UNIVERSITY OF SOUTHERN QUEENSLAND

DEVELOPMENT OF A CLIMATE-BASED COMPUTER MODEL TO REDUCE WHEAT HARVEST LOSSES IN AUSTRALIA

A dissertation submitted by

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ABSTRACT

Grain harvest represents a period of high risk and is also a bottleneck in a grain production. This study develops a climate-based systems simulation model to investigate the economics of high moisture grain harvesting in Australia. The optimum harvesting and drying strategies were determined. The role of grain aeration cooling was also examined. The model software was developed in MATLAB. This model was run on an hourly basis using 15 years of historical weather data (1991-2005) for three main wheat production areas in Australia, represented by Goondiwindi (QLD), Tamworth (NSW) and Scaddan (WA).

The Wheat Harvest System Simulation Model (WHSSM) consists of four submodels of weather data, machinery performance, crop loss and economic calculations. Each submodel is represented by mathematical functions and supported by available theoretical and field data. The weather submodel is used to predict dynamic grain moisture contents for a standing crop in the field. Machinery submodel was developed to calculate machinery performance and its operating costs at different grain and weather conditions. The main machinery involved are combine harvester, cooling aerator, and four categories of grain driers. Crop loss submodel is used to quantify grain losses involved during harvest and storage periods, including shedding (yield) losses, header losses, threshing losses, crop quality downgrading losses (due to rainfalls), and storage spoilage losses.

The model has been used to predict and compare the possible return for different harvesting and postharvest management strategies. For the reference case (a 1000 ha farm with a high-capacity harvester and medium-capacity drier in Goondiwindi), it is found that the optimum harvest moisture content for using continuous flow drier and batch drier is 14 and 13% (wet basis) respectively. For aeration simulation, it is found that the use of an aeration cooling system would slightly increase grower's return when the drier capacity is inadequate. No positive impact can be achieved on return if growers use either high or medium capacity driers. Generally, high capacity harvester travelling at lower speed is preferred.

It is also demonstrated that local weather conditions/rainfall patterns can have a very significant influence on grower returns. Growers in dry and warm

location (e.g. Goondiwindi) will gain better return. It is predicted that at the given model control values, the long-term optimum harvest moisture contents for Goondiwindi, Scaddan and Tamworth are 14, 15 and 17% respectively.

CERTIFICATION OF DISSERTATION

This is to certify that the work contained in this dissertation including model development, model application, analyses and conclusions are entirely my own effort, except where acknowledgment and reference is made. I also certify that this work is original and has not been submitted for any other award, except where otherwise acknowledged.

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NOTATIONS

B_e	burning efficiency	%
C	value of the top quality wheat	\$/t
C_a	capital cost of aerated storage	\$
C_c	aeration cost	\$/t
C_d	capital cost of drier	\$
C_e	annual drying cost	\$/yr
C_f	fuel cost	\$/yr
C_h	capital cost of harvester	\$
C_l	cost of labour	\$/yr
C_m	annual machinery cost	\$/yr
C_r	rated capacity of combine harvester	ha/h
C_s	capital cost of aerated storage	\$
C_t	annual total costs (fixed and variables cost) of machinery	\$
C_x	annual maintenance and repair costs	\$/yr
C_{ae}	annual aeration cost	\$/yr
C_{ec}	effective capacity of the harvester	ha/h
c_d	specific cost of LPG	\$/L
c_e	specific cost of electricity	\$/kWh
c_f	specific cost of fuel (diesel)	\$/L
c_l	specific cost of labour	\$/h
c_p	specific heat of air	kJ/(kg ºC)
D	harvesting delay due to rainfall	d
D_a	astronomical day length	h
D_b	depth of grain bed	m
D_t	drier throughput	t/h
d_m	day since crop maturity (30% moisture content)	d
E_d	annual energy demand for drying	kWh/yr
F_a	fan power required for aeration	kW/m^2
F_d	fan power required for drier	kW
F_s	farm size	ha
f_e	fuel use rate for harvester	L/h
f_1	repair coefficient for harvester and drier	decimal
f_2	maintenance coefficient for harvester and drier	decimal
H_c	cumulative hours of using harvester and drier	h
I_p	initial purchase price	\$
i	real estate interest	%/yr
i_g	annual inflation rate	%/yr

i_n	market interest rate	%/yr
L_h	header losses	t/ha
L_s	shedding losses	t/ha
L_t	threshing losses	t/ha
L_u	unharvested grain losses	t/ha
L_w	total value of grain losses	$/ha
M	grain moisture content at any time, t	% dry basis
M_a	average grain moisture content	% dry basis
M_b	grain moisture content at the start of a rain period	% dry basis
M_d	grain moisture content during dry period	% dry basis
M_h	harvest grain moisture content at any time, t	% wet basis
M_i	initial grain moisture content	% dry basis
M_o	final grain moisture content	% wet basis
M_r	grain moisture content during rain period	% dry basis
m_d	flow rate of air used for drying	kg/s
N_a	hours aeration is used per year	h/yr
N_d	hours drier is used per year	h/yr
N_h	hours harvester is used per year	h/yr
n	useful life of machine	yr
P	atmospheric pressure	kPa
Q	air flow rate per square meter of the floor	m/s
Q_d	quality losses due to degradation	$/ha
Q_s	quality losses due to spoilage	$/ha
R	annual return	$/ha
R_d	rainfall duration	h
R_q	rainfall amount	mm
r	daily rainfall	mm
S	forward speed of harvester	km/h
S_a	safe storage period of grain	d
S_c	storage capacity	t
S_o	rated speed of harvester	km/h
S_p	safe storage period of grain without aeration	d
S_v	salvage value of machine	$
T	air temperature at daytime	ºC
T_c	average grain temperature	ºC
T_d	drying temperature	ºC
T_g	mean grain temperature above ambient	ºC
T_n	night time temperature	ºC
T_{avd}	average daily ambient air temperature	ºC
T_{ave}	average of night temperature	ºC
T_{db}	dry bulb temperature	ºC
T_{max}	daily maximum temperature	ºC

T_{min}	daily minimum temperature	ºC
T_{set}	temperature at sunset	K
T_{sky}	sky temperature	K
T_{wb}	wet bulb temperature	ºC
t	24 hour clock time	h
t_h	time since the end of a rain period	h
t_{min}	time when the minimum temperature occurs	h
t_r	time of sunrise	h
t_s	time of sunset	h
t_x	time when the maximum temperature occurs	h
V	vapour pressure	kPa
V_s	saturation vapour pressure	kPa
V_{wb}	saturation vapour pressure at wet bulb temperature	kPa
W_c	comb size of combine harvester	m
W_e	equilibrium moisture content	% dry basis
W_{eo}	equilibrium moisture content at the end of a rain period	% dry basis
Y	crop yield	t/ha
Y_o	standard crop yield	t/ha
z	the elevation of location measured from the sea level	m
ψ_1, ψ_2	constant loss factor for shedding losses	decimal
ψ_3	constant loss factor for header losses	kg/ha/d
φ	grain to straw ratio	decimal
ω	speed index	decimal
ϕ	relative humidity	%
ΔP_g	static pressure drop over grain bed depth	N/m^2
γ	psychrometric constant	kPa/ ºC
δ	declination (north positive)	degrees
Γ	latitude (north positive)	degrees
χ	yield index	decimal
λ	latent heat of vaporization	MJ/kg
δM	change in grain moisture content during a rain period	% dry basis
ε	emissivity	decimal
β	ratio of molecular weight of water vapour to dry air	decimal
θ	grain moisture index	decimal
μ	field efficiency for combine harvester	%

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CHAPTER 1

Introduction

Wheat is one of the most valuable crops and important commodities in Australia. The gross value of the Australian wheat industry is approximately $A 5 billion per annum. In recent years, Australia has typically exported around 60% of its grain production, with wheat accounting for 67% of its total grain exports (ABARE, 2006a). In 2004-05, Australia exported 15.6 Mt of wheat mainly to Indonesia, Egypt, China, Japan, the Republic of Korea and Malaysia.

Australia is one of the largest wheat exporters in the world, ranking fourth behind the United States, Canada and the European Union. A major factor that influences the level of Australia's wheat export is its excellent reputation as a supplier of premium quality wheat. Therefore, to retain that reputation, Australia needs to maintain a consistency of its wheat production and quality so that its long term contracts for exporting the premium quality wheat are secured. Typically, only 20% of Australian wheat is classified as Australian Prime Hard or Australian Hard quality.

In Australia, both quantity and quality of the wheat production are often subject to unfavourable seasonal weather conditions, particularly summer rainfall. A long period of drought and flood are also typical natural problems to the wheat industry in Australia. The effect of the climate variability is demonstrated by national average wheat yields which have ranged from 1.14 to 2.14 t/ha over the last decade. In addition, Australian wheat yield is also dictated by several factors such as soil type, soil fertility and topography. Furthermore, management factors such as planting and harvesting time, harvesting strategy and postharvest management can also significantly influence the wheat yield and quality.

As seasonal weather conditions are out of growers' control, there are only limited tools that can be utilised by growers to minimise negative effects of weather conditions on their crops. In order to reduce the negative effects of weather conditions, the entire system of current management practices in grain harvesting system must be re-evaluated and optimised. However, due to the complexity of the grain harvesting system, which includes a series of production processes such as cutting, threshing, cleaning, drying and storage, it is difficult to evaluate the entire system without the use of a simulation model. By using a simulation model, the grain harvesting system can be divided into several basic components and each component can be represented using appropriate mathematical functions. This study describes the use of the simulation model to find the best management strategy in the wheat harvesting system.

1.1 Problem Statement

Wheat is harvestable when it reaches physiological maturity at 30% moisture content (wet basis, (wb)). In Australia, however, wheat is only accepted for commercial safe storage and delivery when its moisture content is at 12% (wb) or below. This limitation of 12% moisture content provides an excellent reputation for Australian wheat in the international market. However, it also causes a significant challenge for many growers especially those who do not have a drying facility. As a result, growers have only two options, either to harvest their wheat earlier and then artificially dried or to leave the wheat in the field until the wheat dries naturally to the desired level of moisture content.

At present, neither of these approaches is satisfactory. On one hand, if growers choose to use a grain drier, they often find difficulty in justifying the large capital investment required for drying facilities, with common types of grain drier (e.g. continuous flow drier) costing around $A 80,000 to $A 150,000 depending on the drying capacity. Most Australian growers see this as "too expensive" as the drier is only required for the short period of time during the harvest period. Consequently, grain drying has not been widely practised, and only 10% of the wheat crop is artificially dried in Australia.

On the other hand, if growers leave the wheat in the field after maturity, their wheat is at serious risk as it can be degraded in both quantity and quality, as a result of possible unfavourable weather conditions. Abawi *et al*. (1995) estimated that losses due to weather damage during harvest cost the Australian wheat industry around $A 30-50 million annually. Many studies have been done to quantify the magnitude of yield losses during harvest in Australia. On average, it has been reported that the daily yield loss due to delayed harvest in Australia is between 0.18 and 2.5% (Tullberg and Rogers, 1982; Bolland, 1984; Abawi, 1994; Banks, 1999; Cameron and Hughes, 2005; Saunders, 2006). In addition to the yield losses, every year, about 10 to 20% of premium Australian wheat is downgraded to the General Purpose classification due to weather damage. Biddulph *et al*. (2007) estimated that growers in Australia typically lose 22% of the value of their grain ($A 60/t) due to sprouting which downgrades the wheat from Australian Standard White to Feed Quality grades.

Until today, harvest losses remain unacceptably high in Australia, particularly in the summer dominant rainfall regions in northern New South Wales and southern Queensland where storms tend to coincide with the harvest season. In these locations, on average, serious harvest losses occur every 3-5 years. In the affected areas of Western Australian wheat belt, the grain losses due to preharvest sprouting may occur in 1 out of every 4 years (Biddulph *et al*., 2007). To some extent, it may be fair to say that the crop does not belong to growers until it is harvested and placed into a bin.

Theoretically, to reduce the quantity and quality losses, wheat should be harvested as soon as it reaches physiological maturity at high moisture content and then artificially dried until its moisture content is reduced to a commercial safe storage level. To achieve this objective, the appropriate selection and operation strategy of a combine harvester would be required. Several researches have been conducted to study the optimum harvesting capacity and strategy in order to reduce grain losses (Boyce and Rutherford, 1972; Philips and O'Callaghan, 1974). Some researchers have extended those studies by incorporating a drying facility in their grain harvesting system to study the economics of high moisture grain harvesting (Morey *et al.*, 1972; Audsley and Boyce, 1974; Muir *et al.*, 1983; Abawi, 1993).

However, none of the previous studies have considered a grain aeration system in their simulation model. As wheat is harvested at higher moisture levels, a grain aeration system can be used as a cheaper alternative supplement to prevent grain spoilage especially when drying capacity is inadequate. The main problem of the high moisture grain in storage is that it is particularly prone to insect and fungal attack. According to Foster and Tuite (1982), the main purposes of grain aeration are to maintain a uniform temperature in the grain bulk and to keep that temperature as low as practical to reduce the risk of storage losses due to insects and mould growth. However, to secure growers' returns, the equipment cost involved in a wheat harvesting system must be less than the cost of harvest losses in the field (Figure 1.1).

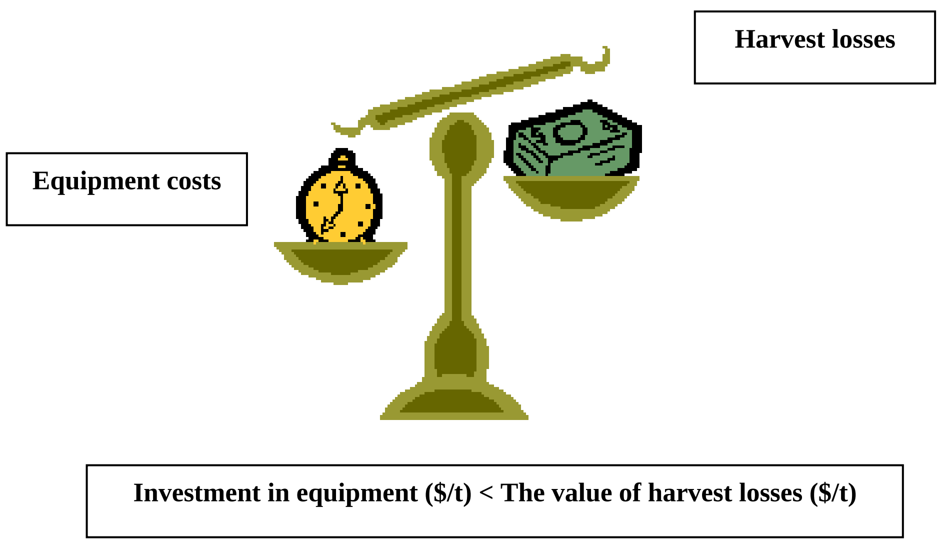

Figure 1.1 Basic principle for the optimum high moisture grain harvesting strategy

Abawi (1993) developed a simulation model of wheat harvesting and drying to examine the effect of many variables on the total cost of wheat production in northern Australia. However, Abawi excluded the grain aeration system in his model. Furthermore, his model has never been applied to other wheat growing regions in Australia. Therefore, a new simulation model which can be used to evaluate the economics of drying and aeration system in different locations must be developed. The optimum harvesting strategy involving the use of a drier and an aeration system will be investigated. In this study, the economics of using an aeration cooling will be examined as it is the most suitable for Australian winter crop, particularly wheat.

Based on a survey conducted by Turner *et al*. (2001), it was found that in 1998-99 season, approximately only 11% or 1.5 Mt of total on-farm storage capacity in Australia was equipped with aeration facilities. The reason why few growers opted to use grain aeration is because they were often poorly informed about the strategies, costs, benefits and the expected return from using aeration (Cameron *et al*., 2003). Ideally, the benefits and expected economic return from using grain aeration must be clearly explained to growers. Therefore, by developing a new computer-based simulation model, the suitable equipment needed by each grower in different regions and the best schedule for grain harvesting and drying in different years can be determined.

1.2 Objectives

The purpose of this study is to develop a Wheat Harvest System Simulation Model (**WHSSM**) which can be used to examine various management options and strategies in dealing with high moisture grain harvesting in three main wheat growing locations in Australia, represented by Goondiwindi (Queensland), Tamworth (New South Wales) and Scaddan (Western Australia). This model is important to help growers to effectively manage the risks associated with weather damage at harvest, thus reducing crop harvest losses. The specific objectives of this study are:

1. To develop the WHSSM for wheat growers across Australia.
2. To incorporate the aeration cooling model into the WHSSM and examine the economics of this system in overall wheat harvesting system.
3. To incorporate a range of driers with different drying capacities into the WHSSM and determine their effects on return at different grain moisture content.
4. To determine the optimum harvesting and drying strategy for different wheat growing locations under different weather conditions.
5. To determine the effect of different harvesting capacity on growers return.
6. To determine the economics of using the aeration cooling system at different drier capacities.

1.3 Structure of the Dissertation

This dissertation consists of nine chapters. A brief outline for each chapter is given below:

Chapter 1

This chapter provides an introduction to the Australian wheat industry and the statement of the problem for this research.

Chapter 2

This chapter provides an overview of the Australian wheat industry. It also describes the importance of the wheat industry to the Australian economy and the attributes of this industry in Australia.

Chapter 3

This chapter reviews the literatures of the previous simulation studies in a grain production system, including harvesting, drying, aeration, harvest losses, and machinery costs.

Chapter 4

This chapter discusses the key submodels which are developed in this simulation model. Several mathematical functions related to weather conditions, machinery capacities, crop losses and economic factors in the grain harvesting system are discussed in detail.

Chapter 5

This chapter explains the assumptions and simplifications made in this study. It also describes the operation flowchart of this model, fixed parameters and control values used in this study. The scope of this research is also defined in this chapter.

Chapter 6

This chapter discusses the effect of climate conditions on grain moisture content in a standing crop and harvest starting date in the reference location (Goondiwindi).

Chapter 7

This chapter discusses the simulation results for the reference location. It also discusses the sensitivity of individual machinery performance and grain loss for growers return.

Chapter 8

This chapter presents the detailed information of geographical and climatic conditions in the study locations. Then, it discusses and compares the simulation results for those locations.

Chapter 9

This chapter presents the conclusions which can be drawn from this study. Recommendations for future research are also discussed.

CHAPTER 2

The Australian Wheat Industry

Wheat is one of the most important cereal grains in the world in terms of production and export. Over the past 20 years, global wheat production levels have been growing, on average, at 1% per annum. The USDA (2005) reported that global wheat production has increased about 13% from 553 Mt in 2003-04 to 624 Mt in 2004-05. In terms of production, the European Union, China, India, the United States and Russian Federation are among the major wheat producers in the world (Table 2.1). However, China, India and Russian Federation are the minor players in the global wheat market as the domestic demand for wheat in these countries is high due to their large populations. In terms of export, the five major wheat exporting countries are the European Union, the United States, Canada, Australia and Argentina. The averages of production and export for these countries are shown in Table 2.2. Generally, these exporters supply around 75% of the global wheat trade.

Table 2.1 Average of wheat production in major wheat producing countries (1999/00 – 2004/05)

	Production (Mt)	Export (Mt)
The European Union	106.2	13.4
China	95.9	1.2
India	71.0	3.0
The United States	57.1	31.4
Russian Federation	40.4	5.2

(Source: Australian Bureau of Agricultural and Resource Economics, ABARE, 2005a)

Table 2.2 Average of wheat production in major wheat exporting countries (1999/00 – 2004/05)

	Production (Mt)	Average Yield (t/ha)	Area (million ha)	Export (Mt)
The European Union	106.2	5.6	19.2	13.4
The United States	57.1	2.8	20.5	31.4
Canada	23.3	2.3	10.2	15.5
Australia	21.3	1.8	12.0	15.3
Argentina	15.1	2.4	6.2	10.0

(Source: ABARE, 2005a)

Generally, the production of wheat in the exporting countries from the Northern Hemisphere (the United States, the European Union and Canada) is higher than the exporting countries in the Southern Hemisphere (Australia and Argentina). Among these countries, the European Union has the highest wheat production. Hamblin and Kyneur (1993) claimed that the producers in the Northern Hemisphere have the highest yield because of their temperate climates, where cropping is carried out on young, post-glacial soils of greater inherent fertility than those of the semi-arid and tropical regions of the world. In contrast, the production of wheat in the Southern Hemisphere is relatively low due to the influence of unfavourable weather conditions. Moreover, the cultivation program in the Northern Hemisphere is more intensive than that in the Southern Hemisphere.

In the Southern Hemisphere, the production of wheat in Australia is lower than in Argentina even though these two countries have similar environmental and economic conditions. A lower production in Australia is mainly due to its highly variable weather, leading to droughts or good seasons. Furthermore, Australian wheat production is relatively low compared to Argentina because it has old soils, highly weathered and deficient in many plant nutrients. However, Australia has an excellent reputation in the international market because it predominantly produces white hard-grained wheat of prime quality. It is different from its major competitors which mainly produce red-grained wheat. Australia's white hard-grained wheat varieties are particularly suitable for the production of food products such as high protein, high volume breads, Chinese style yellow alkaline noodles and Japanese Ramen noodles.

In Australia, wheat is one of the largest grain crops and most important export commodities. In 2003-04, Australia produced 26.1 Mt of wheat with the gross value of $A 5.6 billion (ABARE, 2004). This value represented 15% of the total value of farm production. The level of Australian wheat exports is basically determined by its level of production. With a constant domestic demand of 5.5 Mt per annum, the rest of its wheat production is available for export. Generally, Australia exports around 60%

of its wheat production worldwide. The level of its wheat export for the five year period (1999-00 to 2004-05) has averaged around 15.3 Mt per annum (Table 2.2). In recent years, the Asian market has become important for Australian wheat suppliers. Nowadays, Australia's total wheat exports represent around 15% of the global wheat trade annually.

The main wheat species grown in Australia is bread wheat (***Triticum aestivum***). This wheat species is well known for its hard white-grain and high level of good quality protein. To maintain the production level of high quality wheat, wheat growers in Australia have to improve their farm management practices. So far, many changes in farm management practices have been made including the introduction of mixed farming, crop rotation, application of better fertilisers, and mechanization programs. The improvement of bulk grain handling systems, development of chemicals to combat diseases, pests and weeds, and further development of higher yielding disease resistant wheat strains have also contributed to the production of high quality wheat in Australia.

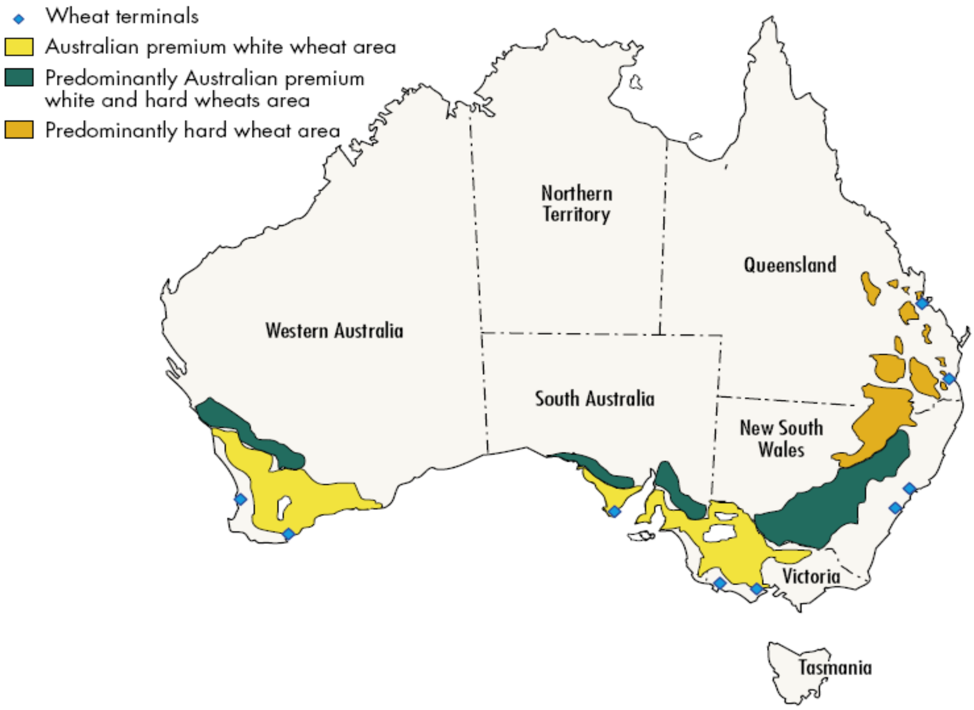

Figure 2.1 The Australian wheat belt and its attributes (Source: ABARE, 2005b)

2.1 Wheat Production Areas in Australia

Australian wheat is primarily grown under the wide range of geographical and weather conditions on the mainland in a narrow crescent form known as the Australian wheat belt. The Australian wheat belt stretches in a curve from central Queensland through New South Wales, Victoria, southern South Australia and up into the north of Western Australia. The curve of the Australian wheat belt together with its wheat terminals and specific growing locations for Australian premium white and hard wheat quality is shown in Figure 2.1. In order to reflect markets and production differences, Grains Research and Development Corporation (GRDC) has divided the Australian wheat belt into three regions: the northern, southern and western grain region (Figure 2.2).

Figure 2.2 The Australian wheat belt regions (source: ABARE, 2005c)

2.1.1 Northern Region

Grain farms in northern New South Wales and Queensland are located in this region. This region typically produces around 20% of the Australian grain crop. The farms in this region are of substantial enterprise size and receive premiums for high protein wheat in both export and domestic markets (Knopke *et al.*, 2000). The soil fertility in this region is inherently high. However, intensive cropping has lowered nitrogen levels and water erosion has reduced topsoil (Squires and Tow, 1991). This region has a climate ranging from subtropical to temperate.

2.1.2 Southern Region

The farms in central and southern New South Wales, Victoria and South Australia are located in the southern region. This region produces around half of the Australian grain crop. The southern region has a temperate climate and yield depends on reliable spring rainfall. Its soils tend to be relatively infertile (Knopke *et al*., 2000). Farms in this region are generally smaller in size than in the other regions but produce a wider diversity of crops.

2.1.3 Western Region

All grain farms in Western Australia are located in the western region. The grain farms in this region produce around one third of the Australian grain crop. These farms tend to be large in size and have a greater reliance on the export market because the domestic market is small (Knopke *et al*., 2000). The soil fertility in this region is relatively low with sandy-textured soils, usually with gravel and/or clay in the subsoil.

2.2 Agronomic and Cultural Requirements

In Australia, most wheat is planted in autumn from April to June as seed requires colder weather to germinate. During planting and germination, a significant amount of rain is needed. The seed grows during spring months and matures from early to mid-summer (October-January). Nowadays, Australian wheat is grown with growing season between 5 and 7 months with monthly mean temperatures between 6 and 29 ºC and annual rainfall between 300 and 700 mm.

Once planted, sowed wheat will undergo profound changes in structure through its life cycle. From germination to flowering, grain will develop its vital vegetative organs such as roots, leaves, spikelets and tillers. The vegetative stage in the wheat life cycle ends when plant begins to form an ear. After the end of ear formation stage, plant enters its most rapid growth phase as its stem extension begins. The growth of the plant will continue until the wheat reaches anthesis stage. Anthesis stage indicates that wheat has reached the final phase of its life cycle. This final phase will end when wheat reaches its maturity.

Audsley and Boyse (1974) defined grain crop maturity as when the grain moisture content reaches 30% (wb). At this grain moisture content, wheat is assumed to have reached its physiological maturity. Physiological maturity is the stage where the grain crop has reached maximum dry matter yield and its kernels are no longer growing. It also has lost its green chlorophyll colour and turned brown. At this stage, the fluctuation of grain moisture content and the rate of moisture decline depend on prevailing climatic conditions (Philips and O'Callaghan, 1974). Usually, grain may take several days or several weeks to lose its water before it becomes ready to be harvested.

Crop is harvestable when it reaches physiological maturity. After reaching maturity, the crop is subject to an increasing risk of yield losses due to natural shedding, lodging, preharvest sprouting, hail, and biological stresses. Figure 2.3 shows the typical factors of yield losses and quality degradation for a standing crop in the field.

The harvest normally begins in Central Queensland in September/October and gradually progresses southward, finishing in Victoria and the southern part of Western Australia in January/February. Much of the harvest is undertaken by specialist contractors. Usually, the harvesting operation is commenced when grain moisture content has decreased to below 20% (wb). Theoretically, the harvesting can be started earlier at high grain moisture contents if drying facilities are available. This practice could reduce standing time of the crop in the field, thus reducing risk from weather damage. However, if growers choose that practice, they must consider the cost that will incur from using a grain drier.

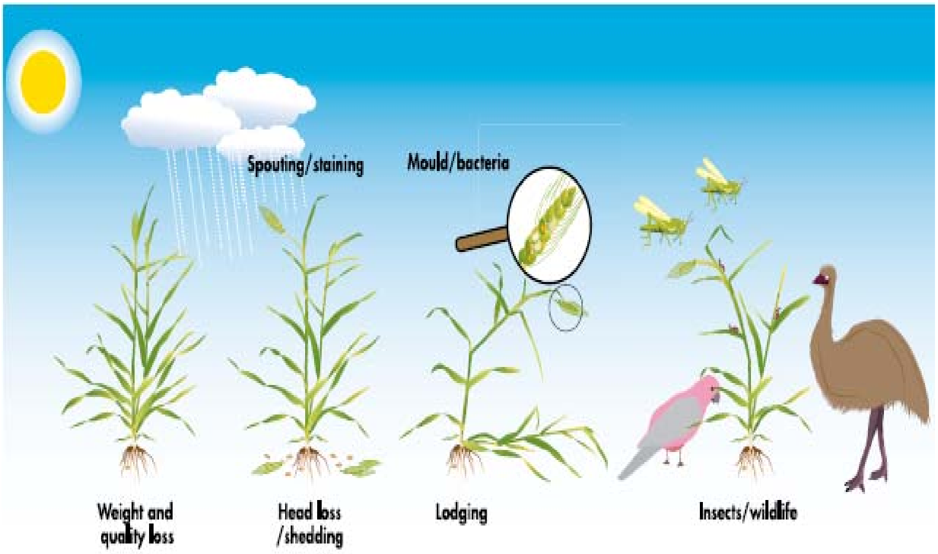

Figure 2.3 The typical factors of yield losses and quality degradation for a standing crop in the field. (Source: Metz, 2006)

2.3 Wheat Production and Yield Variability

The variability of wheat production in Australia is mainly dependent on climatic factors, particularly rainfall. Rainfall during ground preparation, seeding and harvesting has a significant effect on wheat yield and quality. In addition to rainfall, typical devastating climatic events like temperature extremes, drought, floods, bushfires, and tropical cyclones can also have a significant influence on Australian wheat production.

Besides the climatic factors, the variation in annual wheat yield from state to state and year to year is also due to varying soil fertility, soil type, topography, the availability of cultivated area, farming practice and machinery capacity. In addition, wheat price relative to other products is also important. For example, since the early 1990s, wheat growing areas across Australia have considerably increased as growers switched from wool production to wheat production following a drop in the wool price.

Since 1995-96, the total area sown to wheat across Australia increased by 30% to 11.9 Mha in 2004-05 (Table 2.3). For the same duration, the production of wheat has increased by 23.6% from 16.5 to 20.4 Mt. In 2003-04, almost 30,000 farmers in Australia grew wheat. The highest average yield (2.11 t/ha) was recorded in 2001-02 season while the lowest yield (0.91 t/ha) was recorded in 2002-03 season. The lowest yield in the season of 2002-03 was due to severe drought.

Table 2.3 Summary of the Australian wheat statistics (1995-2005)

year	Area ('000 ha)	Total Production (kt)	Average Yield (t/ha)	Total Export (kt)
1995-96	9,221	16,504	1.79	13,319
1996-97	10,936	22,924	2.10	19,224
1997-98	10,441	19,224	1.84	15,725
1998-99	11,543	21,464	1.86	16,448
1999-00	12,168	24,758	2.03	17,838
2000-01	12,141	22,108	1.82	16,142
2001-02	11,529	24,299	2.11	16,317
2002-03	11,170	10,132	0.91	9,107
2003-04	13,067	26,132	2.00	17,867
2004-05	11,991	20,376	1.70	14,694
Average	10,936	20,792.1	1.82	15,668.1

(Source: ABARE, 2005a)

Table 2.4 Summary of the Australian wheat production in 2003-04

State	Number of Farm (no.)	Area ('000 ha)	Average Farm Size (ha)	Total Production ('000 t)	Average Yield (t/ha)
New South Wales	10,859	3,983	367	7,288	1.83
Queensland	2,035	790	388	1,110	1.41
South Australia	5,542	1,960	354	3,490	1.78
Tasmania	289	8	27	26	3.25
Victoria	5,743	1,409	245	3,145	2.23
Western Australia	5,053	4,917	973	11,070	2.25
Australia	29,524	13,067	443	26,132	2.0

(Source: ABARE, 2004)

Table 2.4 shows that Western Australia is the largest wheat producing state in Australia. In 2003-04 growing season, it had 4.9 Mha of wheat growing areas with total production of 11.1 Mt. In the same growing season, the lowest yield was recorded in Queensland with an average of 1.41 t/ha. The low yield average in Queensland has a very significant effect on Australian wheat industry as this state is the main production area of the Australian Prime Hard (APH), the best wheat quality in Australia.

Table 2.4 also shows that New South Wales has the largest number of farms in 2003-04 season. This state has 10,859 wheat farms with an average size of 367 ha. Tasmania has the least farm numbers with only 289 farms. The average size of its farms is only 27 ha. In Western Australia, even though it has smaller farm numbers than New South Wales, its average farm size is significantly larger than other states in Australia.

2.4 Australian Wheat Quality

Varying soil types and climatic conditions across Australia enable a range of wheat types with different quality categories to be produced. For example, high protein hard wheat is often grown in northern New South Wales and Queensland, while lower protein soft wheat is grown in southern states. In addition to soil types and climatic conditions, wheat varieties and harvesting conditions also influence the appearance and properties of the grain. Owing to the difference in its wheat qualities, Australia has developed a wheat grading system to segregate its wheat quality based on customers' specific demands in the global market.

Australia always makes a significant effort to ensure the uniformity and continuity in the quality of its wheat which is produced in different production regions. As a range of protein levels is available, Australian Wheat Board (AWB) has provided different wheat categories to suit the end-use requirements of buyers. Before 1974, Australia marketed its wheat under the single classification system known as Fair Average Quality (FAQ).

However, from 1974, Australia replaced the FAQ system with the new wheat quality classification system.

Under the new system, Australian wheat is classified into five basic categories: Australian Prime Hard (APH), Australian Hard (AH), Australian Standard Wheat (ASW), General Purpose (GP) and Feed Quality (FQ). However, due to continuous research in the wheat breeding program, several new wheat categories have been added to the original classification. The example of the wheat classification in 2001 is shown in Table 2.5.

Table 2.5 Wheat categories and their properties

Wheat category	Minimum protein content, (%)	Screenings, (%)	State
Australian Prime Hard, APH	13	5	Qld & NSW
Australian Hard, AH	11.5	5	All states
ASW Noodle, ASWN	10.5	5	WA
Australian Premium White, APW	10	5	All states
Australian Standard White, ASW	10	5	All states
General Purpose, GP	10	5	All states
Australian Soft White, ASF1	8.5	5	WA & SA
Feed quality, FQ	-	-	All states

(Source: Abawi, 1994)

The classification of these wheat categories is based on several factors such as protein content, grain hardness, falling number, test weight, flour dough strength and milling quality (flour yield and flour colour). Among these factors, protein content is the most important factor in quality classification because it has a major influence on overall processing quality. The protein content depends on both wheat variety and environmental conditions. While grain hardness and milling quality are varietal characteristics, they are not influenced by environmental conditions. Flour dough strength is related to a combination of total protein content and protein quality. It is therefore influenced by the environmental condition and genetic component. Sometimes, Australian wheat quality classification is based on wheat variety and region of production.

APH wheat is a white hard-grained with a minimum protein content of 13%. APH wheat is the top quality grade in Australia. It is well known for its high milling quality, well-balanced dough properties, high resistance to rust pathogens and the maximum resistance to preharvest weather damage. Its high protein content allows it to be blended with lower protein wheats to produce flours which are suitable for a wide range of baked products. The main products from this wheat category are Chinese style yellow alkaline noodles and Japanese Ramen noodles. APH wheat is exclusively grown on the deep, black soils of northern New South Wales and southern Queensland.

AH wheat is a hard-grained variety with minimum protein content of 11.5%. This wheat category is limited to hard-grained wheat varieties that have good milling performance and excellent dough qualities. AH wheat is grown and segregated in all states. The flour derive from AH wheat is used to produce European style pan and hearth breads, Middle Eastern flat breads and Chinese steamed products and Chinese style yellow alkaline noodles.

Both APW and ASW wheats have a minimum guaranteed protein content of 10%. APW wheat is made up of a unique blend of hard-grained white wheat varieties with high milling performance and flour quality at excellent extraction rates. ASW wheat is the benchmark of Australian wheat. It has versatile medium to low protein white wheat product. It constitutes about 70% of Australian wheat exports. ASW wheat is segregated throughout Australia and for this reason there is a wide range of qualities available. Both of these wheat categories are suitable for the production of Middle Eastern, Indian and Iranian style flat breads and Chinese steamed bread.

ASWN wheat category is usually blended with hard wheat variety to produce excellent noodle wheats for the production of both Udon White Salted and Chinese noodles. This wheat category has a minimum protein content of 10.5%. This wheat category is grown only in Western Australia.

ASWN wheat varieties are blended with hard wheat products in order to maintain their quality. These wheat categories are mainly exported to the Japanese and South Korean markets.

ASFI wheat is exclusively grown in Western Australia and South Australia. ASF1 wheat is a unique blend of white, soft-grained wheat varieties, and is segregated at a guaranteed maximum protein level of 8.5%. This wheat is an outstanding product which is consistently clean and dry. Flour derived from ASF1 is ideal for producing a variety of biscuits, cookies, pastries, cakes and steamed buns.

Wheat which does not meet the specifications of the above category is classified as GP or FQ. The GP wheat comprises wheats that have failed to meet the minimum receival standards for milling wheat grades due to low test weight, presence of screenings, presence of foreign material, excessive weed seeds or a mild degree of sprouting. The FQ wheat category consists of severely sprouted wheat which has been affected by rain. It has low nutritional value and is only suitable for animal feeding purposes.

2.5 Australian Wheat Price

The price structure for basic wheat categories in 1990 and 2005 for Queensland is shown in Table 2.6. This wheat price structure is thought to be representative of the average market price in the last few years. This is because the wheat price varies from year to year depending on the global wheat supply and demand. From Table 2.6, it can also be seen that there is only small movement in the wheat price in the past 15 years. The wheat price structure for Western Australia is shown in Table 2.7. This data was obtained from South East Premium Wheat Growers Association (SEPWA), Western Australia (SEPWA, 2008).

Table 2.6 Basic wheat categories and prices in Queensland

Wheat category	Price ($A/ t)	
	2005*	1990**
Australian Prime Hard, APH	180.00	170.00
Australian Hard, AH	165.00	160.00
Australian Standard Wheat, ASW	140.00	153.00
General Purpose, GP	140.00	144.00
Feed Quality, FQ	140.00	126.00

(Source: *AWB, Toowoomba, ** Abawi, 1993)

Table 2.7 Wheat categories and prices in Western Australia (2005)

Wheat category	Price ($A/ t)
Australian Prime Wheat, APW	167
Australian General Purpose, AGP	147
Feed Quality, FQ	107

(Source: SEPWA, Western Australia)

2.6 Influence of Climate on Grain Quality

Wheat production in Australia is regularly affected by damaging rainfall during harvest, leading to preharvest sprouting. Preharvest sprouting refers to the grain germination in the head prior to harvest as a result of rain at harvest, where moisture penetrates the outer layers of the grain, initiating the germination process. Preharvest sprouting is a major cause of wheat downgrading which affects many wheat producing countries of the world, including the United States, the European Union, Canada, South Africa, Australia and Central Asia.

Preharvest sprouting causes a reduction in grain yield and quality with adverse effects on nearly all of its end products. Studies have shown that the increased levels of sprouting in unharvested wheat are directly related to the rainfall and the stage of crop maturity (Gordon *et al*., 1979; Mares, 1987; Abawi, 1993). Gordon *et al*. (1979) found that the germination potential increased exponentially with time after anthesis. This increase was directly correlated to the decline in the grain moisture content. He also found that the average of germination potential increased from 50% at 20% moisture content (wb) to 73% at 12.5% moisture content (wb). This result shows that most grain harvesting in Australia is carried out when moisture levels are at a point where the grain is highly susceptible to sprouting and quality damage.

The average of wheat production by category in each state is shown in Table 2.8. It can be seen that a significant higher proportion of weather damaged wheat occurred in New South Wales and Queensland, as a result of dominant summer rainfall that coincides with harvest operation. The long term averages of crops affected by dominant summer rainfall every year in these locations was approximately 15% (Mares, 1993). Unfortunately, these affected locations are the main producing area of APH and AH, the premium quality wheat. In Western Australia and South Australia, longer harvest duration is possible without adverse effect on grain quality due to lower levels of rainfall during the harvest period.

Table 2.8 Average of wheat intake by category in each state (1970 – 1990)

State	Total production, (%)			
	APH	AH	ASW	GP
New South Wales	15.7	24.2	48.9	11.1
Victoria	-	4.4	88.4	7.1
South Australia	-	18.9	75.3	5.7
Western Australia	-	4.1	89.6	6.3
Queensland	27.7	33.3	23.4	15.5
Australia	6.3	14.1	70.6	9.0

(Source: AWB)

2.7 Wheat Marketing

Since 1939, Australian wheat marketing for domestic and international market has been controlled by AWB, a government controlled statutory authority formed under the Wheat Marketing Act. The main objective of the AWB is to secure, develop and maintain export markets for Australian wheat in order to maximise returns for its shareholders (wheat growers). As the sole exporter of Australia’s wheat, the AWB carries the collective risk of international price and financial exposures on behalf of Australia’s wheat growers.

However, the domestic market for wheat was deregulated in 1989. Since then, grain growers are free to sell their grain to any domestic markets. A Wheat Industry Fund levy was established in the same year to enable the AWB to gain sufficient capital base for its privatisation plan. In July 1999, it became AWB Limited, a private company owned by wheat growers. In 2001, AWB Limited became a public company. For domestic wheat and other grains trading and the export of non-wheat grains, it is controlled by AWB (Australia) Limited, a subsidiary company of AWB Limited. AWB (International) Limited, another subsidiary company of AWB Limited, is responsible for the wheat export pools under the Single Desk system. The Single Desk system was established under the Wheat Marketing Act 1989 giving AWB Limited a formal obligation to maximise returns to wheat growers from the national pool through being the only exporter of Australian wheat.

AWB has established a series of pools based on variety, quality and protein windows, some of which also contain segregations and payment scales based on the protein level of the wheat. It also enables the AWB to meet the needs of the customer more specifically, as they have a full range of wheat qualities available to market. At harvest, wheat growers receive an advance payment of 80% of the expected pool return. The remaining 20% of the return will be paid after the wheat is sold. This gives wheat growers some payment for their product even though the product hasn’t been sold.

However, starting from 2008, AWB no longer holds a monopoly over wheat export. There are now at least 19 grain exporting companies which have been accredited by the Australian Wheat Export Authority to export wheat overseas. Thus, growers are able to sell their grain into a deregulated export market. Nowadays, growers can choose either to put their grain into the pool or to sell it to cash market. The five major grain bulk handlers/marketers in Australia are shown in Table 2.9.

Table 2.9 Australian major bulk handlers/marketers

Company	Attributes
Co-operative Bulk Handling Group	Operating almost 200 country receival sites and 4 export terminals in Western Australia
ABB Grain Limited	Operating 111 country receival sites and 7 export terminals in South Australia, along with two receival sites in Victoria
GrainCorp Limited	Operating over 350 country receival sites and 7 export terminals in New South Wales, Victoria and Queensland
AWB GrainFlow	Operating 22 receival sites in New South Wales, Victoria, Queensland and South Australia
Australian Bulk Alliance (ABA)	Operating 4 country grain receival sites in southern New South Wales and three in Victoria

(Source: ABARE, 2006b)

CHAPTER 3

Literature Review

This chapter reviews the available literature of the previous simulation studies in a grain production system. Then, it discusses the previous simulation models in a grain harvesting system, focusing on the machinery management during harvest. The available literature in grain aeration simulation models is also discussed. Finally, this chapter reviews the literatures related to grain losses during the harvest period particularly in Australia.

3.1 Grain Crop Growth Simulation Models

Climate-based crop simulation models have long been used to study the interaction of many variables in a grain production system under the influence of local climatic conditions. They are also used to investigate the effects of various factors such as water and nutrient supply, soil condition and fertility, biotic stresses, timing of planting and harvesting and weather conditions on the crop growth and yield. Recently, the improvements in climate forecast technology have led to new use of crop models for exploring potential benefits of tailoring crop management to expected weather conditions (Royce *et al*., 2001). The development of such models is important because most of the farm activities in the grain production system such as ground preparation, seeding, harvesting, drying, storage and transportation are dependent on weather conditions. Several grain crop management models were reviewed and are discussed below.

The Erosion-Productivity Impact Calculator (EPIC) model was developed in 1981 to evaluate the relationship between soil erosion and soil productivity for a wide range of agronomic practices, soil, and climate conditions in the United States (Williams *et al*., 1984). This model can also be used to investigate the effects of crop management strategies on crop productivity and soil quality. Since its establishment, it has continuously been improved and applied in a wide range of studies in agriculture, meteorology, and environment all over the world. For example, this model has been widely used to study the crop growth and yield, impacts of climate change, nutrient cycling and nutrient loss, wind and water erosion, pesticide losses, impacts of irrigation on crop yields, soil temperature, soil carbon sequestration, and economic–environmental analysis (Liu *et al*., 2008). Lately, EPIC is known as the Environmental Policy Integrated Climate.

A common and widely used crop growth model is DSSAT/CERES models. DSSAT stands for the Decision Support System for Agrotechnology Transfer while CERES stands for Crop Estimation through Resource and Environment Synthesis. DSSAT was developed by the International Benchmark Systems Network for Agrotechnology Transfer (IBSNAT). It contains multiple crop models which can be used to simulate crop sequences. The members of the DSSAT family include CERES-Rice, CERES-Wheat and CERES-Maize. The DSSAT/CERES models simulate crop growth, crop development, and crop yield taking into account the effects of weather, management, genetics, soil, water and Nitrogen. The examples of application for each DSSAT/CERES family member are discussed below.

Sadras and Monzon (2006) used the CERES-Wheat model to quantify the changes in wheat phenology in 17 locations in the Pampas, Argentina, between 1971 and 2000. The aim of this study was to quantify the actual magnitude of phenological changes, the relative changes in the duration of pre- and post-flowering phases, and the interaction between changing temperature and sowing date. This study found that a minimum rate of mean temperature increase about 0.02 ºC/yr can shorten the time to flowering and season length. This study also found that the rate of change in modelled time to flowering and maturity was 7 d/ ºC. However, the duration of the post-flowering phase was largely unchanged. This was associated with the lack of change in temperature, or where temperature increased, earlier flowering that shifted post-flowering development to relatively cooler conditions, thus neutralising the trend of increasing temperature.

Royce *et al*. (2001) conducted research to optimize a profitability of varying crop management practices by linking CERES–Maize to an Adaptive Simulated Annealing (ASA) and a partial budget calculator. The ASA was selected as the optimization algorithm in this study, while the crop management practices were optimized by El Niño–Southern Oscillation (ENSO) phase using 67 years of historical daily weather data in Argentina. This optimization study consisted of nine management variables, where each variable has two levels of resolution (step size). In this study, it was found that earlier planting date, higher N applications, and increased plant density could lead to higher yields during El Niño, as compared to neutral and La Niña years. The study also concluded that the linkage between the CERES–Maize and the ASA is useful for investigating the optimal combinations of management practices.

Xiong *et al*. (2008) examined the performance of CERES-Rice at the regional scale across China using a cross calibration process based on limited experiment data, agroecological zones (AEZ) and 50km×50km grid scale geographical database. The CERES-Rice performance was examined using rice yields from experimental sites at the plot scale, and/or observed yield data at the county scale. This study found that the CERES-Rice model was able to simulate the site-specific rice production with good performance in most parts of China, with a root mean square error (RMSE) of 991 kg/ha and a relative RMSE of 14.9% for yield across China.

Besides the DSSAT/CERES models, the Agricultural Production Systems Simulator (APSIM) was developed in 1991 by the Agricultural Production Systems Research Unit (APSRU), Australia. APSIM is a modular modelling framework that has been developed to simulate biophysical processes in farming systems, in particular where there is an interest in the economic and ecological outcomes of management practice in the face of climatic risk (Keating *et al*., 2003). The APSIM can be used in several applications such as crop management, cropping systems, water balance, climate impacts, species interactions, land use studies, soil impacts (erosion, acidity and nitrate leaching) and crop breeding. Moreover, the APSIM can also be used to simulate the effect of one crop on another in intercropping/weeds/mixed species systems.

