University of Southern Queensland
Faculty of Engineering & Surveying

Investigating the Economic Viability and Methods of Harvesting and Storing Leucaena

A dissertation submitted by

Emile Seiler

in fulfilment of the requirements of

ENG4112 Research Project

towards the degree of

Bachelor of Agricultural Engineering

Submitted: November, 2006

Abstract

Leucaena leucocephala is a legume tree that is becoming increasingly popular in beef production systems Australia wide and especially Queensland. Its high nutritional value, fast fodder production and drought tolerance mean that it is becoming an integral part of many Central and Southern Queensland properties. Killara Cattle Company is a property in South-East Queensland that is interested in making better use of its leucaena resources.

The physical nature of the plant restricts the use of the conventional fodder preservation method of baling as hay. For situational and management reasons, it was desirable to develop a viable alternative to preserving as silage which to date, has not been accomplished with leucaena alone. The idea of using cement and molasses in combination with leucaena was developed as a means of preservation. This would theoretically avoid the need for expensive artificial drying as the leucaena could be used fresh. The moisture present would be immobilised by the cement, thus preserving the leucaena.

Testing of this theory required a means of harvesting to be developed, a mixing method to be investigated and the optimal economical ratios of ingredients required for preservation to be found. Some small scale experiments were initially conducted to test the idea and as these were successful, research continued. After the acquisition and testing of a suitable harvester, the second experiments were aimed at testing on a larger scale and finding a lower limit for the cement required. These were sufficient to evaluate a theoretical optimal mixture.

An economic comparison was then made between the feed resulting from this method and other high quality feed alternatives available to Killara. This included comparing the cement and molasses method to the other conventional option of ensiling leucaena, should it prove possible. The conclusions were that the cement and molasses method is economically viable at Killara although further work may prove leucaena silage to be a better option.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111/2 *Research Project*

Limitations of Use

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Emile Seiler

0050016652

Signature

Date

Acknowledgments

I would like to acknowledge the support and guidance of Dr. Guangnan Chen whose help has always been encouraging.

Thanks must also go to Col and Pete Seiler of Killara Cattle Company whose seemingly infinite combined wisdom and experience is a constant source of inspiration. The project would never have been possible without their assistance and resources at Killara.

I would like to thank the rest of my family who have provided prompt and unfailing assistance on countless occasions. This includes my housemates who have endured my irregular and unaccommodating habits during the completion of this project.

Finally, I must recognise the assistance that has been given to me by everyone I have contacted in person, by phone or email. This help has, at times, been infinitely more helpful than all formal literature combined.

Emile Seiler

University of Southern Queensland

November 2006

Contents

List of Figures

List of Tables

Nomenclature

Biomass: The general term given to bulk plant matter.

Chip Size: The size of the individual plant pieces created by the harvester or chipper.

Crude Protein: An essential element for cattle growth. Its percentage is a common gauge of the nutritional value/quality of a feed.

Cultivar: A variety of a plant that is developed by human intervention from a natural species and maintained under cultivation.

Cut and Carry: The process of manually cutting and carrying plant material to stock or another desired location.

Degradation: In this instance refers to the undesirable spoiling of plant material in a way that nutritional value is lost.

Drive Train: The mechanical linkages and shafts used to transfer power from one location to another.

Dry Matter: The proportion of plant material that remains after heating at 105℃ for a period so that all water is removed.

Dry Matter Yield: The capacity of a plant to grow and produce biomass - measured on a dry matter basis.

Ensiled : The process of creating *silage*.

Feed Analysis: A chemical analysis undertaken to determine the nutritional value of a substance from a stock feed perspective.

Feedstuff: Food for domestic livestock.

Fodder: Coarse stock food composed of entire plants or the leaves and stalks of the crop.

Forage: Stock food suitable for browsing or grazing.

Gel Water: The ill-defined substance present within solid concrete after hydration is complete. It is neither "water" or solid "gel."

Genus: Taxonomic group containing one or more species.

Green Chop: Freshly harvested (green) biomass that is obtained directly from a forage harvester.

Green Manure: Biomass that is incorporated into soil for enrichment purposes.

Hay: Fodder that is dried to a moisture content low enough to be preserved. Usually rolled or packed into bales.

Hybridising: The act of mixing different species or varieties of plants to produce new hybrids or crossbreeds.

Hydration: In this case refers specifically to the reaction of cement with water, i.e. the cement becomes *hydrated.*

Hydrophilic: Having a strong affinity for water; tending to dissolve in, mix with, or be wetted by water.

Hygroscopic: In this case refers to a material that will readily absorb moisture from the air.

Industrial Mixer: Refers to a large capacity ($>$10m^3), tractor-powered mixer for combining feedstuffs.

Legume: A type of pea or bean plant. Noted in this case for its ability to maintain or increase nitrogen levels within the soil.

Maize: Tall annual cereal grass bearing kernels on large ears. A common high quality forage crop that is often *ensiled.*

Mallee: A low-growing Australian eucalypt tree.

Molasses: A dark syrup produced as a by-product of refining sugar cane. A popular stock supplement due to its high levels of energy.

Nitrogen Fixation: The act of fixing or converting nitrogen into a plant-usable form within the soil.

Pick-up Front: An attachment designed for the front of forage harvesters and other machines that enables the mechanical picking up of *fodder* that has been deposited in rows in the paddock.

PTO: Acronym of Power Take-Off. A system for delivering power from a tractor that is independent of axle power.

Silage: Fodder harvested while green and kept succulent by partial fermentation as in a silo.

Water Activity: A measure of the mobility that water in a substance has.

Weight Gain: A desirable effect of feeding stock. Usually requires high quality feed and is a measure of productivity. Generally calculated over a period to find a daily average in *kg*.

Metabolisable Energy (ME): In this case refers to the energy that is readily metabolised by cattle.

Chapter 1

Introduction

1.1 Leucaena

Leucaena leucocephala is a species of legume fodder tree from the *Leucaena* genus that is grown primarily for beef cattle grazing although it also proving to have beneficial applications into environmental areas such as salinity and erosion control. It is capable of producing crude protein in levels equal to or better than other conventional crops such as lucerne and for this reason, it is gaining immense popularity across South-East and Central Queensland. Figure 1.1 shows the areas that have potential for leucaena grazing production Although relatively expensive to establish, new cultivars are proving to have excellent drought tolerance and a production period in excess of 20 years.

The cultivars that are predominately used in Australia have been *Peru*, *Cunningham* and more recently, *Tarramba*. The original leucaena leucocephala species can grow to a height of 20m with a trunk diameter at breast height of 40cm (Brewbaker & Sorensson 1990). In a grazing situation however, it is undesirable to allow the plant to grow above 1.5-2m so that the highly nutritious leaf remains within reach of stock. One way of achieving this is with suitable grazing practices such as using large stock to cause some plant destruction. Other methods may include manual slashing or cutting and in colder areas, winter frosts kill the plant above the ground and it regrows from ground level in spring. The benefits of using leucaena for grazing in Australia are aptly

Figure 1.1: Areas of Australia considered potentially suitable for Leucaena production on the basis of climate and soil type. The criteria used were clay soils in the 550 to 800 mm rainfall zone. (Source: Fiona Coates and Max Shelton, University of Queensland (Lefroy 2002).)

Figure 1.2: Leucaena in a grazing situation (Personal Photo).

described in the following passage from Lefroy (2002):

> "Australian research has clearly demonstrated the value of this plant [Leucaena] for animal production. The highest rates of N [Nitrogen] fixation in a tropical legume have been recorded from Leucaena systems in Queensland with 575 kg/ha of N in edible material (Hutton 1960) and 480 kg/ha in total above ground growth (Ferraris 1979). The highest recorded liveweight gains from a tropical pasture legume (2000 kg liveweight/ha/yr) have been achieved on Leucaena in the Ord River Irrigation Area (Pratchett and Petty 1993). Under rainfed conditions in Central Queensland, liveweight gains of up to 1.25 kg/hd/d and 300 kg/hd/yr have been recorded (Jones and Megarrity 1986). Most significantly, growth rates during autumn (March-June) have been achieved at lower cost with Leucaena than is possible with alternative supplementary feeds [1]."

This demonstrates the importance of leucaena grazing systems in Australia, especially Queensland. Figure 1.2 gives a visual representation of leucaena in a grazing situation.

[1] Full references of the ones given within this passage were unfortunately not given with Lefroy (2002).

1.2 The Problem

One of the major drawbacks that is experienced with growing leucaena in the more southerly areas shown in Figure 1.1, is its susceptibility to frosts. The plant originated in Central America which means that in the southern Queensland climate frosts generally kill the plant back in winter and the plant is forced to regrow from the ground or close to every spring. While this has the advantage of preventing the tree becoming too large and hence, unsuitable for grazing, it does mean that a significant amount of potential production is lost during the colder months. For conventional crops, there are well-established methods of preserving fodder to maintain production. These existing methods can be broadly summarised into *hay* and *silage*. The problem is that leucaena fodder from summer growth cannot be cut and sun-dried for preservation in the paddock like the hay-making process with other grasses and legumes. This is because the plant becomes brittle on drying and the small, protein rich leaves cannot be retrieved from the paddock with conventional machinery. While leucaena has previously been chopped and ensiled with some success, the practice is not common and the details of why it is desirable to avoid this process will be discussed later in Chapter 3.

The central idea to this research is the concept of using molasses and cement in combination with fresh leucaena green chop to create a mixture whereby the moisture present in the leucaena is immobilised by the cement, thus preserving it. In this way, it is hoped that an economically viable method of preserving leucaena fodder can be effected. The process of adding cement to animal feed is not harmful and recipes for home-made protein blocks for stock feed where cement is the setting agent are readily available. Two of these are shown in Table 1.1 & 1.2 to demonstrate this practice. The hope is that by substituting leucaena green chop for the protein meal and simplifying the other ingredients to molasses and cement, the resulting block will retain its food value while remaining edible. Research will also be conducted into possible alternatives to cement as while it is easily the cheapest, a more organic substance would probably give a better result in terms of food value and palatability.

While time became prohibitive, another aspect of this research that will be investigated in future is the prospect of resistance to weathering. It is broadly proposed that there

Table 1.1: High molasses content protein block (Blackwood 2001).

Ingredient	**Proportion by Weight**	**Mixing Order**
Hot Water	-	-
Molasses (heated)	40%	1
Urea	0-10%	2
Salt	5-10%	3
Phosphorous source	2%	3
Protein meal	30-40%	4
Cement	10-15%	5

Table 1.2: Low molasses content protein block (Blackwood 2001).

Ingredient	**Proportion by Weight**	**Mixing Order**
Hot Water	10%	1
Urea	0-10%	1
Salt	5-10%	2
Molasses (heated)	20%	3
Phosphorous source	2%	4
Protein meal	30-40%	5
Cement	10-15%	6

are two main avenues for the application of this idea. One is preserving leucaena in small blocks that can be handled easily enough to allow rolling off the back of a truck out in the paddock for feed supplementing. The other is preserving in bulk in a pile as is the practice with cottonseed and other stock feeds that don't degrade. For both of these methods, weather resistance would be a significant benefit. This would enable their storage without the need for shed space or tarpaulins.

The composition of these two mixtures will be developed according to fundamentally different criteria. For the preservation in bulk, it is desirable to include as much leucaena in the mixture as possible. In a block situation, however, the aim is to provide a high quality supplement and leucaena would only be included as necessary to achieve this. It is likely that the blocks will have a higher molasses content along with various other additives such as urea, phosphorous and any other elements desired. The bulk storage will probably have a lower molasses content and only as much cement (or alternative) as required to preserve it; not necessarily enough for the mixture to set hard. While the weather resistance has not yet been investigated, it is proposed that the mixture might require the addition of a small amount of vegetable oil or maybe a post-mix application of a non-toxic, water repellent substance to prevent rain damage.

1.2.1 Sponsorship Property

The property of Killara Cattle Company that will be frequently referred to throughout this dissertation is responsible for sponsoring the experimental work and purchases. It is located approximately 100km west of Kingaroy in South-East Queensland on cracking clay/alluvial soil with an annual average rainfall of 600mm. This rainfall has been extremely infrequent and below average for the last decade. The management at Killara have begun to rely heavily on leucaena, particularly the Tarramba cultivar as a staple feed source due to its drought tolerance and fast, high quality feed production.

The property is predominately a beef cattle breeding and production operation. The breeding regime is such that calves are born within 2-3 months of each other and they are weaned as close to the same time as logistically possible. This generally occurs in the late summer/early autumn period and in a good season, there would be sufficient leucaena growth left from summer rain for feeding the weaners. With the more infrequent rainfall patterns, a more opportunistic system whereby leucaena can be harvested and stored whenever the rain dictates good growth would be greatly advantageous. In this way, weaners could expect high quality feed if rain was insufficient to prolong the leucaena growth into autumn. If the method could be economically effected for large enough quantities, production could be enhanced by feeding weaners for a longer period until spring rains bring new growth.

1.3 Objectives

The main objective of this research is as stated in the title of this paper:

- Investigate the economic viability and methods of harvesting and storing leucaena.

To achieve this, a number of steps were taken:

1. Research previous attempts (if any) to preserve this particular stock fodder;
2. Research previous attempts (if any) of harvesting the leucaena plant for fodder;
3. Trial own ideas for preserving the fodder;
4. Investigate the subsequent cost involved in any of the practicable methods researched and nutritional value of the product;
5. Suggest methods of mechanising production of a consumable stock supplement;

   As time permits

6. Attempt construction of various components required to economically produce a consumable product.

This regime was basically adhered to although after experimentation began, it was found that the machinery required already existed and minimal modification was required. This basically meant that "attempt construction" became "perform necessary modifications" and to date, this is yet to be done although there is little to be done anyway.

As the aim of the project is to investigate the preservation of leucaena, the main focus will be to determine the mixture required for the preservation of leucaena in a bulk storage situation. The preservation of leucaena in blocks as a feed supplement was found to be unfeasible by the lower than anticipated crude protein levels achievable. This does not mean that the inclusion of leucaena in a supplement block would not be beneficial; it suggests that leucaena does not need to be the main ingredient. When the aim shifts to a supplementing ration, the preservation of leucaena ceases to be the main point of interest and as such, this project will focus on the bulk storage aspect where preservation remains the issue.

1.4 Dissertation Overview

Chapter 2 - Literature Review

This outlines all of the relevant literature that was used throughout the course of the project. The sources themselves are discussed along with their relevance and overall value to the project.

Chapter 3 - Methodology

This chapter outlines the processes and methods used to evaluate the concept of the project. The initial experiments are described along with the research conducted into existing preservation and harvesting techniques. The results of the second experiments and nutritional tests are discussed along with the research into other preservation substances.

Chapter 4 - Second Experiments

The purpose of this chapter is to give a more detailed description of the second stage of the experiments. The harvesting that was carried out after the tests described in Chapter 3 will be discussed along with the details of the mixing and block making. A brief analysis of the results is also conducted.

Chapter 5 - Discussion of Results

This chapter will outline the results of the experimentation and research in terms of their relation to the project as a whole. A summary of the results is provided in Section 4.3 but this chapter will go into more depth and provide the results of costing and the implications of this. The success of the initial experiments, the harvesting and second experiments will be addressed as well as a comprehensive economic analysis including some sensitivity analyses.

Chapter 6 - Conclusions

The conclusion gives a brief summary of how the results of the various stages of the project meet the objectives as stated in the *Project Specification* (Appendix A). A description of the goals that need to be met by future work and the direction that the work will take to achieve these is also given.

Chapter 2

Literature Review

This chapter will outline all of the relevant literature that was used throughout the course of the project. The information can be grouped into three main areas:

1. Information specific to leucaena;
2. Information about harvesting methods;
3. information about Preservation techniques

The sources themselves will be discussed along with their relevance and overall value to the project.

2.1 Leucaena

The majority of the information available on leucaena focuses on such topics as food value, the development and hybridising of different cultivars and their global application. The most useful and accessible source for such information was found to be the internet, as was largely the case for all areas of research. The main benefit apart from the accessibility was that it yielded the most current information. The latter point is extremely important as this field of research has been moving at a fast rate for the last two decades. Garcia, Ferguson, Neckles & Archibald (1996) reports extensively on the nutritional value of leucaena in different parts of the plant at different stages of growth under different conditions. This is pivotal information for this project as it helps to establish which direction the harvesting aspect needs to focus on.

