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Valuing a Test for Nitrogen Status in Rice

Rajinder P. Singh, Robert Williams, John Mullen, Khaled Faour and Laurie Lewin *

* Rajinder P. Singh is a Research Economist with NSW Department of Primary Industries at the Yanco Agricultural Institute, Yanco, Robert Williams was a Research Agronomist with NSW Agriculture at the Yanco Agricultural Institute, Yanco, John Mullen is a Principal Research Scientist with NSW Department of Primary Industries at Orange, Khaled Faour was an Economist with NSW Department of Primary Industries at the Yanco Agricultural Institute, Yanco and Laurie Lewin is a director, Rice CRC at the Yanco Agricultural Institute, Yanco

Corresponding author: Dr Rajinder P. Singh, Economist, NSW Department of Primary Industries, Yanco Agricultural Institute, Yanco, NSW 2703 Ph: 02 69 512 618 Fax: 02 69 557 580Email: Rajinder.pal.singh@agric.nsw.gov.au

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Abstract

Nitrogen is a crucial input for the efficient production of rice and is generally applied in two split treatments, before flooding the rice paddocks at sowing time and within a week after the beginning of the panicle initiation stage. There is no pre-sowing test to estimate nitrogen requirements and farmers use cropping history to make this decision.

The aim of this study was to first value the information to growers provided by a nitrogen test for soils of rice paddocks and then estimate the returns to the industry from investments in R&D to develop this test. In our approach the information provided by the test allowed growers to revise their expectations about soil nitrogen status according to Bayesian decision theory and consequently to use nitrogen more profitably. We found that the test is likely to provide information potentially valuable to growers at around $2/ha and that research in developing the test has been a profitable investment for the Rice CRC with a benefit cost ratio just above one. As the accuracy of the test is improved to current industry standards, its use will become more profitable.

Key words : rice, nitrogen, risk

1. Introduction

Rice is the most significant summer crop in southwestern NSW. To maintain soil fertility farmers rotate their rice fields between all rice-suitable areas on the farm. Until the 1960s, the cropping sequences were such that there was a little pressure on soil fertility because farmers grew rice after four or five years of pasture. This rotation maintained crop yields because soil nutrients (N, P, K) removed from the paddock by rice were replenished under pasture.

Around 1970, restrictions preventing continuous rice cultivation were removed. Also, changes in water-use policy by the Department of Land and Water Conservation (DLWC) increased water availability for rice growing. This led to more intensive growing of rice with a reduced pasture phase. Later the area under winter cereals increased, leading to a further decline in the pasture phase in rotations. Now some farmers are moving away from pasture altogether. This has led to more pressure on soil fertility from intensive cropping and a greater reliance on chemical fertilisers for rice production.

Nitrogen (N) is a crucial input for efficient rice production. Most of the investigations conducted all around the world including Australia reveal that split application of nitrogen is beneficial in achieving better rice yields (Bacon & Heanan, 1984; Barmes, 1985; Fujisaka, 1993; Heanan & Lewis 1982) **.** Application of nitrogen fertilisers on rice is best either at the pre-flooding (PF) stage or at panicle initiation (PI). This maximises the availability and uptake of nitrogen by the rice plant and minimise losses (NSW DPI, 2004). The first application is given before flooding the rice paddocks at sowing time in late September to early November, i.e. at the PF stage. The second application is applied within a week after the beginning of the PI stage, which occurs in late December to late January, depending upon variety and sowing date. Crop yields are highly responsive to both treatments of nitrogen fertilisers. Nitrogen applied at the PF stage is essential for growth of the rice plant, from sowing through to the PI stage, whereas nitrogen applied at the PI stage is critical for healthy grain formation. However the application of nitrogen at PI stage cannot fully compensate for yield losses if too little nitrogen is applied at PF stage.

Temperature conditions after the PI stage are crucial for proper growth of the plant and for achieving maximum grain yields. Low temperature conditions during late January or early February damage pollen and adversely effect grain formation. Crops with high rates of nitrogen application at the PF stage are likely to experience the highest yield losses from cold conditions after the PI stage because more of the plant is out of water and exposed to the atmosphere.

From the database for the NIR tissue test over the last five years, about 40% of rice farmers use the Near Infra-red Reflectance (NIR)-based nitrogen tissue testing technique carried out by the Ricegrowers' Co-operative Limited. This test determines the nitrogen content in the plant at the PI stage. It is the basis for recommendations about any additional amounts of nitrogen that may be required to achieve the potential yield.

However there is no pre-sowing test to estimate the nitrogen status of the soil and farmers use cropping history to make decisions about the amount of nitrogen to apply. The aim of a Rice CRC funded project titled '*A Strategic Soil Nitrogen Test for Flooded Rice*,' has been to develop a soil based NIR test to determine the N available in the soil before sowing and how much more is required to meet the N requirements of the crop.

In this paper we attempt to value the information that would be provided to the rice growers by the soil test at PF stage. Being able to demonstrate the value of the test may encourage more widespread use of the test. It will also provide a basis for evaluating the returns from investments in this area by the CRC.

The decision problem faced by rice growers, as described above, is a complex one with decisions on nitrogen use to be made at several points in the production cycle and uncertainty arising from both the nitrogen status of the soil and plant and temperature before flowering. This decision problem is first laid out in a decision tree framework which identifies the fertiliser strategies open to farmers at the PF and PI stages; the uncertainties about the nitrogen status of soil and plants at these stages; and the payoffs from the possible combinations of nitrogen use and states of nitrogen availability at the PF and PI stages. From this decision tree representation of the problem can be estimated the nitrogen use strategy that gives the greatest expected payoff amongst the alternative nitrogen use strategies when farmers have no objective tests of nitrogen availability.