In Australia, the APSIM is widely used as a research tool. Recently, the APSIM was used to study the potential impact of climate change on wheat production in South Australia (Luo *et al*., 2005) and Western Australia (Ludwig and Asseng, 2006). In both studies, APSIM-Wheat module was used. Both studies assumed that the changes in wheat production are due to the combinations of changes in regional rainfall, temperature and atmospheric CO_2 concentration. Luo *et al*. (2005) found that the median grain yield in South Australia most likely will decrease across all locations from 13.5 to 32% due to changes in regional rainfall, regional temperature and atmospheric CO_2 concentration. Ludwig and Asseng (2006) concluded that the effects of higher temperatures, elevated CO_2 and changed rainfall in Western Australia were generally not linear and differed significantly between soil types and location. The same authors also concluded that elevated CO_2 can reduce grain protein concentration while lower rainfall can increase protein levels.

Pirmoradian and Sepaskhah (2005) developed a very simple model (VSM) to simulate rice grain and biomass yields under different irrigation and nitrogen application management strategies in Iran. The VSM assumed the leaf area changes in a triangular pattern and biomass are proportionately accumulated to the intercepted solar radiation. By using multiple regression equations, the VSM can estimate the grain and biomass yields based on maximum leaf area index, harvest index, and light use efficiency. The inputs for VSM are Nitrogen application rate, seasonal amount of applied irrigation water, plant population, maximum applied water in flood irrigation, and mean daily solar input before and after flowering. The VSM was verified with independent data from other experiments in the study area to prove its accuracy. The authors claimed that this well-calibrated model produced good estimates of dry matter and grain yields.

The Cropping Systems Simulation Model (CropSyst) is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management practices on cropping systems productivity and the environment (Stockle *et al*., 2003). The CropSyst can be used to simulate the soil water and nitrogen budgets, crop growth and development, crop yield, residue production and decomposition, soil erosion by water, and salinity. The CropSyst model can be run together with other components such as a weather generator (ClimGen), a GIS-CropSyst simulation co-operator (ArcCS), and a watershed analysis tool (CropSyst Watershed). To predict the crop productivity in terms of crop yield, the model requires four input data namely, location, soil, crop and management files.

All of the models reviewed above have been developed to simulate weather conditions to tailor grain crop management practices in order to maximise crop yields. However, none of these crop simulation models have been extended into harvesting and postharvest areas, studying the costs interaction between harvesting, drying and aeration operation. Furthermore, those models also did not study the effect of the interaction between machinery and crop on grain yield and quality.

3.2 Simulation Models in a Grain Harvesting Operation

Several climatic-based simulation models have been developed in a grain harvesting system involving harvesting and drying operation. Generally, those models were developed to quantify grain losses associated with harvesting, drying, and storage. The use of a simulation model in the grain harvesting system is important because this system is very complex and difficult to be realistically represented using other analytical techniques. A simulation model will allow all components in the grain harvesting system to be divided into several submodels and each submodel can be investigated in order to get a practical view of the entire system. The models related to the grain harvesting system which include harvesting and postharvest management were reviewed and are discussed below.

Morey *et al*. (1972) used a dynamic programming model to optimise the harvesting and drying operation for corn and soybean. This model was developed to serve as a decision making tool in scheduling the harvesting operation. This model has considered the effects of the harvest rate, drying rate, weather and marketing alternatives on optimal harvesting policy. This study was classified as a dynamic programming formulation as the harvest season was divided into several stages of one week and at each stage the growers were provided with the most appropriate harvest strategy. As this model considered the effect of weather condition on the harvesting operation, it can be adopted and improved to make it suitable for the grain harvesting simulation study in Australia.

Boyce and Rutherford (1972) developed a simple deterministic model to study the effect of various management decisions on the total cost of the harvesting operation. In this study, the total cost of the harvesting operation was defined as the sum of the machine costs and the value of grain lost. In order to determine the optimum harvest strategy, the selection of machinery capacity and operating speed was made independently. However, this study only considered the magnitude of threshing and front losses for different harvest dates. The effect of shedding and quality losses on total cost was ignored. This work also excluded the use of drying facilities, aeration system and the effect of weather conditions on harvesting operation and grain losses.

Based on the work of Boyce and Rutherford (1972), Audsley and Boyce (1974) developed a new simulation model to minimise harvesting and drying costs. This new model was improved by incorporating a wet grain storage and a high temperature drier. This new model also used optimisation techniques to determine the optimum combine capacity, operating speed, and the size of wet grain storage which can minimise the total harvesting cost. This model also studied the effect of different weather regions, different drier and different storage size on overall return. The effect of several crops maturing at different stages, harvesting date, farm size and the choice of more than one harvester on overall return were also studied. For large farm size, several crops maturing on different dates were recommended. However, in both models, the effects of actual weather condition and grain moisture content that could affect harvesting operation were ignored. Instead, the grain moisture content was assumed to be independent of the weather.

Kabernick and Muir (1979) developed a simulation model for seeding, swathing, combining and drying of wheat, barley and oats in south-eastern Manitoba, Canada. In this study, fixed and variable costs for equipment and penalty costs for reduction in grain grade were calculated using 100 years of simulated rainfall data. Costs and harvesting completion dates were compared for farm sizes ranging from 120 to 960 ha. A range of harvesting and drying capacities were used in this simulation study. It has found that relatively large combines were most economical and only a small grain drier was needed on large farms. This model can be useful in deciding optimum capacities of harvesting and drying. However, the results of this study are more specific to the cereal growing areas of Canada and Europe as the model simulates swathing instead of direct harvesting.

Muir *et al*. (1983) developed a computer simulation model to determine the optimum system with minimum costs for harvesting and in-bin drying of barley in Scotland. This simulation was run for 5 years of weather data. The optimization subroutine was written according to the simplex method for function minimization. In this study, both grain moisture content and maturity date were assumed to be deterministic elements. This study found that the harvesting costs are the largest proportion of total costs. This study also found that the combine speed and size are very sensitive parameters in this simulation system. The authors concluded that crop condition and some management factors such as harvesting commencing date and harvesting period had considerable effect on the optimum systems and their costs.

Philips and O'Callaghan (1974) developed a simulation model to examine a conventional cereal harvesting system with the aid of mathematical models. The main objective of this study was to examine the effect of machine loss and combine throughput on the overall cost of cereal harvesting. The model examined various major variables affecting the total cost of cereal harvesting such as harvester capacities and the quantity of machine losses to determine the optimum machinery selection. In this study, the model was simulated with a dynamic nature of grain moisture content, calculated from historical weather data on an hourly basis.

This study found that the timeliness losses are a major component of the total cost. Therefore, it was concluded that a large combine harvester can be economically justified for harvesting relatively small acreages of cereals. However, in this study, cereal was assumed to be harvested when its grain moisture content fell below 24% and artificially dried to 16% (wb). In Europe, harvested cereal can be safely stored at 16% moisture content without the risk of deterioration due to its favourable weather conditions. However, in Australia, harvested grain is only acceptable for safe storage if its grain moisture content does not exceed 12% moisture content (wb).

Abawi (1993) developed a simulation model of a conventional wheat harvesting and drying system to examine the effect of many variables on the total cost of wheat production in northern Australia. In his model, Abawi studied the effect of machinery capacities and grain moisture contents at harvest on the overall system costs. He also studied the effect of grain losses, operational strategies and maturity date on production costs. In addition, he has also examined the losses in grain quality before harvest as this factor has not been studied in previous models. He found that the maximum return can be obtained if grain is harvested between 15 and 19% moisture contents (wb), depending on crop area and harvesting capacity.

Generally, all of the reviewed models were developed to optimise the harvesting operation and minimise the overall cost. Some of them included a drying facility and wet storage as a support system for high moisture grain harvesting. However, none of them have included grain aeration systems in their study. In fact, the grain aeration system is an important component of a wheat harvesting system. The need for the grain aeration system is even crucial when grain is harvested at higher moisture content under unfavourable weather conditions. Further literatures on grain aeration system simulation are presented in the next section.

All the above models are able to provide general recommendations to growers. However, the recommendations provided by some models are not very accurate. This is because, among all of the models reviewed, only the models developed by Philips and O'Callaghan (1974) and Abawi (1993) were simulated based on a dynamic nature of grain moisture contents for a standing crop in the field. Other models merely assumed the grain moisture contents to be independent of the weather conditions. Due to this simplified assumption, all of their results which are influenced by the fluctuation of the grain moisture contents such as harvest duration, drying cost, available working hours and timeliness losses were inaccurate. As a result, the models failed to properly study the interaction between crop physiology, weather condition and machine performance.

Furthermore, except for Abawi's model, other models were developed for grain growers in north America and Europe. Therefore, results from these studies may not be directly applicable to the Australian conditions due to the inherent differences in agricultural practices and climatic conditions. For example, cool weather conditions during harvest in north America and Europe allow growers in these countries to safely store their grain at moisture contents of 16% (wb). In Australia, however, hot weather conditions during harvest would not allow growers to store their grain at moisture contents exceeding 12% (wb).

In Australia, only Abawi (1993) developed the simulation model to study the harvesting and drying strategy, considering the dynamic nature of grain moisture content in a standing crop in the field. However, his study merely focussed on the wheat growing region in northern Australia. This model has also not been applied to other wheat growing regions across Australia. Thus, the results of his study are only suitable to guide growers in that region and may not be applicable to be used by growers in other regions. This limitation is due to the fact that farming practices and weather conditions for every state in Australia are different. As with other models, his study also excluded the aeration system. Furthermore, his work only considered one drier model. Nowadays, across Australia, many types of driers are available with different models, capacities and sizes. Therefore, the best drying capacity and size to suit growers' needs must be studied as well.

3.3 Simulation Studies in Aeration System

None of the models discussed in Section 3.2 have studied the benefits of using grain aeration in the grain harvesting system. In contrast, those simulation models only considered the optimum setting of harvesting and drying. On the other hand, many simulation models were developed to study the benefits and strategies of a grain aeration system in a grain harvesting system. According to Bridge *et al*. (2005), computer simulation has been a popular tool for researchers to investigate the dynamics of grain drying and storage systems, especially where ambient weather conditions need to be considered.

Basically, aeration is a forced movement of ambient air through stored grain to maintain the grain temperature to the desired level (Maier and Montross, 1997). Grain storage above 13% moisture content (wb) for long periods without aeration can result in quantity and quality losses due to biological activities of insects, fungi, bacteria and mould. Several simulation studies in aeration are reviewed and discussed below.

Harner and Hagstrum (1990) investigated how to utilize a grain aeration system with high airflow rates for cooling wheat during summer. This study found that an airflow rate of 1.7 m^3/min/t (28.3 L/s/t) would allow wheat growers to cool wheat by an average of 6 °C with approximately 9 h of fan operation. This practice also can reduce the growth of insect population by 80 to 97%. Reed and Harner (1998a) investigated aeration fan controllers to determine their usefulness for insect control in hard red winter wheat in Kansas. They found that aeration fan controllers can cool the grain faster than manual fan operations using standard recommendations. Reed and Harner (1998b) also determined that insect population and grain damage were significantly reduced when aeration fan controllers were used to cool the grain shortly after the harvest.

Sinicio and Muir (1998) studied aeration strategies to determine the best airflow rates and fan control methods for preventing spoilage of wheat stored in large horizontal storages and round bins. This study was carried out in several locations under tropical and subtropical climatic conditions in Brazil. This study found that the best fan control method for wheat is a differential thermostat method. This study also found that the best aeration conditions for grain at 13% initial moisture content (wb) are a differential thermostat setting between 5 and 7 °C, a linear airflow rate between 1 and 3 $L/s/m^3$, and the air temperature increment between 1 and 5 °C. This study also concluded that the maximum allowable storage time for storing aerated wheat at 13% initial moisture content (wb) in horizontal grain storage was 3 months shorter than in round bins.

Casada and Alghannam (1999) conducted laboratory and computer studies to investigate aeration strategy for over-dry wheat in the Northwest of the United States. In this study, a wide range of high humidity aeration conditions was produced in the laboratory to study the effect of moisture condensation on grain and moisture adsorption during and after cooling the grain. Computer simulations were used to evaluate long-term temperature and moisture changes from aeration. It was found that moisture accumulation by adsorption needs to be monitored for safe aeration management. Unsafe storage conditions can occur when aerating for long, or even short, periods with high relative humidity air. This study concluded that the large additions of moisture could create unsafe storage conditions quickly, in less than 100 hours.

Montross *et al*. (2004) determined the optimum seasonal aeration rates using contour maps to provide a starting reference point for sizing aeration fans and temperature limits in the eastern United States. The plots were based on 30 years of historical weather data and indicated the potential benefits of changing airflow rates and temperature limits. This study found that the optimum airflow rates of 0.6 m^3/min/t (10 L/s/t) was sufficient to completely move an aeration front through a bin for summer harvested grain from September to April in Southern regions of the United States. During July and August, only the northern part of the United States would have a sufficient amount of time available for cooling grain below 17 °C using an airflow rate of 0.1 m^3/min/t (1.7 L/s/t). During the same period, most of the mid−South part of the United States would have sufficient time available to cool wheat if the airflow rates were between 0.8 and 2.2 m^3/min/t (13.3 – 36.7 L/s/t).

Bridges *et al*. (2005) studied the effect of seasonal variation in weather on aeration costs for two axial fans and one centrifugal fan. In this study, the simulations were conducted using 30 years of weather data in mid−South of the United States. Aeration costs for each fan were compared for four initial grain temperatures: 21.1, 23.9, 26.7, and 29.4 ºC, four harvest dates: 1 June, 15 June, 1 July, and 15 July and two aeration temperature windows: 0 to 15 ºC and 0 to 17 ºC. This study found that the total aeration cost increased with initial grain temperature, decreased with later harvest dates, and was not significantly affected by aeration temperature window.

However, almost all of the available studies for aeration were based on the United States weather conditions. Thus, the results of those studies are not directly applicable to Australia weather conditions. Ideally, all crop-related models should be evaluated in the environment of interest if the results of applications are to be credible (Timsina and Humphreys, 2006). Unfortunately, there is little published research concerning the aeration strategies for stored wheat in Australia. The applications of an aeration system in Australia are reviewed and discussed in the following section.

3.4 Aeration System in Australia

In Australia, there are three categories of aeration namely: aeration drying, aeration cooling and aeration maintenance (Darby, 1998). Aeration drying with air flow rate of 5 to 20 L/s/t is used to remove moisture from the grain to the final grain moisture level. It is suitable for summer crops and coastal grain harvesting locations. Aeration cooling with flow rate of 1 to 5 L/s/t is used to rapidly cool grain, protect grain quality and seed viability, and limit insect activity. Aeration maintenance is used to protect grain quality and prevent temperature increases. The typical flow rate for this aeration system is 0.2 to 1 L/s/t.

Hughes *et al.* (2004) claimed that an aeration cooling with 2 L/s/t is a relatively low cost way to cool grain, suppress moulds and insects and maintain grain quality in storage for a longer period. The aeration cooling system can be used to cool the grain during summer. This aeration category is suitable for winter crops, particularly wheat. However, cooling grain with aeration may not eliminate the need for insect control, but will slow insect development dramatically. This is because, at temperatures below 15°C, most insects will stop their reproduction activities.

Many farms in Australia have permanent and temporary storage capacity for grains (ABARE, 2006b). However, a grain aeration system is not widely used in Australia. Turner *et al*. (2001) did a survey and found that approximately only 11%, or 1.5 Mt, of total on-farm storage capacity in 1998-99 was equipped with aeration facilities. In Queensland, only 40% of permanent storage is equipped with aeration facilities, reflecting the high humidity in this state. Cameron *et al*. (2003) explained the reason why few growers opted to use aeration was because they were often poorly informed about the strategies, costs, benefits and the expected return from using grain aeration. Therefore, this study is aimed to provide a clear picture to growers about the benefits and expected economics return of using aeration associated with a drying facility.

3.5 Grain Losses during the Harvest Period

Harvest period is the period with the highest risk in a wheat production system, particularly in northern Australia. This is because, most of the grain losses occur during this period due to crop ageing, wildlife and weathering. Grain losses during harvest period are referred to any losses that occur from grain maturity to grain delivery. Generally, grain losses can be divided into three stages; preharvest losses, harvest losses and postharvest losses.

Technically, grain losses during harvest period can be minimized if the mature grain in the field is harvested as soon as possible then artificially dried. This is because, grain losses increase as harvest time increases after grain has reached a maturity. However, if growers choose this option, the economic value of grain price as compared to drying cost must be considered in deciding when to begin harvesting. By having a grain drier, growers can harvest grain much earlier at flexible time, reduce risk of yield losses due to bad weather and wildlife, improve marketing strategies and produce better quality product. In Australia, occasionally, grain must be harvested earlier at higher moisture contents due to unfavourable weather conditions. Thus, by having a drier, grain can be uniformly dried regardless of weather conditions.

3.5.1 Preharvest Losses

Most preharvest losses occur in the field due to natural shedding, lodging, weathering and crop ageing. Preharvest losses which can affect both quantity and quality occur as a result of wheat that has fallen to the ground by the time harvest begins. Preharvest losses can be minimized by planting shatter-resistant varieties and harvesting earlier in the season. Ideally, wheat in Australia should be harvested shortly after their moisture content has reached 20% and below.

Many studies have been undertaken in Australia to quantify the magnitude of yield losses during preharvest stage. Yield losses associated with delayed harvesting can vary from crop to crop and from year to year. Trials with ripe crops in the Esperance region of Western Australia, for example, indicated yield losses of around 0.5% a day for barley and 0.35 % a day for wheat (Cameron and Hughes, 2005). Bolland (1984) reported that yield loss for wheat is 0.5% per day due to delayed harvesting in the Esperance region of Western Australia.

Tullberg and Rogers (1982) conducted field trials in the Darling Downs region in 1980 and found that an average yield loss for wheat was 2.5% per day. In the same region, Abawi (1994) reported that yield losses between 0.4 and 1.0% per day due to delayed harvest during 1989 to 1990. Banks (1999) reported that loss of dry matter in the head post-maturity is 0.5 to 1.0% per day during wheat harvesting in coastal areas of northern New South Wales and Queensland. Saunders (2006) reported that wheat loss is less than 0.1% per day before reaching 12% moisture content, but can be up to 0.52% per day after reaching this point and was not harvested up to 15 days later.

In Holland, it was reported that yield losses of 0.16 to 0.6% per day for spring wheat (Konning, 1973). In Ohio, the United States, the yield losses of soft red winter wheat amounted to 13.5 kg/ha each day due to delayed harvesting (Hunt, 1977). He also found that harvesting at optimum grain moisture content of 20%, for an average year, would produce about 70 kg/ha more grain which can help pay for the drying cost.

3.5.1.1 Yield Losses due to Natural Shedding

Yield losses due to natural shedding (shedding losses) are the most significant losses during preharvest stage. Shedding losses affects a standing crop in the field. Shedding losses are related to crop variety, stage of maturity, weather conditions and damage from insects and wildlife. Audsley and Boyce (1974) used the following relationship to define shedding losses as a function of days past maturity (30% wb):

$$L_s = 0.001\,(0.675 d_m - 0.0062\, d_m^2)\, Y \qquad (3.1)$$

where L_s is shedding losses, t/ha; Y is crop yield, t/ha; and d_m is day since crop maturity, d.

Abawi (1993) developed a new mathematical function to quantify shedding losses by considering the time since the crop reaches maturity (Equation 3.2). In this model, the effect of the natural shedding on grain losses is high when harvesting is delayed after wheat has reached maturity. During the first 10 days since crop maturity, the rate of shedding losses is slow. The rate of shedding losses is much higher after that period.

$$L_s = \psi_1\, d_m\, Y \qquad \text{if } t<10 \qquad (3.2)$$
$$L_s = \psi_2\, (d_m - 10)\, Y \qquad \text{otherwise}$$

where L_s is shedding losses, t/ha; ψ_1 and ψ_2 are constant loss factors which depend on a crop variety. Based on the field experiment, Abawi recommended the value of ψ_1 and ψ_2 to be 0.045 and 0.45 % respectively.

3.5.1.2 Quality Losses due to Preharvest Sprouting

Preharvest sprouting is a major cause of wheat downgrading during preharvest stage. Preharvest sprouting occurs when grain that remains on the farm is exposed to rain. Preharvest sprouting causes an acceleration in various metabolic processes, leading to reduction in grain yield (dry weight) and quality with adverse effects on its end products. Preharvest sprouting occurs in all areas across the Australian wheat belt because locally adapted high yielding cultivars lack sprouting tolerance, and there is a yield penalty associated with growing older, sprouting tolerant cultivars (Biddulph *et al.*, 2007).

Abawi (1993) reported that in 1983-84, a record of 20 Mt of wheat was produced in Australia but over 20% was downgraded to GP classification due to sprouting and weather damage. Biddulph *et al*. (2007) estimated that growers in Australia lose about 22% of the value of their grain ($A 60/t) with downgrading due to sprouting from Australian Standard White to Feed grades. The same authors also claimed that in the Western Australian wheat belt, preharvest sprouting is a problem in affected areas in 1 out of every 4 years. In northern New South Wales and Queensland, summer thunderstorms and high humidity during harvesting lead to downgrading of wheat quality by an average of 18% per year (Banks, 1999).

Currently, many researches have been done in Australia to produce a new wheat variety with high sprouting tolerance. Much of Australia's wheat and other grain variety breeding programs are managed by the GRDC, which is a statutory authority funded by a levy on grain growers and contributions from the Australian Government (ABS, 2006). For example, in 2007, Department of Agriculture and Food, Western Australia (DAFWA), supported by GRDC has produced several wheat varieties with high tolerance to preharvest sprouting, e.g. Ega 2248 A, Ega Eagle Rock A, Braewood A and Cascades (DAFWA, 2007). In Queensland, the best variety from APH wheat category with high preharvest sprouting tolerance is Sunlin (DPIF, 2007).

3.5.2 Harvester Losses

Harvester losses occur due to the interaction between the crop and the combine harvester during the cutting, threshing and separation processes. The header losses (also known as front losses or cutter bar losses) are the losses that occur during the cutting process. Header losses refer to the wheat that is not gathered into the combine. The magnitude of these losses depends on crop maturity, grain moisture contents, design and sharpness of the cutting knives, action of the cutter bar, reel and auger, forward speed, straw feed rate, machine adjustment and the efficiency of the operator. Only seed heads above the level of the knife are capable of being harvested mechanically.

Klinner (1979) reported that header losses of 1.5% of the potential yield could occur in 3 weeks after combine ripeness (15% moisture content) and 2% after 5 weeks due to the combined effects of crop height and a decrease in shatter resistance with advancing maturity. According to PAMI (1998), as much as 86% of wheat was threshed by the header. Johnson (1959) found that the header losses vary from 0.5% at 26% moisture content (wb) to 1% at 13% grain moisture content. Audsley and Boyce (1974) used the following relationship to link the header losses with days past maturity (30% moisture content, wb):

$$L_h = 0.001\,(15.3 + 0.882\,d_m - 0.0065\,d_m^2)\,Y \qquad (3.3)$$

where L_h is the header losses in t/ha.

Threshing or cylinder losses occur when wheat is carried out of the back of the machine with the stalks. Separation losses are usually insignificant unless the combine is overloaded. Threshing and separation losses are dependent on harvester parameters, in particular the height of cut (straw intake), cylinder speed, concave clearance and the forward speed of the harvester. Higher cylinder speed and small concave clearance improves threshing efficiency but increase grain damage. In addition, good adjustment to optimise performance usually depends on operator skill and experience. Quick (2004) claimed that grain is significantly lost over the back when a combine is travelling too fast, harvest a more dense crop area, or driven into heavy weed infestations. He also reported that at high throughput, the cleaning shoe or the separator becomes overloaded.

Threshing losses increase with an increase in throughput. At low throughput, before throughput reaches the design capacity of the machine, losses increase very slowly. Further increases overload the grain and straw separation mechanism, causing a very large increase in threshing losses. Audsley and Boyce (1974) used the following equation to calculate threshing losses:

$$L_t = 0.02\ Y\ \{Y\ S/\ (Y_o\ \varphi\ S_o)\}^2 \qquad (3.4)$$

where L_t is the threshing losses, t/ha; Y_o is the standard crop yield, t/ha; S is the forward speed, km/h; φ is the grain-straw ratio (decimal); S_o is the rated speed of the harvester in a crop yielding Y_o, t/ha. This relationship calculates the threshing losses in terms of variation of speed and yield from standard values that would give threshing losses of 2%.

Abawi (1993) modified Equation 3.4 by including the effect of grain moisture content on the threshing losses. The new equation for the threshing losses is shown in Equation 3.5.

$$L_t = 0.02\ Y\ (\theta\ \chi\ \omega\ /\varphi)^2 \qquad (3.5)$$

where θ is a grain moisture index, expressed as the ratio of harvest moisture content, M_h, to the base moisture content of 12% (wb); χ is a yield index, expressed as the ratio of crop yield, Y, to the standard crop yield, Y_o; ω is a harvester speed index, expressed as the ratio of average forward speed, S, to the rated speed of the harvester, $S_{o,}$ in km/h; φ is the grain to straw ratio where in this study, the value of φ is taken as 1.2. The S_o is defined as:

$$S_o\ = 12C_r / (C_r + 4.3) \qquad (3.6)$$

where C_r is a rated harvester capacity, ha/h, at the rated speed of the harvester in a crop yielding 2 t/ha. C_r can be calculated as follows:

$$C_r = 1.2W_c - 4.3 \qquad (3.7)$$

where W_c is the comb size of combine harvester, m.

3.5.3 Postharvest Storage Losses

Postharvest losses are the losses that usually occur during drying, storage and transportation operations. Losses during drying process usually increase with the increase in grain moisture content. Incorrect drying methods could also be a reason for losses during drying. Losses during transportation are mainly due to spillage. However, if the grain is caught in bad weather such as rain or frost during transit, it may cause grain spoilage due to infection by microorganisms.

In this study, however, only postharvest losses during storage will be considered. Grain deterioration during storage is due to biological agents like insects, moulds, bacteria and rodents coupled with inadequate storage structures. Insects could spark infestation problem. The extent of infestation depends on the cultivar, grain moisture, relative humidity, temperature, proportion of damaged grains, level of initial infestation, interaction between various insects and period of storage (Salunkhe *et al*., 1985). In addition, damaged kernel can also create a favourable condition for insect infestation. Insects also can damage the germ during storage, which can result in loss of seed viability.

However, the primary factors which can cause and control grain spoilage are grain moisture content and grain temperature. High grain moisture content and temperature will favour fungal growth, leading to serious grain spoilage. In fact, loss in quality due to fungal infection is more serious than weight loss. Fraser and Muir (1981) developed a mathematical model of grain deterioration to predict the allowable safe storage period for stored wheat in an aerated storage. This mathematical model is a function of grain moisture content and grain temperature (Equation 3.8). This equation is based on static conditions of grain temperature and moisture.

$$S_a = 10^{(a+bMh+cTc)} \tag{3.8}$$

Where:

S_a = the maximum allowable safe storage period before seed germination drops by 5% or when visible mould appears, d;

T_c = average grain temperature, ºC;

M_h = grain harvest moisture content, % (wb);

For $12 \leq M_h \leq 19\%$ (wb);

$a = 6.2347$, $b = -0.21175$, $c = -0.05267$

For $19 \leq M_h \leq 24\%$ (wb);

$a = 4.1286$, $b = -0.09972$, $c = -0.05762$

On the other hand, Ziauddin and Liang (1986) developed a mathematical model to predict the maximum allowable safe storage period of harvested wheat which is placed into wet storage without aeration system. This mathematical model is a function of the initial grain moisture content and grain temperature as shown below:

$$S_a = kM_a^{u}(T+T_g)^{v} \tag{3.9}$$

where S_a is a safe storage period of grain in days, d; M_a is an average moisture content of grain, % (dry basis); T is a mean ambient air temperature, ºC; T_g is a mean grain temperature above ambient, ºC. The typical value of T_g is 7ºC (Williamsom, 1964). For cereal grain, $k = 379.23\times10^{10}$; $u = -6.658$; and $v = -2.039$.

In both models, the random nature of weather makes the analysis of safe storage period a difficult task. Therefore, in this study, the allowable safe storage period for wheat is calculated based on the average daily air temperature. Wheat is considered spoiled and attracts GP classification if it is kept beyond the safe storage period.

3.6 Conclusion

In this chapter, the literatures pertinent to climatic-based crop simulation model in grain production system have been reviewed. Generally, the climatic-based simulation models can be divided into two categories: grain crop growth simulation model and grain harvesting system simulation model. However, for this study, a special emphasis is given to the grain harvesting system simulation model. From the available literature in grain harvesting simulation models, it has been found that only the work of Abawi (1993) was developed in Australia.

Based on the literatures study, it has also been found that the common deficiency in all available models is the exclusion of an aeration system in their grain harvesting system. This chapter has also found that few studies on aeration strategy and benefits for stored wheat in Australia are available. In contrast, most simulation studies in aeration systems were carried out in the United States.

Furthermore, none of the above literatures studied the complete set of the grain harvesting system involving machinery such as a combine harvester, grain drier and grain aerator. Other models ignored the interaction between crop physiology, machinery operation and weather conditions in estimating the total costs of wheat harvesting system. Some of the models also excluded the losses in grain quality before harvest with the exception of Abawi (1993). All these problems will be addressed in this research.

CHAPTER 4

Formulation of the Simulation Model

The Wheat Harvest System Simulation Model (WHSSM) will be developed in this chapter to study the economics of high moisture grain harvesting in several wheat growing locations across Australia. This model will be developed by integrating several key submodels involved in the wheat harvesting system. Each submodel will be represented by appropriate mathematical functions adapted from the previous grain harvesting simulation studies. The WHSSM will be written in **MATLAB** language. All of the grain moisture contents in this chapter are presented in wet basis unless it is otherwise stated.

4.1 Model Description

The main submodels involved in this model are weather submodel, crop loss submodel, machinery submodel and economic submodel. Each submodel will consist of several components. The components for each submodel and the relationships among them will be discussed in the next section of this chapter. Eventually, this model will be used to determine the optimal strategy in dealing with high moisture grain harvesting. A schematic diagram showing the overview of the WHSSM is illustrated in Figure 4.1.

4.2 Weather Submodel

In this section, several mathematical functions will be defined and used to represent weather patterns during the harvest. The mathematical functions will be used to simulate the effect of weather conditions on the grain harvesting system in the next chapter. The mathematical functions will also be used to convert daily weather data into hourly weather data.

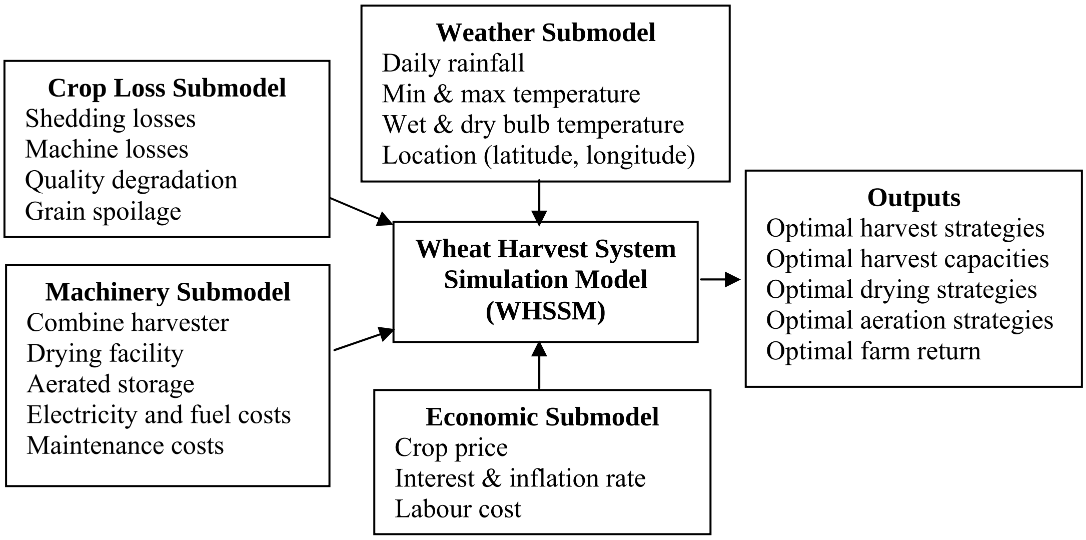

Figure 4.1 Schematic diagram of the Wheat Harvest System Simulation Model (WHSSM)

4.2.1 Weather Data

Three wheat growing locations across Australia are chosen in this study namely, Goondiwindi (QLD), Tamworth (NSW) and Scaddan (WA). The selection of these three locations is important in order to study the effect of different weather pattern on return. Detailed explanation of geographical and weather conditions for these locations can be found in Section 8.1. The historical weather data for each study location from 1991 to 2005 (15 years) are used in this simulation study. The weather data for Goondiwindi and Tamworth were obtained from the Australian Bureau of Meteorology (ABM). For Scaddan, the weather data was obtained from Mr Nigel Metz, a project officer of the SEPWA, Western Australia. The weather data used in this simulation are daily minimum and maximum temperatures, dry and wet bulb temperatures, and the amount of daily rainfall.

4.2.2 Temperature

Since the weather data provided by both weather data providers (ABM and SEPWA) is in daily basis, it was first converted into hourly basis using procedures developed by Kimball and Bellamy (1986). The conversion of weather data from daily basis into hourly hour basis is important because the available model for predicting grain moisture content requires the weather data in hourly basis. Abawi (1994) tested the hourly predicted temperature generated from the procedures of Kimball and Bellamy against the hourly observed temperature collected from Gatton Research Station between August and November 1989. Based on this experiment, he found a close agreement between the predicted and observed data with RMSE of 3°C and a correlation coefficient of 0.87. The difference between the predicted and observed hourly temperature found in this experiment is shown in Figure 4.2.

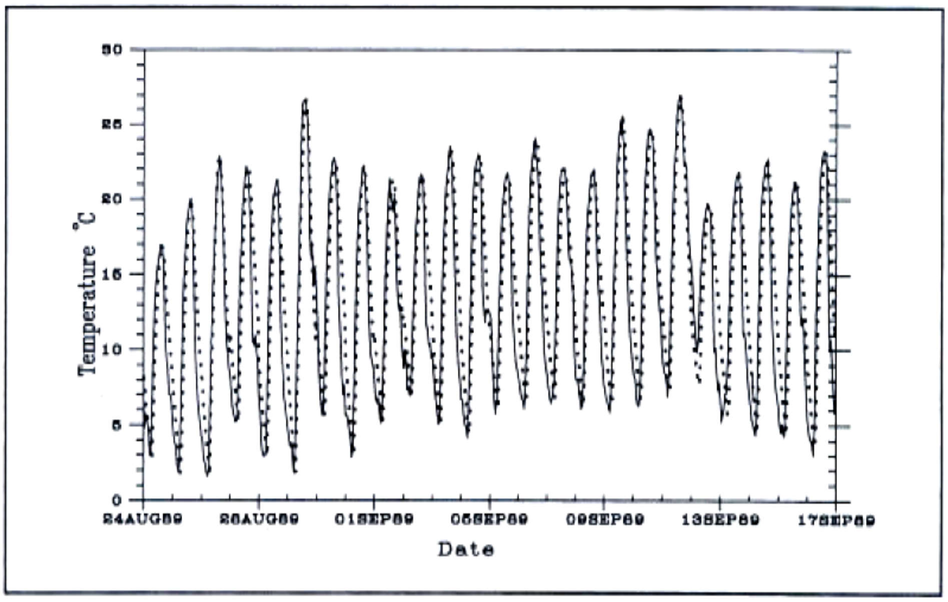

Figure 4.2 Comparison between observed and predicted hourly air temperature. Solid lines are based on daily minimum and maximum air temperature (Kimball and Bellamy, 1986). Dots represent actual temperatures. (Source: Abawi, 1994)

Based on the procedures suggested by Kimball and Bellamy (1986), the air temperature at any time of the day can be determined provided that the daily minimum temperature, T_{min}, and maximum temperature, T_{max}, are known. In this study, the values of T_{min} and T_{max} are provided by the weather data providers. During daytime, the air temperature, T_d, at any time, t, is defined by Equation 4.1.

$$T_d = T_{min} + (T_{max} - T_{min}) \cos \{[\pi(t - t_x)]/[2(t_x - t_{min}]\} \quad (4.1)$$

Where t_x is a time at which the maximum temperature is placed midway between noon and sunset and is calculated as follows:

$$t_x = 12 + (D_a / 4) \tag{4.2}$$

where D_a is the astronomical day length and calculated using Equation 4.5. The time at which the minimum temperature occurs, t_{min}, can be computed by:

$$t_{min} = t_r + \alpha D_a \tag{4.3}$$

where α is 0.06 and t_r is the time of sunrise and can be calculated by:

$$t_r = 12 - (D_a / 2) \tag{4.4}$$

The astronomical daylength, D_a, was calculated from the procedures proposed by Sellers (1965).

$$D_a = 2 \{\arccos [-\tan (\Gamma) \tan (\delta)]\} (180/\pi) (1/15) \tag{4.5}$$

where Γ (degrees) is the latitude of the location and δ (radians) is the declination which is measured from the equator. The declination can be calculated using an equation below:

$$\delta = 23.5 (\pi/180) \cos [2\pi(q-172)/365] \tag{4.6}$$

where q is a day of year.

At night, the air temperature, T_n, at any time, t, is computed by:

$$T_n = T_{sky} + (T_{set} - T_{sky}) \exp\{-k [t - (12 + D_a/2 - \alpha D_a)]\} \tag{4.7}$$

where T_{set} is a temperature at sunset calculated from Equation 4.8; T_{sky} is the sky temperature computed from Equation 4.14; and k is the decay constant computed from Equation 4.12. However, if t is between 0 (midnight) and t_{min}, then 24 hours are added to t.

$$T_{set} = T_{min} + (T_{max} - T_{min}) \cos \{[\pi(1 - 4\alpha)]/[2(3-4\alpha)]\} \tag{4.8}$$

$$T_{sky} = [(T_{set} + 273 + T_{min} + 273)/2]\ \varepsilon^{0.25} - 273 \tag{4.9}$$

where ε is the sky emittance, computed from the equation developed by Idso and Jackson (1969) as shown in Equation 4.10.

$$\varepsilon = 1 - 0.261 \exp(-7.77\ T_{ave}{}^{2} / 10000) \tag{4.10}$$

T_{ave} in this equation is an average of night temperature and its value can be computed using equation below:

$$T_{ave} = (T_{set} + T_{min}) / 2 \tag{4.11}$$

The decay constant, k, for Equation 4.7 is chosen to force $T=T_{min}$ at $t=t_{min}$.

$$k = \log_e [(T_{set} - T_{sky}) / (T_{min} - T_{sky})] / (24 - D_a + 2\alpha D_a) \tag{4.12}$$

4.2.3 Relative Humidity

Relative humidity is one of the regulating factors that can influence grain moisture content for a standing crop in the field. Relative humidity is required to predict the level of moisture content in standing grain. Relative humidity, ϕ, is defined as the ratio of actual vapour pressure, V, of water in the atmosphere to saturation vapour pressure, V_s, at the same temperature. The relationship between them is shown below:

$$\phi = (V / V_s) \times 100\% \qquad 4.13)$$

The saturation vapour pressure, V_s, for a temperature range from 0 to 100°C can be computed from the equation described by Hunter (1987):

$$V_s = (6x10^{25} / (T + 273.15)^5) \exp [-6800 / (T + 237.15)] \quad (4.14)$$

where T is the hourly air temperature calculated from Equation 4.1 (daytime) and Equation 4.7 (at night).

The actual vapour pressure, V, can be determined from the difference between the dry and wet bulb temperatures. The relationship is expressed by the following equation:

$$V = V_{wb} - \gamma (T_{db} - T_{wb}) \quad (4.15)$$

where V_{wb} is the saturation vapour pressure at wet bulb temperature which can be determined using Equation 4.14. T_{db} is a dry bulb temperature and T_{wb} is a wet bulb temperature. The values of T_{db} and T_{wb} are provided by weather data providers. The psychrometric constant, γ, can be computed from the Equation 4.16. This formula and all its constant values can be found in (Richard *et al.*, 1998):

$$\gamma = (c_p P) / (\beta\lambda) = 0.665x10^{-3} P \quad (4.16)$$

where λ is a latent heat of vaporization, 2.45 MJ/kg; c_p is a specific heat of air at constant pressure, $1.012x10^{-3}$ MJ/ (kg°C); β is a ratio of molecular weight of water vapour to dry air, 0.622; and P is the atmospheric pressure at elevation, z (measured from the sea level, m) calculated using Equation 4.17 as found in (Richard *et al.*, 1998).

$$P = 101.3 [(293-0.0065 z) / 293]^{5.26} \quad (4.17)$$

However, the actual vapour pressure close to a wet surface decreases with dewfall at night and increases during the daytime, but its diurnal fluctuations at screen level (1.5 meters above ground) are relatively small

(Campbell, 1977). Kimball and Bellamy (1986) noted that the simplest model to predict humidity is to assume that actual vapour pressure is constant and equal to the average for the day. Abawi (1994) found that the observed relative humidity from three months of hourly weather data collected at Gatton Research Station and the computed relative humidity from Equation 4.13 did not show any significant diurnal fluctuations (Figure 4.3).

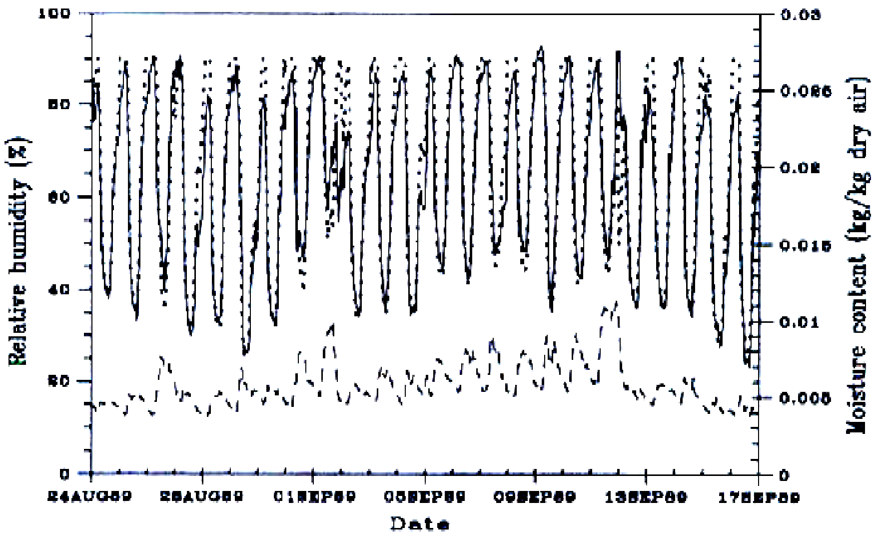

Figure 4.3 Comparison between observed and predicted relative humidity. Solid lines are actual relative humidity; dotted lines are predicted relative humidity. Dashed lines show the fluctuation in moisture content (humidity ratio) of air. (Source: Abawi, 1994)

4.2.4 Rainfall

Rainfall is also an important weather element which can influence the grain moisture content, harvesting operation, transport operation and grain quality. As rainfall data provided by weather data providers are in daily basis, the determination of rainfall in hourly basis is difficult. However, Abawi (1993) used a simple model to desegregate daily rainfall based on typical rainfall patterns in the northern region of Australia. This model is shown in Table 4.1.

Table 4.1 Relationship between rainfall magnitude and rainfall duration (Decimal values show the fraction of rain that fell in each hour)

Rainfall duration, R_d (h)	Daily rainfall, R_q, (mm)		
	$R_q < 20$	$20 < R_q < 40$	$R_q > 40$
1	0.5	0.3	0.1
2	0.5	0.4	0.2
3		0.2	0.3
4		0.1	0.2
5			0.1
6			0.1

(Source: Abawi, 1993)

The model assumes that the amount of rainfall is related to rainfall duration. Thus, hourly rainfall data can be generated based on rainfall duration from the daily data rainfall. In this study, it was assumed that the hourly rain starts occurring from the first hour or at 12.00 p.m. (midnight) of the rainy day. For example, if 30 mm of rain fell on a day it was assumed that the rainfall duration was 4 h starting from 12.00 p.m. (midnight) to 4.00 a.m. (Table 4.1).

4.3 Prediction of Grain Moisture Content for a Standing Crop

Grain moisture content is one of the most important factors in this study. This factor will determine the available time for harvesting, the harvesting starting date, the length of grain safe storage period and the suitable strategy for postharvest management. The level of moisture content for a standing crop in the field depends on its maturity stage and weather condition. Several empirical models have been developed to study the effect of ambient weather condition on grain moisture content for a standing crop in the field (Crampin and Dalton, 1971; Van Elderen and van Hoven, 1973; Atzema, 1993).

Based on the model of van Elderen and van Hoven, Atzema (1993) developed a new model to calculate the diurnal course of the moisture content of wheat and barley using real-time weather data. This model has been proven to give a good correspondence (within 1.0%, wb) with measured moisture contents (Atzema, 1998). This model requires hourly values of air temperature, dew point temperature, wind speed, global radiation, cloud cover and daily rainfall. Although this model can produce high accurate prediction, some of the inputs required by this model are not available in many wheat growing locations in Australia. For example, the weather data of wind speed, global radiation and cloud cover are not available especially for long periods of record. Therefore, this model is not suitable to be used in this study.

Van Elderen and van Hoven (1973) suggested that the model developed by Crampin and Dalton (1971) was the best model to characterize the variation of grain moisture content for a standing crop in the field. This is because the Crampin and Dalton model only requires hourly weather data of rainfall, temperature and relative humidity. These hourly weather data can be generated from daily weather data using the mathematical functions developed by Kimball and Bellamy, as discussed in Section 4.2.2.

The predicted grain moisture contents generated from Crampin and Dalton model were validated by Abawi (1994) over three successive seasons (1987-1990) using field data collected in the Darling Downs region, Queensland. In his work, Abawi found that the correlation coefficients in each season were 0.82, 0.84, and 0.83 with RMSE of 4.1, 3.6 and 3.4% (wb) respectively. The difference between observed and predicted grain moisture content in a standing crop is shown in Figure 4.4.

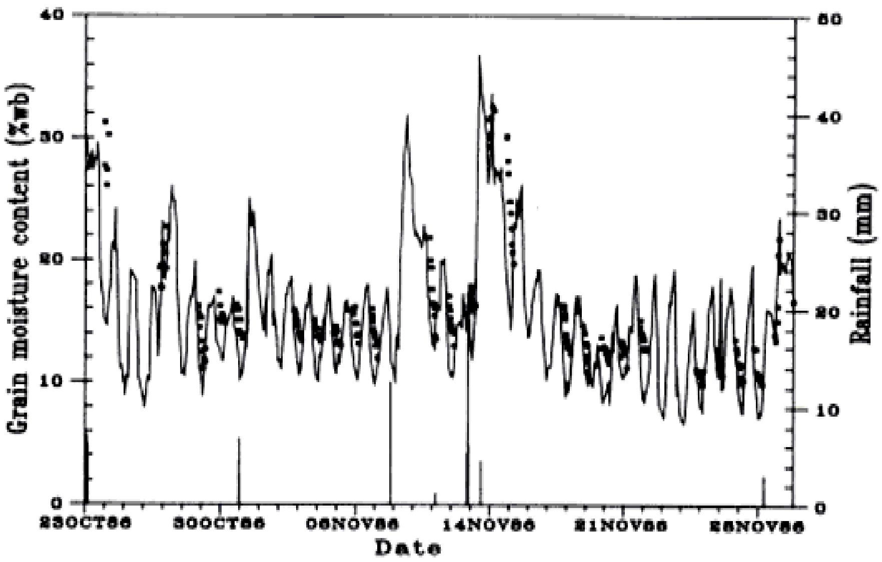

Fig. 4.4 Comparison between observed and predicted grain moisture content in a standing crop. Vertical bars are daily rainfall. Solid lines are predicted moisture content. Dots represent field moisture content. (Source: Abawi, 1994)

4.3.1 The Crampin and Dalton Model

The Crampin and Dalton model can be used to predict the grain moisture contents of standing crop during a period of rain and a period without rain (dry period). The prediction of grain moisture content, M_r, for wheat (% dry basis, db) during a period of rain is defined by:

$$M_r = M_b + \delta M \tag{4.18}$$

where M_b is the grain moisture content at the beginning of a rain period. The changes in grain moisture content between the initial moisture content at the start of the rain period and the final moisture content at the end of the rain period, δM, can be calculated by the following function:

$$\delta M = 0.345R_q + 6.118\log_e R_d + 0.5482 \tag{4.19}$$

where R_q is the amount of rain within a rain period, mm; and R_d is the duration of rain, h.

The prediction of grain moisture content for wheat in a period without rain, M_d, is computed by:

$$M_d = W_e + A\, e^{-0.04t} + 2.5 \sin [(t-6)\, \pi / 12] + 1.1 \qquad (4.20)$$

where We is the equilibrium moisture content defined by Equation 4.21. A is a constant for any given dry period defined by Equation 4.22, and t is the time in hours measured from the beginning of the dry period.

$$W_e = m\, \{[-\log_e (1-\phi)] / [1.8T + 492]\}^{(1/n)} \qquad (4.21)$$

where T is the air temperature, °C; ϕ is the air relative humidity (decimal); for wheat, n is 3.03 and m is 113.1.

The constant A in Equation 4.20 is a difference between the actual moisture content immediately after a period of rain and the equilibrium moisture content, W_e. This constant can be calculated as follows:

$$A = M_b + \delta M - W_{eo} \qquad (4.22)$$

where W_{eo} is the equilibrium moisture content at the end of the rain period. The initial value of A at the start of each simulation is set at 42.9-W_{eo}. 42.9 is a value of grain moisture content in dry basis which is equal to 30% moisture content in wet basis.

