4. Results

4.1 Overview

The results of applying the method detailed above are presented and analysed in this chapter. The estimated value of climate forecasting to the representative farmer under various decision settings is reported in Section 4.2. Patterns in relationships between various planting conditions, risk attitude and the value of forecasting are explored in Section 4.3. The implications of climatic uncertainty for monetary outcomes in the prior situation, in which the forecasting system is not used, are investigated in Section 4.4. The investigation involves analysis of statistics summarising the prior probability distributions of monetary outcomes associated with each decision setting. The ways in which these prior distributions are changed as a consequence of using the system are examined in Section 4.5. Effects on stage 1 actions of using the system are discussed in Section 4.6. Finally, reported in Section 4.7 are probabilities of use of the system leading to monetary outcomes in a particular season which are better or worse than would otherwise have been the case.

4.2 Value of the Climate Forecasting System

Estimates of the value of the forecasting system under various sets of planting conditions are presented in Tables 4.1, 4.2 and 4.3 for the cases where the representative farmer was assumed to be risk-indifferent (ie., $R_r = 0$), to demonstrate a 'lower than typical' level of risk aversion (ie., $R_r = 0.75$) and to demonstrate a 'typical' level of risk aversion (ie., $R_r = 1.5$) respectively.

As explained in Section 3.5.2, (a) the probability of each of the five dates of planting opportunity occurring is approximately the same, (b) the probability of each of the two levels of initial soil nitrogen occurring is approximately the same; and (c) the

Table 4.1: Value of climate forecasting under various planting conditions when R_r equals 0

Initial soil nitrogen	Initial soil moisture	Date of planting opportunity				
		15th May	26th May	3rd June	15th June	28th June
		\$/ha	\$/ha	\$/ha	\$/ha	\$/ha
40 kg/ha	50%	6.30	4.75	2.51	1.04	0.00
	80%	11.27	5.75	3.39	2.80	1.84
70kg/ha	50%	7.42	4.74	3.21	1.28	0.28
	80%	2.53	6.01	4.20	2.88	1.87

Table 4.2: Value of climate forecasting under various planting conditions when R_r equals 0.75

Initial soil nitrogen	Initial soil moisture	Date of planting opportunity				
		15th May	26th May	3rd June	15th June	28th June
		\$/ha	\$/ha	\$/ha	\$/ha	\$/ha
40 kg/ha	50%	6.97	4.66	2.16	0.97	0.00
	80%	4.34	6.14	3.22	2.94	1.64
70kg/ha	50%	7.83	4.90	2.84	1.16	0.12
	80%	5.14	6.26	4.23	2.86	1.94

probability of each of the two levels of initial soil moisture occurring is approximately the same. It is therefore valid to use the sample of 20 (= 5 x 2 x 2) combinations of planting conditions to estimate the mean value of the forecasting system given a particular risk attitude.

Table 4.3: Value of climate forecasting under various planting conditions when R_r equals 1.5

Initial soil nitrogen	Initial soil moisture	Date of planting opportunity				
		15th May	26th May	3rd June	15th June	28th June
		$/ha	$/ha	$/ha	$/ha	$/ha
40 kg/ha	50%	7.30	4.58	1.88	0.90	0.00
	80%	7.36	6.24	3.62	3.10	1.47
70kg/ha	50%	8.21	4.81	2.49	1.05	0.03
	80%	7.79	6.29	4.55	2.92	2.02

The mean value for a risk-indifferent farmer ($R_r = 0$) was thereby estimated to be $3.70 per hectare available for wheat growing. For a farmer who is ‘less risk-averse than typical’ ($R_r = 0.75$), the estimated mean value was $3.52 per hectare available for wheat growing. The mean value for a farmer who is ‘typically risk-averse’ ($R_r = 1.5$) was $3.83 per hectare available for wheat growing. It is evident that the relationship between degree of risk aversion and mean value of the forecasting system is not consistent in direction.

4.3 Patterns in the Relationship Between the Value of Climate Forecasting, Planting Conditions and Risk Attitude

With 20 possible combinations of planting and three alternative farmer risk attitudes, the climate forecasting system was evaluated under 60 distinct scenarios. The value of the forecasting system was estimated to be positive in all but three of these scenarios. The exceptions are associated with all three risk attitudes and the following combination of planting conditions: 28th June (ie., latest) date of planting opportunity; 40 kg/ha initial soil nitrogen (ie., the lower level); and 50% initial soil moisture (ie., the lower level). Under these conditions the value of forecasting was zero.

The estimated value of climate forecasting varied considerably according to farmer risk attitude and planting conditions. The highest estimated value was \$11.27/ha/yr (ie., \$2,367/yr for the 210 ha wheat growing area of the representative farm) where the farmer is risk-indifferent ($R_r = 0$) and where planting conditions are as follows: 15th May (ie., earliest) date of planting opportunity; 40 kg/ha soil nitrogen; and 80% soil moisture (ie., the higher level).

The results shown in Tables 4.1 to 4.3 were scrutinised to ascertain whether the value of the climate forecasting system varies in a consistent direction when (1) the planting opportunity becomes later; (2) the level of mineralised soil nitrogen at planting increases; (3) the level of soil moisture at planting increases; and (4) degree of risk aversion increases.

With respect to the relationship referred to in (1), there was a predominant tendency for the value of forecasting to decline as planting opportunity becomes later. However, there were three exceptions to this pattern, two of them associated with 70 kg/ha soil nitrogen and 80% soil moisture at planting when R_r alternately equals 0 and 0.75 and the other exception associated with 40 kg/ha soil nitrogen and 80% soil moisture at planting when $R_r = 0.75$. In these cases the value of forecasting for the earliest date of planting opportunity is lower than that for the second earliest date of planting opportunity.

With respect to the relationship referred to in (2), another predominant tendency was for the value of the forecasting system to be greater when soil moisture at planting is at the higher level. There were, however, four exceptions to this pattern. These were the three identified in the previous paragraph plus the case where $R_r = 1.5$ and planting conditions are as follows: 15th May planting opportunity and 70 kg/ha soil nitrogen at planting.

With respect to the relationship referred to in (3), a further predominant tendency was for the value of forecasting to be higher when mineralised soil nitrogen at planting is at the higher level. There were four exceptions to this pattern. Two were associated with farmer risk indifference and planting conditions as follows: (a) 15th May planting opportunity and 80% soil moisture at planting; and (b) 26th May planting opportunity and 50% soil moisture at planting. The third and fourth exceptions were associated with a 15th June planting opportunity associated with 80% initial soil moisture and risk attitude alternately characterised by R_r equal to 0.75 and 1.5.

The tendencies noted in the previous three paragraphs indicate that climate forecasts can usually be expected to benefit the wheat grower more when planting conditions are relatively good than when they are relatively poor. This finding is likely to run counter to the intuition of many.