The PF test gives farmers information about the nitrogen status of the soil which is valuable if it results in a more profitable use of nitrogen. We accept the view of Chavas and Pope (1984) that ‘the valuation of information is best analysed in the context of decision making under uncertainty’ (p705) and we have followed an extensive literature (including Anderson et al., 1977 and Schimmelpfennig and Norton, 2003) in which the probabilities about states of nature are revised according to Bayesian decision theory leading to changed expectations about the payoffs from alternative input decisions. In particular we followed the approach used by O’Connell et al. (1999) in a study of the value of information about soil acidity status. Here the information provided by the PF test was used to revise perceived probabilities of the nitrogen status of the rice crop and hence to allow more informed decisions about nitrogen use. The value of the information provided by the test was estimated as the difference in expected returns between the situation where no test is used and the situation where the farmer uses the PF test to update his information on the nitrogen status of the soil. Using this information, returns to investment on R&D to develop this test can then be measured in a benefit cost framework.

2. Background

2.1 Uncertainty about pre sowing nitrogen (N) availability

Paddock crop history has a significant impact on the soil N available for the rice crop at sowing time. A common rotation in the rice growing areas is three years of rice, two to three years of winter cereals and three years of pasture. Soils vary in their N status. For example, paddocks with sub-clover, containing high organic N, may be able to release N into the second rice crop after the pasture phase, whereas a heavily cropped rice paddock may leave little N available for even the first rice crop.

It is highly likely, although not certain, that paddocks are high in N immediately after a pasture phase. Similarly, it is highly likely that after two years of rice, the N status of paddocks is low. The N status of paddocks after one year of rice is more uncertain, hence this is the scenario this paper has focussed on. The value of tests providing information about the N available to the rice plant is likely to be higher for these paddocks, about one third of all rice fields, where the farmers’ perceptions of N availability are less certain.

2.2 Nitrogen used

The decision problem is that in early October farmers select a paddock to sow rice. At that time they know the paddock’s previous history of three years of pastures followed by rice in the previous year. In the absence of any test, they are uncertain about N status of the soil but must select a rate of N to be applied before sowing. In the decision tree below we have allowed for four states of N availability in the soil and a choice of four rates of N application at the PF stage.

Because of the uncertainty about soil N status at PF stage, there is uncertainty about how much N will be available to the rice plant at PI stage under any of the PF N strategies. We have allowed for four states of N availability to the plant at the PI stage. In the absence of the PI test, the information available to the farmer in assessing the probabilities of these four states is the visual appearance of the crop, and knowledge of paddock history and the amount of N applied at PF stage. Other relevant information is that research has found that up to PI stage, the plant uses only one third of the total N applied at sowing time under average weather conditions. Whereas another one third of the N applied is used by the plant between PI to the maturity of the crop and the rest is either lost in the air or through deep drainage in the soil (Williams, R. pers. comm.). Again we have allowed growers a choice of four rates of N application at the PI stage.

2.3 Weather conditions at PI

Temperature exceeding 17˚C when early microspores of pollen are developing (midway between PI and flowering) is ideal for healthy pollen formation and to achieve potential crop yields, whereas any temperature below 17˚C damages yield (Gunawardena, 2002). Different levels of temperature below the critical limit lead to different levels of yield damage.

In this study maNage rice, a crop model was used to simulate rice yields for each of 46 years from 1955-2001.The average yield of these years was used in this study. maNage rice is a computer software program, being used by the rice farmers as a decision support tool, which calculates the potential response of rice crops to top dressed N fertiliser at panicle initiation. It requires crop sampling to obtain data on Fresh Weight and N% at PI. It simulates the yields that can occur for an average season using weather data from the last forty years (Angus, Williams and Dunkin 1996 and NSW DPI, 2004).

3 . Decision Tree Analysis of the No Test Scenario

Description of the Nitrogen Decision Problem

Important components of a risky decision problem include (Hardaker et al., 1997):

- *Acts*: A given set of alternative options, denoted by a j, between which a farmer must choose. These acts are mutually exclusive and exhaustive. In this case the acts are the rate of application of N at PF and PI stages of plant development. It is assumed that at PF farmers choose between N application rates of 0kg, 60kg, 120kg, and 180kg of N/ha and at PI the N application rates of 0kg, 30kg, 60kg and 90 kg/ha were considered. Analysis of the Ricecheck database from 1986 to 2002 on different rates of nitrogen used by farmers for growing rice has revealed that the rates selected purposely for the analysis are the rates of nitrogen application used by the farmers in growing rice in Australia . Urea (46% N) fertiliser was used to meet the N requirements of the crop and to calculate the cost of nitrogen and its associated application costs. These choices or acts are denoted by squares in the decision trees outlined in Figure 1;
- *States*: Possible uncertain states of nature over which the farmer has no control and are denoted by q i. States must also be defined as mutually exclusive and exhaustive for a cropping season. The set of states for this study included the N status of the soil at PF and that of the plant at PI stages. Uncertain events are denoted by circles in Figure 1. The possible states of nature are discussed below;
- *Prior probabilities*: prior subjective probabilities or the degree of belief about the chances of occurrence of the possible states of nature with respect to N status at PF and PI stages. These are denoted by P(q i). The soil test provide a means of revising the growers' perceptions of these probabilities. The derivation of probabilities is discussed below;
- *Outcomes*: The payoffs from each combination of acts and states of nature are expressed in terms of gross margins reflecting yield and fertiliser differences. Yields at each rate of nitrogen were estimated using maNage Rice, which calculates the response of Riverina rice crops to top-dressed N fertiliser by taking into account the crop N uptake level at PI and the amount of N applied to the crop at PI. This analysis was based on Amaroo, the most widely grown rice variety in the MIA. It was sown on 15 October and PI started on 10 January under deep standing water conditions. The gross margins from the alternative N use strategies and N availability events were estimated as:

$$GM = P*Y - NC - OVC$$

where P = Price of rice; Y = Yield of rice; NC = cost of N; OVC = other variable costs. Information on fertiliser costs and other variable costs were obtained from Faour and Whitworth (2001). The long term average price of rice was used to calculate gross margins;

- *Choice criterion* or Objective function: Outcomes were compared on the basis of the expected net return from the uncertain events. This criterion assumes that the grower is risk neutral. The assumptions that growers are risk neutral whose preferences accord with expected utility theory is a strong one (Machina, 1987). If risk averse farmers regard N fertiliser as adding to risk they may well use less N than would a risk neutral grower although it is not clear how significant preferences over the risk profile of total household income translate to input choice at a paddock level. Moreover the impact of this assumption on the value of information about N status is also unclear and may depend on whether the farmer regards the information as a risk complement or risk substitute (Chambers and Quiggin, 2000).