Harris (2004) helps to validate this research project by analyzing the benefits of leucaena in a beef cattle production system as part of a wider report. While the information in itself is cited from various other sources, it is a very good collection of the more important points. This section of the report shows that while leucaena does have some problems that are slowing its adoption, the productivity that can be gained from using it as a primary cattle feed source is ahead of any other system in tropical (and increasingly subtropical) Queensland.

An extremely comprehensive source of information has been Shelton et al. (1994) which is voluminous but contains virtually everything that anyone might want to know about leucaena. Due to the size of this publication, it is only applicable only in part to this project and the difficulty is finding which part. The article is extremely detailed in its description of the various applications for leucaena all over the world, any associated problems and their solutions and various research avenues that have been explored; past, present and future. These applications include high protein fodder for a variety of animals and their associated weight gain, milk quality etc., a fast, renewable firewood resource and soil rehabilitation both in a nitrogen-fixing capacity and through the use of biomass as a green manure. There are in depth descriptions of the development of cultivars and their propagation, hybridising programs aimed at improving various facets of leucaena in various locations worldwide. The entire document is some 200 pages in length with relatively little of it directly applicable to this research. In spite of this, it is probably the most comprehensive, universally applicable article about leucaena ever produced. Figure 2.1 gives a good representation of the various research and development programs that are being undertaken and is a fairly good summary of the main topics covered by the article in general. The figures are actually the results of a survey conducted at the the leucaena workshop with participation from 19 countries to find a democratic opinion of research priorities.

Another comprehensive source of information on leucaena and its various pest issues

Region	Africa [4][1]	America [5]	Australia [12]	Asia [18]	Global [5]	Overall Average [44]
1. Limitation						
Environmental	**57**	**40**	**34**	**45**	**35**	**41**
(a) Cool/Frost	6	14	9	2	4	6
(b) Acid soils	22	10	3	9	9	9
(c) Psyllids	8	0	15	17	8	13
(d) Other	21	16	7	17	14	13
Agronomic	**9**	**21**	**13**	**11**	**28**	**15**
(a) Establishment	**5**	15	8	6	9	7
(b) Seed production	**3**	5	4	4	12	5
(c) Other	**1**	1	1	1	7	3
Management	**11**	**12**	**11**	**10**	**6**	**10**
(a) Farming systems	9	5	5	6	0	5
(b) Other	2	7	6	4	6	5
Forage Quality	**14**	**15**	**32**	**10**	**10**	**17**
(a) Animal production	7	5	10	5	0	6
(b) Tannins	6	6	15	1	7	6
(c) Other	1	4	7	4	3	5
Wood Utilisation	**4**	**4**	**2**	**10**	**2**	**6**
Adoption	**5**	**8**	**8**	**14**	**19**	**11**
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**

Figure 2.1: Leucaena R & D priorities: values in columns show priority ratings as percentages out of 100 for each region (Shelton et al. 1994).

and production advantages and disadvantages by Halim & Chen (1996). This is in the same vein as Shelton et al. (1994), being voluminous, extremely detailed and varied although again, issues pertaining directly to the nature of this research are few and far between. There is a large amount of data given on issues such as crude protein levels and dry matter yield under different conditions. The results given, however cannot easily be applied as they are under different circumstances and are fairly inconsequential to this project.

Similarly useful but not very applicable information on the leucaena production efforts globally can be found in Nakahara (2000), Ngugi (2002), Phuc & Lindberg (2001), Nhan (2000) and Pascal & Salvator (1994). Throughout these works, there is the occasional mention of harvest and preservation techniques which invariably entails small scale hand harvesting and sun drying. Again, the information presented is useful although not directly to this research. The converse of this is that it serves to reinforce the worth of this exercise by the fact that there is no mention of attempting to preserving leucaena in the manner proposed in this project.

Lefroy (2002) gives a thorough description of leucaena production in Australia and the recommended R & D topics which are repeated throughout include optimising production on a site-specific basis. Again, this suggests that preserving leucaena in areas subject to frosts is a useful avenue of research. The article is full of the usual dry matter yields and crude protein levels and the presence of this information enhances another point made in the article, cited as Jones (1994):

> "... there is no justification for further research to document the value of Leucaena for animal production. He suggests instead that more work is required to demonstrate its value on-farm, particularly as its optimum use varies depending on the country, region and farm under consideration. In other words, the present need is for site-specific on-farm demonstration."

An interesting piece of information that was found in this article is an annotated bibliography of leucaena publications which is extremely useful for a quick analysis of what research has been conducted by whom. For completeness, this bibliography is included in Appendix B.

A source that focuses on the negative but important facet of leucaena is an article by Calvert (1998). It addresses the problem of weeds in general, primarily in Queensland and leucaena receives a harsh, but not unjust, mention. Although the issue of leucaena being a potential weed will not be addressed by this project, it should be noted that infestations of leucaena are common in coastal and riparian areas of northern Australia. Another source dedicated solely to leucaena is by Walton (2003). This is very good, comprehensive and objective assessment of the grazing and growing methods as well as the risks associated with leucaena spreading and growing outside of controlled environments. It is highly recommended as further reading. As is the case with any introduced species, flora or fauna, there is always the risk of it achieving a weed or pest status and this aspect cannot be ignored. Leucaena production systems, however, are estimated to provide an annual benefit to Queensland of $14 million (Walton 2003, 2). While this provides a good argument for the implementation of leucaena, it also creates a bias such that the environmental effects are sometimes overlooked.

A vast amount of the less specific information has and probably will continue to be gleaned from personal communications that have taken place extensively since the commencement of research. The nature of this information is largely qualitative but is nevertheless invaluable as a means of giving direction and focusing further research and experimentation.

2.2 Harvesting Methods

While there is virtually no documentation on the harvesting of leucaena, it is possible to make some educated judgments and assumptions based on the information that exists pertaining to other crops, forage or otherwise. As well as this, some information was received from Burchmann (2006) and Kenyon (2006) that some leucaena harvesting had indeed been carried out with small New Holland 33 crop choppers and other single row forage harvesters.

2.2.1 Forage Harvesters

There are a number of harvesters available built primarily for crops such as corn, barley, alfalfa and forage sorghum. A good review of a selection of different makes and model is done by Ragan (2002) but the results have limited use as, understandably, the crops tested were corn, barley and alfalfa which are inherently much softer than leucaena.

2.2.2 Tree Harvesters

There is some basic information available about mallee tree harvesting from the *Oil Mallee* (2001) website which is helpful because it has some images of the harvester that has recently been developed and how it works as well as outlining the various markets for mallee and the resulting biomass. This has some application as it suggests some possible uses of leucaena outside the ones focused on in this project, also helping to justify the research. The area of established tea tree and resulting products is fairly well documented in various journals and websites. Murtagh (1998) gives a very good well-rounded description of the industry in general while some information more specific to the harvesting is available from MacDonald (2006). Here some images are given which were illustrative in their similarity to the way it was proposed leucaena would be harvested. As yet, directly harvesting leucaena is still too innovative and no specific documentation has been available.

2.3 Preservation

2.3.1 Conventional Methods

Most information found on the preservation of leucaena fodder has only been mentioned in passing and none has been applicable to large scale operations. Again, a comprehensive source of this has been Shelton et al. (1994) but another useful article is by Ngugi (2002) in which a comprehensive description of the wider agroforestry problems present in parts of Africa is given. Leucaena forms an important part of this study and as such, Ngugi (2002) briefly describes the practice of drying fodder but this is applicable only to small operations as it involves the labour intensive method of "cut and carry" for a small number of animals. The possibility of making pellets from leucaena was investigated through *Lockyer Lucerne Pellets* (2005) and although quickly deemed to be of little use in this application due to cost, the information gathered was still useful for directing the scope of this project.

Kenyon (2006) has been a good source of knowledge on preserving leucaena in a silage form. He has been directly involved in the large scale procedure of ensiling leucaena although to date, it has only been achieved in combination with maize. The information received from this source has formed the mainstay for the comparison of the innovative preservation method outlined in this project with conventional methods. As will be explained in Chapter 5, silage is the most applicable conventional method to this problem and this information has been invaluable as a result.

A mention should also be made about the conventional methods of preserving conventional crops. A particularly useful source for this has been Raymond, Shepperson & Waltham (1972) which, although somewhat outdated, is extremely comprehensive and gives thorough descriptions of forage harvesting, hay and silage making and even mechanical drying methods/machinery. Unfortunately the focus is exclusively European and while the many of the techniques described have been applied to Australian conditions, none are applicable to the scope of this project. The agricultural needs in Europe are very different to those in Australia and this, coupled with the differences in climate, results in very different crops and preservation methods. The best example of this is the complicated machinery described for drying grass both in the paddock and in the shed. Not only is this largely unnecessary in Australia's climate but the financial gain would not be enough to warrant the capital cost of such machinery, especially in today's economic environment.

2.3.2 Cement

To gain an understanding of the cement hydration process, it was necessary to consult some civil engineering texts in the shape of Czernin (1980) and Gani (1997). While the vast majority of information presented in these texts was irrelevant for this line of research, they yielded some very useful data which formed the basis for the analysis of the cement reaction.

2.3.3 Cement Alternatives

The results from the initial experiments as discussed later in Section 3.1 prove that the hydrophilic substance necessary for preservation does not, by any means, need to be limited to cement. Through an informal source, the use of *calcium lignosulphonate* was recommended and subsequent research resulted in the eventual acquisition of some for testing. The properties of this substance appear to be somewhat shrouded in mystery but the most definitive information came from the *Lignin Institute* (2005). This is an organisation devoted to the promotion of various lignosulphonate products. It gives a reasonably detailed description of the manufacturing process (Appendix C) and various proven and potential applications. Many of these applications involve stock feed and its various production techniques such as an additive to improve the pelleting process. The general applications are summarised as follows:

- Binder;
- Emulsifier;
- Dispersant;
- Sequestrant.

Some fairly inconclusive information is also given concerning the food value and this is best summarised by the following quote:

> "Treatment of protein with lignin sulfonates that contain wood sugars chemically alters the protein so that it is not digested by rumen bacteria and moves into the small intestine where it can be used to support milk production."

While this is not supplied with any supporting evidence, it is suggestive that calcium lignosulphonate or something similar may be a more suitable active ingredient for the preservation of leucaena for stock feed.

2.4 Chapter Summary

This chapter has given a description of most of the literature that was accessed for the completion of this project. Much of the general knowledge that was used for making estimations and directing the course of the research and experimentation was gleaned from personal experiences. The management at Killara is also a veritable mine of information of which little is able to be referenced but is nonetheless relevant and invaluable.

The information available on leucaena is copious but unfortunately it was difficult to find material that is strictly relevant to this project. The texts that have been described were the most appropriate and useful to this topic directly.

A similar result was obtained with harvesting methods. There is a vast amount of information available in the well-established area of forage harvesting but virtually none on mechanically harvesting leucaena.

Documentation on large scale preservation of leucaena was definitively non-existent. Preserving leucaena as silage has been accomplished and the qualitative, unpublished source of this information was extremely useful. In terms of the preservation method using cement and molasses, the most informative texts were those available about cement and its reaction and properties.

Chapter 3

Methodology

This chapter outlines the processes and methods used to evaluate the concept of the project. The initial experiments are described along with the research conducted into existing preservation and harvesting techniques. Some further experimentation was then carried out and the results from the nutritional tests are discussed along with the research into other preservation substances.

3.1 Initial Experimentation

Initial experimentation involved the trialling of readily available hydrophilic substances in different concentrations to try and preserve some leucaena. This was done in a simple fashion using a small quantity of leucaena that was harvested by hand, cement, molasses and a kitchen blender (an old one). Gelatine was also experimented with as it is another readily available substance that absorbs water although it was expected, and subsequently proved, to be too expensive when compared with other options.

The aim of these experiments was to firstly determine if it is possible to preserve the biomass using a substance to absorb as much water as possible and secondly, at what percentages of the different ingredients this is achieved and what is the physical form of the result. To do this, three different mixtures were made for both cement and gelatine and the composition of these mixtures is shown in Figure 3.1 and 3.2.

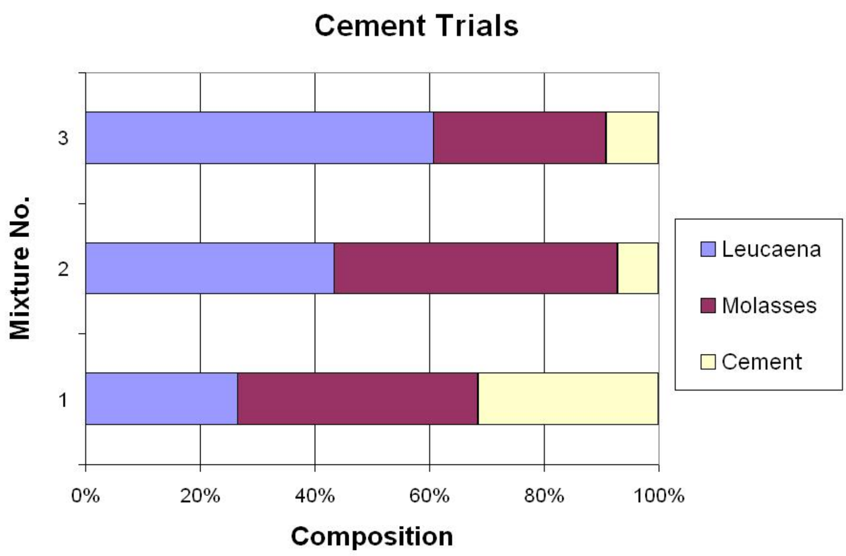

Figure 3.1: Mixture composition of cement-based blocks.

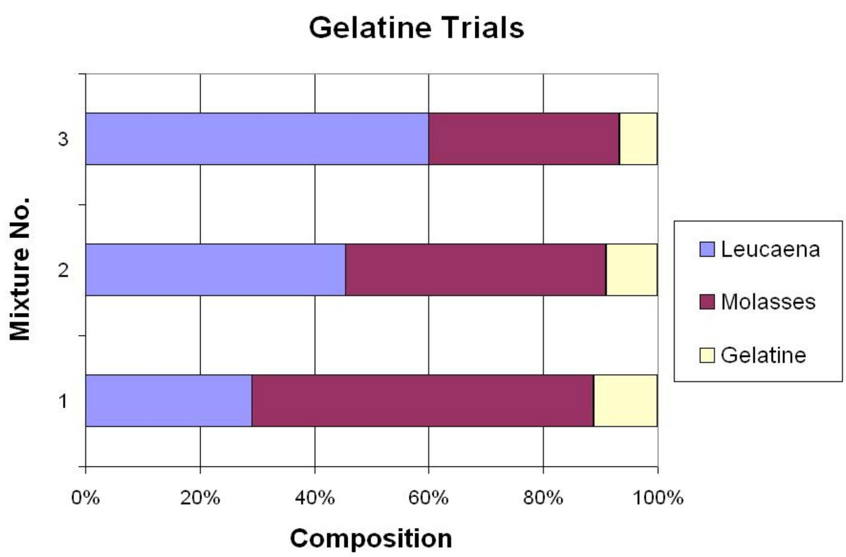

Figure 3.2: Mixture composition of gelatine-based blocks

This was sufficient to prove that leucaena could be preserved in such a mixture as no evidence of any degradation was evident after a period of several weeks. This gave enough confidence to enable the direction of the research to be planned. In fact the level of preservation was such that the resulting blocks have not changed at the time of this writing, a period in excess of six months. It also enabled some initial costing using estimation and this was also encouraging as the results were comparable to other feed sources available. In doing so, it immediately became apparent that at $12.5/kg, gelatine was simply too expensive to be a feasible option. This is contrast to cement at $0.30/kg. In terms of the quality of the resulting block, however, the gelatine was easily more superior as the texture and aroma were far better from a stock feed perspective. This means that further investigation into cement alternatives could be worthwhile.

3.2 Preservation Methods

There are two main options that are currently used for the preservation of conventional stock fodder:

- Cutting and drying as hay using machinery.
- Ensiling either as bales or in bulk, usually in constructed pits.

Both of these methods rely heavily on machinery for their profitability except for small scale operations where inexpensive labour is readily available. It is worth noting that the process of cutting and drying leucaena for later use is a practice that can be assumed to be in use and is mentioned in passing by Mutangadura & Matarirano (2002). This was addressed in an agroforestry study of southern Africa and without wishing to make generalizations, it is a reasonably safe assumption that the practice is restricted to a small scale and has a high labour input.