The data included in Tables 4.1 to 4.3 were reconfigured in Tables 4.4 to 4.7 below to be in a form more suitable for exploring the relationship referred to in (4).

With 40 kg/ha of soil nitrogen and 50% soil moisture at planting (Table 4.4), only in the case of the earliest planting date does the value of the climate forecasting system increase with increasing risk aversion. The value declines with increasing risk aversion for the subsequent three planting dates and is unaffected (ie., remains at zero) for the latest planting date.

With 40 kg/ha of soil nitrogen and 80% soil moisture at planting (Table 4.5), the value of the climate forecasting system consistently increases with increasing risk aversion in the case of the 26th May and 15th June planting opportunities. With regard to the 15th May and 3rd June planting dates, the value declines as R_r increases from 0 to 0.75, but then increases as R_r increases from 0.75 to 1.5. The value declines with increasing risk aversion for the 28th June planting date.

Table 4.4: Effect of risk attitude on value of climate forecasting when soil nitrogen = 40 kg/ha and soil moisture = 50%

R_r	Date of planting opportunity				
	15th May	26th May	3rd June	15th June	28th June
	\$/ha	\$/ha	\$/ha	\$/ha	\$/ha
0	6.30	4.75	2.51	1.04	0.00
0.75	6.97	4.66	2.16	0.97	0.00
1.5	7.30	4.58	1.88	0.90	0.00

Table 4.5: Effect of risk attitude on value of climate forecasting when soil nitrogen = 40 kg/ha and soil moisture = 80%

R_r	Date of planting opportunity				
	15th May	26th May	3rd June	15th June	28th June
	\$/ha	\$/ha	\$/ha	\$/ha	\$/ha
0	11.27	5.75	3.39	2.80	1.84
0.75	4.34	6.14	3.22	2.94	1.64
1.5	7.36	6.24	3.62	3.10	1.47

With 70 kg/ha of soil nitrogen and 50% soil moisture at planting (Table 4.6), only in the case of the earliest planting date does the value of the climate forecasting system consistently increase with increasing risk aversion. In the case of the 26th May planting date, the value increases as R_r increases from 0 to 0.75, but then decreases as R_r increases from 0.75 to 1.5. The value declines consistently with increasing risk aversion for the subsequent three planting dates.

Table 4.6: Effect of risk attitude on value of climate forecasting when soil nitrogen = 70 kg/ha and soil moisture = 50%

R_r	Date of planting opportunity				
	15th May	26th May	3rd June	15th June	28th June
	$/ha	$/ha	$/ha	$/ha	$/ha
0	7.42	4.74	3.21	1.28	0.28
0.75	7.83	4.90	2.84	1.16	0.12
1.5	8.21	4.81	2.49	1.05	0.03

Table 4.7: Effect of risk attitude on value of climate forecasting when soil nitrogen = 70 kg/ha and soil moisture = 80%

R_r	Date of planting opportunity				
	15th May	26th May	3rd June	15th June	28th June
	$/ha	$/ha	$/ha	$/ha	$/ha
0	2.53	6.01	4.20	2.88	1.87
0.75	5.14	6.26	4.23	2.86	1.94
1.5	7.79	6.29	4.55	2.92	2.02

With 70 kg/ha of soil nitrogen and 80% soil moisture at planting (Table 4.7), the value of the climate forecasting system consistently increases with increasing risk aversion in the case of all planting dates except 15th June. In this case, the value declines slightly as R_r increases from 0 to 0.75, but then increases as R_r increases from 0.75 to 1.5.

It is apparent that there is no general empirical relationship to the effect that the value of the climate forecasting system to the representative farmer consistently increases (or decreases) as s/he becomes more risk-averse. As noted in Section 2.2.3, Byerlee and

Anderson (1982) and Mjelde and Cochran (1988) made similar findings. The direction of the effect in this study depends on conditions experienced at planting. However, from the foregoing analysis a few tendencies can be noted. Namely, the relationship between system value and risk aversion is more likely to be positive (a) the earlier a planting opportunity occurs; (b) the higher the level of soil nitrogen at planting; and (c) the higher the level of soil moisture at planting. In short, the relationship between the value of climate forecasting to the representative farmer and his/her degree of risk aversion will more certainly be positive the more optimal are planting conditions.

The answer to questions (1) to (4) above is therefore negative in each case. This confirms Hilton's (1981) conclusion that variation in factors external to an information system (instanced in this study by risk attitude and planting conditions) will not necessarily have a consistent directional effect on its value.

4.4 Characteristics of the Prior Probability Distributions for Monetary Outcomes

Some insight into the patterns of climate forecasting system value discussed above can be obtained by examining the effect that use of the system has on the probability distribution for monetary outcomes (ie., by comparing the prior and posterior probability distribution functions (PDFs)). In this study such a comparison was performed by summarising each PDF by a subset of its moments including the mean (first moment about the origin), its variance (second moment about the mean) and its skewness (third moment about the mean). The standard deviation measure (ie., square root of variance) was used for ease of exposition instead of variance and a measure of relative skewness was used instead of skewness *per se* for the same reason. Relative skewness was measured by:

$$\alpha_3 = \{n / [(n-1)(n-2)]\} \sum_{i} [(x_i - \bar{x}) / s]^3 \qquad (4.1)$$

where n is the number of observations in the sample, x_i is the value of the ith observation, $\bar{x}$ is the sample mean and s is the sample standard deviation.

In this section patterns identified with respect to the various prior PDFs are discussed. In the next section patterns identified in relation to the effect of use of climate forecasting on the PDF for monetary outcomes are discussed. For ease of exposition (ie., because of the smaller mean values involved) the PDFs in each case refer to monetary outcomes in terms of wheat enterprise profit rather than terminal wealth. The shape of the PDFs is the same in either case (the only difference is that the mean of the PDF for profit is lower by the amount of initial wealth).

Descriptive statistics for the prior and posterior PDFs for profit under various planting conditions and degrees of risk aversion are shown in Tables 4.8 to 4.19.

Based on the data in these tables, a number of generalisations can be made regarding the mean of the prior PDF for profit: (1) mean profit increases as planting opportunity becomes earlier; (2) mean profit is greater when initial soil moisture is at the higher level; (3) mean profit is greater when initial soil nitrogen is at the higher level; and (4) mean profit either remains constant or declines as degree of risk aversion increases (depending on whether the change in risk attitude is sufficient to obtain a change in the prior optimal action). As these findings accord with *a priori* expectations, it is only necessary to note further that a change in initial soil moisture from its lower to its higher level in general increases mean profit considerably more than a change in initial soil nitrogen from its lower to its higher level.