Decision trees are developed in a chronological sequence from left to right with the first choice represented at the extreme left and the eventual consequences shown at the extreme right. The end nodes or the terminal nodes are payoff nodes reflecting the gross margin from the yield and N use outcomes along the respective branches of the decision tree. Subjective probabilities were assigned (in a manner described below) for each of the uncertain soil N states at PF stage and plant N states at PI stage.

The expected payoff and associated rate of N application at PF stage is identified by replacing each of the event forks with a certainty equivalent and choosing the act that gives the highest certainty equivalent. Under our assumption of risk neutrality certainty equivalents are estimated as the probability weighted sum of relevant outcomes. At each event node for each of the N application rates an optimal path on the decision tree was developed by marking off the lower certainty equivalents until the base of the tree is reached as is shown in Table 3. This allowed the (prior) optimal act to be identified by selecting the highest certainty equivalent value in the absence of the PF soil test and PI NIR tissue test.

States of Nature and Prior Probabilities

We identified four states of N status at both the PF and PI stages, designated f i and q i. We refer to these states as low, medium, high and excessive.

As already noted, there is a great deal of uncertainty about the N status of soil and plants at PF and PI stages. In forming our assessments of the probabilities (necessarily subjective) of occurrence of the four states at these stages, we have been guided by past research results. Recall that we have limited our attention to paddocks going into their second year of rice. Williams and Angus (1994) measured the soil N status of paddocks with no N applied at PF through the N uptake level in rice plants at PI. To find out the relative probability of occurrence of different levels of N in those second year crops, the status of such crops at PI stage was used as proxy for their N status at PF stage (Table 1)**.** These probabilities are the same for all rates of N applied at PF but they change for another paddock history (i.e. first or third rice crop after pasture). Using this information from their study, N status of soils before second rice crop was classified into four different categories. A soil with N uptake of less than 70 kg/hectare was classified as a low N status soil, whereas the soils with plant N uptake between 70-120, between 120-150, and 150-180 kg/hectare were classified as medium, high and excessive N status soils respectively (Table 1). The information on probabilities of such states was based on the findings from the same study (Williams and Angus, 1994).

Table 1: N uptake, N status of soil, and probability of such states before sowing

Plant N uptake (kg/ha)	N Status	Probability of occurrence (P(f i)
Between 40 - 70	Low	0.4
Between 70 -120	Medium	0.3
Between 120 -150	High	0.2

Information to guide an assessment of the probabilities of the four N status states at PI stage is even more scarce and we relied heavily on the experience of research and extension staff involved in rice research at the Yanco Agricultural Institute. As described above, each N rate considered at PF could lead to four different states of N availability in the plant at PI stage (low, medium, high and excessive). To illustrate the method used for estimating probabilities, the example of an application of 60 kg N/ha applied at PF is used. Following Williams and Angus (1994), one-third of N applied at PF will be used by the crop before PI, and a further one-third will remain in the soil for use after PI. Thus, if 60 kg N/ha is applied at PF, the N status will be 20 kg N/ha higher at PI.

For example, if the soil N status at the PF stage was low (ie, 40-70 kg N/ha), adding 60 kg N/ha to the soil will increase the soil N status to 60-90 kg N/ha at PI. After this application, the soil will either remain at the low N status or increase to the medium N status, depending on what the (unknown) level of N was initially. If the outcome lies in the range 60-70 kg N/ha, the soil N status remains low. If, however, the outcome lies in the range 70-90, the soil N status after PI is medium. Given an assumption that each possibility along the range 60-90 kg is equally likely, the probability of the soil remaining of low N status after the application is 10/30 or one-third, while the probability of the soil being medium N status after the application is 20/30 or two-thirds. These are conditional probabilities in the sense that, for example, the probability of the N status of the plant at PI is low after applying 60 kg N/ha is 1/3 given that soil N status at PF stage was low.

The impact of applying 60 kg N/ha to soils of each N state at PF is shown in Table 2. Where the initial N state of the soil was medium, application of 60 kg N/ha leads to a range of outcomes of 90-140 kg N/ha, so that the probabilities of medium and high status are 60% and 40%, respectively. Similarly, where the initial N status of the soil was high, application of 60 kg N/ha leads to a range of outcomes of 140-170 kg N/ha, so that the probabilities of high and excessive status are 33% and 67%, respectively. Applying N to a soil already classed as having excessive N at the PF stage means that the probability of the N state being excessive at the PI stage is 1.

Table 2: Impact of application of 60 kg/ha of N on different soil N status

Initial N status		**(kg N/ha)**	**Probability of N status after application**			
			Low	**Medium**	**High**	**Excessive**
Low	40 - 70	60 – 90	33%	67%		
Medium	70 - 120	90 – 140		60%	40%	
High	120 - 150	140 – 170			33%	67%
Excessive	150 - 180	170 - 200				100%

If no N is applied at PF, then the nitrogen status of the plant at PI stage will be the same as it was at the PF stage. The conditional probabilities will all be 1, that is, it is certain that if N status was low at PF stage and no N is applied at PF stage, then the N status at PI stage remains low, for example.

Similarly the impact of the application of 0kg, 120kg and 180 kg of N on different N status soils was estimated and the probabilities of the four states of N status at PI stage after the application of N at PF stage were assessed (Figure 1 and Appendix 1). The probabilities of the four states of N at PI stage are same for each rate of N applied at PI, but they change as the farmers change the PF rate, because the more N applied at PF stage the greater the probability of an increase in the N status at the PI stage. They also vary with the initial N state at the PF stage.

The Prior Optimal Act

Figure 1 shows the payoff matrix of different N use strategies both at PF and PI stage for different N status soils. For example, there is a probability of 0.4 that the soil N status before sowing is low (Table 1). With 0 kg of N at PF there is a probability of 1 that the crop N at PI would be low. Further at PI stage 0kg of N would lead to a payoff of $ 851 whereas 30kg, 60kg, and 90kg of N would lead to a payoffs of $912, $964 and $993 per hectare respectively. Following the same procedure the payoff matrix was developed for different N use strategies both at PF and PI (Figure 1).

