use efficiency, or plant production, at least in the short term, of *Avena sativa* (oats). The possibility of utilising such mulches or green manures, apart from being a general soil ameliorant, to address specific problems, therefore, definitely exists. To do this, however, a modelling approach is needed to predict the effect of specific mulches or green manures at specific rates of application on soil characteristics.

UITTREKSEL

Invloed van deklaag en groenbemesting van meerdoelige bome op grondtoestande

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Promotor: Prof. N.F.G. Rethman

Voorgelê ter vervulling van 'n deel van die vereistes vir die graad

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Die gebruik van deklae en groenbemesting, twee grondverbeteringstegnieke, word algemeen gebruik in agrobosboustelsels, en veral gangverbouïng stelsels. Dit is noodsaaklik om 'n meganistiese benadering te volg indien die invloed van deklae en groenbemesting op die grondomgewing, en die effek van faktore soos toedieningspeil en -frekwensie en spesies (waarvan plantmateriaal geoes word), op die geskiktheid van die deklaag of groenbemesting bepaal word.

Die invloed van plantmateriaal, afkomstig van *Sesbania sesban* (sesban) en *Morus alba* (moerbei), op die grondomgewing,is in 'n reeks klein perseel proewe en potproewe bepaal. Beide hierdie spesies is goed aangepas by 'n verskeidenheid habitatte in Suid-Afrika en kan materiaal produseer wat vir brandhout, veevoer en ook vir grondverbetering aangewend kan word.

Dié studie het getoon dat deklae van beide hierdie spesies die voedingstatus van die grond oor die kort termyn (10 weke) kan beïnvloed en dat spesies bepalend is tot die tipe en hoeveelheid voedingstowwe wat vrygestel word. Altwee deklae het die maksimum grondtemperatuur binne die boonste 200mm van die grondprofiel verlaag. Die moerbei deklaag het ook die minimum grondtemperatuur verhoog. Daar was egter geen betekenisvolle interaksie tussen temperature by verskillende gronddieptes en spesie nie. Die invloed van die deklaag op die grondtemperatuur is dus op die oppervlak uitgeoefen en hitteoordrag na die dieper lae is nie hierdeur beïnvloed nie. Die deklae het slegs 'n tydelike invloed op die mikrobe aktiwiteit in die grond gehad, 'n aanduiding dat die deklaag nie die grond se spesifieke kapasiteit om mikrobe aktiwiteit te onderhou kon verhoog na slegs een toediening van 'n deklaag nie. Herhaalde toedienings mag wel so 'n invloed hê. Deklae of groenbemesting afkomstig van sesban of moerbei kan die watergebruiksdoeltreffendheid of opbrengs van *Avena sativa* (hawer), ten minste oor die kort temyn, verhoog.

Die moontlikheid om sulke deklae of groenbemesting aan te wend om 'n spesifieke probleem op te los, en nie net vir algemene grondverbetering nie, bestaan dus wel. Om dit, egter, effektief te doen sal dit nodig wees om te modelleer om sodoende die invloed van spesifieke deklae of groenbemesting, teen spesifieke toedieningspeile en -frekwensie, op die grondomgewing te bepaal.

CHAPTER 1

Prepared according to the guidelines of South African Journal of Plant and Soil.

Mulch and green manure, products of multipurpose trees, as low cost soil improvement strategies in agroforestry.[1]

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Mulching and green manuring are two soil improvement practices commonly found in agroforestry systems, especially in alley-cropping systems and variations thereof. Although the beneficial effects of a mulch or green manure within agroforestry systems is commonly recognised, these effects have not been quantified. Both the mulch and the green manure applications can influence the nutrient supply and the microclimate within the system. The possibility exists, therefore, that these applications can influence the potential productivity of an agroforestry system, where the local constraints are nutrient supply or water availability.

[1] Being part of a study for the degree M Sc. Agric. conducted by the first author under the supervision of the latter.

To quantify such effects on an agroforestry system, research will have to be orientated to a mechanistic understanding of the influence of mulches or green manures on the soil environment.

Keywords:Mulch, green manure, multipurpose trees.

INTRODUCTION

Agroforestry is: " the collective name for land use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) and/or livestock in a spatial arrangement, a rotation, or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system" (Young, 1989). This definition alone implies endless combinations and even more interactions. Although there is little factual information of the benefits of agroforestry systems, compared to other traditional land use systems, the potential of these systems is well recognised (Kiepe & Rao, 1994).

Furthermore, it is unfortunate that much of the reported research has been empirical and has often only involved the success of one system, and variations thereof, in a specific area. Research has largely been limited to alley farming systems in the humid areas with an annual rainfall greater than 1200 mm (Kang *et al.*, 1990). Very few attempts have been made to understand the soil moisture regime, the cycling of nutrients and the modification of the microclimate in alley cropping systems in arid and semi-arid conditions (Sauerhaft *et al.*, 1999). Kang *et al.* (1990) identified the need to facilitate synchronization of the woody component with crop growth and the pattern of nutrient uptake. Research should, therefore, be orientated to a mechanistic understanding of the processes involved rather than an empirical assessment of effect. An understanding of the interactions as stated in the abovementioned definition is, therefore, essential. This understanding of the modes of action and mechanisms of micro-climatic variations will enhance the ability to extrapolate results from trials to other areas and systems.

ALLEY-CROPPING

Alley-cropping is one of the most widely used and researched forms of agroforestry. It is also a very adaptable system. The ability to quantify the merits and limitations of agroforestry systems is mainly due to research in alley-cropping (Kang *et al*, 1990). This system developed as a result of a reduction in the available arable land (or an increase in the pressure on arable land, because of population growth), and the resulting decrease in the time allowed for fallow. Kang *et al* (1989), as quoted by Kang *et al* (1990), claims the alley-cropping technique can be considered as an improved bush-fallow system as it retains the basic features of the traditional bush fallow system. The trees in this agroforestry system perform the same function as the trees and shrubs in a fallow system. Although there are different variations of alley-cropping they all consist of trees planted in rows with other crops being cultivated between the rows. Alley-cropping is also sometimes referred to as avenue cropping or hedgerow intercropping (Kang *et al*, 1990) . The tree rows may be planted on the contour to reduce runoff in a system known as contour hedgerow intercropping (Kiepe & Rao, 1994). If the trees are planted on the perimeter of a small field the hedgerow may also serve as a living fence. Hedgerow intercropping is an alley-cropping system where clippings from the hedgerow trees are taken regularly and applied specifically to the soil in the alleys between the hedgerows where the intercrop is grown (Kiepe & Rao, 1994).

The basic components of the alley-cropping system are the inter-crop, that is able to grow between the trees, and the trees. These trees can be defined as multi-purpose trees (MPT's). Apart from a multitude of purposes, that these trees can and do fulfill, such as that of a windbreak, control of erosion, source of fuel-wood and poles, they are also a regular source of fresh plant material when they are pruned. These trees are pruned regularly to reduce the shading effect on the intercrop. The clippings can be utilised either as feed for livestock or as green manure or mulch. The short term economic advantage of the utilization of these clippings as fodder and feed is a powerful incentive for the farmer for the adoption of applicable agroforestry systems (Ali, 1999). The two alternative uses: mulch and fodder, implies a reciprocal opportunity cost (Kang *et al*, 1990). The advantages of applying the clippings as green manure or mulch are not so easily recognisable and usually not easily converted to monetary terms. To evaluate the opportunity cost of not applying the clippings as green manure or mulch, the effect that a mulch or green manure will have on the system will have to be quantified.

MULTI PURPOSE TREES AS SOIL IMPROVEMENT CROPS

There are a number of factors that enhance the value of multi-purpose trees as soil improvement crops. Many of the trees currently in use, and investigated as multi-purpose agroforestry trees, are legumes. Not only does this indicate soil improvement through nitrogen fixation but there are also indications of improvement in the soil phosphate availability (Bin, 1983). The trees can protect the soil against water- and wind erosion. The clippings from these trees can, also, be added to the soil as a mulch or as green manure.

The utilization of green manure and mulch

The principle of enriching soil with plant material in order to enhance agricultural production is not a new technology. 2100 years ago farmers in China encouraged weed growth during the winter which was worked into the soil for green manure to enhance subsequent grain yields. Specific crops were cultivated for the purpose of green manure as many as 1500 years ago in China (Bin, 1983).

The use of plant material as soil ameliorant seems to depend on different economical and practical constraints. Ali (1999) reported a significant decrease in the utilisation of green manure in Japan, Taiwan, India and the United States during the last three decades. This is ascribed to a greater increase in land and labour prices than inorganic fertilizer prices. In contrast, Gutteridge (1992) reported that increasing use was being made of leaf material from leguminous trees as a source of nutrients for crop growth in the tropics and sub-tropics. The reason for this is most probably the relative scarcity of chemical fertilizers, the lack of marketing infrastructure and the high cost of chemical fertiliser in these areas (Dakora & Keya, 1997).

Green manure

Ali (1999) defined green manure as: "... any plant or plant part produced exclusively to supplement, or substitute, nitrogen from mineral fertiliser..." For the purpose of this paper the definition of green manure will be refined further, as being plant material that is actively worked into the soil. This distinction is made because there are significant differences in the effects which plant material applied to the soil surface as a mulch or worked into the soil as a green manure, may have on the soil.

Mulch

"A mulch can be defined as any material on the soil surface through which continuous liquid water films from the soil are not present" (Wagner-Riddle *et al*, 1996). The most important principle inherent to this definition is that the conductance from the soil to the atmosphere is lower when the soil is covered with the mulch than when there is no mulch . The purpose of such a mulch would be to manipulate the micro-environment by preventing water loss through evaporation and by influencing the soil temperature (Wagner-Riddle *et al*, 1996).

CONCLUSION

Mathuva *et al.* (1998) reported that the nett benefit of an alley-cropping system, such as hedgerow intercropping, depends not only on the extent of the competition between the hedges and the crops, but also on the improvements in the water and nutrient balances. The ability of an alley-cropping system to improve yields depends on the local constraint. If the alley-cropping system can improve the nutrient cycling, where the local constraint is nutrient supply, or if the system can improve soil water availability, where the local constraint is water, the system could potentially increase the yield. Both the application of a mulch and green manure can influence the soil nutrient status, either directly through the nutrients released from the plant material to the soil or by enhancing the breakdown of organic material through increased temperature or microbial activity. The moisture status of the soil is also influenced by the application of a mulch and green manure by the reduction of runoff and evaporation by the mulch and increased infiltration by the green manure. It is, therefore, conceivable that the correct application of mulch, or green manure, could have a significant influence on the effectiveness of an alley-cropping system. Kiepe and Rao (1994) concluded that the addition of hedge clippings to the soil as a mulch is essential for the sustainability of the system. Although the influence of the soil improvement strategy has been identified, the extent of this effect and the factors which influence the extent of this effect have not as yet been studied in detail.

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CHAPTER 2

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Assessing the potential of two multi-purpose trees, *Morus alba* and *Sesbania sesban*, to produce green manure or mulch.[1]

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The choice of species is a very important factor which influences the effectiveness of the woody component in agroforestry systems, especially due to the cost and time implication of establishment of this component. *Sesbania sesban* (sesban) and *Morus alba* (mulberry) are both tree species that can produce material for fuel, fodder or soil amelioration purposes, in the form of green manure or mulch. The amount of above ground material produced by the trees will, however, vary with differences in environmental conditions, management practices and, possibly, accession and cultivar differences. Morphological differences between the species will influence the effect of soil amelioration practices where plant materials from the two trees are used.

[1] Being part of a study for the degree M Sc. Agric. conducted by the first author under the supervision of the latter.

To determine the quality of a mulch or green manure it is important that all aspects, which influence the soil environment, be studied and quantified. The purpose of the soil amelioration, whether it is to improve soil fertility, to increase water infiltration or reduce evaporation, must also be considered when determining the quality of the mulch since quality is a measure of how successful the method is in achieving the intended purpose. Plant material from trees which differ morphologically and in their nitrogen fixing capability, will have different effects on the soil environment. To determine the suitability of plant material, from a specific tree species, for soil amelioration it is necessary to determine what soil parameters will be influenced and to what extent.

Keywords: *Sesbania sesban*, *Morus alba*, agroforestry, mulch, green manure

INTRODUCTION

The success of an agroforestry system depends on a wide range of factors varying from management practices to environmental constraints. These factors interact with, and influence each other. One very important consideration when implementing an agroforestry system is the choice of species. Although the choice of all the relevant species should be considered as important, the woody component will probably be considered paramount. The trees incorporated into an agroforestry system is usually, but not always, perennial, while the other crop or crops may be annuals or perennials. The tree component can be replaced at great cost and with considerable impact, as a result of the time implication of such a replacement, on the productivity of the system.

Most of the trees used in agroforestry systems will not realize their full production potential within the first season, thus limiting the productive potential of the system for the first few years. The crop component may be replaced annually as a matter of practice.

Many tree species have either been used in agroforestry systems or have been identified as being suitable for use in agroforestry. These trees exhibit a range of adaptations, tolerances and susceptibilities. When choosing a tree for a system in a specific environment these characteristics will serve as selection criteria. In addition, management and utilisation practices must also be considered when choosing a tree species. Even though two species might show the same adaptation to a certain environment one might tolerate direct grazing better than the other, while the other is better adapted for a cut and carry system.

Sesbania sesban (sesban) is a tree that has been used and has been evaluated as an agroforestry tree in different systems. The white mulberry (*Morus alba*), in contrast, is relatively unknown -apart from its role in the silkworm industry and a few studies reporting on its use as a multipurpose tree in areas of Tanzania. The aim of this study is to review the white mulberry and sesban as possible agroforestry species with special reference to the production of plant material that can be utilised for soil amelioration in the form of green manure or mulch. To determine the environmental adaptation the current distribution and areas of cultivation will be assessed. Observations made during a field trial will indicate the ease of establishment of the mulberry while a literature survey and a germination trial will demonstrate the viability of sesban seeds. Most research, concerning these two species and, in fact, most agroforestry species, has been directed towards their value as animal feed and not towards the production of plant material for soil amelioration. An evaluation of these studies will indicate the factors that can influence the production and quality of the plant material produced.

