Selecting wheat varieties in a stochastic environment

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Introduction

The Western Australian wheat industry is moving toward increased segregation of quality wheats and greater payment premiums for protein. This has complicated the varietal selection process and nitrogen application decision for wheat farmers. Net returns to a wheat crop are dependant upon yield, input costs and price The changing relationship between price and protein percent as new segregations appear, and the interaction between yield and protein, render the use of average yield and protein data of little use for paddock specific fertiliser and varietal decisions.

Studies of tactical application of nitrogen inputs in response to climatic information have indicated that conditional crop-season applications are more profitable than blind strategies where a fixed rate of nitrogen is set regardless of season type (Nordblom *et al.* 1985; Burgess *et al.* 1992a). Optimal choice of variety will be paddock specific, influenced in particular by rotation phase, and depend upon the rate of nitrogen applied and seasonal events. At seeding the amount and timing of summer rains and the date of planting is known. The farmer can adjust his inputs and fertiliser rates accordingly. The value of this information on a whole-farm basis has been shown by Kingwell *et al* (1991).

In the absence of seasonal forecasts, weather conditions nearing the season finish are not known when fertiliser and variety decisions are made. Temperature, rainfall and atmospheric dryness during this period all significantly affect yield and grain protein. In the absence of seasonal forecasts, probabilities based on historical weather data can be used to provide probabilistic information about conditions at the season finish. Crop simulation models have been used in this way to provide yield probabilities for given season starts (Abrecht and Robinson 1993).

If functional relationships between yield and protein can be specified, and the major limiting factors to crop production other than rainfall represented, then yield and protein may be predicted for different wheat varieties and fertiliser regimes for the range of season types possibly faced.

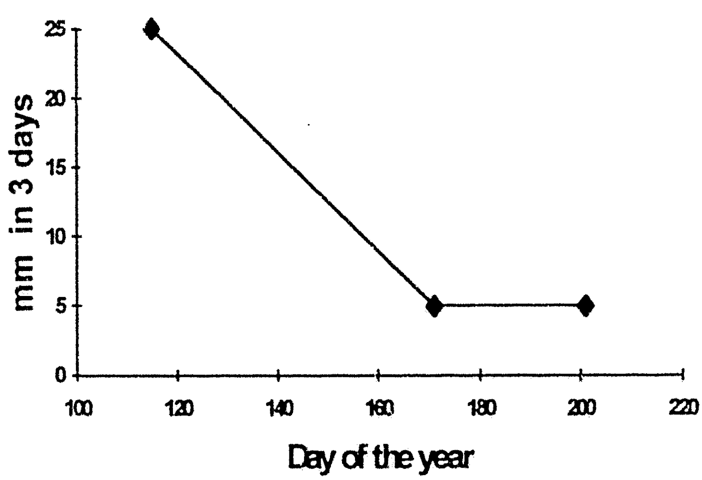
This paper describes output from a model which compares gross margins of selected wheat varieties under different scenarios of seasonal rainfall, weed and disease burden, soil nitrogen status and applied nitrogen. The model, tentatively named SPLAT (Seasonal Protein Likelihoods And Trade-offs), is being developed by the Department of Agriculture Western Australia as a paddock specific varietal and nitrogen decision aid.

Deriving probability distributions of potential yield

In order to describe seasonal variation in a crop–specific context, historical seasonal rainfall (approximately 70 years) was translated into potential wheat yield. This can be done using a variety of procedures including simulation (Robinson and Abrecht 1993), regression (Coelli 1990; Karimi and Siddique 1991), water stress index (Stephens et. al. 1989) and water–use efficiency (French and Schultz 1984) models. It is intended that the varietal decision aid produced will cover the entire wheatbelt of Western Australia. For this reason, the soil specific and site–specific nature of available simulation and regression models is undesirable, and a water–use efficiency calculation was employed to produce potential yields.

Historical daily rainfall data was collected for four representative sites for each of six defined regions in Western Australia. These six regions were determined according to climate and the zones referenced by the Crop Variety Sowing Guide (Crook et al 1995). Similar to the approach of Tennant (1995), a water balance model, based on the CERES–wheat simulation model, was used to calculate stored water at seeding. Seeding dates were calculated for each historical weather year using a variable planting rule as shown in Figure 1.

Figure 1. Planting rule used to calculate seeding dates



A survey of 25 wheatbelt farmers indicated that the amount of rain needed before they would start seeding declines as the season progresses (Kerr and Abrecht 1992). The planting rule used was an 'average' of the seeding rules indicated by the interviewed farmers.