Working back leftward from the terminal branches, at each event node the chance events were replaced by their certainty equivalents. At each decision node, the application rate that gave the highest certainty equivalent was selected as the preferred alternative act.

For example for the branch where 120 kg of N was applied at PF to a soil whose N status at PF is medium, 0 kg of N at PI leads to a payoffs of $1135, $1308, and $1334 depending on whether N status at PI is medium, high and excessive. The probability of these events is 0.2, 0.6 and 0.2 respectively. A certainty equivalent value of $1278 was estimated as the probability weighted sum of payoffs of these three events. Following the same procedure, certainty equivalent values of $1266, $1265, and $1263 for 30kg, 60kg and 90kg of PI N respectively were estimated. For a soil of medium N status at PF and to which 120 kg of N was applied at PF stage, the rate of N at PI stage (when N status at this stage is uncertain) which returns the highest certainty equivalent - $1278/ha - is 0 kg N . The same procedure was followed for all other decision nodes at the PI stage. The certainty equivalents for all 16 nodes are listed in Table 3.

Continuing with our analysis of the 120 kg at PF branch, the payoffs (estimated as certainty equivalents at the PI stage) for the four possible N states at PF are $1125, $1278, $1385 and $1435. Applying the probabilities ((P(f i)) of the four states of N availability at PF to these payoffs gives a certainty equivalent for the 120 kg branch of $1254 per ha.

Following a similar procedure for the other event nodes gives four certainty equivalents, $1183, $1210, $1254 and $1266/ha for the 0, 60, 120 and 180 rates of N application at PF stage. For a risk neutral grower, knowing only the probabilities and yields above, the rate of N application at PF stage giving the highest expected return of $1266 per ha is 180 kg/ha

The information in the decision tree can also be summarised in a payoff table constructed with alternative acts at PF as column heads and possible states at PF as row headings as shown in Table 3. Using the certainty equivalent values of each event node given on the optimal path and the prior probabilities of each state (Table 1), the expected gross margin from each N act for different N status soils were calculated.

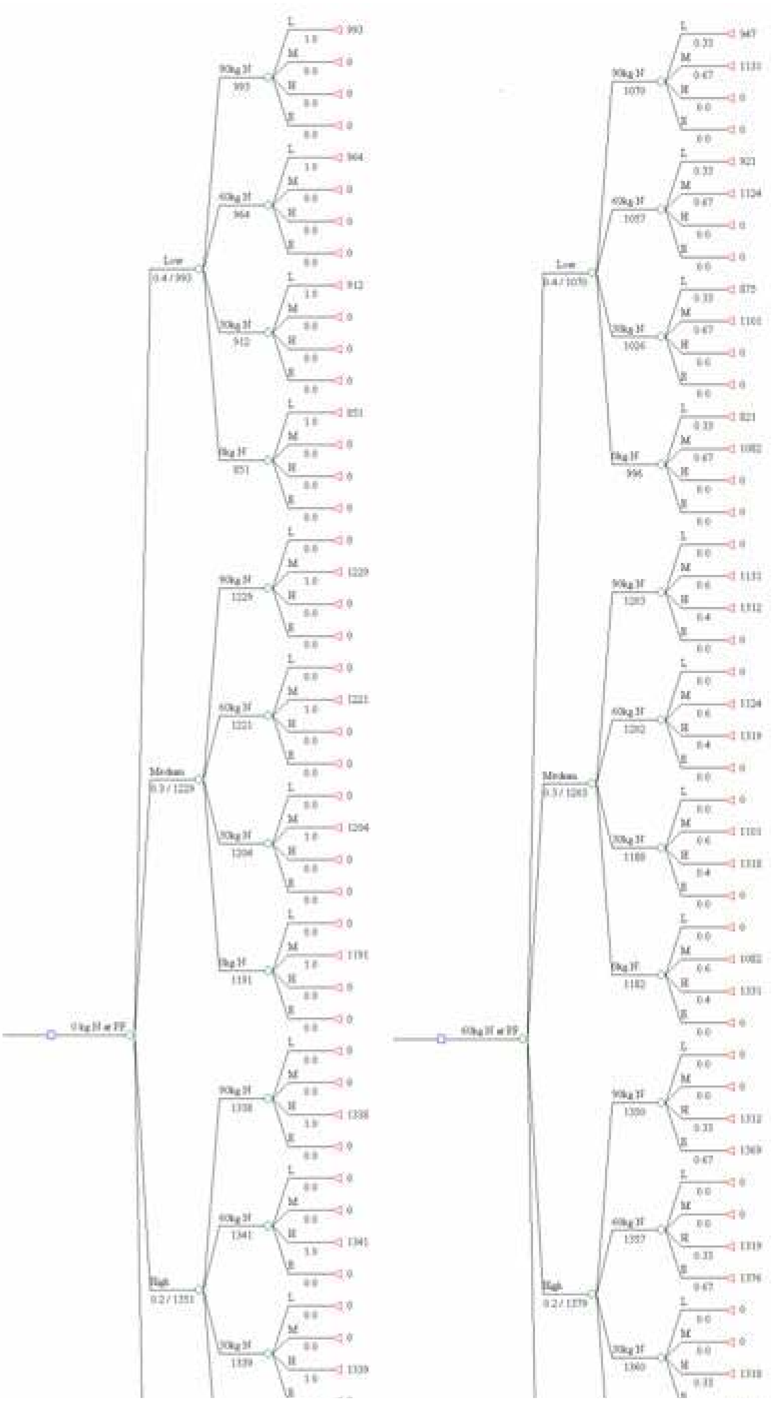
Table 3: Expected gross margins for each N use strategy

		Expected Gross Margin of N applied (kg/ha)