With respect to generalisation (4) above, the effects of two increases in risk aversion could be examined given the design of this study: (a) where R_r increases from 0 to 0.75; and (b) where R_r increases from 0.75 to 1.5. Since the climate forecasting system was valued for 20 possible combinations of planting conditions, there were 40 (= 2 x 20) situations in which to observe the effect of increasing risk aversion on the prior PDF for profit. Scrutiny of Tables 4.8 to 4.19 revealed that the prior PDF for profit changes in only five of these 40 situations. All of these five instances are associated with an increase in R_r from 0.75 to 1.5. The planting conditions corresponding with

Table 4.8: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 50%; $R_r = 0$

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	(13 006)	19 189	(0.91)
	Posterior	(11 682)	18 160	(0.51)
26th May	Prior	(13 283)	14 480	(1.47)
	Posterior	(12 285)	14 882	(1.19)
3rd June	Prior	(15 392)	12 777	(1.24)
	Posterior	(14 866)	14 287	(0.95)
15th June	Prior	(19 150)	9 481	(0.64)
	Posterior	(18 932)	9 927	(0.39)
28th June	Prior	(22 213)	7 330	(0.28)
	Posterior	(22 213)	7 330	(0.28)

Table 4.9: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 80%; $R_r = 0$

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	7 378	34 889	(1.49)
	Posterior	9 746	33 386	(1.32)
26th May	Prior	4 491	22 276	(2.12)
	Posterior	5 698	21 573	(2.38)
3rd June	Prior	2 704	18 630	(2.22)
	Posterior	3 415	19 568	(2.38)
15th June	Prior	373	14 079	(2.11)
	Posterior	961	13 497	(2.13)
28th June	Prior	(6 156)	11 631	(1.54)
	Posterior	(5 770)	12 693	(1.27)

Table 4.10: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 70kg/ha; soil moisture = 50%; $R_r = 0$

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	(5 092)	18 889	(0.92)
	Posterior	(3 533)	18 272	(0.39)
26th May	Prior	(5 212)	16 398	(1.25)
	Posterior	(4 216)	15 283	(1.23)
3rd June	Prior	(7 579)	12 481	(1.25)
	Posterior	(6 905)	14 763	(0.96)
15th June	Prior	(11 199)	9 155	(0.68)
	Posterior	(10 932)	9 899	(0.43)
28th June	Prior	(14 386)	7 029	(0.27)
	Posterior	(14 327)	8 377	(0.06)

Table 4.11: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 70kg/ha; soil moisture = 80%; $R_r = 0$

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	13 321	26 585	(1.89)
	Posterior	13 851	28 052	(1.61)
26th May	Prior	12 657	22 095	(2.16)
	Posterior	13 919	21 484	(2.39)
3rd June	Prior	10 446	18 431	(2.22)
	Posterior	11 329	18 289	(2.35)
15th June	Prior	8 176	13 901	(2.11)
	Posterior	8 780	13 945	(2.22)
28th June	Prior	1 814	13 270	(1.29)
	Posterior	2 206	12 971	(1.16)

Table 4.12: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 50%; R_r = 0.75

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	(13 006)	19 189	(0.91)
	Posterior	(11 273)	16 602	(0.56)
26th May	Prior	(13 283)	14 480	(1.47)
	Posterior	(12 285)	14 882	(1.19)
3rd June	Prior	(15 392)	12 777	(1.24)
	Posterior	(14 866)	14 287	(0.95)
15th June	Prior	(19 150)	9 481	(0.64)
	Posterior	(18 932)	9 927	(0.39)
28th June	Prior	(22 213)	7 330	(0.28)
	Posterior	(22 213)	7 330	(0.28)

Table 4.13: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 80%; R_r = 0.75

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	5 469	26 951	(1.85)
	Posterior	6 028	23 631	(1.56)
26th May	Prior	4 491	22 276	(2.12)
	Posterior	5 670	20 767	(2.47)
3rd June	Prior	2 704	18 630	(2.22)
	Posterior	3 329	17 782	(2.47)
15th June	Prior	373	14 079	(2.11)
	Posterior	961	13 497	(2.13)
28th June	Prior	(6 156)	11 631	(1.54)
	Posterior	(5 776)	12 494	(1.30)

Table 4.14: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 70kg/ha; soil moisture = 50%; R_r = 0.75

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	(5 092)	18 889	(0.92)
	Posterior	(3 583)	16 905	(0.53)
26th May	Prior	(5 274)	14 225	(1.51)
	Posterior	(4 226)	14 672	(1.22)
3rd June	Prior	(7 579)	12 481	(1.25)
	Posterior	(6 910)	14 055	(0.95)
15th June	Prior	(11 199)	9 155	(0.68)
	Posterior	(10 932)	9 899	(0.43)
28th June	Prior	(14 386)	7 029	(0.27)
	Posterior	(14 339)	7 889	(0.09)

Table 4.15: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 70kg/ha; soil moisture = 80%; R_r = 0.75

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	13 321	26 585	(1.89)
	Posterior	14 098	23 618	(1.59)
26th May	Prior	12 657	22 095	(2.16)
	Posterior	13 892	20 957	(2.42)
3rd June	Prior	10 446	18 431	(2.22)
	Posterior	11 281	17 504	(2.49)
15th June	Prior	8 176	13 901	(2.11)
	Posterior	8 770	13 730	(2.19)
28th June	Prior	1 814	13 270	(1.29)
	Posterior	2 206	12 971	(1.16)

**Table 4.16: Measures of the prior and posterior PDFs for profit.
Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 50%; R_r = 1.5**

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	(13 207)	16 747	(1.07)
	Posterior	(11 273)	16 602	(0.56)
26th May	Prior	(13 283)	14 480	(1.47)
	Posterior	(12 285)	14 882	(1.19)
3rd June	Prior	(15 392)	12 777	(1.24)
	Posterior	(14 940)	13 395	(1.09)
15th June	Prior	(19 150)	9 481	(0.64)
	Posterior	(18 932)	9 927	(0.39)
28th June	Prior	(22 213)	7 330	(0.28)
	Posterior	(22 213)	7 330	(0.28)

**Table 4.17: Measures of the prior and posterior PDFs for profit.
Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 80%; R_r = 1.5**

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	5 469	26 951	(1.85)
	Posterior	5 918	22 035	(1.43)
26th May	Prior	4 244	19 980	(2.41)
	Posterior	5 467	19 411	(2.45)
3rd June	Prior	2 704	18 630	(2.22)
	Posterior	3 302	17 367	(2.52)
15th June	Prior	373	14 079	(2.11)
	Posterior	961	13 497	(2.13)
28th June	Prior	(6 156)	11 631	(1.54)
	Posterior	(5 779)	12 443	(1.30)

Table 4.18: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 70kg/ha; soil moisture = 50%; R_r = 1.5