The date of the end of growing season for each location was calculated using a phenology model (Kirby 1990) based on thermal time using average daily temperature data. Growing season rainfall was calculated from the historical data for each location. Non–productive water was assumed to be 80mm and water–use efficiency 20 kg/ha/mm. A function was added to reduce water–use efficiency when growing season rainfall exceeded 290mm. This assumed that every mm of growing season rainfall over 290 mm reduced potential yield by 5 kg/ha. The function was based on empirical data and was intended to reflect water–logging and radiation limitations which are not included in the estimation of paddock yields in SPLAT.

Stored water at seeding was added to summer rainfall for each historical weather year and multiplied by the respective water–use efficiency factor. Using these water–use efficiency calculations a discrete probability distribution of water–limited potential yield (nutrient, weeds and disease non–limiting) was generated for each of the six regions. These distributions reflect the range of potential yields faced by a farmer at seeding, in the absence of conditional information. The seasonal outcome experienced will determine potential yield, but at seeding the outcome is unknown hence the range of possible outcomes is presented based on what has happened in the past. The term *potential* yield in the paper refers to these water–limited, nutrient–non–limiting, weed–free and disease–free yields.

Calculating conditional continuous distributions of potential yield

In order to evaluate whether summer rainfall has a significant effect on final crop yield, the set of potential yields generated for the Eastern Wheatbelt (EW) were classified into three equal samples based on a simple summer rainfall index :

Effective summer rain = (Jan mm)/5 + (Feb mm)/4 + (Mar mm)/3 + (Apr mm)/2.

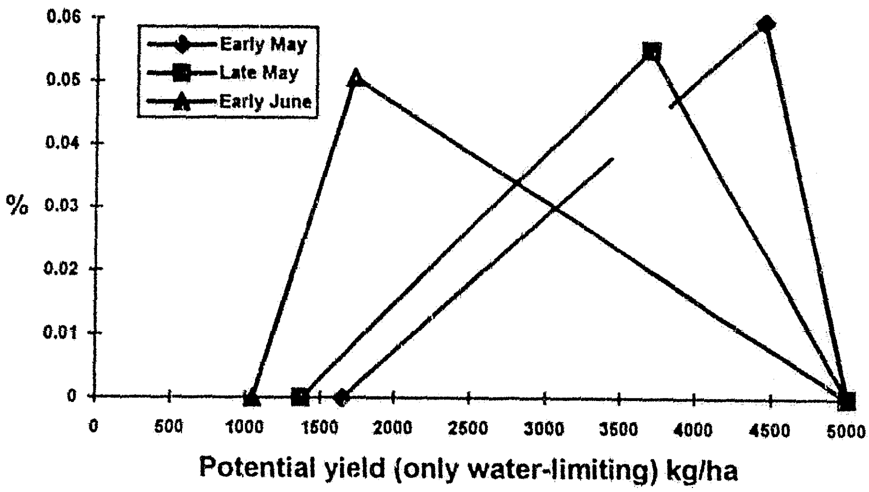
Analysis of variance of the three classifications of EW yields yielded a significant F test ($p < 0.01$) indicating the significant influence of summer rain on final crop yield.

The original unclassified set of potential yields for the EW was then re–classified according to five 10–day sowing periods in order to examine the effect of sowing date on final crop yield. Again, analysis of variance produced a highly significant F test ($p < 0.01$). However, when the set of potential yields was re–classified into 15 treatments (3 summer rain x 5 sowing periods) analysis of variance revealed no significance between treatments.

In light of these results it was decided that due to the effects of soil type and weed burden over summer, classification according to a stored summer rainfall calculation would not be as representative as classification according to sowing date. Each of the six regions' yield distributions were sub–classified into these five sowing periods. Each set of data represents the potential yields resulting from the range of season finishes that could be experienced given a particular season start, with calculated sowing date from the planting rule used as a proxy for season start.

To simplify the sampling of season finishes the discrete probability distributions were approximated as continuous triangular distributions. The triangular function, as specified in Anderson, Dillon and Hardaker (1977), is characterised by three parameters; the lowest possible value a, the mode m and the greatest possible value *b*. An example of the probability density function is shown in Figure 2. Three potential yield distributions are plotted for the Central region, for early, mid and late sowing dates.