N status at PF	**Prob.** **(P(f i)**	**0**	**60**	**120**	**180**
Low	**0.4**	**993**	**1170**	**1125**	**1161**
Medium	**0.3**	**1229**	**1203**	**1278**	**1280**
High	**0.2**	**1351**	**1379**	**1385**	**1375**
Excessive	**0.1**	**1467**	**1449**	**1435**	**1421**
Expected GM ($/ha)		**1183**	**1210**	**1254**	**1266**

Table 3 shows that the expected gross margin was highest with 180kg of N applied at the PF stage in the absence of any test to measure the N requirements of the crop. This is referred to as the **prior optimal act.**

Figure 1: The decision tree with the N uncertainty event


0 kg N at PP
Low
0.4 / 993
90kg N
993
L 1.0 993
M 0.0 0
H 0.0 0
E 0.0 0
60kg N
964
L 1.0 964
M 0.0 0
H 0.0 0
E 0.0 0
30kg N
912
L 1.0 912
M 0.0 0
H 0.0 0
E 0.0 0
0kg N
851
L 1.0 851
M 0.0 0
H 0.0 0
E 0.0 0
Medium
0.3 / 1229
90kg N
1229
L 0.0 0
M 1.0 1229
H 0.0 0
E 0.0 0
60kg N
1221
L 0.0 0
M 1.0 1221
H 0.0 0
E 0.0 0
30kg N
1204
L 0.0 0
M 1.0 1204
H 0.0 0
E 0.0 0
0kg N
1191
L 0.0 0
M 1.0 1191
H 0.0 0
E 0.0 0
High
0.2 / 1351
90kg N
1338
L 0.0 0
M 0.0 0
H 1.0 1338
E 0.0 0
60kg N
1341
L 0.0 0
M 0.0 0
H 1.0 1341
E 0.0 0
30kg N
1339
L 0.0 0
M 0.0 0
H 1.0 1339
60kg N at PP
Low
0.4 / 1070
90kg N
1070
L 0.33 947
M 0.67 1131
H 0.0 0
E 0.0 0
60kg N
1057
L 0.33 921
M 0.67 1124
H 0.0 0
E 0.0 0
30kg N
1026
L 0.33 875
M 0.67 1101
H 0.0 0
E 0.0 0
0kg N
996
L 0.33 821
M 0.67 1082
H 0.0 0
E 0.0 0
Medium
0.3 / 1203
90kg N
1203
L 0.0 0
M 0.6 1131
H 0.4 1312
E 0.0 0
60kg N
1202
L 0.0 0
M 0.6 1124
H 0.4 1319
E 0.0 0
30kg N
1188
L 0.0 0
M 0.6 1101
H 0.4 1318
E 0.0 0
0kg N
1182
L 0.0 0
M 0.6 1082
H 0.4 1331
E 0.0 0
High
0.2 / 1379
90kg N
1350
L 0.0 0
M 0.0 0
H 0.33 1312
E 0.67 1369
60kg N
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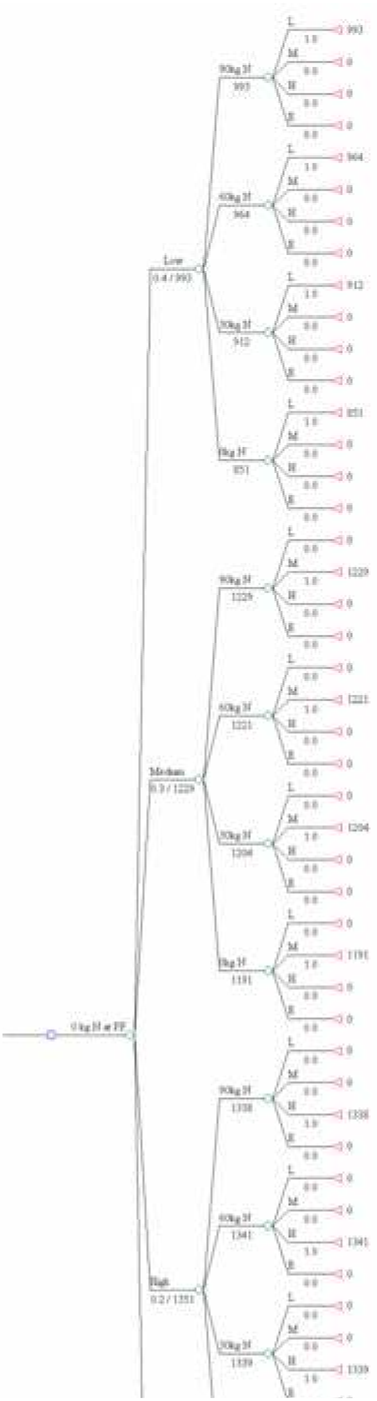
L 0.0 0
M 0.0 0
H 0.33 1319
E 0.67 1376
30kg N
1360
L 0.0 0
M 0.0 0
H 0.33 1318


0 kg N at PP
Low
0.4 / 993
90kg N
993
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1.0
993
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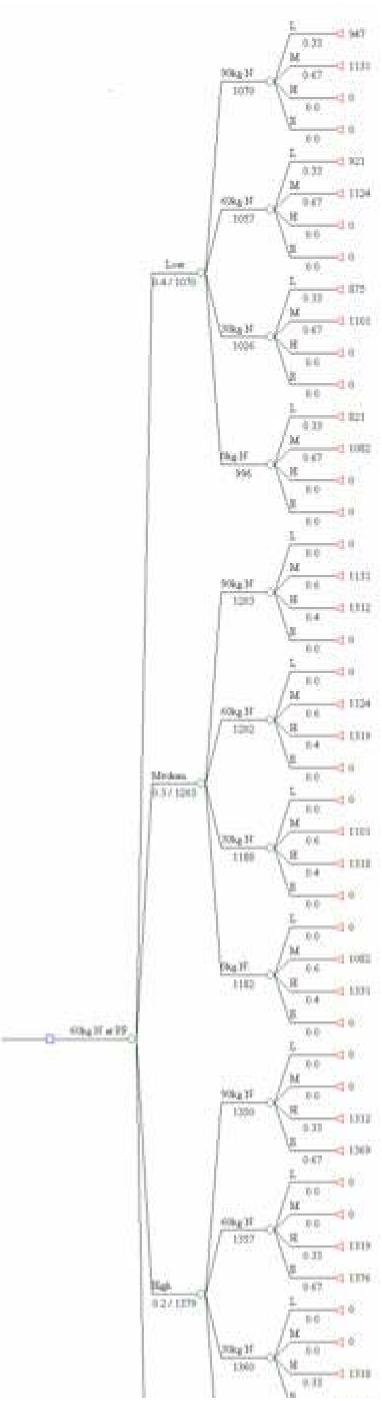
60kg N at PP
Low
0.4 / 1070
90kg N
1070
L
0.33
947
M
0.67
1131
H
0.0
0
E
0.0
0
60kg N
1057
L
0.33
921
M
0.67
1124
H
0.0
0
E
0.0
0
30kg N
1026
L
0.33
875
M
0.67
1101
H
0.0
0
E
0.0
0
0kg N
996
L
0.33
821
M
0.67
1082
H
0.0
0
E
0.0
0
Medium
0.3 / 1203
90kg N
1203
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High
0.2 / 1379
90kg N
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0
H
0.33
1312
E
0.67
1369
60kg N
1357
L
0.0
0
M
0.0
0
H
0.33
1319
E
0.67
1376
30kg N
1360
L
0.0
0
M
0.0
0
H
0.33
1318
E