ENVIRONMENTAL ADAPTATION AND GEOGRAPHICAL DISTRIBUTION

Sesban is well adapted to a range of circumstances and is distributed through tropical and subtropical parts of Africa, Asia (Gutteridge, 1995; Evans, 1994) and Australia (Evans,1994). *Sesbania sesban* (L.) Merr subs *sesban* variety *nubica* is indigenous to the eastern parts of the Northern Province, Mpumalanga and Kwazulu Natal occurring mostly in low lying areas and near watercourses (Palgrave, 1977; Palmer & Pitman, 1972). Although tolerant of a variety of adverse conditions, including periodic water logging, periodic flooding, alkaline and acidic soils (Evans, 1994), a lack of longevity is seen as one of the most limiting factors regarding the use of Sesban as a fodder tree (Karachi & Matata, 1997). In South Africa the lifespan of sesban is limited to two to three years in its natural habitat (Pooley, 1993). A sensitivity to low temperatures and especially frost (Evans,1994) is seen as a major cause for this lack of longevity.

Very little has been published about the geographical distribution of the white mulberry in South Africa. The only indication to the environmental adaptation can be found in the studies concerning the mulberry as an invasive species. The white mulberry is a prominent weed species in the savannah- and grassland biomes in Mpumalanga, Kwazulu-Natal and the eastern Free State (Versveld *et al*, 1998). The mulberry is also found along the forest margins of what was formerly known as the Transvaal, now Northern Province, Mpumalanga, North West and Gauteng, but is not dispersed widely (Geldenhuys *et al*,1986). The rainfall in grassland and savannah biomes varies from a minimum of 300mm - 600 mm p. a. to a maximum of 1 500 p. a. (Henderson, 1989). In the study by Henderson (1989) there was only one veld type where white mulberry was not detected: temperate grassland. This veld type is situated at an elevation of 1500 m to 3000m and is the coldest area in southern Africa. The rainfall here is abundant (700 mm p.a. to 1000 mm p.a.). Cold is, therefore, the most likely restrictive factor. The white mulberry is only mentioned as an invasive alien in areas in South Africa with a rainfall higher than 600 mm p.a. From the abovementioned it is possible to conclude that the white mulberry is susceptible to severe cold and to dry conditions.

INVASIVE POTENTIAL

Although *Sesbania sesban* is indigenous to South Africa, occurring naturally in parts of the Northern Province and Kwazulu-Natal, if it should be considered for introduction into other areas, its potential as an invasive species should be considered. Sesban produces a large amount of hard coated seeds. These seeds can survive for long periods in the soil, resulting in the buildup of a large seedbank that can survive for long periods. The buildup of this seedbank should be controlled to suppress the potential invasiveness of sesban. It has been observed that when sesban was planted late in the growing season in Pretoria very little seed was produced. In areas where frosts occur, and sesban is consequently restricted to an annual growth pattern, the time of planting could, therefore, be manipulated to minimize seed production. This strategy to reduce the invasive potential of sesban should, however, be evaluated on a larger scale before being recommended.

The white mulberry is already regarded as a weed in the savannah and grassland biomes of Mpumalanga, Kwazulu-Natal and the eastern Free State (Versveld *et al*, 1998). Although the white mulberry is able to grow and reproduce on the forest margins of what was formerly known as the Transvaal, now Northern Province, Mpumalanga, North West and Gauteng, it is not widely dispersed (Geldenhuys *et al*,1986). Frugivores are mainly responsible for distribution of mulberry in this area. No strategy has, as yet, been formulated to control or eradicate the mulberry.

EASE OF ESTABLISHMENT

Both species have been noted for their ease of establishment, but they are, however, established quite differently. Many species currently being studied, or used as multi-purpose trees, including *Sesbania sesban* have seeds with very hard seedcoats. This is a dormancy mechanism that ensures long term survival of seeds. If these seeds are planted without any treatment a very low germination rate would occur. It is, therefore, important to pre-treat seeds to break seedcoat induced dormancy before planting. This seed pre-treatment is a form of scarification to break the seed coat, without injuring the seed. The effectiveness of two basic seed pre-treatments, as recommended by the Nitrogen Fixing Tree Association, or NFTA (Nitrogen Fixing Tree Association)

(1990a,b), and variations of these methods were evaluated in the local programme. Two basic treatments and variations thereof were evaluated.

Hot water treatment

The hot water treatment recommended by the NFTA was used as a control (Nitrogen Fixing Tree Association) (1990a). This method consists of a volume of boiling water at least five times the volume of the seeds poured over the seeds. The seeds were left in the water for a period of twenty four hours and allowed to cool. The control will be referred to as the cool down method. Three other hot water treatments were tested. Again a volume of boiling water at least five times the volume of the seeds was poured over the seeds but the seeds were kept immersed in the hot water for only: one minute, two minutes or four minutes respectively. The hot water was then drained off and the seeds were covered with cold tapwater for the remainder of the twenty four hours. At the end of the twenty four hours the seeds were placed in the petri dishes in the growth cabinets. A germination rate of nearly 70% or more were achieved with all the hot water treatments, except the two minute immersion in hot water. The cool down method, being relatively simple and easy, as well as being very effective, is recommended for the scarification of sesban seeds.

Sulphuric acid treatments

Four different acid treatments were evaluated. The seeds were covered with concentrated sulphuric acid for either fifteen, thirty, sixty or a hundred and twenty minutes. The seeds were then rinsed with clean water and placed in water for twenty four hours to imbibe before they were placed in the petri dishes in the growth cabinets for the remainder of the trial. Although relatively good results were achieved with the sulphuric acid, and especially the two hour treatment, this method is not recommended for two reasons. Firstly: sulphuric acid can be a dangerous substance if handled improperly and it could be difficult and expensive to obtain, especially in rural areas. Hot water can also be dangerous when handled improperly, but a handler could be expected to have some experience with hot water. It is also cheap and relatively easy to obtain. Secondly: although good germination rates were achieved with the sulphuric acid, a high incidence of fungal infection occurred on these seeds during germination. This could be attributed to the fact that the integrity of the whole seedcoat was compromised by the acid treatment, while the hot water will only crack the seedcoat at specific places.

Morus alba can be propagated vegetatively, by means of cuttings or by grafting or it can be propagated using seed (Kruger *et al*, 1995). Cuttings are made from regrowth that is approximately six weeks old. The following method has been recommended by Kruger *et al* (1995): Cuttings should be long enough to include at least five buds. These cuttings are then planted directly into the soil, with two buds below the soil surface. These cuttings could also be planted into bags and then transplanted into the field when rooting has occurred (Shayo, 1997)

Mulberry cuttings from four different cultivars were planted *in situ* on the Hatfield Experimental Farm. Cuttings were obtained from Tsakane Silk Farm situated in the Bosbokrand area of the Northern Province. The two most prominent cultivars that had been used on the farm were Waterkloof and Noi. Tai shang and another cultivar (identified only as "a chinese cultivar") have also been used on a small scale on this farm. None of the cuttings from the chinese cultivar or Tai shang survived in Pretoria, however. The cuttings from these two cultivars were, however, made from relatively young stems that had not yet turned woody and this could be the cause of their failure. Waterkloof had a survival rate of 80 %, while Noi had a survival rate of 44%. Cuttings from Noi and Waterkloof were made from wood that had already turned woody. The maturity of the stems from which cuttings are made, as well as cultivar, therefore, influences the survival rate of cuttings during the establishment phase. The optimum age of the cuttings had not been determined but using cuttings that had already become woody, but had not yet started to form secondary branches, yielded successful results.

FACTORS INFLUENCING THE BIOMASS PRODUCTION

The production potential of the trees that are envisaged for mulch and/or green manure production will definitely influence their suitability. There are conflicting reports on the production potential of *Sesbania sesban*. Although Evans (1994) reported an experimental yield of fodder cuttings of 20/tons/ha dry matter in the first year alone, Gutteridge (1995) could only find evidence in the literature of yields ranging from four to 18 tons. Very little, apart from studies conducted in Central Tanzania (Shayo, 1997), has been reported on the use of mulberry for agroforestry purposes. It is clear from these reports that estimating a possible yield for trees in agroforestry systems is almost impossible without modelling. Although no examples could be found in the existing literature of attempts to model the growth and yield of sesban an evaluation of the literature identified those factors that can influence the production potential of sesban. The factors that influence the production of sesban can be divided into three broad categories namely the plant itself, environmental factors, which include climatic and soil characteristics, and managerial practices.

Gutteridge (1995) stated that the five varieties of sesban, that are recognized botanically, do not differ in agricultural value. In a study by Karachi and Matata (1997) accession was recognised as a very important determinant of yield potential. Further research into the effect of accession or cultivar is, therefore, needed. The environmental conditions conducive to the growth of sesban have been discussed in the section concerning the environmental adaptation, geographical distribution and applications. The importance of climatic and soil factors in determining the growth and development of plants has been well researched and documented and will not be emphasized here. It is important, however, to realise that, when sesban is produced outside a natural ecosystem, the effect of environmental factors may be overshadowed by managerial practice, as can be seen from the following example.

Jama *et al* (1998) conducted a study in Kenya to evaluate the effect of sesban tree fallows on maize yield on two phosphorous-deficient sites. The standing biomass production differed between these two sites, more material being produced at the lower rainfall site than the higher rainfall site. Jama *et al* (1998) attributed this difference to three factors: establishment method, plant spacing and differences in the P status. The trees that were planted as seedlings also had a higher initial growth rate than those planted by relay sowing. The evenly spaced (1 m by 1 m grid) trees also had a significantly higher standing biomass production than where the rows were spaced 2.25 m apart. There was also a difference in P status with a higher P deficiency exhibited at the site with the lowest biomass production. Soil moisture was not the most limiting factor in the abovementioned study. Shayo (1997) also found that the optimum spacing for the mulberry varied between different study sites and that biomass production was influenced significantly by plant spacing. The optimum spacing will have to be determined for each specific environment. Other possible factors that could influence production potential of the trees should be investigated before a conceptual model can be developed.

FACTORS INFLUENCING THE QUALITY OF THE MULCH OR GREEN MANURE

Green manure and mulch are not cash crops and the value of these crops are, therefore, not easy to determine. There will, however, always be an opportunity cost linked to the production of the mulch or green manure. These opportunity costs can be seen as the loss in income incurred by devoting the area of land to these crops cultivated for the purpose of soil improvement rather than using it for the production of cash or fodder crops. By applying the plant material to the soil as ameliorant rather than using it for other purposes, such as feed or fodder for livestock, can also be seen as opportunity costs incurred. The latter type of opportunity cost is linked to the suitability of this material for the purpose for which it is being used compared to the suitability of the material for the purpose for which it could have been used. Assessing a certain crop for its suitability as green manure or mulch from this perspective will have to deal with the effect that this material can have on the soil and the resulting influence on the production potential of the soil.

To define quality in relation to mulch it would be necessary to determine the factors that affects the effectiveness of the mulch for the purpose it is intended. The purpose that is most cited is the use of mulch as a source of nitrogen. If the only reason for applying a mulch is to supply nutrients to the follow-up- or inter-crop it is possible to define the quality of the mulch in terms of the amount of the specific nutrient applied to the soil. It is, however, not so simple. A mulch or green manure can influence the soil in a multitude of other ways. A mulch may alter the surface properties while a green manure may alter soil structure in such a way that soil temperature, moisture interception, -infiltration and -runoff may be influenced. An alteration in the physical soil properties can also influence other soil parameters such as the microbial activity of the soil. It is, therefore, necessary to assess the affect that the mulch can have on all of the soil physical parameters as well as soil fertility status in order to determine the quality of the mulch.

The properties of the material that will be used for the green manure, or mulch, will vary greatly from species to species. Factors such as the ability to fix nitrogen and even to assimilate other nutrients vary from species to species and, therefore, the potential of a species to recycle nutrients and supply nutrients to the soil, when applied as a mulch, or green manure. Morphological differences in the leaves such as leaf size and shape will influence the ability of a mulch to alter soil surface hydrological factors such as the prevention of runoff, evaporation from the soil surface or raindrop impact on the soil surface.

While sesban, as a legume, has the ability to fix nitrogen, the mulberry cannot, theoretically, fix nitrogen. The leaves of the mulberry are singular and large. Sesban, in contrast, has compound leaves with small leaflets. It is, therefore, reasonable to assume that a mulch, or green manure, from these two tree species will have different effects.

CONCLUSION

The natural distribution of sesban and the spread of the mulberry indicate that both of these trees are well adapted to a range of environments in South Africa. The most limiting factors to the spread of these trees are low temperatures, frost and a rainfall of less than 600 mm p.a for the mulberry and 500 mm p.a for sesban. Although establishment practices differ greatly between sesban, which is established by seed, and mulberry, which is established vegetatively, both of these trees are easily established.

The yields that have been reported in the literature, for these two tree species, indicate that both are capable of producing enough material to utilize as a mulch or green manure. It is, however, clear that the yield of both varies greatly and that many factors, including genotype, environment and management can influence the yield. Plant spacing has already been identified as an important determinant of production. Soil fertility and establishment practices also influence the production of sesban. These factors interact with other managerial and environmental factors to determine the production potential. The effect of all of these parameters as well as their influence on each other has not, as yet, been quantified. It is, therefore, recommended that a detailed study into the effect of environmental factors and managerial factors be conducted to facilitate the modelling of the growth and development of the trees in order to predict potential yield capacity for specific environments and managerial regimes.

The structure of mulch and green manure from either species will vary as a result of the morphological differences between the two tree species. Soil amelioration with plant material from the two tree species will, therefore, differ. It is, therefore, recommended that, in order to determine the influence of a mulch or green manure, consisting of plant material from either of the tree species, the effect of these soil amelioration practices be evaluated in terms of their influence on soil physical properties such as temperature and soil hydrology as well as soil fertility.