4.4 Grain Losses Submodel

In this section, several mathematical functions used to quantify the magnitude of grain losses which occur in the wheat harvesting system will be discussed. Basically, grain losses submodel can be divided into two categories: quantity losses and quality losses.

4.4.1 Quantity Losses

Basically, quantity losses occur due to the interaction of the crop in the field with its surroundings environment and machinery. In this study, three main grain losses considered in this study is shedding losses due to natural shedding, header losses and threshing losses. In order to quantify the magnitude of these losses, many studies have been done to represent them in mathematical functions (Section 3.5). The related mathematical functions used in this simulation study are discussed below.

4.4.1.1 Shedding Losses

In Queensland, Cameron (2004) claimed that a typical amount of wheat losses due to natural shedding are between 0.3 and 2.5% per day, or between 6 to 50 kg/ha per day (based on the crop yield at 2 t/ha). In this study, the amount of shedding losses is quantified using the empirical equation developed by Abawi (1993), as shown in Equation 3.2.

4.4.1.2 Machine Losses

Machine losses occur due to grain-machinery interaction. Most machine losses occur during the cutting and threshing operations. The common types of machine losses are header losses and threshing losses. These losses may account for up to 2% of crop yield. Header losses occur during the cutting operation. It is increased with time as a mature crop is left unharvested in the field. With time, the height of heads decreases and the crop becomes more brittle resulting in an increase in the level of header losses (Klinner, 1979). In this study, the header losses are calculated as a function of days past maturity:

$$L_h = \psi_3 \, d_m \tag{4.23}$$

where L_h is the header losses, t/ha; ψ_3 is a constant loss factor, which is assumed to be 0.0025 t/ha/d (2.5 kg/ha/d), based on the field study reported by Hughes *et al*. (2005).

Threshing losses occur during the separation operation. Threshing losses refer to grain lost in the rear of the combine harvester in the form of unthreshed heads. Threshing losses are directly related to harvester throughput. Increasing harvester speed and grain moisture content will cause an increase in threshing losses. In this study, threshing losses are calculated using Equation 3.5.

4.4.2 Quality Losses

Quality losses of wheat occur mainly during preharvest period and storage period. During preharvest period, quality losses occur due to rainfall and the crop maturity stages. During storage, quality losses occur due to biological activities of insects, bacteria and mould. Quality losses during storage usually referred to as spoilage losses. The criteria for both forms of quality losses are discussed below.

4.4.2.1 Quality Losses Due to Rainfall and Crop Maturity

Quality losses due to rainfall and the maturity stage of a crop are one of the important factors in the grain harvesting system which affects the unharvested grain in the field. Abawi (1993) used the criteria shown in Table 4.2 to link the grain quality degradation with the rainfall amount and the stage of maturity. In his model, wheat is assumed to be APH wheat category at maturity and it is then downgraded in discrete steps to AH, ASW, GP and FQ, depending on both the amount of rainfall and the number of days past maturity.

For example, if a rainfall amount of 75 mm has occurred 20 d after the crop reached maturity, the wheat quality will be downgraded from its current category, APH, to two grades lower (ASW). The cost of quality losses due to degradation can be computed using the following equation:

$$Q_d = (C_1 - C_2) * Y \qquad (4.24)$$

where Q_d is a quality losses due to degradation, \$/ha; C_1 and C_2 are the prices of the APH and GP wheat categories respectively, \$/t. Abawi (1993) also suggested that any grain which is not harvested after 60 days from maturity is assumed to be downgraded to ASW classification.

Table 4.2 Criteria used to model grain quality downgrading as a function of maturity and rainfall. Quality is downgraded in discrete steps from APH to FQ.

Rainfall, R_q (mm)	Day past maturity, d_m (d)		
	$d_m < 7$	$7 < d_m < 30$	$d_m > 30$
30	No effect	No effect	1 Step
40	No effect	1 Step	1 Step
50	No effect	1 Step	2 Steps
60	No effect	1 Step	2 Steps
70	1 Step	2 Steps	3 Steps
80	1 Step	2 Steps	3 Steps
90	1 Step	3 Steps	3 Steps

(Source: Abawi, 1993)

4.4.2.2 Quality Losses due to Grain Spoilage during Storage

Quality losses due to grain spoilage occur during storage as a result of biological activity of mould, bacteria, insects and even grain itself. Grain spoilage can occur when the grain is placed either into a grain storage with or without aeration system. The maximum allowable safe storage period for grain in aerated storage is calculated from the mathematical model developed by Fraser and Muir (1981) as shown in Equation 3.8. However, if grain is placed into wet storage (without aerator) or on the floor, the maximum allowable safe storage period for this grain is calculated from the mathematical model developed by Ziauddin and Liang (1986) as shown in Equation 3.9.

4.5 Machinery Submodel

There are three main machines involved in this study namely a combine harvester, grain drier and aerated storage. Each of them will be represented by mathematical functions in order to study the effect of different machine parameters on its performance. It will also be used to study the effect of the machinery on the grain harvesting system.

4.5.1 Combine Harvester Capacity and Cost Model

A combine harvester is very expensive machinery. Its prices range from \$A 300,000 to \$A 400,000 depending on capacity and model. The capital cost of the combine harvester, C_h, based on the new value of harvesters in 2003, can be calculated by Equation 4.25. The value of the C_h is essentially a function of a comb size.

$$C_h = 10,000\ (4.5\ W_c - 9) \tag{4.25}$$

where C_h is the capital cost of harvester, \$A; and W_c is the comb size (width of cut), m. In this study, the effective harvesting capacity, C_{ec}, is calculated using Equation 4.26 as found in Abawi (1993). Field efficiency, μ, for combine harvester is assumed to be 75% as this is a typical value for grain harvesting operations (Abawi, 1993).

$$C_{ec} = \mu\ \chi\ \omega\ C_r \tag{4.26}$$

Fuel cost for a combine harvester, C_f, is calculated as an hourly cost using Equation 4.27.

$$C_f = N_h\, c_f\, f_e \tag{4.27}$$

where N_h is the total number of working hours in the harvesting operation, h/yr; c_f is the specific cost for fuel, \$/L; and f_e is the harvester fuel consumption rate, L/h. The maintenance and repair costs, C_x, tend to increase with machine age. The maintenance and repair costs for the combine harvester and drier are computed using Equation 4.28 as suggested by Rotz (1987).

$$C_x = I_p\, f_1\, (0.001\, H_c\, \omega)^{f_2} \tag{4.28}$$

where f_1 and f_2 are coefficients for the repair and maintenance costs. H_c is the cumulative hours of use and ω is the speed index. The values for all parameters and control values used in this study are defined in Section 5.2.

4.5.2 Drier Cost and Capacity Model

In this study, driers are modelled based on actual continuous flow drier models, manufactured by Agridry-RFM, Toowoomba, Queensland. According to Agridry-RFM, driers are rated on the basis of drying wheat from 15 to 12% moisture contents at an ambient condition of 20°C and a relative humidity of 50% using drying temperatures of 70°C. Details of the driers used in this simulation are shown in Table 4.3. The price of the driers shown in Table 4.3 is based on their price in 2005.

Table 4.3 Drier models and their specification

Drier type	Drier model	Drying capacity, (t/h)	Fan power, (kW)	Airflow rate, (Kg/s)	Capital cost, ($A)
High capacity	AR 1614	27	22	15	102,500
Medium capacity	AR 1214	20	22	15	92,500
Low capacity	AR1210	12	22	15	85,000

(Source: Agridry-RFM, Toowoomba)

Figure 4.5(a) AR 1614

Figure 4.5(b) AR 1214

Figure 4.5(c) AR 1210

Figure 4.5 (a to c) A series of AR continuous flow grain drier models (Source: Agridry-RFM, Toowoomba)

The equation of drier capacity as described by Radajewski *et al.* (1987) is shown in Equation 4.29. Based on this equation, a drier throughput will be determined by the initial grain moisture content, the drying air temperature and the drier characteristics. However, to suit the rated capacity of Agridry-RFM driers, this equation was modified by multiplying them with a coefficient x. The values of the coefficient x are determined based on the rated capacity of these driers.

$$D_t = x\,[0.0056(C_1+C_2T+C_3T^2)\, e^{(C4+C5T+C6T2)\ln(Mi-Mo)}\,] \qquad (4.29)$$

where:

D_t = drier throughput, t/h;

$T = 0.1\, T_d$;

T_d = drying temperature ranging from 40 to 90°C;

M_i = the initial grain moisture content varying from 16 to 35% (db);

M_o= the final grain moisture content which is assumed to be 12% (wb);

C_1 = -1567.6; C_2 = 1447.1; C_3 = -42.78; C_4 = -1.0; C_5 = 0.032; C_6 = 0.00044.

x = coefficient values for the drier models of AR1614, AR1214 and AR1210 are 4.12, 3.05 and 1.83 respectively.

For a batch drier (low temperature drier), the above format of drier capacity equation is still used, but the capital cost of this drier is assumed to be \$A 5,000 for 1 t/h of rated drying capacity. In this study, the batch drier is assumed to have 3 t/h drying capacity with 3% moisture reduction at 40°C. The air flow rate and fan power for this drier are assumed to be 8 kg/s and 12 kW respectively. The actual cost of this drier is assumed to be \$A 15,000. For the above equation, coefficient x for this drier is 0.75.

The variable costs of drying are primarily associated with the operation of the drying fan and the heating system. Fuel cost for drying increases with airflow rate and generally decreases with drying temperature. The annual cost for drying, C_e, is computed from:

$$C_e = F_d\, N_d\, c_e + E_d\, c_d \qquad (4.30)$$

where F_d is the fan power for drier, kW; c_e is the specific cost of electricity, \$A/kWh; c_d is the specific cost of Liquid Propane Gas (LPG), \$A/kWh. The value of c_d is calculated based on the price of LPG at \$0.56/L with heat content/fuel heating value of 25.5 MJ/L. N_d is the total number of working hours in drying operation, h/yr; and E_d is the energy required for drying and can be generated by:

$$E_d = (c_p N_d \; m_d \; [T_d - T_{avd}]) / B_e \quad (4.31)$$

where T_d is the drying temperature, °C; T_{avd} is an average daily ambient air temperature during harvest period, °C; m_d is the flow rate of air used for drying, kg/s; and c_p is the specific heat of air, kJ/kg°C; B_e is the burning efficiency for fuel, 85%. The maintenance and repair costs for drier are calculated using the same equation as shown in Equation 4.27. However, the values of f_1 and f_2 for a drier are different from those values for a combine harvester (See Table 5.2).

4.5.3 Aerated Storage Cost Model

Aerated storage helps to keep the high moisture grain until a drier is available. In this study, it is assumed that the aerated storage is equipped with a low volume aeration or aeration cooling. Aeration cooling uses cool ambient air to lower grain temperature thus prolong the safe storage period of higher moisture grain. Aeration cooling decreases biological activity in the grain ecosystem and prevents moisture migration (Muir *et al*., 1989). The aerator is assumed to be continuously used day and night, at the airflow rate of 2 L/s/t.

In this study, it is assumed that the storage capacity, diameter and overall height of the silo are 145 t, 5.8 m and 10.0 m respectively (based on Kotzur silo GPE 8-5-35 manufactured by Modern Engineering & Construction Co. Pty. Ltd). The capital cost for an aerated storage is calculated using the following equation:

$$C_a = S_c \, C_c \quad (4.32)$$

where C_a is the capital cost of the aerator, including the costs of fan, motor and storage bin, \$A; S_c is a storage capacity, t; and C_c is the aeration cost per tonne, \$A/t, which in this study, is assumed to be \$A 150/t. Other auxiliary items such as augers and concrete pads are assumed to be readily available. The required power for fan, F_a, per unit inlet area of the bin floor at 50% efficiency is calculated using the following equation (Arinze *et al*., 1994):

$$F_a = 2\Delta P_g Q \tag{4.33}$$

where Q is the air flow rate per square meter of the floor area, m/s; and ΔP_g is a pressure drop of air passing through the bulk of grain, N/m^2. The value of ΔP_g for clean wheat can be calculated using Equation 4.34, as found in ASABE (2007). The duct system resistance is assumed to be constant at 300 N/m^2. The value of this constant is added to the ΔP_g to obtain the total pressure drop.

$$\Delta P_g = (aQ2\ D_b) / (\ln (1+bQ)) \tag{4.34}$$

where D_b is the depth of grain bed, m. For wheat, the value of constants a and b are 2.7x104 and 8.77 respectively. The annual cost for aeration, C_{ae}, is calculated as follows:

$$C_{ae} = F_a c_e N_a \tag{4.35}$$

where N_a is the total number of working hours for aeration, h/yr.

4.6 Economic Submodel

In this section, the economic functions and the calculation of economic return in a grain harvesting system will be discussed. The economic submodel for machinery such as a combine harvester, grain drier and grain aerator consist of two components of fixed and variable costs. The fixed costs are the costs such as depreciation and interest, which are independent of use. Labour, maintenance and fuel costs are grouped as variable costs.

4.6.1 Fixed Cost Annuity Model

The annual fixed costs of ownership for the machinery are determined using the annuity method of capital recovery (Smith and Oliver, 1974; Bartholomew, 1981). Based on this method, the annual cost of machinery purchased, C_m, is calculated as follows:

$$C_m = (I_p - S_v)\{ i (1+ i)^n / [(1+ i)^n - 1] \} + S_v i \qquad (4.36)$$

where I_p is the initial purchase price of machinery, \$A; S_v is a salvage value and is assumed to be zero in this study; n is the recovery period, yr; and i is the real interest rate and can be calculated by using the method of Barthlomew (1981):

$$i = (i_n - i_g) / (1+i_g) \qquad (4.37)$$

where i_g is the general inflation rate, %/yr; and i_n is the nominal or market interest rate, %/yr.

4.6.2 Labour Cost

Labour cost is categorised as variable costs. In this study, labourers are employed for harvesting and drying operations. It is assumed that labourers are employed for both operations continuously from the beginning until the end of each operation. For the harvesting operation, labourer is employed from the beginning of harvest until all of the grain on the farm is harvested. For the drying operation, labourer is employed from the first time when grain is dried until all harvested grain is dried. The annual labour cost, C_l, for both operations can be calculated as follows:

$$C_l = (N_h + N_d)c_l \qquad (4.38)$$

where c_l is the specific cost of labour where in this study, it is assumed to be $A 15/h.

4.7 Conclusion

In this chapter, several mathematical functions related to the wheat harvesting system have been developed. These mathematical functions represent four main submodels namely weather submodel, crop loss submodel, machinery submodel and economic submodel. It has been found that all of the mathematical functions in the weather submodel have been validated using the field trial in the Darling Downs region, Queensland.

The relationships and interactions between crop, weather elements and machinery have been defined using appropriate mathematical functions. The amounts of grain losses due to weather conditions have also been quantified. All variable values used in the formation of the mathematical functions are based on the previous theoretical and field data. Furthermore, the machinery performance and its operating and ownership costs have also been determined using suitable functions. Therefore, it is now possible to find the optimum machinery capacity in order to maximise growers' return.

CHAPTER 5

Model Assumptions and Operation

This chapter presents relevant assumptions and simplifications made to the wheat harvesting system and the scope of this study. It also presents the flowchart, fixed simulation parameters and control values used. The main application of the **WHSSM** is to calculate and compare the possible return for different harvesting strategies in different locations at grain moisture content ranging from 12 to 22% (wb). In particular, this simulation model will be used to investigate the effects of different crop parameters, machinery capacities, economic parameters and harvesting strategies on return. All simulation results shown in this study are averages for the 15 years of simulation study (1991-2005).

5.1 The Assumptions, Simplifications and a Scope of the Model

Due to limited study period, variability of grain price and machinery costs, and complexity of the wheat harvesting system which involves many submodels and components, many assumptions and simplifications have to be made in this study. Thus, the results of this study would be regarded as being comparative and indicative of the discussed parameters. The scope of this study is from wheat harvesting to aerating and drying (until grain moisture content reaches 12% (wb)). The costs for crop establishment including land preparation, seeding and fertilizing are not studied. The costs of grain delivery from a farm to a commercial storage or grain bulk handing are also excluded. All of the assumptions and simplifications made in this model are discussed below.

5.1.1 Harvest Period

Harvest period begins when standing wheat in the field reaches its physiological maturity. This implies that the wheat is assumed to reach its physiological maturity when its grain moisture content becomes 30%. From this maturity date, the number of days past maturity is calculated. In Goondiwindi and Tamworth, the harvest period is assumed to start on October 1 while for Scaddan is on November 1. The maximum time for the harvest period is set as 80 d, counted from the time of crop physiological maturity.

However, if the harvesting is not completed within this period, the remaining crop is assumed lost and has zero value. This assumption is considered reasonable, because the costs associated with harvesting low yielding feed quality grain often exceed the value of the crop. The remaining crop in the field is then called as unharvested grain losses, L_u. The L_u, can be computed by the following equation:

$$L_u = ((F_s - C_{ec} H_a) Y) / F_s \qquad (5.1)$$

where F_s is the farm size, ha; and H_a is the available harvesting hours at each grain moisture content, h. Further discussion for the H_a is available in Section 6.3.

5.1.2 Harvesting Operation

Harvesting operation commences when grain moisture content falls below the desired level in the range of 12 to 22% moisture contents. The harvesting operation is assumed to be carried out at a constant speed (8 km/h) for 11 h/d, from 7 a.m. to 6 p.m. Harvesting operation will be delayed depending on the magnitude of daily rainfall. The delay due to rainfall is counted by step function as shown below:

Table 5.1 Harvesting delay related to antecedent rainfall

Rainfall magnitude, r (mm)	Delay, D (d)
$r \leq 2$	0
$2 < r \leq 8$	1
$8 < r \leq 20$	2
$20 < r \leq 40$	3
$40 < r \leq 80$	4
$r > 80$	6

Source: Abawi (1993)

Where D is the delay, d; and r is the daily rainfall magnitude, mm. If rain falls on two or more successive days, the delay is computed from the accumulated rainfall over those days.

5.1.3 Farm Size

The average farm size in Australia in 2003-04 is 443 ha (Table 2.4). However, in this study, the farm size for the control value is assumed to be 1000 ha as this size will better respond to the high moisture grain harvesting study.

5.1.4 Grain Drier

A grain drier is assumed to be operated continuously throughout the harvest season 24 h/d until all harvested wheat has reached 12% moisture content. No grain drier would be used at or below 12% harvest moisture content.

5.1.5 Aeration System

In this study, a low volume aeration or an aeration cooling is used. An aeration cooling is a mechanical system where fans are used to pass small volumes of ambient air through grain in order to reduce its temperature to the level necessary to prevent deterioration (McLean, 1989). An aeration cooling is important to safely store high moisture grain until a drier is available. A wet grain storage equipped with the aeration cooling can act as buffer storage to increase a seasonal throughput of drying capacity. The contents of such buffer storage can be dried later at night or when harvesting is interrupted, e.g. due to rainfall. This aeration system is assumed to be operated continuously 24 h/d.

5.1.6 Shelter for Wet Grain

The grain which can not be placed into a grain drier and aerated storage due to inadequate capacity of both machinery will be placed on the ground under the shelter close to the aerated storage and drier facilities. No cost is calculated for shelter as this structure is assumed to be readily available. Typically, the shelter is always available on farm, particularly to store farm machinery.

5.1.7 Wheat Price Structure

A price structure for the basic wheat categories used in this study is based on the wheat price in 2005. The wheat price structure used for Goondiwindi and Tamworth is shown in Table 2.6 while for Scaddan is shown in Table 2.7.

5.2 Model Operation

At the beginning of the harvest period, all input parameters are set to default values as shown in Table 5.2. Then, all simulations are run based on that default values at the control values given in Table 5.3, unless it is stated otherwise. In each simulation, the model first reads the weather data from the study location. Based on the weather data, the predicted grain moisture contents in an hourly basis during the harvest period are generated. Then, the number of days past maturity for each grain moisture content is computed. After the model reads the simulation parameters (Table 5.2) and control values (Table 5.3), the effect of weather conditions on quantity and quality losses at any grain moisture content is computed.

Table 5.2 Fixed values of parameters used in the simulation

Parameter	symbol	Unit	Value	First appearing in page no.
Specific fuel cost	c_f	$/L	0.85	56
Specific labour cost	c_l	$/h	15	62
Specific heat of air	c_p	kJ/kg °C	1.012	51
Specific cost of electricity	c_e	$/kWh	0.10	59
Fuel use rate for harvester	f_e	L/h	35	56
Repair coefficient	f_1 (harvester)	decimal	0.08	57
Maintenance coefficient	f_2 (harvester)	decimal	2.1	57
Repair coefficient	f_1 (drier)	decimal	0.12	57
Maintenance coefficient	f_2 (drier)	decimal	1.8	57
Annual inflation rate	i_g	%/yr	3	61
Market interest rate	i_n	%/yr	9	61
Standard crop yield	Y_0	t/ha	2.0	39
Crop yield	Y	t/ha	3.0	36
Useful life of machine	n	Annual	15	61
Grain to straw ratio	φ	decimal	1.2	40

Table 5.3 Summary of the control values used in the simulation

Parameter	Symbol	Unit	Control value	Values simulated
Forward speed	S	km/h	8	6,8,10,12
Cutting width	W_c	m	9.2	6.1, 6.7, 7.3, 9.2
Farm size	F_s	ha	1000	500, 1000, 1500, 2000
Drier capacity	-	-	Medium	High, medium, low, batch drier

When harvesting is carried out at a desired level of grain moisture content, all grain losses and machinery costs (fixed and variable costs) that occur during the harvesting, drying, and aeration are calculated and accumulated. Finally, the accumulated grain losses and machinery costs from the beginning of the harvesting until all of the harvested grain is dried are added up to calculate the final return.

Simulations at 12% moisture content are carried out without a drier and aeration in order to compare the economics of high moisture grain harvesting between growers with and without postharvest machinery. Therefore, the capital and operating costs associated with a grain drier and aerated storage at that moisture content are excluded from this analysis. A simplified flow diagram showing the operation sequence of the model is shown in Figure 5.1.

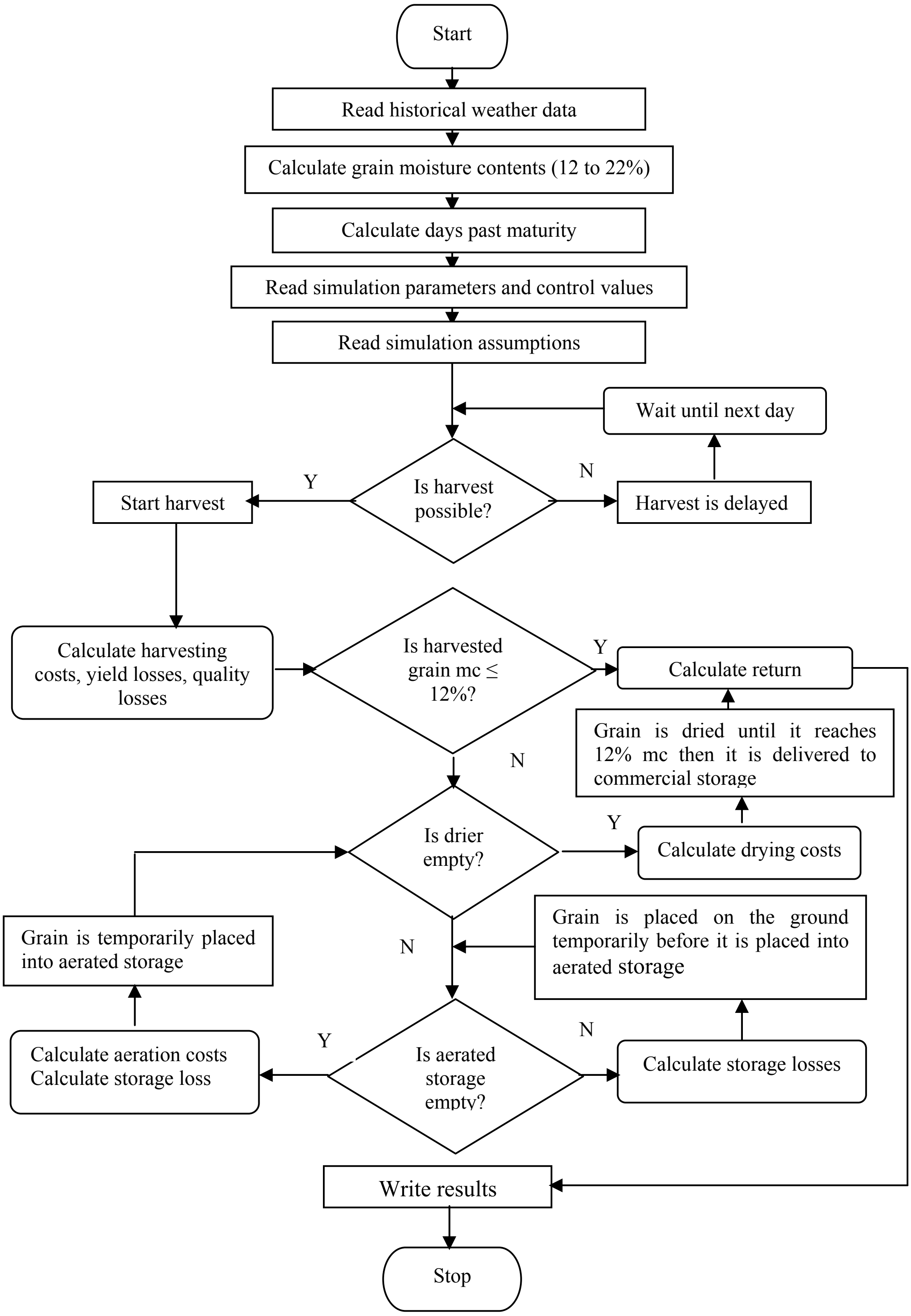

Figure 5.1 Simplified flowchart of the Wheat Harvest System Simulation Model (WHSSM)

In this study, it is assumed that wheat at 12% moisture content or lower is directly delivered to a commercial storage or central bulk handling. Wheat with moisture content higher than 12% is first delivered into a grain drier. Then, when the grain drier capacity is exceeded, and growers do not have an aerated storage, harvested grain will be placed on the floor under the shelter. If growers have an aerated storage, harvested grain will be put into an aerated storage. An aerated storage plays the role as a buffer zone between a harvester and a grain drier.

However, if an aerated storage capacity is also exceeded, the balance of the harvested grain will be dumped on the floor as well. Once an aerated storage becomes empty, the harvested grain from the floor will be then placed into the aerated storage. Once drier space becomes available, grain from the aerated storage will be transferred into it. Finally, when grain has reached 12% moisture content, it will be delivered to a commercial storage.

5.2.1 Calculation of the Grain Spoilage

Table 5.4 shows the amount of harvested grain that must be placed into wet storage due to inadequate drying capacity. This table is generated using weather data in 2005 for Goondiwindi. Hourly harvesting capacity is calculated by multiplying the harvester capacity, C_{ec}, with the crop yield (3 t/ha). C_{ec} (Equation 4.26) is calculated based on the combine forward speed and comb size of 8 km/h and 9.2 m, respectively. Daily harvesting capacity is determined by multiplying the hourly harvesting capacity with 11 h. The value of the daily harvesting capacity is constant for all grain moisture contents. For the drier, its daily capacity per day is calculated by multiplying hourly drier capacity with 24 h as the drier is assumed to be operated 24 h/d. Hourly excess grain, t/h, is a difference between the hourly harvesting capacity and the hourly drying capacity.

Table 5.4 The amount of excess grain in 2005 (drier type: low capacity drier)

Grain moisture content, % wb	14	15	16	17	18	19	20	21	22
Hourly harvest capacity, t/h	24.84	24.84	24.84	24.84	24.84	24.84	24.84	24.84	24.84
Daily harvest capacity, t/d	273.24	273.24	273.24	273.24	273.24	273.24	273.24	273.24	273.24
Hourly drying capacity, t/h	30.71	22.69	18.21	15.31	13.25	11.71	10.50	9.53	8.72
Daily drying capacity, t/d	736.98	544.52	437.05	367.36	318.02	281.00	252.03	228.66	209.34
Hourly excess grain, t/h	0.00	2.15	6.63	9.53	11.59	13.13	14.34	15.31	16.12
Daily excess grain, t/d	0.00	0.00	0.00	0.00	0.00	0.00	21.21	44.58	63.90

Daily excess grain, t/d, is the difference between the daily total harvesting capacity and the daily total drying capacity. When the harvesting capacity is higher than the drying capacity, there will be excess grain that should be placed temporarily into wet storage or on the floor. For example, at 16% moisture content, hourly excess grain for using AR1210 drier is 6.63 t/h. However, as the hourly excess grain is accumulated every hour during harvesting, the amount of the daily excess grain is increased. Since the harvesting operation is carried out only 11 h/d, there will be no harvested grain coming into a drier at night. Therefore, at night, a drier will dry all remaining harvested grain for that day. For example, at 16% moisture content, daily accumulated grain for AR1210 is nil as all harvested grain for that day is dried overnight.

In the following day, the daily excess grain from the previous day is dried at first. The freshly harvested grain for that day will have to wait until all of the previous grain is completely dried. In this study, the time from the harvested grain placed on the floor or into aerated storage until it is placed into a drier is called waiting time. For growers with no aerated storage, harvested grain is considered safe without quality deterioration if the waiting time is less than the allowable safe storage period as defined by Ziauddin and Liang (1986).

For growers with an aerated storage, the daily excess will be placed straight away into an aerated storage. The model developed by Fraser and Muir (1981) is then used to calculate the allowable safe storage period for an aerated storage. In both cases, however, if the waiting time is longer than the allowable safe storage period, the affected grain is assumed to be downgraded from APH to GP category. The maximum allowable safe storage periods for different study locations are discussed in Section 8.6.

Table 5.5 The amount of spoiled wheat in the first day of the harvesting operation in 2005 (drier type: batch drier)

Grain moisture content, % wb	15	16	17	18	19	20	21	22
Hourly harvest capacity, t/h	24.84	24.84	24.84	24.84	24.84	24.84	24.84	24.84
Hourly drying capacity, t/h	3.26	2.53	2.08	1.76	1.53	1.35	1.21	1.09
Drying time, h	7.6	9.8	12.0	14.1	16.3	18.4	20.6	22.8
Waiting time, h	66.2	88.0	109.7	131.2	152.7	174.3	196.1	218.0
Safe storage, h	527.7	317.3	195.7	123.4	79.3	51.9	34.5	23.2
Spoiled wheat, t	0	0	0	24.8	124.2	198.7	223.6	223.6

Table 5.5 shows the amount of spoiled wheat in the first day of the harvesting operation in 2005 for a farm without an aerated storage. This table is useful in explaining how to calculate the storage quality losses. Drying time is the time taken to dry a batch of harvested wheat (24.84 t/batch) at particular moisture content. The waiting time shows the time for the last batch of the harvested grain in the first day of harvesting operation has to wait before it can be placed into a drier. It can be seen that, as long as the safe time is greater than the waiting time, no spoiled wheat occurs. However, at 18% moisture content, 24.84 t of harvested wheat is considered spoiled and categorized as GP category. The equation used to calculate the amount of quality losses due to spoilage, Q_s, is shown below:

$$Q_s = (W_h (C_1 - C_2))/F_s \tag{5.2}$$

where W_h is the amount of spoiled wheat, t.

5.3 Return

Finally, after all of the machinery costs and grain losses are determined using appropriate mathematical equations, the return, R, will be calculated by the following equation:

$$R = (C\ Y) - (C_t / F_s) - ((L_w * C) + Q_d + Q_s) \qquad (5.3)$$

where R is the return, \$A/ha; C is the wheat price for APH category, \$A/t; C_t is the annual total costs (fixed plus variable costs) of machinery used, \$A/yr; L_w is the total value of the grain losses, including L_s, L_h, L_t, and L_u, \$A/ha; Q_d and Q_s are the values of the quality losses due to degradation and spoilage respectively, \$A/ha. Then, the return for each year is used to calculate the average return for 15 years of the simulation study period. However, the return generated from Equation 5.3 does not include input costs for crop establishment such as seeds and fertilizers.

5.4 Conclusion

This chapter has defined the scope of the model. It also has presented a number of basic assumptions and simplifications made. Most of the assumptions and simplifications are related to machinery operation. The justifications for the assumptions and simplifications made are also provided. The value of the simulation parameters and the control values used in this simulation study are also displayed.

A simplified flowchart of the model is provided to show the operational flow of the wheat harvesting system. The amount of grain losses in terms of quantity and quality and the fixed and variable costs of machinery involved are calculated for each grain moisture content. The accumulated grain losses and machinery costs from the beginning of the harvesting until all of the harvested grain is dried are added up to calculate the final return. Then, the return from each year is used to generate the average return for the 15 years of simulation study (1991-2005).

CHAPTER 6

The Effect of Climate Conditions on Grain Moisture Content and Harvest Starting Date

This chapter first discusses basic geographical and climatic information for the selected reference location, Goondiwindi. Then, it presents the relationship between the fluctuation of grain moisture contents in a standing crop in the field and climatic factors such as air temperature, relative humidity and rainfall. The available harvesting hours for the driest and the wettest years are also discussed. It also investigates the effect of rainfall on harvest starting date.

6.1 Reference Location

In this study, Goondiwindi is chosen to be the reference location. Goondiwindi is located in the southern part of Queensland (latitude 28º 33′ S, longitude 150º 19′ E). The elevation of this location from the sea level is 217 m. Detailed explanations on geographical and climatic information for Goondiwindi can be found in Section 7.1. Goondiwindi is chosen as the reference location because it is one of the main wheat growing areas in the northern wheat belt region, Australia. Furthermore, most of the parameters and their values used in this study are based on Queensland conditions. Many submodels used in this study have been validated by Abawi (1993) with field data in Queensland.

Goondiwindi is frequently subject to summer rainfall and storms during the harvest period. The rainfall pattern with the average rainfall curve during the typical harvest period in this location is shown in Figure 6.1. The figure shows that the rainfall intensity increases over time during the harvest period. This figure suggests that, if growers want to minimise the risk of weather damage, the harvesting operation must be done as earlier as practical for the season.

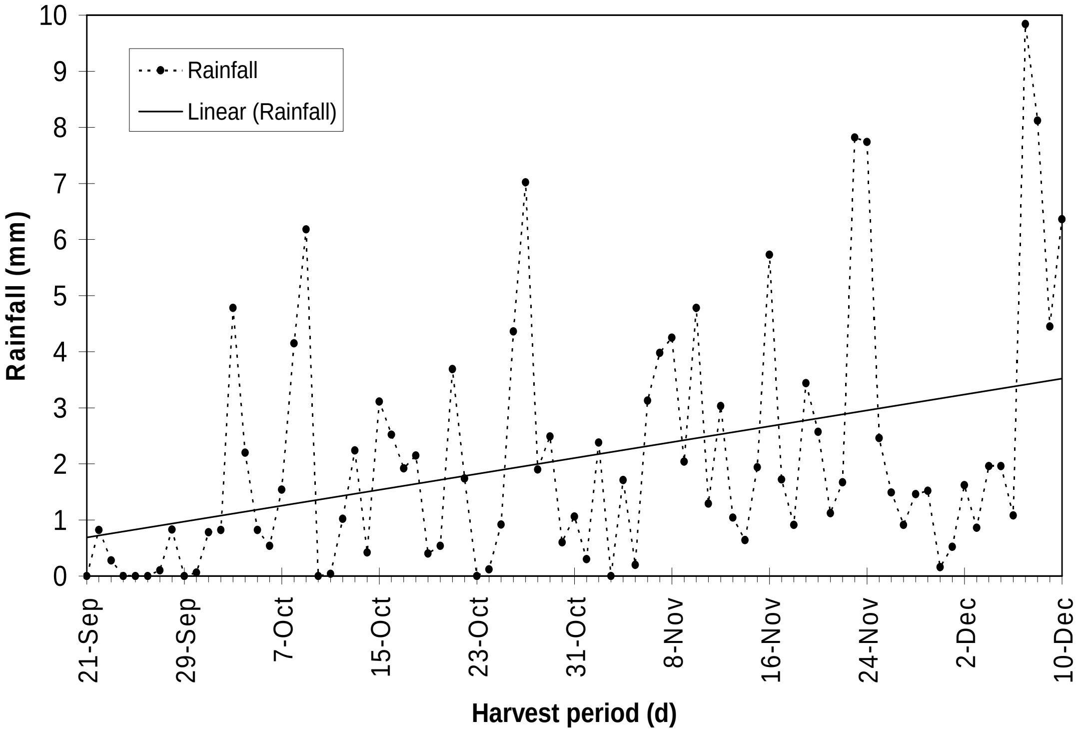

Figure 6.1 The average of rainfall pattern during typical harvest period in Goondiwindi

6.2 The Selection of the Driest and the Wettest Years

Table 6.1 shows the accumulated rainfall and the average air temperature and relative humidity during the harvest period (October 1 to December 20) in Goondiwindi from 1991 to 2005. It can be seen that the maximum average temperature was recorded in 2002 at 25ºC and the minimum average temperature was recorded in 1992, 1998, 1999, 2001 and 2003 at 22ºC. The average temperature for this period of study is 23ºC. Goondiwindi received the highest amount of rainfall during harvest period in 2005 with an accumulated rainfall of 280 mm and the lowest amount of rainfall in 2002 with an accumulated rainfall of 124.10 mm. Since this study is primarily aimed to examine the effect of rainfall on the harvesting operation, 2002 is set as the driest year while 2005 as the wettest year.

Table 6.1 Average weather conditions during the harvest period in Goondiwindi (1991-2005)

Year	Temperature (ºC)	Relative Humidity (%)	Accumulated Rainfall (mm)
1991	23	53.3	191.70
1992	22	54.6	124.40
1993	23	53.1	142.60
1994	23	49.3	137.60
1995	23	56.9	209.30
1996	23	54.9	171.80
1997	24	57.7	224.40
1998	22	60.2	167.70
1999	22	68.5	220.60
2000	23	58.4	185.10
2001	22	59.8	151.00
2002	25	52.4	124.10
2003	22	57.9	254.60
2004	23	59.2	208.40
2005	24	60.0	280.00
Average	23	57.1	186.2

6.3 Available Harvesting Hours

Figure 6.2 shows the average of available harvesting hours in Goondiwindi from 1991 to 2005. The available harvesting hours are generated using a cumulative frequency analysis, based on the formula discussed in Section 4.2.3. Based on this method, the time in hours is counted when the grain moisture content falls below the specified level throughout the harvest period. This analysis assumes that harvesting takes place for 11 h/d, from 0700 h to 1800 h.

During the period of study, the average of available harvesting hours at 12 and 22% moisture contents are found to be between 105.1 and 843.3 hours. In the driest year (2002), the available harvesting hours at 12% moisture content were 182 hours, 2.8 times higher than that in the wettest years. At 22% moisture content, the available harvesting hours in the driest year were 861 hours, 3.5% higher that in the wettest year.

In the driest year, the grain moisture content of a standing crop in the field was relatively low due to high temperature, low relative humidity and low rainfall amount. Consequently, the available harvesting hours in that season increases. In the wettest year, the grain moisture content was relatively higher than it is in the average climate condition due to higher relative humidity and rainfall.

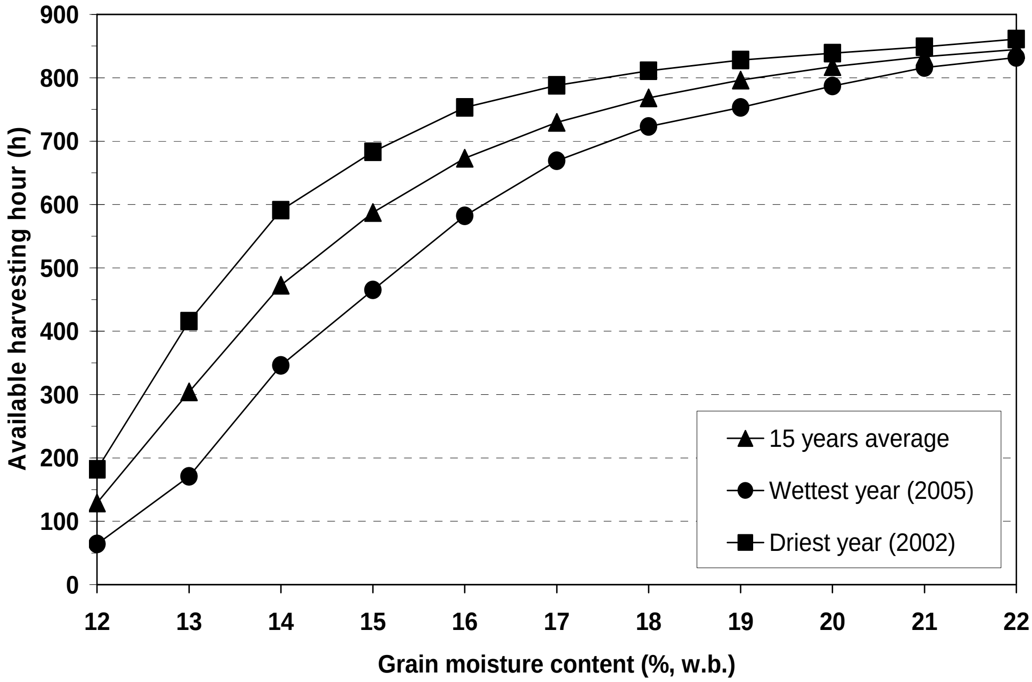

Figure 6.2 Available harvesting hours at different grain moisture contents in Goondiwindi

6.4 Grain Moisture Content Variation in the Driest and the Wettest Years

The difference in grain moisture contents between the driest and the wettest years are shown in Figure 6.3. It can be seen that, generally, the grain moisture content in 2005 is considerably higher than in 2002. The initial grain moisture content for both years is 30% and gradually decreases to around 12% as it approaches the end of the harvest period. The fluctuation of the grain moisture content is mainly due to the rainfall (Section 6.5). The moisture content drops particularly quickly in the first four days. A standing crop first reached 12% moisture content in 6 and 9 days after maturity, in 2002 and 2005 respectively.

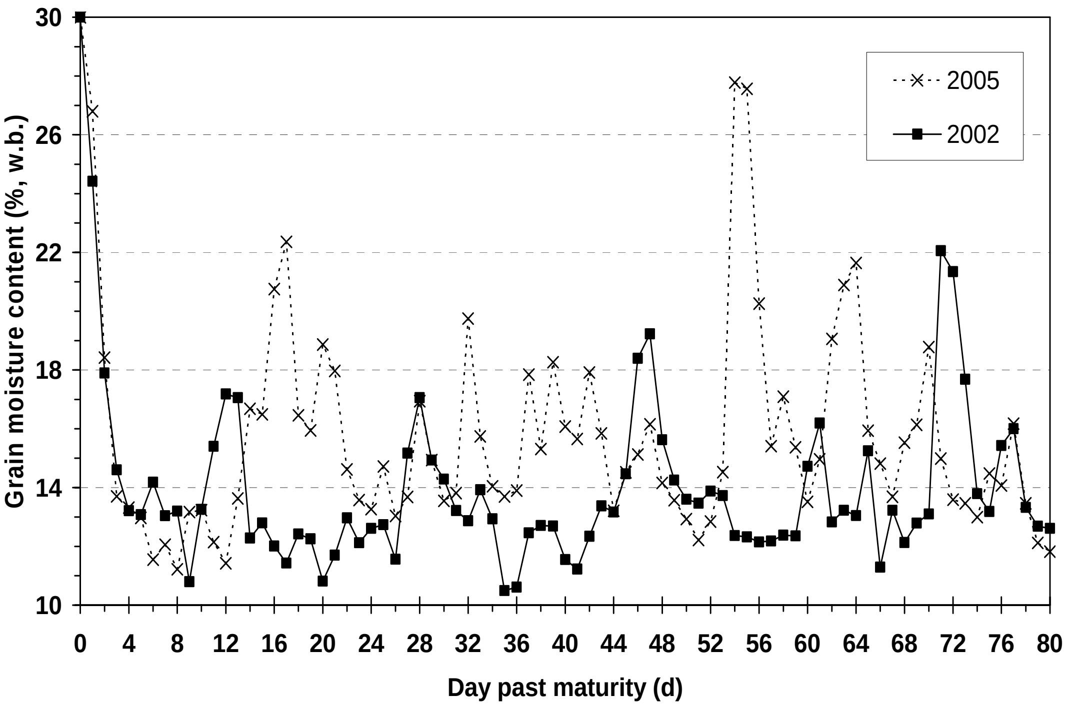

Figure 6.3 The difference of grain moisture contents between the driest and the wettest years

6.5 Effect of Rainfall on Grain Moisture Content

Figure 6.4 shows the relationship between rainfall and grain moisture content for a standing crop in the field in the driest year (2002). It can be seen that the fluctuation of grain moisture content is mainly dictated by the rainfall. Basically, rainfall wets the grain and as a result, the moisture content of the grain increases. However, after a rain, the grain moisture content can then drop rapidly as other weather elements will dry the grain. For example, in 12 days after maturity, a rainfall of 7.4 mm has caused the grain moisture content to increase up to 17.2%. However, its moisture content then rapidly dropped back to 12% in the next day.

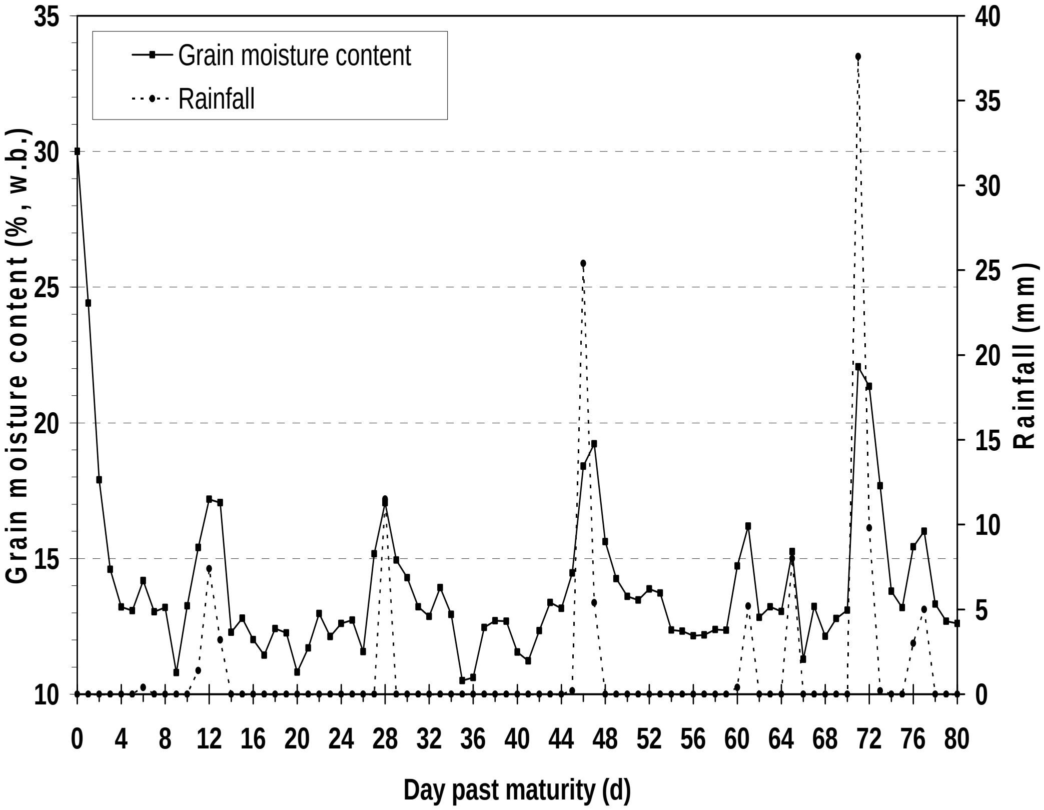

Figure 6.4 The effect of rainfall on grain moisture contents for a standing crop in the driest year (2002)

6.6 Effect of Air Temperature on Grain Moisture Content

Figure 6.5 shows the relationship between air temperature and grain moisture content in the driest year (2002). It can be seen that, generally, temperature has an inverse correlation with the grain moisture content. This is reasonable as high air temperature will increase evaporation rate and cause grain to lose its moisture rapidly. Furthermore, in a location with warm temperatures, the loss of water from crop by transpiration is greater than in a location with cloudy and cool temperatures.