4. Valuing the Soil test at PF Stage

The next step is to value the information provided by the soil test at PF stage. Provision of new information would help to reduce the uncertainty regarding the soil N that will be available to the plant and how much more N can be applied profitably. The Bayesian framework suggested by O'Connell et al. (1999) and Anderson, Dillon and Hardaker (1977) was applied, where the information provided by the test is used to revise perceived probabilities of N status at the PF stage. It provides a logical way to adjust the prior probabilities taking into account the new information weighted according to the accuracy of the test results.

Revising probabilities about N status at PF stage might indicate that farmers apply different amounts of N at this time to what would have been applied in the absence of the test. Hence we again estimate the optimal decision for the farmer as in the decision tree approach. The difference in the outcomes from these two situations, referred to as the prior optimal act and the revised optimal act, is an estimate of the value of the information provided by the test.

The accuracy of the soil test will be a critical factor in determining its value. It has been found that the new soil test correctly identifies the soil N status 70 percent of the time at this stage of its development. (Russell C., personal communication). There is no evidence that the accuracy of the test is related to the N status of the soil. The probabilities of false readings for a given soil N status, also based on laboratory experience, is given by row entries in Table 5 where the rows sum to one.

This information about the reliability of the test can be interpreted as 'likelihoods', denoted as P(z k| f i), which are the conditional probabilities of a test result z k given a N state f i. In this case, for example, there is a 70 percent likelihood that when the N status is low the test result will say it is low (Table 5).

Table 5: Probabilities of various N test results given N status at PF.

N State	**Prior probabilities**	**Likelihoods, P(z k| f i)**			
(f ii)	**P (f i)**	**z 1 (test result low)**	**z 2 (test result medium)**	**z 3 (test result high)**	**z 4 (test result excessive)**
Low	0.4	0.70	0.22	0.06	0.02
Medium	0.3	0.13	0.70	0.13	0.04
High	0.2	0.04	0.13	0.70	0.13
Excessive	0.1	0.02	0.06	0.22	0.70

One can find out how often particular N test results will occur by first calculating the joint probabilities, P(z k and f **i**), of state f **i** . and N test result z i occurring together as P(f ***i***) * P(z .k| f **i**) as shown in Table 6. The sum of the joint probabilities in each column of table 6 provides information on the probability of a certain test result, P(z k).

Table 6: Joint probabilities for different N states at PF

N State at PF	**Prior probabilities**	**Joint probabilities of test results, P(z k and f i)**			
(f i)	**P(f i)**	**z 1 (test result low)**	**z 2 (test result medium)**	**z 3 (test result high)**	**z 4 (test result excessive)**
Low	0.4	0.28	0.088	0.024	0.008
Medium	0.3	0.039	0.21	0.039	0.012
High	0.2	0.008	0.026	0.14	0.026
Excessive	0.1	0.002	0.006	0.022	0.07
Probability of test result z k, P(z k)		**0.329**	**0.33**	**0.225**	**0.116**

Table 6 shows that given the prior probabilities and likelihoods, 33% of all tests undertaken would return a low result, 33% medium, 23% high and 12% excessive results.

The next step is to estimate the revised or posterior probabilities that a farmer now holds about N status given the test results. Revised probabilities give the probability of the state f **i** given test result z k, calculated as P(z k and f **i**) /P(z k) as shown in Table 7.

Table 7: Revised probabilities for different N states at PF Branch

N State	**Prior probabilities**	**Revised probabilities of test results, P(f i| z k)**			
(f i)	**P(f i)**	**z 1 (test result**	**z 2 (test result medium)**	**z 3 (test result high)**	**z 4 (test result excessive)**

		low)			
Low	0.4	0.85	0.27	0.11	0.07
Medium	0.3	0.12	0.64	0.17	0.10
High	0.2	0.02	0.08	0.62	0.22
Excessive	0.1	0.01	0.02	0.10	0.60
Sum of the revised probabilities		**1**	**1**	**1**	**1**

The revised probabilities in this case tell us that if the test result returned is medium, there is a 27 percent chance that soil N is low, a 64 percent chance that soil N is medium and a 8 percent chance that N is high and 2 percent chance that N is excessive. A similar interpretation holds for the other test results.

Based on this information, one can calculate the expected gross margins conditional on the test results. These are displayed in the bottom section of Table 8. They are calculated as:

E(GM(a i)|z k) = SGM(a i).P(***f*** i|z k) for i = 1,…4 and then k = 1,….4

Table 8: Expected gross margins after the PF test for different N levels

	N test results			
GM from revised probabilities	**z 1 (test result low)**	**z 2 (test result medium)**	**z 3 (test result high)**	**z 4 (test result excessive)**
Gross margins from Table 3 0 kg 60kg 120kg 180kg				
Low N	993	1170	1125	1161
Medium N	1229	1203	1278	1280

The interpretation of these expected conditional gross margins is as follows: If the soil test at PF suggests N available to the plant is excessive then the expected gross margin from applying 120 kg N at PI is $1386/ ha. A grower contemplating buying the test however needs to know the unconditional expected gross margin and this is given by weighting the best outcome for each rate of N (emboldened above) by the probability of the four test results, P(z k). The results of the analysis shows that the expected gross margin using information from the soil test is **$1268**

The value of the information provided by the soil test is the difference in the expected gross margin from the prior optimal act, $1266ha, and that from the revised optimal act, $1268. Therefore the value of the soil test for this scenario is $2.00/ha.