The process of making hay on a larger scale is reliant on machinery and the physical nature of the plant. Conventional crops that are cut and dried in the paddock are invariably baled and the machinery used is designed for these crops which are physically more homogenous and cohesive. This is in contrast to leucaena which has stiff stalks and stems with soft leaves. Upon drying, the highly nutritious leaves become brittle and readily dissociate from the rest of the plant. For these reasons, it is virtually impossible to make hay bales from leucaena.

Due to leucaena being a relative newcomer as an improved pasture for grazing cattle in Australia, there is little documentation available on the subject of preservation with the focus generally on the establishment and direct uses of the crop. Despite this, a significant amount of work has been done with irrigated leucaena in the north of Western Australia (Kenyon 2006). In this instance, the leucaena was chopped and ensiled in pits in combination with maize. This was basically successful although the standard methods for making silage were apparently modified to achieve the result.

The process of making silage is a very efficient method of preserving fodder as the crop maintains high levels of nutrition until feeding although it does introduce a number of complications into the management of the farming enterprise.

Some infrastructure and/or specialized machinery is needed to cut and store the silage and this is dependent on the which of the four storage methods is chosen:

1. Individually wrapped bales;
2. Loose chop wrapped in a tubular fashion;
3. Purpose built silos; or
4. Purpose built earthen bunkers or above ground pad storage.

Each of these options have advantages and disadvantages of their own but the physical nature of leucaena means that individually wrapped bales are an impossibility and the remaining three all have a common disadvantage in that an airtight seal needs to be maintained for as much time as possible. Research did not reveal any instances of leucaena being ensiled in tubular wrap and it is probable that the woody stems in the green chop would present a significant puncture hazard to the plastic wrapping.

The most viable option for Killara would be bulk storage and due to the geography and soil type, this would have to be above ground. The main problem with this method, apart from the initial need for a complete airtight seal for the anaerobic processes, is that when the stack is opened to the air it is best if feeding continues until the stack is finished. The feed can be sealed again but it invariably results in some spoilage occurring for a small distance from where the material was exposed to the air. The method also requires inoculants for best results and at present, it is far from perfected for a purely leucaena situation

Silos were not investigated in this research as they typically have a very high capital cost. The other piece of machinery that is usually needed to generate a feed quality sufficient for Killara's needs is a feed mixer for combining silage with other high quality feedstuffs such as molasses and grain. This is necessary as silage generally does not have enough nutritional value in its own right. It is hoped that this research will provide a viable alternative to these methods.

Another practice that was investigated is the pelletization of fodder into a high density, high value product. The process is reasonably common with conventional high protein crops such as lucerne but it has a number of disadvantages which inhibit its application for leucaena:

1. Machinery required: the process uses a number of large, stationary, expensive machines that use copious amounts of energy.
2. Input requirements: the material that is commonly used is lucerne hay in a bale form. This does not solve any of the relevant problems as it means that the fodder needs to be dried to approximately 10% - 20% moisture content and baled; processes that this research is endeavouring to find alternatives for.
3. Cost: due largely to the energy input required, the process generally adds around \$100/tonne on top of the initial harvesting and handling costs (*Lockyer Lucerne Pellets* 2005). This does not include the massive freight costs that would be incurred in transporting the biomass to the pelletization plant and as such, the process can be excluded from further research.

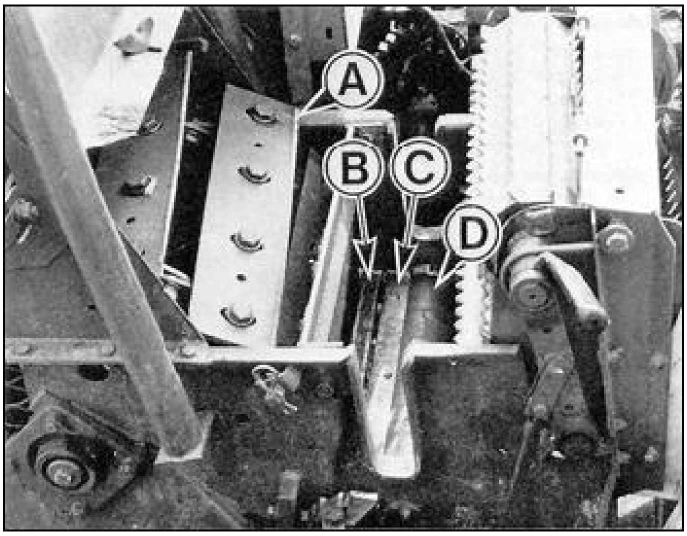

Figure 3.3: Drum chopper assembly showing (A) Rotating Knives, (B) Shear Plate, (C) Scraper, (D) Smooth Feedroll. Material flows from right to left (Ragan 2002).

3.3 Harvesting Methods

There are two main existing harvesting methods that were analysed for their potential application for the harvesting of leucaena. Forage harvesting is not a new concept and the documentation available is comprehensive and more than enough to work with. The other option is an Australian invention and is used for harvesting mallee for oil production (*Oil Mallee* 2001).

All forage harvester operate on the principle of fast moving blades chopping material that is fed in at a set rate. The way in which this is done may vary significantly but the basics remain the same and this is also true for the mallee harvester. Some harvesters may consist of two cutting points such as flail harvesters where the crop is mown in the same way as a conventional flail mower and passed through a secondary cutting stage. The flail mower is simply a number of blades, usually mounted with flexible chains, which rotate around a horizontal axis as opposed to the vertical axis as in conventional lawn-mowers. The secondary chopping action is basically a shearing action with one stationary edge and other fast moving blades. The blades can either be mounted such that their axis of rotation is at 90° to the direction of material flow as seen in Figure 3.3 or in an offset disc fashion with the axis in the same direction as the flow. An example of this second configuration is shown in Figure 3.4

Figure 3.4: Disc chopper configuration where material is chopped and ejected with the same disc (Personal Photo).

Figure 3.5: John Deere forage harvester with pick-up front (left) and header front (right) (*John Deere Self-Propelled Forage Harvester Web Brochures* 2006).

3.3.1 Self-propelled Harvesters

Mechanical forage harvesters are available in a number of different types but they can be broadly classified into tractor-powered or self-propelled varieties. Some good examples of the type of large, heavy duty machine that is available in the self-propelled type are shown in Figure 3.5. As can be seen from the pictures, this type of machine was deemed to be unsuitable for this application as leucaena is generally grown in single rows that can be anywhere from 3m to 15m apart, depending on the grower's preference. The pick-up front is only used where it is desirable to dry the crop before chopping with the forage harvester and as explained in Section 3.2, this is impossible to do with leucaena

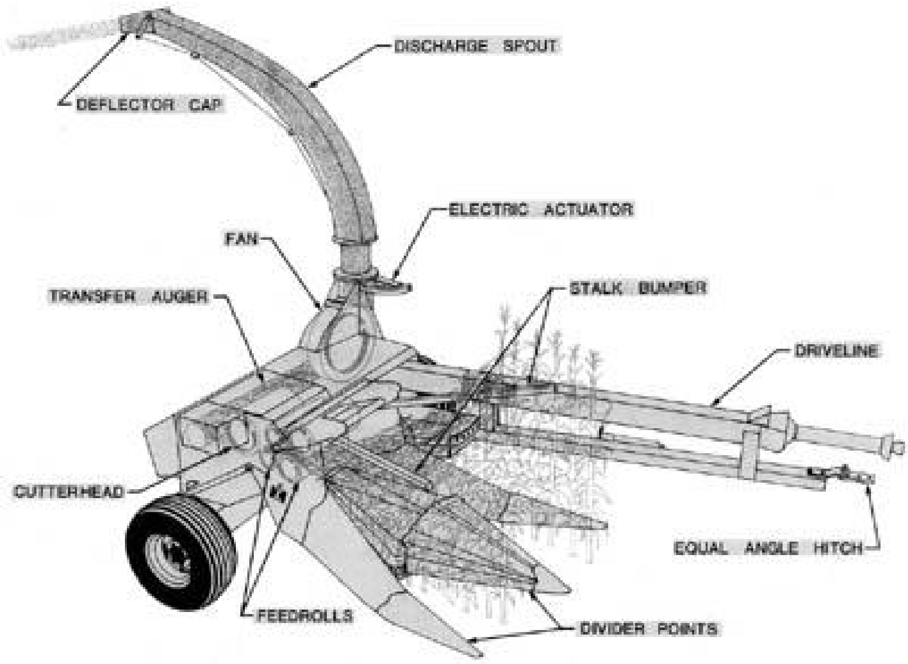

Figure 3.6: Cut and blow design (Slingerland 2003).

due to its inconsistent physical nature.

3.3.2 Tractor-powered Harvesters

The tractor-powered forage harvesters can further be classified into two basic types known as “cut and throw” and “cut and blow” (Slingerland 2003), diagrams of which are shown in Figure 3.6 and 3.7. The cut and throw performs the cutting and ejection of material in the same part of the machine whereas the cut and blow design does the two tasks in separate areas. Both of these harvesters are available with a number of different cutting methods. As well as this, they can also be configured with a pick-up front. The basic types of cutting fronts are row crop headers and mowers where depending on the machine, 1, 2 or 3 rows can be cut in a single pass. Because leucaena is commonly grown in rows with a comparatively large spacing, a single row crop header was decided to be the most economic.

Another machine that is worth noting is the New Holland forage chopper which has previously been used for chopping leucaena (Burchmann 2006) and can be seen chopping tea tree in Figure 3.8. This machine was not chosen as it is less suitable to rows

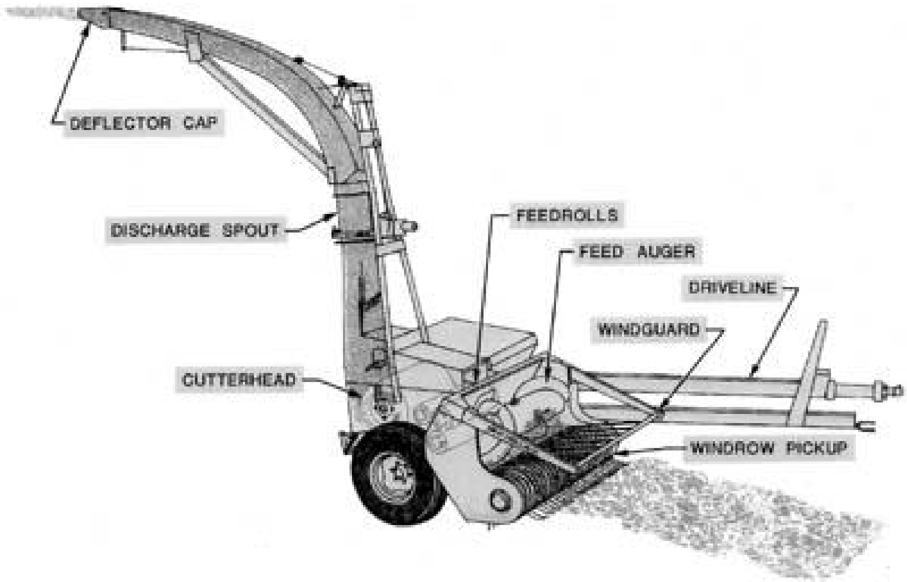

Figure 3.7: Cut and throw design (Slingerland 2003).

Figure 3.8: Tea tree harvesting in action (MacDonald 2006).

Figure 3.9: Purchased POTTINGER forage harvester (Personal Photo).

and modifications would have been needed to cut at the desired height.

Purchased Harvester

The machine that was chosen and later purchased, was therefore dependent on price, availability and the single row design. The machine that met these requirements was a second-hand POTTINGER MEX II, shown in Figure 3.9. The machine is a "cut and throw" which has several advantages for the work it was used for. It is compact and fits close to the tractor which makes it suitable for the leucaena on Killara as it is established in rows at 3m spacings. The design is simple and easy to maintain with a continuous scissor cutting action (Figure 3.10) which proved, despite doubts, to be effective for leucaena and the machine could easily be set to the desired cutting height of around 400mm.

3.3.3 Mallee Harvester

The mallee harvester is also worth noting although its application into leucaena harvesting is probably fairly limited and definitely outside the scope of this research. The harvester is designed for the purpose of chipping large mallee trees where they stand and as shown in Figure 3.11, is far more heavy duty than needed for the leucaena stands

Figure 3.10: Cutting action of POTTINGER harvester (Personal Photo).

Figure 3.11: Mallee harvester in action at Tincurrin (*Oil Mallee* 2001).

at Killara. As this project is focussed on attaining a high feed quality, the leucaena is harvested when there is much more leaf present than wood. In a situation where biomass or wood chip is the desired product and stock feed quality is unimportant, the mallee harvester or something similar may have some application. This would occur when leucaena is allowed to grow to a significant size such that a forage harvester is no longer capable of handling the plant.

3.4 Second Experiments

The second experiments were essentially the same as the initial experiments except on a larger scale. The POTTINGER harvester was adjusted to the purpose by fitting the cutting disc with a full complement of blades for a finer cut and setting to the desired height. It was tested first with some hand-picked pieces of leucaena to make sure the chipping action worked well enough. The continuous scissor action was then tested on a heavily grazed stand of leucaena with some stalks in excess of 30mm in diameter. Such a stand was deemed to be at the most demanding end of the scale and its performance was easily adequate. The chips of leucaena produced were in the range of approximately 5-30mm long, no thicker than a pencil and relatively soft considering the dry, leafless state of the plant.

At this point, it was deemed that the POTTINGER would be easily sufficient for the purpose and the next stage of experimentation began in earnest. Chapter 4 gives the complete description of these second experiments as they were sufficiently complex to warrant their inclusion in a separate chapter. The end result of these experiments was nine different mixtures of leucaena green chop, molasses and cement and this chapter will continue with the methodology process after the second experiments were completed.

3.5 Nutritional Analysis

A selection of the samples were chosen for a feed analysis to further determine the worth of the exercise. The test results include:

- Metabolisable Energy (ME) (Ruminant);
- Protein;
- Fat;
- Crude Fibre;
- Ash;
- Moisture;
- Nitrogen-Free Extract (NFE).

The samples chosen for this test were:

- The initial test block with the highest cement component;
- The block from the second experiments with 8% cement and 40% leucaena;
- And some sun-dried leucaena green chop.

These were chosen to give the best representation of the range of results that might be expected with this method and the results are shown in Figure 3.12. The initial test block was chosen as it seems to have an indefinite shelf life and is some measure of a worst case scenario in terms of feed quality. The block with 8% cement and 40% leucaena had attained the highest level of preservation of all the blocks from the second experiments and as such it is a reasonable gauge of a near maximum feed quality that can be expected while maintaining some shelf life. The feed quality of the dried leucaena biomass is also very useful to know as it gives a measure of the quality of the principal material that is then subjected to changes that dilute and alter its composition.

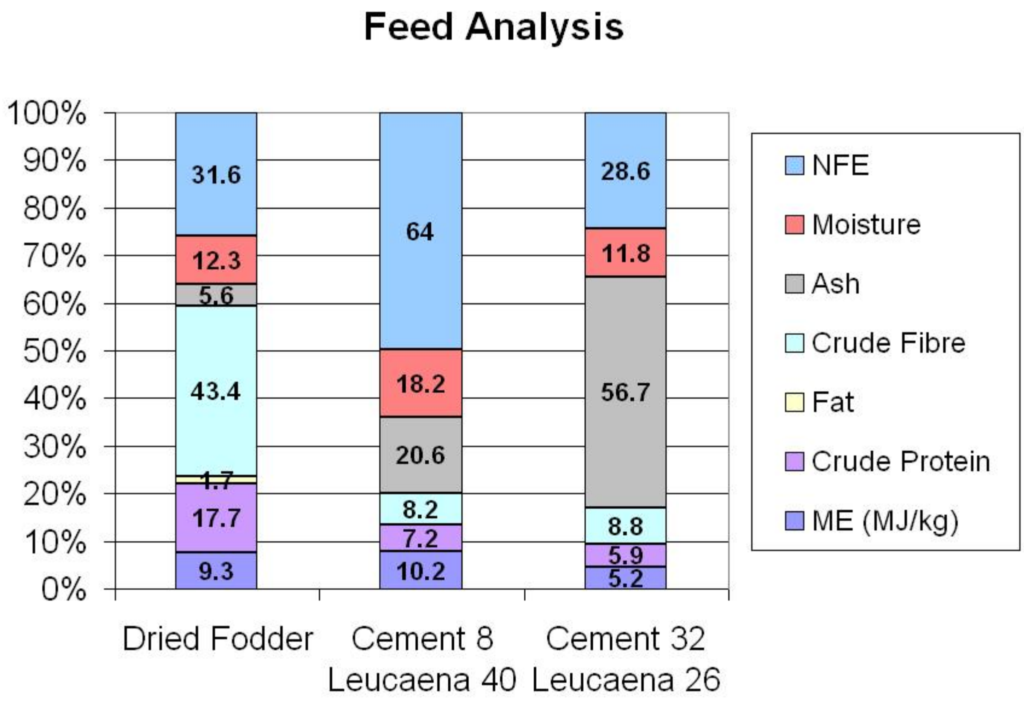

Figure 3.12: Chemical composition of fodder materials.