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CHAPTER 3

Prepared according to the guidelines of South African Journal of Plant and Soil

Seed treatment techniques to break seed coat imposed dormancy in various multi-purpose trees.[1]

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Many multi-purpose trees, including *Sesbania sesban* have seeds with very hard seedcoats, a dormancy mechanism that ensures long term survival of seeds. If these seeds are planted without any treatment a very low germination rate would occur. The effectiveness of two basic seed pretreatments, to break the seed coat and, therefore, enhance germination rate, as recommended by the Nitrogen Fixing Tree Association, or NFTA, and variations of these methods were evaluated in the local programme. Seeds from different species responded differently to the treatments. A general recommendation for these trees is, therefore, impossible.

[1] Being part of a study for the degree M Sc. Agric. conducted by the first author under the supervision of the latter.

To find the best seed treatment for breaking seedcoat imposed dormancy, species should be assessed individually.

Keywords: Seed pre-treatment, multi-purpose trees

INTRODUCTION

Many species currently being studied, or used as multi-purpose trees, including *Sesbania sesban* have seeds with very hard seedcoats. This is a dormancy mechanism that ensures long term survival of seeds. If these seeds are planted without any treatment a very low germination rate would occur. It is, therefore, important to pre-treat seeds to break seedcoat induced dormancy before planting. This seed pre-treatment is a form of scarification to break the seed coat, without injuring the seed. The effectiveness of two basic seed pre-treatments, as recommended by the Nitrogen Fixing Tree Association, or NFTA, (1990a,b) and variations of these methods were evaluated in the local programme.

Two basic treatments and variations thereof were evaluated: Hot water treatments were tested on *Leucaena leucocephala*, *Leucaena pulverulenta*, *Leucaena diversifolia*, *Calliandra calothyrsus* and *Sesbania sesban*. Acid treatments, also recommended by the NFTA (1990a), were tested on *C. calothyrsus*, *Cassia sturtii*, *Gledistia triacanthos* and *S. sesban*.

MATERIALS AND METHODS

After the pre-treatments were applied the seeds were kept in a growth cabinet. The temperatures within the growth cabinet were set at a night-time temperature of 17°C and a daytime temperature of 27°C. The seeds were not exposed to light except for the period during which they were evaluated.

Each replicate consisted of 25 seeds of the relevant specie placed in a petri dish on wet filter paper. The filter paper was kept wet using tap water. The replicates were arranged according to a complete randomized design. Each treatment was replicated three times.

Hot water trial

The hot water treatment as recommended by the NFTA was used as a control. This method consists of a volume of boiling water at least five times the volume of the seeds poured over the seeds. The seeds were left in the water for a period of twenty four hours and allowed to cool. The control will be referred to as the cool down method. Three other hot water treatments were tested. Again a volume of boiling water at least five times the volume of the seeds was poured over the seeds but the seeds were kept immersed in the hot water for only one minute, two minutes or four minutes respectively. The hot water was then drained off and the seeds were covered with cold tapwater for the remainder of the twenty four hours. At the end of the twenty four hours the seeds were placed in the petri dishes in the growth cabinets. Each treatment was replicated three times.

Sulphuric acid trial

Four different acid treatments were evaluated. The seeds were covered with concentrated sulphuric acid for either fifteen, thirty, sixty or a hundred and twenty minutes. The seeds were then rinsed with clean water and placed in water for twenty four hours to imbibe before they were placed in the petri dishes in the growth cabinets for the remainder of the trial.

RESULTS AND DISCUSSION

The results of these trials are illustrated for each species seperately. A significance level of $p<0.05$ was used throughout the trial.

Hot water trial

No significant differences were obtained between treatments with *Lucaena diversifolia* or *Calliandra calothyrsus*. The average percentage germination of the *L. diversifolia* seeds were 76.67% while *C. calothyrsus* had a much lower average germination of 44.33%. The sensitivity to treatment of the other species varied between species. For example: *L. pulverulenta* (Fig. 2) responded differently to the different hot water treatments while there had been no significant differences in the responses of *L. diversifolia* seeds to the different hot water treatments.

For *L. leucocephala* both the two minute hot water treatment and the cool down method yielded good results (Fig. 1). The cool down and two minute hot water treatments also yielded significantly better results with *L. pulverulenta* than the one and four minute hot water treatments (Fig. 2). Any of the hot water treatments can be recommended for *L.diversifolia* while none of them gave good results with *C. calothyrsus*. *S. sesban* seeds responded best to the cool down treatment, although the one and four minute treatments did not differ significantly from the former. The two minute treatment was the poorest (Fig. 3).

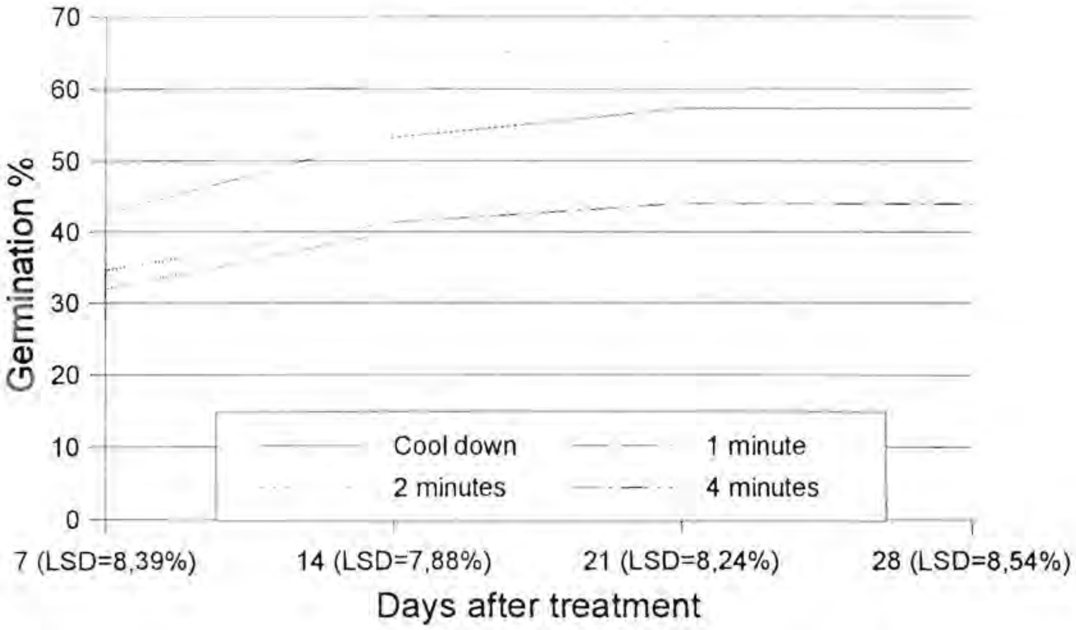

Fig.1 The germination of *L. leucocephala* seeds in response to different durations of immersion in hot water as seed pre-treatment.

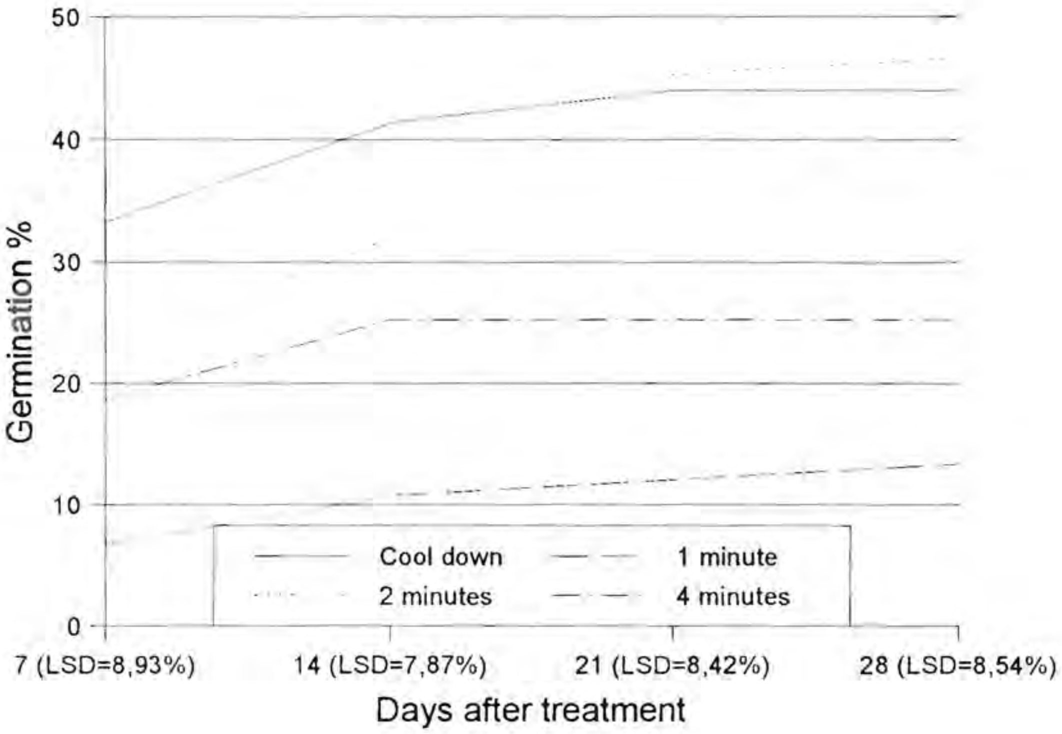

Fig.2 The germination of *L. pulverulenta* seeds in response to different durations of immersion in hot water as seed pre-treatment.

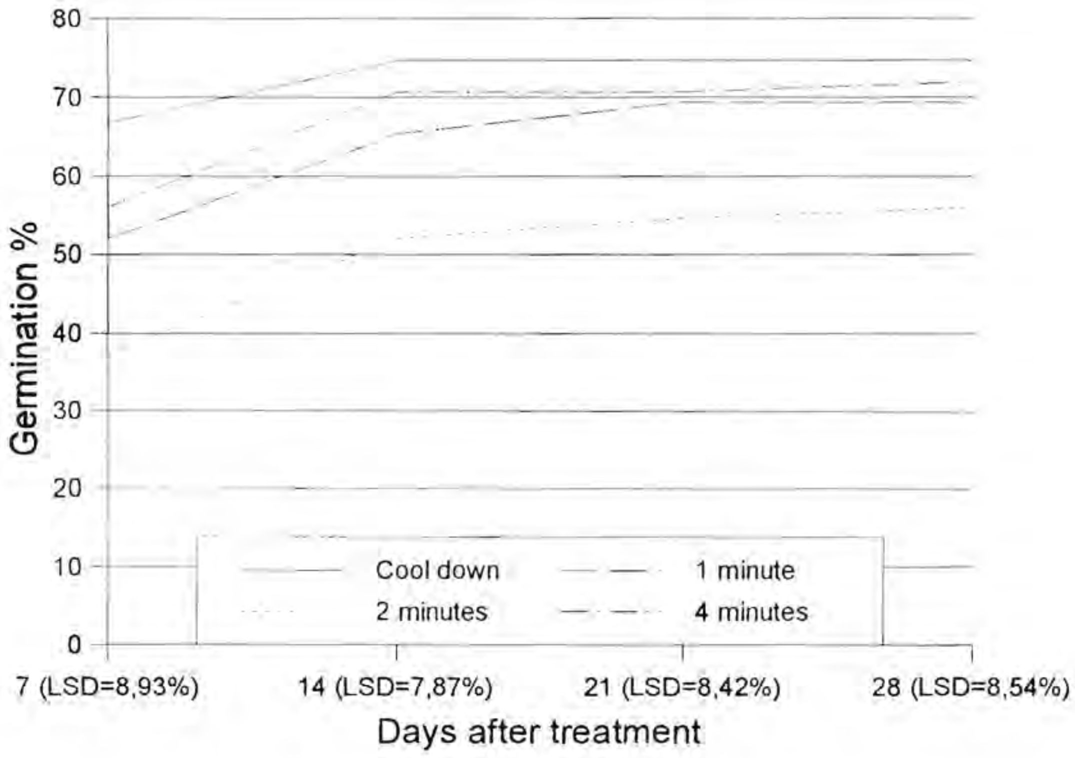

Fig.3 The germination of *S. sesban* seeds in response to different durations of immersion in hot water as seed pre-treatment.

Sulphuric acid trial

No significant differences between acid treatments were obtained with *Cassia sturtii* or *Gledistia triacanthos*. While the average germination of *C. sturtii* was 72.67%, *G. triacanthos* had a very low percentage germination of only 6,50%. Although moderate to good germination rates were achieved with *C. calothyrsus* and *S. sesban* with the sulphuric acid treatments (Figs. 4 and 5) a high incidence of fungal infection occurred on these seeds and the trial was, consequently, stopped after only six days. This high rate of contamination, relative to the hot water treatments, could be attributed to the fact that the integrity of the whole seedcoat was compromised by the acid treatment, while the hot water only cracked the seedcoat at specific places. *C. sturtii* responded very well to all of the acid treatments with an average germination in excess of 70%.