Figure 2 : Triangular yield distributions for the Central region



Random sampling is affected using an 'inverse-CDF transformation' (Anderson and Dillon 1992) , or more commonly termed Monte-Carlo simulation, whereby uniform variates, u, on the probability axis, are transformed to the required variates (yield) through the cumulative distribution of frequency.

For a triangular probability density function yield is read off the cumulative distribution function (CDF) using one of the following equations :

$$u^* = (m-a)/(b-a)$$
$$\text{yield} = a + [u(b-a)(m-a)]^{0.5} \qquad \text{if } 0 \leq u \leq u^*$$
$$\text{yield} = b - [(1-u)(b-a)(b-m)]^{0.5} \qquad \text{if } u^* \leq u \leq 1$$

Typically, the user of SPLAT will decide which levels of probability to include in the analysis. Each probability chosen will represent a specific seasonal outcome in terms of potential yield. For example, the user may wish to calculate how gross margin differs if the season finish ends up in the top 10 percent of past finishes, the bottom 10 percent or the median season finish.

If an expected value is required this can most easily be approximated by using yields read off the CDF by choosing a small sample of equal interval probabilities between 0 and 1. For example, nine yields can be read of the CDF using 0.1, 0.2, 0.3 etc on the probability axis.

Calculating achievable paddock yields

In practice, potential yields are seldom realised. There are many factors which reduce yield below the calculated water–limited potential. SPLAT reduces yield according to weed burden and estimated levels of take–all, rhizoctonia bare patch and leaf disease to estimate an *achievable paddock yield*.

Figure 3. Reduction in yield potential due to weeds				
	Grass weed burden			
	None	Low	Medium	High
Plants / sq metre	0	< 50	50 – 150	> 150
Reduction in potential yield	0%	10%	25%	50%

The yield reductions in figure 3 are estimations based on trial results of yield reductions due to varying densities of wild oats and barley grass (Poole and Gill 1987).

The calculation of take–all incidence is based on grass biomass in the cleaning crops (MacNish and McLeod 1988). Severity of take–all is modelled as an exponential function of incidence, nitrogen source, and nitrogen application rate (Bowden *et al* 1988). Severity therefore varies according to the rotation and phase of the wheat crop. Density of grass growth is assumed to differ between crop and pasture phases.

An adjusted yield, taking into account the effects of take–all, is calculated from take–all severity for the current season according to the formula :

$$Yd = Y(1 - S/(100 + y/80))$$

where Yd = yield with take–all, S = severity of take–all this season, y = yield in the absence of take–all.

Reduction of yield due to rhizoctonia bare patch is assumed to be directly proportional to the area affected. Loss of yield due to leaf disease is calculated for levels of incidence of low, moderate and high as 5%, 15% and 35% respectively (Anderson W. *pers. comm*).

Rotation phase, weed burden, inoculum level for take–all, rhizoctonia incidence and leaf disease index are all variables in the model to enable paddock specific predictions to be made.

The relationship between paddock yields, nitrogen uptake and variety

Once *achievable paddock yield* has been calculated from potential yield by calculating the yield–reducing effects of weeds and disease, yield is adjusted according to variety and nitrogen uptake to calculate a *predicted paddock yield*.

Differential achievable yields for wheat varieties are calculated according to sowing date and the location of the paddock in the wheatbelt. The five sowing periods, one of which is selected by the user in SPLAT, coincide with the sowing periods presented in the Crop Variety Sowing Guide (Crook *et al* 1995). This book presents yield relativities for each sowing period based on the cereal variety testing (CVT) trials. The corresponding adjustment is made to achievable yield to calculate variety-specific achievable yields.

Predicted paddock yields are calculated as a function of achievable yield and nitrogen uptake (Burgess *et al* 1991). This relationship takes the form :

$$GY = A \times [\, 2 \times (N_{up} / g / A) - (N_{up} / g / A)^2 \,]$$

where GY = predicted paddock yield (kg/ha)
A = achievable paddock yield (kg/ha)
N_{up} = nitrogen uptake in kg N /ha
g = constant at 0.04