The main points to note from Figure 3.12 are the crude protein (CP) and ash levels. The significant increase in the ash proportion of the block with 32% cement and 26% leucaena is partly a result of the high proportion of cement which itself contains a substantial amount of ash. For the most part, however, the cement effectively transforms water into dry matter and hence, ash. This will be explained further in Sections 4.3.2 and 5.3.2. This is an undesirable but unavoidable result as ash is an indigestible part of the feed. It is highly desirable to maintain as much crude protein as possible in the resulting product as it is the protein levels of leucaena fodder that makes it such high quality.

3.6 Alternative Substances

While the experimentation was being conducted, research continued into alternatives to cement that might be used. The most attractive aspect of cement is its low cost. It can be readily obtained for around 30c/kg which allows the cost of ingredients in the experiments conducted to fall in the range of around $40-$100 (see Section 5.4) per tonne of feed produced. Even so, the cost of cement is something of a dead weight as it is a cost input from which no direct nutritional benefit is obtained and for this reason, some alternatives have been researched and even purchased. It is hoped that a higher quality feed might be obtained with an alternative.

3.6.1 Calcium Lignosulphonate

The existence of this particular chemical was discovered by chance from an informal conversation with an unlikely source. Further research revealed that lignosulphonates are used in various forms for a number of applications such as dispersants in a wide variety of industrial processes, dust suppressants, sequestering metal ions and most notably, binding and gelling agents for animal feed products. The impression obtained from the research is that there is still a vast number of potential applications for this particular family of chemicals that are yet to be realised. An example of this is the way in which proteins that have been treated with lignosulphonates are apparently altered in such a way as to become more usable in the ruminant digestion system (*Lignin Institute* 2005).

The main point to note with calcium lignosulphonate when compared with cement is that the former is organic and as such, a more suitable addition to animal feed. The most obvious disadvantage with it at this stage is that the cost may well prove prohibitive as it was purchased at the rate of $5.60/kg. This is almost 20 times the cost of cement which means that the quality of the product needs to be significantly better to justify its use. A schematic of the production process of lignin-based products is shown in Appendix C to give a better indication of the nature of the chemical.

Actual experimentation with calcium lignosulphonate was prohibited by the onset of winter and the considerable time lapse between the ordering and delivery of the chemical. Unfortunately this means that a proven comparison cannot be made to cement within the project timeframe but future experimentation is planned.

3.6.2 Magnesium Oxide

Continued research for this project has recently discovered the practice of using magnesium oxide to form hard, weather-resistant blocks (Skoch & Hodge 1979). This is apparently achieved by using molasses as the principle medium and adding a water-absorbing clay and magnesium oxide along with some water. These ingredients form the essentials to which the desired nutritional ingredients are added. Apparently the actual reactions and behaviour of the magnesium oxide in the mixture are not completely understood but it appears that it has significant water binding properties. The process of binding with water and as such, lowering the water activity in the product is the key to the success of preserving leucaena in such a form. For this reason, further research and experimentation with magnesium oxide may prove useful.

3.7 Chapter Summary

The methodology is a chronological description of the research and events that were carried out during the course of the year. It has given a description of the activities at various stages of the project and why these were undertaken. Some limited results and conclusions have been described and the reason that these have been included here is that they are essentially intermediate results that were needed for focussing remaining work. The section about the second experiments was summarised but largely omitted as it was chosen to include the full description of this stage in a separate chapter. This is because it is pivotal to the project as a whole and warranted an in depth description that could not be accommodated in the methodology.

Chapter 4

Second Experiments

The purpose of this chapter is to give a more detailed description of the second stage of the experiments. The harvesting that was carried out after the tests described in Chapter 3 will be discussed along with the details of the mixing and block making. A brief analysis of the results will also be conducted.

4.1 Harvesting

Figure 4.1: Leucaena harvesting (Personal Photo).

After the initial testing on the thick, woody leucaena, the POTTINGER was then used to harvest a quantity of leucaena from a long-suffering crop. Unfortunately, it was the best available and its poor state was due to the dry season and the approach of winter (Figure 4.1). The harvester performed well throughout with the only notable problem being that the leucaena plants sometimes missed the head of the machine due to the occasional sprawling nature of the plant. This was not an issue for the purposes of experimentation and could easily be remedied with some minor modifications. The green chop produced by the harvester as shown in Figure 4.2 is reasonably fine although from an animal feed point of view; the finer, the better. The problem with decreasing the chip size is that it inevitably requires a more complicated machine with an increase in the power and energy input. A smaller chip size would also be beneficial for preserving leucaena in the molasses and cement mixture as it would enable better release of moisture and hence, a more efficient cement reaction.

Figure 4.2: Leucaena green chop (Personal Photo).

The design of the harvester proved to be nearly ideal for the situation. Because of the relatively close row spacing (3m) of the leucaena at Killara, it was imperative that the design allowed the tractor to drive between the rows of plants. As shown in Figure 4.3, the harvester fits very neatly on the tractor used (90hp SAME EXPLORER II) and allows harvesting of any row without the need to straddle other rows; a practice which tends to cause plant and/or tractor damage.

Figure 4.3: Leucaena harvesting (Personal Photo).

4.1.1 Cutting Height

The cutting height is an area that may require further investigation and perhaps some more serious modifications to the harvester. Due to the nature of the crop and the design of the harvester, the cutting height was set at approximately 400mm. As can be seen in the pictures, the plants still had a significant quantity of leaf below 400mm and because harvesting occurred at the end of the growing season, a low cutting height would have excessively stressed the plant. To achieve a cut any higher, the POTTINGER would need an extension for the supporting wheel and for a significant increase, major modifications to the PTO drive train.

There has been some previous work done by Krishnamurthy & Gowda (1983) (Garcia et al. 1996) in Hawaii and Central America which suggests that the maximum herbage and crude protein yield is obtained when repeated harvesting is restricted to around 1.5m. Before jumping to conclusions, however, it must be understood that there are a number of important differences between the previous work and this research compiled in this report. Firstly, the climate at Killara is fairly different in that frosts invariably occur during winter which results in a near complete plant regrowth. The leucaena grown in Hawaii was also subjected to repeated harvests on a 70 day frequency, regardless of the season. The leucaena at Killara, however, generally experiences two or three grazings during the summer months only (depending on rainfall). It is also probable

Figure 4.4: “Good” leucaena stand (Personal Photo).

that any single stand will only be harvested in this way once every few years. As well as this, the cultivars on which this previous work was done vary substantially with the “Tarramba” cultivar at Killara in their branching, plant height and frost tolerance characteristics. While the crude protein levels may be slightly reduced by harvesting in the manner proposed, it is anticipated that this will not present any significant production problems.

4.1.2 Harvesting Rate

The actual harvesting was reasonably time-consuming and this can almost solely be attributed to the sad state of the crop. Because of the rough surface of the heavy, cracking clay, groundspeed had to be limited to approximately 2km/hr and this meant that it took around 5hrs to harvest approximately one tonne of green chop. Figure 4.4 is included so that a comparison can be made between what is a “good”and “bad (Figure 4.3)” crop. With this picture in mind, it is easy to imagine the output could be substantially increased from such a crop and a rough estimate puts the possible output at somewhere near 4 tonne/hr.

4.1.3 Power Requirements

The harvester uses a PTO power input of 540rpm and initially, this was done with the standard 540rpm PTO output and the engine running at 2200rpm. The power generated from this configuration proved to be excessive for the situation and the PTO was changed to the 1000rpm output with the engine running at 1300rpm to maintain the 540rpm speed. This proved adequate for the crop at the time and would increase efficiency considerably although it is probable that a more vigorous crop will require the higher powered configuration.

4.2 Mixing

The green chop produced by the harvester was then mixed with measured quantities of molasses and cement in a cement mixer. While this method was adequate for the small batches needed for the experiment, it very quickly became apparent that a cement mixer is totally unsuitable for use in anything other than small scale tests. The nature of the action is too gentle and there are no opposing surfaces to mix effectively. The blend of leucaena and molasses, although varied, is generally made with the object of minimising the molasses component. Molasses is significantly more expensive than the estimated leucaena cost and as the preservation of leucaena is the main objective, it is logical to minimise the molasses. This results in a mixture that tends to form clumps and in this situation, required significant human intervention inside the mixer in order to obtain a thorough blend. The conclusion was quickly drawn that an industrial feed mixer would be an essential part of the process.

The proportions of the ingredients needed were estimated from the results of the initial experiments and this led to nine variations. The amount of cement added was either 2%, 5% or 8% with leucaena added in proportions of 40%, 60% or 80% with everything measured on a weight basis. A graph illustrating these mixtures is shown in Figure 4.5 where C is the cement concentration and L the leucaena. One of the objects of this testing was to determine the limit recipe for which the mixture degrades and has no storage properties. This is the reasoning for the much lower percentages of cement than

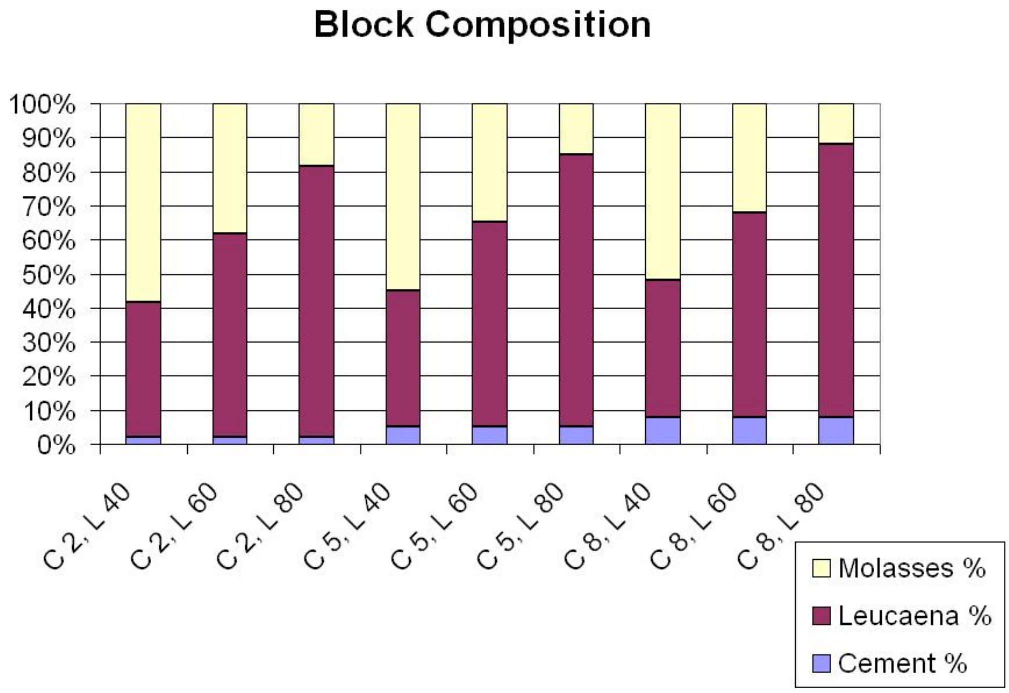

Figure 4.5: Mixture composition of second experiments.

used in the initial experiments.

The object of using the varying molasses ratios was to determine its effect on the preservation of leucaena. At this stage, it was not known whether leucaena would be preserved in molasses alone and 40% leucaena was chosen as the lowest physically and economically feasible limit for this. Each mixture was poured into either a cardboard box or a plastic drum as a mould with the aim being to determine which would be the better method of storage (Figure 4.6).

A number of batches mixed in the cement mixture were also combined in a large polythene container. The total net weight of this resulting mixture was approximately 170kg. The object of this exercise was partly to determine the storability of the mixture in a larger amount and partly to enable a useful stock feeding experiment. Due to time and equipment constraints, the ingredient ratios were unable to be accurately measured although it was probably close to a 8% Cement, 40% Leucaena and 52% Molasses configuration. This exercise also served to vehemently reinforce the need for an industrial feed mixer for further work.

Figure 4.6: Resulting blocks in assorted moulds (Personal Photo).

The excess leucaena green chop was sun-dried and also fed to stock. The resulting feed was reasonably coarse and unpalatable in appearance but this did not dissuade the stock in their hearty consumption of it. While the bulk of the feed was readily consumed, the cattle were somewhat selective and a small amount of the coarser woody chips remained in the feed trough when they had finished eating. The guinea pig stock happened to be the small herd of dairy cows at Killara and there was a sufficient quantity of the dried leucaena to notice an immediate improvement in milk yield. Such a marked result from what was basically a below average crop of leucaena serves to reinforce its nutritional value.

4.3 Results and Analysis

4.3.1 Leucaena Moisture Content

The moisture content of the fresh leucaena green chop was also tested by placing four samples in a moderate oven for about 3hrs, the outcome of which is shown in Table 4.1. Sample 4 was ignored in the calculation of the mean Moisture Content (MC) and Dry Matter (DM) as it was deemed to be not completely dried. The equipment used for this procedure was not ideal as accurate readings of the temperature and weights were difficult. Nonetheless, the uniformity of the first three samples suggests that it was still a reliable result.

Table 4.1: Moisture content of fresh leucaena green chop.

Sample no.	Wet Weight (g)	Dry Weight (g)	MC (wet basis)	DM
1	130	50	62%	38%
2	230	85	63%	37%
3	265	100	62%	38%
4	*285*	*120*	*58%*	*42%*
		Mean:	**62%**	**38%**

4.3.2 Block Results

The blocks were stored out of the weather for several weeks to determine the preservation achieved and the results were, in a word, disappointing. The next step was to determine the moisture content of the blocks but upon inspection, most had developed mould and degradation in varying degrees. Although the mixtures were more solid than they would have been without the addition of cement, they all retained some liquidity in varying levels. Even so, the moisture content experiment was carried out with the best samples of each, bar one that had no suitable material left. Samples of the blocks from the initial experiment were also included although owing to the time lapsed, it is probable that they had dried out somewhat from ambient storage. The results from this exercise are shown in Figure 4.7 as a percentage DM along with the results from the feed analysis for the appropriate blocks. Blocks 1, 2 and 3 are the blocks from the initial experiments and the numbers of the others depict their cement and leucaena percentages respectively.

The theoretical DM was calculated for each case by using the percentage of each ingredient multiplied by its relevant DM fraction. For example, the theoretical DM for block no. 1 with 32% cement, 26% leucaena and 42% molasses was calculated as follows:

$$TheoreticalDM = 32\% + 0.38 \times 26\% + 0.75 \times 42\% = 73\% \tag{4.1}$$

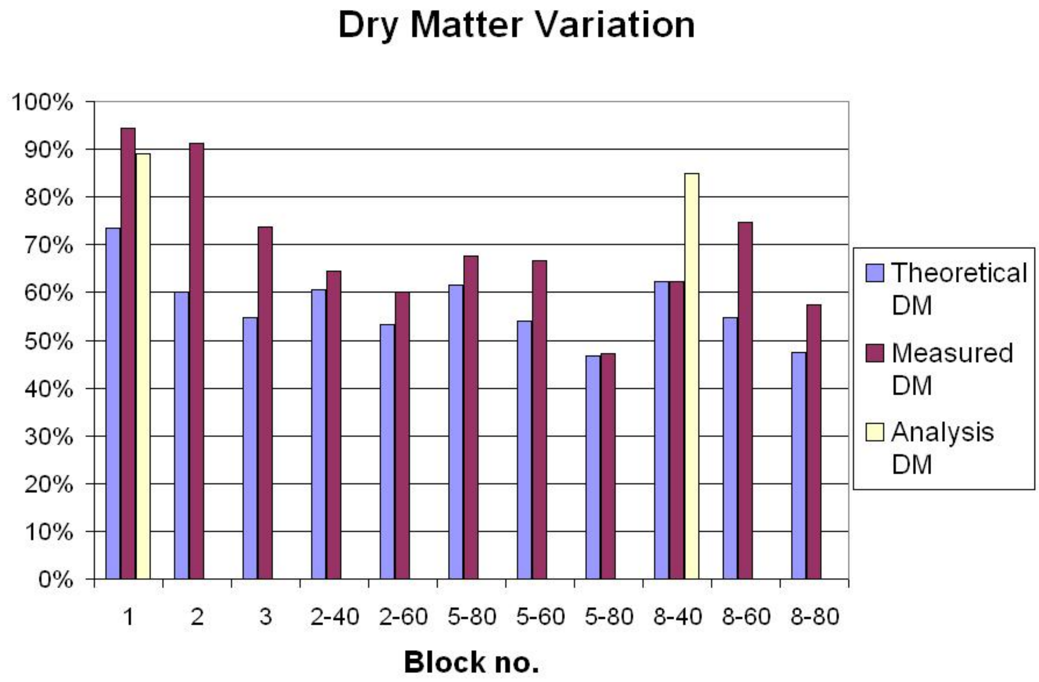

Figure 4.7: Graph showing variation in DM from different methods.