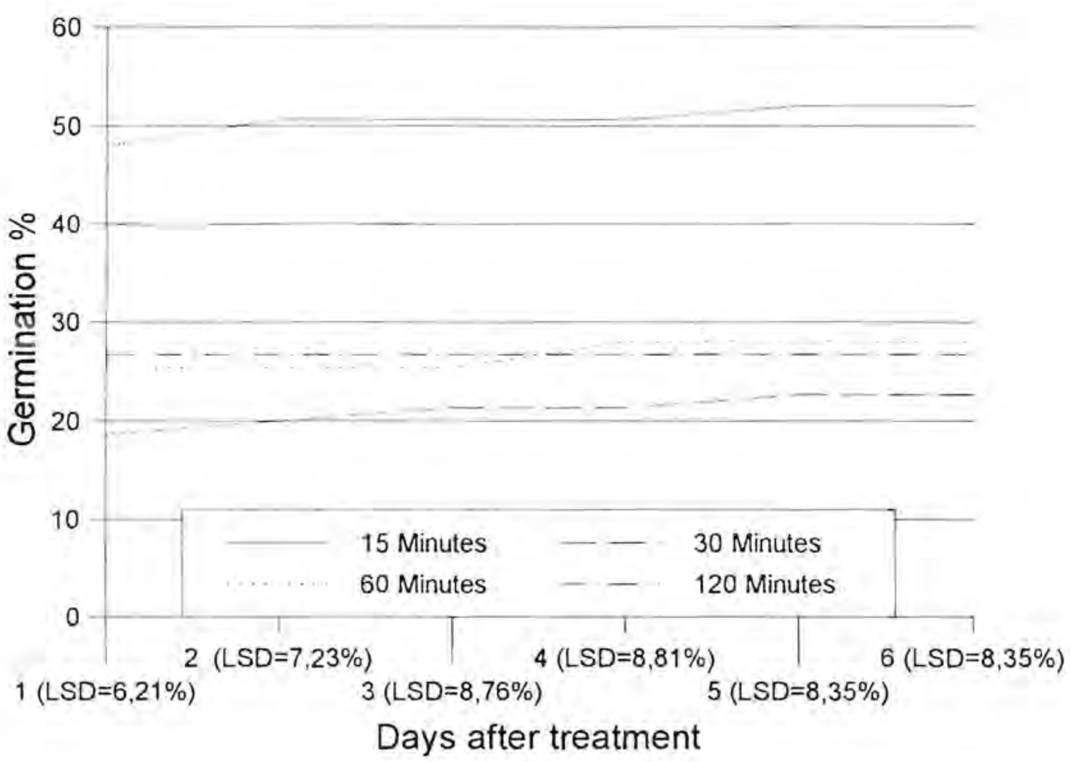

Fig.4 The germination of *C. calothyrsus* seeds in response to different durations of immersion in sulphuric acid as seed pre-treatment.

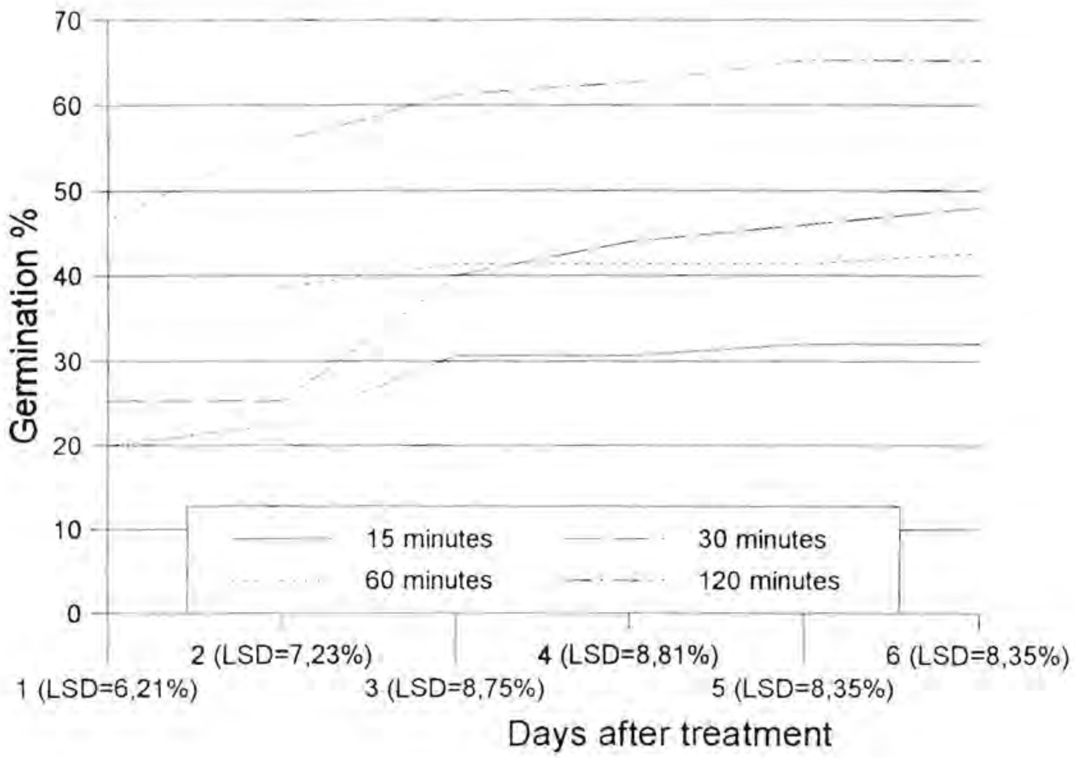

Fig.5 The germination of *S. sesban* seeds in response to different durations of immersion in sulphuric acid as seed pre-treatment.

CONCLUSIONS

Seeds from different species responded differently to the treatments. The hot water, cool down method is recommended for seeds of *Leucaena leucocephala*, *Leucaena pulverulenta*, *Leucaena diversifolia* and *Sesbania sesban*. This method yielded good results and is easy to implement. Any of the acid treatments is adequate for the treatment of *Cassia sturtii* seeds. None of the acid treatments were successful in breaking seed coat induced dormancy of *Gledistia triacanthos* seeds. *Calliandra calothyrsus* did not respond to the hot water treatments and even though good results were achieved with sulphuric acid fungal contamination was a problem. A recommendation for *Gledistia triacanthos* and *Calliandra calothyrsus*, regarding seed treatment, is therefore impossible.

To find the best seed treatment for breaking seedcoat-imposed dormancy species should be assessed individually. The problem of fungal contamination when treating seeds with sulphuric acid should be investigated.

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CHAPTER 4

Prepared according to the guidelines of South African Journal of Plant and Soil.

The short term effects of two multipurpose tree mulches: The microbial activity in the soil.[1]

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The influence of any soil management activity can be analysed physically and chemically. The biological component should, however, also be evaluated as, together with the physical and chemical components, it plays a very important role in the quality of the soil. The rate of hydrolysis of fluorescein diacetate was determined as an indication of microbial activity in soil amended with a mulch consisting of either *Morus alba* or *Sesbania sesban* plant material. The effects of both of these mulches on the microbial activity of the soil were very short lived indicating a specific capacity of the soil to sustain enzyme activity that was only temporarily changed.

[1] Being part of a study for the degree M Sc. Agric. conducted by the first author under the supervision of the latter.

Six weeks after application the two mulches had opposite effects on the soil microbial activity: the *Morus alba* mulch stimulated microbial activity while the *Sesbania sesban* mulch inhibited microbial activity. Although the mulches were able to influence the microbial activity in the soil the effects were only temporary and could only be detected up to a depth of 100 mm.

Keywords: Mulch, green manure, microbial activity, *Sesbania sesban*, *Morus alba*

INTRODUCTION

Soil quality or soil health are concepts that are very difficult to quantify, yet there can be little dispute over the importance of these concepts. The quality of the soil consists not only of the chemical and physical components but also of a biological component (Kennedy & Smith, 1995). These components do not occur and function separately. Kennedy and Smith (1995) defined soil as a: "complex interrelated community of soil organisms, which influence, yet are in part determined by the chemical and physical parameters of the soil."

Soil health was defined by Doran and Parkin (1994), as quoted by Bandick & Dick (1999), as: "the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health." If the functions of the biological component of soil are considered: soil humus formation, maintenance of soil tilth and structure (Lynch & Bragg, 1985) and the recycling of nutrients (Lynch & Bragg, 1985); it is not surprising that the measurement of soil biological activity has been suggested and evaluated as an indication of soil health (Bandick & Dick, 1999). The microbial portion of the soil is further highlighted, by Kennedy and Smith (1995), as an important determinant of sustainability and ecosystem functioning.

Dehydrogenase activity is an easily determinable factor. Apart from being relatively simple and cheap there are other factors that confirm and endorse the suitability of this soil enzyme as an indicator of soil microbial action. There is a general acceptance that soil enzymes are mostly derived from micro-organisms (Ladd, 1978). Nannipeiri *et al.* (1983) reported that fluctuations in soil enzyme activity followed the same pattern as the microbial biomass, as influenced by the addition of glucose to the soil. Soil enzymes, however, are not only the product of microbes but can also be derived from plant material added to the soil (Martens *et al.* 1992). Dehydrogenases, however, are intracellular (Bolton *et al.*, 1985; Ladd, 1978) and are "mainly related to microbial respiratory processes" (Bolton *et al.* 1985). Dehydrogenase activity can, therefore, be seen as a good indicator of microbial activity.

Mulches can influence the soil moisture content, the soil temperature as well as the nutrient status of the soil. Apart from the direct influences these effects may have on accompanying crops, it is also possible that they may influence micro-organisms in the soil.

It is hypothesized that the application of a mulch would increase the enzyme activity in the soil, at least during decomposition and the period of microbial breakdown of the plant material. The objectives of this study were, therefore, to determine whether a freshly deposited mulch would influence the microbial activity in the soil? To what extent would this happen and whether there were temporal and qualitative differences in the effects due to differences in the origin of the mulch?

MATERIALS AND METHODS

Site

The trial was conducted at the Hatfield Experimental Farm(25°45'S 28°16'E, 1327m above see level). The uniform red Hutton soil (Soil Classification Working Group, 1991) had been cultivated for at least ten years prior to the investigation. The natural rainfall was supplemented with irrigation as required.

Design

The design was analysed as a 3x5 factorial with three replications. The three mulching treatments T_1 -T_3 (see "Layout") and the five sampling periods S_1 -S_5 (see "Layout") constituted the factors. An analysis of variance was conducted using a SAS (1996) package. Significant differences were determined using a standard t-test where a $p<0.05$ indicated significance

Layout

The site consisted of three blocks, 2m x 8m, each being a replication. Each block was divided into 16 plots of 1 m^2. One plot in each block was discarded for the purpose of this trial. The remaining 15 plots were made up of five sampling periods (S_1-S_5) and three mulch treatments (T_1-T_3).

The treatments were as follows:

T1: No mulch

T2: *Sesbania sesban* mulch (applied, fresh, to the equivalent of 5 tons dry matter / hectare)

T3: *Morus alba* mulch (applied, fresh, to the equivalent of 5 tons dry matter / hectare)

Sampling periods were as follows:

S_1: 13 April 1999 (2 weeks after emergence of the test crop).

S_2: 27 April 1999 (4 weeks after emergence of the test crop).

S_3: 11 May 1999 (6 weeks after emergence of the test crop).

S_4: 18 May 1999 (8 weeks after emergence of the test crop).

S_5: 25 May 1999 (10 weeks after emergence of the test crop).

Four rows, 20 cm apart, of the test crop, *Sorghum bicolor* (Sorghum) were planted in each plot. The plants were thinned to twenty plants per plot (five plants per row) one week after emergence. At each sampling date a new plot of T_1, T_2 and T_3, in each replicate was sampled destructively for soil moisture, microbial activity and plant yield.

Observations

Soil moisture

Gravimetric assessments of moisture content of samples taken from horizons 0mm - 100mm and 100mm -200mm of T_1, T_2, T_3 and the control plot, were done at each sampling date.

Microbial activity

The hydrogenase activity in the soil was assessed at the start of the trial and at each sampling date (S_1-S_5) on T_1, T_2, T_3. Samples were taken at two depths (0mm-100mm and 100mm-200mm). The hydrogenase activity was determined by measuring the rate of hydrolysis of fluorescein diacetate (FDA) as described by Inbar, *et al* (1991).

Plant production

Plant yields from T_1, T_2, T_3 and the control plot were determined at each sampling date by harvesting the above ground parts of the plants (harvested at ground level). The dry matter content (DM) of harvested material was determined by drying to a constant mass, to facilitate the calculation of DM yields.

RESULTS AND DISCUSSION

Plantproduction

No statistical evidence to indicate the influence of the mulches on the DM yield of the sorghum was found.

Microbial activity

From figures 1 and 2 it is clear that the influence of the mulch on the enzyme activity of the soil is only detectable up to a depth of 100 mm. This difference was only significant at the sixth week sampling period. At this time there was a significantly higher rate of FDA hydrolysis where the mulberry mulch was applied compared to the control. In contrast there was a significantly lower level of FDA hydrolysis where the Sesban mulch was applied compared to the control. Ross (1971), as reported by Bolton *et al* (1985), indicated that dehydrogenase activity could be linked to the microbial activity associated with the initial breakdown of organic matter. This indicates a very rapid rate of organic matter decomposition of the *Morus alba* mulch, with a peak rate of decomposition at six weeks after application, with a return to normal levels of enzyme activity at 10 weeks. Martens *et al.* (1992) concluded that certain organic amendments could inhibit the activity of soil enzymes and this can be seen as a possible explanation for the lower level of enzyme activity where the Sesban mulch was applied, especially at six weeks after planting.

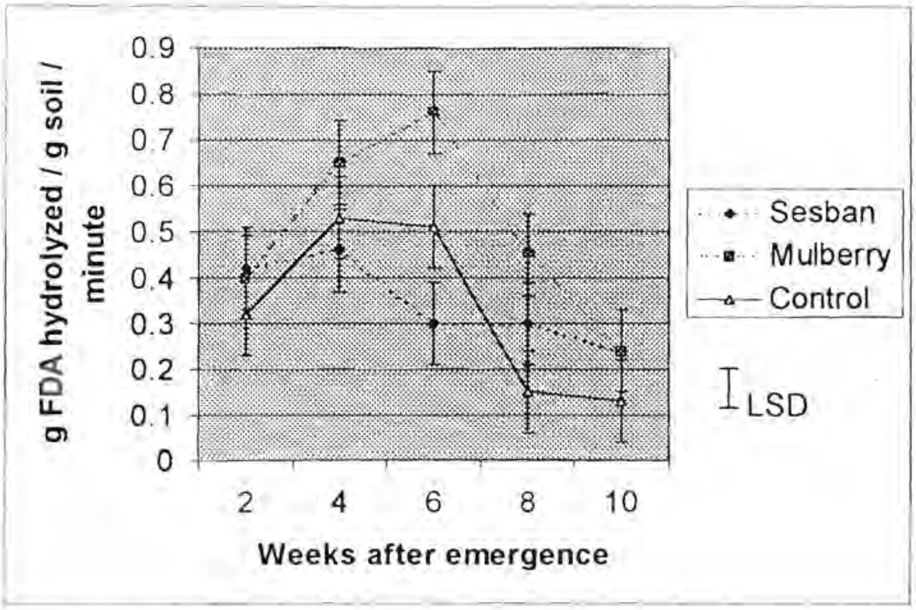

Fig. 1. The rate of FDA hydrolysis in the first 100 mm of soil, taken underneath the Sesban-mulch and the Mulberry-mulch, compared to a control of bare soil, at each sampling period.