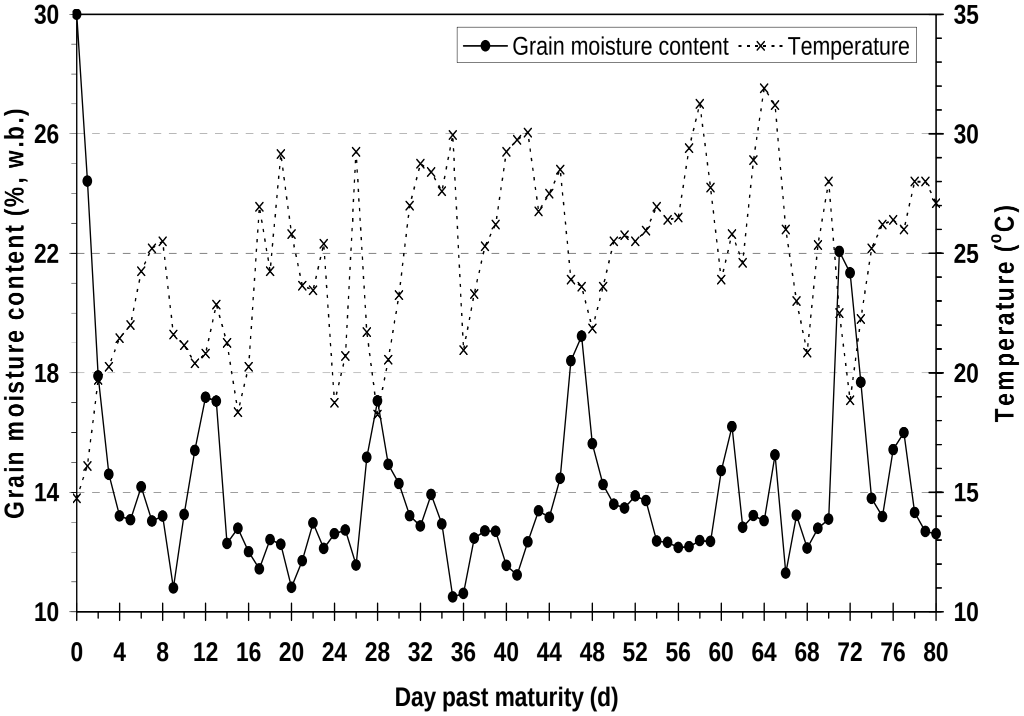

Figure 6.5 The effect of temperature on grain moisture content for a standing crop in the driest year (2002)

6.7 Effect of Relative Humidity on Grain Moisture Content

Figure 6.6 shows the relationship between relative humidity and grain moisture content in the driest year (2002). It can be seen that the fluctuation pattern of the grain moisture content is similar to the relative humidity. This is because grain can take up moisture from its surroundings. Thus, the standing grain in wet locations (higher relative humidity) usually has higher moisture content than grain in dry locations. Therefore, it can be concluded that if relative humidity increases, grain moisture content will increase as well.

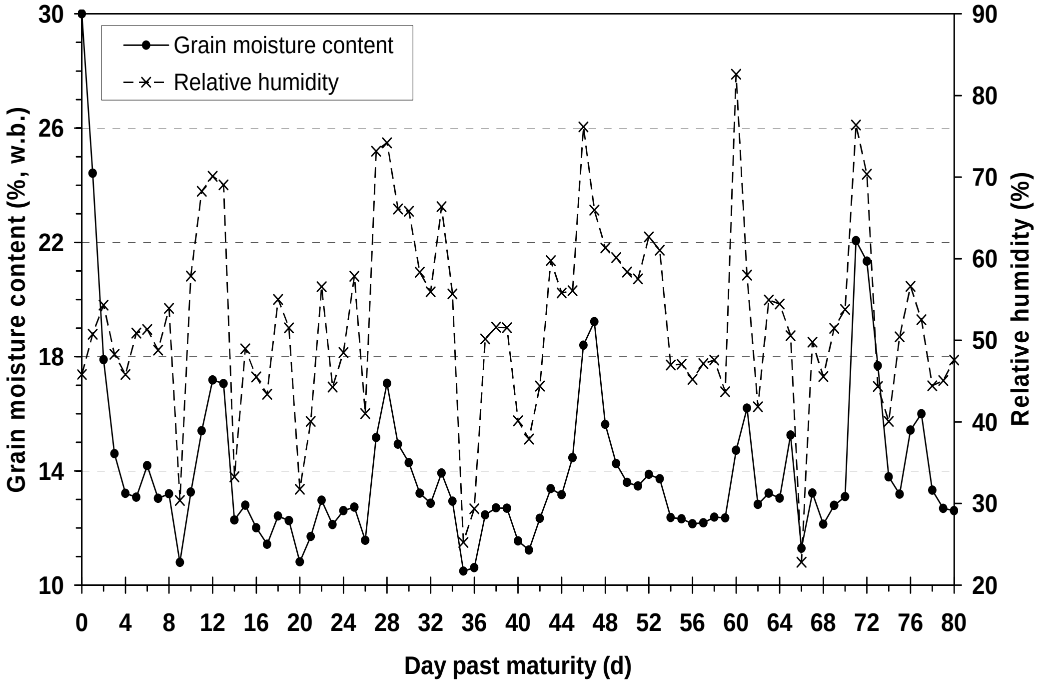

Figure 6.6 The effect of relative humidity on grain moisture content in the driest year (2002)

6.8 Effect of Rainfall on Harvest Starting Date

The rainfall distribution can also cause the harvest starting dates vary from year to year. The rainfall distribution in the years of 1996 and 2002 is shown in Figure 6.7. During 15 years of simulation periods, the year of 1996 is used in this comparison because in this year, the standing crop took the longest time to reach 12% moisture content (28 days after maturity (Figure 6.8)). In contrary, in 2002, it reached 12% moisture content only 9 days after maturity as there was no rain recorded in the earlier stage of the harvest period.

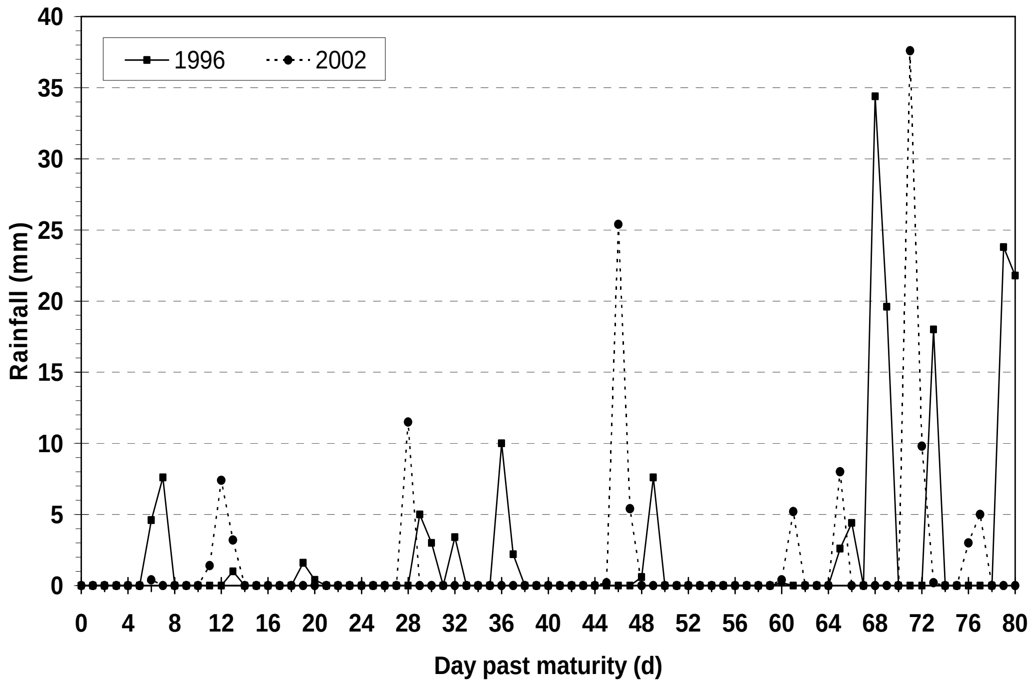

Figure 6.7 The difference in rainfall distributions in 1996 and 2002

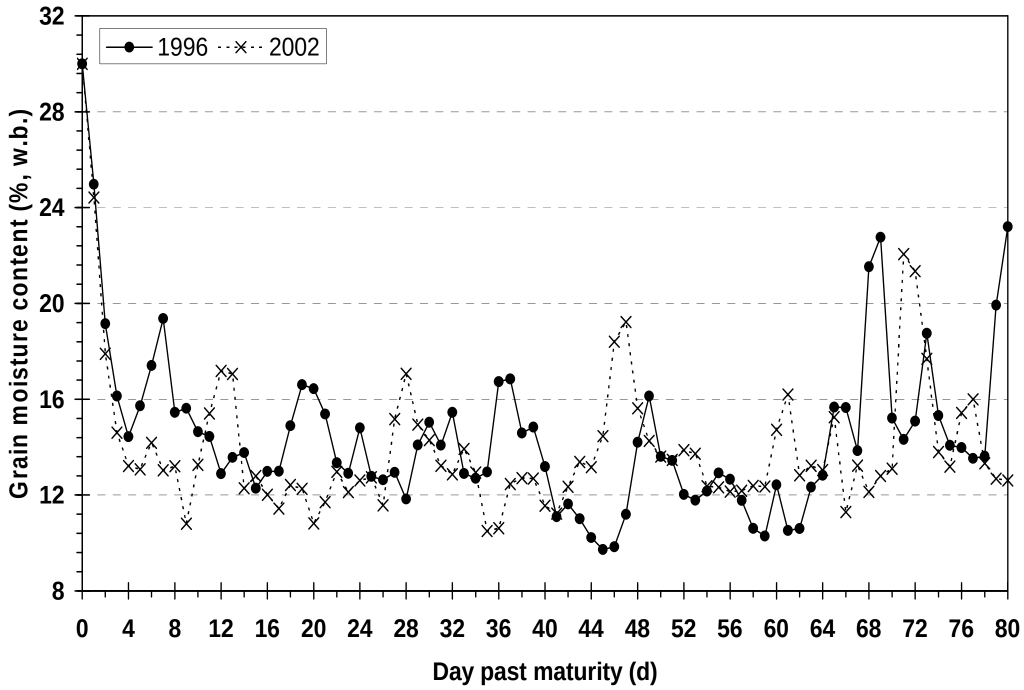

Figure 6.8 The variation of grain moisture contents in 1996 and 2002

Figure 6.8 also illustrates that if the grain is to be harvested from 16% moisture content, the harvesting could theoretically begin just 3 days after maturity in both years (Figure 6.8). This practice could reduce the risk of the weather damage as the period when the grain remaining in the field is reduced. Delaying the harvest will expose the grain to weather conditions for a longer period thus affecting its yield. For example, in 1996, by starting the harvest at 16% instead of 12% moisture content, growers could have reduced the period when the grain remained in the fields and exposed to unfavourable weather conditions from 28 to only 3 days. Harvesting early would however require suitable investment in a grain drier and storage facility.

6.9 Conclusion

This chapter has discussed the effect of climatic factors such as air temperature, relative humidity and rainfall on grain moisture content of a standing crop in the field. The effect of rainfall on the harvest starting date has also been investigated. All results discussed in this chapter are based on the climatic conditions in the reference location during the harvest period. During 15 years of the simulation study, it was revealed that 2002 was the driest year while 2005 was the wettest.

The available harvesting hours at 12% moisture content in the driest and the wettest years are 182 and 64 hours respectively. At 22% moisture content, the available harvesting hours in the driest and the wettest are 861 and 832 hours respectively. In 2002, the moisture content of a standing crop was relatively low because of high temperature, low relative humidity and rainfall. In 2005, the grain moisture content was relatively high because of higher relative humidity, rainfall amount and lower temperature.

It has been found that the fluctuation of the grain moisture content in a standing crop is mainly due to rainfall. This is because, rainfall wets the grain thus increasing its moisture level. The rainfall can also cause the variation in the harvest starting dates. It has also been shown that a temperature has an inverse correlation with the grain moisture content. High temperature will increase evaporation rate and cause grain to lose its moisture rapidly. The fluctuation pattern of the grain moisture content is similar to the relative humidity. This is reasonable as grain can take up moisture from its surroundings.

CHAPTER 7

Effect of Machinery on Harvest Return

A grain harvesting system involves the use of several machines such as a combine harvester, grain drier and grain aeration. Therefore, the selection of correct machinery to match the crop requirement is essential to minimise operating costs thus maximise returns. In this chapter, the effect of machinery performance and operation strategies involving harvesting, drying and aeration are investigated in order to find an optimum combination of those machines. The effect of crop factors such as crop area, crop price and crop yield on return are also discussed. All simulation results discussed in this chapter are based on the weather conditions in the reference location, run at the control values as shown in Table 5.3, unless it is otherwise stated. All simulation results are the average of the 15 years of simulation study.

7.1 Effect of Harvest Grain Moisture Content

Figure 7.1 shows the effect of moisture content on individual costs in the wheat harvesting system in the reference location (Goondiwindi). In this figure, the harvesting, drying and aerating costs refer to the costs associated with that machinery including both fixed and variable costs. It can be seen that the harvesting and aerating costs are 38.75 and $8.86/ha respectively, nearly constant for all grain moisture contents. At a low grain moisture content, the harvesting costs are higher than the drying costs but at higher moisture contents, the costs for both elements are nearly similar. In fact, the cost of running the combine harvester was the largest single expense at about 41% of the total cost (PAMI, 1998). The drying costs gradually increase as grain harvest moisture content increases. For example, the drying cost at 22% moisture content is $39.15/ha, 2.9 times higher than that at 13% moisture content. This is because at higher grain moisture contents, more energy and time are needed to reduce grain moisture content from high level to 12%.

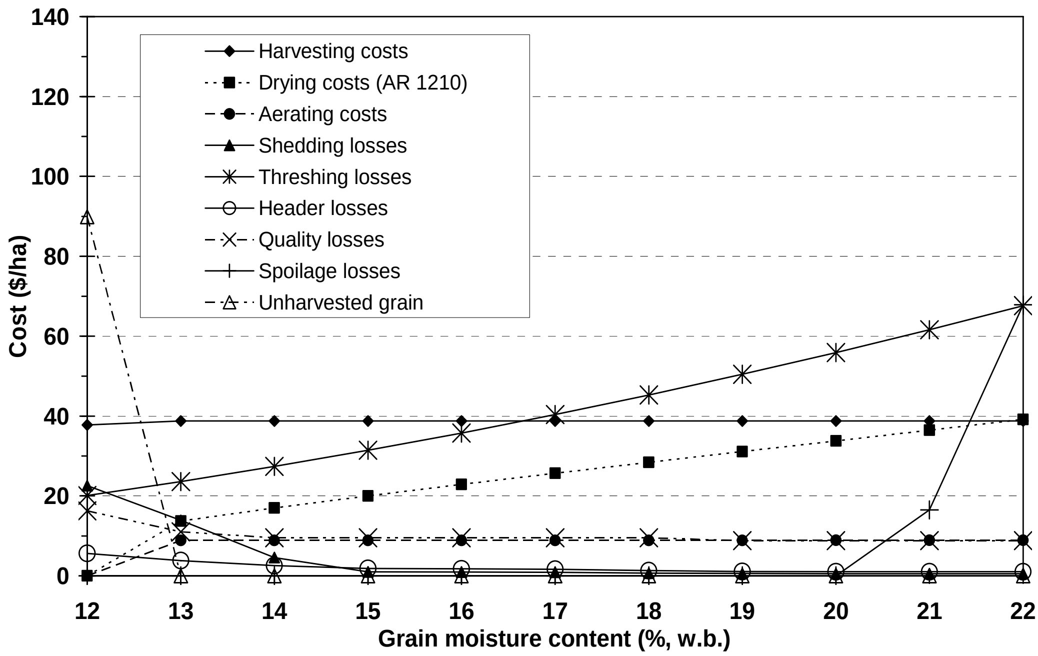

Figure 7.1 The effect of grain moisture content on individual costs for each element in the wheat harvesting system in Goondiwindi

Shedding losses decline if grain is harvested at higher moisture content as the period of the grain exposed to adverse environmental conditions is shortened. At 12% moisture content, the cost of shedding losses is about $22.58/ha. From 15% moisture content and above, the cost of the yield losses due to natural shedding seems to be constant at $0.5/ha. The cost of shedding losses in Goondiwindi is not significant at higher moisture contents because the grain in this location tends to reach low moisture level only several days after maturity due to its warm and dry weather conditions (Table 8.2).

Threshing losses increase as the grain moisture content increases because at higher moisture contents, moist grain still strongly attach to straw and tends to fall during threshing. In Figure 7.1, threshing losses seem to be very significant at higher moisture content. The cost of threshing losses at 22% moisture content is $67.63/ha, 3.3 times higher than the cost at 12% moisture content. Header losses also increase over time as the grain becomes dry on farm. For example, at 12% moisture content, the cost of the header losses is about \$5.6/ha. At 22% moisture content, the cost of header losses is just about \$1.0/ha.

The cost of preharvest quality losses decrease rapidly if grain is harvested at high moisture contents. At 12% moisture content, the cost of these losses is \$16.3/ha. Basically, harvesting the grain earlier at high moisture content could reduce the cost of the preharvest quality losses as this practice would minimise the risk of a standing crop in the field being downgraded by rainfall.

Spoilage losses occur in a storage facility due to bacteria, mould and insects activities. At a given drying capacity, the cost of the spoilage losses increases as the grain moisture content increases. It can be seen that, at 22% moisture content, the spoilage losses is up to \$67.84/ha. Goondiwindi has a high cost of spoilage losses because of its warm and dry weather conditions.

Unharvested grain refers to grain that remains in the field after harvest period is over. At low grain moisture content, the cost of this loss is significantly high due to limited available harvesting hours. At 12% moisture content, the cost of unharvested grain in this reference location is \$89.91/ha. This rapidly decreases to be insignificant after 13% moisture content. This loss can also be reduced if the harvesting capacity is increased.

7.2 Effect of Farm Size on Return

The effect of harvest moisture content on return for four farm sizes ranging from 500 to 2000 ha is shown in Figure 7.2. At the given control parameters, the optimum harvest moisture contents vary between 14 to 15%, depending on farm size. At 12% moisture content, a smaller farm gains the highest return while a larger farm gains the least. This is because, at the same harvesting capacity, a large farm is prone to experience higher grain losses due to inadequate harvesting capacity to complete the harvest within the allowable time. Harvesting at moisture contents exceeding 16% also reduce the return because the drying costs exceed the value of grain losses.

The result in Figure 7.2 also shows that an increase in a farm size will increase a return. A larger farm size gains a higher return because of an improved operating efficiency and better use of capital investment for the machinery. The difference in a return for 1500 and 2000 ha is not significant due to limited harvesting and drying capacity. The inference from these results is that a small farm size of around 500 ha has significant decline in return due to high ownership cost of machinery. However, the results are influenced by the crop variety and harvesting capacity. The result also emphasizes the importance of matching the harvesting capacity with a farm size.

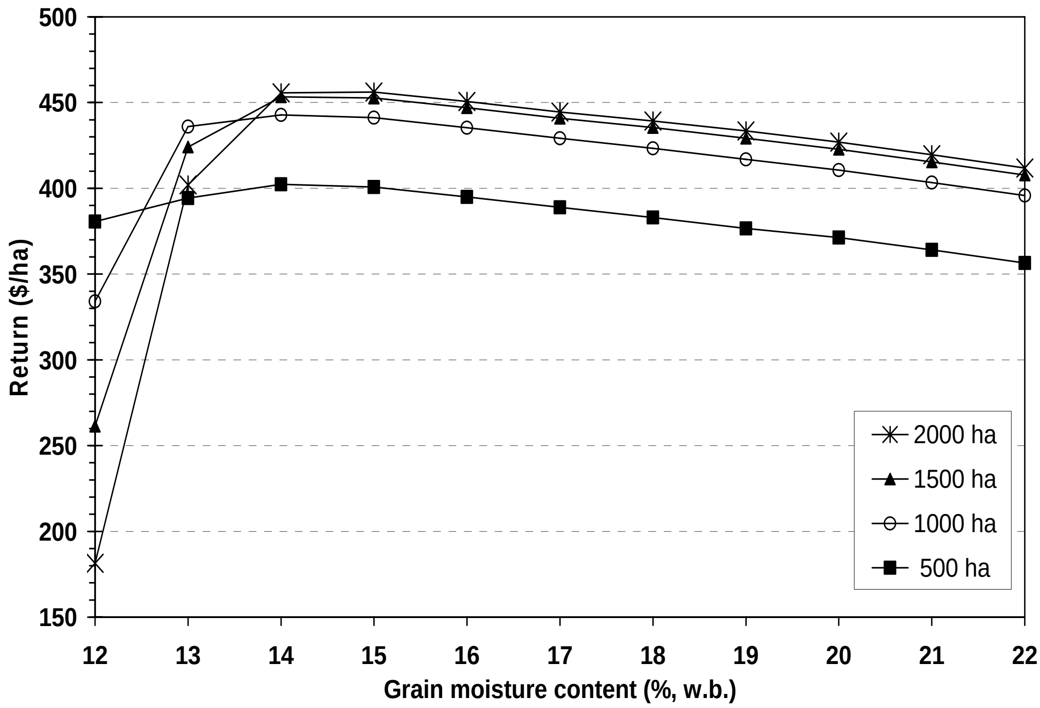

Figure 7.2 The effect of farm size on return

7.3 Effect of a Combine Harvester

Grain harvesting is a mechanical operation where the grain in the field is reaped, threshed, separated and cleaned by a combine harvester. Grain harvesting is often a bottleneck in harvest operation. In practice, the harvesting operation takes a considerable period of time and the optimum date is likely to be a function of the total area to be harvested, the type and size of machines used, the weather pattern during the harvest period and the policies to be followed in day-to-day management (Gupta *et al*., 1990). Average rates of harvest are ranging between 12 and 30 t/h, depending on a type of harvester, crop type and yield (heavier crops usually take longer to harvest), crop condition (for example, free standing or lodged), paddock terrain, and proximity to trucks and field bins (AGHA, 2003). Therefore, grain harvesting operation should be optimized in order to maximise the return.

7.3.1 Effect of Comb Size on Return

Simulation runs are carried out using four different comb sizes of 6.1, 6.7, 7.3 and 9.2 m for a farm size of 1000 ha. The simulation results (Figure 7.3) show that the maximum return can be obtained when growers use the largest comb size. This is because a comb size is proportional to harvesting capacity. The optimum moisture content for all comb sizes is at 14% moisture content.

Basically, a larger comb size can shorten the time of harvesting operation thus reducing the financial losses due to natural shedding, unharvested grain and quality degradation. A higher ownership cost of a larger harvester is offset by lower costs of maintenance, labour, drying and less grain losses. At a given farm size, small comb size needs extra time to complete harvesting. As the harvesting time increases, the chances of a standing crop in the field being downgraded are higher due to the natural interaction between the crop and its environment. The amount of grain losses and quality downgrading will increase as the mature crop has to remain in the field for a longer period.

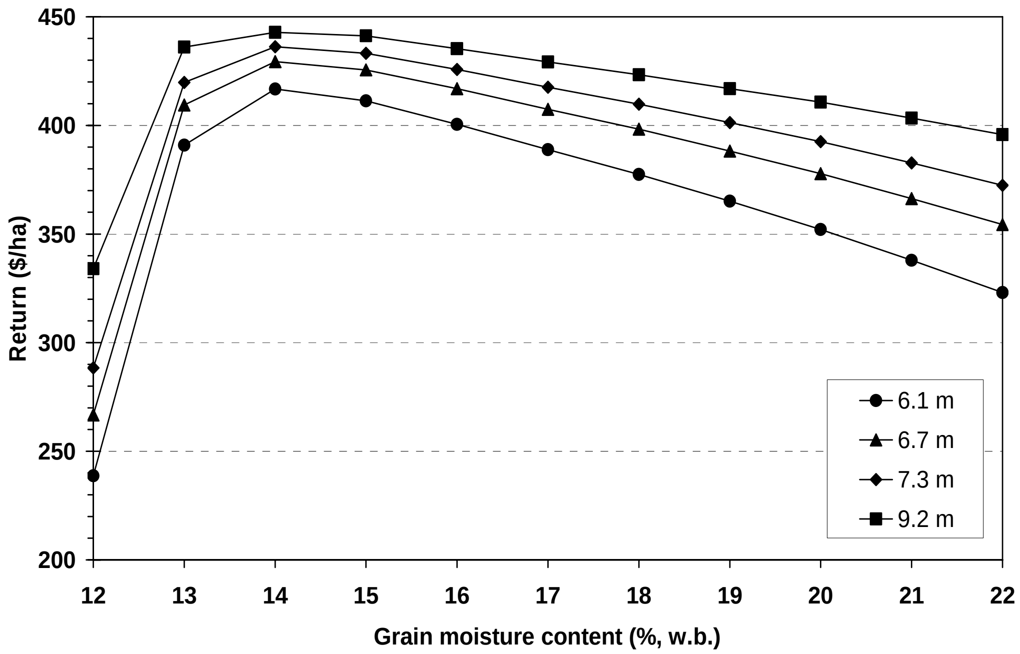

Figure 7.3 The effect of comb size on return

7.3.2 Effect of Forward Speed on Return

Forward speed is one of the important factors in optimizing the performance of a combine harvester. Forward speed is a determining factor for the daily harvest rate. The effect of forward speed on return is shown in Figure 7.4. The result is simulated for four speeds ranging from 6 to 12 km/h. The comb size used in this simulation is 9.2 m. The simulation results show that the optimum grain moisture content for harvesting at these four forward speeds range from 14-15%. Above these moisture contents, increasing the harvester speed will result in decreased return.

Basically, increasing the forward speed means an increase in harvesting capacity. Increasing harvesting capacity would result in increased machine losses, particularly, threshing losses. Furthermore, at higher moisture content, grain is harder to thresh and may increase the fuel consumption. The relationship between grain moisture content and forward speed on threshing losses are shown in Figure 7.5. It can be seen that the threshing losses are directly proportional to both the forward speed and the grain moisture content increases.

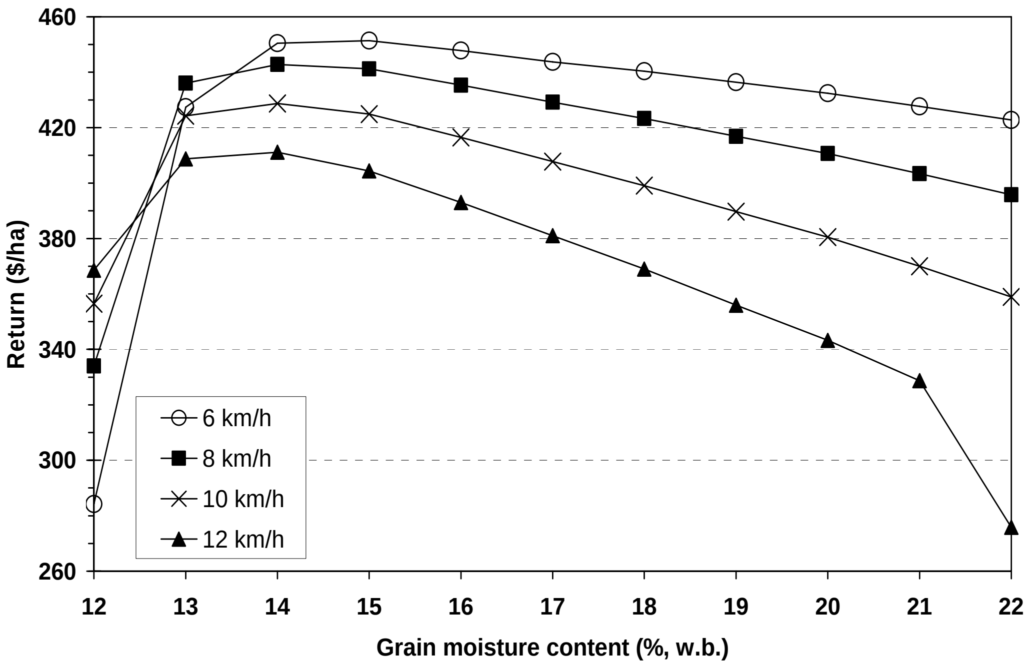

Figure 7.4 The effect of forward speed on return

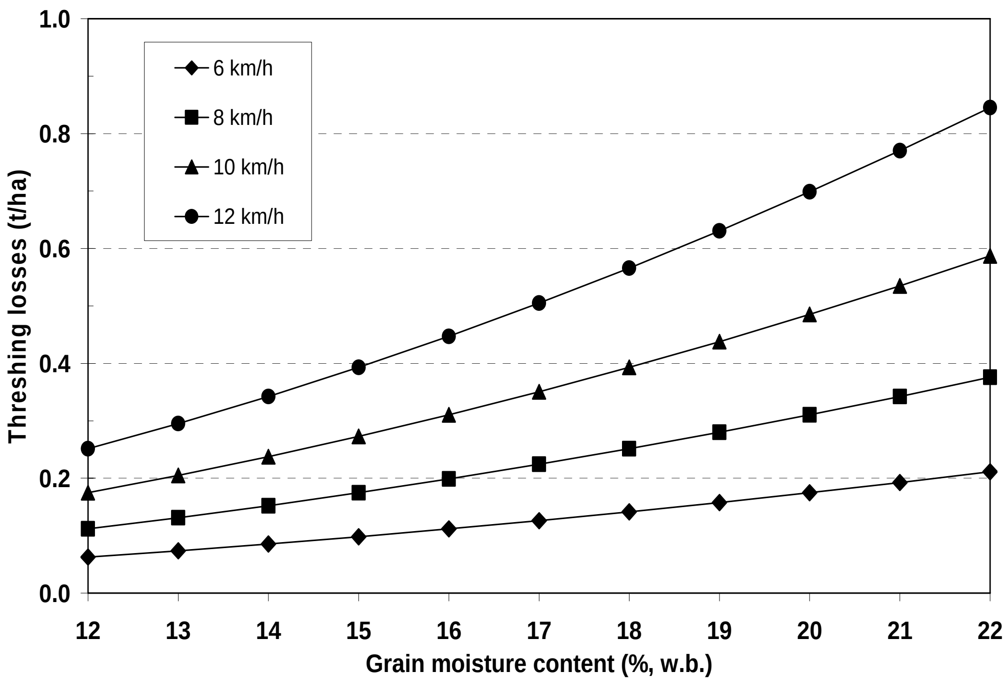

Figure 7.5 The effect of forward speed on threshing losses

Furthermore, higher harvesting capacity exceeding drying capacity would cause grain spoilage due to limited drying capacity. It is because, when the grain is exceeded the drying capacity, the freshly harvested grain must be placed temporarily into a wet grain storage while waiting for the driers become available. In a wet grain storage, the wet grain will deteriorate due to mould and bacteria activity. For example, at 22% moisture content, the amount of the harvested grain which is placed into the wet storage due to insufficient drying capacity at forward speeds of 6 and 12 km/h are 0 and 0.5 t/ha, respectively. This problem is even more serious in the absence of a grain aerator.

Therefore, low speed is generally preferred to reduce field losses. This is because, harvesting at a low speed is more economical than at a higher speed for the moisture content beyond the optimum point. At 12% moisture content, however, harvesting should be done at higher speed to reduce unharvested grain due to limited available harvesting hours.

7.3.3 Comparison of benefits using contract harvesting versus self-harvesting

The economics of owning a combine harvester is dependent on several factors such as the current price of the harvester, operating cost, maintenance cost, farm size and relative cost of contract harvesting. A recommended cost for contract harvesting in 2008 is \$48.18/ha (AGHA, 2008). However, this price is quoted without fuel costs as the fuel needs to be supplied by growers. In this study, the fuel cost is assumed to be \$10/ha. Therefore, the total cost of the contract harvesting is \$58.18/ha. The costs of owning and operating own combine harvester is calculated based on the mathematical function discussed in Section 4.5.1.

Figure 7.6 shows that for both cases, harvesting costs for growers with their own combine harvester decrease with an increase in farm size. This is reasonable because, at a large farm size, the fixed cost of a combine harvester per unit area is relatively small. In terms of harvesting cost, growers who have a small combine harvester (comb size, 6.1 m) spend less money than growers who have a large combine or paying for contract harvesting, regardless of a farm size.

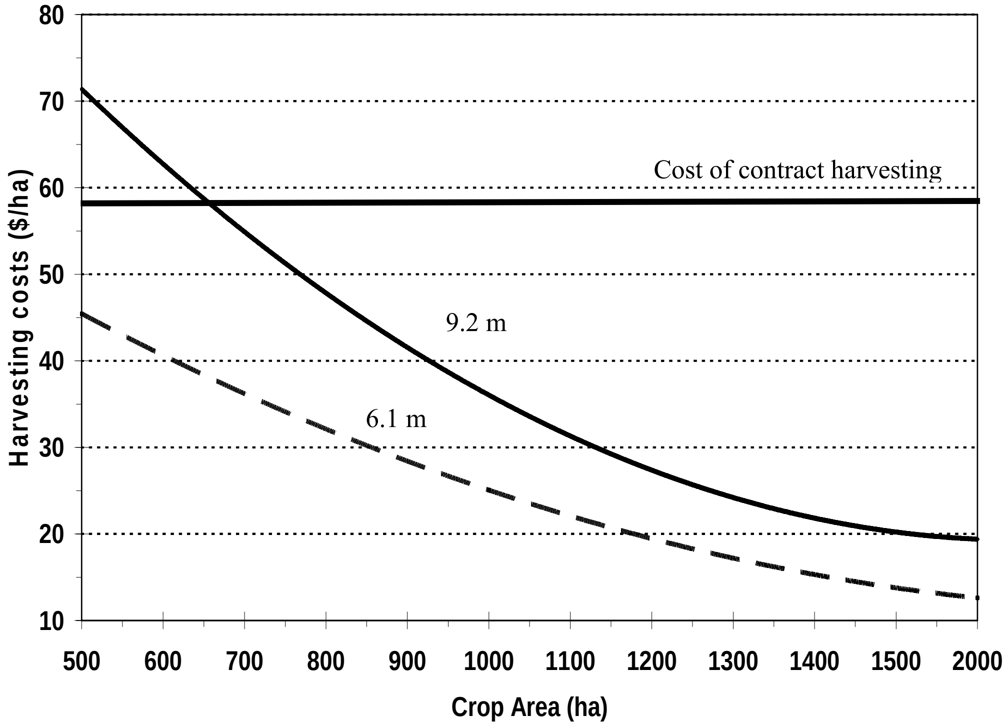

Figure 7.6 Comparison of harvesting cost between contract harvesting and self-harvesting

For growers who have a large combine harvester (comb size, 9.2 m), the economics of having a large combine harvester is obtained only when the crop is larger than 660 ha. In such a case, even though the harvesting cost incurs from using a large combine harvester is higher than using a small combine, its ability to reduce yield losses and shorten the time of harvest makes it to be more economical.

Furthermore, growers who rely on a contract harvesting also carry the risk that their crops would be damaged by weather conditions as the competition to get contract harvesting is very tough during harvest season. Since the contract harvesting operates on a queuing basis, the growers have to wait their turn regardless of their crop and weather conditions.

7.4 Effect of Drier

A drying system is normally compared based on the daily and seasonal drying capacity, annual costs and also purchase costs. In this section, the economics of using four different driers with different drying capacities are analysed. Four driers investigated in this study namely, high capacity drier (AR1614), medium capacity drier (AR1214), low capacity drier (AR1210) and a batch drier. The terms of high, medium and low are used to reflect ranking of comparative performance and costs. Details of the driers are presented in Section 4.4.2. The field efficiency for the continuous flow driers is assumed to be 100% while for the batch drier it is 75%.

7.4.1 Effect of Drier Capacity on Return

Figure 7.7 shows the possible return for using different types of driers in Goondiwindi at the control values (Table 5.3). The simulation results in this section are simulated without an aeration system. As expected, at higher moisture contents, growers with the continuous flow drier types will obtain higher return than growers with the batch drier. The optimum harvest moisture content for using the continuous flow driers is 14% while for the batch drier is 13%. At higher moisture contents, using high capacity continuous flow driers will give a higher return compared to using a batch drier because they have higher drying capacity.

In terms of the drying capacity, using a high capacity drier (AR1610) will give a higher return especially at higher moisture content. The return pattern for this drier is similar to a medium capacity drier (AR1214). However, the difference in return between both driers slightly increases as moisture content increases. For a low capacity drier (AR1210), it still has a similar return pattern with higher capacity driers but at higher harvest moisture contents (19% and above), its return significantly declines due to limited drying capacity.

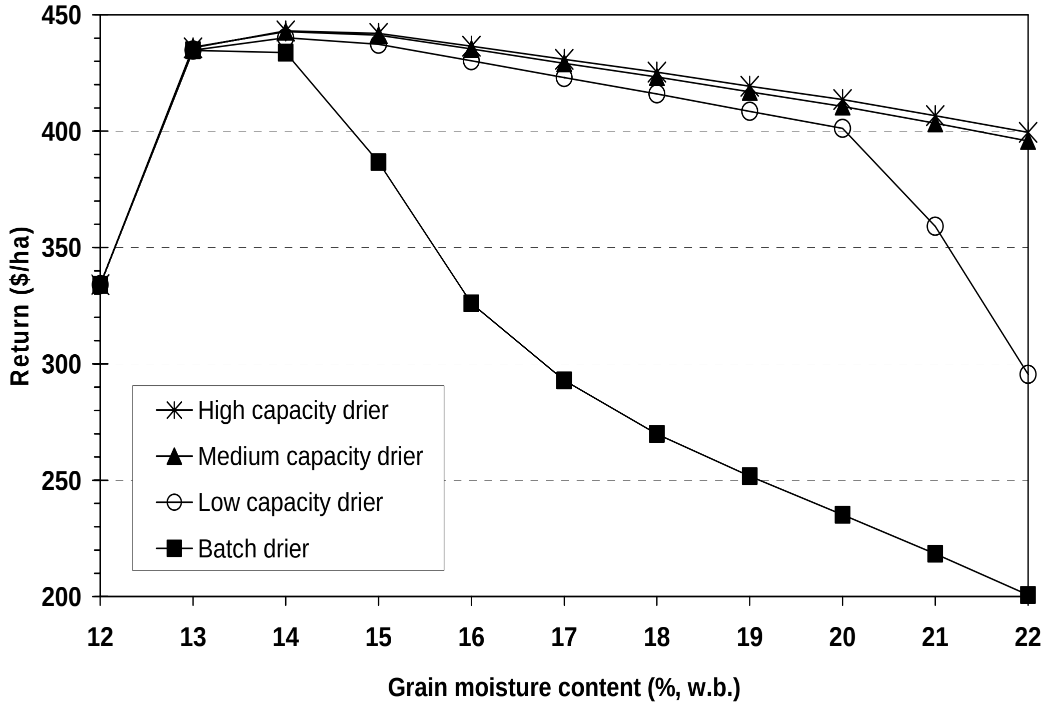

Figure 7.7 The effect of drier capacity on return

From 12 to 19% moisture contents, using a high capacity drier (AR1614) would increase the return about 0.8% higher than using a medium capacity drier (AR1214). At 18% moisture content, using the high capacity drier (AR1614) would increase the return about 0.5% ($2.10/ha) than using a medium capacity drier, and about 2.2% ($9.33/ha) higher than using a low capacity drier (AR1210). In relation to a batch drier at the same moisture content, a high capacity drier would give 57.6% ($155.47/ha) higher return.

At the optimum harvest moisture content (14%), using a medium capacity drier (AR1214) will give 0.6% or $2.6/ha higher return than using a low capacity drier (AR1210). At the same grain moisture content, there is little difference ($0.29/ha) in return between using a medium or a high capacity drier. In the comparison with the batch drier, using the medium capacity drier will give $9.07/ha or 2% increase in return. Therefore, if grain is to be harvested at the optimum harvest moisture content, medium capacity drier is recommended. However, if grain is to be harvested at higher moisture contents, a high capacity drier is recommended.

7.4.2 Effect of an Increased Harvesting Throughput on Optimum Drier Capacity

Figure 7.8 shows the possible return for using two combine harvesters at different types of driers in Goondiwindi at the control values (Table 5.3). This simulation is carried out to study the effect of an increased harvesting throughput on different drier types. It can be seen that the return pattern and the optimum harvest moisture content in this figure are similar to Figure 7.7. However, the overall return has decreased. For example, the return for using a high capacity drier has decreased about 7% from \$443.07/ha (Figure 7.7) to \$411.86/ha (Figure 6.15). Using two combine harvesters will reduce the return because higher ownership and operating costs transcend the benefit of higher throughput.

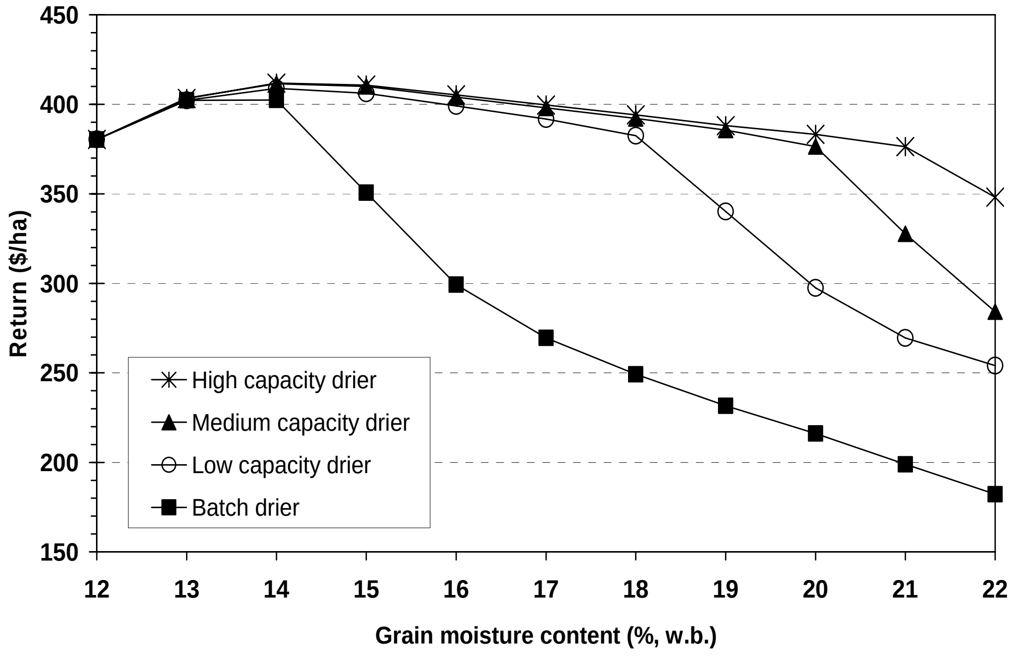

Figure 7.8 The effect of drier capacity on return for an increased harvest throughput

The difference in return between using high and medium capacity driers become more obvious at higher moisture contents. From 20 to 22% moisture contents, the return curve for these two driers in Figure 7.7 declines slowly but in Figure 7.8, it declines significantly. Therefore, for an increased harvesting throughput, using a high capacity drier obviously gives better return compared to other drier types.

7.5 Effect of Aeration

Aeration is often applied to freshly harvested grain at high moisture prior to artificial drying, particularly when drier capacity is insufficient. In this section, the economics of using an aerated storage as a support system for a grain drier when dealing with high moisture grain is presented. All simulation results are based on the weather conditions in the reference location. This section also discusses the comparison of return between a farm with and without an aerated storage at different drier capacities.

7.5.1 Effect of High and Medium Capacity Driers on Aeration

Figure 7.9 and 7.10 show that for high and medium capacity driers, having an aerated storage is not economical because the driers have sufficient capacity to dry harvested grain before spoilage occurs. In these cases, having an aerated storage will reduce the return due to its ownership cost.

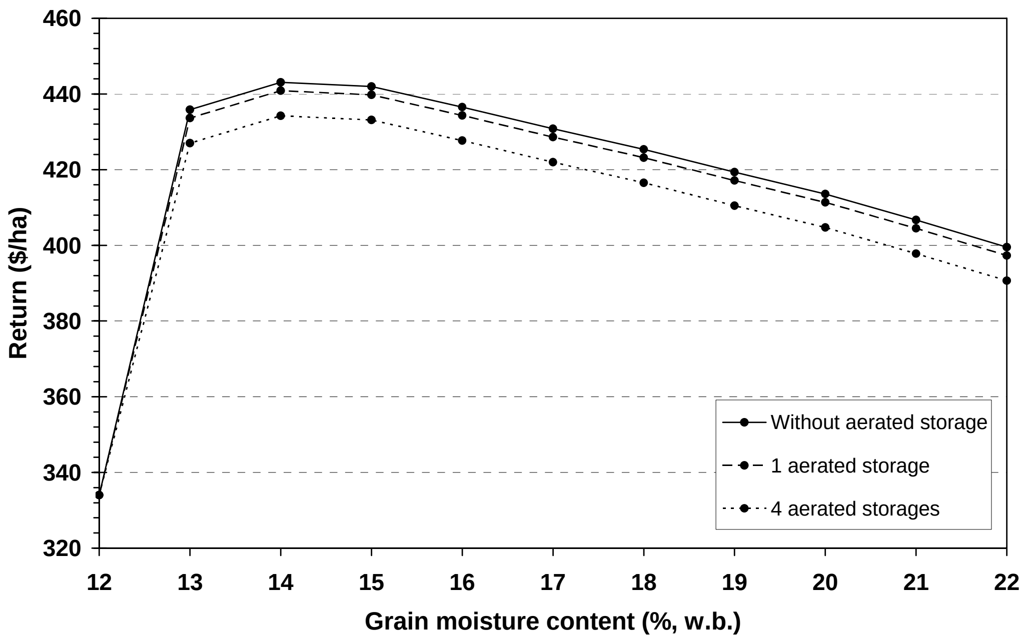

Figure 7.9 The economics of using an aerated storage with a high capacity drier (AR1614)

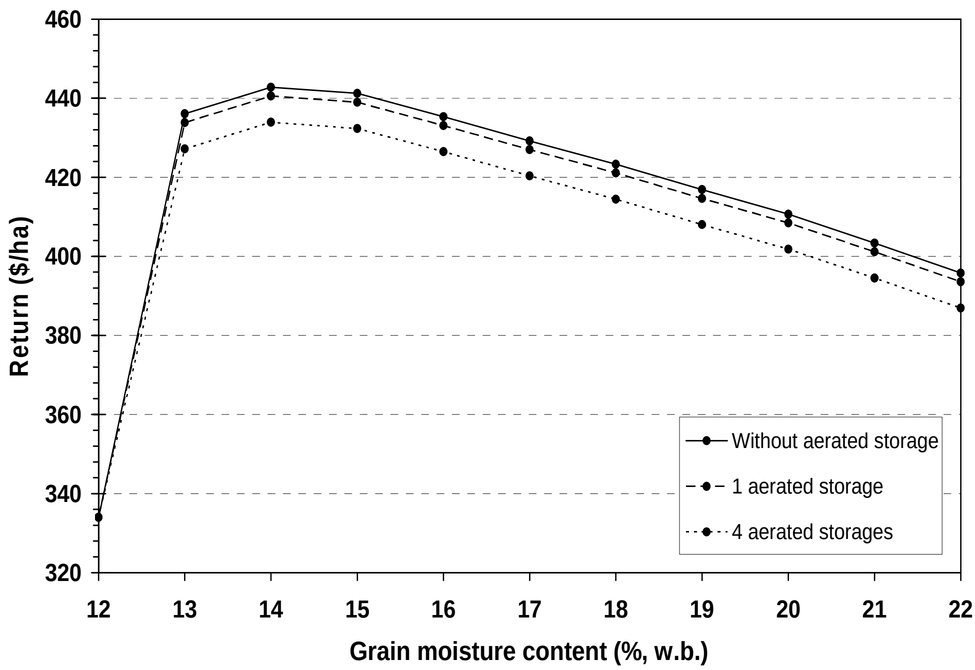

Figure 7.10 The economics of using an aerated storage with a medium capacity drier (AR1214)

7.5.2 Effect of a Low Capacity Drier on Aeration

Figure 7.11 shows the possible return pattern when an aerated storage is used to support a low capacity drier. It can be seen that at low grain moisture contents, aerated storage has a very small influence on the return because the drier is able to dry freshly harvested grain before its quality deteriorates. Aeration is only helpful to increase the return if grain is harvested at higher moisture content. For example, at 21% moisture content, having one aerated storage will increase the return about 1% or $3.32/ha while having four aerated storages will increase the return by 2.3% or $8.26/ha. It is obvious that using four aerated storages is more profitable than using only one.

At lower grain moisture contents (13 to 14%), the drier has enough capacity to dry all harvested grain in reasonable time before the deterioration of grain quality occurs. Therefore, using an aerated storage at these moisture levels is not recommended and will only increase the ownership costs.