The percentage DM of leucaena fodder was taken as 0.38 as calculated in Section 4.3.1 and the approximate DM of molasses of 0.75 was sourced from *Expanded use of molasses for intensive beef cattle feeding* (2000). These results display some curiosities that occur when the cement undergoes hydration in such an environment and this will be explained further in Chapter 5. Figure 4.7 clearly shows that the theoretical DM was consistently lower than the measured DM. This is essentially the crux of this method as it succinctly demonstrates that water was converted to dry matter; the key element for obtaining shelf-life in this particular way.

The immobilisation of water by cement would account for the majority of the reduction in MC. In reality, some errors were probably introduced into the determination of the moisture content by the methods used. The samples used were simply oven-dried as whole pieces but hindsight suggests that some breakdown of their physical structure might have given more accurate results. The hydration of cement is undoubtedly the major cause of the MC reduction and the next section will outline the methods with which this phenomena was analysed.

After several months, the 170kg mixture in the polythene container was fed to some cattle which they appeared to thoroughly enjoy. The animals were not selective in their consumption as was the case with the dried green chop. The mixture was by no means solid but a reasonable level of preservation was achieved as there were only small amounts of mould and degradation apparent near the surface. The result appeared to be combination of preservation by means of water immobilisation with cement and the anaerobic ensiling process. This was inferred from the rich, slightly fermented aroma which was similar to the smell of conventional silage.

4.3.3 Hydration Analysis

For each block, a number of calculations were made based on the percentages of cement and water involved at each step. The full spreadsheet is shown in Appendix D but a summary of the steps will be given here. After calculating the theoretical DM as explained in the previous section, the amount of water that would be required for full hydration of the cement component was calculated. This was based on the maxim that 100kg of cement requires 25L of water for full hydration (Czernin 1980) and as the percentages are on a weight basis, it was taken as 25kg of water for 100kg of cement.

As the cement had cured, a different measured DM could be expected from the theoretical and from this difference, a measure of the water used in permanent hydration (immobilised) could be found. This was further substantiated by using the results from the feed analysis and their appropriate blocks. The implications of these results will be explained in more detail in Chapter 5.

4.4 Chapter Summary

The second experiments were the crux of the experimental work in this project. This chapter has discussed the aims and procedures that were used for this section of the research.

The harvesting procedure revealed that the use of the POTTINGER harvester at Killara is simple and effective. The only thing that was lacking in this work was rainfall to generate a good crop for testing. The resulting green chop appears to be adequate for the purpose of this project and there are minimal improvements that need to be made to the harvester.

The most definitive result from the mixing stage was the realisation that an industrial mixer is essential to the process. This will need to trialled but it is likely that most of the feed mixers currently available would be sufficient.

The results of these experiments introduced a number of problems and curiosities to be explained. In terms of the success of the method, the results show that an ideal cement concentration is yet to be confirmed but the process still appears to be viable.

Chapter 5

Discussion of Results

This chapter will outline the results of the experimentation and research in terms of their relation to the project as a whole. A summary of the results is provided in Section 4.3 but this chapter will go into more depth, provide the results of costing and the implications of this. The success of the initial experiments, the harvesting and second experiments will be addressed as well as a comprehensive economic analysis including some sensitivity analyses.

5.1 Initial Experiments

The results of the initial experiments essentially proved two things:

1. Preservation of leucaena in a molasses mixture with a hydrophilic substance is possible; and
2. The cost is such that further investigation was warranted.

The costing of the process was approximately evaluated very early in proceedings which demonstrates the importance of this angle. Figure 5.1 shows the cost of the cement and gelatine methods against each other. The important point to note from this graph is that firstly the gelatine is extremely expensive and secondly, that the highest input

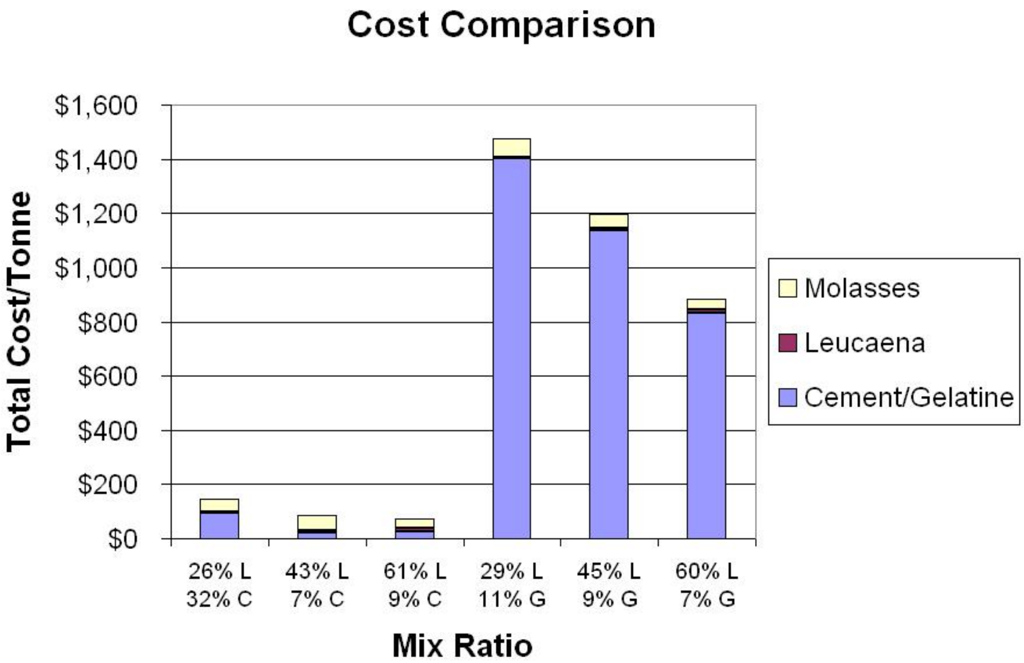

Figure 5.1: Total cost of ingredients per tonne of feed produced from initial experiments where L is leucaena, C is cement and G is gelatine.

cost is the hydrophilic additive. Even in the cement mixtures, it is a considerable cost input, especially when there no direct feed benefit is derived from this input. The cost of cement was set at \$0.30/kg although this may vary depending of the place of purchase. Gelatine costs around \$12.50/kg, molasses can be assumed at \$0.11/kg although this can fluctuate significantly and a cost for the leucaena component was estimated at \$0.02/kg. The spreadsheets in Appendix E show in more detail these costs and how they were applied. The impact of a variable leucaena cost will be discussed further in Section 5.4 although it is obvious that it is a minor part of the overall cost.

5.2 Harvesting

The harvesting aspect of the project was, by comparison, reasonably easy and well defined although considerably expensive. The POTTINGER harvester as described in Chapter 3 was purchased for approximately \$6000; a substantial outlay for a research project. This was justified by the reasoning that the harvester alone would be beneficial to Killara, regardless of the outcome of the preservation experiments. In terms of forage handling equipment, this is a meagre sum when compared with some of the bigger and more complicated items that can be used. An example of this is the feed mixer which was coincidentally purchased by Killara to help cope with drought feeding issues. In the event, it will be an essential addition to the leucaena preservation process but it comes at a cost in excess of $70,000.

Part of the problems that were encountered with the preservation in the second experiments may have stemmed from the coarseness of the green chop. Considering the nature of the plant and the simplicity of the harvester, the green chop was relatively fine but there is definitely scope for further work in this area to try and achieve a more efficient preservation. It is anticipated that as the chip length decreases, the cement reaction will work more effectively and perhaps result in a reduction in the amount of cement required. This would have the advantage of reducing the overall cost and increasing viability but it would come at a price. To significantly reduce the size of the chips generally means a second stage to the chopping and this is invariably a function of the harvester. This results in a much more complicated and expensive machine. The other means of reducing the chip size may be in the mixing process which, to date, has not been tried but this will be explained further in the next section.

5.3 Second Experiments

5.3.1 Mixing

As already summarised in Section 4.3, the second experiments did not yield the results that were anticipated. It was expected that a number of the mixtures would not be preserved as one of the aims was to determine a lower limit for the ratio of cement required. Unfortunately, only one mixture retained any semblance of shelf-life and thankfully, it was no surprise which one. As the leucaena has the highest moisture content of any of the ingredients, it follows that if one mixture was to be preserved, it would be the one with the least leucaena and the most cement (40% leucaena and 8% cement) which was indeed the case. The same reasoning held for the others as although

Figure 5.2: Picture of Killara's feed mixture showing knife arrangements (Personal Photo).

the blocks were only monitored in a spasmodic fashion, it was reasonably obvious that the first block to show signs of degradation was the one with the least cement and the most leucaena (80% leucaena and 2% cement).

After the success of the initial experiments, the cement ratio was probably estimated with a little too much optimism for the bigger scale second experiments. As has already been outlined, it is suspected that the chip size plays an important part in the behaviour of the cement reaction. The other major difference was the mixing method. While a blender was used for the initial experiments, this was clearly unsuitable for larger batches. A blender has a much faster and more destructive action than the cement mixer's slow, tumbling action. In hindsight, the estimation of the cement required should have been increased to allow for these factors. The easiest factor to remedy is the mixing method as in future, this will be undertaken with Killara's industrial feed mixer; this has a much more destructive action than the cement mixer and will hopefully result in a more thorough incorporation of cement into the mix and hence, a better result.

The action of the mixer deserves some more elaboration as it is reasonably probable that some further reduction of chip size will occur. As shown in the left of Figure 5.2, there are a number of internal knives over which material is passed as well as a blade running full length along the top of the machine (shown right). The latter is primarily for cutting hay from a bale but the point is that the action is reasonably aggressive and far more destructive than the humble cement mixer. Further destruction of the green chop, in particular the woody pieces, will almost definitely result in a more homogenous mixture that is less susceptible to air pockets and entry points and more able to react with cement. In addition to this, smaller woody chips will be more readily consumed and digested by stock. While a drastic improvement in the chip size is considered unlikely in this machine, there will probably be some further destruction and definitely an improvement in the general quality of the mix.

5.3.2 Cement Hydration

The reaction of cement is an interesting topic and from the research conducted, it appears there are still some unanswered questions concerning its manner of hydration. The figure of 38L per 100kg of cement is commonly quoted in Gani (1997) and Czernin (1980) as the amount of water actually required for full hydration as some water becomes unavailable for reaction in the process. The type of solution that is encountered by the cement in a leucaena preservation situation is one with an large excess of water and the spreadsheets developed in an attempt to explain this process are shown in Appendix D.

The basic theory appears to be that the water required for hydration becomes the cement gel and is no longer evaporable at 105℃. Some of the water forms the "gel water" and this portion is evaporable at 105℃ but cannot react further with cement. Whether this water is "active" and available for the degradation process is unknown but the conclusion is probably not. The other portion of water if there is still an excess is apparently dispersed and given the label "capillary water." The behaviour of this water in the molasses and leucaena mixture can probably be assumed as active although it is likely that its mobility is reduced. A useful diagram to gain a better understanding of this process is shown in Figure 5.3.

This would not appear to apply directly to this situation, however, as Appendix D shows that the hydration apparently achieved in the molasses and leucaena process can be in excess of 1000%. From the mixtures used it is also apparent that the best

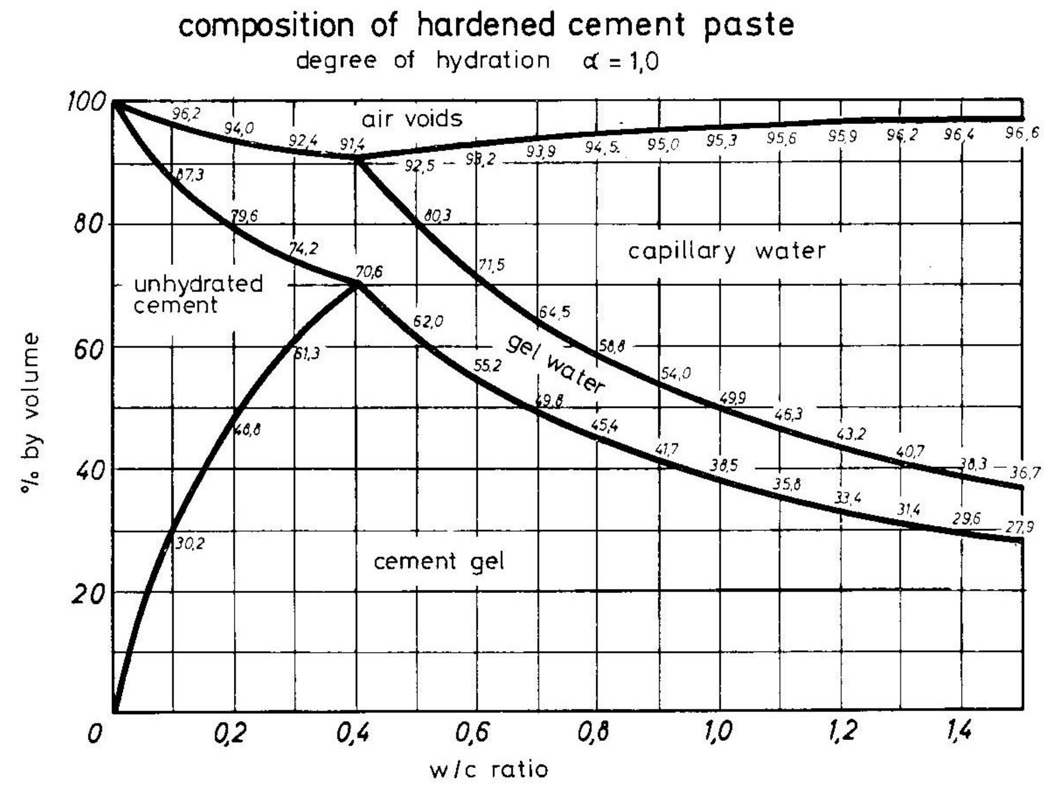

Figure 5.3: Parts by volume of the respective components of hardened cement past as a function of water/cement ratio, 100% hydration (Czernin 1980, 63).

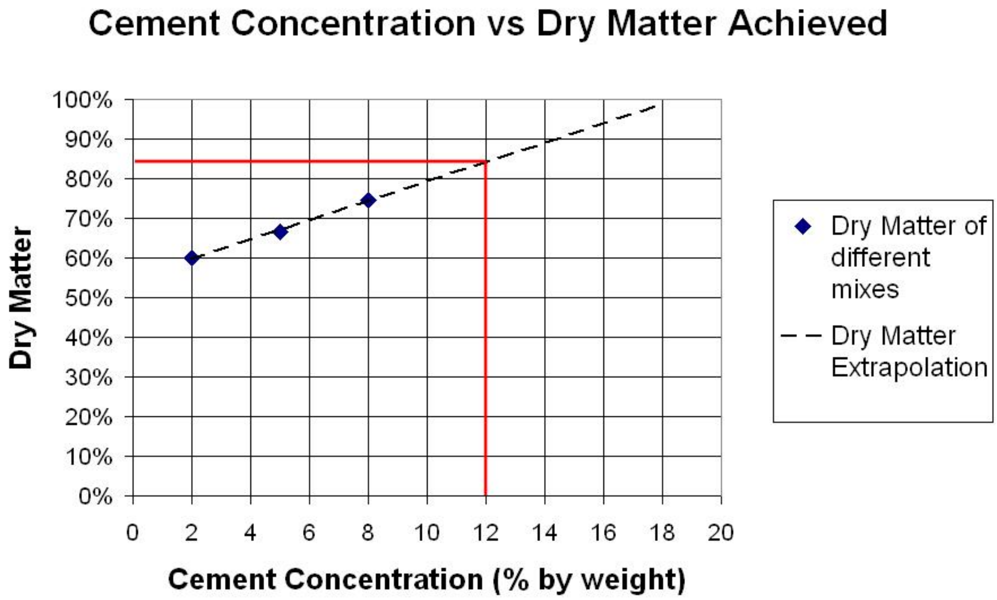

Figure 5.4: Extrapolation of cement ratio vs dry matter achieved.

hydration is achieved when the leucaena ratio is 60% although from the inconsistencies present in the results, this result is fairly inconclusive but still logical. The 80% leucaena is a coarse mixture and it is easy to imagine that a poor environment exists for the hydration of cement. Therefore, it follows that hydration would be less and this appears to be backed up by the experiment results.