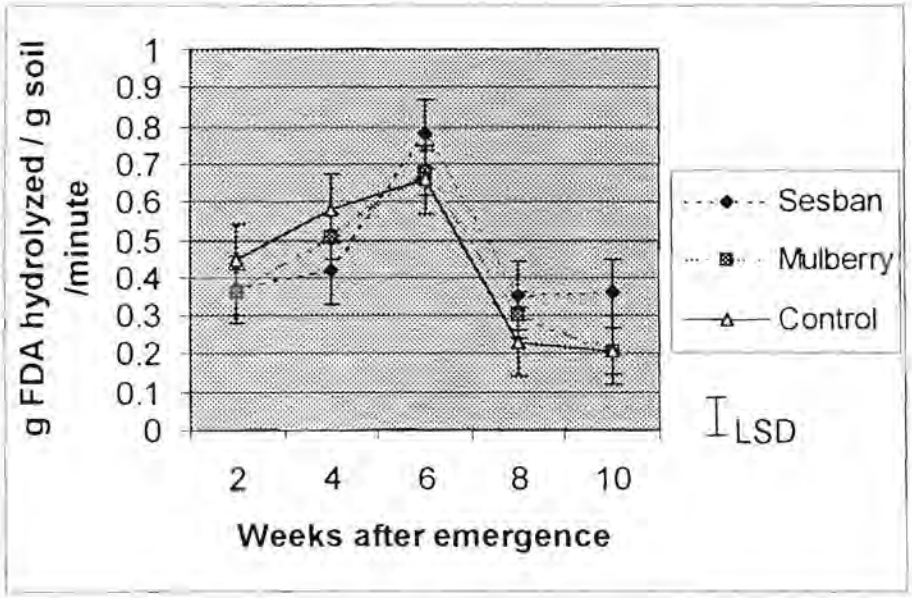

Fig. 2. The rate of FDA hydrolysis in the soil, taken from the 100 mm-200 mm soil layer, underneath the Sesban-mulch and the Mulberry mulch, compared to a control of uncovered soil, at each sampling period.

Soil water content

If we consider the pattern of enzyme activity over time, as evident in the control as well as at the 100 mm - 200 mm depth, where no significant differences were detected, we can assume that other factors had a much greater influence on the enzyme activity in the soil than the application of the mulch. Temperature and precipitation can, for example, influence the microbiological activity in the soil (Bandick & Dick, 1999). There were, however, no significant differences in soil water content between treatments in this trial. The pattern of gravimetric water content displayed in figures 3 and 4 does not correlate with the pattern of enzyme activity as displayed in, respectively, figures 1 and 2 . The soil moisture had, therefore, no apparent effect on the enzyme activity in the soil under these circumstances. Although the effect of the different mulches on the soil temperature is discussed in depth in chapter 5, no conclusions concerning the effect of soil temperature, as influenced by a mulch, on microbial activity can be made.

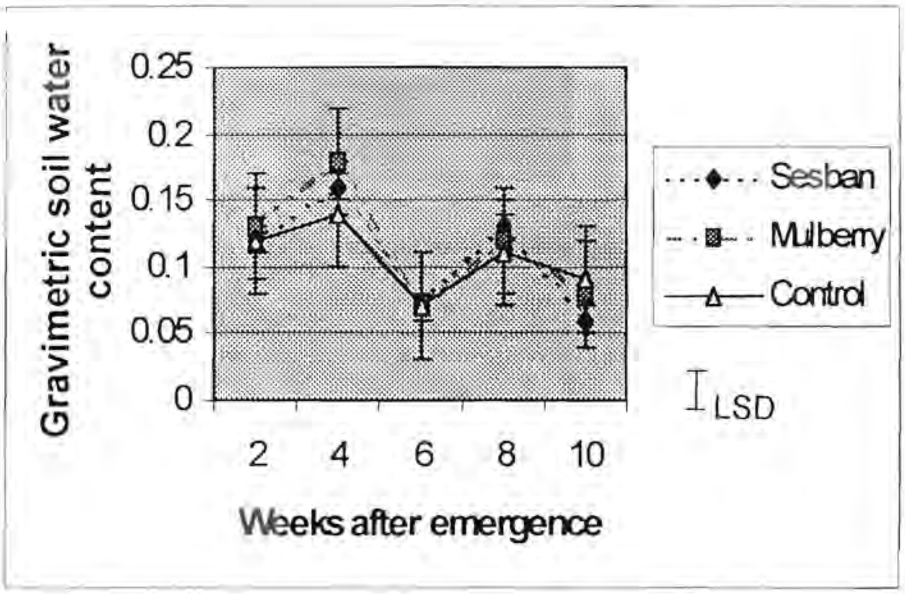

Fig. 3. The gravimetric soil water content of the top 100 mm of soil at each sampling period.

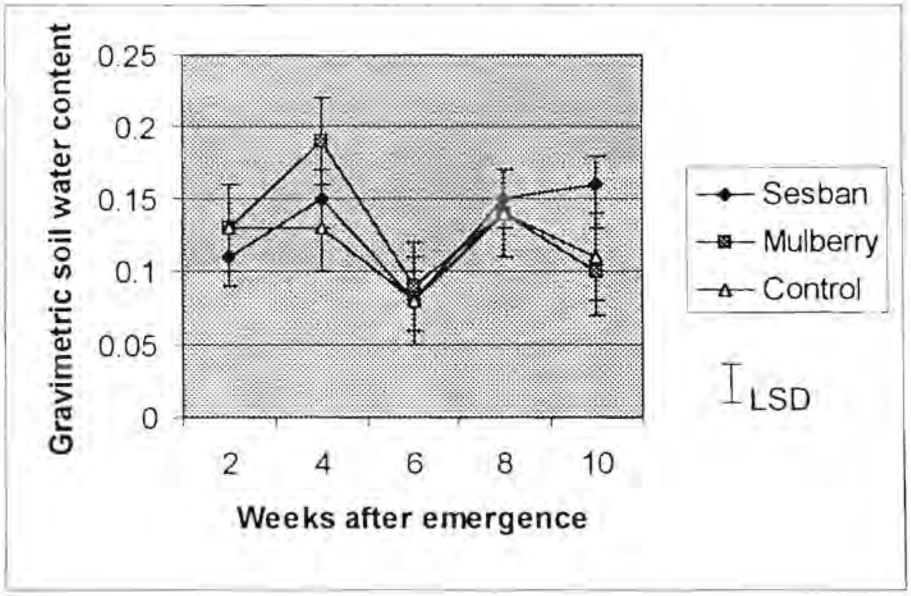

Fig. 4. The gravimetric soil water content in the 100 mm -200mm soil layer at each sampling period.

CONCLUSIONS AND RECOMMENDATIONS

Nannipeiri *et al.* (1983) supported the hypothesis that each soil has a specific capacity with respect to microbial biomass and enzyme activity. They found that factors that could influence the microbial activity, such as amendment with glucose, only affected microbial biomass for as long as higher glucose levels are present in the soil. The effect that the mulches had on the microbial activity in the soil was only temporary, suggesting that the mulch could not change the specific capacity of the soil to sustain microbial biomass after only one application of a mulch. The influence of a repeated mulching treatment should, however, be investigated to determine whether regularly repeated mulch applications could increase the microbial activity long enough to alter the specific capacity of the soil due to changes in soil structure (as a result of microbial action) or increases in soil organic matter content. The effect of a green manure or a green manure- mulch combination should also be evaluated to determine whether the effect of the plant material can be increased to greater depths in the soil profile.

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CHAPTER 5

Prepared according to the guidelines of South African Journal of Plant and Soil.

The short term effects of two multipurpose tree mulches: Soil fertility.[1]

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Pressure on the available land to produce enough food and fibre has increased with a decrease in the amount of time available for fallow, an important component of many traditional methods for restoring soil fertility. Alternative methods such as improved fallows are, therefore, being developed and used to sustain soil fertility levels in low input farming systems. Trees are still being used, as in fallow systems, to cycle nutrients that are beyond the reach of the crop, for crop use. Nutrients captured in the plant material can be returned to the soil for use by the crop by applying it directly to the soil as green manure or mulch, indirectly as manure, or via the natural process of litter fall.

[1]Being part of a study for the degree M Sc. Agric. conducted by the first author under the supervision of the latter.

Applying the plant material directly to the soil ensures the minimum possibility for nutrient losses from the system. It also increases the management options available to the farmer. To aid the farmer in synchronising the nutrient supply with the crop need it is, however, important to understand the release of nutrients from the plant material as well as the factors influencing it. Research has thus far concentrated on the role of nitrogen-fixing trees in these improved fallow systems and the influence they have on the nitrogen balance of these systems. In this study it is clear that the rate of release of different nutrients from leaf material varied. Leaves, applied as a mulch, from a non-nitrogen fixing tree (*Morus alba*) served as a source of soil magnesium (Mg) in a short (10 weeks) period of time, where leaf material from a well known nitrogen fixing tree (*Leucaena leucocephela*) served as a source of potassium (K). No other nutrients, except carbon, were released into the soil at significant levels during this short period of time. It is important for synchrony, *i.e.* the timing of release of nutrients from plant material to coincide with the needs of the plant, to understand the release of nutrients from leaf material as it is influenced by the source of the plant material.

Keywords: Soil fertility, mulch, *Sesbania sesban*, *Morus alba*

INTRODUCTION

Trees and shrubs have been utilized by farmers in the tropics and sub-tropics for the restoration and maintenance of soil fertility. After a few years of cultivation lands were left to return to natural vegetation in the bush-fallow slash-and-burn cultivation system.

In the more arid areas of Africa migratory pastoralists practised a system where the land was also left for long periods unutilized to restore the natural vegetation and to maintain soil fertility. An increase in population density and the increase in the pressure on the available land to supply the necessary food and fibre as well as other competing land use demands led to a decline in the time available for fallow (Kang *et al*, 1990). Fallow periods decreased until the available fallow periods were not able to sustain soil fertility and the related production potential of the soil.

The use of chemical fertilizers has been restricted in Africa. These fertilizers are costly and relatively unavailable. Together with poor infrastructure this has contributed to the low level of use in Africa (Dakora & Keya, 1997). Other methods for the maintenance of soil fertility as well as the restoration of soil fertility in depleted soils became necessary.

A short duration tree or shrub fallow, where trees are cultivated and grown in short rotation with crops and known as an improved fallow system (Jama *et al*, 1998) evolved. This system still includes a period in which no food crops can be cultivated. This could be problematic for the subsistence farmer for whom the continuous production of food for household use is important.

Alley cropping can be seen as an improved bush-fallow system as all the basic features of the traditional bush-fallow system are retained (Kang *et al*, 1990). The advantage of the alley cropping system is that the cropping and the fallow phases occur concurrently on the same piece of land. There is, therefore, no period during which no food crops are being produced, a very important consideration for the subsistence farmer.

Trees and nutrient cycling

Trees are capable of using nutrients unavailable to other crops e.g. deep in the soil profile or in adjacent open spaces (Van Noordwijk *et al*, 1996). This ability will depend on the root distribution of the tree. It is, generally, accepted, that most trees are deep rooted, a statement often made as an argument for the inclusion of woody species in cropping systems. This is, however a generalization. There are large differences between different species, and even within species as influenced by the environment, concerning the distribution pattern of the roots (Van Noordwijk *et al*, 1996).

Nutrients are captured in the plant material including the leaves. The leaves can either be utilised by browsers or drop onto the soil surface as litter. Minerals are released from the leaves and litter through leaching and from the litter through decomposition (Heady & Child, 1994). Trees and shrubs are, therefore, capable of enriching the soil beneath the canopies (Heady & Child, 1994). This is what usually happens in natural ecosystems. It is, however, possible for man to manipulate or simulate this system.

Clippings from multipurpose trees can enhance the soil environment by contributing nutrients to the soil. The basics of nutrient cycling have been described for trees in forest ecology, and undoubtably these principles will apply to agroforestry systems, where trees and crops are grown in close proximity (Palm, 1995). In these systems, however, another dimension enters the equation: management. Management strategies such as type of tree, type of system, arrangement and spacing of components, pruning regime and the fate of the clippings (green manure, mulch or fodder) will all influence the ability of the tree to cycle nutrients in the system.

The following shortcomings were identified in the existing literature concerning research into understanding the ability of agroforestry trees to enhance soil fertility and ultimately the sustainability of these systems. Most research concerns the nitrogen balance of the system (Palm, 1995). Shortcomings in the nitrogen balance were identified as the most limiting factor in traditional agronomic practices in Tropical Africa. It is, therefore, important to assess this specific problem. It would, however, be shortsighted to restrict research to the nitrogen balance. A holistic approach should always be taken where the sustainability of a system, especially a low input system, is concerned, since factors influencing the sustainability of a system rarely function independently of each other.

Another problem arising as a result of the shortcomings in the nitrogen balance is that nearly all the species tested were nitrogen-fixing trees. This was logical considering the nitrogen deficit. There is, however, evidence that at least some of these nitrogen fixing trees cannot cycle phosphorous adequately (Jama *et al*, 1998; Palm, 1995). In this study the well known nitrogen fixing tree, *Sesbania sesban*, which is used in many agroforestry systems and has been tested for its ability to cycle nutrients (especially nitrogen) is compared with *Morus alba*, a relatively unknown tree as far as agroforestry is concerned.

It would also be shortsighted to focus research and practices concerning nutrient cycling on only a few nutrients. The target of these nutrient cycling systems is mostly food crops. Although the aim of these systems would be to ensure food self sufficiency, quantity should not be the only concern. Malnutrition is at least as important as undernourishment. The quality of the product should, therefore, also be considered.