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	(5 335)	16 449	(1.08)
	Posterior	(3 583)	16 905	(0.53)
26th May	Prior	(5 274)	14 225	(1.51)
	Posterior	(4 226)	14 672	(1.22)
3rd June	Prior	(7 579)	12 481	(1.25)
	Posterior	(6 910)	14 055	(0.95)
15th June	Prior	(11 199)	9 155	(0.68)
	Posterior	(10 932)	9 899	(0.43)
28th June	Prior	(14 386)	7 029	(0.27)
	Posterior	(14 346)	7 695	(0.10)

Table 4.19: Measures of the prior and posterior PDFs for profit. Assumptions: soil nitrogen = 70kg/ha; soil moisture = 80%; R_r = 1.5

Date of planting opportunity	Distribution	Measures of PDF for profit		
		Mean ($)	Standard deviation	Relative skewness
15th May	Prior	13 321	26 585	(1.89)
	Posterior	13 984	22 031	(1.46)
26th May	Prior	12 339	19 590	(2.55)
	Posterior	13 892	20 957	(2.42)
3rd June	Prior	10 446	18 431	(2.22)
	Posterior	11 257	17 231	(2.52)
15th June	Prior	8 176	13 901	(2.11)
	Posterior	8 765	13 653	(2.16)
28th June	Prior	1 814	13 270	(1.29)
	Posterior	2 206	12 971	(1.16)

each of these instances are: (i) both levels of initial soil nitrogen in association with 50% initial soil moisture and 15th May planting opportunity (Tables 4.16 and 4.18); (ii) both levels of initial soil nitrogen in association with 80% initial soil moisture and 26th May planting opportunity (Tables 4.17 and 4.19); and (iii) 70 kg/ha initial soil nitrogen in association with 50% initial soil moisture and 26th May planting opportunity (Table 4.18).

Standard deviations of the prior PDFs for profit generally remain constant or decline as the degree of risk aversion assumed increases (declining for only the five situations identified in the preceding paragraph). Standard deviations also generally (a) become greater as planting opportunity becomes earlier; and (b) are greater when initial soil moisture is at the higher level. These increases in standard deviation are associated with the increases in mean profit noted in (1) and (2) of two paragraphs earlier. However, standard deviation is more frequently less when initial soil nitrogen is at the higher level (and mean profit is higher as noted in (3) of two paragraphs earlier) than it is when soil nitrogen is at the lower level.

The prior PDFs for profit are in general negatively skewed (as evidenced by the measure of relative skewness being negative for all combinations of risk attitude and planting conditions). However, the degree of negative skewness (a) varies substantially (but in an inconsistent direction) as date of planting opportunity becomes earlier; and (b) increases considerably when initial soil moisture is at its higher level. In contrast, degree of risk aversion and level of initial soil nitrogen predominantly have a minor effect on the relative skewness of the prior PDF.

4.5 Effect of Climate Forecasting on Probability Distributions for Monetary Outcome

The effect of using the climate forecasting system on PDFs for profit could also be examined by comparing the statistics in Tables 4.8 to 4.19 characterising the prior and posterior PDFs for each particular decision setting.

Use of forecasting increased mean profit in all of the 60 situations analysed except for three in which mean profit was unchanged. These situations were those identified in Section 4.2 as associated with the forecasting system having zero value. They correspond with the three assumed levels of risk aversion and the following combination of planting conditions: 40 kg/ha initial soil nitrogen, 50% initial soil moisture and 28th June planting opportunity (Tables 4.8, 4.12 and 4.16). These situations represent the least agronomically favourable of the combinations of planting conditions analysed.

The directional effect of use of climate forecasting on the standard deviation of profit is complex. Most noticeable of the patterns is that use of climate forecasting *tends* to (a) increase standard deviation of profit when initial soil moisture is at the lower of the two levels and (b) reduce standard deviation of profit when soil moisture is at the higher of the two levels.

The effect of use of climate forecasting on the skewness of the profit distribution is also not consistent in direction. When soil moisture is at the lower of the two levels, use of forecasting does consistently reduce the negative skewness of the distribution. When soil moisture is at the higher of the two levels, however, the effect is not consistent in direction.

4.6 Effect of Use of Climate Forecasting on Stage 1 Options

As noted in Section 2.2.2, information has value only to the extent that actions are changed from what they would otherwise have been. The extent to which the climate forecasting system of interest affects stage 1 actions of the representative farmer in various decision settings can be assessed with reference to Tables 4.20 to 4.31.

Note that in preparing the tables, code was used to abbreviate the description of options associated with each action. Take for example the action code:

M120 x 2
L80 x 1

The letters *M* and *L* commencing the two lines of code refer to medium and late maturing varietal types respectively. The number immediately following the letter refers to the rate of nitrogen application (kg/ha) at planting. The multiplication operator and the following number refer to the number of 70 ha paddocks devoted to that option. Thus in this case the action consists of undertaking two options. The first, to which two paddocks are allocated, involves planting the medium maturing varietal type with 120 kg/ha of nitrogen. The second, to which one paddock is allocated, involves planting the late maturing varietal type with 80 kg/ha of nitrogen. Note that *E* commencing a code in the following tables refers to the early maturing varietal type.

Only in three of the 60 situations analysed does use of the forecasting system result in optimal actions associated with all forecast types being identical to the prior optimal action. These situations were those identified in Section 4.2 as associated with the forecasting system having zero value and in Section 4.5 as those having no effect on mean profit.

Inspection of the tables reveals that for none of the risk attitudes or sets of planting conditions analysed was the option of maintaining a fallow included in a prior optimal or Bayes' action. Hence even when the forecast type applying to the imminent season signifies a climatic outlook that is less favourable than average (ie., phase 1 and phase 3 forecast types as noted in Section 1.3), the utility of the representative farmer is invariably maximised by planting wheat on each of the three paddocks available to this enterprise.

It is also apparent that actions involving specialisation in a particular option feature much more frequently than do actions involving diversification among options. Specialisation is of course the only strategy that a rational risk-indifferent farmer would pursue. When risk aversion of degrees $R_r = 0.75$ and $R_r = 1.5$ was assumed, however, a minority of prior optimal and Bayes' actions did involve diversification among options. Contrary to what may have been expected, diversification features no more frequently in prior optimal and Bayes' actions when risk aversion of degree $R_r = 1.5$ was assumed

Table 4.20: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 50%; $R_r = 0$

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M120 x 3	M140 x 3	M100 x 3	M180 x 3	M200 x 3	L60 x3
26th May	E100 x 3	E60 x 3	E120 x 3	E120 x 3	M140 x 3	E80 x 3
3rd June	E80 x 3	E40 x 3	E120 x 3	E100 x3	E120 x 3	E80 x 3
15th June	E60 x 3	E20 x 3	E80 x 3	E60 x 3	E80 x 3	E60 x 3
28th June	E40 x 3	E40 x 3	E40 x 3	E40 x 3	E40 x 3	E40 x 3