5.3.3 Theoretical Recipe

After analysing the results of the moisture content in Section 4.3, a theoretical recipe was developed according to the inadequacies of the second experiments. To do this, the dry matter of the 60% leucaena mixes was plotted against the appropriate cement quantity. This is shown in Figure 5.4 where it appears that a reasonably linear relationship exists between the cement added and the dry matter of the resulting mix after cement hydration is complete. As shown, the extrapolation of this revealed that a cement ratio of 12% is necessary. Theoretically, this should yield a dry matter percentage of about 84% or a moisture content of 16%. The moisture content recommended for the storage of hay varies between 12% and 18% depending on the fibrosity and hygroscopic prop-

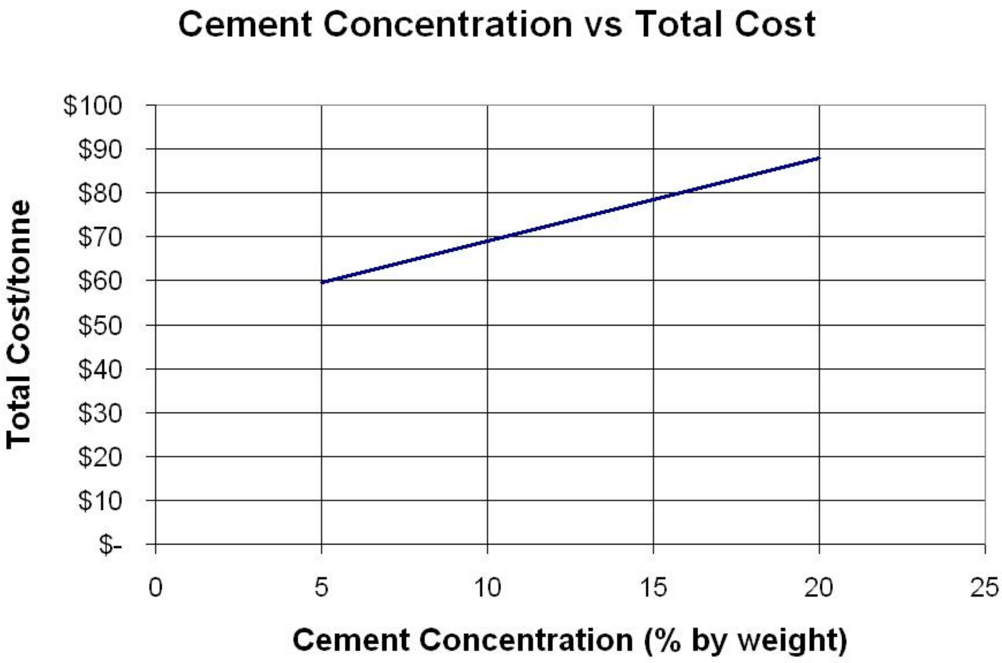

Figure 5.5: Extrapolation of cement ratio vs dry matter achieved.

erties of the individual hay crop (Raymond et al. 1972). Due to the relatively airtight feed that is produced in the leucaena mix, it is expected that a moisture content of 16% will be sufficient for indefinite storage. If this proves to be to low in future, the process will become more expensive as a decrease in the required moisture content means an increase in the cement ratio and hence, a cost increase. The rate of this increase is shown in Figure 5.5 and as is evident, even if a cement concentration as high as 20% is required, the total cost is still under $90/tonne.

5.4 Economic Analysis

5.4.1 Available Feed Comparison

The process of comparing the costs of various feed is a complex task and is dependent on a number of factors but the three main ones can be summarised as follows:

1. Seasonal availability and cost variation;

2. Ability of feed to meet stock requirements/management objectives;

3. Freight costs.

This is obviously very situational as freight costs are governed by the availability of the feed within a certain area and the location also determines the types of feed available. For the location of Killara, 5 main feed alternatives were chosen as drought feeding options:

1. Lucerne Hay;

2. Steam-flaked Grain Mix;

3. Cottonseed;

4. Silage;

5. Poor Grass/Stubble Hay.

This by no means guarantees that these feeds are available year round, they are simply given as an indication of what can be available. At present, all except silage are reasonably available for varying costs. It must also be noted that the term “silage” in this chapter refers to maize, barley and other conventional crops that are typically grown under irrigation. When comparing these feeds, their quality must also be accounted for and this in itself can be a complex task. To simplify the process, the various feeds were assigned a weighting according to how well they meet the needs of Killara. The general management plan at Killara is to have a quantity of high quality feed allocated for the weaners such that a growth rate is maintained and the profit margin is conserved. Because of this requirement, the ration must be sufficient to maintain a respectable growth rate and the feeds were analysed according to how well they meet these demands. The weighting is also intended to account for any difficulties relating to the storage and distribution of the various feeds and although this has only been done in an approximate fashion, it is accurate enough for comparisons to be made

The costing shown in Table 5.1 is all on a per tonne basis landed at Killara such that freight costs are approximately included. The functional cost is the measure by which

Table 5.1: Feed alternatives and their applicability.

Feed Type	Current Cost	Normal Cost	Weighting	Functional Cost
Lucerne Hay	$1000	$500	100%	$500
Steam-flaked Grain Mix	$320	$260	80%	$325
Cottonseed	$550	$200	65%	$308
Silage	-	$40	50%	$80
Poor Grass/Stubble Hay	$230	$200	10%	$2000
Leucaena Bulk Mix	-	*$73*	*70%*	*$104*

the various feeds should be compared. This is a relatively arbitrary measure in which the lower cost, the better the feed is for Killara. It was calculated using the *Normal Cost* in the following way:

$$Functional\ Cost = Normal\ Cost \div Weighting \tag{5.1}$$

The situation on paper appears that silage is the most economic option for Killara but at present, silage is simply unavailable in a feasible vicinity due to the drought. While its functional cost is significantly lower than the leucaena mix, there is the added requirement of a storage facility that would need to be constructed at Killara. In addition to this, it is likely that the supply of silage in the vicinity of Killara will continue to be unreliable with poor rainfall patterns. The change in feed quality that can also be expected with these variations will also have an impact on the weighting factor and hence, its functional cost.

5.4.2 Leucaena Mix Analysis

The cost of the leucaena component can only be estimated at present as the harvesting was conducted on a sparse crop and harvesting did not continue long enough to determine fuel consumption costs. With an harvesting rate of 4 tonne/hr considered possible, the running cost including fuel, wear and tear and labour was estimated at

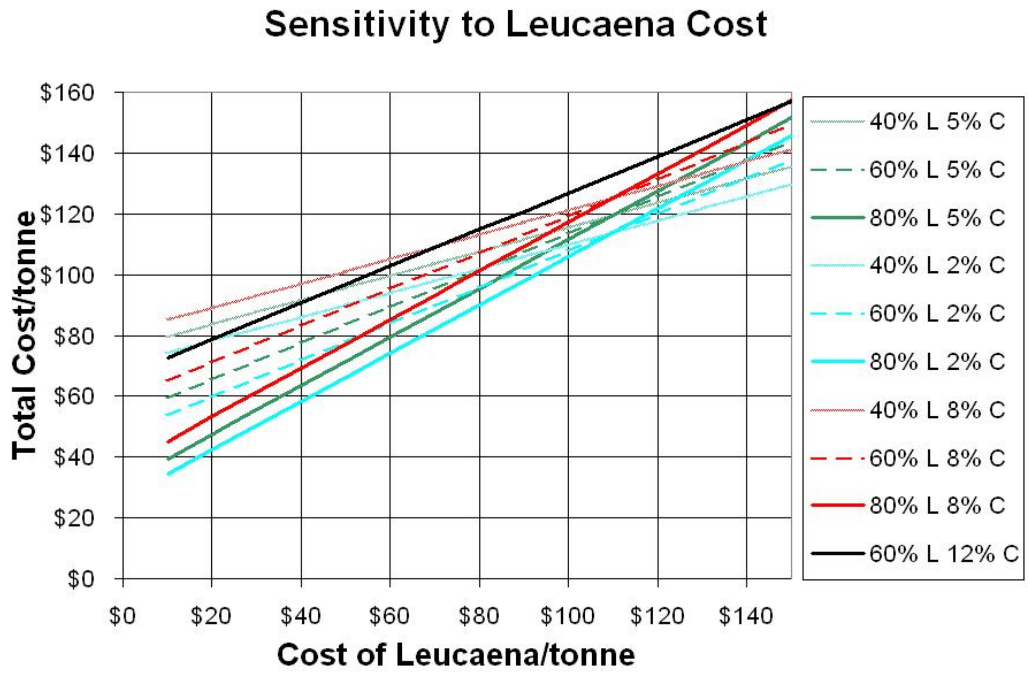

Figure 5.6: Sensitivity analysis of feed cost to varying leucaena harvesting costs where L represents leucaena and C is cement.

$40/hr. In this way, the leucaena component was estimated to cost $10/tonne.

A graph showing the sensitivity of the overall cost of the leucaena preservation method to the cost of the leucaena input is shown in Figure 5.6. The 10 different mixes depicted are the results of the second experiments plus a hypothetical mix which is estimated to be the optimum combination, shown by 60% L 12% C. The expected actual cost of producing this mix is located at the lower end of this yellow curve where the leucaena component is $10/tonne. This results in an expected total cost of ***$73/tonne*** and this is the figure used in Table 5.1 for comparing this feed mix with other conventional types.

5.4.3 Final Comparisons

The main comparison to be done is to compare the functional costs of the various feeds. The graph shown in Figure 5.7 essentially shows the same data as Table 5.1 but with the addition of approximate current (drought conditions) functional costs.

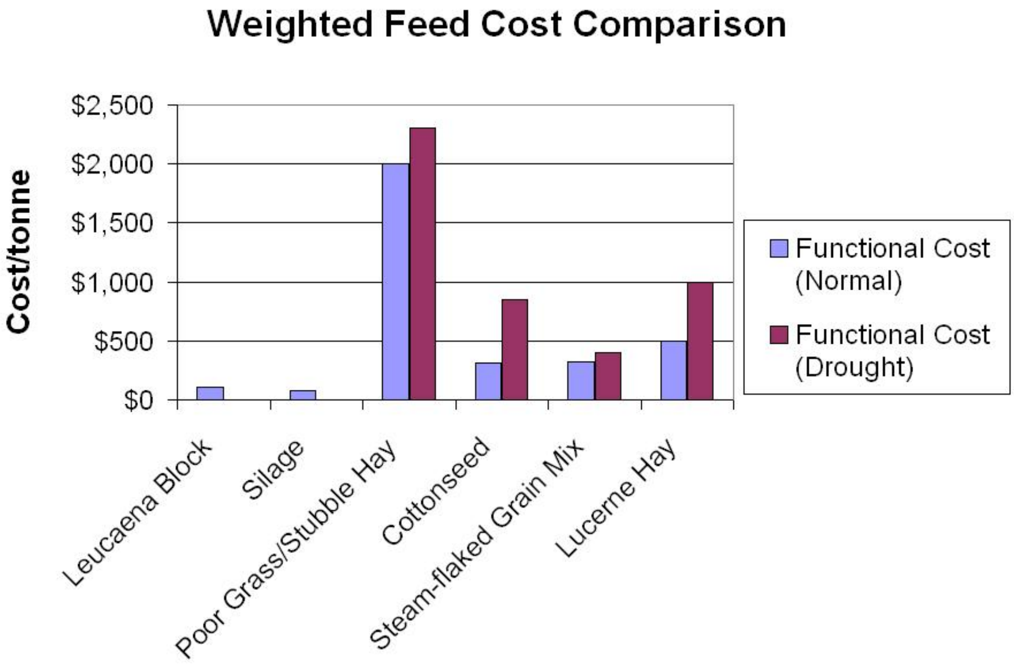

Figure 5.7: Comparison of the functional costs of the various feed alternatives at Killara.

The exceptions to this are the leucaena mix and silage where silage can be assumed as having an infinite cost due to its scarcity. The leucaena mix, on the other hand, should have very little variability in future. This is because it is almost a guarantee that sufficient leucaena can be harvested at some stage of every summer. It also has the distinct advantages of negligible freight costs and no price variation according to demand as is inevitable with external sources.

An important comparison that needs to be made is the prospect of ensiling leucaena. This was not included in the costing and comparisons of the feeds as it has not actually been performed with pure leucaena. As explained previously in this dissertation, leucaena has been ensiled in combination with maize. If it is found to be easily possible with just leucaena, it may well prove to be as economical as the cement and molasses preservation suggested in this project. The problems associated with using silage as described in Section 3.2 are such that an economic alternative for preserving leucaena would have been an advantage to Killara. The conclusion is that while using cement and molasses to preserve leucaena is economically competitive, the optimum method for Killara may be leucaena silage. The best way to determine this will be with large scale, long term comparisons that encompass harvesting and preparation through to feeding and weight gain trials. This is of course dependent on the probability that ensiling leucaena is possible.

Nutritional improvement of the bulk leucaena mix was also investigated using a feed cost calculator available on the *NSW Department of Primary Industries* (2005) website. By entering the anticipated cost and characteristics of the theoretical leucaena mix, it is possible to estimate the nutritional value and cost of a mix following the addition of conventional feedstuffs. It was found that with the addition of 5% soybean meal and 5% urea, a much improved product was obtained. These two ingredients were chosen as they are easily accessed by Killara. The full screenshot of the results is shown in Appendix F. This process demonstrates the ease with which the theoretical leucaena mix can be improved to give crude protein levels such as the 24.6% given in Appendix F. Using the current costs of urea and soybean meal landed at Killara with the theoretical cost of the leucaena mix, the total cost is given as $141/tonne of dry matter.

With the addition of soybean meal and urea during the mixing of leucaena, cement and molasses, it may be possible to store the resulting mix in this improved state. This would greatly facilitate the feeding of stock as the time-consuming mixing process would not need to take place during feeding. With a high-quality feed that requires no further processing after storage, the critical feeding of stock would be subjected to fewer threats from machinery failures and time constraints. This may not be possible in the silage method as the addition of urea into silage can disrupt the fermentation process. The addition of protein-rich meals, however, should pose no problems to the ensiling process. In a silage feeding situation, nutritional improvement is more effective after fermentation when the silage is being fed to stock. This leaves the process susceptible to time and machinery constraints that may be avoidable by using the cement method to preserve the mixture as a complete, high quality feed.

5.5 Chapter Summary

The purpose of this chapter was to apply the results of the year's endeavours in terms of their economic value to Killara. It was important to evaluate the economics of preserving leucaena with cement and molasses but to do this, relative comparisons with other alternatives also had to be made.

The initial experiments were basically a small feasibility test to determine the viability of the idea and it is because of the success of these that the project continued.

The harvesting was a relatively clear cut exercise where no direct measure of the economics was needed. Forage harvesting is a well established exercise and the main objective was to find/adapt an existing harvester for the leucaena at Killara. After an effectiveness analysis of the harvester, there is little else that can be done as it is basically a non-negotiable part of the exercise.

The full analysis of the second experiments entailed descriptions of the mixing, the hydration of cement and the theoretical recipe. It was concluded that the industrial feed mixer at Killara is well suited to further work in this area. A study of the cement reaction concluded that hydration levels in excess of 1000% appear to be occurring. The actual mechanisms by which this occurs are largely irrelevant to this study but the important result is that water is most efficiently immobilised in a 60% leucaena mix (of the ratios experimented with). This leads to the theoretical optimal mixture of 12% Cement, 32% Molasses and 60% Leucaena.