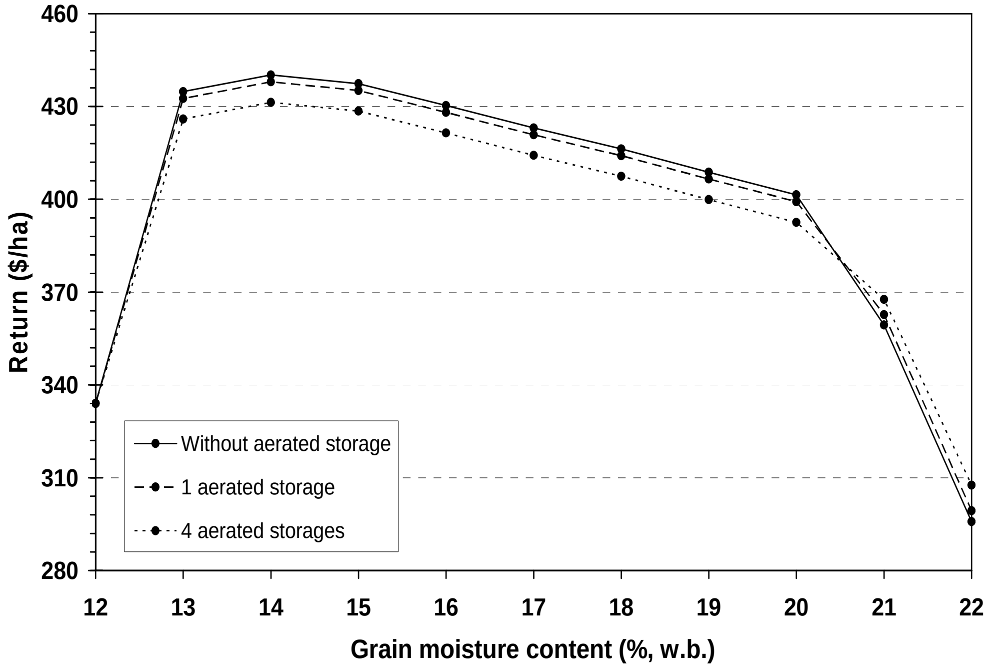

Figure 7.11 The economics of using an aerated storage with a low capacity drier (AR1210)

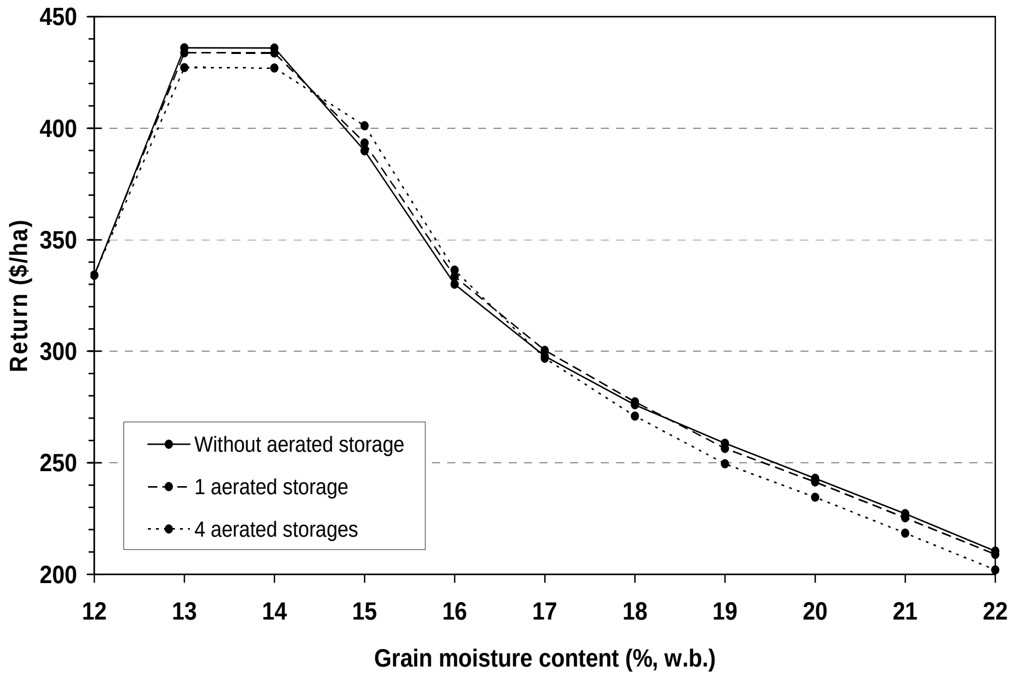

Figure 7.12 The economics of using an aerated storage with a batch drier

7.5.3 Effect of a Batch Drier on Aeration

Figure 7.12 shows the possible return when an aerated storage is used to support a batch drier. The economics of using an aerated storage can be seen at 15 to 17% moisture contents. It also can be seen that, at these moisture levels, using four aerated storages is more profitable than using only one.

At 15% moisture content, it has been shown that the investment in one aerated storage will only increase the return about 1.1% or $3.56/ha. At the same moisture content, using four aerated storages is more economical with the increase in return up to 2.9% or $11.28/ha. The economics of using four aerated storages is three times higher than using one aerated storage.

From 15-22% moisture contents, return is decreasing regardless of the number of aerated storages used because at these range of grain moisture contents, grain is too wet and the aeration system is unable to treat it. At these moisture contents, using a high capacity drier is critically important.

7.5.4 Effect of Harvesting Capacity on the Usefulness of Aeration

To study the economics of an aerated storage at high harvesting capacity, the simulation is run using two combine harvesters at the control values (Table 5.3). This is based on the fact that the daily harvest capacity dictates the minimum size of an aerated storage and the drying capacity. The result (Figure 7.13) shows the usefulness of an aerated storage is more significant when it is used at high harvesting capacity. At high harvesting capacity, drier capacity will be the bottleneck in a grain harvesting system. At this time, aeration then becomes useful to prolong the safe waiting period of grain before it is dried down to 12% moisture content.

Figure 7.13 is comparable with Figure 7.10. All parameters used for both figures are the same except for the number of combine harvesters. It can be seen that, using two combine harvesters is only economical if grain is harvested at 12% moisture content. However, if the grain is to be harvested earlier at higher moisture contents, having two combine harvesters is not economical due to high ownership and operating costs. From Figure 7.13, it can be seen that now aeration has a positive effect on return from 21 to 22% moisture contents (Figure 7.12). However, at the same moisture contents, Figure 7.10 shows that the aeration system is not economical. Therefore, it can be concluded that at a given drying capacity, the usefulness of aeration is significant only at high harvesting capacity.

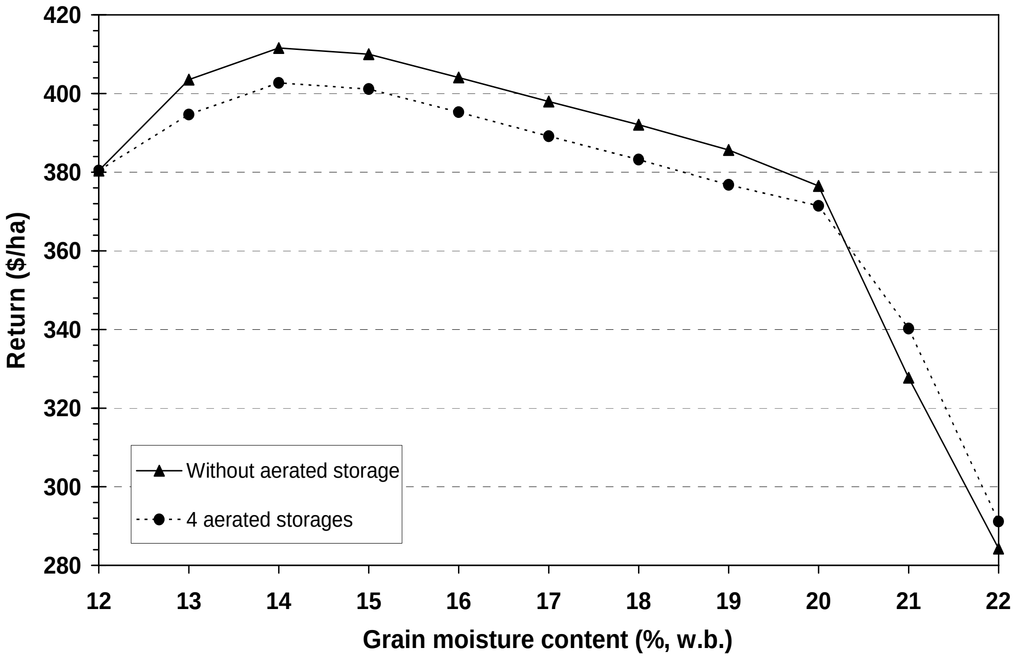

Figure 7.13 The effect of an aerated storage on return when two combine harvesters are used

7.6 Effect of Crop Factors

The crop factors such as crop price, crop yield, crop losses, and crop quality have a significant effect on overall return gained by growers. All of these factors vary from year to year, depending on crop variety, weather conditions, machinery used, and global conditions (crop price). Therefore, to study the effect of these factors in a grain production system, sensitivity analysis is conducted and is discussed in this section.

7.6.1 Effect of Crop Price and Yield

Crop price and crop yield are the most important factors that determine growers income. However, these two factors vary from year to year and sometimes, from one state to another. The sensitivity of these factors in a wheat harvesting system is shown in Table 7.1. It can be seen that, 10% increase in the crop price can increase the return up to 11.5%. In terms of crop yield, the reduction in crop yields of 1 t/ha can decrease the return up to 62.8%. However, in both cases, the real percentage of the difference depends on grain moisture content.

Table 7.1 Sensitivity analysis study for crop parameters

		Grain harvest moisture content, % (wb)					
		12		14		20	
		($A/ha)	±, %	$/ha	±, %	($A/ha)	±, %
Crop price	Standard	334.00	-	442.78	-	410.68	-
	+ 10%	371.18	11.1	492.38	11.2	458.05	11.5
	- 10%	296.83	11.1	393.19	11.2	363.30	11.5
Crop yield	3 t/ha	334.00	-	442.78	-	410.68	-
	2 t/ha	124.24	62.8	282.06	36.3	272.05	33.8
	1.5 t/ha	12.81	96.2	194.84	56	190.80	53.5

7.6.2 Effect of Shedding Losses

In Queensland, losses between 0.3 and 2.5% per day for wheat have been reported (Cameron, 2004). In order to study the influence of crop yield losses on the grower's return, five scenarios (ψ_2 = 0.45%, 0.75%, 1.0%, 1.25% and 1.5% yield losses per day) have been investigated with a medium capacity drier (AR1214) at the control parameters. It can be seen from Figure 7.14 that higher yield losses can have a very significant impact on return at the lower range of moisture content. This is because most losses occur at the later stages of harvesting (in the first 10 days passing the maturity, there are little losses).

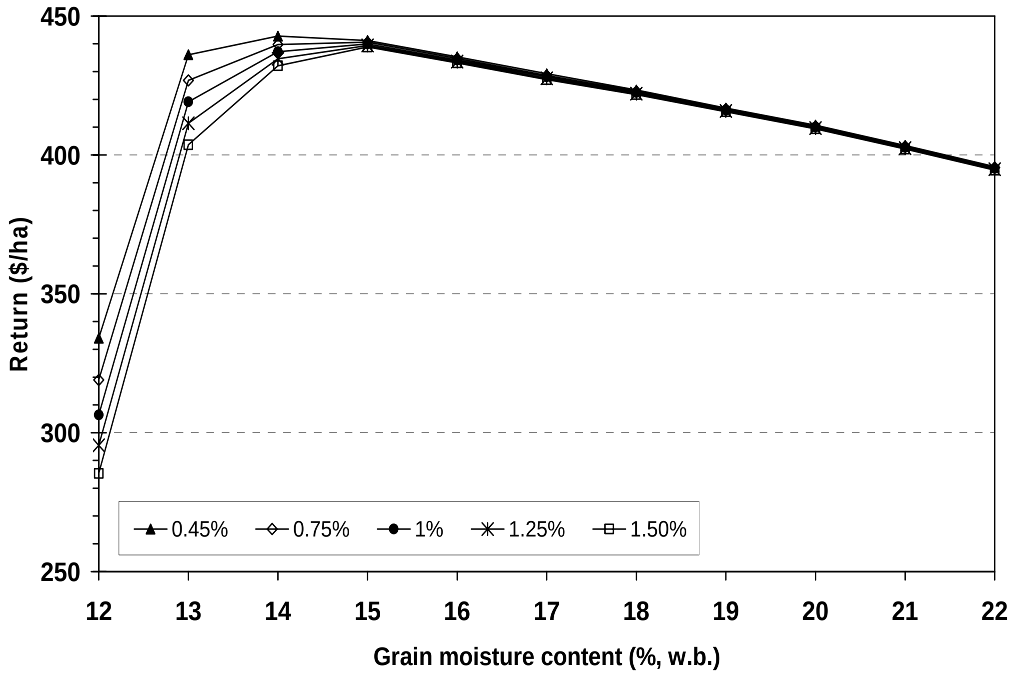

Figure 7.14 The effect of shedding losses on return

7.6.3 Effect of Crop Loss Model

Significant rainfall during the harvest period can greatly increase grain losses. It has been identified that two main factors affecting the quality losses are the rainfall and the stage of crop maturity. From limited experiment, Abawi (1993) showed that the degradation of wheat category in Queensland was positively correlated to rainfall during harvest. Detailed explanation of his quality degradation model can be found in Section 4.4.2.1. However, new field trials conducted by GRDC suggested that the protein of modern varieties may not be affected by the time of harvest as much as previous research had shown (Saunders, 2006). Queensland's Department of Primary Industry and Fishery (DPIF), also found that protein content seems to be less influenced by rainfall than previously thought. This also appears to be consistent with the anecdotic evidence reported in the United Kingdom by Mercer (2004).

Table 7.2 A new wheat quality downgrading matrix model

Rainfall, R_q (mm)	Days past maturity, d_m (d)		
	$d_m < 7$	$7 < d_m < 30$	$d_m > 30$
30	No effect	No effect	No effect
40	No effect	No effect	No effect
50	No effect	No effect	No effect
60	No effect	No effect	No effect
70	1 Step	1 Step	1 Step
80	1 Step	2 Steps	2 Steps
90	1 Step	2 Steps	3 Steps

Therefore, a new wheat quality downgrading matrix (Table 7.2) is proposed to study the sensitivity of the both models on return. The difference in return between the models proposed by Abawi and the new model is shown in Figure 7.15. It can be seen from Figure 7.15 that the difference in return is fairly insignificant (about \$3/t at 14% grain moisture content) because the small (actually no) difference in grain prices received for lower categories in the year of study (2005).

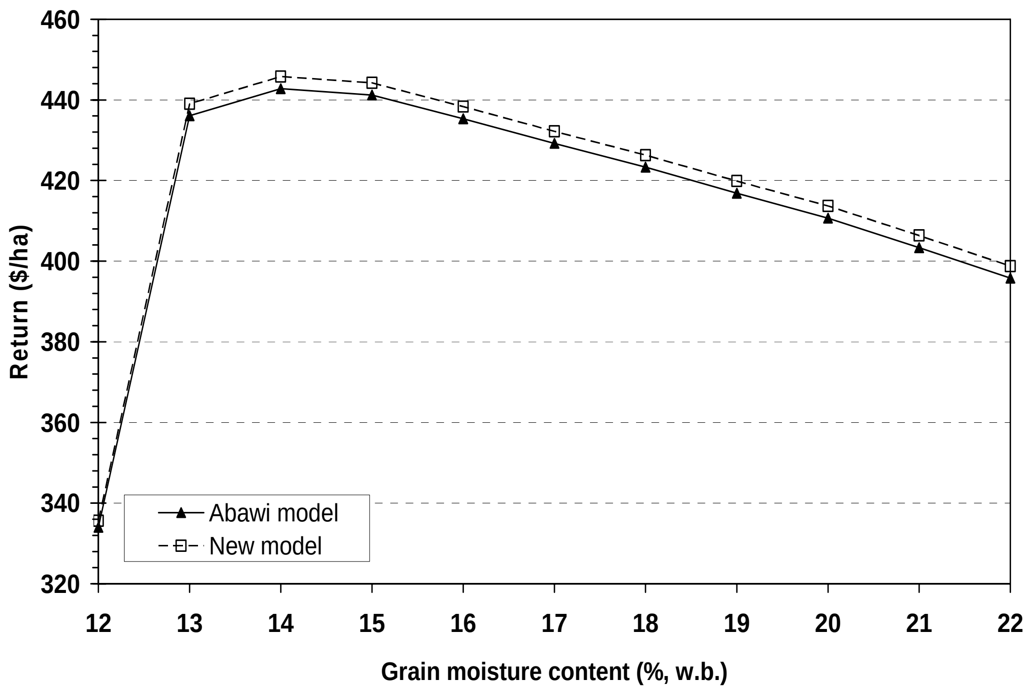

Figure 7.15 The difference in return generated from different quality models

7.7 Conclusion

Based on the simulation results presented in this chapter, several conclusions related to machinery and crop performance in Goondiwindi can be drawn. First of all, at the given control parameters, the optimum harvest moisture content in this location is 14%. At the extremes, the unharvested grain and threshing losses are the most significant losses at 12 and 22% moisture contents, respectively.

The simulation results also show that the maximum return can be obtained if growers use the largest comb size (9.2 m). In terms of combine speed, generally, low speed is generally preferred to harvest high moisture grain. At 12% moisture content, however, harvesting should be done at a high speed to reduce unharvested grain due to limited available harvesting hours.

It has also been shown that the possible optimum harvest moisture content for using continuous flow driers is 14% while for a batch drier is 13%. At higher moisture contents, using high capacity drier will give higher return than using a batch drier. In terms of aeration, an aerated storage is only practical to be used to support inadequate drying capacity of a low capacity drier (AR1210) and a batch drier. No positive effect of using an aerated storage can be achieved on return if growers use either high or medium capacity driers.

CHAPTER 8

Effect of Different Weather Patterns on Return

This chapter presents the detailed information of geographical and climatic conditions in Goondiwindi, Tamworth and Scaddan. Then, it discusses the difference in harvesting availability and possible return for each location as a result of different weather patterns for different study locations. The effects of grain moisture content on the total costs and the safe storage periods in these locations are also discussed.

8.1 Geographical and Climatic Information of the Study Locations

The magnitude of local climatic factors such as rainfall, air temperature and relative humidity is different for different wheat growing locations across Australia. Therefore, three wheat growing locations representing three states in Australia are chosen for this study. The selection of the different representative locations is important to study the effect of different weather patterns on the overall return in different locations. The geographical information of those study locations is shown in Table 8.1. The position of the study locations is shown in Figure 8.1.

Table 8.1 Geographical information of the study locations

Location	State	Latitude	Longitude	Altitude (m)
Goondiwindi	Queensland	28º 33′ S	150º 19′ E	217
Tamworth	New South Wales	31º 05′ S	150º 55′ E	404
Scaddan	Western Australia	33º 27′ S	121º 43′ E	174

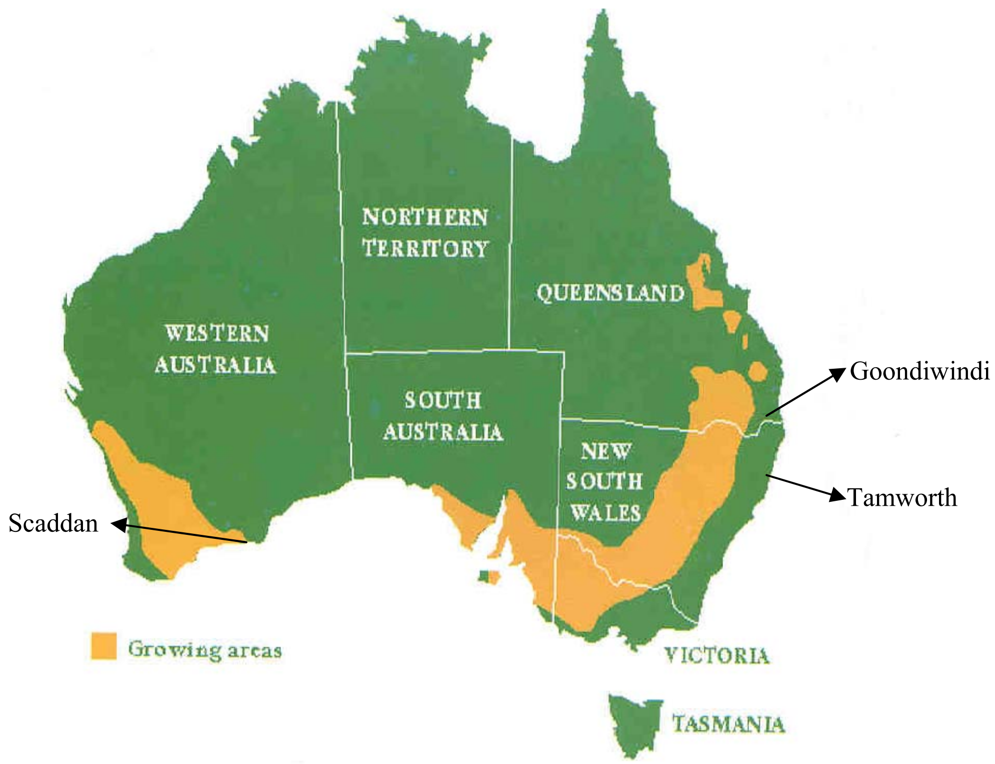

Figure 8.1 The position of the study locations in the Australian wheat belt

Goondiwindi and Tamworth are located in the northern wheat belt region. Goondiwindi has a subtropical climate of hot and erratic storm rainfall in summer. Its annual rainfall is approximately 597.3 mm. In Tamworth, the climate is generally less intensive than Goondiwindi with typically warm to hot summers and cool to mild winters. Rainfall is experienced all year round, with summer storms providing infrequent heavy rainfall. The annual rainfall in Tamworth is approximately 579.1 mm.

Scaddan is located in the western wheat belt region. Scaddan typically experiences a Mediterranean climate with generally warm to hot, dry summers and cool and wet winters. Summer rainfall is rare but can be significant due to summer thunderstorms and tropical cyclones. Annual rainfall in this location is approximately 574.9 mm. The patterns of monthly mean rainfall and temperature for these study locations are shown in Figure 8.2 and 8.3 respectively. However, as there is no ABM weather station in Scaddan, the ABM in Esperance Aero is used to represent that location in this comparison.

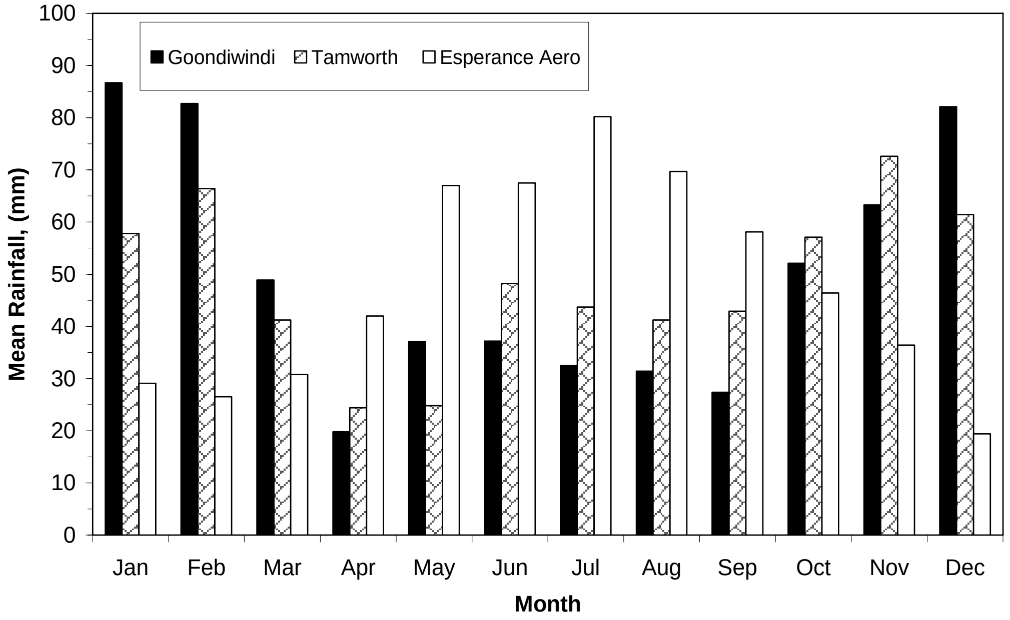

Figure 8.2 The pattern of annual mean rainfall for the study locations (Source: ABM)

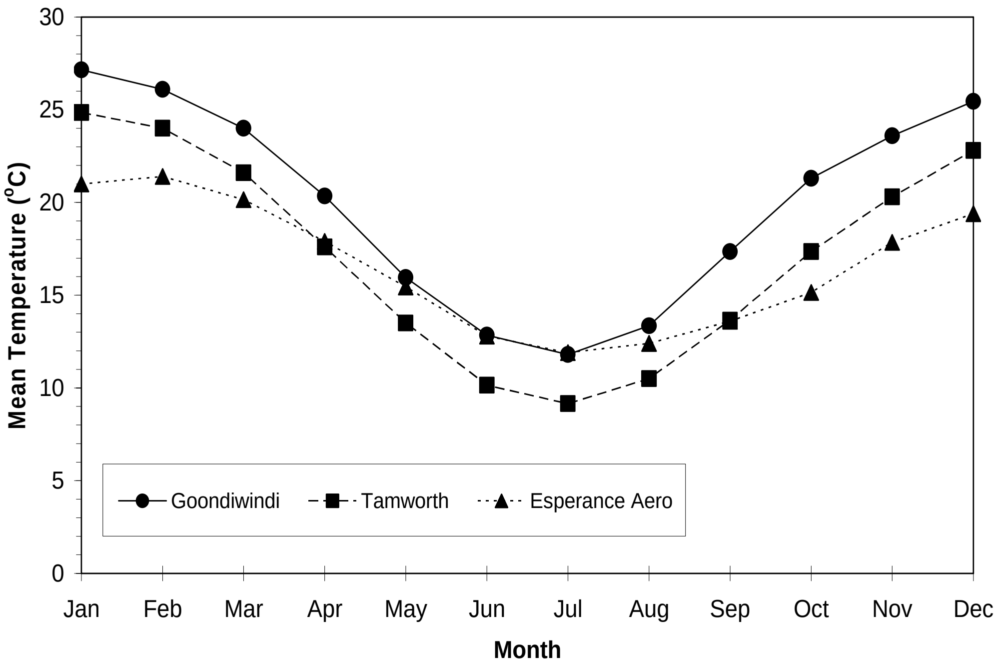

Figure 8.3 The pattern of annual mean temperature for the study locations (Source: ABM)

8.2 Weather Data for the Study Locations during the Harvest Period

Table 8.2 Average weather conditions for the study locations during harvest from 1991 to 2005

Location	Temperature (ºC)	Relative Humidity (%)	Accumulated Rainfall (mm)
Goondiwindi	23	57.1	186.2
Tamworth	19	66.3	217.3
Scaddan	19	79.9	72.0

Rainfall, air temperature and relative humidity are the main weather parameters affecting grain quality and harvesting operation. The averages of these weather parameters during the harvest period for the study locations are shown in Table 8.2. Based on average temperature, it can be seen that among these three locations, Goondiwindi is the warmest location. Tamworth and Scaddan are cooler than Goondiwindi and share the same average temperature. In terms of relative humidity, Scaddan is the wettest while Goondiwindi is the driest location. For rainfall comparison, Tamworth receives the largest amount of rainfall (217.3 mm) while Scaddan receives the least (72.0 mm).

8.3 Available Harvesting Hours for the Study Locations

Figure 8.4 shows the amount of average available harvesting hours at different grain moisture contents during harvest for each study location. The available harvesting hours are generated using a cumulative frequency analysis (Section 6.3). Overall, Goondiwindi has high available harvesting hours at any grain moisture content compared with Tamworth and Scaddan. At 12% moisture content, for example, the available harvesting hours in Goondiwindi, Tamworth and Scaddan are 128.9, 74.5 and 68.3 hours respectively. Goondiwindi has more available harvesting hours because it has relatively higher temperature, lower relative humidity and receives moderate rainfall. These three factors keep the grain moisture content relatively low throughout the harvest period and as a result, the available harvesting hours for any grain moisture content, particularly at the low level increase.

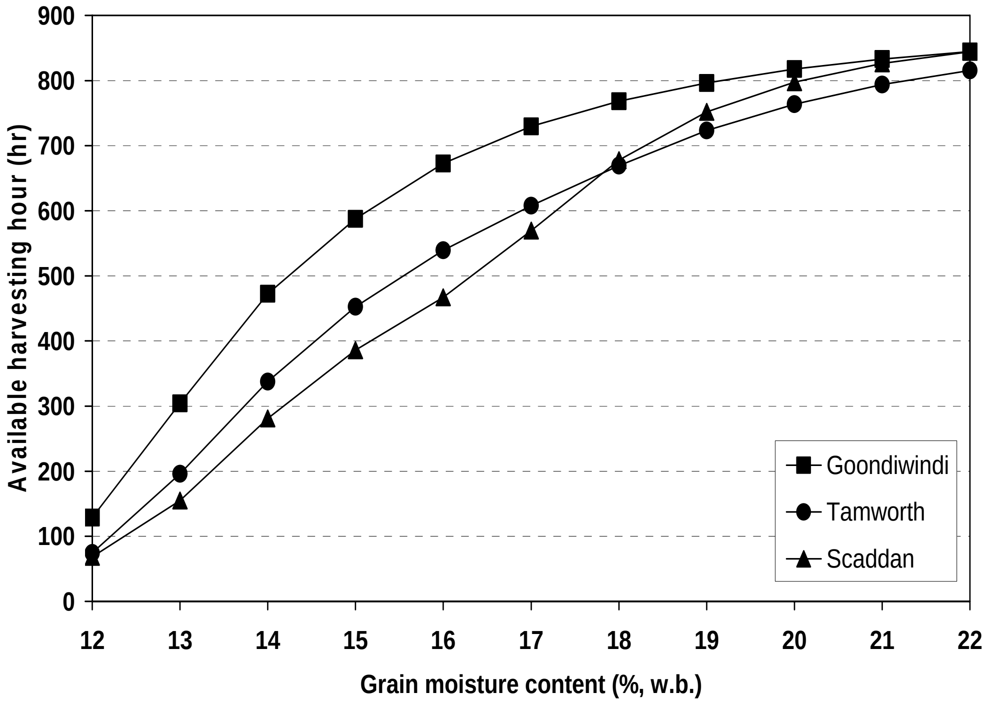

Figure 8.4 Comparison of available harvesting hours at different grain moisture contents

Tamworth has fewer available harvesting hours than Goondiwindi because it receives more frequent rainfall, experiences low temperature and high relative humidity during the harvest period. The rainfall can wet the grain and increase its moisture content. Furthermore, low temperature and high relative humidity in this location can also increase the grain moisture content thus reducing the available harvesting hours.

From 12 to 17% moisture contents, Scaddan has the least available harvesting hours compared to Goondiwindi and Tamworth because of its moist ambient condition as indicated by its temperature and relative humidity (Table 8.2). The moist ambient condition causes the grain moisture content to be relatively higher. However, at 18% moisture content and above, Scaddan has more available harvesting hours than Tamworth. This is because, at higher grain moisture contents, the effect of rainfall on grain moisture content transcends the effect of relative humidity.

8.4 Return Comparison for the Study Locations

Figure 8.5 shows the comparison of return for the three study locations at the same simulation parameters except for weather elements. The return for Scaddan-(a) is generated using the wheat price structure in Western Australia (Table 2.7). However, since the purpose of this study is to investigate the effect of different local weather patterns on return, the wheat price structure for these three locations is assumed to be the same, based on the wheat price structure (2005) in Toowoomba (Table 2.6). Therefore, the return pattern for Scaddan based on the wheat price structure in Toowoomba is represented by Scaddan-(b). In this section, for comparison purposes, all discussions related to Scaddan is based on the return of Scaddan-(b).

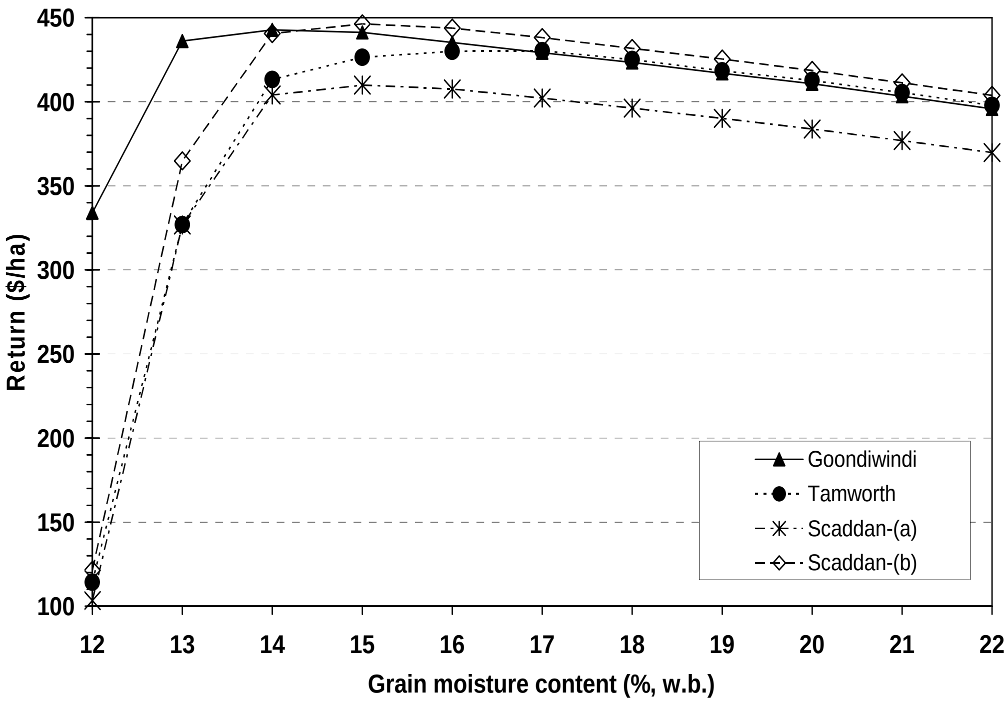

Figure 8.5 Comparison of return for the study locations

Generally, at high grain moisture contents, the return patterns in the study locations are quite similar to each other. It can be seen that the difference in weather patterns has less significant effect on return when grain is harvested at high moisture contents. This is because, the major elements affecting the return at higher grain moisture contents such as threshing losses, drying costs and grain spoilage do not vary significantly in the study locations (Figure 7.1, 8.6 and 8.7).

However, the difference in return is significant at low grain moisture content, particularly at 12%. At this moisture content, the return in Goondiwindi is \$334.01/ha, 2.9 times higher than the return in Tamworth and 2.75 times higher than the return in Scaddan. A higher return in Goondiwindi is possible due to its favourable weather conditions. In Tamworth and Scaddan, the return at low grain moisture contents is significantly low due to the wet and cool weather conditions. The wet and cool weather conditions could reduce the available harvesting hours thus increase the unharvested grain losses. Furthermore, at low grain moisture contents, the wet and cool locations are prone to experience a serious problem of quality degradation and shedding losses due to delayed harvesting (see Section 8.5).

Figure 8.5 also shows that the optimum harvest moisture content in Goondiwindi is 14%. The optimum harvest moisture content in Goondiwindi is relatively low because its warm and dry weather conditions keep the grain moisture contents at a low level. These conditions will allow the harvesting operation to be completed in a short time since harvesting can be started earlier in the morning and stop later in the evening. This practice can significantly reduce harvest losses.

In Tamworth, due to its low temperatures and large amount of rainfall, wheat is often harvested in slightly damp conditions. The maximum return in this location can be obtained if grain is harvested at 17% moisture content. The large amount of rainfall can excessively wet the standing crop thus increase its moisture content level. Wet grain will delay the harvesting operation because harvesters need to wait until the grain moisture contents fall to a desirable level before commencing the harvesting operation. Rainfall can also downgrade wheat quality. Furthermore, heavy rainfall can affect the soil trafficability which will limit the available hours for the harvesting operation. All these factors will prolong the harvesting period which will increase overall costs, particularly labour costs.

In Scaddan, it is predicted that 15% will be the optimum moisture content to start harvesting. This is because, Scaddan has wet and cool ambient conditions which cause the grain moisture content to remain at a higher level most of the time. Bolland (1984) reported that in Western Australia, grain moisture content of mature wheat regularly exceeds 12% during harvest as a result of cool moist sea breezes from the south coast, and summer rainfall. This problem can cause substantial delay in harvesting. Delaying harvesting will increase harvest losses and quality degradation which will decrease the return. Furthermore, harvesting moist grain will increase the drying and aeration costs.

8.5 Effect of Grain Moisture Content on Machinery Costs and Grain Losses

The effect of grain moisture content on machinery costs and grain losses during the harvest period for the study locations can be broken down into individual costs as shown in Figure 7.1 (Goondiwindi), 8.6 (Tamworth) and 8.7 (Scaddan). The machinery costs and grain losses in each study location are plotted for grain moisture contents ranging from 12 to 22% at the control values given in Table 5.3. In this section, a low capacity drier (AR1210) is used in order to show the effect of an aeration cooling on the whole system. A detailed discussion on individual costs for Goondiwindi is available in Section 7.1. Therefore, any comparison related to Goondiwindi must be referred to that section.

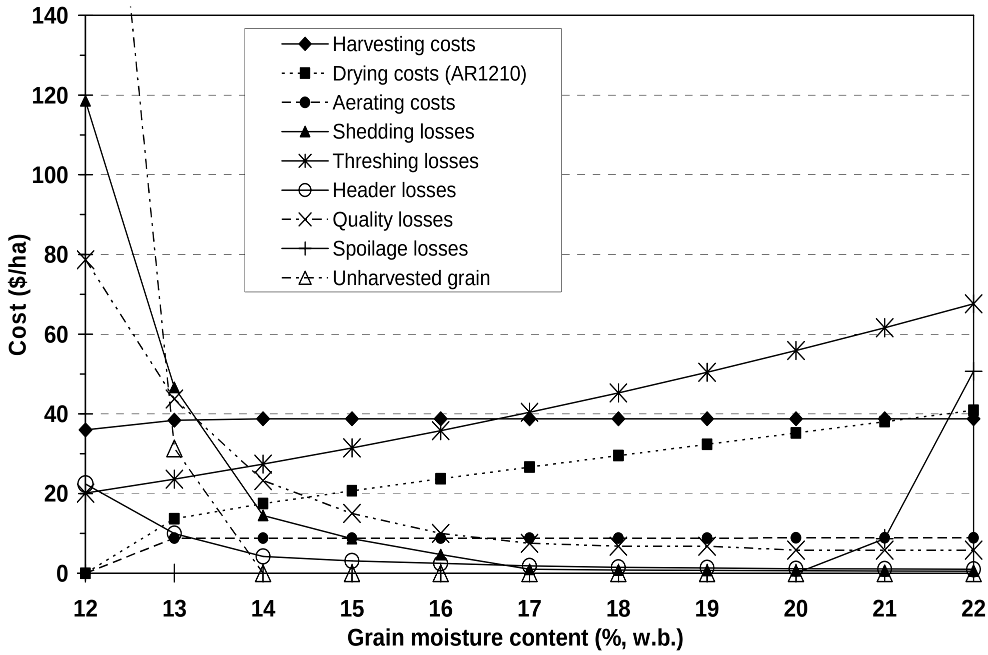

Figure 8.6 The effect of grain moisture content on individual costs for each element in the wheat harvesting system in Tamworth

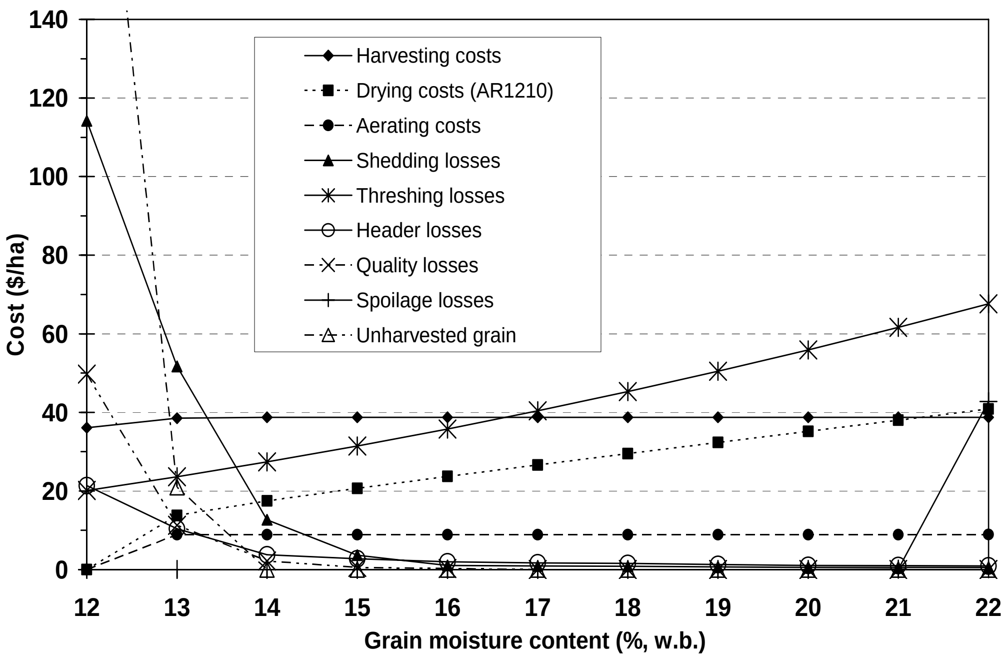

Figure 8.7 The effect of grain moisture content on individual costs for each element in the wheat harvesting system in Scaddan-(b)

Figure 8.6 and 8.7 show the effect of grain moisture content on individual costs in Tamworth and Scaddan respectively. It can be seen from these figures that the most significant losses at low grain moisture contents are contributed by the unharvested grain. For example, at 12% moisture content, the costs of the unharvested grain in Goondiwindi, Tamworth and Scaddan are 89.91, 256.4 and $239.30/ha respectively. The unharvested grain losses are significant in Tamworth and Scaddan because these two locations have fewer available harvesting hours.

Shedding losses are also significant component of the overall losses, particularly if grain is harvested from 12 to 15% moisture contents. At 12% moisture content, Tamworth has the most severe shedding losses of $118.50/ha, 5 times higher than that in Goondiwindi. The amount of shedding losses in Scaddan is $105.93/ha. High shedding losses in the wet locations are due to substantial delayed in the harvesting operation. A delay in the harvesting operation causes the grain to remain on farm longer thus increase the shedding losses.

In addition to the shedding losses, the header losses are also affected by a delayed harvesting. For example, at 12% moisture content, the header losses in Tamworth and Scaddan are higher than that in Goondiwindi. For the threshing losses, it has a similar pattern in all study locations. This is because, weather conditions has little influence on the threshing losses as these losses are mainly dependent on harvesting strategy.

At 12% moisture content, the quality losses in Goondiwindi, Tamworth and Scaddan are 16.3, 78.6 and $49.7/ha respectively. It shows that the location with less rainfall experiences lower quality losses. For the spoilage losses, it can be seen that, at 22% moisture content, the spoilage losses in Goondiwindi, Tamworth and Scaddan are 72.78, 54.30 and $44.23/ha respectively. Goondiwindi has the highest level of spoilage losses because the temperature in this location is higher.

The cost comparison for each element in the wheat harvesting system at the optimum harvest moisture content and at 12% grain moisture content for the study locations are summarised and shown in Table 8.3 and 8.4 respectively. For both tables, the return for Scaddan is generated based on the wheat price structure in Western Australia (Table 2.7).

Table 8.3 Cost comparison for each element in a wheat harvesting system at the optimum harvest moisture content

Location	Goondiwindi	Scaddan	Tamworth
Optimum harvest moisture content, % wb	14	15	17
Machinery costs, $/ha			
Harvesting costs	38.75	38.75	38.75
Drying costs	17.00	20.7	26.65
Aeration costs	8.86	8.86	8.86
Grain losses, $/ha			
Quality losses	9.5	0.7	7.5
Shedding losses	4.58	3.40	1.0
Threshing losses	29.90	29.17	40.4
Front losses	2.6	2.5	1.83
Spoilage losses	0	0	0
Unharvested grain	0	0	0

Table 8.4 Cost comparison for each element in a wheat harvesting system at 12% moisture content

Location	Goondiwindi	Scaddan	Tamworth
Optimum harvest moisture content, % wb	12	12	12
Machinery costs, $/ha			
Harvesting costs	37.76	36.11	35.95
Drying costs	0	0	0
Aeration costs	0	0	0
Grain losses, $/ha			
Quality losses	16.3	73.8	78.6
Shedding losses	22.58	105.93	118.5
Threshing losses	20.12	18.67	20.1
Front losses	5.6	19.8	22.41
Spoilage losses	0	0	0
Unharvested grain	89.91	222.02	271.5

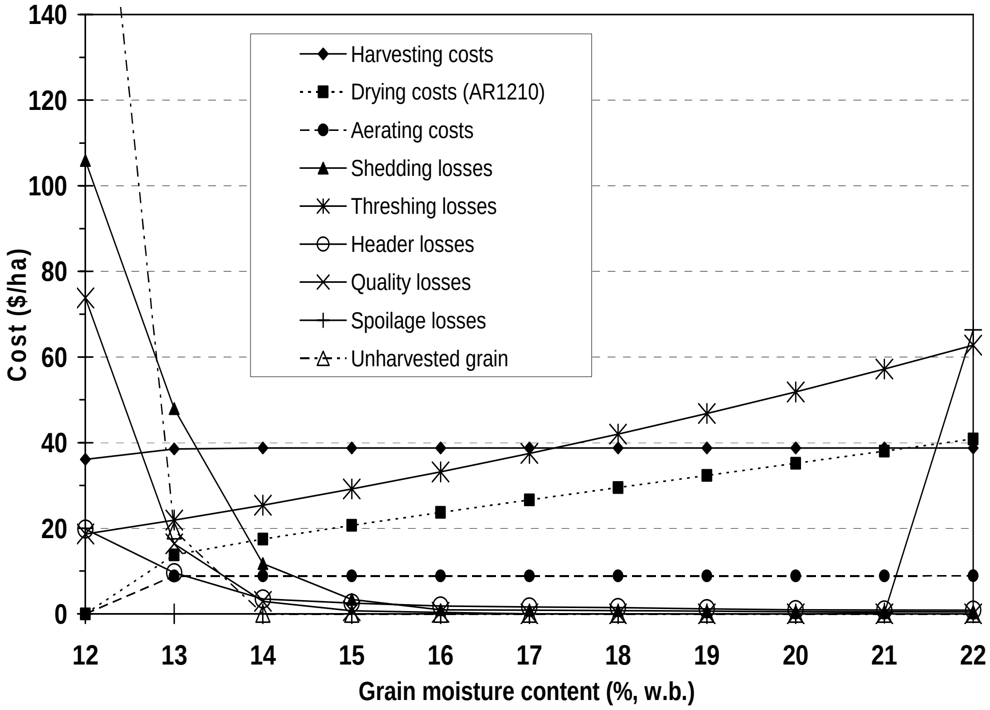

Figure 8.8 The effect of grain moisture contents on individual costs for each element in wheat harvesting system (Scaddan-(a))

The actual individual costs for each element in the wheat harvesting system in Scaddan based on the wheat price structure in Western Australia (Table 2.7) is illustrated in Figure 8.8. Generally, there is no significant difference between this figure and Figure 8.7. The machinery costs which are independent of wheat price remain the same while other losses which are price dependent vary between both figures. For example, at 12% moisture content, the cost of shedding losses for Scaddan-(b) is $114.18/ha while for Scaddan-(a) is 7.2% less. This is consistent with the percentage of difference in price for the first category wheat between Queensland and Western Australia.

8.6 The Safe Storage Periods of Wheat in Study Locations

Figures 7.9 to 7.11 show the difference of safe storage period for wheat in different study locations. The details of calculation for the safe storage period are shown in section 3.5.3. At these study locations, wheat is often harvested at higher temperature which exceeded the safe storage temperature. Burgess and Burrell (1964) recommended the safe storage temperature to sufficiently prevent insect and mould development in stored grain is at or below 15°C. Beyond this limit, the grain in storage will be susceptible to deterioration due to mould, bacteria and insects activities. Therefore, due to the lack of sufficient weather conditions to cool the wheat to acceptable storage temperatures, these three study locations need to use aerated storage to allow rapid cooling below 15°C.