Table 4.21: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 80%; $R_r = 0$

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M320 x 3	M320 x 3	M300 x 3	M360 x 3	M360 x 3	M240 x 3
26th May	M240 x 3	M180 x 3	M260 x 3	M280 x 3	M240 x 3	M220 x 3
3rd June	M200 x 3	M140 x 3	M200 x 3	M200 x 3	M260 x 3	M220 x 3
15th June	E180 x 3	E120 x 3	E180 x 3	E160 x 3	E200 x 3	E180 x 3
28th June	E140 x 3	E160 x 3	E180 x 3	E140 x 3	E160 x 3	E120 x 3

Table 4.22: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 70kg/ha; soil moisture = 50%; R_r = 0

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M80 x 3	M40 x 3	M60 x 3	M180 x 3	M180 x 3	L20 x 3
26th May	E80 x 3	E20 x 3	E80 x 3	E80 x 3	M100 x 3	E60 x 3
3rd June	E40 x 3	E0 x 3	E80 x 3	E60 x 3	E80 x 3	E60 x 3
15th June	E20 x 3	E0 x 3	E40 x 3	E20 x 3	E40 x 3	E20 x 3
28th June	E0 x 3	E0 x 3	E0 x 3	E0 x 3	E20 x 3	E20 x 3

Table 4.23: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 70kg/ha; soil moisture = 80%; R_r = 0

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M200 x 3	M200 x 3	M250 x 3	M225 x 3	M350 x 3	M160 x 3
26th May	M200 x 3	M140 x 3	M220 x 3	M240 x 3	M200 x 3	M180 x 3
3rd June	M160 x 3	M100 x 3	M160 x 3	M160 x 3	M180 x 3	M160 x3
15th June	E140 x 3	E80 x 3	E140 x 3	E140 x 3	E160 x 3	E160 x 3
28th June	E120 x 3	E120 x 3	E140 x 3	E100 x 3	E120 x 3	E100 x 3

Table 4.24: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 50%; R_r = 0.75

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M120 x 3	M80 x 3	M100 x 3	M160 x 3	M200 x 3	L60 x 3
26th May	E100 x 3	E60 x 3	E120 x 3	E120 x 3	M140 x 3	E80 x 3
3rd June	E80 x 3	E40 x 3	E120 x 3	E100 x 3	E120 x 3	E80 x 3
15th June	E60 x 3	E20 x 3	E80 x 3	E60 x 3	E80 x 3	E60 x 3
28th June	E40 x 3	E40 x 3	E40 x 3	E40 x 3	E40 x 3	E40 x 3

Table 4.25: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 80%; R_r = 0.75

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M240 x 3	M240 x 3	M280 x 3	M260 x 3	M240 x 3	M200 x 2 L160 x 1
26th May	M240 x 3	E140 x 2 M180 x 1	M260 x 3	M280 x 3	M240 x 3	M200 x 3
3rd June	M200 x 3	M140 x 3	M200 x 3	M200 x 3	M220 x 3	M160 x 2 M220 x 1
15th June	E180 x 3	E120 x 3	E180 x 3	E160 x 3	E200 x 3	E180 x 3
28th June	E140 x 3	E140 x 3 E160 x 3	E180 x 3	E140 x 3	E160 x 3	E120 x 3

Table 4.26: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 70kg/ha; soil moisture = 50%; R_r = 0.75

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M80 x 3	M40 x 3	M60 x 3	M120 x 3	M180 x 3	L20 x 3
26th May	E60 x 3	E20 x 3	E80 x 3	E80 x 3	M100 x 3	E40 x 3
3rd June	E40 x 3	E0 x 3	E80 x 3	E60 x 3	E80 x 3	E40 x 3
15th June	E20 x 3	E0 x 3	E40 x 3	E20 x 3	E40 x 3	E20 x 3
28th June	E0 x 3	E0 x 3	E0 x 3	E0 x 3	E20 x 3	E0 x 2 E20 x 1

Table 4.27: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 70kg/ha; soil moisture = 80%; R_r = 0.75

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M200 x 3	M200 x 3	M240 x 3	M220 x 3	M220 x 3	M160 x 3 L120 x 1
26th May	M200 x 3	M140 x 3	M220 x 3	M240 x 3	M200 x 3	M160 x 3
3rd June	M160 x 3	M100 x 3	M160 x 3	M160 x 3	M180 x 3	M120 x 2 M160 x 1
15th June	E140 x 3	E80 x 3	E140 x 3	E120 x 2 E140 x 1	E160 x 3	E160 x 3
28th June	E120 x 3	E120 x 3	E140 x 3	E100 x 3	E120 x 3	E100 x 3

Table 4.28: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 50%; R_r = 1.5

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M100 x 3	M80 x 3	M100 x 3	M160 x 3	M200 x 3	L60 x 3
26th May	E100 x 3	E60 x 3	E120 x 3	E120 x 3	M140 x 3	E80 x 3
3rd June	E80 x 3	E40 x 3	E80 x 1 E120 x 2	E100 x 3	E100 x 3	E80 x 3
15th June	E60 x 3	E20 x 3	E80 x 3	E60 x 3	E80 x 3	E60 x 3
28th June	E40 x 3	E40 x 3	E40 x 3	E40 x 3	E40 x 3	E40 x 3

Table 4.29: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 40 kg/ha; soil moisture = 80%; R_r = 1.5

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M200 x 3	M240 x 3	M280 x 3	M260 x 3	M240 x 3	M180 x 1 L160 x 2
26th May	M200 x 1 M220 x 2	E140 x 3	M260 x 3	M180 x 2 M280 x 1	M240 x 3	M180 x 3
3rd June	M200 x 3	M140 x 3	M200 x 3	M200 x 3	M220 x 3	M160 x 3
15th June	E180 x 3	E120 x 3	E180 x 3	E160 x 3	E200 x 3	E180 x 3
28th June	E140 x 3	E140 x 3	E180 x 3	E140 x 3	E160 x 3	E120 x 3

Table 4.30: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 70kg/ha; soil moisture = 50%; R_r = 1.5

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M60 x 3	M40 x 3	M60 x 3	M120 x 3	M180 x 3	L20 x 3
26th May	E60 x 3	E20 x 3	E80 x 3	E80 x 3	M100 x 3	E40 x 3
3rd June	E40 x 3	E0 x 3	E80 x 3	E60 x 3	E80 x 3	E40 x 3
15th June	E20 x 3	E0 x 3	E40 x 3	E20 x 3	E40 x 3	E20 x 3
28th June	E0 x 3	E0 x 3	E0 x 3	E0 x 3	E20 x 3	E0 x 3

Table 4.31: Stage 1 prior optimal and Bayes' actions.
Assumptions: soil nitrogen = 70kg/ha; soil moisture = 80%; R_r = 1.5

Date of planting opportunity	Type of forecast available					
	None	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
15th May	M200 x 3	M200 x 3	M240 x 3	M220 x 3	M220 x 3	M140 x 1 L120 x 2
26th May	M160 x 2 M200 x 1	M140 x 3	M220 x 3	M240 x 3	M200 x 3	M160 x 3
3rd June	M160 x 3	M100 x 3	M160 x 3	M160 x 3	M180 x 3	M120 x 3
15th June	E140 x 3	E80 x 3	E140 x 3	E120 x 3	E160 x 3	E160 x 3
28th June	E120 x 3	E120 x 3	E140 x 3	E100 x 3	E120 x 3	E100 x 3

than it does when risk aversion of degree $R_r = 0.75$ was assumed.