Figure 5. Paddock yield vs nitrogen uptake

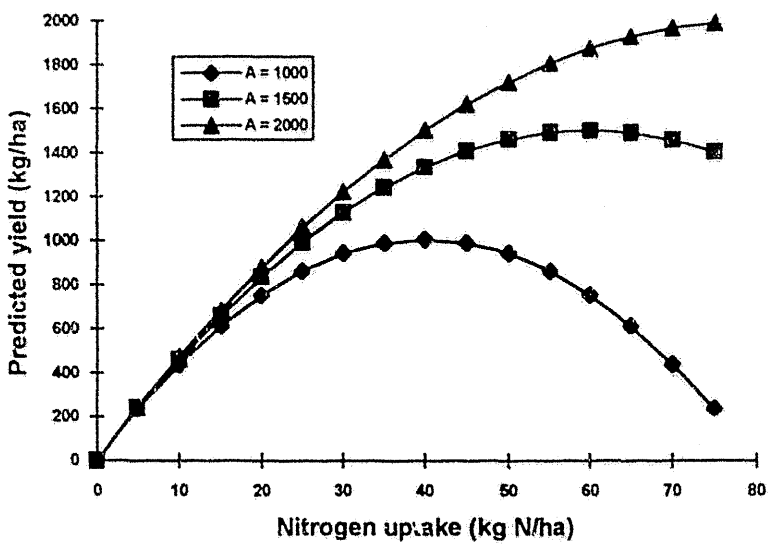


Figure 5 shows the relationship between predicted paddock yield and nitrogen uptake for three seasonal outcomes. The seasonal outcomes are represented by different *achievable* paddock yields (denoted by A) which are potential yields (read off the triangular potential yield distributions) and adjusted for weeds, disease and variety.

For every season finish there will be a unique predicted yield vs nitrogen uptake relationship. Predicted yield for a given season finish is read off this curve.

Estimating available soil nitrogen

There is no attempt made in SPLAT to estimate background levels of soil nitrogen. Much effort has been devoted in this area (Bowden and Burgess 1993) and it is assumed that users would utilise available information to estimate nitrogen status for individual paddocks. Nitrogen status is expressed in terms of two pragmatically partitioned soil nitrogen pools, namely residue organic nitrogen (RON) and stable organic nitrogen (SON).

RON relates to nitrogen derived from recent inputs of crop and pasture residues. This source of nitrogen mineralises rapidly and can be a major contributor of nitrogen for subsequent plant growth. SON collectively relates to the rest of the soil organic nitrogen which is assumed to be in relatively stable, slowly mineralised forms. Most soil nitrogen is in this form although each unit of SON is much less available to plants than a unit of either fertiliser nitrogen or RON.

Paddock specific situations can therefore be addressed by adjusting the size of the RON and SON pools and adjusting the availability of these according to, among other factors, rates of mineralisation, root growth rates and leaching rates (Burgess *et al* 1992b). Typically the availability of RON within a season is in the order of 30 to 50 percent, and the availability of SON between 2 and 3 percent. The availability of applied inorganic nitrogen also varies, the analyses presented assuming an availability within the season of 85 percent.

To calculate total available soil nitrogen (N_{avail}), the products of the three sources of nitrogen (RON, SON and N fertiliser) and their respective per unit availability are summed. This provides a paddock specific available nitrogen estimate in kg nitrogen per ha.

Estimating nitrogen uptake

Maximum nitrogen uptake is linked to achievable paddock yield to reflect the seasonal conditions that affect both parameters. For every seasonal outcome specified there therefore will be a unique maximum nitrogen uptake ceiling. The relationship defined is :

$$N_{max} = 0.06 \times A$$

where N_{max} = maximum nitrogen uptake in kg N /ha and
A = achievable paddock yield in kg /ha.

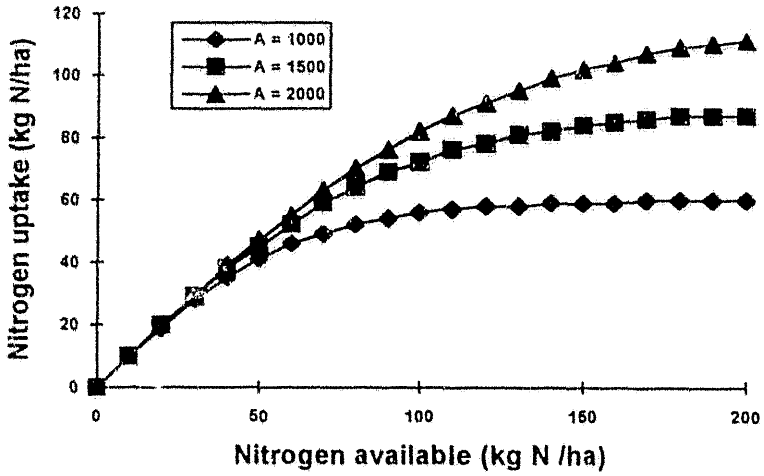
Actual nitrogen uptake is a function of maximum nitrogen uptake and nitrogen available (Burgess *et al* 1991) :

$$N_{up} = N_{max} \times \tanh(N_{avail} / N_{max})$$

where N_{up} = nitrogen uptake in kg N/ha
N_{max} = maximum nitrogen uptake in kg N/ha
N_{avail} = available nitrogen in kg N/ha

Figure 6 shows the relationship between nitrogen uptake and nitrogen available for three seasonal outcomes.