It has been stated earlier that nutrients captured in the leaves of trees can be returned to the soil through different pathways. In natural ecosystems the nutrients are often returned to the soil through a process of litter fall. This process, however concentrates the nutrients beneath the canopy of the tree (Heady & Child, 1994).

The aim of nutrient cycling in agroforestry systems is not only for the tree to capture the nutrients but to distribute the captured nutrients to the inter-crop. The natural process of litter fall would, therefore, not be acceptable, especially in the semi-arid areas where the trees would be spaced further apart to reduce competition. Nutrients can also be cycled back to the soil via manure. The added benefit of supplying fodder to animals serves as an incentive for farmers to include trees into their systems. Manure from these animals can then be collected and worked into the soil. Mathuva *et al.*(1998) reported that significant amounts of nutrients were lost from manure through volatilization and urine even when great care was taken in the collection and preservation of the manure. These losses can be greatly aggravated when the manure is left for long periods in open "bomas" before removal, a problem identified by McCown *et al* (1992) in the semi-arid areas of eastern Kenya. The availability of enough manure was also a problem in this area. Pruning the trees and applying the clippings to the soil is an easy and manageable method of cycling nutrients captured by the tree to the crop that leaves very little opportunity for nutrient loss.

Nutrient release from plant material

Nutrients are released from plant material via two pathways. Nutrients can be leached from plant material. This process even occurs when the leaves are still on the tree (Heady & Child, 1994) . This leaching continues after litterfall has taken place. This is a rapid process. The second process of nutrient release is through decomposition.

Synchrony is the management strategy where the timing of application of nutrients to the soil is synchronised with the need of the crop. Apart from the crop needs it will be necessary to understand the rate of release of nutrients from plant material as a result of leaching and decomposition before any attempts at synchrony can be made.

AIM

Within the scope and finances available it was possible to determine in this trial whether there was a difference between the two MPT's regarding the effect of mulching on soil fertility. This was unfortunately limited to short term observations. To determine whether, and to what extent, synchrony is possible it is necessary to know how soon significant amounts of nutrients are released from the plant material and whether there is a difference in the release rate of different nutrients. The aim of this study was to determine whether a mulch could influence the soil fertility in a relatively short period of time and if there was a difference in the effect of mulches from different trees on the soil.

MATERIALS AND METHODS

Site

The trial was conducted at the Hatfield Experimental Farm of the University of Pretoria (25°45'S 28°16'E, 1327m above see level).The uniform red Hutton soil (Soil Classification Working Group, 1991) had been cultivated for at least ten years prior to investigation. The natural rainfall was supplemented with irrigation as required.

Design

The experiment was conducted in the form of a randomized block with four treatments, two sampling depths, replicated three times. An analysis of variance was conducted using a SAS package (SAS Institute Inc., 1996). Significant differences were determined using a standard t-test where a $p<0.05$ indicated significance.

Layout

The site consisted of three blocks, 2 m x 8 m, each being a replication. Each block was divided into 16 plots of 1 m^2. In each replication four plots, each receiving a different treatment, were destructively sampled to determine soil fertility status relative to a control sample taken before the treatments were applied.

The treatments were as follows:

T1: *Sesbania sesban* mulch (applied fresh at the equivalent of 5 tons dry matter / hectare) with test crop.

T2: *Morus alba* mulch (applied fresh at the equivalent of 5 tons dry matter / hectare) with test crop.

T3: No mulch with test crop.

T4: No mulch, no test crop.

Soil samples were taken at two depths beneath each treatment:

D1: 0mm to 100mm

D2: 100mm to 200mm

Four rows, 20 cm apart were planted, with *Sorghum bicolor* (sorghum) on the 21st March 1999. The plants were thinned to twenty plants per plot (five plants per row) one week after emergence.

Observations

The soil samples were analysed at the soil analysis laboratory of the Department of Plant Production and Soil Science of the University of Pretoria. The concentration of the following cations was determined by extraction with ammonium acetate: Ca, K, Mg, Na. The concentration of P in the soil samples was determined using the Bray I method. The percentage carbon and the pH, determined in H_2O, were also determined for each soil sample. Although the dry matter content and yield of the crop was determined, the crop production levels are not such a good indication of the soil fertility status since the effect of a mulch on crop production can be ascribed to a combination of factors.

RESULTS

Crop production

The average DM yield of the sorghum crop, as harvested ten weeks after plant differed greatly between the treatments; 26.12g m^{-1}, 17.56g m^{-1} and 12.44g m^{-1} of above ground dry matter were harvested from the mulberry, sesbania and no mulch treatments respectively. Statistical analysis, however, indicated that these differences were not significant. The degree of variation in the replicates of each treatment was too high. The effect of the mulches on crop production was not strong enough to ensure a significant and uniform yield response at this stage.

Soil pH

There was a slight increase in the soil pH from the beginning of the trial to the end, but none of the treatments influenced the pH of the soil (Table 1).

Table 1 The pH (H_2O) of the soil, measured at two different sampling depths, before the crop was planted (and the mulching treatments were applied) and again ten weeks after application of the treatments and planting of the crop.

	Sampling depth		
	0-100mm	100-200mm	Average
pH (H_2O)			
Before treatments were applied	5.97^a	6.37^b	6.17
pH (H_2O) (ten weeks after application of mulches)			
Sesban mulch	6.83^c	6.73^c	6.78
Mulberry mulch	6.83^c	6.87^c	6.85
No mulch (no treatment)	6.93^c	6.93^c	6.93
Control (no crop, no treatment)	6.97^c	6.97^c	6.93
Average	6.71	6.76	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Soil P

The P levels beneath the sesban and mulberry mulch decreased during the ten week period (Table 2).

Table 2 The P content of the soil, measured at two different sampling depths, before the crop was planted (and the mulching treatments were applied) and again ten weeks after application of the treatments and planting of the crop.

	Sampling depth		
	0-100mm	100-200mm	Average
P ($mgkg^{-1}$)			
Before treatments were applied	66.6	50.3	58.4[ab]
P ($mgkg^{-1}$) (ten weeks after application of mulches)			
Sesban mulch	50.3	34.7	42.5[c]
Mulberry mulch	52.0	42.8	47.4[cb]
No mulch (no treatment)	63.4	56.3	59.9[ab]
Control (no crop, no treatment)	67.3	59.8	63.6[a]
Average	59.9[d]	48.76[e]	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

P is immobile in soil and it could, therefore, be assumed that the decrease in soil P beneath the mulches was as a result of either an increase in the ability of the plants to take up P or the availability of soil P for plant uptake, and not as a result of increased leaching.

Soil C

The soil carbon level decreased significantly in the control plot as well as the no mulch treatment (Table 3).

Table 3 The C content of the soil, measured at two different sampling depths, before the crop was planted (and the mulching treatments were applied) and again ten weeks after application of the treatments and planting of the crop.

	Sampling depth		
	0-100mm	100-200mm	Average
C (%)			
Before treatments were applied	1.0	1.0	1.0^{a}
C (%) (ten weeks after application of mulches)			
Sesban mulch	0.77	0.87	0.82^{ab}
Mulberry mulch	0.81	0.81	0.81^{ab}
No mulch (no treatment)	0.73	0.69	0.71^{bc}
Control (no crop, no treatment)	0.52	0.54	0.53^{c}
Average	0.77	0.78	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Although there was a slight decrease in the soil carbon levels of the mulching treatments this was not significant. This effect of the mulch on soil carbon levels did not differ from the surface layer to the deeper layer, which was surprising considering that the organic material was not incorporated into the soil.

Soil Mg

The amount of Mg in the soil decreased in all the treatments except under the mulberry mulch (Table 4). Enough Mg was released from the mulberry mulch to sustain the soil Mg levels.

Table 4 The Mg content of the soil, measured at two different sampling depths, before the crop was planted (and the mulching treatments were applied) and again ten weeks after application of the treatments and planting of the crop.

	Sampling depth		
	0-100mm	100-200mm	Average
Mg ($mgkg^{-1}$)			
Before treatments were applied	200.3	2001.3	200.8[a]
Mg ($mgkg^{-1}$) (ten weeks after application of mulches)			
Sesban mulch	168.3	186.7	177.5[b]
Mulberry mulch	228.3	196.3	212.3[a]
No mulch (no treatment)	187.3	178.7	183.0[b]
Control (no crop, no treatment)	180.7	182.7	181.7[b]
Average	193.0	189.1	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Soil K

K is relatively mobile in the soil. The decrease in K in the soil beneath the no mulch treatment could, therefore, be as a result of plant uptake or of leaching. The K released from the mulches was, however, sufficient to sustain (beneath the mulberry mulch) or increase the soil K level (beneath the sesban mulch) (Fig. 5).

Table 5 The K content of the soil, measured at two different sampling depths, before the crop was planted and the mulching treatments were applied; and again ten weeks after application of the treatments and planting of the crop.

	Sampling depth		
	0-100mm	100-200mm	Average
K ($mgkg^{-1}$)			
Before treatments were applied	36.3	33.0	34.7^a
K ($mgkg^{-1}$)(ten weeks after application of mulches)			
Sesban mulch	46.0	33.7	39.8^b
Mulberry mulch	43.0	25.3	34.2^a
No mulch (no treatment)	31.7	20.7	26.2^c
Control (no crop, no treatment)	37.3	27.7	37.5^a
Average	38.9^a	28.1^b	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Soil Ca

The Ca levels decreased significantly in all the treatments with no significant differences between treatments (Table 6).

Table 6 The Ca content of the soil, measured at two different sampling depths, before the crop was planted and the mulching treatments were applied; and again ten weeks after application of the treatments and planting of the crop.

	Sampling depth		
	0-100mm	100-200mm	Average
Ca ($mgkg^{-1}$)			
Before treatments were applied	638.0	607.0	622.5^a
Ca($mgkg^{-1}$)(ten weeks after application of mulches)			
Sesban mulch	454.7	495.3	475.0^b
Mulberry mulch	507.3	486.3	496.8^b
No mulch (no treatment)	511.3	501.3	506.3^b
Control (no crop, no treatment)	457.7	496.7	477.2^b
Average	513.8	517.3	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Soil Na

No significant differences in Na levels were detected in any of the treatments (Table 7).

Table 7 The Na content of the soil, measured at two different sampling depths, before the crop was planted and the mulching treatments were applied; and again ten weeks after application of the treatments and planting of the crop.

	Sampling depth		
	100mm	200mm	Average
Na ($mgkg^{-1}$)			
Before treatments were applied	13.7	13.4	13.5
Na ($mgkg^{-1}$) (ten weeks after application of mulches)			
Sesban mulch	12.3	8.6	10.5
Mulberry mulch	7	11.6	9.3
No mulch (no treatment)	17	12	14.5
Control (no crop, no treatment)	14.3	13.3	13.8
Average	12.9	11.8	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

CONCLUSIONS

The processes of nutrient release, sorption and desorption are dynamic. The dynamics of these processes are further complicated by a changing soil environment. The mulches in this study were applied as fresh material. Nutrients are released from the plant material by means of leaching and microbial action (Heady & Child, 1994). The rate of leaching and decomposition varies as a result of changing environmental conditions such as temperature and rainfall and soil conditions such as soil biological activity. Soil conditions did change during this trial period. The biological activity in the soil varied with time and treatment during the trial period (Chapter 4). Unfortunately only one sampling period after plant and treatment application was executed. Such a "single slice in time" view is not sufficient to understand the full extent of the influence that a mulch can have on the soil nutrient status. This study did, however, indicate that mulches can influence the soil nutrient status significantly during even such a short period and that the tree species is also a factor that might influence the release of nutrients from leaf material.

These results are important if synchrony is to be considered. To supply the nutrient needs of the crop at the right time requires a clear understanding of the rate of release of each nutrient from the fresh and decomposing plant material. To be able to apply a mulch at the right time to supply the needed nutrient it will be necessary to predict the rate and amount of nutrients released from different mulches. It is, therefore, necessary to define a protocol for identifying trees suitable for nutrient cycling and to gather the necessary information to model the nutrient cycling ability of these trees, as affected by environmental factors and management practices, as well as the rate of release of different nutrients from plant material.

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CHAPTER 6

Prepared according to the guidelines of South African Journal of Plant and Soil.

The short term effects of two multipurpose tree mulches: Soil temperature.[1]

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Mulching is a major part of many agroforestry systems. An improved soil temperature regime is often noted in addition to soil conservation, increased fertility and moisture conservation benefits of mulching. Mulches from plant material of *Morus alba* and *Sesbania sesban* were evaluated for their potential to influence the soil temperature regime. Although both mulches decreased the daily maximum temperature the *Morus alba* mulch was more effective. The average daily temperature was not, however, influenced by a mulch. The effect of the mulch declined rapidly with time as decomposition took place and *Sorghum bicolor* had an increasing shading effect.

Keywords: Soil temperature, mulch, *Sesbania sesban*, *Morus alba*

[1] Being part of a study for the degree M Sc. Agric. conducted by the first author under the supervision of the latter.

INTRODUCTION

Mulching is a major feature of many agroforestry systems. Farmers use mulch to improve soil fertility, to conserve moisture and to reduce runoff and evaporation losses. Ong (1996) stated that mulching also has a direct effect on soil temperature. Olasantan (1985) ascribed an increase in plant height, number of branches and fruits, and yield of mulched tomatoes to the effect of the mulch on root temperature, among other reasons. In the sub-humid region of western Nigeria mulch is utilised to increase the viability of dry season yam production. The mulch not only increases the available moisture but also reduces the damage of supra optimal temperature (Olasatan, 1985). The response of crop-development to temperature and temperature change is well understood. The concept of thermal time, a temperature dependent time scale at which development rate of organisms is constant, is discussed in detail by Campbell & Norman (1998). There are different temperature thresholds that are important. T_b, the base temperature, is the lowest temperature at which development will take place. T_x is the temperature at which development will cease. T_m is the temperature at which maximum development occur. Any factor that can influence the soil temperature, above or below these thresholds, will thus influence the development of the crop. Many different species of agroforestry trees are being used in different agroforestry systems. The leaves of these trees vary in characteristics such as shape and size. *Morus alba* has large simple leaves whereas *Sesbania sesban* has compound leaves with small leaflets.