As would be expected in an environment where the optimal period for flowering of a crop is short (see Section 3.2), scrutiny of these tables demonstrates that the maturity of the varietal type/s chosen in optimal actions becomes shorter as the planting opportunity becomes later.

Nitrogen application rates associated with optimal actions are considerably increased when soil moisture is at the higher initial level. To the extent that mineralised soil nitrogen and applied nitrogen are substitutes, it would be expected that the optimal rate of nitrogen application would be lower when mineralised soil nitrogen is at the higher of the two levels. This was the case in all situations examined except in one where the optimal rate of nitrogen applied was the same under both levels of initial soil nitrogen. In all there were 180 pairs of comparable actions (the product of six possible forecast-use scenarios, five planting opportunities, three risk attitudes and two initial soil moisture levels). Five of these pairs involved an action involving diversification into two options. In each of these cases the weighted average rate of applied nitrogen was less when initial soil nitrogen was at the higher level.

Inspection of the tables also reveals that nitrogen application rates associated with optimal actions invariably decline as planting opportunity becomes later.

A tendency for the optimal rate of applied nitrogen to decline as the degree of risk aversion increases would also be expected to the extent that the standard deviation of profit becomes greater as applied nitrogen increases. There were 120 pairs of actions comparable on the basis of increased risk aversion (the product of six possible forecast-use scenarios, five planting opportunities, two initial soil moisture levels, two initial soil nitrogen levels and two increases in risk aversion - from $R_r = 0$ to $R_r = 0.75$ and from $R_r = 0.75$ to $R_r = 1.5$). In 39 of these instances the weighted average rate of applied nitrogen was less with the higher degree of risk aversion. In all of the remaining instances the rate of applied nitrogen was unaffected by degree of risk aversion.

A further issue concerns whether there is a consistent directional effect of various forecast types on the optimal rate of nitrogen application. This issue is of interest because it might be intuitively supposed by non-economists that (a) when seasons are good climatically, and hence wheat yields are higher than average, the optimal rate of nitrogen application will be greater than the optimal rate when seasons are poor climatically, and hence when yields are lower than average; and therefore that (b) optimal nitrogen application rates will invariably be higher with phase 2 and phase 4 forecast types (associated with better than average climatic conditions in the following season (see Section 1.3)) than with phase 1 or phase 3 forecast types (associated with climatic conditions less agronomically favourable in the following season than on average).

According to production economics theory, however, the optimal rate (ie., profit-maximising rate if certainty is assumed) of use of an input such as nitrogen occurs where marginal value product (MVP), which is given by the slope of the total revenue (TR) curve, is equal to marginal factor cost (MFC). This is given by the slope of the total cost curve which in this study is given by the per unit farm-gate price of nitrogen. MVP may be affected by forecast type, whereas MFC is not.

However, there is no logical reason why, if yields associated with one forecast type are higher than yields associated with another forecast type (ie., the former total product (TP) curve lies above that of the latter), the equi-marginal point would invariably be further to the right (ie., higher optimal nitrogen application) in the former case. The direction in which this point moves depends on how the relationship between MVP and rate of nitrogen application differs between forecast types (ie., on how the shape of the TR curve differs).

The effect on the shape of the TR curve of an upward shift in the TP curve depends on (i) how the shape of the TP curve changes; and (ii) how per unit wheat revenue changes as rate of nitrogen application increases (since TR is given by the product of TP and per unit revenue). With regard to (i), the effect on the shape of the TP curve can only be gauged on a case-by-case basis.

With regard to (ii), per unit wheat revenue tends to increase as the rate of nitrogen applied increases. This is because soil nitrogen in the case study district has become limiting (see Section 3.2) with respect to achieving grain protein levels sufficiently high to realise price premiums available for Australian Hard and Prime Hard grades of wheat (see Section A3.4 of Appendix 3). Since nitrogen is less limiting when yields are lower, there is a tendency for per unit wheat revenue to increase as yields decrease. This revenue effect dampens the effect of forecast type on the location of the TR curve and also influences its shape, thereby making hazardous any intuitive judgement regarding the relationship between the relative yield effects associated with various forecast types and relative effects in terms of optimal levels of nitrogen application.

Of the 60 possible combinations of planting conditions and degrees of risk aversion, in 15 cases (25 per cent) the weighted average optimal rate of nitrogen application was greater in association with at least one of the less favourable forecasts (phase 1 and phase 3) than it was in association with at least one of the more favourable forecasts (phase 2 and phase 4). That is, in a substantial minority of cases the ‘intuitive’ reasoning recounted above would lead to sub-optimal adjustments to a farmer’s nitrogen application strategy in response to particular types of forecast.

4.7 Performance of Forecasts in the Short Run

The value of the forecasting system as calculated in this study can be viewed as a value relating to repetitive use of the system over a long run. That is, the representative farmer could expect on average to realise this value if s/he continued to use the system regardless of instances when monetary outcomes were poorer as a result of using the system. The question arises, however, of whether use of the system would in fact continue if initial use led to adverse monetary outcomes. Stone *et al.* (undated) suggested that farmers need to be educated to think probablistically before sustained adoption of the forecasting system is likely.

In order to assess the significance for the representative farmer of this purported impediment to adoption, probabilities of (a) a positive monetary effect of using the forecasting system in the imminent season ('success'); (b) a negative monetary effect of using the forecasting system in the imminent season ('failure'); and (c) no monetary effect ('neutral'); are presented in Tables 4.32 to 4.34 for various combinations of planting opportunity and risk attitude.

Scrutiny of these tables reveals that the highest probability of success in an imminent season is 55 per cent and the highest probability of failure is 54 per cent. Of the 60 combinations of planting conditions and risk attitude represented in the tables, the probability of failure exceeds the probability of success in 17 cases (ie., 28 per cent of cases). Depending on the planting conditions encountered in a particular season and the farmer's risk attitude, a high chance of making oneself worse off (albeit temporarily) might be significant in discouraging farmers from using the forecasting system.