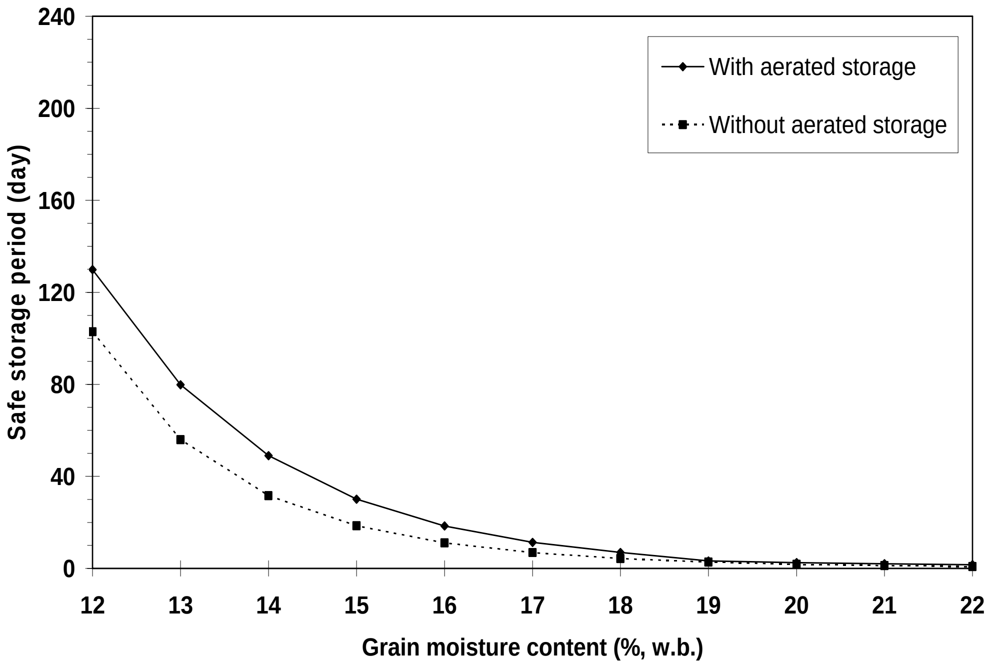

Figure 8.9 Safe storage period of wheat for farm with and without an aerated storage in Goondiwindi (Average daily temperature 23 °C)

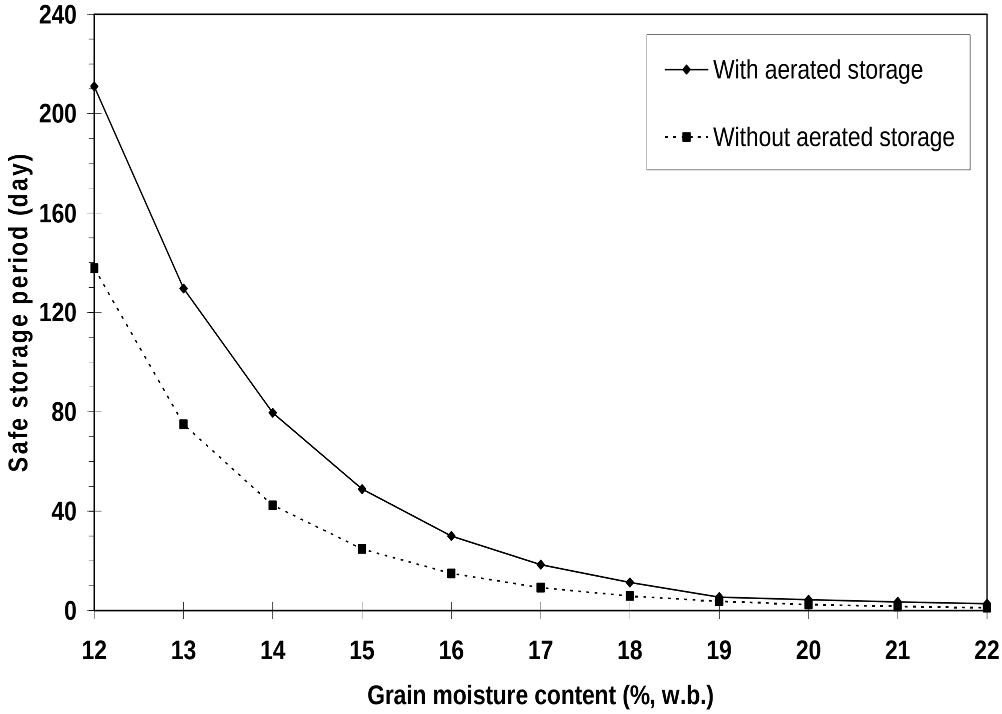

Figure 8.10 Safe storage period of wheat for farm with and without an aerated storage in Tamworth (Average daily temperature 19 ºC)

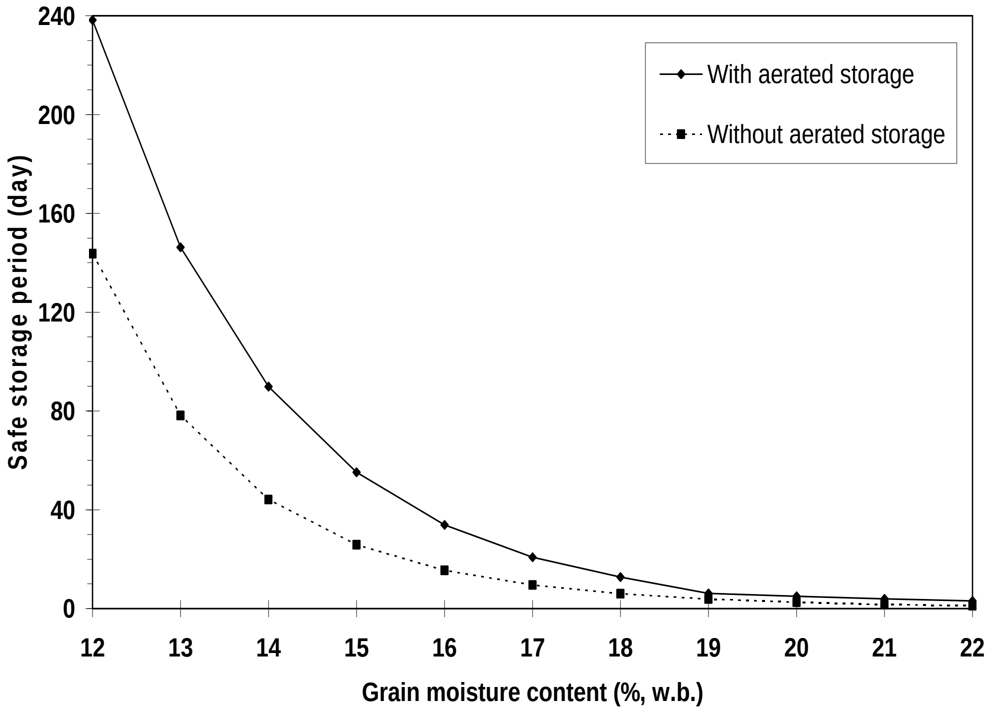

Figure 8.11 Safe storage period of wheat for farm with and without an aerated storage in Scaddan (Average daily temperature 19 ºC)

In Goondiwindi, wheat is harvested at relatively warmer temperatures (23ºC) than the other two locations (19ºC). Due to that reason, at lower moisture content, the safe storage period in Goondiwindi is shorter than the other locations. For example, at 12% moisture content, the safe storage periods for aerated wheat in Goondiwindi, Tamworth and Scaddan are 130, 211 and 238 d respectively. For wheat which is stored without aeration, the safe storage periods in these locations in the same sequence are 103, 138 and 144 d respectively. At higher grain moisture contents, the safe storage period for both storage conditions in these locations is very similar.

The difference in the safe storage period between an aerated wheat and non aerated wheat at low moisture contents is less significant in Goondiwindi but very significant in Scaddan. For example, In Goondiwindi, at 12% moisture content, the difference is only 27 d while in Scaddan it is about 94 d. This is because, in Scaddan, the low temperature permits the wheat to be stored longer. These three figures infer that for non aerated wheat, small changes in temperature can cause significant changes in the safe storage period. This is because, the lower the grain temperature and moisture content, the longer the grain can be safely stored.

8.7 Conclusion

This chapter has discussed the detailed information of geographical and climatic conditions in Goondiwindi, Tamworth and Scaddan. Based on this information, it is found that among these three locations, Goondiwindi is the most suitable location for growing wheat. This is because, Goondiwindi has favourable weather conditions with high temperature, lower relative humidity and receives moderate rainfall amount.

The optimum harvest moisture content in Goondiwindi, Tamworth and Scaddan are found to be at 14, 17 and 15% respectively. The optimum harvest moisture content in Goondiwindi is relatively low because its warm and dry weather conditions keep the grain moisture contents at a low level. These conditions will allow the harvesting operation to be completed in a short time since harvesting can be started earlier in the morning and stop later in the evening. This practice can significantly reduce harvest losses.

The most significant losses at low grain moisture contents are contributed by the unharvested grain. For example, at 12% moisture content, the cost of the unharvested grain in Goondiwindi, Tamworth and Scaddan is 89.91, 256.4 and $239.30/ha respectively. The unharvested grain losses are significant in Tamworth and Scaddan because these two locations have fewer available harvesting hours.

In Goondiwindi, wheat is harvested at relatively warmer temperatures than the other two locations. Due to that reason, the safe storage period for stored wheat in Goondiwindi is shorter than other locations. At 12% moisture content, the safe storage period for aerated wheat in Goondiwindi, Tamworth and Scaddan is about 130, 211 and 238 d respectively. For wheat which is stored without aeration, the safe storage period in these locations in the same sequence is about 103, 138 and 144 d respectively. At higher grain moisture contents, the safe storage period for both storage conditions in these locations is nearly similar.

CHAPTER 9

Conclusions and Recommendations

The management of climate risk and climate variability during harvest period is fundamentally important in Australia, particularly in the northern wheat belt region. This is because the economics of grain production in this country is significantly affected by weather conditions, especially rainfall. Heavy rainfall and thunderstorms during the harvest period can cause substantial losses in both quantity and quality of grain. These losses could be minimized by tailoring grain harvesting strategy and using postharvest machinery such as a grain drier and aeration. The conclusions of this study are discussed below based on several categories.

Conclusion for the Model Development

- A new wheat harvest simulation model, called the WHSSM has been successfully developed. Based on the calculation of 15 years average returns, this model has been shown to have the ability to produce reasonable results. The sensitivity studies of the model in Chapters 7 and 8 have shown that in all cases, the model is able to produce correct numerical trends when the model parameters are changed. This indicates that the model has a good potential to be used as an effective tool to quantify and examine the various management options to manage the risks associated with weather damage at harvest.
- The new aeration cooling submodel has been successfully incorporated into this new model.
- The WHSSM has been successfully used to study the effect of different drier capacities.
- The WHSSM has been successfully applied to study the effect of different weather patterns on return in different wheat growing locations across Australia.

Conclusion for the Model Applications

Harvesting Operation

- For the reference location (Goondiwindi), at the given control parameters, simulation results have shown that the maximum return could be obtained if grain is harvested at the moisture content of 14% and then artificially dried.

- Harvester capacity affects the total predicted return for growers. The simulation results have shown that, at the optimum harvest moisture content (14%), a large combine harvester (comb size, 9.2 m) produces the highest return while a small combine harvester (comb size, 6.1 m) produces the least. The predicted return at the optimum harvest moisture content for 9.2, 7.3, 6.7 and 6.1 m of comb sizes are 442.78, 436.18, 429.40 and $416.77/ha respectively. The large combine harvester could produce approximately 6.3% higher return than a small combine harvester.

- The effect of harvester forward speed is dependent on grain moisture content. At low moisture content (12%), higher forward speed will give more return to growers as this practice will reduce unharvested grain due to timeliness factor. However, if grain is to be harvested at the optimum grain harvest moisture content, low forward speed will be recommended as this practice could reduce threshing losses and pressure on drying. The optimum harvest moisture content for forward speed at 6 km/h is 15% while for 8, 10 and 12 km/h is 14%.

Grain Drier

- For the reference location and at the control parameters, at moisture contents of 14% and above, using continuous flow driers will give a higher return than a batch drier. The optimum harvest moisture content for continuous flow drier and batch drier is 14 and 13% respectively. Among three types of continuous flow driers, a drier with the highest drying capacity (AR1614) has been shown to give the best return to growers.

- The predicted return for using a batch dryer is much lower, particularly at high grain moisture contents. This emphasizes the need to have a high capacity dryer, in order to match the harvester capacity with the drying capacity.

- At optimum harvest moisture content, a high capacity drier (AR1614) is the best drier for the assumed crop area. However, if grain is to be harvested at low moisture content, a batch drier will be the best option. If grain is to be harvested at higher moisture contents (16% and above), using a large capacity drier (AR1614) is the most economical.

Grain Aeration

- The safe storage period for wheat varies for different locations. For example, at 12% moisture content, the safe storage periods for wheat in aerated storage in Goondiwindi, Tamworth and Scaddan are 130, 211 and 238 d respectively. For wheat which is stored without aeration, the safe storage periods in those three locations in the same sequence are 103, 138 and 144 d respectively. At higher grain moisture contents, the safe storage period for these locations is very similar.

- The aeration cooling is only practical to be used to support inadequate drying capacity of a low capacity drier (AR1210) and a batch drier. No positive effect of using aeration cooling could be achieved on return if growers use either high or medium capacity driers. This is because, the higher capacity driers have enough drying capacity to dry all harvested grain before deterioration occurs.

- For growers with a low capacity drier, the economics of using aeration cooling is achieved at higher grain moisture contents from 21 to 22%. For example, at 21% moisture content, having one aerated storage will increase the return by about 1% or $3.32/ha while having four aerated storages will increase the return by 2.3% or $8.26/ha.

- For growers with a batch drier, the economics of using an aerated storage is achieved if grain is harvested from 15 to 17% moisture contents. At 15% moisture content, the investment in one aerated storage will increase the return by about 1.1% or $3.56/ha. At the same moisture content, using four aerated storages will increase the return up to 2.9% or $11.28/ha.

- Using aeration cooling does not change the optimum harvest moisture content.

Harvesting Strategies

- For the reference location (Goondiwindi), a large farm size will produce higher returns at any given moisture content. This is because, a large farm size will allow better use of available facilities, increase farm efficiency and reduce ownership costs of machinery per unit of area.

- Grain losses due to natural shedding, quality downgrading, unharvested grain and header losses have a very significant impact on grower's return, particularly at the lower range of harvest moisture contents.

- For a farm size of 500 ha, the simulation results have shown that the difference in return between harvesting at optimum harvest moisture content (14%) and at 12% moisture content is only \$21/ha. However, for a crop area of 1000 ha, the difference could be as high as \$108.77/ha.

Location

- This study has demonstrated that the weather conditions during the harvest period in different study locations have significant influence on the predicted returns. The growers in a dry and warm location (e.g. Goondiwindi) will gain better return. It also shifts the optimum harvest moisture content to the low range of moisture contents, allowing the flexibility of a delay in grain harvesting. For wet and cool regions (e.g. Tamworth and Scaddan), delaying the harvesting operation could result in increased yield losses due to unharvested grain, quality losses and shedding losses.

- Weather condition has a major effect on grain quality, harvest operation and profitability. At 12% moisture content, the difference in predicted return between Goondiwindi and Tamworth is \$219.75/ha for the same size of farm and machinery availability.

- At the given control parameters, the optimum harvest moisture content for Goondiwindi, Scaddan and Tamworth is 14, 15 and 17% respectively.

Recommendations for Future Research

This simulation model has been developed so that it can be used as a guide for growers to make decisions in their wheat harvesting system in order to gain a higher return. Even though this model is able to produce reasonable results, there are some points in this study, which could be improved in the future. The recommendations for the future research are:

- Due to limited time and information, the simulation results show in this thesis have not been validated yet. Therefore, to check the validity of the results from this simulation model, the validation and verification study should be carried out in the future.

- From the available literature, the quality losses model that relates grain quality to rainfall was only available for the northern Australian wheat belt, particularly for Queensland. Ideally, such a model must also be developed in other states where quality losses are high.

- This model was purposely developed for a wheat harvesting system. However, by changing some crop-related variables, this climatic based model could be used to study the economics of other grain crops like barley, sorghum and so on under different weather conditions. It also could be used to investigate the viability of the idea to move rice planting to northern Queensland.

- In Australia, the magnitudes of shedding losses, header losses and threshing losses have not been empirically quantified since 1993. As there are many new varieties emerging, their tolerance towards natural shedding and machinery interaction should be studied.

- Since the wheat price structure used in this study is based on the price in 2005, the results may be inaccurate for other periods. Therefore, the simulation model should be updated in order to gain more accurate results.

- For growers with a small farm size, the use of a grain drier may not be economical. Thus, the possibility of using natural drying in this case is high. Therefore, further economics study of using natural drying should be carried out.

- For growers with small farm size, using central drying facilities might be economical. Therefore, in the future, the study of harvesting strategy using centralized grain drying would need to be undertaken.

- This simulation model only studies the wheat harvesting system operation from harvesting, aeration to drying. However, the effects of harvester pattern, field bin allocation and the road transport operation are not covered in this study. Therefore, this model could be extended to study the optimization of those factors in order to make this model becoming much more comprehensive.

- Instead of studying the economics of aeration cooling, the economics of using aeration maintenance and aeration drying could also be studied.

- In the future, an attempt to integrate this simulation model with crop growth models such as **APSIM** and **CropSyst** should be made in order to simulate the whole grain production system starting from planting though to harvesting, aeration, drying and delivery to a commercial storage.

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APPENDIX A

Source Code Listings of the Wheat Harvest System Simulation Model (WHSSM)

% * MAIN SIMULATION FUNCTION *** %**

```
% Determine Predicted Grain Moisture Content of the Standing Crop in the Field
run GrainMoistureContent

% Calculate the Fixed Costs For Machinery Used
run FixedCosts

% Calculate the Variable Costs For Machinery Used
run VariableCosts

% Calculate the Yield Losses due to Crop, Weather and Machinery Factors
run YieldLosses

% Calculate the Quality Losses due to Rainfall
run QualityLosses

% Calculate the Quality Losses due to Spoilage
run StorageLosses

% Calculate the Return
for m=12:22
TotalCost(m)=(FixedCost(m)+VariableCost(m));
Return(m)=((CropPrice*Y)-(TotalCost(m)/Fs)-QualityLosses1(m)-
SpoilageLosses(m)-LsdC(m)-LhC(m)-LtC(m)-LuC(m));
end

display ('If you want to know the predicted return, please type Return and press
ENTER');

m=12:22;
plot(m,Return(m),'r-s')
xlabel('Grain moisture content, %wb')
ylabel('Return, $/ha')
title('The effect of grain moisture content on Return')
axis([12,22,100,500])
hold on
```

% * END *** %**

% * GENERATING OF PREDICTED GRAIN MOISTURE CONTENT *** %**

```
%   Latitude
Latitude = -28.52;

%   Height
Height = 217.6;

%   Load historical weather data

YearSelect=input('Select year between 1991 and 2005:');
if YearSelect==1991
  load Year1991
  clipboarddata=Year1991;
  elseif YearSelect==1992
  load Year1992
  clipboarddata=Year1992;
  elseif YearSelect==1993
  load Year1993
  clipboarddata=Year1993;
```

```
  elseif YearSelect==1994
  load Year1994
  clipboarddata=Year1994;
 elseif YearSelect==1995
  load Year1995
  clipboarddata=Year1995;
 elseif YearSelect==1996
  load Year1996
  clipboarddata=Year1996;
  elseif YearSelect==1997
  load Year1997
  clipboarddata=Year1997;
  elseif YearSelect==1998
  load Year1998
  clipboarddata=Year1998;
  elseif YearSelect==1999
  load Year1999
  clipboarddata=Year1999;
 elseif YearSelect==2000
  load Year2000
  clipboarddata=Year2000;
 elseif YearSelect==2001
  load Year2001
  clipboarddata=Year2001;
  elseif YearSelect==2002
  load Year2002
  clipboarddata=Year2002;
 elseif YearSelect==2003
  load Year2003
  clipboarddata=Year2003;
 elseif YearSelect==2004
  load Year2004
  clipboarddata=Year2004;
  elseif YearSelect==2005
  load Year2005
  clipboarddata=Year2005;
  else
  display('Sorry ! no weather data found for this year ')
  YearSelect=input('Select year between 1991 and 2005:');
end

%   Save clipboarddata

for d=2:81
Year(d) = clipboarddata(d,1);
Month(d) = clipboarddata(d,2);
Date(d) = clipboarddata(d,3);
Tmax(d) = clipboarddata(d,8);
Tmin(d) = clipboarddata(d,9);
TdbC(d) = 0.5*(clipboarddata(d,4)+clipboarddata(d,6));
TwbC(d) = 0.5*(clipboarddata(d,5)+clipboarddata(d,7));
RainFall(d) = clipboarddata(d,10);
TAmbient(d)=0.5*(clipboarddata(d,8)+clipboarddata(d,9));
TMeanAmbient=mean(TAmbient(d));
Tc=round(TMeanAmbient)+7;
Delays(d)=clipboarddata(d,11);

%   Check which is the leap year

b = 600;
```

```
leap(d) = 28;
for a=450:b
    check=4*a;
    if Year(d) == check
        leap(d) = leap(d)+1;
    end
end

%   Calculate 'n' value
%   n = the number of days of the year

if Month(d) == 1
   n(d) = Date(d);
elseif   Month(d) == 2
   n(d) = Date(d)+31;
elseif   Month(d) == 3
   n(d) = Date(d)+31+leap(d);
elseif   Month(d) == 4
   n(d) = Date(d)+31+leap(d)+31;
elseif   Month(d) == 5
   n(d) = Date(d)+31+leap(d)+31+30;
elseif   Month(d) == 6
   n(d) = Date(d)+31+leap(d)+31+30+31;
elseif   Month(d) == 7
   n(d) = Date(d)+31+leap(d)+31+30+31+30;
elseif   Month(d) == 8
   n(d) = Date(d)+31+leap(d)+31+30+31+30+31;
elseif   Month(d) == 9
   n(d) = Date(d)+31+leap(d)+31+30+31+30+31+31;
elseif   Month(d) == 10
   n(d) = Date(d)+31+leap(d)+31+30+31+30+31+31+30;
elseif   Month(d) == 11
   n(d) = Date(d)+31+leap(d)+31+30+31+30+31+31+30+31;
elseif   Month(d) == 12
   n(d) = Date(d)+31+leap(d)+31+30+31+30+31+31+30+31+30;
else
   display ('Month must be between 1 and 12 only');
end

%   Calculate the declination (Rad-radians from the equator)

Declination=23.5*(3.142/180)*cos((2*3.142*(n(d)-172)/365));

%   Calculate the astronomical daylength

Astdaylength(d)=(2*(acos(-tan(Latitude)*tan(Declination)))*(180/3.142)/15);

%   Calculate air temperature during daytime and night time

tsunrise(d) = 12-(Astdaylength(d)/2);
tsunset(d) = 12+(Astdaylength(d)/2);
tTmax(d) = 12+(Astdaylength(d)/2)-0.06*Astdaylength(d);
tTmin(d) = tsunrise(d)+0.06*Astdaylength(d);

Tset(d) = Tmin(d) + (Tmax(d)-Tmin(d))*cos((3.142*(1-4*0.06))/(2*(3-4*0.06)));
Tavgnight(d) = (Tset(d)+Tmin(d))/2;
Skyemittance(d) = 1-0.261*exp(-7.77/10000*Tavgnight(d)^2);
Tsky(d) = ((Tset(d)+273+Tmin(d)+273)/2)*(Skyemittance(d)^0.25)-273;
Decayconst(d) = log((Tset(d)-Tsky(d))/(Tmin(d)-Tsky(d)))/(24-
Astdaylength(d)+2*0.06*Astdaylength(d));
```

```
for h=1:24
   if h>=1&h<=5
   Temp(d,h) = Tsky(d)+(Tset(d)-Tsky(d))*exp(-Decayconst(d)*(h+24-
(12+(Astdaylength(d)/2)-0.06*Astdaylength(d))));
   elseif h>=6&h<=18
   Temp(d,h) = Tmin(d)+(Tmax(d)-Tmin(d))*cos(22/7*(h-tTmax(d))/(2*(tTmax(d)-
tTmin(d))));
   else
   Temp(d,h) = Tsky(d)+(Tset(d)-Tsky(d))*exp(-Decayconst(d)*(h-
(12+(Astdaylength(d)/2)-0.06*Astdaylength(d))));
   end

%   Calculate Vapor Pressure

TwbF(d) = TwbC(d)/5*9+32;
AstPs=101.3*((293-0.0065*(Height))/293)^(5.26);
PConst=(0.00163*AstPs)/2.45;
wetbulbvapress(d)=6.1078*exp(((9.5939*TwbF(d))-
307.004)/((0.556*TwbF(d))+219.522));
Satwetpress(d)=wetbulbvapress(d)/10;
VapourPress(d)=Satwetpress(d)-PConst*(TdbC(d)-TwbC(d));

%   Calculate Saturated Vapor Pressure

TempA(d)=(Tmax(d)+Tmin(d))/2;
Satvaporpressure(d,h)=((6e25)/(Temp(d,h)+273.15)^5)*exp(-
6800/(Temp(d,h)+273.15))/1000;

%   Calculate Relative Humidity

RelativeHumidity(d,h) = VapourPress(d)/Satvaporpressure(d,h);

%   Calculate Equilibrium Moisture Content

   EqMoisturecont(d,h) = 113.1*((-log(1-
(RelativeHumidity(d,h))))/(Temp(d,h)*1.8+492))^(1/3.03);

end

%   Calculate Grain Moisture Content
%   Initial grain moisture content on 30 September was assumed to be 30% mc (d.b)

Grainmoisturecont(1,24)=42.9;

if RainFall(d)>0
   p=0;
       if RainFall(d)<20
      Grainmoisturecont(d,1) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(2)+0.5482)*0.5;
      Grainmoisturecont(d,2) = Grainmoisturecont(d-
1,24)+0.345*RainFall(d)+6.118*log(2)+0.5482;
      GrainmoistureK = Grainmoisturecont(d,2);
      EqMoistureK = EqMoisturecont(d,2);
      q=2;
      for h=3:24
         Grainmoisturecont(d,h) = EqMoisturecont(d,h)+(GrainmoistureK-
EqMoistureK)*exp(-0.04*(h-2))+2.5*sin(((h-2)-6)*3.142/12)+1.1;
      end
   elseif RainFall(d)>=20 & RainFall(d)<=40
```

```
        Grainmoisturecont(d,1) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(4)+0.5482)*0.3;
        Grainmoisturecont(d,2) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(4)+0.5482)*0.7;
        Grainmoisturecont(d,3) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(4)+0.5482)*0.9;
        Grainmoisturecont(d,4) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(4)+0.5482);
        GrainmoistureK = Grainmoisturecont(d,4);
        EqMoistureK = EqMoisturecont(d,4);
        q=4;
        for h=5:24
            Grainmoisturecont(d,h) = EqMoisturecont(d,h)+(GrainmoistureK-
EqMoistureK)*exp(-0.04*(h-4))+2.5*sin(((h-4)-6)*3.142/12)+1.1;
        end
    elseif RainFall(d)>40
        Grainmoisturecont(d,1) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(6)+0.5482)*0.1;
        Grainmoisturecont(d,2) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(6)+0.5482)*0.3;
        Grainmoisturecont(d,3) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(6)+0.5482)*0.6;
        Grainmoisturecont(d,4) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(6)+0.5482)*0.8;
        Grainmoisturecont(d,5) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(6)+0.5482)*0.9;
        Grainmoisturecont(d,6) = Grainmoisturecont(d-
1,24)+(0.345*RainFall(d)+6.118*log(6)+0.5482);
        GrainmoistureK = Grainmoisturecont(d,6);
        EqMoistureK = EqMoisturecont(d,6);
        q=6;
        for h=7:24
            Grainmoisturecont(d,h) = EqMoisturecont(d,h)+(GrainmoistureK-
EqMoistureK)*exp(-0.04*(h-6))+2.5*sin(((h-6)-6)*3.142/12)+1.1;
        end
    end
elseif RainFall(d) == 0
    if d==2
       GrainmoistureK = 42.9;
       EqMoistureK = EqMoisturecont(2,1);
       p=0;
       q=0;
     else
       p=p+1;
    end
    for h=1:24
            Grainmoisturecont(d,h) = EqMoisturecont(d,h)+(GrainmoistureK-
EqMoistureK)*exp(-0.04*(h+24*p-q))+2.5*sin(((h+24*p-q)-6)*3.142/12)+1.1;
    end
end
end

%   Generating Daily Grain Moisture Content (w.b) During Harvest

for d=2:81
for h=1:24
Gmc(d,h)=(100*Grainmoisturecont(d,h))/(100+Grainmoisturecont(d,h));
end
end
```

```
for d=2:81
    for h=7:17
   gtf(d,6)=0;
   gtf(d,h)=Gmc(d,h)+gtf(d,h-1);
   gtc(d)=gtf(d,h)/11;
    end
    end
gtc(82)=12;

HarHours=11;
%   HarHours = fixed daily harvesting hour (h)

%   Calculate Available Harvesting Hours
%   For the first 60 days (before unharvested grain in the field is downgraded as
ASW)

Count12=0;
Count13=0;
Count14=0;
Count15=0;
Count16=0;
Count17=0;
Count18=0;
Count19=0;
Count20=0;
Count21=0;
Count22=0;
Count30=0;

for d=2:61
    for h=7:17
        if Gmc(d,h)<=12
           Count12 = Count12 + 1;
           Count13 = Count13 + 1;
           Count14 = Count14 + 1;
           Count15 = Count15 + 1;
           Count16 = Count16 + 1;
           Count17 = Count17 + 1;
           Count18 = Count18 + 1;
           Count19 = Count19 + 1;
           Count20 = Count20 + 1;
           Count21 = Count21 + 1;
           Count22 = Count22 + 1;
           Count30 = Count30 + 1;
       elseif Gmc(d,h)<=13
           Count13 = Count13 + 1;
           Count14 = Count14 + 1;
           Count15 = Count15 + 1;
           Count16 = Count16 + 1;
           Count17 = Count17 + 1;
           Count18 = Count18 + 1;
           Count19 = Count19 + 1;
           Count20 = Count20 + 1;
           Count21 = Count21 + 1;
           Count22 = Count22 + 1;
           Count30 = Count30 + 1;
       elseif Gmc(d,h)<=14
           Count14 = Count14 + 1;
           Count15 = Count15 + 1;
           Count16 = Count16 + 1;
```

```
    Count17 = Count17 + 1;
    Count18 = Count18 + 1;
    Count19 = Count19 + 1;
    Count20 = Count20 + 1;
    Count21 = Count21 + 1;
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=15
    Count15 = Count15 + 1;
    Count16 = Count16 + 1;
    Count17 = Count17 + 1;
    Count18 = Count18 + 1;
    Count19 = Count19 + 1;
    Count20 = Count20 + 1;
    Count21 = Count21 + 1;
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=16
    Count16 = Count16 + 1;
    Count17 = Count17 + 1;
    Count18 = Count18 + 1;
    Count19 = Count19 + 1;
    Count20 = Count20 + 1;
    Count21 = Count21 + 1;
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=17
    Count17 = Count17 + 1;
    Count18 = Count18 + 1;
    Count19 = Count19 + 1;
    Count20 = Count20 + 1;
    Count21 = Count21 + 1;
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=18
    Count18 = Count18 + 1;
    Count19 = Count19 + 1;
    Count20 = Count20 + 1;
    Count21 = Count21 + 1;
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=19
    Count19 = Count19 + 1;
    Count20 = Count20 + 1;
    Count21 = Count21 + 1;
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=20
    Count20 = Count20 + 1;
    Count21 = Count21 + 1;
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=21
    Count21 = Count21 + 1;
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=22
    Count22 = Count22 + 1;
    Count30 = Count30 + 1;
elseif Gmc(d,h)<=30
```

```
        Count30 = Count30 + 1;
      end
   end
end

Count(12)=Count12;
Count(13)=Count13;
Count(14)=Count14;
Count(15)=Count15;
Count(16)=Count16;
Count(17)=Count17;
Count(18)=Count18;
Count(19)=Count19;
Count(20)=Count20;
Count(21)=Count21;
Count(22)=Count22;
Count(30)=Count30;

%   Calculate Available Harvesting Hours
%   The whole harvest period (80 days)

Counta12=0;
Counta13=0;
Counta14=0;
Counta15=0;
Counta16=0;
Counta17=0;
Counta18=0;
Counta19=0;
Counta20=0;
Counta21=0;
Counta22=0;
Counta30=0;

for d=2:81
    for h=7:17
      if Gmc(d,h)<=12
        Counta12 = Counta12 + 1;
        Counta13 = Counta13 + 1;
        Counta14 = Counta14 + 1;
        Counta15 = Counta15 + 1;
        Counta16 = Counta16 + 1;
        Counta17 = Counta17 + 1;
        Counta18 = Counta18 + 1;
        Counta19 = Counta19 + 1;
        Counta20 = Counta20 + 1;
        Counta21 = Counta21 + 1;
        Counta22 = Counta22 + 1;
        Counta30 = Counta30 + 1;
      elseif Gmc(d,h)<=13
        Counta13 = Counta13 + 1;
        Counta14 = Counta14 + 1;
        Counta15 = Counta15 + 1;
        Counta16 = Counta16 + 1;
        Counta17 = Counta17 + 1;
        Counta18 = Counta18 + 1;
        Counta19 = Counta19 + 1;
        Counta20 = Counta20 + 1;
        Counta21 = Counta21 + 1;
        Counta22 = Counta22 + 1;
```

```
    Counta30 = Counta30 + 1;
elseif Gmc(d,h)<=14
    Counta14 = Counta14 + 1;
    Counta15 = Counta15 + 1;
    Counta16 = Counta16 + 1;
    Counta17 = Counta17 + 1;
    Counta18 = Counta18 + 1;
    Counta19 = Counta19 + 1;
    Counta20 = Counta20 + 1;
    Counta21 = Counta21 + 1;
    Counta22 = Counta22 + 1;
    Counta30 = Counta30 + 1;
elseif Gmc(d,h)<=15
    Counta15 = Counta15 + 1;
    Counta16 = Counta16 + 1;
    Counta17 = Counta17 + 1;
    Counta18 = Counta18 + 1;
    Counta19 = Counta19 + 1;
    Counta20 = Counta20 + 1;
    Counta21 = Counta21 + 1;
    Counta22 = Counta22 + 1;
    Counta30 = Counta30 + 1;
elseif Gmc(d,h)<=16
    Counta16 = Counta16 + 1;
    Counta17 = Counta17 + 1;
    Counta18 = Counta18 + 1;
    Counta19 = Counta19 + 1;
    Counta20 = Counta20 + 1;
    Counta21 = Counta21 + 1;
    Counta22 = Counta22 + 1;
    Counta30 = Counta30 + 1;
elseif Gmc(d,h)<=17
    Counta17 = Counta17 + 1;
    Counta18 = Counta18 + 1;
    Counta19 = Counta19 + 1;
    Counta20 = Counta20 + 1;
    Counta21 = Counta21 + 1;
    Counta22 = Counta22 + 1;
    Counta30 = Counta30 + 1;
elseif Gmc(d,h)<=18
    Counta18 = Counta18 + 1;
    Counta19 = Counta19 + 1;
    Counta20 = Counta20 + 1;
    Counta21 = Counta21 + 1;
    Counta22 = Counta22 + 1;
    Counta30 = Counta30 + 1;
elseif Gmc(d,h)<=19
    Counta19 = Counta19 + 1;
    Counta20 = Counta20 + 1;
    Counta21 = Counta21 + 1;
    Counta22 = Counta22 + 1;
    Counta30 = Counta30 + 1;
elseif Gmc(d,h)<=20
    Counta20 = Counta20 + 1;
    Counta21 = Counta21 + 1;
    Counta22 = Counta22 + 1;
    Counta30 = Counta30 + 1;
elseif Gmc(d,h)<=21
    Counta21 = Counta21 + 1;
    Counta22 = Counta22 + 1;
```

```
        Counta30 = Counta30 + 1;
      elseif Gmc(d,h)<=22
        Counta22 = Counta22 + 1;
        Counta30 = Counta30 + 1;
      elseif Gmc(d,h)<=30
        Counta30 = Counta30 + 1;

       end
   end
end
Counta(12)=Counta12;
Counta(13)=Counta13;
Counta(14)=Counta14;
Counta(15)=Counta15;
Counta(16)=Counta16;
Counta(17)=Counta17;
Counta(18)=Counta18;
Counta(19)=Counta19;
Counta(20)=Counta20;
Counta(21)=Counta21;
Counta(22)=Counta22;
Counta(30)=Counta30;

%   Estimation of the Days Past Maturity Based on Available Harvesting Hours

for m=12:22
 for d=2:81
if gtc(d)>0 & gtc(d)<=m
    dpm(m)=d-1;
    break
    dpm(m)=0;
end
 end
end
for m=12:22
Dm(m)=dpm(m);
end
```

% * END ***%**

% * FIXED COSTS *** %**

```
% Input for Grain and Farm Size

Fs = 1000;%input('Enter a farm size (ha): ');
CropPrice = 180;
Y = 3;
Yo = 2;
GrainDensity = 750;
YieldIndex = Y/Yo;

%   Input for a Combine Harvester

Wc=input('Enter cutting width of the combine harvester (m): ');
%   Standard values of cutting width is 6.1,6.7,7.3 & 9.2 m

S=input('Enter speed of harvesting (km/h): ');
%   Control value for harvesting speed is 8 km/h.

HarvestingEfficiency=75;
```

```
%   Standard field efficiency for a combine harvester is 75%.

Cr = 1.2*Wc-4.3;
So = (12*Cr)/(Cr+4.3);
SpeedIndex = S/So;
Cec = (0.01*HarvestingEfficiency*YieldIndex*SpeedIndex*Cr);
Ch = (10000*(4.5*Wc-9));

% Ch   = capital cost of harvester ($A)
% Cr   = rated capacity of combine harvester (ha/h)
% Cec = effective capacity of the harvester (ha/h)
% So   = rated speed of harvester (km/h)

% Input for a Drier

DrierModel=input( 'Enter drier model: (1614) for high capacity; (1214) for medium
capacity; (1210) for low capacity; (1) for batch drier: ');

% The constants values for Equation 4.28
C1=-1567.6;
C2=1447.1;
C3=-42.78;
C4=-1;
C5=0.032;
C6=0.00044;

for m=12:22
Mi(m) =(m/(100-m))*100;
Mo=(11.9/(100-11.9))*100;
end

for m=13:22
  DrierCost(12)=0;
if DrierModel==1614
   Td=70;
   x=4.12;
   DrierCost(m)=102500;
   md=15;
   Fd=22;
   DrierEfficiency=100;
elseif DrierModel==1214
   Td=70;
   x=3.05;
   DrierCost(m)=92500;
   md=15;
   Fd=22;
   DrierEfficiency=100;
elseif DrierModel==1210
   Td=70;
   x=1.83;
   DrierCost(m)=85000;
   md=15;
   Fd=22;
   DrierEfficiency=100;
elseif DrierModel==1
   Td=40;
   x=0.75;
   DrierCost(m)=15000;
   md=8;
   Fd=12;
```

```
   DrierEfficiency=75;
else
  display ('Sorry ! The drier model you have entered is not available. Try Again ')
  DrierModel=input( 'Enter drier model: (1614) for high capacity; (1214) for medium
capacity; (1210) for low capacity; (1) for batch drier: ');
end
end

for m=12:22
Dt(m)=x*(DrierEfficiency/100)*0.0056*(C1+C2*0.1*Td+C3*(0.1*Td)^2)*exp((C4+C5*
0.1*Td+C6*(0.1*Td)^2)*log(Mi(m)-Mo));
end

%  DrierCost  = capital cost of the drier ($A)
%  Dt         = drier throughput (t/h)
%  Fd         = fan power required for drier (kW)
%  Mi         =  initial grain moisture content varying from 16-35% (d.b.)
%  md         =  flow rate of air used for drying (kg/s)
%  Mo         =  final grain moisture content, 12% (w.b.)
%  Td         =  10% of the drying temperature, ranging from 40-90 deg C
%

% Input for an Aerated Storage

sc=input('Enter the number of storage (each storage has 145 tonne storage capacity
(t)): ');
Sc=sc;
NoS=sc;
Sc1=sc*145;

if Sc<=0
   StrgSize=0;
   D=0;
   else
   StrgSize=145;
   D=5.8;
end

for m=13:22
Ca(m)=Sc1*150;
Ca(12)=0;
end

%      The Capital Cost of the Combine Harvester,Grain Drier and Aerated Storage

Sv=0;
n=15;
In=0.09;
Ig=0.03;
I=(In-Ig)/(1+Ig);
for m=12:22
Ip(m)=Ca(m)+Ch+DrierCost(m);
FixedCost(m)=(Ip(m)-Sv)*(I*(1+I)^n/((1+I)^n-1))+Sv*I;
end

%   FixedCost   = The annual cost of asset purchase ($)
%   Sv          =   the salvage value and is equal to zero
%   n           =   the recovery period (yr)
%   I           = the real interest rate
%   In          =   the nominal or market interest rate
```

```
%   Ig              =   the general inflation rate
```

% * END *** %**

% * VARIABLE COSTS *** %**

```
%   Calculate Drying Temperature

for d=2:81
TDiff(d)=Td-TAmbient(d);
end
for d=2:81
ToTDiff=cumsum(TDiff);
TotTDiff=ToTDiff(80);
ATDiff=TotTDiff/80;
end

%   Spoilage Model Fraser & Muir(1981)

for m=12:22
      if 12<=m & m<19
          a=6.2347;
          b=-0.21175;
          c=-0.05267;
          SafeStorage(m)=24*(10^(a+b*m+c*Tc));
      elseif 19<=m & m<=22
          a=4.1286;
          b=-0.09972;
          c=-0.05762;
          SafeStorage(m)=24*(10^(a+b*m+c*Tc));
      end
   end

%   Input for Combine Harvester

cf=0.85;
fe=35;
for m=12:22
   if Cec*Counta(m)>Fs
      CropAreaharvested(m)=Fs;
   else
      CropAreaharvested(m)=Cec*Counta(m);
   end

Nh(m)=Fs/Cec;
   if Nh(m)<Counta(m)
     Nh(m)=Nh(m);
   else
      Nh(m)=Counta(m);
   end
Cf(m)=Nh(m)*cf*fe;
Dh=Cec*HarHours;
Hc=Cec*3;
Dhc=Hc*HarHours;
Hd= Fs/Dh;
end

%   Dh   = daily harvesting capacity (ha/d)
%   Cf    = Harvester fuel cost ($/yr)
%   cf    = the specific fuel cost for diesel ($/L)
```

```
%   fe    =  the harvester fuel consumption rate (L/h)
%   Hc   = hourly harvesting capacity (t/h)
%   Hd   = harvest duration (d)
%   Dhc = daily harvesting capacity (t/d)

%   Input for Drier

cdLPG=0.08;
cp=1.012;
Be=0.85;
ce=0.10;

for m=13:22
Nd(12)=0;
Ce(12)=0;
Nd(m)=Y*CropAreaharvested(m)/Dt(m);
Ed(m)=(cp*Nd(m)*ATDiff*md)/Be;
Ce(m)=((Fd*Nd(m)*ce)+(Ed(m)*cdLPG));
Drieroutputperday(m)=Dt(m)*24;
end

%   Ed           =    the energy required for drying (kWh/yr)
%   cp           =    specific heat of air (kJ/kg.deg C)
%   Nd           =    the length of drying process (h)
%   Td           =    drying temperature (deg C)
%   Fd           =    the fan power for drying (kW)
%   TAmbient   =    ambient air temperature (deg C)
%   md           =    the flow rate of air used for drying (kg/s)
%   ce           =   the specific cost of electricity (A$/kWh)
%   Be           =    the effeciency of diesel fuel in converting to the heat
%   cdLPG      =    $A/kWh for LPG

%   Input for an Aerated Storage

Aa=3.14*D^2/4;
Q=0.002;
Ds=300;
MaxHigh=StrgSize*1000/(Aa*GrainDensity);
for m=12:22
    GrainHigh(m)=(Hc*HarHours-Dt(m)*24)*1000/(Aa*GrainDensity);
         if GrainHigh(m)>MaxHigh
        GrainHigh(m)=MaxHigh;
    elseif GrainHigh(m)<0
        GrainHigh(m)=0;
    else
        GrainHigh(m)=GrainHigh(m);
    end
  StoreMaterial1(m)=0.001*(Aa*GrainHigh(m)*GrainDensity);
       if StoreMaterial1(m)<=0
         StoreMaterial(m)=0;
       else
           StoreMaterial(m)=0.001*(Aa*MaxHigh*GrainDensity);
       end

   V(m)=(Q*StoreMaterial(m))/Aa;
   V1(m)=Q*StoreMaterial(m);
       if V(m)<=0
           PD(m)=0;
       else
       PD(m)=(2.7e4*MaxHigh*V(m)^2)/(log(1+8.77*V(m)));
```

```
     end
   Fa(m)=(2*(PD(m)+Ds)*V1(m))/1000;
end

for m=13:22
    if StoreMaterial(m)<=0
Na(m)=0;
    else
 Na(m)=Nd(m);
    end
end

for m=12:22
    if Sc>0
        MaxHigh=MaxHigh;
        PD(m)=PD(m);
        Fa(m)=Fa(m);
        Na(m)=Na(m);
    else
        MaxHigh=0;
        PD(m)=0;
        Fa(m)=0;
        Na(m)=0;
    end

end
for m=13:22
ElecCostAeration(m)=NoS*Fa(m)*ce*Na(m);
ElecCostAeration(12)=0;
end

%  Aa                    = Aeration area
%  ElecCostAeration  = the annual electricity cost used in Aeration (kWh/yr)
%   Fa                   =  the fan power for Aeration (kW)
%   ce                   =   the specific cost of electricity (A$/kWh)
%   D                    = Diameter of Aearation Bin (m)
%   Ds                   = a constant of the duct system resistance
%   Na                   = the length of aeration process (h)
%   PD                   = Air Pressure Drop Due to Grain Resistance(Pa)
%   Q                    =  Air Flow rate (m^3/t.s)
%   V                    =  Air Velocity (m/s)

%  Repairing Costs

f1harvester = 0.08;
f2harvester = 2.1;
f1drier = 0.12;
f2drier = 1.8;

for m=12:22
Cxharvester(m)=Ch*f1harvester*(0.001*Nh(m)*SpeedIndex)^f2harvester;
end
for m=13:22
Cxdrier(m)=DrierCost(m)*f1drier*(0.001*Nd(m)*SpeedIndex)^f2drier;
Cxdrier(12)=0;
end

%   Cx(harvester)       = Maintenance and repair costs for the combine harvester
%   Cx(drier)           = Maintenance and repair costs for the drier
%   f1harvester         = repair coefficient for the harvester
```

```
%   f2harvester          = maintenance coefficient for the harvester
%   f1drier              = repair coefficient for the drier
%   f2drier              = maintenance coefficient for the drier

%   Labour Costs

cl=15;
for m=12:22
Cl(m)=(Nh(m)+Nd(m))*cl;
end

%  Cl        =  the annual labour cost ($/yr)
%  Nh        = the hours labour is required in harvesting processes
%  cl        = the specific cost of labour

for m=12:22
VariableCost(m)=Ce(m)+ElecCostAeration(m)+Cl(m)+Cf(m)+Cxharvester(m)+Cxdri
er(m);
end
```

% ***END*%**

% * YIELD LOSSES *** %**

```
%   Shedding Losses due to natural shedding

for m=12:22
if Dm(m)<10
Lsd(m)=0.00045*Dm(m)*Y;
else
Lsd(m)=0.0045*Dm(m)*Y;
end
LsdC(m)=Lsd(m)*CropPrice;

% Header Losses due to crop-machinery interaction

Lh(m)= 0.0025*Dm(m);
LhC(m)=Lh(m)*CropPrice;

% Threshing Losses due to crop-machinery interaction

Lt(m)=0.02*Y*((m/12)*(YieldIndex)*(SpeedIndex)/(1.2))^2;
LtC(m)=Lt(m)*CropPrice;

% Losses due to limited available harvesting hours (Unharvested Grain losses)
% For grain that downgraded from APH to ASW category after 60 days

   if Cec*Count(m)>Fs
      Lu60(m)=0;
   else
      Lu60(m)=(Fs-Cec*Count(m))*3/Fs;
   end

% For grain that downgraded from APH to FQ category after 80 days

if Cec*Counta(m)>Fs
      Lu80(m)=0;
   else
      Lu80(m)=(Fs-Cec*Counta(m))*3/Fs;
end
```

```
    Lu60C(m)=(Lu60(m)-Lu80(m))*40;
    Lu80C(m)=Lu80(m)*180;
    LuC(m)=Lu80C(m)+Lu60C(m);
end
```

% * END *** %**

% * QUALITY LOSSES DUE TO RAINFALL AND MATURITY STAGE ***%**

```
for i=2:81
    Tot(2)=RainFall(2);
    Tot(1)=0;
    Tot(i)=RainFall(i)+Tot(i-1);
end

%   For the first day

for m=12:22
if Dm(m)<0
   day(m)=0;
else
day(m)=Dm(m);
end

for d=1
realday(1)=day(m);
delay(1,m)=Delays(realday(1));
days(1,m)=realday(1)+delay(1,m);
if delay(1)<=0
rain(1)=Tot(realday(1));
else rain(1)=Tot(days(1,m));
end
if realday(1)>=30 & rain(1)<=30
    dls(1,m)=0;
elseif realday(1)>=30 & rain(1)<50
    dls(1,m)=(CropPrice-165)*3;
elseif realday(1)>=30 & rain(1)>=50
       dls(1,m)=(CropPrice-140)*3;
elseif realday(1)<7 & rain(1)<70
    dls(1,m)=0;
elseif realday(1)<7 & rain(1)>=70
    dls(1,m)=(CropPrice-165)*3;
elseif realday(1)<30 & rain(1)<40
    dls(1,m)=0;
elseif realday(1)<30 & rain(1)<70
    dls(1,m)=(CropPrice-165)*3;
elseif realday(1)<30 & rain(1)>=70
    dls(1,m)=(CropPrice-140)*3;
end
end

% For the second day and afterward

for d=2:30
rld(d)=days(d-1,m)+1;
delay(d,m)=Delays(rld(d));
days(d,m)=rld(d)+delay(d,m);
if delay(d)<=0
rain(d)=Tot(rld(d));
else rain(d)=Tot(days(d,m));
```

```
end
Fdelay(d,m)=24*delay(d,m);

if rld(d)>=30 & rain(d)<=30
   dls(d,m)=0;
elseif rld(d)>=30 & rain(d)<50
   dls(d,m)=(CropPrice-165)*3;
elseif rld(d)>=30 & rain(d)>=50
      dls(d,m)=(CropPrice-140)*3;
elseif rld(d)<7 & rain(d)<70
   dls(d,m)=0;
elseif rld(d)<7 & rain(d)>=70
   dls(d,m)=(CropPrice-165)*3;
elseif rld(d)<30 & rain(d)<40
   dls(d,m)=0;
elseif rld(d)<30 & rain(d)<70
   dls(d,m)=(CropPrice-165)*3;
elseif rld(d)<30 & rain(d)>=70
   dls(d,m)=(CropPrice-140)*3;
end
end

TQL(1,m)=dls(1,m);
for d=2:30
TQL(d,m)=(dls(d,m)+TQL(d-1,m));
TQD(1,m)=dls(1,m);
TQD(d,m)=TQL(d,m)/d;
end
for d=2:30
Hd1=round(Hd);
QualityLosses1(m)=TQD(Hd1,m);
end
end
```