The aim of this study was to determine if a mulch of plant material from agroforestry trees would affect soil temperature, and, if so, to what extent. Would mulches from different sources have different effects? If so, was this difference significant? Leaves from two different agroforestry trees, *Morus alba* and *Sesbania sesban*, were applied to the soil as a mulch to determine the effect of such mulches on soil temperature.

MATERIALS AND METHODS

Site

The trial was conducted at the Hatfield Experimental Farm of the University of Pretoria (25°45'S 28°16'E, 1327m above see level).The uniform red Hutton soil (Soil Classification Working Group, 1991) had been cultivated for at least ten years prior to investigation. The natural rainfall was supplemented with irrigation as required.

Design

The experiment was conducted in the form of a randomized block with four mulching treatments. The temperature was measured at two depths for each treatment. An analysis of variance was conducted using a SAS package (SAS Institute Inc., 1996). Significant differences were determined using a standard t-test where a $p<0.05$ indicated significance.

Layout

The site consisted of three blocks, 2 m x 8 m, each being a replication. Each block was divided into 16 plots of 1 m^2. In each replication four plots, each receiving a different treatment, were used for the measurement of soil temperature.

The treatments were as follows:

T1: *Sesbania sesban* mulch (applied, fresh, to the equivalent of 5 tons dry matter / hectare) with test crop.
T2: *Morus alba* mulch (applied, fresh, to the equivalent of 5 tons dry matter / hectare) with test crop.
T3: No mulch with test crop.
T4: No mulch, no test crop.

Soil temperature measurements were taken at two depths beneath each mulching treatment:

D1: 50 mm
D2: 150 mm

Four rows, 20 cm apart were planted,with the test crop *Sorghum bicolor* (sorghum), in each plot on the 21st March 1999. The plants were thinned to twenty plants per plot (five plants per row) one week after emergence. The first monitoring period was from the 30th of March 1999 to the 4th of April 1999. The test crop emerged during this period. The second monitoring period was a month later from the 30th of April to the 5th of May. Only one block was monitored for temperature at a time due to a shortage of equipment. Each block was monitored for a period of three days. Due to technical difficulties, which were experienced with the thermocouples in one of the replicates, the data collected from only two replications could be used for the statistical analysis.

Observations

Two thermocouples were placed in each plot, one at a depth of 50 mm and the other at a depth of 150 mm. A data logger recorded the temperature registered by each thermocouple at hourly intervals. The average maximum, minimum and daily average temperatures were determined for the three day period during which each replication was monitored.

RESULTS

Maximum soil temperature

The data tabulated in tables1 and 2 illustrates that both mulches depressed the maximum soil temperature.

Table 1 The mean daily maximum soil temperature, measured at two different sampling depths, measured during the first monitoring period, 30th of March 1999 to the 4th of April 1999.

	Depth of measurement		
	50mm	150mm	Average
Maximum soil temperature			
Control (no crop, no treatment)	31.8	26.6	29.2[a]
Sesban mulch	29.6	25.8	27.7[ab]
Mulberry mulch	26.5	24.9	25.7[b]
No mulch (no treatment)	30.8	27.2	29.0[a]
Average	29.7[x]	26.1[y]	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 2 The mean daily maximum soil temperature, measured at two different sampling depths, measured during the second monitoring period, 30th of April 1999 to the 5th of May 1999.

	Depth of measurement		
	50mm	150mm	Average
Maximum soil temperature			
Control (no crop, no treatment)	35.6	29.6	32.6[a]
Sesban mulch	32.5	27.3	29.9[b]
Mulberry mulch	29.2	25.4	27.3[c]
No mulch (no treatment)	34.1	29.9	31.5[a]
Average	32.9[x]	27.8[y]	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

It is, therefore, possible that these mulches could influence the rate of development of a crop if they could decrease the maximum temperature from a level above T_m or T_x to a level below these thresholds.

Minimum soil temperature

The data tabulated in tabels 3 and 4 illustrates that only the mulberry mulch had an influence on the soil minimum temperature, and only during the first sampling period.

Table 3 The mean daily minimum soil temperature, measured at two different sampling depths, measured during the first monitoring period, 30th of March 1999 to the 4th of April 1999.

	Depth of measurement		
	50mm	150mm	Average
Minimum soil temperature			
Control (no crop, no treatment)	15.4	19.4	17.4[a]
Sesban mulch	16.3	19.7	18.0[a]
Mulberry mulch	18.5	20.7	19.6[b]
No mulch (no treatment)	16.1	19.2	17.6[a]
Average	16.6[x]	19.8[y]	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 4 The mean daily minimum soil temperature, measured at two different sampling depths, measured during the second monitoring period, 30th of April 1999 to the 5th of May 1999.

	Depth of measurement		
	50mm	150mm	Average
Minimum soil temperature			
Control (no crop, no treatment)	15.2	18.1	16.7
Sesban mulch	16.8	19.3	18.0
Mulberry mulch	16.5	19.3	17.9
No mulch (no treatment)	17.7	18.7	18.2
Average	16.5^x	18.9^y	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Changes in the minimum soil temperature will not influence the crop development, considering the temperature range relevant to this trial. The minimum temperature will probably only reach a value below T_b during the night-time. The possibility of mulches to protect seedlings and crops of other species against cold and frost damage, especially in the colder months, should, however, be investigated.

Average soil temperature

The data tabulated in tables 5 and 6 indicate that the average soil temperatures were not easily modified by the addition of a mulch.

Table 5 The mean daily average soil temperature, measured at two different sampling depths, measured during the first monitoring period, 30th of March 1999 to the 4th of April 1999.

	Depth of measurement		
	50mm	150mm	Average
Average soil temperature			
Control (no crop, no treatment)	21.5	22.6	22.1
Sesban mulch	21.5	22.5	22.0
Mulberry mulch	21.8	22.7	22.3
No mulch (no treatment)	21.8	22.7	22.3
Average	21.6^x	22.6^y	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 6 The mean daily average soil temperature, measured at two different sampling depths, measured during the second monitoring period, 30th of April 1999 to the 5th of May 1999.

	Depth of measurement		
	50mm	150mm	Average
Average soil temperature			
Control (no crop, no treatment)	23.2	23.1	23.2^{ab}
Sesban mulch	23.0	23.0	23.0^{ab}
Mulberry mulch	21.9	22.3	22.1^{a}
No mulch (no treatment)	24.4	23.7	24.0^{b}
Average	23.1^{x}	23.0^{y}	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

The maximum and minimum soil temperatures respectively decreased (Tables 1 and 2) and increased (Tables 3 and 4) irrespective of mulching treatment or sampling period. The energy transfer to and from greater depths, therefore, did not appear to be influenced by the mulch. The influence of the mulch on the soil temperature in the upper layer was, therefore, reflected in the lower layer.

It is clear from the abovementioned that mulches can modify soil temperature parameters. This will be reflected in crop growth and development if soil maximum temperatures are modified to exceed or to go below T_m and T_x. T_m and T_x are, however, crop dependent and the effectiveness of a mulch to influence crop growth through soil temperature manipulation will also depend on the temperature requirements of the crop.

CONCLUSIONS AND RECOMMENDATIONS

Although both mulch treatments were applied at the same rate, the *Morus alba* mulch was much more effective in reducing the daily maximum temperature. This was most probably due to differences in characteristics of the mulch. The amount of mulch is on its own not a good indicator of the effectiveness of a mulch in terms of soil temperature modification. Wagner-Riddle *et al.* (1996) characterised rye mulch for the purpose of microclimatic modelling. To understand and model the influence of a mulch, from an agroforestry tree, on the soil temperature, it will be necessary to characterize the specific type of mulch because plant material from different trees will have different conductivities as well as different rates of decomposition.

Although the effect of the mulches on the soil temperature could only be monitored for a short time during this trial it is possible that the effect could be more permanent in certain cropping systems depending on the decomposition rate of the plant material. The decomposition rate of a mulch depends on the microclimate and the amount of mulch applied (Wagner-Riddle *et al.* 1996) as well as on inherent characteristics of the fibre component of such plant materials.

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CHAPTER 7

Prepared according to the guidelines of South African Journal of Plant and Soil.

The influence of *Sesbania sesban* or *Morus alba* leaves, utilised as green manure or mulch, on the early growth and water use efficiency of *Avena sativa*.[1]

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The use of techniques, such as waterharvesting, or the reduction in evaporative water losses, to enhance the efficiency of alley cropping systems, have not been taken into consideration in most agroforestry studies. A major feature of the alley cropping concept is the capacity of trees to produce large quantities of biomass for green manure. The aim of this study was to determine whether applying plant material of *Sesbania sesban* (sesban) or *Morus alba* (mulberry) to the soil, either as a mulch or as green manure, would influence the production of *Avena sativa* (oats) and the water balance of a cropping system thereby increasing the amount of plant available water.

[1] Being part of a study for the degree M Sc. Agric. conducted by the first author under the supervision of the latter.

The effect of plant material applied as mulch or green manure on the water balance and fertility of the soil differed. Although green manure or mulch of sesban and mulberry increased water use efficiency and plant production, at least in the short term, a combination of such methods should also be investigated in greater detail.

Keywords: *Morus alba*, *Sesbania sesban*, mulch, green manure, water use efficiency

INTRODUCTION

The increased competition in systems where crops are grown in close proximity to each other, as found in agroforestry systems such as alley cropping, are regularly cited as reasons for the relative inefficiency of these systems in arid and semi-arid areas. According to Mathuva *et al.* (1998) the efficiency of an alley cropping system depends on the ability of the system to improve soil water availability, where water is the limiting factor. Very little research has, however, been done on the water use patterns in alley cropping systems (Kiepe & Rao, 1994). Furthermore, the use of additional techniques, such as waterharvesting and the reduction in evaporative water losses, have not been taken into consideration in most of these studies. Kiepe & Rao (1994) emphasized the importance of research into the different components of the water balance.

There are a range of possible management options available to minimize the competition between hedgerows and crops. These include: choice of suitable tree species, height and frequency of pruning the hedgerows, and hedge spacing (Mathuva *et al.* 1998).

A major feature of the alley cropping concept is the capacity of trees to produce large quantities of biomass for green manure (Ong *et al.* 1996). In a study conducted by Pieterse *et al* (1997) the yield of pot grown maize was increased by the application of plant material from four different leguminous trees as mulches. This increase was ascribed to the conservation of soil moisture, rather than to the addition of N to the soil. The aim of this study was to determine whether the application of plant material of *Sesbania sesban* or *Morus alba* to the soil, either as a mulch or as green manure, would influence the production of *Avena sativa* and the water balance of a cropping system and as a result increase the amount of plant available water for plant production.

MATERIALS AND METHODS

Site

A pot study was conducted in a greenhouse on the Hatfield Experimental Farm. Soil was taken from the upper 300 mm of a uniform red Hutton soil (Soil Classification Working Group, 1991), with a clay content of 35%, and sieved. 2.5 kg of this soil was placed in each pot. The field water capacity (FWC) was determined gravimetrically. After planting with *Avena sativa* the pots were watered every second day.

Design

This experiment was conducted in the form of a completely randomized 4x2x3 factorial, with four different soil treatments, two levels of application of the soil treatment and three watering treatments, replicated three times.

The soil treatments were as follows:

T1: *S. sesban* plant material applied as green manure

T2: *S. sesban* plant material applied as a mulch

T3: *M. alba* plant material applied as green manure

T4: *M. alba* plant material applied as a mulch

The plant material was applied at two levels:

L1: 500g(fresh material)/m^2 (equivalent of 1430 kg DM/ha for *M. alba* and 1360 kg DM/ha for *S. sesban.*)

L2: 1000g (fresh material)/m^2 (equivalent of 2860 kg DM/ha for *M. alba* and 2720 kg DM/ha for *S. sesban.*)

The soil water was restored to three different levels every second day:

W1: Soil water level restored to 90% of FWC

W2: Soil water level restored to 60% of FWC

W3: Soil water level restored to 30% of FWC

Because of the profound effect of the watering treatment the data were sorted and each watering level was analysed individually as a 4x2 multi-factorial using a SAS package (SAS Institute Inc.).

Layout

The treatment combinations were assigned randomly to pots, which were rotated regularly in a completely randomized layout.

Application of treatments

Fresh leaf material was used for the mulch and the green manure treatments. The mulch treatment consisted of fresh leaves from *M. alba* or *S. sesban* spread evenly over the soil surface. The green manure treatment consisted of fresh leaves mixed thoroughly with the total amount of soil in the pot. Each treatment was repeated at three different watering levels. These levels were determined as a percentage of field water capacity. The pots were sealed at the base to prevent any leaching water loss. All the water lost could, therefore, be attributed to evaporation from the soil surface and to transpiration. The control pots did not receive any leaf material.

Observations

Each pot was weighed before watering to determine the water lost from the pot. The plants were harvested six weeks after emergence. The following data was determined; leaf area (LA) and dry matter production (DM) of the above ground parts, water loss from the pots (due to evaporation and transpiration) and water use efficiency of the system (dry matter produced/amount of water added to the pot).

RESULTS AND DISCUSSION

Water loss through evaporation and transpiration

Both mulches, and especially the mulberry mulch, were successful in reducing the amount of water lost at both high and low watering levels (Tables 1 and 3). The mulberry mulch, also reduced the amount of water lost at the intermediate watering level (Table 2). The rate of mulch application did not affect the amount of water lost. In contrast green manuring treatments, irrespective of species or rates of incorporation, increased water losses.