Nevertheless in each of the 17 cases referred to above the value of the forecasting system was calculated to be positive. This is due to the probability distributions for the monetary effect of using the system in these situations being positively skewed. That is, the average magnitude of successes exceeds the average magnitude of failures.

The probability of successes and failures of various magnitudes can, for each combination of planting conditions and risk attitude, be ascertained by referring to cumulative distribution functions for the profit effect of using the system. As an example, cumulative distribution functions (CDFs) for the profit effect of a risk-indifferent farmer using the system when the levels of initial soil nitrogen and initial soil moisture are 70 kg/ha and 50% respectively are illustrated in Appendix 4. Each CDF corresponds with a different date of planting opportunity. With a 15th April planting opportunity, for instance, the probability of use of the system leading to profit

Table 4.32: Probabilities of forecasting success and failure when R_r equals 0

Initial soil nitrogen (kg/ha)	Initial soil moisture	Outcome from using forecasts	Probability (%) of outcome, given date of planting opportunity:				
			15th May	26th May	3rd June	15th June	28th June
40	50%	Success	53	53	42	31	0
		Failure	47	47	32	29	0
		Neutral	0	0	27	41	100
	80%	Success	37	42	29	26	40
		Failure	33	34	36	27	46
		Neutral	31	24	36	48	14
70	50%	Success	50	38	55	32	23
		Failure	50	27	45	28	28
		Neutral	0	36	0	41	49
	80%	Success	45	43	20	26	36
		Failure	41	33	17	39	27
		Neutral	14	24	62	36	38

Table 4.33: Probabilities of forecasting success and failure when R_r equals 0.75

Initial soil nitrogen (kg/ha)	Initial soil moisture	Outcome from using forecasts	Probability (%) of outcome, given date of planting opportunity:				
			15th May	26th May	3rd June	15th June	28th June
40	50%	Success	53	53	42	31	0
		Failure	47	47	32	29	0
		Neutral	0	0	27	41	100
	80%	Success	28	39	34	26	40
		Failure	42	37	31	27	46
		Neutral	31	24	36	48	14
70	50%	Success	52	53	43	32	23
		Failure	48	47	31	28	28
		Neutral	0	0	27	41	49
	80%	Success	33	41	36	33	36
		Failure	53	35	29	46	27
		Neutral	14	24	36	21	38

Table 4.34: Probabilities of forecasting success and failure when R_r equals 1.5

Initial soil nitrogen (kg/ha)	Initial soil moisture	Outcome from using forecasts	Probability (%) of outcome, given date of planting opportunity:				
			15th May	26th May	3rd June	15th June	28th June
40	50%	Success	43	53	40	31	0
		Failure	34	47	34	29	0
		Neutral	23	0	27	41	100
	80%	Success	26	53	34	26	36
		Failure	44	45	31	27	37
		Neutral	31	2	36	48	28
70	50%	Success	44	53	43	32	11
		Failure	33	47	31	28	13
		Neutral	23	0	27	41	76
	80%	Success	32	62	36	33	36
		Failure	54	38	29	46	27
		Neutral	14	0	36	21	38

being reduced by more than $20,000 is zero. The probability of the effect on profit being less than zero is approximately 0.5, whereas the probability of profit being increased by less than $40,000 is 1.0. CDFs for the remaining combinations of risk attitude and planting conditions are available from the author.

4.8 Summary

The estimated values of the forecasting system under various combinations of risk attitude and planting conditions were presented and discussed in this section. A summary of the findings is included in Section 5.1.

5. Conclusions

5.1 Research Findings

In this study the value of a particular climate forecasting system for wheat growing by a representative farmer in the vicinity of Goondiwindi was estimated across a range of decision environments. The decision environments differed both in terms of the farmer's risk attitude and in terms of planting conditions (including date of planting opportunity and levels of mineralised soil nitrogen and soil moisture at that date).

The primary objective of valuing the forecasting system was to provide information of use in assessing the magnitude of benefits from the research and extension invested in its development and promulgation. Subsidiary objectives were to explore whether there are consistent patterns in the relationship between the value of the system and the characteristics of the decision environment.

The value of the system was estimated to be positive in all of the 60 decision environments analysed except for three where it was estimated to be zero. Thus null hypothesis 1, that 'the climate forecasting system is of no value to wheat growers in north-eastern Australia', was rejected in accordance with the criterion set in Section 1.4.

The highest value estimated across decision environments was \$11.27 per hectare available for wheat growing. However, the mean value for a risk-indifferent farmer ($R_r = 0$) was estimated to be \$3.70 per hectare available for wheat growing. For a farmer who is 'less risk-averse than typical' ($R_r = 0.75$) the estimated mean value was \$3.52 per hectare available for wheat growing, while for a farmer who is 'typically risk-averse' ($R_r = 1.5$) the corresponding value was \$3.83 per hectare available for wheat growing.

As noted in Sections 2.1 and 2.2, Stone *et al.* (undated) estimated the value of the same forecasting system assuming the representative wheat grower acts according to a 'safety-first' decision criterion rather than according to an EU-maximisation criterion. The value of the system for the planting-time nitrogen application decision was estimated to be about $2/ha with the grower willing to accept a 30 per cent chance of the wheat enterprise making a loss in the imminent season and about $10/ha with a 10 per cent chance of loss being acceptable. The value of the planting-time decision regarding type of wheat variety was estimated to be between $5-$10/ha. Since the two decisions are interdependent, however, the separate values of the system for the two types of decision cannot validly be added to obtain a total value to be compared with the range of mean values estimated in this study. Nevertheless, since the lower bound for the variety decision is $5/ha, the total value for both decisions must be greater than this. This lower bound for the total value exceeds the highest mean value reported above by 31 per cent. Apart from the difference in the decision criterion, the discrepancy between the values estimated can largely be attributed to the current study (unlike the study by Stone *et al.* (undated)) accounting for within-season tactical responses and the value of residual nitrogen fertiliser for the following wheat crop.

One possible benchmark for assessing the relative significance of the above values is the estimate by Brennan (1989) that on average the release of a new wheat variety provides yield and quality benefits to farmers of $3.38/t (based on a fob export price of $174/t which is lower than the price of $183/t assumed in this study for grain of ASW standard). For an average Goondiwindi wheat yield of 1.4 t/ha (Lawrence 1993), this is equivalent to a farm-level benefit of $4.73/ha/yr. Hence the mean annual benefit to the representative wheat grower from the development of the forecasting system is lower than that from the development of an 'average' new wheat variety. Since the wheat prices assumed were higher in this study than in Brennan (1989), these figures under-estimate the degree to which the per hectare value of an average new wheat variety exceeds the per hectare value of the forecasting system. Assessment of the relative economic merits of the two types of research project, however, would require that the costs of each also be accounted for. However, this task was outside the scope of this study.