From this estimate of the gross value of the information provided by the test must be deducted the cost of having the test done. Based on experience with the PI plant tissue test, the expectation is that the test will cost about $20 per paddock or $0.80 per ha for an average 25 ha paddock. In practice farmers build up some knowledge of the nitrogen status of their fields based on past testing and only test paddocks every second year reducing the cost to $0.40 per ha and giving a net value of the information from the test of $1.60 per ha.

4.1 The Value of a More Accurate Test

In the analysis to date, we have assumed that the accuracy of the test, based on current experimental results, is 70 percent. The accuracy of the existing PI test is 94 percent. Analyses following the same procedure as above were conducted for accuracy levels of 85 and 94 percent. The probabilities for each test result P(z k) for the three levels of accuracy are presented in Table 9.

Table 9: Joint probabilities for different N states at PF

N State		**Joint probabilities of test results, P(z k and f i)**			
(f i)		**z 1 (test result low)**	**z 2 (test result medium)**	**z 3 (test result high)**	**z 4 (test result excessive)**
(@ 70% accuracy)					
Probability of test result z k, P(z k)		0.329	0.33	0.225	0.116
(@ 85% accuracy)		0.365	0.315	0.2125	0.108
Probability of test result z k, P(z k**)**		0.387	0.301	0.2065	0.106
(@ 94% accuracy)					
Probability of test result z k, P(z k)					

Table 9 shows that with the given prior probabilities and likelihoods at 94 percent accuracy levels, 39% of all tests undertaken would return a low result, 30% medium, 21% high and 11% excessive results compared to 33% of low result, 33% medium, 23% high and 12% excessive results at 70 percent test accuracy.

Based on this information, we have calculated the expected gross margins conditional on the test results at 85 and 94 percent accuracy of the test (Table 10).

Table 10: Expected gross margins after the PF test for different N levels at 85 and 94 percent test accuracy Levels

	N test results			
Revised probabilities z 1 (test result z 2 (test result z 3 (test result z 4 (test result **(for 85% accuracy level) Low) medium) high) excessive)**				
Low N	0.933	0.140	0.056	0.037
Medium N	0.053	0.810	0.092	0.056
High N	0.011	0.041	0.800	0.120
Excessive N	0.003	0.010	0.052	0.787
Expected GMs conditional on the test result				
E {gm(0|z k)}	1011	1203	1326	**1422**
E {gm(60|z k)}	1082	1194	1349	1413
E {gm(120|z k)}	1137	1263	**1363**	1409
E {gm(180|z k)} ***Revised optimal act1***	**1170**	**1269**	1357	1398 ***1270***

	N test results			
Revised probabilities z 1 (test result z 2 (test result z 3 (test result z 4 (test result **(for 94% accuracy level) Low) medium) high) excessive)**				
Low N	0.973	0.040	0.039	0.038
Medium N	0.019	0.937	0.036	0.028
High N	0.005	0.017	0.910	0.047
Excessive N	0.003	0.007	0.015	0.887
Expected GMs conditional on the test result				
E {gm(0|z k)}	1001	1223	1334	**1437**
E {gm(60|z k)}	1075	1202	1362	1424
E {gm(120|z k)}	1130	1275	**1372**	1417
E {gm(180|z k)} ***Revised optimal act1***	**1165**	**1278**	1364	1405 ***1271***

Hence as the accuracy of the test improves, the expected gross margin from the revised optimal act increases to $4.00/ha and $5.00/ha and the net value of the information provided by the test, after deducting a cost of $0.40 per ha, increases to $3.60 and $4.60 per ha

5. Returns to Investment in Research to Develop the PF Test

5.1 Some Key Assumptions

The economic analysis has been conducted within a benefit/cost framework (Perkins, 1995). An important step in benefit/cost analysis is to identify the impact of the technology on the industry. Economists find it useful to define ‘with’ and ‘without’ project scenarios. Rarely is it appropriate to assume that without this project the technology surrounding the identified ‘problem’ would remain at a standstill. Defining the ‘with’ and ‘without’ project scenarios requires consideration of the adoption of the technology as well as its potential impact.

We have assumed that had this project not been undertaken, a PF test for soil nitrogen status would not have been developed for 20 years (until 2020). After this period it is anticipated that the technology arising from this project would be replaced by new technology from future research and development.

To measure the benefits of the project, average total area under rice was taken from an industry database for the last five years ie. from 1997 to 2001. Similarly the average price for rice over this period, $208 per tonne, was used in the analysis. A real discount rate of seven percent was applied to the flow of costs and benefits.

Table 11: Data and assumptions used in measuring returns to investment on NIR soil N test

Measure	Result
Total area under rice (000,ha)	154600
Price of rice ($/t)	208
Accounting period (Years)	20
Accuracy of the test (%)	70
Discount rate per annum (%)	7
Research time lag (Years)	5
Maximum adoption rate (% area under rice)	70
Time required to reach maximum adoption (Years)	3
Without project scenarios: Adoption of new technology	0

In an analysis of this nature key parameters are the rate and extent of adoption. Our assumptions concerning these parameters are based on experience with the existing NIR PI tissue test. At present about 40 percent of farmers use the PI test in any one year. This rate of use is down from the high rates experienced after the test was first introduced. The drop in the use of the test suggests that the value of the information carries over for some years and some farmers do not use the test each year. Hence around 80 percent of farmers use the test on a regular basis. Because the PF test may not be as accurate as the PI test we have assumed that the level of adoption will be 70 percent of rice growers.