The economic analysis is a difficult exercise owing to situational, seasonal and individual economic factors. A sensitivity analysis was conducted to determine the effect of the unknown cost of harvesting leucaena. A comparison of available feeds was made with a weighting dependent on how well the feedstuff meets the needs of Killara. The basic conclusion of this exercise is that the cement and molasses method is viable but further work needs to be done to determine if it is more economical than silage. The possibility of ensiling leucaena also needs to be thoroughly investigated.

Chapter 6

Conclusions

6.1 Objectives Summary

For clarity, the objectives of this project are repeated here:

1. Research previous attempts (if any) to preserve this particular stock fodder;
2. Research previous attempts (if any) of harvesting the leucaena plant for fodder;
3. Trial own ideas for preserving the fodder;
4. Investigate the subsequent cost involved in any of the practicable methods researched and nutritional value of the product;
5. Suggest methods of mechanising production of a consumable stock supplement;

   As time permits

6. Attempt construction of various components required to economically produce a consumable product.

The research aspect of this project yielded very little on paper in terms of previous work conducted in this field. In spite of this, the actual preservation of leucaena has been accomplished in the form of silage. For management and geographic reasons, it was desirable to find an economic alternative to this process but it is obvious that the process is highly possible. It should also be noted that the harvester used in this previous work was similar to the one purchased by Killara. The only other instances of leucaena harvesting and preservation unearthed were some small scale operations were leucaena was harvested and sun-dried by hand in small batches, which is an unsuitable method for the needs of Killara.

The preservation of leucaena in a molasses mixture with a hydrophilic substance has been unequivocally proven possible by the fact that the results of the initial experiments conducted in February still show no signs of degradation some eight months later. By using cement and gelatine, it was also proven that a variety of hydrophilic substances might be applicable.

The overall cost of the process is the deciding factor regarding its suitability and cement was found to be easily the most economic of the two tested. Further investigation revealed that the cement option is very competitive when compared with other feed alternatives available at Killara. This was substantiated by the results of the feed analysis which show that while the result is not quite of a premium grade, it is nonetheless a valuable product.

During the course of the project, the forage harvester purchased was found to fulfill most of the harvesting requirements (bar some fine-tuning and slight modifications). Coincidentally, Killara has also purchased a feed mixer which was also found to be an essential part of the process although it has not actually been used for this technique at this stage.

6.2 Further Work

There is still a substantial amount of experimentation and testing of equipment to be done before this process can be used at Killara and this will be undertaken as soon as rains bring some leucaena growth that can be used. There are four main areas that still need further investigation:

1. Recipe refinement for bulk storage;
2. Harvesting fine-tuning;
3. Alternative application of leucaena in supplement blocks;
4. Practical application of leucaena silage and its comparison with the cement and molasses method.

At present, the recommended recipe required for safe preservation of leucaena is still theoretical and the practical aspect is dependent on new leucaena growth. A significant part of this is the possibility of weather resistance to avoid the need for tarpaulin covers. Another side to this is the possibility of using other hydrophilic substances and steps have been taken in this direction already although it seems unlikely that other options will prove economical.

The harvesting process needs some minor work to develop a suitable method of catching the green chop. It is hoped that the feed mixer can also perform this function although a special purpose wagon may prove beneficial and aid in small distance transport problems.

The applicability of leucaena as a crude fibre and minor crude protein source in a molasses based supplement block such as that described in the introduction are yet to be assessed. This will ideally entail weight gain trials with various recipes in conjunction with feed analyses to determine the benefits. The actual preservation of leucaena in this way has been proven by default with the work conducted in the area of storage in bulk.

With the results of the cost comparison, it seems that investigation into preserving pure leucaena as silage is easily justifiable. This is also scheduled as future work for Killara when suitable leucaena becomes available. An accurate economic comparison between the silage method and the cement/molasses method will only be possible after the passing of a season of using both. The process of nutritional improvement through the use of additives such as urea will also be investigated for both the silage and cement methods.

References

Blackwood, I. (2001), *Making your own protein blocks for cattle*, Agnote DAI-10, third edn, New South Wales Department of Primary Industries. http://www.agric.nsw.gov.au/reader/choosing-feeds/dai10.htm.

Blackwood, I. (2004), *Feed cost calculator*, Agnote DAI-201, sixth edn, New South Wales Department of Primary Industries. http://www.agric.nsw.gov.au/reader/4439.

Brewbaker, J. L. & Sorensson, C. T. (1990), New tree crops from interspecific *Leucaena* hybrids, *in* J. Janick & J. E. Simon, eds, 'Advances in New Crops', Timber Press, Portland, pp. 283–289.

Burchmann, R. (2006), Private communications. Contact details: ph.07 4634 3911. Email: russellb@davidevansgroup.com.au.

Calvert, G. (1998), *Weeds - The Silent Invaders*, Australian Plants online. http://farrer.csu.edu.au/ASGAP/APOL16/dec99-2.html.

Czernin, W. (1980), *Cement Chemistry and Physics for Civil Engineers*, second edn, Georg Godwin Limited, London.

Expanded use of molasses for intensive beef cattle feeding (2000), Meat & Livestock Australia, North Sydney, NSW. http://www.mla.com.au/TopicHierarchy/InformationCentre/PublicationsDatabase/PublicationDetails.htm?pubId=636.

Gani, M. S. J. (1997), *Cement And Concrete*, first edn, Chapman & Hall, London, UK.

Garcia, G. W., Ferguson, T. U., Neckles, F. A. & Archibald, K. A. E. (1996), 'The nutritive value and forage productivity of *Leucaena leucocephala*', *Animal Feed Science Technology* **60**, 29–41.

Halim, R. A. & Chen, C., eds (1996), *Feed Resources For Smallholder Livestock Production In Southeast Asia*, number 5, Forage Regional Working Group on Grazing and Feed Resources of Southeast Asia, The Food and Agriculture Organization of The United Nations.
http://www.fao.org/AG/agp/agpc/doc/PUBLICAT/Halim/halim.pdf.

Harris, C. (2004), An economic evaluation of three agro-forestry management systems for beef production in the fitzroy basin of central queensland, Technical report, Department of Natural Resources, Agriculture and Veterinary Science, University of Queensland, St. Lucia, Queensland.

John Deere Self-Propelled Forage Harvester Web Brochures (2006).
http://www.deere.com/en_GB/images/library/brochure/agriculture/forager.html.

Jones, R. J. (1994), Management of anti-nutritive factors - with special reference to leucaena, *in* R. C. Gutteridge & H. M. Shelton, eds, 'Forage tree legumes in tropical agriculture', CAB International, Wallingford, UK, pp. 216–231.

Kenyon, R. (2006), Private communications. Contact details: ph. 0428 988 097.

Krishnamurthy, K. & Gowda, M. K. M. (1983), 'Forage yield of leucaena var k8 under rainfall conditions', **4**(25).

Lefroy, E. C. (2002), *Forage Trees and Shrubs in Australia - their current use and future potential*, Rural Industries Research and Development Corporation.
http://www.rirdc.gov.au/reports/AFT/02-039.pdf.

Lignin Institute (2005).
http://www.lignin.org/.

Lockyer Lucerne Pellets (2005), Private communications. Contact details: ph. 07 5466 5404. Email: sales@lockyerlucerne.com.au.

MacDonald, S. (2006), 'Tea tree harvesting'.
`http://www.abc.net.au/rural/content/2006/s1554976.htm`.

Murtagh, J. (1998), 'Tea tree oil'.
`http://www.rirdc.gov.au/pub/handbook/teatreeoil.pdf`.

Mutangadura, J. & Matarirano, L. (2002), *Agroforestry study visit to Malawi and Zambia, 20-30 January 2002*, chapter Zimbabwe, pp. 99–106.
`http://cta.trafika.co.uk/data/pdfs/8028.pdf`.

Nakahara, K. (2000), Crop production and postharvest technology division, *in* T. Inoue, ed., 'JIRCAS/Annual Report', Japan International Research Center for Agricultural Sciences, chapter Crop Production And Postharvest Technology Division, pp. 44–54.
`http://ss.jircas.affrc.go.jp/kankoubutsu/annual/2000/contents.pdf`.

Ngugi, D. N. (2002), *Agroforestry study visit to Malawi and Zambia, 20-30 January 2002*.
`http://cta.trafika.co.uk/data/pdfs/8028.pdf`.

Nhan, N. T. H. (2000), Utilization of some forages as a protein source for growing goats by smallholder farmers, *in* T. R. Preston & R. B. Ogle, eds, 'National Workshop-Seminar Sustainable Livestock Production on Local Feed Resources', Swedish International Development Cooperation Agency, Department For Research Cooperation-SAREC, Agricultural Faculty, Cantho University, Vietnam.
`http://www.mekarn.org/sarpro/nhan3.htm`.

NSW Department of Primary Industries (2005).
`http://www.dpi.nsw.gov.au/agriculture`.

Oil Mallee (2001).
`http://www.oilmallee.com.au/`.

Pascal, N. & Salvator, K. (1994), Leucaena psyllid in burundi, *in* W. M. Ciesla & L. Nshubemuki, eds, 'Leucaena psyllid: a threat to agroforestry in Africa', Tanzania Forest Research Institute, Food And Agriculture Organization Of The United Nations.
`http://www.fao.org/docrep/008/v5020e/V5020E05.htm#04.1`.

Phuc, B. H. N. & Lindberg, J. E. (2001), *Ileal apparent digestibility of amino acids in growing pigs given a cassava root meal diet with inclusion of cassava leaves, leucaena leaves and groundnut foliage*, Vol. 72.
http://www.bsas.org.uk/Publications/Animal_Science/guidelines_for_paper_submissions/Volume_72_Part_3/511/.

Ragan, G. (2002), *Forage Harvesters*, Agriculture, Food And Rural Development - Alberta Government.
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/eng3051.

Raymond, F., Shepperson, G. & Waltham, R. (1972), *Forage Conservation and Feeding*, Farming Press Limited, Ipswich, Suffolk, Great Britain.

Shelton, H. M., Piggin, C. M. & Brewbaker, J. L., eds (1994), *Leucaena - Opportunities and Limitations*, number 57, Australian Centre for International Agricultural Research.
http://www.aciar.gov.au/web.nsf/doc/JFRN-5J479M.

Skoch, L. V. & Hodge, D. E. (1979), 'Animal feed block containing magnesium oxide'.
http://www.freepatentsonline.com/4171385.html.

Slingerland, D. (2003), *Forage Harvester Operation*, Agriculture, Food And Rural Development - Alberta Government.
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/eng7916.

Walton, C. S. (2003), *Leucaena (Leucaena leucocephala) in Queensland*, Pest Status Review Series - Land Protection, Department of Natural Resources and Mines, Brisbane, Queensland.

Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	Emile Seiler
TOPIC:	Investigating the economic viability and methods of harvesting and storing leucaena
SUPERVISORS:	Dr Guangnan Chen Col & Pete Seiler, Killara Cattle Co.
SPONSORSHIP:	Killara Cattle Co.
PROJECT AIM:	This project aims to investigate methods of storing leucaena biomass in a wet form without the need for drying. It is hoped that a commercially viable stock feed can be developed.

PROGRAMME: **Issue A 12th March 2003**

1. Research previous attempts (if any) to preserve this particular stock fodder.

2. Research previous attempts (if any) of harvesting the leucaena plant for fodder.

3. Trial own ideas for preserving the fodder.

4. Investigate the subsequent cost involved in any of the practicable methods researched and nutritional value of the product.

5. Suggest methods of mechanising production of a consumable stock supplement.

As time permits

6. Attempt construction of various components required to economically produce a consumable product.

AGREED

________________ (Student) _________________, _______________(Supervisors)

___/___/___ ___/___/___ ___/___/___

Appendix B

Annotated bibliography of Leucaena in Australia, 1991-2001

Source and scope	Quantitative data			
	Dry matter prod.	Edible dry matter	Live weight gain	$/ha
Annison and Bryden 1998 *Review* ruminant nutrition and metabolism				
Bolam and Triglone 1998 22 accessions; NW Aust (Ord River Irrigation Area); 46-1333 g/m row/month; 25-2505 g EDM/m row/month; 61-65% digestible	✓	✓		
Brandon and Shelton 1997a Effects of N, P, lime on yield; 220-1010 g DM/m row, SE Qld	✓			
Brandon and Shelton 1997b Effect of AM fungi on growth of Leucaena, Mt Cotton, Qld	✓			
Brandon *et al.* 1997 Effects of soil type, AM fungi, grass competition, P application on yield and nodulation Mt Cotton, Qld	✓			
Bray *et al.* 1997a 2 sites in Aust; N Qld; 10 accessions; 0.05-11.75 t leaf DM/ha after 1 year; 0.1-24.1 t leaf DM/ha after 3 years	✓			
Bray et al. 1997b Complete listing of Leucaena accessions in major collections				
Burrows and Prinsen 1992 South east Qld; performance and palatability (also *Acacia, Albizia, Casuarina* spp.)				
Buxton *et al.* 1996 Kimberly; Development of profitable and sustainable strategies with graziers				✓
Castillo *et al.* 1997 16 accessions of 3 species; Redland Bay 45 km SE Brisbane; 0.25-3.33 kg EDM/tree over 2 years; chemical composition; psyllid scores; digestibility 52-68.3%	✓	✓		
Clem and Hall 1994 3 sites; subcoastal NE Qld; Cunningham; high yielding but only given a productivity rating	✓			
Clem *et al.* 1993 Establishing Leucaena in Qld				
Dalzell *et al.* 1998a Frost tolerance; 25 km west of Dalby, SE Qld; 9 accessions				
Dalzell *et al.* 1998b Chemical composition; 116 accessions; DMD 42-68.9%		✓		
Dalzell and Shelton 1999 Condensed tannins, analytical method				
Dalzell and Kerven 1999 Condensed tannins, genotypic effects				
David 1994 Ord River Irrigation Area; 6-10 t/ha/yr	✓			
Elder *et al.* 1998				

Figure B.1: (Lefroy 2002)

Source and scope	**Quantitative data**			
	Dry matter prod.	Edible dry matter	Live weight gain	$/ha
9 accessions; Raglan, coastal central Qld; infestation ratings				
Faint *et al*. 1998 Palatability; 3 sites – one in Aust with 24 accessions; Mt Cotton				
Follett and Roderick George 1996 Psyllid; Hawaii				
Gilbert *et al*. 1992 Townsville; nutritional characteristics; various legumes; cv. Cunningham; 3 soils; ±N; waterlogging; liming;	✓			
Gutteridge *et al*. 1999 *Review* uses, characteristics and limitations; 50 000 ha in N Aust; 22 species; EDM 3-30 t/ha/yr	✓	✓	✓	
Gutteridge 1999 Productivity under grazing		✓	✓	
Hammond 1995 *Review* Toxicosis				
Jackson *et al*. 1996 Townsville; *L. diversifolia, L. leucocephala, L. pallida*; tannin content; N content; various legumes				
Jeanes *et al*. 1996 Redland Bay QLD; competition effects between Leucaena and maize; alley cropping system; 0.07-0.24 kg/m (0.9 g/m²/d)	✓			
Jones and Bunch 1995 Coastal SE Qld; cv. Peru; 13 year trial; mean liveweight gain 157 kg/hd = 399 kg/ha			✓	
Jones *et al*. 1998 Lansdown Qld & Kununurra WA; animal production; 3 species; 395-814 kg EDM/ha; steer gains 400-723 g/d	✓	✓	✓	
Jones 1994a *Review* Management of anti-nutritive factors				
Jones 1994b *Review* Effect of Leucaena on liveweight gain; improving milk production; reproduction in cattle; grazing management; includes table of liveweight gains from 16 experiments 1980-1991			✓✓	
Jones 1998 26 accessions; 15 species (incl 3 hybrids); 50 km S of Townsville; mean of eight harvests 400-3223 kg/ha ≈ 1.3-10.4 t/ha/yr; 189-1363 kg EDM/ha	✓	✓		
Jones and Palmer 1999 Weight gains of steers grazing var Cunningham			✓	
Karda *et al*. 1998 Palatability				
Larkin *et al*. 1999 Condensed tannins				
Larsen *et al*. 1998 *Review* Grazier's view; pasture agronomists view; intensive irrigated production systems; 1.25 kg/steer/d on raingrown Leucaena/grass (Esdale & Middleton)			✓✓	

Figure B.2: (Lefroy 2002)