Figure 6. Nitrogen uptake vs nitrogen available



Once nitrogen available has been calculated, nitrogen uptake is calculated from the graph for each seasonal outcome specified. The seasonal outcomes shown are for achievable paddock yields of 1, 1.5 and 2 tonnes per ha.

Calculating protein percent

Protein yield is calculated as a function of nitrogen uptake and achievable yield according to Bowden (pers. comm. 1995) :

$$PY = b \times (N_{up} \times (nhi_0 \times (A \times K_{nhi} / (A \times K_{nhi} + N_{up}))))$$

where PY = protein yield in kg protein /ha
A = achievable paddock yield in kg/ha
b = 5.073, conversion factor from N in grain to protein
nhi_0 = 0.9
K_{nhi} = 0.06

The values of nhi_0 and K_{nhi} may vary according to site and season finish. Work is currently being undertaken to further calibrate the relationship between protein yield, nitrogen uptake and achievable paddock yield.

Once protein yield for a given seasonal probability has been estimated, protein percent is calculated by dividing protein yield by the predicted yield.

Stochastic relationship between protein percent and grain yield

Once paddock specific details, such as sowing date, nitrogen status, weed and disease burden have been entered into SPLAT, yield and protein predictions are calculated for specified season outcomes and plotted on a protein percent versus yield graph (Figure 7). Iso–nitrogen curves are plotted, for six rates of applied nitrogen (0 to 50 kg N/ha), so that the relationship between the season finish and yield and protein percent can be studied *for a given rate of nitrogen*. These iso–nitrogen lines are convex to the origin. Iso–season finish curves are shown for five season scenarios, the lines labelled 90%, 75% etc, so that the relationship between bag nitrogen applied and yield and protein percent can be studied *for a specific season finish*.

Figure 7 shows a typical protein vs yield relationship. The probabilities are expressed in terms of greater than the represented yield.

Figure 7. Example of Protein vs Yield for Spear Wheat Under Pasture : Wheat Rotation

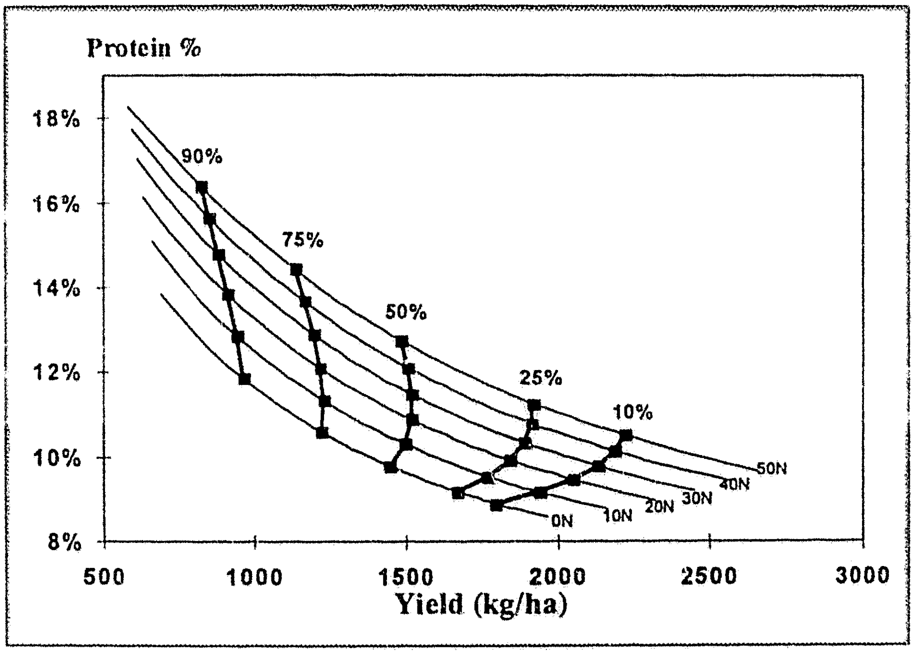


Figure 7 is intended for use in three ways. Firstly, to predict protein and yield for a particular season finish, given a particular application rate of nitrogen. Secondly, to show how yield and protein change with season finish given a particular nitrogen application rate (ie. moving along the iso–nitrogen curves). Thirdly, to show how yield and protein change with nitrogen application rate given a particular season finish (ie. moving along the iso–season curves).