The PF technology will not be ready for adoption on farm before 2005. From then adoption will proceed rapidly until the maximum rate of adoption, 70 percent, is reached in 2008 and will remain at this level until 2020.

Although more efficient use of nitrogen at PF, based on information provided by the soil test, may lead to some environmental benefits in the form of reduction in nitrogen losses through seepage that contaminate the groundwater or evaporation in the air that would pollute the air, these have not been considered in the evaluation.

5.2. Expenditure on research and extension

The project titled 'A Strategic Soil Nitrogen Test for Flood Rice' was funded by Rice CRC for the five year period from 1997-98 to 2001-02. The costs of the project include both direct CRC costs of research and the in-kind contributions from NSW Agriculture (now the NSW Department of Primary Industries) and Charles Sturt University (Table12). All costs were expressed in 2002 dollars after inflating expenditure in early years by the consumer price index. No direct costs of extension activities required to promote this technology are considered in this analysis. It is assumed that the farmers would come to know about the new technology through the Rice Grower's Cooperative Limited Newsletters and through their regular meetings with the extension staff.

Table 12: Cash and In-kind Expenditure on the Research Project during 1997 -2002 in 2001-02 values

Year	**cost $**		
	Cash	**In-kind**	**Total**
1997-98	28906	153363	182269
1998-99	83178	161706	244884
1999-00	88429	143113	231541
2000-01	80753	11770	92523
2001-02	108587	0	108587
Total	**389952**	**469952**	**859804**

The table 12 shows that the total cash expenditure over the five year period was 45 percent whereas the in-kind contribution was 55 percent of the total expenditure of $ 860,000 over this period.

5.3 Benefit-Cost Results

The estimated change in gross margin per ha from adopting the NIR soil nitrogen test is restated in Table 13.

Table 13: Financial Impact of Nitrogen use based on NIR soil N test in rice

Measure	Result
Gross margins from prior optimal act ($/ha.)	1266
Gross margins from revised optimal act ($/ha.)	1268
Increase in gross margins ($/ha.)	2.00

The results of the benefit cost analysis that measured returns to investment on research are presented in Table 14.

Table 14: Pre flood Soil base NIR Nitrogen Test - Results of benefit-cost analysis of the project

Measure	Financial Benefits on Total funds	Financial Benefits on CRC funds
Total benefits in real terms (000, $)	10011	1011
Total costs in real terms (000, $)	721	311
Net Present Value of benefits (000, $)	290	700
Benefit - Cost Ratio (BCR)	1.04	3.25
Internal rate of return (IRR)	11	24

The results presented in Table 14 indicate that the net benefits from the new test with the current test accuracy levels of 70 percent are sufficient to recover the costs of the project. A benefit cost ratio of 1.04 and an IRR of 11 also indicate that the project is financially viable. The results further suggest that the returns to the Rice CRC investment excluding in-kind contributions are higher, as expected, with $700,000 NPV of benefits, a benefit/cost ratio of 3.25 and an IRR of 24 percent.

As noted above, the accuracy level of the new test is very low compared to the existing NIR tissue test. Sensitivity analysis was done to measure the likely impact of different levels of the test accuracy on the benefits from the new test (Table 15).

Table 15: Financial benefits on total investment of the project at different levels of accuracy of the test.

Measure	**Percent Accuracy of the test**	
	85%	**94%**
Increase in gross margins ($/ha)	4.00	5.00
Net Present Value of benefits (NPV, 000 $)	1553	2185
Benefit - Cost Ratio (BCR)	3.15	4.03
Internal rate of return (IRR, %)	22	25

Results presented in Table 15 show that if the scientists were able to improve the accuracy level of the test to 94 percent similar to the existing NIR tissue test, the project would generate $2,185,000 NPV of benefits, a BCR of 4.03 and an IRR of 25 percent.

6. Conclusions

Scientists working on a CRC Rice funded project are trying to develop a test that would determine the amount of N available in the soil and how much more is required to meet the plant N requirements. The results reveal that the information provided by the new soil test is valuable as it helps farmers to use N more profitably by about $2/ha. The findings of the benefit cost analysis show that the benefits at the current accuracy levels are sufficient to meet the total costs of research for developing the test.

The results were achieved for one scenario, the value of the soil based NIR test under average weather and deep water conditions for paddocks entering their second year of rice. To measure the full impact of the new research, the study needs to be extended to consider a range of weather conditions and paddock histories. The analysis is also based on assessments made by scientists as a result of their field experience of the probabilities of various states of N availability in soil and in rice plants. Further research is needed to clarify how the value of the information provided by the PF test is influenced by these prior probabilities. Our expectation is that were the probability distribution more uniform, indicating greater uncertainty, then the value of the N test would increase.

Further the benefits could be quite significant, if the scientists are able to increase the accuracy of the test from 70 percent to 94 percent so they are at par with the accuracy levels of the existing NIR PI test.

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Appendix 1: Impact of Application of N on Different Soil N Status

Initial N status	**N uptake before application (kg N/ha)**	**N uptake after application (kg N/ha)**	**Probability of N status after application**			
			Low	**Medium**	**High**	**Excessive**
0 kg/ha Low	40 - 70	40 - 70	1			
Medium	70 -120	70 -120		1		
High	120 -150	120 -150			1	
Excessive	150 -180	150 -180				1

60 kg/ha Low	40 - 70	60 - 90	0.33	0.67		
Medium	70 -120	90 -140		0.60	0.40	
High	120 - 150	140 - 170			0.33	0.67
Excessive	150 - 180	170 - 200				1
120 kg/ha Low	40 - 70	80 - 110		1		
Medium	70 -120	110 - 160		0.20	0.60	0.20
High	120 - 150	160 - 190				1
Excessive	150 - 180	190 - 220				1
180 kg/ha Low	40 - 70	100 - 130		0.67 0.33		
Medium	70 -120	130 - 180			0.40	0.60
High	120 - 150	180 - 210				1
Excessive	150 - 180	210 - 240				1

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Maintainer: Nanette Esparon, Agriculture and Food Systems
Email: webmaster@landfood.unimelb.edu.au

The University of Melbourne ABN: 84 002 705 224
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