% * END *** %**

%* QUALITY LOSSES DUE TO SPOILAGE IN STORAGE ***%**

```
for m=12:22
Tambient=TMeanAmbient;
Tmean=7;
M(m)=(100*m)/(100-m);
SafeTime(m)=(3792300000000*M(m)^(-6.658)*(Tambient+Tmean)^(-2.039))*24;
hourofprocess(m)=Hc/Dt(m);
Totprocess(m)=hourofprocess(m)*HarHours;
end

% Grain Losses Based on Hourly Operation

% For day 1

for m=12:22
for h=1:11
for d=1
waiting(1,h,m)=(h-1)*(hourofprocess(m)-1);
if waiting(1,h,m)>SafeTime(m)
      lose(1,h,m)=Hc;
     else
      lose(1,h,m)=0;
   end
```

```
        if waiting(1,h,m)>SafeStorage(m)
       lost(1,h,m)=Hc;
      else
       lost(1,h,m)=0;
        end
end
end
end
for m=12:22
for h=1:11
for d=1
Dailylose(1,m)=lose(1,1,m)+lose(1,2,m)+lose(1,3,m)+lose(1,4,m)+lose(1,5,m)+lose(
1,6,m)+lose(1,7,m)+lose(1,8,m)+lose(1,9,m)+lose(1,10,m)+lose(1,11,m);
Dailylost(1,m)=lost(1,1,m)+lost(1,2,m)+lost(1,3,m)+lost(1,4,m)+lost(1,5,m)+lost(1,6,
m)+lost(1,7,m)+lost(1,8,m)+lost(1,9,m)+lost(1,10,m)+lost(1,11,m);
end
end
end

% For day 2

for m=12:22
for h=1:11
for d=2:30
Balance(d,m)=waiting(d-1,11,m)-13;
if Balance(d,m)<=0
      AcBlc(d,m)=0;
  else
      AcBlc(d,m)=Balance(d,m);
  end
  Fdelay(d,m)=24*delay(d,m);
  if delay(d,m)>=1
      FnlBlc(d,m)=AcBlc(d,m)-Fdelay(d,m);
  else
      FnlBlc(d,m)=AcBlc(d,m);
  end
 if FnlBlc(d,m)<=0
     FnlBlc(d,m)=0;
else FnlBlc(d,m)=FnlBlc(d,m);
 end
 waiting(d,h,m)=(h-1)*(hourofprocess(m)-1)+FnlBlc(d,m);
end
end
end

% For day 3

for m=12:22
for h=1:11
for d=3:30
Balance(d,m)=waiting(d-1,11,m)-13;
if Balance(d,m)<=0
      AcBlc(d,m)=0;
  else
      AcBlc(d,m)=Balance(d,m);
  end
  Fdelay(d,m)=24*delay(d,m);
  if delay(d,m)>=1
      FnlBlc(d,m)=AcBlc(d,m)-Fdelay(d,m);
  else
```

```
      FnlBlc(d,m)=AcBlc(d,m);
   end
 if FnlBlc(d,m)<=0
     FnlBlc(d,m)=0;
else FnlBlc(d,m)=FnlBlc(d,m);
 end
 waiting(d,h,m)=(h-1)*(hourofprocess(m)-1)+FnlBlc(d,m);
end
end
end

for m=12:22
for h=1:11
for d=2:30
if waiting(d,h,m)>SafeTime(m)
       lose(d,h,m)=Hc;
      else
       lose(d,h,m)=0;
    end
        if waiting(d,h,m)>SafeStorage(m)
       lost(d,h,m)=Hc;
      else
       lost(d,h,m)=0;
        end
end
end
end
for m=12:22
for h=1:11
for d=2:30
Dailylose(d,m)=lose(d,1,m)+lose(d,2,m)+lose(d,3,m)+lose(d,4,m)+lose(d,5,m)+lose(
d,6,m)+lose(d,7,m)+lose(d,8,m)+lose(d,9,m)+lose(d,10,m)+lose(d,11,m);
Dailylost(d,m)=lost(d,1,m)+lost(d,2,m)+lost(d,3,m)+lost(d,4,m)+lost(d,5,m)+lost(d,6,
m)+lost(d,7,m)+lost(d,8,m)+lost(d,9,m)+lost(d,10,m)+lost(d,11,m);
end
end
end

for m=12:22
for d=2:30
Tqla(1,m)=Dailylose(1,m);
Tqla(d,m)=Dailylose(d,m)+Tqla(d-1,m);
Tqlb(1,m)=Dailylost(1,m);
Tqlb(d,m)=Dailylost(d,m)+Tqlb(d-1,m);
end
end
for m=12:22
for d=2:13
Totallose(m)=Tqla(Hd1,m);
Totallost(m)=Tqlb(Hd1,m);
end
end

% Losses for harvested grain without aerated storage (quality downgrade due to
spoilage)

for m=12:22
    DiffLoss(m)=Totallose(m)-Totallost(m);
    if DiffLoss(m)<=Sc1
        AcDiffLoss(m)=DiffLoss(m);
```

```
    else
        AcDiffLoss(m)=Sc1;
    end
    AcTotallose(m)=Totallose(m)-AcDiffLoss(m);

%   Losses for harvested grain in aerated storage

if Sc1<=0
QL1(m)=(Totallose(m))/Fs*40;
SpoilageLosses(m)=QL1(m);
else
QL2(m)=(AcTotallose(m))/Fs*40;
SpoilageLosses(m)=QL2(m);
end
end
```

% * END *** %**

APPENDIX B

Daily Weather Data in Goondiwindi during the Harvest Period from 1991 to 2005

Daily Weather Data during the Harvest Period in Goondiwindi from 1991 to 2005

Description of the daily weather data table (Source: ABM)

Column no.	Description
1	Year
2	Month
3	Date
4	Air temperature observation at 09 hours (local time), °C
5	Wet bulb temperature observation at 09 hours (local time), °C
6	Air temperature observation at 15 hours (local time), °C
7	Wet bulb temperature observation at 15 hours (local time), °C
8	Maximum temperature in 24 hours after 9 am (local time), °C
9	Minimum temperature in 24 hours before 9 am (local time), °C
10	Precipitation in the 24 hours before 9 am (local time), mm
11	Delays due to rainfall (calculated using function shown in Table 5.1)

1	2	3	4	5	6	7	8	9	10	11
1991	9	30	22	13	27	13.5	28	8	0	0
1991	10	1	20	13.5	30	15	31.2	8	0	0
1991	10	2	22	15.7	31.5	17	32.5	10.7	0	0
1991	10	3	25.5	14	32.7	16.5	34	15.5	0	0
1991	10	4	22	16.9	31	17.5	31.5	14.5	0	0
1991	10	5	20.7	15.5	27.5	17.5	29	14.4	0	0
1991	10	6	22	15.4	29.5	16.5	30.5	14.2	0	0
1991	10	7	23.5	16	19	16	30	14.5	0	0
1991	10	8	20.5	17	28	18.5	29.5	13.5	2.2	1
1991	10	9	21	12	25.5	14.6	26.5	9	0	0
1991	10	10	21.5	16	27	16	28.3	7.5	0	0
1991	10	11	21.5	16.5	29	15.5	29.5	11.9	0	0
1991	10	12	21	16.1	28.5	17	29.9	13.6	0	0
1991	10	13	25.1	15.5	31.6	16.6	32.3	10.1	0	0
1991	10	14	23.7	17	31	18	32.5	15	0	0

1991	10	15	23.5	18	33	18.5	33.5	16.5	0	0
1991	10	16	28	17	36.5	18	37	17.5	0	0
1991	10	17	20.5	12	26.6	13.5	27.9	14	0	0
1991	10	18	21	14	26.5	16.5	28.5	15	0	0
1991	10	19	20.5	14	26.6	16	28.9	12	0	0
1991	10	20	22	15.7	30.3	17.6	31	14.3	0	0
1991	10	21	24	18	32.5	19	34.5	16	0	0
1991	10	22	26.5	18	34	20	34.5	20.5	0.2	0
1991	10	23	25	18.5	21.2	19	31.6	16.5	0	0
1991	10	24	18.5	16.5	24.5	19.5	29.5	15.5	16.4	2
1991	10	25	22	18.5	25	20	27.4	15.5	0	1
1991	10	26	22.6	16.9	28	15.2	28.7	12.2	0	0
1991	10	27	19.8	12	25.5	13	26.6	8.2	0	0
1991	10	28	18.5	13	26	14.5	27.5	11.2	0	0
1991	10	29	17	14	27.5	18	28.5	13.5	0	0
1991	10	30	16.5	15.5	19.5	17.5	25	16	1.2	3
1991	10	31	19	16.5	29.5	20.5	31	15	3	2
1991	11	1	21	19	27	21.5	29.6	15	18	1
1991	11	2	22.1	19	29.3	20.6	31.4	17	0	0
1991	11	3	22.9	18.5	31.7	21.6	32	18	0	0
1991	11	4	33	19	31.5	21	31.5	19.5	0	0
1991	11	5	21.5	15.5	30	16	32.2	15	0	0
1991	11	6	21	13.5	31.5	16	34	11	0	0
1991	11	7	27	20.5	36.5	19.5	38	20	0	0
1991	11	8	22	13.5	28.5	15.5	30.5	18.5	0	0
1991	11	9	21.5	11.5	27.5	13.5	29	10	0	0
1991	11	10	20.5	11	29	14.5	29.5	11	0	0
1991	11	11	23	14.5	29	16.5	31.5	18	0	0
1991	11	12	24.5	19.5	31	18	33	19.5	0	0
1991	11	13	22.5	14	29	17	31	17	0	0
1991	11	14	21	17	30	18	32.5	16	0	0
1991	11	15	21.5	16.5	30	19.5	31	16.5	0	0
1991	11	16	21.3	17.2	30	18	25.4	19.6	0	0
1991	11	17	18.8	18	29.7	17	30.5	15	8	1
1991	11	18	21	18	30	19.5	31.5	16	0	0
1991	11	19	22	18	31.5	20.5	33	18	0	0
1991	11	20	24	17	33.5	21	35.5	18.5	0	0
1991	11	21	20	19	26.5	21	29	19	12.4	2
1991	11	22	20.9	16.6	27.5	18	29.6	14.9	0	1
1991	11	23	19.5	14.5	25	15	30	13.4	0	0
1991	11	24	21.8	16.4	29.4	18	31	25.4	0	0
1991	11	25	23	17	30	18	31.7	18.5	0	0
1991	11	26	23.6	16.8	30.7	19.5	32.7	18.5	0	0
1991	11	27	25.7	18.4	34	21	35.6	19.3	0	0
1991	11	28	23.4	20.2	31.3	20.6	33.3	19.5	7.2	1
1991	11	29	24.2	19	32.5	20.5	34.5	19.2	0	0
1991	11	30	22.9	20.1	21.5	18.5	31.5	16.5	5.7	1
1991	12	1	22	18	30.5	17.9	31.5	16	0	0
1991	12	2	20.5	16.5	27.5	18.5	30.3	16	0	0
1991	12	3	20.4	16	28.5	18	30.6	17	0	0
1991	12	4	25.4	19.8	37.5	18	37.5	18.4	0	0
1991	12	5	25	14.5	30	15	31.5	14	0	0
1991	12	6	22.5	17	31	17.5	32.5	16.5	0	0

1991	12	7	21.8	17.6	30.1	21	30.6	18.8	0	0
1991	12	8	21.2	17.4	29.7	18.6	31	14.7	11.6	2
1991	12	9	23	18	30.2	18.1	31.5	16	0	1
1991	12	10	32	17.5	30.5	18.5	31.5	18.5	0	0
1991	12	11	19	18	21	20	23	18	13.6	6
1991	12	12	20.5	19	22	18.5	23.5	18	28.2	5
1991	12	13	18.5	17.5	27	19.5	27.9	16	64	4
1991	12	14	24.2	18.9	28.1	20.2	29.7	17.5	0	3
1991	12	15	23.7	20	30	20.6	31.2	17.1	0	2
1991	12	16	25.2	17.5	28.2	17	29.5	17.5	0	1
1991	12	17	21.5	16	26.6	15.7	28	12.5	0	0
1991	12	18	23.2	16.5	31.5	20	32.6	14.5	0	0
1991	12	19	25.5	20	32	22	33.5	17	0	0

1	2	3	4	5	6	7	8	9	10	11
1992	9	30	12.5	7	20	10	20.5	3.5	0	0
1992	10	1	15	10.6	23.5	11.9	24	4	0	0
1992	10	2	18	11.5	22.9	11.5	27	5	0	0
1992	10	3	21.9	15.8	28.7	16.3	29.3	15	0	0
1992	10	4	17.8	16	21	17.8	22	16	0.6	1
1992	10	5	20	14.5	25	15.5	25.5	12	3.4	0
1992	10	6	18	13	27	15.5	27.5	5.5	0	0
1992	10	7	20.5	16	28	14.5	27.5	9.5	0	0
1992	10	8	21.2	16.2	28.5	18.5	29.5	14.5	0	0
1992	10	9	21	15.5	19.5	18	28.5	14.5	0	0
1992	10	10	14.5	13	24	14.5	24.5	6	1.6	0
1992	10	11	19	12.2	25.3	14.4	26	5.5	0	0
1992	10	12	20.5	14	27	15	27.9	7.5	0	0
1992	10	13	19.5	14	26.5	15.5	27.2	11	0	0
1992	10	14	19.5	12.9	27	15.5	27.5	10.5	0	0
1992	10	15	21.5	16	28.5	16.5	29.5	12	0	0
1992	10	16	21.5	14	31	18	32.6	15	0	0
1992	10	17	27.2	16.7	32.8	17.8	35	14.6	0	0
1992	10	18	18.6	18	18.7	17.5	21.1	16.9	3.4	2
1992	10	19	16	11.5	21	11.5	22	7.5	8.4	1
1992	10	20	18	12.5	24.5	13	25	7.5	0	0
1992	10	21	14.5	10.2	22	11	23	5	0	0
1992	10	22	15.1	8.1	24.4	11.8	25	5.9	0	0
1992	10	23	16.5	8.5	25.4	12.5	25.8	8.5	0	0
1992	10	24	19	12.6	26	14.8	26.6	10.2	0	0
1992	10	25	22.4	25.5	27.9	16	29	11.6	0	0
1992	10	26	24	15.8	31	15	32	12.5	0	0
1992	10	27	22.4	17	31.5	21.3	32.2	17.2	0	0
1992	10	28	22	16.9	29.8	19.3	31.5	17	0	0
1992	10	29	20.2	16	29	18.6	30.5	13.9	1.8	0
1992	10	30	22.5	16.8	27.5	17.5	28.6	17.2	0	0
1992	10	31	23.5	17.5	28.5	18.5	29.7	17	0	0
1992	11	1	23.2	17	19	18.6	26	17	0	0
1992	11	2	22.9	17	30	19.3	31.5	15.6	0.8	2
1992	11	3	20.8	16.8	30	20.3	32.4	17.5	4.2	1
1992	11	4	23	19.3	31	19.4	32.4	17.3	5.4	0

1992	11	5	20.2	13.1	17	11.2	26	15.4	0	0
1992	11	6	15	12	23	15.4	24.4	7.8	2.8	1
1992	11	7	19.9	14	26	13.8	27.7	8.2	0	0
1992	11	8	21.4	14.8	27.6	17.9	29.5	13.2	0	0
1992	11	9	24	18	33.8	21.3	35	16	0	0
1992	11	10	18.8	12	25.2	14	25.8	9.8	0.4	0
1992	11	11	20.5	11.8	16	12.3	23	9	0	0
1992	11	12	16.6	10.9	23	13.5	24.3	8.5	3	1
1992	11	13	19.4	14	26.5	15.8	28	9	0	0
1992	11	14	23	17	30.4	18.6	30.8	14	0	0
1992	11	15	24.1	18	28.5	18.8	29.9	17.5	0	0
1992	11	16	21.3	18.3	30.4	19.6	31	17.2	16.2	2
1992	11	17	25	19	31	20.4	31.5	18.5	0	1
1992	11	18	23	20	30.5	20.6	31.9	18.5	1.6	1
1992	11	19	26	20	33	20.4	34	17.5	1.6	0
1992	11	20	25.5	22.2	36	23	36.6	19	4.4	0
1992	11	21	29.5	22	27	21	34	21	0	0
1992	11	22	25	13.1	29.5	15.5	30.5	17	0	0
1992	11	23	27	15.5	31.5	16.2	33	11.5	0	0
1992	11	24	28.2	17.2	33.5	16.5	35.1	14.5	0	0
1992	11	25	31	21	19	17	35.2	20.2	0	0
1992	11	26	23.5	14.3	28	16	28.9	15.1	8.6	2
1992	11	27	24.5	14	30.5	15.5	31.2	15	0	1
1992	11	28	26.8	14.6	32	15.8	34.5	15	0	0
1992	11	29	29	15.6	31.1	15.6	32.2	15	0	0
1992	11	30	22.9	13	26	13	26.9	15	0	0
1992	12	1	19.5	12	27	15	28	10.5	0	0
1992	12	2	23.3	14.5	30	14	32	12.7	0	0
1992	12	3	26.5	19	34.5	19.5	35.5	18.5	0	0
1992	12	4	20.5	19.5	22.5	20.5	25	19	20	4
1992	12	5	23.5	21.3	26.6	22	29.5	17.4	21	3
1992	12	6	26.2	18.8	31.2	17.8	32.2	17.2	0	2
1992	12	7	28.5	18.5	32.5	17.8	33	16	0	1
1992	12	8	26	19	31.4	18	32.5	17	0	0
1992	12	9	23.5	19	28.9	19	30.5	17	0	0
1992	12	10	23.5	17.5	29.5	17.5	31	15.5	0	0
1992	12	11	24	18.8	31.5	18	32.5	17	0	0
1992	12	12	25.1	19.4	34.3	19.3	35.1	18	0	0
1992	12	13	22.2	20.5	32	20.1	30.2	19.9	0	0
1992	12	14	23.1	21	32.6	23	32.5	18.5	10.8	2
1992	12	15	26.5	21	32.6	21.6	33	20	0	1
1992	12	16	24	19	29	19.5	29.9	20	0	0
1992	12	17	22.2	18.5	27.5	19.5	28.5	19.9	4.4	1
1992	12	18	28.5	22.2	28	19	29.6	19.5	0	0
1992	12	19	22.6	17	24.8	17.3	25.8	19.3	0	0

1	2	3	4	5	6	7	8	9	10	11
1993	9	30	20.5	14.5	26	14	27.7	9.9	0	0
1993	10	1	19.5	11.2	26.5	16	27	12.5	0	0
1993	10	2	21	15.6	26.5	17.1	28	15.1	0	0
1993	10	3	22.7	16.7	30.4	18.4	31	16	0	0

1993	10	4	16	15.5	19	16	21	15.5	4.4	2
1993	10	5	13	12	18.9	14	20	10.5	10.4	1
1993	10	6	16.5	12	24	13.7	24	6	0.2	0
1993	10	7	19	14.5	27	16	28.5	8.5	0	0
1993	10	8	22.5	16.2	31	16.5	31	11.5	0	0
1993	10	9	24.8	16.9	34.3	17.2	34.9	14.2	0	0
1993	10	10	23.1	15.6	28	16.5	29	17.5	0	0
1993	10	11	15.5	9	21	11	21.5	8.5	0	0
1993	10	12	17	11	23	13	24	7	0	0
1993	10	13	18.5	13	24.2	14	25.5	9.5	0	0
1993	10	14	18	13.5	24	14	24	14	0	0
1993	10	15	18	16	24	18	25	14.2	6.8	1
1993	10	16	21.3	18	20.5	20	26.7	13.9	0	0
1993	10	17	22.6	20	28.6	22.1	30.5	18	0	0
1993	10	18	27	19.5	31	21.5	34	18.5	5.2	1
1993	10	19	18.2	11.7	24	12.3	25	12.2	1.6	0
1993	10	20	18.5	12.5	19.5	13.5	21.5	9	0	0
1993	10	21	18	13.8	24.5	14.5	26	8.5	0	0
1993	10	22	19	15.5	24.4	15	25.2	13.5	10.6	2
1993	10	23	20.4	15.6	27.3	16.9	27.7	14.1	0	1
1993	10	24	22.5	16	28.6	18.9	30.2	15.5	0	0
1993	10	25	23.5	17.9	30.5	20	32	17	8.2	2
1993	10	26	21.8	13.5	25.9	14	27	15	0	1
1993	10	27	21	14.5	27.9	15.5	28.5	8	0	0
1993	10	28	22.5	14.1	31.8	16.7	32	15	0	0
1993	10	29	20.5	16.7	28	15.4	28.3	18.5	0	0
1993	10	30	22.4	15.4	30.6	15.5	31.2	9.8	0	0
1993	10	31	16.6	14.5	22.7	16.4	24	14.4	13.2	2
1993	11	1	18.8	12.9	25.6	14.3	25.6	9.3	0	1
1993	11	2	20.5	16	27.8	18.2	29	13.8	0	0
1993	11	3	19.5	13.1	25.5	13.4	27	12.5	0	0
1993	11	4	22.6	13.3	27.5	15	29.5	9.2	0	0
1993	11	5	19.6	10.9	25.2	13.3	26	12	0	0
1993	11	6	21.5	13.5	28.3	15.7	29.4	10.6	0	0
1993	11	7	25.5	14.2	31	16.5	31.9	11.3	0	0
1993	11	8	24.5	16.8	32.5	17	33.5	14.5	0	0
1993	11	9	28.6	19.9	34.5	16.9	35	19	0	0
1993	11	10	24.4	18.5	31.1	19.2	32.5	19.8	0.4	0
1993	11	11	22.6	17	28	19.6	29	16.8	0	0
1993	11	12	20.1	16.6	28.8	19.3	30.8	18	0	0
1993	11	13	22	17.6	24.4	19.8	26.9	19.5	0	0
1993	11	14	24.9	20.6	30.7	21	31.6	18.5	5.4	1
1993	11	15	25.5	18.6	30.8	23.1	32.4	16.5	0	0
1993	11	16	24.2	18.3	31	20.5	33.6	19	0	0
1993	11	17	32.4	18.3	30.3	20.5	32.5	19.2	0	0
1993	11	18	23.1	18.6	31	21.5	34	20.6	0	0
1993	11	19	29.3	21.7	26.5	22.3	38	20.4	0	0
1993	11	20	34.9	23.4	37.5	23.2	38	22	0	0
1993	11	21	24	21.6	31.8	19.8	32.5	19.6	8.2	2
1993	11	22	25	20.4	33.8	19.8	33.8	19.5	0	1
1993	11	23	25.6	14.9	29.3	15.6	30	17.1	0	0
1993	11	24	23.6	19.8	29.5	18.5	30.6	16.8	0	0
1993	11	25	22	16.5	31	18	31.5	16	0.6	0

1993	11	26	22	15	30	17	30.8	15.2	0	0
1993	11	27	23.4	16.8	31.5	18.5	33.3	15.2	0	0
1993	11	28	29.4	17.9	38.4	19.4	39.1	15.6	0	0
1993	11	29	29.5	20.5	38	20	39.5	23	0	0
1993	11	30	30.5	20	37.5	17.6	38.9	23	0	0
1993	12	1	29.5	21	36	20.5	37.2	22.5	0	0
1993	12	2	29.2	21	37.5	21	38.9	22.5	0	0
1993	12	3	28.1	19.5	35.2	21.7	36.2	23	0	0
1993	12	4	26.2	18.5	36.8	20.7	37	22	0	0
1993	12	5	27.5	20.9	33	22.5	34	21	1	0
1993	12	6	24.8	19	28	20.6	29.9	19	0	0
1993	12	7	23.8	20.7	28.2	21.5	29.5	20	2.4	4
1993	12	8	18.1	17.5	17.5	16.5	22.5	18	33.6	3
1993	12	9	22.5	16.5	26	17.5	26.8	16	19.4	2
1993	12	10	23	16.5	26	18.5	27.5	16.2	0	1
1993	12	11	21.6	15.4	27	17.1	29	16.1	0	0
1993	12	12	23.9	17.4	29.5	18.2	30.4	16.4	0	0
1993	12	13	24	17.2	29.5	18.5	31.2	17.5	0	0
1993	12	14	25.5	19	32	20.5	33	19.9	0	0
1993	12	15	28.5	20.5	35.2	21.2	36	20.9	0	0
1993	12	16	23.9	22	30	17.5	31	21.2	11	2
1993	12	17	24.5	17.5	30.5	20.5	31.4	17.5	0	1
1993	12	18	23.3	17.4	30	19	30.7	18	0	0
1993	12	19	22.1	16	30	18.4	31	17	0	0

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1994	9	30	20	9.4	25	12.4	26	13.5	0	0
1994	10	1	22	11.5	30.4	14.3	31.1	6.1	0	0
1994	10	2	26.6	17.9	29.7	18.8	30.9	19.5	0	0
1994	10	3	21	12.5	26.5	13.1	27.1	14	3.4	1
1994	10	4	22.5	11.4	33	14.9	33.6	6.5	0	0
1994	10	5	21.5	12	27	13.9	27.2	11.5	0	0
1994	10	6	22.6	12.9	30	14.9	31.5	8	0	0
1994	10	7	19.5	17	18.2	12.1	20.2	18.5	0.6	0
1994	10	8	16.6	8.5	23.1	10.2	24	5.9	1	0
1994	10	9	15.2	8.4	22.2	11	23.9	4.4	0	0
1994	10	10	18.7	12.4	26	13.2	26.7	7.5	0	0
1994	10	11	22	14	28.2	13.8	29	9	0	0
1994	10	12	21.7	14.4	29	15.5	29.8	9.8	0	0
1994	10	13	21	15.5	27.2	16.2	29	13.2	0	0
1994	10	14	21	14	26.5	15.5	28.2	10.5	0.2	0
1994	10	15	19.4	13.1	27.5	15	28.5	11.2	0	0
1994	10	16	21.5	16	28.9	16.5	29.5	14.2	0	0
1994	10	17	21	15	28.5	16.5	29.8	15	0	0
1994	10	18	24.5	16.2	35	16.4	35.3	13.8	0	0
1994	10	19	26.5	18	34.5	17.1	35.5	17.5	0	0
1994	10	20	28	18.4	23	12.5	34	20	0	0
1994	10	21	19	12.4	26.7	14.3	28	12	0	0
1994	10	22	20.4	13.5	27.3	15.3	29.3	12.8	0	0
1994	10	23	19.6	13.6	15.4	14.7	20.2	15.6	0	0
1994	10	24	19.5	15	25.2	16.1	25.6	14.3	2.8	1

1994	10	25	20	14	27.2	14.9	28.5	12	0	0
1994	10	26	20.4	14.5	29	15	29.5	13.5	0	0
1994	10	27	22.5	16	30.5	17	32	15	0	0
1994	10	28	24	16.5	28.5	17.7	30.5	17.5	0	0
1994	10	29	16.5	16.2	21	17	22.1	16	17.6	2
1994	10	30	20	12.3	25.5	14	26.1	9.5	1.6	1
1994	10	31	21.6	15.7	28	15.6	28.2	11	0	0
1994	11	1	24	16.8	28.8	17.8	32	16.5	0	0
1994	11	2	20.7	12	25.6	13.1	26.5	15.5	6.4	1
1994	11	3	20.3	13.1	27	14.1	27.5	9.5	0	0
1994	11	4	25.5	14.9	30	15.4	32	14	0	0
1994	11	5	21.4	14.2	26	14.9	27	12.3	0	0
1994	11	6	23.4	14.7	31.5	16.9	32	13	0	0
1994	11	7	26.5	15.9	31.8	17.6	32.5	16.3	0	0
1994	11	8	22.4	13.5	28.2	14.8	29	15	0	0
1994	11	9	25.4	13.4	32.5	16.1	33	11.5	0	0
1994	11	10	24.8	17.8	33	17.4	34.5	17.5	0	0
1994	11	11	25.5	19.6	33.5	21.5	35	19	0	0
1994	11	12	28.5	20.5	35.5	19.6	36	20.9	0	0
1994	11	13	27.7	19.8	36.4	21.5	0	0	0	0
1994	11	14	28	17.9	35.7	19.3	36.1	24.3	0	0
1994	11	15	26.4	18.8	26.1	18	29.5	21.5	0.2	3
1994	11	16	20.6	16.9	17.3	16.9	21	19.3	0.6	2
1994	11	17	20	18	26.5	20.5	27.5	13.5	32.2	1
1994	11	18	25.5	21.2	31.8	21.1	32.8	19.2	0	0
1994	11	19	24.4	19.4	28	20.5	20.3	20.3	0	0
1994	11	20	23.2	20.3	29.3	23.6	30.5	18.5	16.4	3
1994	11	21	23	16.9	27	16.4	28	19.5	15	2
1994	11	22	21.5	14	28	14.4	28.5	14	0	1
1994	11	23	25	17.8	30.5	18	30.7	15.5	0	0
1994	11	24	24.5	18	31	18	31.5	17	0	0
1994	11	25	24.7	18.7	28.5	19.5	30.1	20	0	0
1994	11	26	24.8	18.2	31.8	21.3	32.8	20.9	0	0
1994	11	27	27.1	19.8	31.2	20.4	32	21.6	0	0
1994	11	28	25.5	19.5	32.5	19.8	33.2	19.8	0	0
1994	11	29	25.5	19	32	20.9	33.1	20	0	0
1994	11	30	24.5	20.5	31	20.4	31.5	19.7	3.8	3
1994	12	1	26	20.5	26	20	30.5	19	0.8	2
1994	12	2	18.5	16.5	22	16.5	22.5	16	33.4	1
1994	12	3	21.7	17.3	25.5	18.5	26	16.7	0	0
1994	12	4	20.8	15.4	27.7	17.8	28.8	15.5	0	0
1994	12	5	22	16.8	27	17	28.2	13.5	0	0
1994	12	6	23.5	17.5	28.5	18	29	14.5	0	0
1994	12	7	23.5	16	29	17.5	30	15.5	0	0
1994	12	8	24.5	17	31.5	19.5	31.5	17	0	0
1994	12	9	23.5	17.5	29	19.5	30.2	19.5	0	0
1994	12	10	21	16.5	26.7	19.3	27.2	18.9	0	0
1994	12	11	22.6	16.6	29.4	19.1	30.2	14.6	0	0
1994	12	12	25.5	18.7	32	20	33.5	18	0	0
1994	12	13	25.5	19	33.4	20.1	34	18.5	0	0
1994	12	14	26.5	19.5	33.5	21.6	35.2	20	0	0
1994	12	15	26	19.5	33	20	34	19	1.6	0
1994	12	16	26	19.5	34	20.2	35.2	21	0	0

1994	12	17	29.5	20.5	38	20.9	38	24	0	0
1994	12	18	31	20.4	38	21.9	38.5	22	0	0
1994	12	19	26	20	33	20	34	21.5	0	0

1	2	3	4	5	6	7	8	9	10	11
1995	9	30	20.5	10.5	28.7	18.1	29.4	13.5	0	0
1995	10	1	24	15.6	30.9	17.7	32.8	16.3	0	0
1995	10	2	22.5	15.5	22.7	17.2	29.8	17.5	0	0
1995	10	3	16.5	15.5	17.2	12.9	19	15.5	10.8	0
1995	10	4	14.5	11	20.5	12	21.1	8	0.2	0
1995	10	5	18	11.6	24.5	13.4	25.1	5	0	0
1995	10	6	18.2	14.4	25.2	16.9	27.9	14.8	0	0
1995	10	7	25.5	19.5	32.5	17.6	32.8	14	0	0
1995	10	8	18.1	15	16.2	14.9	23.1	16.2	1	0
1995	10	9	17.7	15.1	23	13.5	25	11	2.8	0
1995	10	10	17.5	12	25	15	25.9	8.8	0	0
1995	10	11	21	15	28	17	28.4	12	0	0
1995	10	12	22.5	16.3	30	17.3	30.9	15.6	0	0
1995	10	13	25.8	17.5	34	18.4	34.8	15	0	0
1995	10	14	20.5	12.5	24.7	13.1	25.5	14	0.2	0
1995	10	15	19.5	12	25.6	14	26.2	11.9	0	0
1995	10	16	19.7	12.7	23.8	13.6	25.5	11.5	0	0
1995	10	17	20	12.5	24.5	13.3	25	13.8	0	0
1995	10	18	21.5	15.8	29.5	16.5	30.5	11	0	0
1995	10	19	22.8	16.1	30.5	17.1	31.5	12	0	0
1995	10	20	22.2	16.4	30.2	17.3	32	14.2	0	0
1995	10	21	22.2	16.4	30.3	18.6	31.2	16.2	0	0
1995	10	22	22.6	17.9	28.7	20	30.5	17.8	0	0
1995	10	23	17	11.5	25.5	14.9	26	12	0.6	0
1995	10	24	21	14	27	15.5	28.8	9.5	0	0
1995	10	25	23.5	17	26.2	17.3	28.2	15.5	0	0
1995	10	26	19	18	22	18.5	24.2	15.5	21	3
1995	10	27	19.8	17.6	25.5	19	26.8	14	4	2
1995	10	28	23	18.5	29.5	17.4	30.5	16	0	1
1995	10	29	25.8	19.6	34.5	18.2	35	17.5	0	0
1995	10	30	26.5	15.2	31.5	16.7	32.1	15.6	0	0
1995	10	31	25	16	32.5	18.2	33	14	0	0
1995	11	1	23.2	17.4	31.2	20.3	32.2	17.2	0	0
1995	11	2	26.8	20.6	36	22.4	36.6	20	0	0
1995	11	3	30.5	22	36.8	21.5	37.6	22.5	0	0
1995	11	4	27	18.1	29.8	19.3	30.6	22.1	0	0
1995	11	5	20.7	17	24.4	18.5	27.2	18.9	0	0
1995	11	6	21.8	14.6	28.5	14.2	29	15.8	0.6	0
1995	11	7	25.5	12.9	30.5	14.9	31	11	0	0
1995	11	8	26.5	15.4	33.5	16.6	34.5	11.5	0	0
1995	11	9	31	17.5	38.5	20.2	39.7	14	0	0
1995	11	10	34.5	20.3	39.2	22	40.2	22.5	0	0
1995	11	11	23.9	17.1	28	16.7	28.4	21	0.8	0
1995	11	12	25.5	16	32.5	18.8	33.7	18.2	0.2	0
1995	11	13	24.5	17	31.5	19	31.8	17.5	0	0
1995	11	14	23.5	16	30	18	30.5	14.9	0	0

1995	11	15	21.8	19.1	22.5	20	23.1	20	0.2	0
1995	11	16	19.8	19.1	20.5	19.2	23.1	19	13.6	0
1995	11	17	22.5	20.5	21.8	19.4	28.5	18.8	7	0
1995	11	18	20	19.5	22.5	21.8	25	18	22.6	0
1995	11	19	25	22.5	26.8	23.9	30	18.5	12.4	0
1995	11	20	23	22	26	22.5	26.5	20	40.6	0
1995	11	21	22.5	18.5	26.5	21	27.5	19.5	5	0
1995	11	22	20	19	24.2	21.3	26.9	18	24.8	0
1995	11	23	21	18.5	24.9	16.5	26	16	2	0
1995	11	24	22.2	14.3	27.5	15.4	28	12	0	0
1995	11	25	25.5	17	31.5	18.6	32.1	13.5	0	0
1995	11	26	27.6	17.9	33	18.9	34.5	13.4	0	0
1995	11	27	30	20.5	36	22	36.5	22	0	0
1995	11	28	32	20	34.6	20.4	36.5	21.8	0	0
1995	11	29	27.5	18	33.5	18.1	34.5	21.9	0	0
1995	11	30	28.8	20.6	34	19.9	34.5	21	0	0
1995	12	1	23	21.7	19.2	18.8	24.6	21	0.4	2
1995	12	2	21.5	18.5	28.1	19.9	28.9	14	15.2	1
1995	12	3	23.5	18.4	28.7	18.8	29.7	16.6	0	0
1995	12	4	26.5	21.3	32.5	23.4	33.8	19	0	0
1995	12	5	29	23.4	34.3	30.5	34.4	25	0	0
1995	12	6	21.4	17.2	24.9	24.5	26	17	14.6	2
1995	12	7	23	15.9	28.5	15.9	29.5	11.5	0	1
1995	12	8	25	19.5	30.7	21.8	31.8	17.5	0	0
1995	12	9	25.1	19.4	30.7	22.5	32.8	19	0	0
1995	12	10	28.1	21.4	34.9	27.2	35.2	21.6	0	0
1995	12	11	25	22	24.9	22.8	25.5	20.5	7.8	1
1995	12	12	22	14	26.3	14.5	26.5	14.5	0.1	0
1995	12	13	20.8	16.2	27.4	17.2	27.5	10	0	0
1995	12	14	23.5	18.4	30	19	30.1	15.9	0	0
1995	12	15	24.6	18.9	31	19.4	32	20	0	0
1995	12	16	26.4	18.9	34	21.4	34.6	18.9	0	0
1995	12	17	27.4	20.6	36	22.4	36.5	21.9	0	0
1995	12	18	22.2	20.3	31.6	23.9	34	22	0.8	0
1995	12	19	27.4	16.3	31	16.4	32.5	15.9	0	0

1	2	3	4	5	6	7	8	9	10	11
1996	9	30	23.5	21	25.5	17.9	27.5	17	7.6	0
1996	10	1	17	11.2	21	13	21.8	8.8	0	0
1996	10	2	17	12	23.5	15	24.5	5.5	0	0
1996	10	3	21	15.5	27.8	17.9	28.8	9.9	0	0
1996	10	4	23	15.8	28	20	28.8	16	0	0
1996	10	5	22	19	29.9	21.9	30.5	14.1	0	0
1996	10	6	21.6	19.3	20.4	19.6	23.8	17	4.6	2
1996	10	7	19.5	18	25	18.5	25.5	15.5	7.6	1
1996	10	8	19.8	14.6	22.8	16.1	23.8	14.5	0	0
1996	10	9	25	19.2	15.2	12	25.2	12	0	0
1996	10	10	20.6	16.1	28	18.4	28.4	11.2	0	0
1996	10	11	24.5	19	30.8	20.6	32	13.2	0	0
1996	10	12	24.5	19.2	14	12	29	20.5	0	0
1996	10	13	18.5	12	25	14.5	25.8	6.4	1	0

1996	10	14	21.4	15.6	27.6	17.5	28.2	12	0	0
1996	10	15	21.2	13.9	27.5	15	27.8	12	0	0
1996	10	16	21	14.2	27.2	16.3	28	11	0	0
1996	10	17	23	16.5	29	17.9	30	14.6	0	0
1996	10	18	21.5	16	19	18.5	26	16.2	0	0
1996	10	19	22.5	20.2	23	20	27.5	18.5	1.6	0
1996	10	20	21	15	26.5	14.5	27.5	13	0.4	0
1996	10	21	19.2	14.1	26.5	15	27	5.8	0	0
1996	10	22	19	13	26.5	15.5	27.5	10.5	0	0
1996	10	23	20	13.3	26.5	15	27.5	9.5	0	0
1996	10	24	20.2	15.7	26.5	18.9	27.6	12	0	0
1996	10	25	19.7	13.5	26.7	16.4	28.2	12.4	0	0
1996	10	26	22	15.6	30.7	17.6	31.4	12.4	0	0
1996	10	27	22.4	16.4	29	17.9	30.5	14.6	0	0
1996	10	28	20.6	15.4	31	16.7	32.5	16	0	0
1996	10	29	24.5	18.4	26.7	17	33.6	16	5	1
1996	10	30	24.6	18.7	33.6	16.8	33.6	15.5	3	0
1996	10	31	23	16.8	30	18.1	30.2	15	0	0
1996	11	1	19.7	16.9	25.5	16.6	27.4	13	3.4	1
1996	11	2	20.6	13.8	26.1	14.7	27.7	11.4	0	0
1996	11	3	22.6	15.1	28.2	16	28.7	12.4	0	0
1996	11	4	22	15.6	27.2	16.8	28.5	14.5	0	0
1996	11	5	19.2	17.1	20	17.1	24.9	16	10	2
1996	11	6	19.5	16.4	24	15.9	25.6	12.1	2.2	1
1996	11	7	19.4	15.1	23.8	14.4	26.5	10	0	0
1996	11	8	21.6	15.7	25.9	17.6	27.4	10.9	0	0
1996	11	9	22.2	15.9	29.4	18	30	13.2	0	0
1996	11	10	23.8	13.5	26.3	13.6	28.4	15.5	0	0
1996	11	11	19	11	26.1	12.9	26.6	7.2	0	0
1996	11	12	23.5	12.4	29	14.4	29.6	9.4	0	0
1996	11	13	29	14.8	35	16.4	36	11.1	0	0
1996	11	14	31	16.9	38.5	17.6	39.8	19.4	0	0
1996	11	15	33	18.4	42.5	20	42.6	22	0	0
1996	11	16	34.1	21	35.5	21.7	42.4	23.1	0	0
1996	11	17	26.1	21	29.9	24.4	34.4	23.1	0.6	2
1996	11	18	23	14.9	27.8	15.8	29.3	13.8	7.6	1
1996	11	19	21.9	14.7	28	14.6	29.9	10.9	0	0
1996	11	20	24	17.5	30	18.4	31.8	15.3	0	0
1996	11	21	24.2	18.9	31	14.9	32.1	18	0	0
1996	11	22	24	15.4	26.5	12.4	28	10.8	0	0
1996	11	23	15.5	10	21.5	10.6	22.4	8	0	0
1996	11	24	18	12.3	24.1	13.2	25	7.5	0	0
1996	11	25	22.5	15.5	28.5	15.7	29.9	10.1	0	0
1996	11	26	27.5	18	33.5	17.6	35	14	0	0
1996	11	27	30.5	19.2	37.5	17.6	39.2	18.5	0	0
1996	11	28	32.5	19.8	40.5	18.5	42	18.8	0	0
1996	11	29	35.5	19.6	42	19.3	44.2	24.8	0.2	0
1996	11	30	30.9	14.9	34.9	16.8	36	23.2	0	0
1996	12	1	31	15.9	36.9	18.3	39	15	0	0
1996	12	2	30.5	20.5	32.8	21.9	34.8	26	0	0
1996	12	3	29.5	22.5	36.8	22.4	38	20	0	0
1996	12	4	25	21	30.2	20.8	31	20.8	2.6	1
1996	12	5	25.5	20	33	19.9	34.5	16.2	4.4	0

1996	12	6	27.5	20.5	34	21.4	35	19.5	0	0
1996	12	7	18.5	18.3	26	22.5	26.5	18	34.4	4
1996	12	8	22.5	20.5	29	22	29.9	18.2	19.6	3
1996	12	9	26	15.9	29	16.9	30.5	14.5	0	2
1996	12	10	28	17	31.5	22.4	32.9	15.8	0	1
1996	12	11	27.5	24.2	24.5	19.2	33.5	18.8	0	0
1996	12	12	23.2	19.9	29.5	21	31.8	17.8	18	0
1996	12	13	25.5	21.5	33.1	21	33.9	19.2	0	0
1996	12	14	23.4	17.1	28.9	20.1	29.8	17.9	0	0
1996	12	15	22	17	28.4	19.6	29.6	15.9	0	0
1996	12	16	23.2	17.9	31	20.4	31.5	16.5	0	0
1996	12	17	24.5	19	30	21.9	31.5	20.5	0	0
1996	12	18	24.6	21.5	20.5	20.5	30	20	23.8	4
1996	12	19	23.5	19.8	29	17.9	29.5	16	21.8	3

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1997	9	30	19	13.5	25.5	15.5	26.2	10.8	0	0
1997	10	1	21	14.5	28.5	16	29.2	13.2	0	0
1997	10	2	19	14	28.5	17.5	30.1	14.5	2.8	2
1997	10	3	24.5	18	33.5	20	34	16.5	5.4	1
1997	10	4	16.5	10	24.5	12.8	25.4	12.2	0	0
1997	10	5	18.6	13.5	24.6	16.8	25.1	14	0	0
1997	10	6	17.5	16.5	20	17	20.6	15.2	9.6	0
1997	10	7	17	16	18.2	17.5	19.5	15.5	15.9	5
1997	10	8	19.5	14.5	24.5	15	25	11.8	61.8	4
1997	10	9	20	14.5	25.2	15.2	25.5	10	0	3
1997	10	10	19.5	15	26.5	16.5	28.2	11	0	2
1997	10	11	22.6	17.5	30.6	18.4	31.2	12.4	0	1
1997	10	12	25.2	18.2	34	19.6	34.7	14.5	0	0
1997	10	13	21.5	13.5	25.5	14	26	13	0	0
1997	10	14	21	15.5	26.5	17.5	27.2	10.2	0	0
1997	10	15	23.5	16.8	28.5	15.5	29.5	14.5	0	0
1997	10	16	23.5	15	31.5	16	32	10.5	0	0
1997	10	17	24.5	14.2	31	15	31.8	11	0	0
1997	10	18	23	15	23.4	12	24.8	15	0	0
1997	10	19	17.9	13.5	18.5	15.5	20	12.5	0	0
1997	10	20	16	13.5	22.5	12.5	23	11	8.6	2
1997	10	21	18	12.6	23	13	24	10	0	1
1997	10	22	18.5	13	25.5	15.5	26.5	9	0	0
1997	10	23	20.5	15.5	26.5	17	27.5	11.5	0	0
1997	10	24	22	17	27.5	17.6	28.6	14.5	0	0
1997	10	25	21.5	16.1	28.7	19	29	16	0	0
1997	10	26	22.6	17	29.5	19	31	16.5	0	0
1997	10	27	23.5	17.4	31.7	19.8	32.4	17	0	0
1997	10	28	25.5	18	32.7	20.5	33.4	16	0	0
1997	10	29	26.5	19.4	31	21.5	31.7	18.2	0	0
1997	10	30	26.7	20.2	34.1	21.4	34.5	18.3	0	0
1997	10	31	24.6	18.9	32.3	21	33.1	19.6	0	0
1997	11	1	25.4	18.6	31.1	19	32.1	20.2	0	0
1997	11	2	27.2	20.1	31.6	21	33	17.1	0	0
1997	11	3	22	19.5	26	19.5	27	18.6	2.6	2

1997	11	4	22.6	18.5	28.6	19.4	29.5	16.5	1	1
1997	11	5	24	17.9	23.2	17.6	26.2	17.6	10.5	0
1997	11	6	21.9	17.4	29.1	19.4	29.6	17	0	0
1997	11	7	22.6	17.9	29.6	19.2	31	15.4	0	0
1997	11	8	26.4	19.4	31.2	19.9	32.9	17	0	0
1997	11	9	25.2	18.5	31.9	20.5	33.8	17.5	0.6	0
1997	11	10	24.1	19.9	30	20.9	31.4	18	0	0
1997	11	11	26	21	32	21.5	33	21	0	0
1997	11	12	26.4	20.6	34.1	21	35.1	19	0	0
1997	11	13	27.1	20.1	33.6	21.5	35.1	17.4	0	0
1997	11	14	29.1	22.5	27.1	21.6	31.8	24.2	0	0
1997	11	15	20.3	19.4	31.2	22.6	32	18.9	14	2
1997	11	16	27.2	21.7	23.7	20.6	32.2	19.9	0	1
1997	11	17	25.5	20	23.2	18.8	29	19.1	4.2	1
1997	11	18	19.8	18.9	21.3	18	23.1	17	2.6	0
1997	11	19	22.6	17.7	28.9	18	29.2	12.6	0	0
1997	11	20	24	19	31.5	19.5	31.7	15.5	0	0
1997	11	21	26.5	19	32	20	32.5	16	0	0
1997	11	22	24.8	18.2	30.9	20.8	31.4	15.9	0	0
1997	11	23	25	19	31.3	20.7	32.3	19	0	0
1997	11	24	25.5	20	35	20.5	36	17.5	0	0
1997	11	25	32	20.5	38	21	38.5	21	0	0
1997	11	26	29	20.5	37	21	38	20.5	0	0
1997	11	27	31	20.5	38.8	21.3	39.5	21	0	0
1997	11	28	31.5	22.4	40	22.4	40.5	23.2	4.4	1
1997	11	29	32.5	20.6	38.5	22.3	39	22.5	1	0
1997	11	30	30.6	21.9	30.5	22.5	35.5	25.9	0	0
1997	12	1	31	22	38.5	20.5	39.5	21.5	0	0
1997	12	2	32	22	39	19	40.5	18.5	0	0
1997	12	3	32.5	18	38	20	38.5	18	0	0
1997	12	4	26.5	19.5	34	22	36	20.5	0	0
1997	12	5	28.5	20.5	35.5	22.4	37.3	20.5	0	0
1997	12	6	26.2	22.8	32.3	23.6	33.9	21.2	12.6	2
1997	12	7	31.2	24	37.4	23	37.8	22.5	0	0
1997	12	8	28	23.5	33	24	33.5	22.2	21.6	4
1997	12	9	21.5	21.2	30	23.5	31.8	20.5	13.2	3
1997	12	10	26	24	23.5	22.5	28.3	21	7.6	2
1997	12	11	23.4	17.6	30	19.5	30.2	16	11.2	1
1997	12	12	23.5	17.5	26.5	19	26.8	18.5	0	0
1997	12	13	24	18.4	29.5	20.5	30.2	17	0	0
1997	12	14	26.5	22	24.6	22.8	30.2	21	0	0
1997	12	15	30.2	26	31.5	22	32.8	19.5	12.6	2
1997	12	16	29	21	34	20	34.5	17.5	0	1
1997	12	17	30.5	22.1	36	22	37	17.5	0	0
1997	12	18	31.5	22	37.5	22.5	38.2	23.2	0	0
1997	12	19	29	22	32.5	22.6	33	23	0.6	0

1	2	3	4	5	6	7	8	9	10	11
1998	9	30	22.5	18.5	30	20	30.8	13.2	0	0
1998	10	1	23.5	18.5	30.5	17.5	30.8	15.2	0	0
1998	10	2	21	17.2	28.2	16.5	29.7	14	0	0
1998	10	3	23	16.9	29.5	17.7	30	13.5	0	0