Source and scope	Quantitative data			
	Dry matter prod.	Edible dry matter	Live weight gain	$/ha
Lowry 1995 Deciduous trees in tropical woodlands				
Ltd 1997 Plant variety 'Tarramba'				
t'Mannetje 1997 *Review* References to Leucaena N fixation, liveweight gains of 2000 kg/ha/yr (Pratchett & Petty 1993)			✓✓	
Middleton *et al*. 1995 *Review* Establishment difficulties; psyllid problem; environmental limitations; forage quality; management limitations; potential for development; non-irrigated 255-330 kg liveweight gain/steer/yr (0.6-1.0 steer/ha) (Wildin 1993); irrigated 1500-1730 kg liveweight/ha/yr (Pratchett & Triglone 1989)			✓✓	
Minson *et al*. 1993 *Review* Pasture yield and quality; pasture management; forage consumption; leaf DM up to 22t/ha/yr (Bray et al. 1988)	✓✓			
Mullen *et al*. 1999b Rhizobium specificity				
Mullen and Shelton 1996 Grazing buffalo grass compared with Leucaena				
Mullen and Shelton 1998 Sub-tropical Australia; 116 accessions (22 species incl. subspecies and hybrids); Brisbane; warm season growth = 8-439 g/m row/ month; cold season growth = 1-223 g/m row/month; highest yielding accessions produced the most EDM	✓	✓		
Mullen and Shelton 1999 Performance of 118 accessions in SE Queensland	✓	✓		
Mullen *et al*. 1998 25 accessions (14 species, incl. 2 hybrids); 19 sites (5 in Australia) 61 'environments'; 2-568 g/m row/month (9-173 g/m row/month in Australia)	✓			
Mullen *et al*. 1999a Psyllid resistance				
Noble and Jones 1999 Soil acidity under Leucaena				
Noble *et al*. 1998 SE Qld; soil acidification effects				
Petty *et al*. 1994 Ord River Irrigation Area; 12-48 t/ha/yr; growth rates 200-250 kg per animal ≈ 1.7 t liveweight/ha/yr; $1700-$2000/ha	✓		✓	✓
Petty *et al*. 1998a Ord River Irrigation Area; liveweight gain 0.73-1.1 kg/d ≈ 1575-2112 kg/ha/yr; mean dry season 0.89 kg/d, wet season 0.63 kg/d	✓		✓	
Petty *et al*. 1998) Ord River Irrigation Area; liveweight gain of cattle rotationally grazing Leucaena/pangola pastures supplemented with four levels of molasses and 2 levels of maize			✓	

Figure B.3: (Lefroy 2002)

Source and scope	**Quantitative data**			
	Dry matter prod.	Edible dry matter	Live weight gain	$/ha
Poppi *et al*. 1999 Forage quality				
Pratchett *et al*. 1992 Ord River Irrigation Area; 2 steer genotypes; liveweight gain 0.662-0.716 kg/d			✓	
Quirk 1994 *Review* Burnett Region, Qld; suitable sites; agronomy; grazing systems and cattle production; commercial adoption; liveweight changes from Addison et al. 1984, Quirk et al. 1990; liveweight gain 0.73-1.30 kg/hd/d (Mullaly unpubl data)			✓✓	
Ryan *et al*. 1992 Ord River Irrigation Area; consumer assessment of beef finished on Leucaena				
Shelton 1998 *Review* Of workshop on taxonomy; agronomy and environmental adaptation; wood quality and woodiness; forage quality; future opportunities;				
Shivas *et al*. 1996 Kununurra; infestation of *Cercosporella*				
Siaw *et al*. 1993 Gas production and rumen degradation of multipurpose trees				
Sparling *et al*. 1998 *Review* N cycling				
Wheeler *et al*. 1996 Dry Matter Digestibility		✓		
Wildin 1994 *Review* Central Qld; annual liveweight gains of 250-300 kg at 1-1.5 ha/steer, other pers comm. Figures; Prime cattle $500-800/ha			✓✓	
Wilson 1998 Effect of *L. diversifolia* on pasture growth; Munduberra, SE Qld	✓			

Figure B.4: (Lefroy 2002)

Appendix C

Lignosulphonate Manufacturing Process

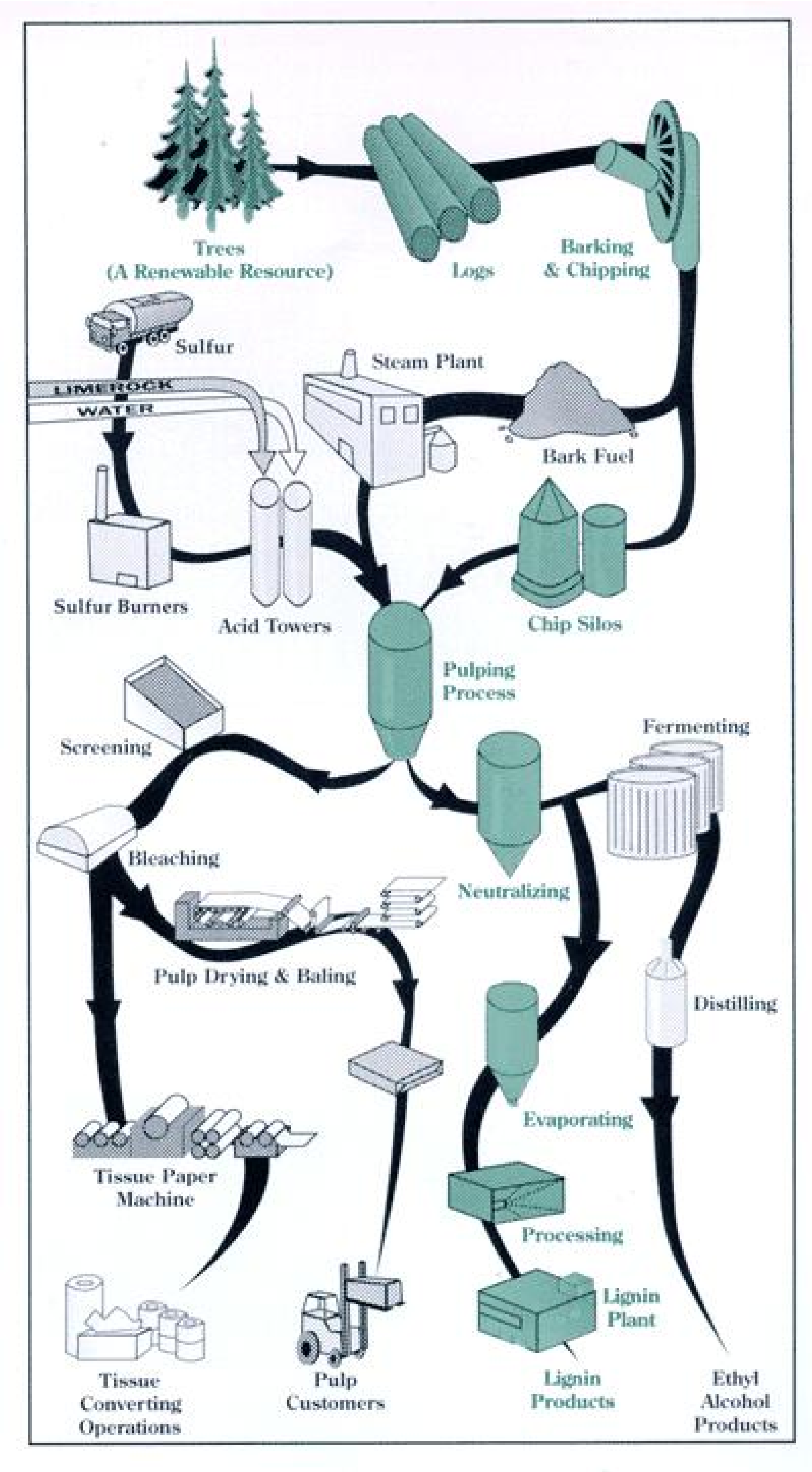

Figure C.1: (*Lignin Institute* 2005)

Appendix D

Cement Hydration Spreadsheet

Block No.	Cement	Leucaena	Molasses	Theoretical DM	Theoretical MC	Water req'd for full hydration	Hydration Achieved	Measured DM	Water Immobilised	Analysis DM	Water Immobilised
1	32%	26%	42%	73%	27%	6.72%	232%	94%	21%	89%	16%
2	7%	43%	49%	60%	40%	1.47%	2123%	91%	31%		
3	9%	61%	30%	55%	45%	1.89%	1006%	74%	19%		
2-40	2%	40%	58%	61%	39%	0.42%	909%	65%	4%		
2-60	2%	60%	38%	53%	47%	0.42%	1595%	60%	7%		
5-80	5%	40%	55%	61%	39%	1.05%	578%	68%	6%		
5-60	5%	60%	35%	54%	46%	1.05%	1202%	67%	13%		
5-80	5%	80%	15%	47%	53%	1.05%	50%	47%	1%		
8-40	8%	40%	52%	62%	38%	1.68%	1357%	62%	0%	85%	23%
8-60	8%	60%	32%	55%	45%	1.68%	1179%	75%	20%		
8-80	8%	80%	12%	47%	53%	1.68%	599%	57%	10%		

Appendix E

Costing of Initial Experiments

		26% Leucaena 32% Cement				
Ingredients	**Amount**	**Cost $/kg**	**Bulk Cost $/unit**	**Bulk units**		**Percentage of ingredients by weight**
Molasses (ml)	75					
Molasses (g)	100					42%
Cement (g)	75					32%
Leucaena (g)	63					26%
Total wt Sample (g)	238					
Molasses (kg)	420	$ 0.11	$ 110.00	tonne		
Cement (kg)	315	$ 0.30	$ 12.00	40	kg bag	
Leucaena (kg)	265	$ 0.02				
Total wt Sample (kg)	1000					
Cost molasses component ($/tonne)	$ 46.22					
Cost cement component ($/tonne)	$ 94.54					
Cost leucaena component ($/tonne)	$ 5.29					
Cost all ingredients ($/tonne)	$ 146.05					
Jumbo height(mm)	900					
Jumbo diameter(mm)	1,000					
Volume of jumbo block(cu m)	0.707					
Wt Jumbo block (tonnes)	0.941					

		43% Leucaena 7% Cement				
Ingredients	**Amount**	**Cost $/kg**	**Bulk Cost $/unit**	**Bulk units**		**Percentage of ingredients by weight**
Molasses (ml)	36					
Molasses (g)	48					49%
Cement (g)	7					7%
Leucaena (g)	42					43%
Total wt Sample (g)	97					
Molasses (kg)	495	$ 0.11	$ 110.00	tonne		
Cement (kg)	72	$ 0.30	$ 12.00	40	kg bag	
Leucaena (kg)	433	$ 0.02				
Total wt Sample (kg)	1000					
Cost molasses component ($/tonne)	$ 54.43					
Cost cement component ($/tonne)	$ 21.65					
Cost leucaena component ($/tonne)	$ 8.66					
Cost all ingredients ($/tonne)	$ 84.74					
Jumbo height(mm)	900					
Jumbo diameter(mm)	1,000					
Volume of jumbo block(cu m)	0.707					
Wt Jumbo block (tonnes)	0.941					

		61% Leucaena 9% Cement				
Ingredients	**Amount**	**Cost $/kg**	**Bulk Cost $/unit**	**Bulk units**		**Percentage of ingredients by weight**
Molasses (ml)	15					
Molasses (g)	20					30%
Cement (g)	6					9%
Leucaena (g)	40					61%
Total wt Sample (g)	66					
Molasses (kg)	303	$ 0.11	$ 110.00	tonne		
Cement (kg)	91	$ 0.30	$ 12.00	40	kg bag	
Leucaena (kg)	606	$ 0.02				
Total wt Sample (kg)	1000					
Cost molasses component ($/tonne)	$ 33.33					
Cost cement component ($/tonne)	$ 27.27					
Cost leucaena component ($/tonne)	$ 12.12					
Cost all ingredients ($/tonne)	$ 72.73					
Jumbo height(mm)	900					
Jumbo diameter(mm)	1,000					
Volume of jumbo block(cu m)	0.707					
Wt Jumbo block (tonnes)	0.941					

29% Leucaena 11% Gelatine

Ingredients	Amount	Cost $/kg	Bulk Cost $/unit	Bulk units		Percentage of ingredients by weight
Molasses (ml)	88					
Molasses (g)	117					60%
Gelatine (g)	22					11%
Leucaena (g)	57					29%
Total wt Sample (g)	196					
Molasses (kg)	597	$ 0.11	$ 110.00	tonne		
Gelatine (kg)	112	$ 12.50	$ 25.00	2	kg bag	
Leucaena (kg)	291	$ 0.02				
Total wt Sample (kg)	1000					
Cost molasses component ($/tonne)	$ 65.66					
Cost cement component ($/tonne)	$ 1,403.06					
Cost leucaena component ($/tonne)	$ 5.82					
Cost all ingredients ($/tonne)	$ 1,474.54					
Jumbo height(mm)	900					
Jumbo diameter(mm)	1,000					
Volume of jumbo block(cu m)	0.707					
Wt Jumbo block (tonnes)	0.941					

45% Leucaena 9% Gelatine

Ingredients	Amount	Cost $/kg	Bulk Cost $/unit	Bulk units		Percentage of ingredients by weight
Molasses (ml)	23					
Molasses (g)	30					45%
Gelatine (g)	6					9%
Leucaena (g)	30					45%
Total wt Sample (g)	66					
Molasses (kg)	455	$ 0.11	$ 110.00	tonne		
Gelatine (kg)	91	$ 12.50	$ 25.00	2	kg bag	
Leucaena (kg)	455	$ 0.02				
Total wt Sample (kg)	1000					
Cost molasses component ($/tonne)	$ 50.00					
Cost cement component ($/tonne)	$ 1,136.36					
Cost leucaena component ($/tonne)	$ 9.09					
Cost all ingredients ($/tonne)	$ 1,195.45					
Jumbo height(mm)	900					
Jumbo diameter(mm)	1,000					
Volume of jumbo block(cu m)	0.707					
Wt Jumbo block (tonnes)	0.941					

60% Leucaena 7% Gelatine

Ingredients	Amount	Cost $/kg	Bulk Cost $/unit	Bulk units		Percentage of ingredients by weight
Molasses (ml)	8					
Molasses (g)	10					33%
Gelatine (g)	2					7%
Leucaena (g)	18					60%
Total wt Sample (g)	30					
Molasses (kg)	333	$ 0.11	$ 110.00	tonne		
Gelatine (kg)	67	$ 12.50	$ 25.00	2	kg bag	
Leucaena (kg)	600	$ 0.02				
Total wt Sample (kg)	1000					
Cost molasses component ($/tonne)	$ 36.67					
Cost cement component ($/tonne)	$ 833.33					
Cost leucaena component ($/tonne)	$ 12.00					
Cost all ingredients ($/tonne)	$ 882.00					
Jumbo height(mm)	900					
Jumbo diameter(mm)	1,000					
Volume of jumbo block(cu m)	0.707					
Wt Jumbo block (tonnes)	0.941					

Appendix F

Nutritional Improvement

Feed cost calculator

27 November 2002 [reviewed 16 November 2004] | Agnote DAI-201 (sixth edition)

See Feed cost calculator-instructions.

Instructions	Feed 1	Feed 2	Feed 3	Feed 4
	Miscellaneous Select Feed	Prot-rich meals Soybean Meal	Miscellaneous Urea 46% N	Category Select Feed
Comments		By-pass 30%	See instructions	
Warnings			**Urea can be toxic**	
Name of feed	Leucaena Mix	Soybean Meal	Urea	
Cost $/t (on farm) $	73	490	640	
Dry matter %	84	90	90	
Energy MJ/kg DM	10	12.0	0.000001	
Crude protein %	9	50.0	280.0	
$/t Dry Matter	86.9	544.44	711.11	
MJ per tonne DM	10000	12000	0	
Cost cents MJ	0.87	4.54	71111000	
MJ per $100	11507	2204	0	
Cost $/Kg protein	0.97	1.09	0.25	

Calculate Clear Form

Feed Mixes

%feed 1	%feed 2	%feed 3	%feed 4
90	5	5	

Calculate Clear Mix%

	Feed Mix
Crude Protein %	24.6
Cost per tonne Dry Matter $	140.99
MJ per tonne DM	9600
Cost cents MJ	1.47
MJ per $100	6809
Cost $/Kg protein	0.94

Figure F.1: (Blackwood 2004)