Table 1 The water loss, expressed as a percentage of the untreated control, from pots planted with *A. sativa*, determined six weeks after emergence, as influenced by either a mulch or green manure from either *S. sesban* or *M. alba*, where the soil moisture content was kept at 30% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	103	111	107^a
S. sesban mulch	76	62	69^b
M. alba green manure	118	111	115^a
M. alba mulch	77	71	74^b
Average	94	89	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 2 The water loss, expressed as a percentage of the untreated control, from pots planted with *A. sativa*, determined six weeks after emergence, as influenced by either a mulch or green manure from either *S. sesban* or *M. alba,* where the soil moisture content was kept at 60% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	98	99	99^a
S. sesban mulch	107	71	89^a
M. alba green manure	106	104	105^a
M. alba mulch	66	62	64^b
Average	94	84	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 3 The water loss, expressed as a percentage of the untreated control, from pots planted with *A. sativa*, determined six weeks after emergence, as influenced by either a mulch or green manure from either *S. sesban* or *M. alba*, where the soil moisture content was kept at 90% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	122	122	122^{a}
S. sesban mulch	88	89	88^{bc}
M. alba green manure	105	117	111^{ab}
M. alba mulch	72	76	74^{c}
Average	97	101	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Total leaf area

While no significant differences in the total leaf area were detected at the intermediate watering level, the relative leaf areas at high and low watering levels (Tables 4 & 5) were affected. The higher rate of mulch or green manure application, irrespective of the treatment, resulted in a higher total leaf area. The mulberry green manure treatment had a significantly higher total leaf area than the rest of the treatments at the high watering level (Table 5). The green manure treatments had significantly higher total leaf areas than the mulch treatments of the same species at the low watering level (Table 4)

Table 4 The total leaf area, expressed as a percentage of the untreated control, of *A. sativa* determined six weeks after emergence, as influenced by mulch or green manure from *S. sesban* or *M. alba*. The soil moisture content was kept at 30% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	152	165	158^{ab}
S. sesban mulch	106	109	108^{c}
M. alba green manure	154	220	187^{a}
M. alba mulch	91	190	140^{bc}
Average	139^{x}	227^{y}	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 5 The total leaf area, expressed as a percentage of the untreated control, of *A. sativa* determined six weeks after emergence, as influenced by mulch or green manure from *S. sesban* or *M. alba*. The soil moisture content was kept at 90% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	134	168	151^{b}
S. sesban mulch	123	157	140^{b}
M. alba green manure	165	215	190^{a}
M. alba mulch	117	140	128^{b}
Average	138^{x}	170^{y}	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Water use efficiency (WUE)

The higher rate of application, irrespective of the treatment, resulted in a higher water use efficiency of the test crop (Table 6, 7 & 8). The WUE of the test crop, at the intermediate watering level, beneath the mulberry mulch, was significantly higher than the rest of the treatments (Table 7). This was, probably due to a reduction in evaporation, since there was also a reduction in evapotranspiration (Table 2), but not in the total leaf area (Table 5).

Table 6 The water use efficiency (dry matter produced/amount of water applied), expressed as a percentage of the untreated control, of *A. sativa* determined six weeks after emergence, as influenced by mulch or green manure from *S. sesban* or *M. alba*. The soil moisture content was kept at 30% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	129	164	146
S. sesban mulch	148	201	174
M. alba green manure	150	225	187
M. alba mulch	130	317	223
Average	139^x	227^y	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 7 The water use efficiency (dry matter produced/amount of water applied), expressed as a percentage of the untreated control, of *A. sativa* determined six weeks after emergence, as influenced by mulch or green manure from *S. sesban* or *M. alba*. The soil moisture content was kept at 60% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	175	149	162^{a}
S. sesban mulch	136	215	176^{a}
M. alba green manure	166	203	185^{a}
M. alba mulch	202	277	239^{b}
Average	170^{x}	211^{y}	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 8 The water use efficiency (dry matter produced/amount of water applied), expressed as a percentage of the untreated control, of *A. sativa* determined six weeks after emergence, as influenced by mulch or green manure from *S. sesban* or *M. alba*. The soil moisture content was kept at 90% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	115	146	130^{a}
S. sesban mulch	143	200	171^{b}
M. alba green manure	162	221	192^{b}
M. alba mulch	164	190	177^{b}
Average	146^{x}	189^{y}	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Dry matter production

The higher rate of application, irrespective of the treatment, resulted in a higher dry matter production of the test crop at the low watering level (Table 9). The green manure treatments had significantly higher DM production levels than the mulch treatments of the same species at both high and low watering levels (Tables 9 and 11). The DM production under the mulberry mulch treatment was significantly lower than the other treatments at the intermediate watering level, despite the higher WUE (Table 7).

Table 9 The dry matter production (DM), expressed as a percentage of the untreated control, of *A. sativa* determined six weeks after emergence, as influenced by mulch or green manure from *S. sesban* or *M. alba*. The soil moisture content was kept at 30% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	184	174	179^{ab}
S. sesban mulch	111	123	117^{c}
M. alba green manure	177	251	214^{a}
M. alba mulch	101	216	158^{bc}
Average	143^{x}	191^{y}	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 10 The dry matter production (DM), expressed as a percentage of the untreated control, of *A. sativa* determined six weeks after emergence, as influenced by mulch or green manure from *S. sesban* or *M. alba*. The soil moisture content was kept at 60% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	98	99	99^{a}
S. sesban mulch	107	70	89^{a}
M. alba green manure	106	104	105^{a}
M. alba mulch	66	62	64^{b}
Average	94	84	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

Table 11 The dry matter production (DM), expressed as a percentage of the untreated control, of *A. sativa* determined six weeks after emergence, as influenced by mulch or green manure from *S. sesban* or *M. alba*. The soil moisture content was kept at 90% of field water capacity.

Control			100.00
	Application rate		
Treatment	500g m^{-1}	1000g m^{-1}	Average
S. sesban green manure	122	122	122^{a}
S. sesban mulch	88	88	88^{bc}
M. alba green manure	105	117	111^{ab}
M. alba mulch	72	76	74^{c}
Average	97	101	

Values with the same superscript do not differ significantly. Significant differences were determined using a standard t-test where a p value <0.05 indicated significance. Significance is only indicated at the highest order of treatment combinations where significance was detected.

The treatments that produced a positive yield response did not necessarily produce an increase in WUE. It can, therefore,be deduced that nutritional factors probably also played a significant role. Bin (1983) confirms that green manure may increase the availability of nitrogen and phosphorous in the soil while Gajri *et al* (1997) found that a straw mulch increased the WUE of sunflower by increasing the root development and, thereby, the ability to extract water from the soil.

CONCLUSIONS

Green manure and/or mulch of sesbania and mulberry can increase water use efficiency or plant production, at least on the short term. The specific mode of action is not as yet known and was not determined in this trial.

Kiepe & Rao (1994) identified the importance of identifying criteria for the choice of technologies for different purposes. It is clear from the results of the trial that the effect of plant material on the water balance and fertility of the soil differ for the two application methods: mulch and green manure. It is, therefore, important to recognize the different application possibilities. Where soil moisture is not limiting, plant material as green manure could be sufficient. Where soil water is limiting ,however, a combination of green manure an mulching could be a better option. This combination of methods should be investigated in greater detail.

Although similar results were reported on more sandy soils (Gutteridge, 1991, Pieterse *et al* 1997), this research field should ideally be broadened to include a wider range of soil and climatic conditions to expand the criteria for choice of technology.

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CHAPTER 8

GENERAL CONCLUSIONS AND RECOMMENDATIONS

These trials form part of the ongoing agroforestry research project conducted on the Hatfield Experimental Farm by the Department of Plant Production and Soil Science of the University of Pretoria. Multipurpose tree species are evaluated for environmental adaptation and production potential under different management strategies. Multipurpose trees, by definition, are utilised for different products and purposes. These products and purposes are evaluated in an effort to quantify the value of a tree component in an agricultural system, a difficult task, as the value of certain purposes, such as a windbreak, and products, such as firewood, are not easily estimated in monetary terms.

One of the possible uses of multipurpose trees is as a potential soil ameliorant in the form of mulch or green manure. Apart from supplying **N** to the soil (the most widely studied effect of mulch and green manure), other nutrients can also be supplied to the soil, soil biology can be altered and soil physical parameters, such as soil temperature can be altered by mulch or green manure. In order to determine the value of plant material, from a multipurpose tree, as soil ameliorant, the influence of the material on the soil physical, -biological and -chemical properties needs to be determined. Two multipurpose tree species were selected as source of mulch and green manure. *Sesbania sesban* (sesban) is a well known leguminous tree that has been used and has been evaluated as an agroforestry tree in different systems. The white mulberry (*Morus alba*), in contrast, is a relatively unknown non-nitrogen fixing tree. The natural distribution of sesban and the spread of the mulberry indicate that both of these trees are well adapted to a range of environments in South Africa. The most limiting factors affecting the spread of these tree species are low temperatures, frost and a rainfall of less than 600 mm p.a for the mulberry and 500 mm p.a for sesban. Establishment practices differ greatly between sesban, which is established by seed, and mulberry, which is established vegetatively, but both of these trees are, however, easily established. Although both of these tree species are capable of producing enough material to utilize as a mulch or green manure, the yield of both species varies greatly. Many factors, including genotype, environment and management practices -such as plant spacing and establishment methods -may influence the production. The effect of all of these parameters, as well as their influence on each other, has not, as yet, been quantified. It is, therefore, recommended that a detailed study be conducted into the environmental and managerial factors to facilitate the modelling of the growth, development and productivity of the trees to facilitate the prediction of potential yield for specific environments and managerial regimes.

In preliminary studies leaf DM production levels of high density stands (3 700 trees/ha) varied between 3000 to 6000 kgDM/ha for a newly established mulberry plantation, and approximately 5000 kgDM/ha for sesban. One hectare of these trees would, therefore, be able to supply only one application of mulch or green manure for one hectare of cultivated land if an application level of 4000 to 5000 kgDM/ha is considered. Even where a higher DM production, as a result of better environmental conditions or better management practices, is expected, the additional plant material may not be available for soil amelioration, but might be utilised for other purposes such as fodder or firewood. A further limitation on the amount of plant material available for soil amelioration is the configuration of most agroforestry systems, and especially alley cropping, where less than half of the available land is planted with trees. Considering the limited amount of plant material available for soil amelioration purposes, single applications should be optimised since multiple applications would rarely materialise. One way of optimising a single application of a soil ameliorant would be to synchronise the effects of the soil ameliorant with the needs of the crop. A thorough understanding of the effects of a mulch or green manure on the soil environment will, however, be necessary.

The short term effects of sesban and mulberry mulches on soil fertility, temperatures and microbial activity were evaluated in a range of small plot and green house trials and the following general conclusions reached.

SOIL FERTILITY

Mulches of both sesban and mulberry plant material significantly influenced the soil nutrient status during a short (ten week) experimental period. The type and amount of nutrients released into the soil varied between the different mulches. In order to apply a mulch at the right time to supply the nutrient requirements of specific crops it will be necessary to predict the rate and amount of nutrients released from different mulches.

It is, therefore, necessary to develop a procedure for identifying trees suitable for nutrient cycling and to gather the necessary parameters to model the nutrient cycling ability of these trees, as affected by environmental factors and management practices.

SOIL TEMPERATURES

Both mulches evaluated reduced maximum soil temperatures, while the mulberry mulch also increased the minimum temperature. It is, therefore, possible that these mulches could influence the rate of development of a crop by reducing the maximum temperature from a level above T_m (temperature at which maximum plant growth occurs) or T_x (the maximum temperature at which plant growth occurs) to a level below these thresholds. T_m and T_x are, however, crop dependent and the effectiveness of a mulch to influence crop growth through soil temperature manipulation will also depend on the temperature requirements of the crop.

Although both mulch treatments were applied at the same rate the *M. alba* mulch was much more effective in reducing the daily maximum temperatures. This was most probably due to differences in characteristics of the mulch. To understand and model the influence of mulches from agroforestry tree species, on soil temperatures it will be necessary to characterize the specific type of mulch, because plant material from different trees will have different conductivities as well as different rates of decomposition.

MICROBIAL ACTIVITY

The effects which the mulches had on the microbial activity in the soil were only temporary, suggesting that the mulch could not change the specific capacity of the soil to sustain microbial biomass after only one application of a mulch. The influence of repeated mulching treatments should, however, be investigated to determine whether regularly repeated mulch treatments could increase the microbial activity long enough to alter the soil in terms of soil structure (as a result of microbial action) or increased soil organic matter content and, therefore, the specific capacity of the soil to sustain microbes.

WATER USE EFFICIENCY

The influence of sesban or mulberry leaves, utilised as green manure, or mulch, on the early growth and water use efficiency of *Avena sativa* (oats) was also determined. Green manure, or mulch, of sesban and mulberry increased water use efficiency and plant production, in the short term. The specific mode of action is, however, not, as yet, known and was not examined in this trial. It is, however, clear that the effect of plant material on the water balance and fertility of the soil differ for the two application methods: mulch and green manure. It is, therefore, important to recognise the different application possibilities and limitations.

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The possibility of utilising a mulch or green manure, apart from being a general soil amelioration, to address specific problems, exists. To achieve this, however, a modelling approach is needed. A databank, of a wide range of species, covering the parameters that will influence the structure of the mulch or green manure, the rate of decomposition and the nutrients in the plant material should be compiled. This databank, combined with a model covering the environmental factors and management strategies to determine the influence of these factors on the mulch structure and decomposition rate, could be used to predict the influence of the mulch on the soil. Parameters collected would include leaf morphology and size as well as the inherent characteristics of the fibre component of the plant materials. The effect of the micro-climate and microbial population in the soil on the decomposition rate should also be investigated and quantified.

If the influence of mulch or green manure on the soil can be predicted by a model it would be possible to time the application of a mulch to meet a specific crop need. WUE could, for example, be increased by the application of a suitable mulch at a time when a crop is sensitive to drought, such as during anthesis. An accurate estimation would, however, be needed , especially where only one application is possible, since the effect of the mulch or green manure will only be temporary and will decline over time as a result of decomposition of the plant material.

A model could, therefore, optimize the application of plant material to the soil as soil ameliorant. Without such a model the opportunity cost could exceed the value of the plant material as soil ameliorant. In which case the plant material would be better utilised for other purposes such as fodder or firewood.