1998	10	4	24.4	18	31.1	18.2	31.8	13.4	0	0
1998	10	5	24	18	31.5	18.5	32	15.8	0	0
1998	10	6	23.5	17.5	27.5	18.5	29	19.8	0	0
1998	10	7	16	12	19.5	12.5	20.5	11.5	15.2	2
1998	10	8	15	10.5	19	12	19.8	7	0	1
1998	10	9	15.5	10.5	21.5	14	22.5	11.2	0	0
1998	10	10	15.4	10.4	18.4	12.1	20.2	11	0.4	0
1998	10	11	16.1	12.2	21.2	12.7	22	7.2	0	0
1998	10	12	20.5	13.5	27.8	16.8	28.5	11	0	0
1998	10	13	27.5	22	31.5	21.5	32.2	16.8	0	0
1998	10	14	21.5	13.5	26.5	14	27	12	0	0
1998	10	15	21.5	14	28.2	15.5	28.5	8.8	0	0
1998	10	16	22	15.5	30	16.5	30.5	11.8	0	0
1998	10	17	22	17	30	17	30.5	14.8	0	0
1998	10	18	25.4	18.6	32.5	19	33.5	16.1	0	0
1998	10	19	26.5	18	34.5	19.2	35	19	0	0
1998	10	20	14.5	13.5	22	12.5	22.5	14.5	0	0
1998	10	21	16	10	22.5	13	23.5	5.5	0.2	0
1998	10	22	20	14.2	25.5	16	21	9	0	0
1998	10	23	20	14.5	26.5	15	27.5	7.5	0	0
1998	10	24	22	17	29	18.5	29.5	14.5	0	0
1998	10	25	16	16	16.5	16.5	20.5	16	25.8	6
1998	10	26	20	19	23.9	20.6	24.1	15.5	59.6	5
1998	10	27	21.6	18.3	23.2	17.6	25.6	17	0	4
1998	10	28	15	8.4	20	11.1	20.5	7	0	3
1998	10	29	17.8	13.4	24.6	16.5	25.7	10	0	2
1998	10	30	17	16	20	17.5	22.2	16.5	0.4	1
1998	10	31	22.2	18.8	25.1	18	25.9	16.1	0.3	0
1998	11	1	20.2	15.4	26.4	17	26.6	10.9	0	0
1998	11	2	18	13.1	23	16	24.4	14	0	0
1998	11	3	17.4	13.4	24.4	15	25	11	0	0
1998	11	4	19.5	14.6	25.5	16.6	27	11.5	0	0
1998	11	5	21.4	16.6	27.6	18.7	28.5	14	0	0
1998	11	6	23.1	18.2	30.5	19.5	31	17.6	0	0
1998	11	7	24.1	19.1	30.8	21.1	31.4	18	0	0
1998	11	8	25	19.1	28.6	21	29.8	19.6	0	0
1998	11	9	25	20.6	30.9	21.2	31.2	17.5	0	0
1998	11	10	23.5	19	29	20.6	29.4	18	0	0
1998	11	11	21	16.7	25.6	18.9	26.5	16	0	0
1998	11	12	21.6	19.2	22	19.1	22.4	19.6	0.2	1
1998	11	13	20	19	27.6	22.2	28	17.5	3.4	0
1998	11	14	23.2	20.2	28.9	19.6	29.8	15.8	0	0
1998	11	15	24.1	19	31.2	22	31.6	13.2	0	0
1998	11	16	25.7	20.6	32.9	19.2	33.4	16.9	0	0
1998	11	17	24.5	19	31	20.5	32.2	17	0	0
1998	11	18	24	20	19	17.2	27	18.1	9.8	2
1998	11	19	20.5	15.5	26.5	17.2	26.5	12.5	3.4	1
1998	11	20	18.5	14	24	16	26	12	0	0
1998	11	21	21	16.8	28	18.4	29	12.7	0	0
1998	11	22	24.7	20.5	30.6	20.2	31	16.2	0	0
1998	11	23	25	20	32.5	23	33.5	17	0	0
1998	11	24	26	22	20	18.5	35.5	17.5	0.4	0
1998	11	25	24	20	27.5	20	27.7	18	10.6	2
1998	11	26	23.5	17.5	28	18.5	29	14.5	1.6	1
1998	11	27	22.5	16	28.5	17.5	28.9	13.5	0	0
1998	11	28	22.2	19.5	28	19.5	29	19	0	0

1998	11	29	21.3	16	26	14.5	27	9.9	0	0
1998	11	30	22.5	14	28.5	16	29	9.8	0	0
1998	12	1	22	16	28.5	16.5	28.8	13.5	0	0
1998	12	2	22.5	16	28.5	16.5	29.2	13	0	0
1998	12	3	23	17	30.5	18	31	14.5	0	0
1998	12	4	29.5	18.5	34.5	19.2	35.8	15.8	0	0
1998	12	5	28.1	18.4	32.6	17.6	33.3	17.9	0	0
1998	12	6	24.6	16.2	31.1	16.5	32.1	13.1	0	0
1998	12	7	27.5	21	32.8	19.8	34.2	19.5	0	0
1998	12	8	27.5	21	33.2	21.5	34.5	22	0	0
1998	12	9	25.6	19.8	31.8	21	32	18.3	34.4	3
1998	12	10	25.5	19.5	31.5	20	33	17.8	0	2
1998	12	11	26.5	19.5	30.5	20	31.5	19	0	1
1998	12	12	25	18	31.5	19.8	32	17.8	0	0
1998	12	13	25	18.4	32.5	19	32.8	19.4	0	0
1998	12	14	26.8	21	33.2	22.5	34.5	20	0	0
1998	12	15	27.5	20.5	31	22	33.5	21	0	0
1998	12	16	27	21	33.2	20.5	34.5	19.2	2	0
1998	12	17	28.5	22.2	36.8	21	37	20	0	0
1998	12	18	30.5	24	36.5	24	37.1	24	0	0
1998	12	19	28	22	35.7	21	36.5	21.9	0	0

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1999	9	30	21.5	16.2	25.5	16.2	27.2	12	0	0
1999	10	1	21	16.5	27.5	17.5	28.8	12.8	0	0
1999	10	2	21.5	17	27.1	18.2	28.8	14.5	0	0
1999	10	3	18.5	18	25.9	19.7	26.8	17	1.4	2
1999	10	4	19.5	18	22	19	27.5	17	4.6	1
1999	10	5	17	16	25.5	18.5	26.8	9.5	5.4	0
1999	10	6	21.5	16.5	27.2	18	29	13.5	0	0
1999	10	7	20	13.5	26.5	17.5	27.5	12.8	0	0
1999	10	8	21.5	16	28.5	18.5	29	13.8	0	0
1999	10	9	23.1	16.6	30.1	18.8	30.9	13.7	0	0
1999	10	10	23.6	16.1	30.1	17.2	31	15.1	0	0
1999	10	11	25	16	33	19.5	34	19	0	0
1999	10	12	27	20	32	17.5	32.5	14.9	0	0
1999	10	13	24.5	18	32.5	19.5	32.5	15	0	0
1999	10	14	21	17.5	22.5	19	28.5	18.5	0.6	3
1999	10	15	23	20	29	21	30	15.2	25.2	2
1999	10	16	25	20	31.5	21.2	32	16.8	0	1
1999	10	17	23.5	19.5	31.6	21.1	32	19	0	0
1999	10	18	24	19	31	19	32.3	17.5	0	0
1999	10	19	19.3	16.7	17	16	19.5	17.4	0	0
1999	10	20	17.8	12.5	21.5	12	22.5	8	1.4	0
1999	10	21	21	13.5	28	14.5	28.8	7	0	0
1999	10	22	23.5	17.5	29.5	18	30	16	0	0
1999	10	23	19.3	18	28	18.4	28.8	16.6	1.2	2
1999	10	24	16.9	16	22	13	22.5	15.9	9.2	1
1999	10	25	18.5	11.5	26	15.5	26.5	6.5	0	0
1999	10	26	24.5	15.5	31.5	17	32.3	10.2	0	0
1999	10	27	19.4	17.4	24	20	25	15	9.6	2

1999	10	28	21.5	19.5	29.5	18.5	32	15	1.2	1
1999	10	29	24.5	17.5	30.5	19.5	31.2	14.8	0	0
1999	10	30	24.5	17.6	30.5	18.5	31.5	17.4	0	0
1999	10	31	21.5	18	25.5	19	26.8	18.5	2.4	1
1999	11	1	20	17	22.5	19.5	28	16.5	0	0
1999	11	2	21	15	26	17.5	26.5	12.5	0	0
1999	11	3	20	13.5	26	15	27	10	0	0
1999	11	4	21.5	14	25.5	15.5	27.2	12	0	0
1999	11	5	22.5	16	25.5	17	27.2	14	0	0
1999	11	6	21.5	17.2	19.1	18.5	28.9	19.4	0	0
1999	11	7	22.2	20.1	25.2	19.8	28.5	15.2	41.6	6
1999	11	8	22.5	19	22	20.5	23	17.5	0.6	5
1999	11	9	18.8	13.5	21.5	14	22.8	14	47.2	4
1999	11	10	18.5	11.5	22.4	12.4	23.5	8	0	3
1999	11	11	18.8	14.5	23.5	13.4	24.5	9.5	0	2
1999	11	12	20	15.5	23.5	14	25.4	9.5	0	1
1999	11	13	19	15	26	16.5	27	9.5	0	0
1999	11	14	24	17.5	29	18.1	29.9	9.5	0	0
1999	11	15	32.9	20.5	17.4	21	33	26.5	0	0
1999	11	16	23.6	18.1	24.5	19.5	28.1	17.5	9.6	2
1999	11	17	19.5	15.4	25.5	16	25.8	9.9	0	1
1999	11	18	25.5	18.4	17.5	19	27.9	22.8	0	0
1999	11	19	21	16.6	24.3	18.4	26.6	9.9	0.5	0
1999	11	20	20.8	17.2	24.4	18.6	24.7	14.4	0	0
1999	11	21	15.9	15.1	21.4	17	24.4	15.1	4.3	2
1999	11	22	24.4	21	30.3	21	31.1	15.2	1.6	1
1999	11	23	23.3	19.2	28.5	19.1	29.4	16.5	11.2	0
1999	11	24	24.5	19.3	30	19.9	30.4	13	0	0
1999	11	25	23.9	19.6	27.5	20.6	28.8	13	0	0
1999	11	26	22.1	18.1	28.8	21.1	29	13.1	0	0
1999	11	27	23.6	20	27.7	20.4	28.1	13	1.2	0
1999	11	28	22.4	17.4	26.1	19	28.2	12.6	0	0
1999	11	29	20	16	25.4	18.5	26	12.5	0	0
1999	11	30	22.2	17.5	28.6	19.5	29	12.5	0	0
1999	12	1	22	19	29.8	21	30.2	12.5	0	0
1999	12	2	23.6	19.1	30.5	21.3	30.9	12.5	0	0
1999	12	3	22.6	19	30.2	20.5	31.2	12.5	0	0
1999	12	4	25.4	20.5	33.3	22.8	35.3	12.5	0	0
1999	12	5	25	21.2	32.4	23.1	34.1	19.5	0	0
1999	12	6	25.7	21.2	32.9	23.5	34.8	19.4	0	0
1999	12	7	24.5	20	32.5	23.2	32.9	18.4	0	0
1999	12	8	24.5	20.5	32.5	23.5	33.1	17	0	0
1999	12	9	26.4	22.4	32.6	24.1	34.2	17	0	0
1999	12	10	29.9	23.6	32.1	25.9	33.1	17	0.2	0
1999	12	11	21.9	20.4	17	17	23.7	17	0	0
1999	12	12	19.4	17.5	27.4	20	28.4	15.5	12.8	2
1999	12	13	23.1	20	27.8	20.6	29.4	14.5	0	1
1999	12	14	23	19.5	28.6	21.2	29.7	14.5	0	0
1999	12	15	23.7	19.9	29.8	22.4	30.6	14.5	0	0
1999	12	16	25	21.5	31	23.5	32	14.5	0	0

1999	12	17	24.5	22.5	22	21	29	20.5	0	0
1999	12	18	18.9	18.3	24.9	20.1	26	18.3	27.6	3
1999	12	19	22.8	17.7	29.6	20	30.5	16.2	0	2

1	2	3	4	5	6	7	8	9	10	11
2000	9	30	29.5	21	34	21.5	36.5	23	0	0
2000	10	1	25	15.5	29.5	17.4	31	16	0	0
2000	10	2	19	12.5	25.5	15	26.9	9	0	0
2000	10	3	20.2	13	27.5	15	28.5	8.3	0	0
2000	10	4	22.5	14	29.5	16.5	30.5	7.5	0	0
2000	10	5	21	17	29.5	16	30	14	0	0
2000	10	6	21.5	15	30.5	17	31.2	14	0	0
2000	10	7	23.3	16.3	31.6	16.2	33.1	14.8	0	0
2000	10	8	26.1	19.7	33.8	18	34.5	17.8	0	0
2000	10	9	27.5	18	34.5	19	36	20	0	0
2000	10	10	25.5	17	25.8	19	30.8	18	0	0
2000	10	11	16.2	12.5	24.5	17.5	26.5	12.8	5	1
2000	10	12	21.5	15	26.5	15.5	27.2	11	0	0
2000	10	13	19.5	14	26	17.5	27	14.5	0	0
2000	10	14	16.5	14	19.9	13.5	21.5	13.5	19	2
2000	10	15	18	12	25	14.5	25.8	7.2	0	1
2000	10	16	22.5	14	26.8	15.5	28	10	0	0
2000	10	17	23	17	28.5	18.5	29	12.5	0	0
2000	10	18	20.2	15.5	23.5	16	28.2	15	0	0
2000	10	19	20.5	14.5	24	16.5	24.8	17	0	0
2000	10	20	22.5	18	28	17	30.2	16.5	2.2	1
2000	10	21	23.8	15.4	28.8	17.3	30.1	14.1	0	0
2000	10	22	21.7	16.2	27.9	19.2	28.8	17.6	0	0
2000	10	23	23.2	18	27.5	16	29.8	18	0	0
2000	10	24	23.5	17.5	29	19	29.1	17.8	0	0
2000	10	25	22.5	18.5	27.5	19.3	29.1	16.5	12	2
2000	10	26	25	19.2	30.9	17.5	31.9	14.4	0.4	1
2000	10	27	23.5	16	28.2	16.3	29.7	12.2	0	0
2000	10	28	20.9	13.8	25.6	13	27.1	11.4	0	0
2000	10	29	21.8	16.3	25	17.8	26.9	12.9	0	0
2000	10	30	16.1	15.4	20.4	15.6	20.9	14.5	7.2	1
2000	10	31	19.6	14.8	22.1	16.4	23.2	14	0.3	0
2000	11	1	20.6	15.6	27.1	17.4	28	11.2	0	0
2000	11	2	23	18	24.3	18.9	28	17	0	0
2000	11	3	21.4	18.1	28.1	19.8	29.4	15	3.5	2
2000	11	4	23.6	20	32.2	19.4	33.4	16.9	1	1
2000	11	5	24.2	19	27.1	18.2	32.4	16.6	9	0
2000	11	6	24.4	19.4	31.1	18.2	32.5	17	0	0
2000	11	7	24.4	18.5	28.8	16.6	30	13.3	0	0
2000	11	8	21.8	15.1	26.1	17.5	28	15.5	0	0
2000	11	9	20	13	21.5	15.6	24.5	15	0	0
2000	11	10	18.7	15.6	22	16	23	14.5	3.2	6
2000	11	11	21.9	16	24	16.3	25.5	16.5	0.1	5
2000	11	12	20	15.6	26	17.9	28	17.4	1.8	4
2000	11	13	22.8	18.1	28.4	18.8	28.6	17	3	3
2000	11	14	18.7	17.9	20.3	17.9	20.7	17.1	19.2	2
2000	11	15	18.9	17.5	23.1	19.4	24	17	17.9	1
2000	11	16	21	18	24.4	19.5	25.2	17.5	0.8	0
2000	11	17	20.9	18.9	21.6	20.4	22.9	18.1	4.1	0

2000	11	18	24.9	21.3	19.9	21.5	27.9	22.9	14.4	0
2000	11	19	22.5	21	22.1	20.9	26	19.1	8.2	0
2000	11	20	21.4	20.7	27	23	28	19.5	11.2	0
2000	11	21	20.9	19	26.7	21.8	27.9	20.5	2.8	0
2000	11	22	22.1	17.5	25	18.9	26	18	0	0
2000	11	23	22.5	16.5	26.6	18	27.5	16.9	0	0
2000	11	24	22	17.5	26.5	19.5	27.5	15.5	0	0
2000	11	25	24	19	30.5	20.5	31.5	16.5	0	0
2000	11	26	24	19	29.5	20.2	30.5	17.5	0	0
2000	11	27	26	20.5	31.5	21.5	33.2	18.5	0	0
2000	11	28	25.5	20	32	21.5	33.5	18.5	6.4	1
2000	11	29	28	19.6	34	21.5	35.2	18.5	0	0
2000	11	30	30.5	20	35	22.5	36	22.5	0	0
2000	12	1	28	21.2	28.5	21	29.5	21.5	4	1
2000	12	2	25	15.5	30.5	16	31.2	14	0	0
2000	12	3	24	17	31	19.8	31.8	18	0	0
2000	12	4	23.5	17.5	31	19.5	31	17.8	0	0
2000	12	5	25	17	30	19	31	16.5	0	0
2000	12	6	25.5	19	32.5	19.5	33.2	18	0	0
2000	12	7	29.5	20.5	35	21	35.5	21	0	0
2000	12	8	26.5	20.5	30	19	35	21	0	0
2000	12	9	29.6	20.4	35.5	19.4	36.8	17.2	0	0
2000	12	10	29.4	20.4	35.5	19.1	37	21.1	0	0
2000	12	11	29	21.5	36	19.5	37	21.8	0	0
2000	12	12	31.5	21	37	20.5	39.5	22.5	0	0
2000	12	13	30.5	20.2	34.5	21	35.5	24	0	0
2000	12	14	24	20.8	24.5	21.5	28	19.5	23	3
2000	12	15	24	21.5	23.5	20.5	27.5	21.4	0.8	2
2000	12	16	24.5	19.4	30.2	19.8	30.7	18.1	4.6	1
2000	12	17	24.1	18.2	30.2	18.8	31	17.5	0	0
2000	12	18	25.5	19.5	31	20.9	32	17.5	0	0
2000	12	19	26	20	32.5	26	33	19.5	0	0

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2001	9	30	19.6	16	29	17.7	29.5	12.4	0	0
2001	10	1	21.5	16.5	28.5	18	29.9	13.5	0	0
2001	10	2	21	16.5	29	18.5	29.9	17.5	0	0
2001	10	3	22.2	17	25.5	18.7	27.5	18.5	0	0
2001	10	4	20.5	14	25.5	14.2	26.5	11	0	0
2001	10	5	21	13	25	14.3	26	7.5	0	0
2001	10	6	23.6	13.9	29.3	15.9	30.1	7.7	0	0
2001	10	7	20.2	12.8	23.6	14.4	24.5	13.4	0	0
2001	10	8	18	11.5	24.5	13	24.5	7	0	0
2001	10	9	21	12	25.2	12	26	7	0	0
2001	10	10	22	15.5	29	16.9	29.5	12	0	0
2001	10	11	17.5	16.5	18	17.5	18	12	3.8	2
2001	10	12	18	15	23.5	15.5	24.5	15.5	15	1
2001	10	13	23.6	14.9	30.6	17.9	31.2	10.3	0	0
2001	10	14	18.6	15.6	23.1	14.6	23.9	16.6	3.8	1
2001	10	15	19	13.5	24.4	14.4	25.8	8.5	0	0
2001	10	16	22.5	16.5	28	16.5	29.5	11.5	0	0
2001	10	17	19.5	16.4	16.5	16	21	15.6	1.2	1
2001	10	18	17.5	15.5	25.5	16	26.8	10	4	0
2001	10	19	21	13.5	25	13.5	26	12.5	0	0
2001	10	20	16.3	9.5	24.5	12.2	25	6.5	0	0

2001	10	21	19.5	14	26	14.9	27	9.5	0	0
2001	10	22	20.9	15	28	16	29	12.5	0	0
2001	10	23	23	16	30	17	31	15	0	0
2001	10	24	22.5	16.5	26.5	19	26.5	18.5	0	0
2001	10	25	26.5	18.5	29	19	31.2	18.5	1.2	3
2001	10	26	19	18	20.5	19.5	20.5	17.5	10.2	2
2001	10	27	20	15	26	15.6	26.5	12.5	9.4	1
2001	10	28	23	16	30	16.5	30.5	11	0	0
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2001	10	30	27.5	17	31.5	17.5	32.6	17.5	0	0
2001	10	31	24.5	14	30.5	17.6	30.5	11.9	0	0
2001	11	1	24.4	16.5	31.1	17.8	31.5	11.3	0	0
2001	11	2	27.3	17	32.2	19.5	33.9	12.6	0	0
2001	11	3	24.3	18	31.6	19.3	32	14.2	0	0
2001	11	4	23.5	17.9	29.2	20.5	30	16.2	0	0
2001	11	5	23.5	17.6	30	19.9	31	15.5	0	0
2001	11	6	23.4	17.7	30	21.4	30.8	18.2	0	0
2001	11	7	27	22.9	26.9	23.1	28.9	20.7	0.9	1
2001	11	8	24.6	21.2	31.1	21.3	31.9	15.6	6.2	0
2001	11	9	24.9	21.6	22.2	21	30.2	19.4	0	0
2001	11	10	19.6	19.3	21.5	20.4	22.9	17.5	8.1	2
2001	11	11	20.6	19.4	20.6	18.9	26	18	9.8	1
2001	11	12	18.9	13.6	24.2	15.6	24.9	13	0	0
2001	11	13	20.5	13.9	26.4	17.3	26.5	7.7	0	0
2001	11	14	21.7	16.6	27.9	17	28.2	11.4	0	0
2001	11	15	22.1	17	24.6	17.9	25	18.6	0	0
2001	11	16	22.5	18.9	28	19.1	28.9	16.8	0.2	0
2001	11	17	22	17.9	28.8	19.5	30	18.2	0	0
2001	11	18	24.9	18.9	33	20.5	34.4	20	0	0
2001	11	19	18.5	11.9	21.9	12.2	22.2	14	13.6	2
2001	11	20	18	12.9	25.2	15.2	26	9.6	0	1
2001	11	21	20.4	14.2	27.1	16.1	27.9	11.2	0	0
2001	11	22	23.8	16.2	30.5	18.6	30.8	12.5	0	0
2001	11	23	25.1	19	31.1	20	32.6	17.5	0	0
2001	11	24	28.7	20.2	36.4	22.8	37.4	21.2	0	0
2001	11	25	24.8	21.6	24.9	21.1	27.6	20.8	2.9	3
2001	11	26	24	21.3	28	22	30.5	19.5	7.5	2
2001	11	27	21.5	19	21.2	17.2	27	16.5	11.2	1
2001	11	28	22.9	16	28	18	29	14.5	4.4	0
2001	11	29	22.5	17.5	29	19	30.2	15	0	0
2001	11	30	26.5	20.5	32.5	21.5	33.2	18	0	0
2001	12	1	26.2	20.9	34.5	20.5	35	16.5	0	0
2001	12	2	29.5	21	37	21.4	38.2	15	0	0
2001	12	3	31	21.2	38	24	38	24.9	0	0
2001	12	4	30	22	36	23	36.5	21.5	9	2
2001	12	5	29	19.8	34.5	19	34.5	16.8	0	1
2001	12	6	26	21.5	29.5	22.5	30	23.6	0	0
2001	12	7	24.5	22	29.5	23.8	30.4	21	7.8	1
2001	12	8	25.1	21.4	29.2	17.7	30.9	18.8	0	0
2001	12	9	18.8	16.7	30.2	19.4	31.5	16.1	0	0
2001	12	10	26	20.2	30.5	18.5	32	18.8	0.6	0
2001	12	11	26	14.5	30.4	16.2	31.6	18.5	0	0
2001	12	12	26.5	17.5	32	18	33	13.5	0	0
2001	12	13	25.5	19.5	32	20.5	33.5	19.5	0	0
2001	12	14	27	21	24	21.5	30.5	20.5	0	0
2001	12	15	25	22	27	23.2	27.5	21	7.6	3

2001	12	16	21	20	26	21.5	27.5	18.5	12.6	2
2001	12	17	24	20	30.5	19.5	31.5	17	0	1
2001	12	18	24.5	19.5	30.8	20.5	32	18	0	0
2001	12	19	26.5	20.5	34.5	22.5	35	19.5	0	0

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2002	9	30	15.5	9.5	23	11.8	23	6.5	0	0
2002	10	1	17	11.5	25.1	12.8	26	6.2	0	0
2002	10	2	19.5	14.2	27	15.5	28.9	10.5	0	0
2002	10	3	20.2	14.2	27.2	15.2	28	12.5	0	0
2002	10	4	21	15	28.5	15.5	29	13.9	0	0
2002	10	5	21.9	15.5	29.9	17.4	30.4	13.6	0	0
2002	10	6	22.5	17.1	30.8	18.6	31.9	16.6	0.4	0
2002	10	7	23	16.8	32	19.5	33	17.4	0	0
2002	10	8	23.5	17.9	31.5	20.5	32.5	18.5	0	0
2002	10	9	24.5	14	30	13.8	31	12.2	0	0
2002	10	10	22.5	16.8	29	17	29.8	12.5	0	0
2002	10	11	22	16.5	23.9	18	26.3	14.5	1.4	2
2002	10	12	17.7	14.7	19.5	17.5	27.2	14.4	7.4	1
2002	10	13	21.5	18	29.3	20.4	30.5	15.2	3.2	0
2002	10	14	22.5	12.5	27	14.5	28	14.5	0	0
2002	10	15	21.5	13	26.5	15	27.7	9	0	0
2002	10	16	24.5	14.5	31	16.2	31.5	9	0	0
2002	10	17	28.2	19	36.5	18.2	39	14.9	0	0
2002	10	18	26	18	36	19.5	36.5	12	0	0
2002	10	19	27.8	21.4	38.5	21.5	39.5	18.8	0	0
2002	10	20	26.6	15.4	34.1	17.5	35	16.6	0	0
2002	10	21	27	16	31.2	17.5	31.8	15.5	0	0
2002	10	22	25.5	19	32.8	18.5	32.9	14	0	0
2002	10	23	30	19.5	29.1	17.1	32.8	18	0	0
2002	10	24	19.5	12.6	24.9	14.8	25.6	11.9	0	0
2002	10	25	25.5	15.4	32.2	18.5	33.4	8	0	0
2002	10	26	30.5	20	37.4	20.7	38.5	20	0	0
2002	10	27	23.4	18.8	17.8	17.3	24.5	18.9	0	0
2002	10	28	19.3	15.2	25	17.6	25.5	11	11.5	2
2002	10	29	20.8	16.2	28.4	18.4	28.9	12.2	0	1
2002	10	30	24	18.6	31.8	20.6	32	14.5	0	0
2002	10	31	27.5	19.6	35.8	23.4	36	18	0	0
2002	11	1	29.9	21.3	37	23.6	37.9	19.6	0	0
2002	11	2	27.6	22.4	36	24.9	36.6	20.2	0	0
2002	11	3	27	22.5	34.4	20	36	19.2	0	0
2002	11	4	30.2	17.8	34.4	17.5	34.5	25.4	0	0
2002	11	5	21.1	11.3	29.8	14.5	30.4	11.5	0	0
2002	11	6	23.5	17.5	32	17.4	32.4	14.2	0	0
2002	11	7	25.5	19.1	32.1	19.1	33	17.6	0	0
2002	11	8	24.4	18.7	33.5	20.4	33.9	18.5	0	0
2002	11	9	28.7	19.8	36.8	20.1	38	20.5	0	0
2002	11	10	31.5	19.4	38.3	21	39.4	20.1	0	0
2002	11	11	29.6	20.5	34.5	22.5	34.5	25.6	0	0
2002	11	12	26.1	20.6	34	22.2	34.5	19	0	0
2002	11	13	27.3	21.5	32.2	21.1	34	21	0	0
2002	11	14	29.4	22	35.2	23	35.6	21.4	0.2	3
2002	11	15	23.2	20.5	29.4	22	30.2	17.6	25.4	2
2002	11	16	23.2	18.8	27.5	20.3	28.8	18.4	5.4	1
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2002	11	18	22.5	17.6	30.5	20	31.2	16	0	0
2002	11	19	24.4	19.1	32	21	33	18	0	0
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2002	11	22	24	19.5	30.8	21.9	31.7	20.2	0	0
2002	11	23	25.2	19.6	33.5	19.2	34	19.9	0	0
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2002	11	25	25.5	18	32.8	19.5	34.2	18.8	0	0
2002	11	26	27.5	20	36.5	22.2	37.8	21	0	0
2002	11	27	31	22.2	37	23.7	38	24.5	0	0
2002	11	28	28	18	29	20.5	31.5	24	0	0
2002	11	29	21.5	20	25.2	23	27.8	20	0.4	1
2002	11	30	26.6	21.7	33	19.3	34.1	17.5	5.2	0
2002	12	1	28.1	16.4	33.9	19	34.8	14.4	0	0
2002	12	2	28.5	21.5	36.2	22.8	37.8	20	0	0
2002	12	3	32	25	38.5	24.5	39.2	24.6	0	0
2002	12	4	31.5	24.5	38.5	21.9	40.2	22.2	8	2
2002	12	5	27	14	32.5	16	33	19	0	1
2002	12	6	24.5	16.5	31.6	19.2	28.5	17.5	0	0
2002	12	7	22.4	14.4	30	16	31.1	10.6	0	0
2002	12	8	24.6	18.1	31.6	19.8	32.7	18	0	0
2002	12	9	27.5	21.4	19.5	17.5	33.5	22.5	0	0
2002	12	10	22.5	20.5	21	18	27	18	37.6	4
2002	12	11	17.5	15	19.5	15.5	23.5	14.2	9.8	3
2002	12	12	23.5	16	31	16	32	12.5	0.2	2
2002	12	13	26.5	17.2	35	18	35.2	15.2	0	1
2002	12	14	28.5	20	35.5	19.8	36.2	16.2	0	0
2002	12	15	23	20	31.3	20.2	32.8	20	3	2
2002	12	16	26.5	19.5	32.5	20	34	18	5	1
2002	12	17	26.5	18.8	34.5	20.5	36	20	0	0
2002	12	18	26.5	18.5	35	21.5	35	21	0	0
2002	12	19	27	18.6	33	21	34	20.2	0	0

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2003	9	30	21.5	12.2	26.2	14.5	27.8	8.2	0	0
2003	10	1	16	14.5	18.5	17.5	18.8	15.5	2	4
2003	10	2	18.8	18	13.5	13.5	24	15.5	44.2	3
2003	10	3	19	15.5	19.5	16	21.2	12.5	15.2	2
2003	10	4	16	13.5	20.6	16	21.5	12	3.6	1
2003	10	5	18.5	15.5	23.5	16.6	25	12.5	0	0
2003	10	6	20	17.8	21.5	19	23	16.2	0.2	1
2003	10	7	15.5	14.5	23.8	16.5	23.8	14	2.8	0
2003	10	8	19.5	15	25	15.5	25.5	9.2	0	0
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2003	10	10	14.5	9.8	21.5	12	22.6	9.5	0	0
2003	10	11	14.1	9.2	20.1	11	21	5.9	0	0
2003	10	12	15.6	11.7	21.9	14.1	22.9	4.8	0	0
2003	10	13	18.3	14	24	15.5	24.2	9.5	0	0
2003	10	14	18	14.5	25	16.5	25.5	9	0	0
2003	10	15	19.5	16.2	26.5	17.5	27	9.2	0	0
2003	10	16	21.5	17	25	18	26.2	15.5	0	0
2003	10	17	17.5	16.5	24.7	16	25.5	13.8	0.2	0
2003	10	18	21	15.6	27	16	27.8	12.5	0	0
2003	10	19	22.5	17	29.5	17	30	13.2	0	0
2003	10	20	18.8	17.8	24.5	18.8	25	17	18.6	2

2003	10	21	19.5	14.5	26.8	15.2	28.5	10	0.2	1
2003	10	22	25	15.8	30.4	15.8	31	12	0	0
2003	10	23	23.1	16	30.1	17.1	31	12	0	0
2003	10	24	24	18	31.1	20	33.1	14	0	0
2003	10	25	25.8	19.7	31.9	20	33.6	14.9	0	0
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2003	10	27	22	13	27	14	28	10	0	0
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2003	10	29	25	15.1	27.1	15	28	23	1	0
2003	10	30	20.5	13.1	25.1	14.1	26.1	10	0	0
2003	10	31	21.1	14	26.1	15.1	28.5	13	0	0
2003	11	1	19	12.1	24.1	14	25.1	13.1	0	0
2003	11	2	21	12.1	24.1	14	26.1	7	0	0
2003	11	3	18	12	25	14.1	26	8	0	0
2003	11	4	20.1	15.1	27.6	17.5	28	12	0	0
2003	11	5	23	16.1	29.1	18.1	30.5	13.1	0	0
2003	11	6	22.1	17	30.1	18.9	30.5	15.1	0	0
2003	11	7	24.1	19	27	19	29.7	17	0	0
2003	11	8	24.6	19.7	27.4	20.6	29.9	16.1	0.2	0
2003	11	9	23	19.2	28.4	17.4	30	16.7	0	0
2003	11	10	24	17	31.1	18	32	16.1	0	0
2003	11	11	23	17.1	31	19	32	17	3.2	1
2003	11	12	26.1	19	35	18.8	36	18	0	0
2003	11	13	26	19	33	20	33.1	20	0	0
2003	11	14	24	17	31	20	31	17	0	0
2003	11	15	23.1	16.1	31.1	18.1	33	16.1	0	0
2003	11	16	25	18.1	34.1	20	35.1	19	0	0
2003	11	17	28.1	20	38	21	39	21	0.2	0
2003	11	18	27	19	34.8	22	36	21.1	0	0
2003	11	19	28	20.1	35.1	22	36.5	21	0	0
2003	11	20	28.5	20.5	36	22.5	37.5	22.5	0	0
2003	11	21	29.5	21	36.2	22.2	37.8	24	0	0
2003	11	22	22.6	21.6	26.1	21.9	29.4	21.8	27.2	3
2003	11	23	20.1	18	26.6	16.4	27.2	16.6	1.8	2
2003	11	24	21	14.5	22.5	15.5	25	12.5	0	1
2003	11	25	24	13.5	26.8	15.2	27.2	11.5	1.4	0
2003	11	26	22	15.5	26.8	15	28.5	13	0	0
2003	11	27	21.5	14.2	27	15	28.5	13.5	0	0
2003	11	28	22.3	15.1	28	16.5	28.8	14.2	0	0
2003	11	29	22.7	16.8	29.8	18.2	30.5	14.8	0	0
2003	11	30	24	16.8	31	16.6	32	16.5	0	0
2003	12	1	25	18	31.8	19.2	32.5	19	0	0
2003	12	2	25.5	18.2	30.2	15.9	31.5	20	0	0
2003	12	3	25.2	19.2	31	19.5	31.7	20.5	0	0
2003	12	4	27.5	21	33.5	21.5	34.5	21.2	0	0
2003	12	5	23	21.5	26.5	21.5	28.4	21.5	5.4	6
2003	12	6	17.4	17.3	20.1	17.2	21.4	17.4	85.8	5
2003	12	7	20.1	15.6	22.8	17.5	24.8	15.4	16.4	4
2003	12	8	24	13.5	28.2	19.5	29.2	15.8	0	3
2003	12	9	26.5	22	31.5	21.5	32.8	18.5	0	2
2003	12	10	26	21	32	21	32.8	20	0	1
2003	12	11	25	21.8	32.5	22.7	32.8	21.2	0	0
2003	12	12	28	23	33.8	22.8	34.5	23.5	0	0
2003	12	13	28	23.5	34.5	24	35.2	21.5	10	3
2003	12	14	27.6	21.4	33.9	23.8	34.8	21.3	15	2
2003	12	15	27.5	22	32.5	22.5	33.5	20	0	1

2003	12	16	27	21.2	31.5	22	32.2	19.5	0	0
2003	12	17	23.5	17	29.5	18.5	30.5	18	0	0
2003	12	18	24.5	18	30	21	30.5	17	0	0
2003	12	19	25.7	18.8	32.5	20.5	32.8	17.8	0	0

1	2	3	4	5	6	7	8	9	10	11
2004	9	30	21.8	18	30.9	21.5	31.2	19	0.2	0
2004	10	1	20.9	18.8	25.5	19.5	26.6	18	5.8	1
2004	10	2	14.6	11.4	22.4	15.3	23.1	10.9	0.8	0
2004	10	3	19.6	13.9	26	14.7	26.9	8.6	0	0
2004	10	4	22.2	14	29	16	30.1	9.8	0	0
2004	10	5	21.7	13.8	28.5	15	29	9.9	0	0
2004	10	6	21.5	15.9	29.5	16.9	30.5	9.4	0.6	0
2004	10	7	22.2	15.9	30.6	16.9	31.6	10.2	0	0
2004	10	8	22.9	14.5	27	14	27.9	14.2	0	0
2004	10	9	18.5	11.9	26.1	14.4	26.5	6	0	0
2004	10	10	20.6	15.6	27.5	17.5	28.1	11	0	0
2004	10	11	21.5	17.2	28	18.2	29.1	14.5	0	0
2004	10	12	23.5	17.2	31.9	19.8	32	14.5	0	0
2004	10	13	25.2	17.5	33	20.8	33.5	14.5	0	0
2004	10	14	25.8	18	34.5	21	35.1	16.5	0	0
2004	10	15	28.1	18	31.5	21	33	15.2	0	0
2004	10	16	21.7	13.1	29.5	14.6	30.2	10.9	0	0
2004	10	17	21.6	16.4	26.1	18.4	27.4	15.7	0	0
2004	10	18	18	15.2	22.5	17.2	23.8	15.5	0	0
2004	10	19	20.2	16.2	24.9	17.5	26.9	11.2	3.8	3
2004	10	20	18.5	16.5	23.8	18.5	25.2	13.2	0.2	2
2004	10	21	16.8	15.5	20.5	16.8	24.3	14.5	16.6	1
2004	10	22	24.3	18	32.2	17.2	33	13	0	0
2004	10	23	27.5	16.5	33.1	17.4	34.7	14.5	0	0
2004	10	24	29.5	17.7	36.1	20	37	18.7	0	0
2004	10	25	27.9	18	35	19	35.5	17	0	0
2004	10	26	26.5	20.3	34.5	21	35.6	17.7	0	0
2004	10	27	27	22	33.2	23.5	35.5	21.5	0	0
2004	10	28	19	11.5	26.5	14.2	27.9	12.2	0	0
2004	10	29	21.2	15	27	16.8	28.5	11	0	0
2004	10	30	21.3	15.4	27.9	18.1	28.1	12.9	0	0
2004	10	31	21.7	16.4	28.4	18.2	29.6	12.8	0	0
2004	11	1	23.2	17.2	30.4	19.9	31	14.2	0	0
2004	11	2	25	19.2	33.5	22.8	34.5	19	0	0
2004	11	3	23.9	21.4	30	20.6	31.3	19	11	2
2004	11	4	26	20.3	33.5	21.3	34.4	19	0	1
2004	11	5	22.4	19.4	20.2	18.9	22.4	20.2	1.8	3
2004	11	6	21.2	16.8	24.9	17.7	25.4	17	26.4	2
2004	11	7	24.6	16.8	29.6	17.7	30	15	0	1
2004	11	8	23.5	20	28	21	29.5	15	0	0
2004	11	9	21	18	28.5	20	29	16.5	0	0
2004	11	10	21.9	17.3	29.1	18.7	29.9	13.5	1.6	0
2004	11	11	23.6	19.2	30.6	22.1	31.4	19.4	0	0
2004	11	12	22.6	21.7	28.2	17.6	29.1	16.4	8.4	2
2004	11	13	27.4	19.1	34.6	18.3	36.7	13.9	0	1
2004	11	14	22.2	12.8	28.6	16.1	29.2	10.1	0	0
2004	11	15	26.4	16.1	30.6	17.2	32	11.4	0	0
2004	11	16	28	17	32.5	17.9	33.5	14	0	0
2004	11	17	28.5	22.3	32.5	21.8	34.4	20.2	0	0

2004	11	18	26.3	19.9	32	20.2	32.9	20.2	0	0
2004	11	19	26.5	19.6	32	20.4	33.1	18.8	0	0
2004	11	20	26.8	20.8	25	21.9	27.6	20.6	0	0
2004	11	21	21.8	18.9	24.1	20	25	17.8	9.6	4
2004	11	22	21.9	18.8	26	20.9	26.5	16.1	48.8	3
2004	11	23	20.4	15.4	25.8	16.1	26.6	13.7	4.2	2
2004	11	24	20.1	16.1	26	16.3	26.8	12.8	0	1
2004	11	25	21.4	16.3	27.4	17.8	27.4	14.6	0	0
2004	11	26	22.2	15.4	28.4	17.5	29	13.8	0	0
2004	11	27	23.4	17.2	30	18.7	31	15.6	0	0
2004	11	28	26.6	18.8	34.1	20.2	34.5	17.4	0	0
2004	11	29	27.9	19.5	36.2	20.1	37	17.8	0	0
2004	11	30	29.5	20.6	37.5	20.5	37.9	21	0	0
2004	12	1	30	20.9	37.9	20.8	38.5	23.5	0	0
2004	12	2	27.3	19.5	30.5	19.9	32.2	21.2	0	0
2004	12	3	27	20.5	33.8	20	34	15.9	0	0
2004	12	4	23	16.5	28.1	18.7	30	18.5	0	0
2004	12	5	19.2	17.5	25	17.7	25.8	17	1	0
2004	12	6	24.2	18.8	23.5	20	30	16.2	0	0
2004	12	7	23.5	19.5	27.5	21.5	28	17.8	21.8	3
2004	12	8	24.5	19.5	28.5	21.9	30.2	17.5	3.2	2
2004	12	9	25	20.8	30.8	21.8	31.8	20.2	0	1
2004	12	10	22.6	21.4	20	19.5	23.8	22.2	0.6	4
2004	12	11	23.1	19.7	28.7	21.4	29.2	16.5	42.2	3
2004	12	12	27.7	21.6	33.2	21.8	34	20.1	0	2
2004	12	13	31	22.2	35.5	20.2	35.5	21.8	0	1
2004	12	14	28.5	20.5	31.8	20.2	32.8	18.5	0	0
2004	12	15	28	19.5	31.8	20.8	31.8	17.8	0	0
2004	12	16	24.6	19.6	29.5	21.9	30.7	19.1	0	0
2004	12	17	27	22	32	22.2	32.8	20.2	0	0
2004	12	18	27.6	22.4	31.5	23.2	32.1	22.6	0	0
2004	12	19	28	20	33	21.6	34.2	20.2	0	0

1	2	3	4	5	6	7	8	9	10	11
2005	9	30	21.4	15.4	29.3	18.4	29.6	11.7	0	0
2005	10	1	25.6	14.1	30.1	14.9	30.8	12.8	0.4	0
2005	10	2	24.1	16	32.9	16.4	33.8	11.4	0	0
2005	10	3	24.6	13.7	33.5	17	34	11.9	0	0
2005	10	4	25	18.7	35.4	18.9	35.7	15	0	0
2005	10	5	24.4	19.3	35.4	20	35.6	17	0	0
2005	10	6	29	17.9	37.5	19.6	38.1	15	0	0
2005	10	7	25.8	17.1	34.8	20.1	35.9	16	0	0
2005	10	8	30	17.4	26.1	17.2	36.9	20.1	0	0
2005	10	9	18.2	12.1	24.3	14.7	24.3	9.9	0	0
2005	10	10	18.8	12.2	25.5	15	26.5	6.9	0	0
2005	10	11	22.4	15.8	29.8	15	31.4	10.6	0	0
2005	10	12	24.4	16.2	33	16.1	33.6	13.5	0	0
2005	10	13	24.3	17.7	19.4	18.7	32.4	17.6	0	0
2005	10	14	21.8	19	28.2	16.4	28.7	18.9	7.7	1
2005	10	15	20.5	17.3	24	18.4	24.3	16.5	0	0
2005	10	16	16	15.7	19.3	17.5	20.2	15.8	19.2	3
2005	10	17	17.4	16	23.4	19.1	24.6	15	20.1	2
2005	10	18	20.4	15.7	26.2	18.8	26.6	16	0	1
2005	10	19	19.1	15	20.6	17.6	21.4	16.5	0	0
2005	10	20	18.4	17	20.6	18.5	21	16.8	5.5	1

2005	10	21	20.9	19.3	28.5	19	29.1	17.8	0.4	0
2005	10	22	23.9	17.5	30.6	17.6	30.8	12.8	0	0
2005	10	23	24.5	17.6	30.2	17.4	30.8	13.1	0	0
2005	10	24	28.2	20.8	33.5	19.8	33.9	16.7	0	0
2005	10	25	24.5	19.6	31.5	25	31.9	17.5	4.6	1
2005	10	26	26	22	33.3	19.9	33.5	19.8	0	0
2005	10	27	27	21.7	34.3	22.7	34.4	19.2	0	0
2005	10	28	24	19.7	32	19.8	32.9	17.3	12.2	2
2005	10	29	25	20.1	30.4	20.2	30.8	20.2	0	1
2005	10	30	24.1	19	31.4	20.3	31.9	20.6	0	0
2005	10	31	24	19.9	29.6	20.4	30.2	21.4	0	0
2005	11	1	22	18.1	29	20.8	29.1	18	20.4	3
2005	11	2	24	18.8	29.8	20.3	30.4	17.6	0	2
2005	11	3	24.2	19	29.5	19.4	30	18	0	1
2005	11	4	24.8	19.5	30.5	20.4	30.8	17.6	0	0
2005	11	5	25.3	21.1	32.1	22.5	32.2	19.4	0	0
2005	11	6	24	21.3	30.9	22.6	31.1	18.8	11.2	2
2005	11	7	24.3	19.1	30.4	22.6	30.6	19.1	0	1
2005	11	8	24.1	20.7	30.5	23.6	30.8	20.5	13.4	2
2005	11	9	28.1	23.8	33.6	24.5	34.3	21	0	1
2005	11	10	27.3	23	29.9	24.4	31.2	22.4	0	0
2005	11	11	21.5	16.8	25	15.7	35.9	15.6	17.2	2
2005	11	12	23.1	17	27.4	16.4	27.8	12	0	1
2005	11	13	23.2	16.8	29.1	14.8	30.1	12.4	0	0
2005	11	14	24.8	20.4	30.6	21	31.4	17.6	0	0
2005	11	15	26.5	22.2	31.2	23.4	33.1	19	0	0
2005	11	16	21.5	15.1	28.4	15.1	28.6	15	1.2	0
2005	11	17	21.5	14	27.5	16.1	28	11.9	0	0
2005	11	18	22.2	16	30	18.6	30.5	14.4	0	0
2005	11	19	24.8	18.6	33.1	19.9	33.8	17.2	0	0
2005	11	20	28	20.9	35.5	19.6	35.7	20.5	0	0
2005	11	21	27.7	20.3	33.7	21.2	34.6	19.5	0	0
2005	11	22	26.6	20.8	30.4	20.5	31.3	17.6	0.6	6
2005	11	23	18.8	18.7	24.5	20.8	25.2	18.1	60.2	5
2005	11	24	24.5	20.2	29.2	21.4	29.3	17.6	24.2	4
2005	11	25	21.6	18.8	26.8	21.8	27.6	19	0	3
2005	11	26	26.1	21.6	32.6	20.3	32.9	18.3	0	2
2005	11	27	26.7	21.4	26.2	18.1	30.6	20.2	2.2	1
2005	11	28	20.6	15.5	24.6	15.3	24.6	11.4	0	0
2005	11	29	22.8	15.8	28.2	16.4	29.3	11	0	0
2005	11	30	25.5	21	28.6	21.8	29.9	19.3	0	0
2005	12	1	27.2	21.1	32.6	32.2	33.1	17.4	12.2	4
2005	12	2	21.6	20	23.6	20.4	25.1	20	8.6	3
2005	12	3	20.6	15.3	20.6	17.4	25.2	15.9	19.6	2
2005	12	4	24.3	17.4	29.2	17.6	30.5	14.8	0	1
2005	12	5	26.7	21.3	34.6	21.5	35.3	16.2	0	0
2005	12	6	31	23.9	36.6	22.4	36.7	20.1	0	0
2005	12	7	28.1	22.9	33.4	25.5	36	24.5	0.8	2
2005	12	8	28.9	23.9	22.7	22.4	32.9	23	0.1	1
2005	12	9	25.4	22.7	32.1	19.8	32.7	20.2	16	0
2005	12	10	26.8	20.6	32.9	18.7	33.1	16.8	0	0
2005	12	11	28.4	19.6	34	20.8	34.4	16.9	0	0
2005	12	12	26	21	35	22.6	35.6	20.2	0	0
2005	12	13	30.6	23.7	27.5	21.6	38.1	24.3	0	0
2005	12	14	28.6	19.1	33.7	18.4	33.9	20.8	0.4	0
2005	12	15	28.3	20.8	33.6	22.2	35.8	19.4	0	0

2005	12	16	25.5	20.9	25	21.6	30	22	1.6	0
2005	12	17	28	22.9	34.5	19.3	34.9	20.2	0	0
2005	12	18	24	14.5	27.4	16	28.1	16.9	0	0
2005	12	19	23.6	13.7	30	16.2	30.5	10.6	0	0