As discussed in Section 4.3, the estimated value of the forecasting system varied considerably according to farmer risk attitude and planting conditions. Thus null hypothesis 2, that 'the value of the forecasting system is unaffected by a farmer's attitude to risk', was rejected. Similarly, null hypothesis 3, that 'the value of the forecasting system is unaffected by planting conditions', was also rejected.

Of particular significance were findings illustrating the veracity of Hilton's (1981) conclusion that attributes of the decision-maker and the decision setting do not exhibit a consistent directional effect on information value. Thus it is not possible to conclude that the value of the forecasting system will invariably be higher (a) the earlier a planting opportunity occurs; (b) the higher the level of initial soil nitrogen; (c) the higher the level of initial soil moisture; or (d) the more risk-averse the farmer; nor that it will be invariably lower. This finding is of course not helpful to climatological researchers seeking a heuristic to assist them in setting priorities within their programs. However, an appreciation of this ambiguity is necessary if past mistakes in priority setting resulting from reliance on an over-simplistic heuristic are not to be repeated.

5.2 Contributions to a Method of Valuing Farmer Benefits from Climate Forecasts

Significant contributions were made in this study toward development of a method by which expected utility theory can be applied to value a climate forecasting system.

Following Mjelde *et al.* (1988), a sequential decision model was developed to account for tactical opportunities available to farmers as climatic events unfold during the season. Failure to have accounted for such pre-existing opportunities for on-farm response to climatic variability would have resulted in biased estimation of the value of the forecasting system. Unlike in Mjelde *et al.* (1988), however, where sequential decision-making was modelled using stochastic dynamic programming (SDP), a recursive stochastic programming (RSP) approach was used in this study.

All things otherwise being equal, SDP would be the superior approach since its solution by backward recursion endogenously accounts for opportunity costs of decisions at each stage in terms of options precluded in subsequent stages. However, the approach developed in this study has the significant pragmatic advantage of not requiring as high a level of mathematical programming (MP) expertise as does SDP. This is because:

(a) the RSP approach is conceptually simpler to grasp; and

(b) it is more 'user friendly' to apply because popular spreadsheet packages combined with add-in MP software can be used whereas SDP requires use of specialised software with which spreadsheet interaction is more complicated. Forward recursion can be handled relatively simply in the RSP approach by writing spreadsheet macros to transfer solutions of the MP model for one stage to the constraint set of the MP model for the subsequent stage.

However, reliance on forward recursion requires opportunity costs of decisions at each stage to be calculated exogenously from the MP algorithm, and therefore more arbitrarily. In this case, however, loss of modelling accuracy due to using RSP instead of SDP was judged to be outweighed by the pragmatic advantages of the approach.

An advantage of the approach used over the approach used by Mjelde *et al.* (1988) was that it allowed for EU theory to be applied consistently in both (i) using a decision model to identify prior optimal and Bayes' actions; and (ii) deriving the value of the forecasting system. As noted in Section 2.3, the approach used by Mjelde *et al.* (1988) was internally inconsistent because prior optimal and Bayes' actions were identified assuming risk-indifference, but varying degrees of risk aversion were assumed in deriving the value of the forecasting system. In this study the utility function used in the RSP model to identify prior optimal and Bayes' actions was the same as used in valuing the forecasting system, thereby avoiding the possibility of valuation being biased by inconsistency in this area.

5.3 Limitations of the Study

At this stage it is appropriate to discuss the limitations of the method used in relation to the objectives of the study.

Perhaps the most substantial limitation of the study relates to the enterprise and location specificity of the single case study analysed. It is obviously not possible to estimate the aggregate value of the climate forecasting system for wheat growing in north-eastern Australia on the basis of studying a single situation. Nevertheless the method developed in this study could be adapted for application in a range of other situations throughout this region, thereby developing a data base which would allow such an estimate to be derived with reasonable confidence.

Another limitation was that not all tactical decisions that may benefit from the forecasting system were accounted for in the sequential decision model. For instance, Stone *et al.* (undated) suggested that tactical decisions regarding timing and method of harvesting may benefit from forecasts available from this system.

There are also additional tactical options available at stage 1 that involve expanding or reducing the wheat area such that there are offsetting changes to the areas of other enterprises. The only alternative to planting wheat allowed in the decision model was maintaining a fallow. In reality, a farmer may switch between wheat and other enterprises depending on planting conditions, risk attitude and the prevailing forecast type. For example, in a year where the prevailing forecast type indicates above average probability of a dry season, the farmer may decide to grow less wheat than usual and increase the area allocated to fodder crops. These additional tactical decisions were not considered in the study due to the considerable increase in modelling complexity that would have been involved.

A final limitation of the study was that time precluded testing the sensitivity of estimated values of the forecasting system to changes in the pricing scheme assumed in Section A3.4 of Appendix 3.

5.4 Priorities for Further Research

Having identified a number of limitations of the study in Section 5.3, it is apparent that there are opportunities for further significant research in this area. Perhaps most urgent among these is adaptation of the approach used in this study to value the benefits of the climate forecasting system in a range of other decision environments, thereby gaining sufficient observations to be able to estimate more confidently the aggregate benefits of use of the system for wheat growing in the north-eastern grain belt.

Since double-cropping is uncommon in the district used as a case study for the research reported herein, it would be of particular interest to investigate whether the value of the system is greater or lower in districts where double cropping is a normal practice (eg. Darling Downs). Double-cropping is likely to involve more tactical decisions which may benefit from use of the forecasting system. Nevertheless, even without a climate forecasting system, double-cropping systems provide significant scope for monetary consequences of adverse climatic variability in one season to be dampened due to availability of 'catch-up' tactical options in the following season. It is unclear therefore whether the value of the forecasting system would be higher or lower for double-cropping systems than it is for single-season cropping systems.

The sensitivity of the value of the forecasting system to changes in the pricing scheme for wheat should also be explored as a matter of priority. Changes in the average level of prices across wheat grades may have a significant effect on the value of the system, as also may changes in the premiums paid according to grain protein level.

A further research avenue lies in attempting to account more completely for the full range of tactical decisions benefiting from use of the forecasting system, thereby removing the possible tendency in this study to under-estimate the value of the system.

The method developed in this study could also be adapted to value climate forecasting systems other than the one addressed in this study. Prospects for progress in climatological research of relevance to seasonal forecasting (Nicholls 1994; Hunt

1994) suggests climate forecasting systems, like other agricultural inputs, will be subject to innovation in coming years.

Finally, as noted in Section 2.3, CVM could also be used to value the information provided by a climate forecasting system. This approach circumvents the problems faced in this study of specifying a decision-maker's attitude to, and subjective assessment, of risk. Pluske (1994) found that the values of information obtained from wool growers using the CVM approach were valid and reliable estimates of the true values.