For example, if the best 10% of season finishes occurs what is the minimum amount of bag nitrogen required to achieve at least 10% protein? Or viewed from the other perspective, what odds are there of achieving 10 % protein if only 20 kg of bag nitrogen are applied?

Relationship between gross margin, seasonal outcome and nitrogen

The next step in the analysis of wheat variety and nitrogen application decisions is to calculate gross margin from the figures provided in Figure 7. SPLAT requires that the user provide variable costs other than nitrogen and the cost per unit of nitrogen including freight and application. Current segregations must be provided with acceptable varieties listed and the protein limits for each segregation. Typical output for a noodle wheat in a wheat:pasture rotation would be as shown in Figure 8.

Figure 8. Gross margin vs Nitrogen Rate for Noodle Wheat Under Pasture:Wheat Rotation

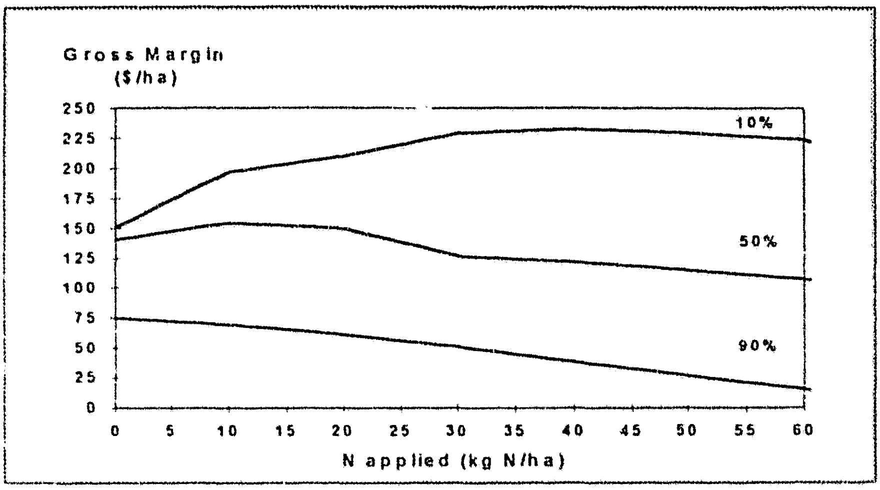


Figure 8 shows a typical gross margin versus nitrogen applied relationship for a noodle wheat given a particular season start on a paddock. The three lines shown are iso–season curves, representing the top 10 % of season finishes, the median season finish and the worst 10 % of season finishes. The irregularities in the curves are due to protein premiums changing as protein percent changes reflecting the movement in and out of segregations with differing payments.

As the seasonal outcome in terms of yield improves from the worst 10% to the best 10%, it can be observed in Figure 8 that the gross margin – maximising nitrogen rate increases. The downward slope in iso–season curves with increasing nitrogen application reflects both diminishing returns to applied inputs and, in the case of premium segregations with distinct protein limits, the wheat moving out of the higher paying segregation as the protein level exceeds the upper limit.

Figure 8 shows the risks associated with applying a given rate of nitrogen; the opportunity cost of applying a sub–optimal rate can directly be read off the graph for a range of season outcomes. To users of this information with analytical skills, this information may be best presented as cumulative frequency distributions of the differences in gross margin between one application rate and another. The chance of one strategy being superior to another by a given amount can be read directly off such a chart. However, the skill in presenting this kind of analysis to users of SPLAT is to represent difference analyses in an understandable manner. It is postulated that Figure 8 is the most understandable graphical representation, and a difference analysis is effected by reading off the Y axis the differences for a given nitrogen rate.

Figure 7 is used as a reference to indicate the percent protein and grain yield underlying the dollar returns, taking away the black box nature of gross margin graphs.

Selecting wheat variety using gross margin versus nitrogen rate relationship

Figure 8 can be reproduced with any number of additional varieties included. Figure 9 compares an ASW wheat (Spear) to a noodle wheat (Cadoux) for a typical mid-season sown paddock in a pasture:wheat rotation.

Figure 9 : Gross Margin of Cadoux vs Spear Wheat

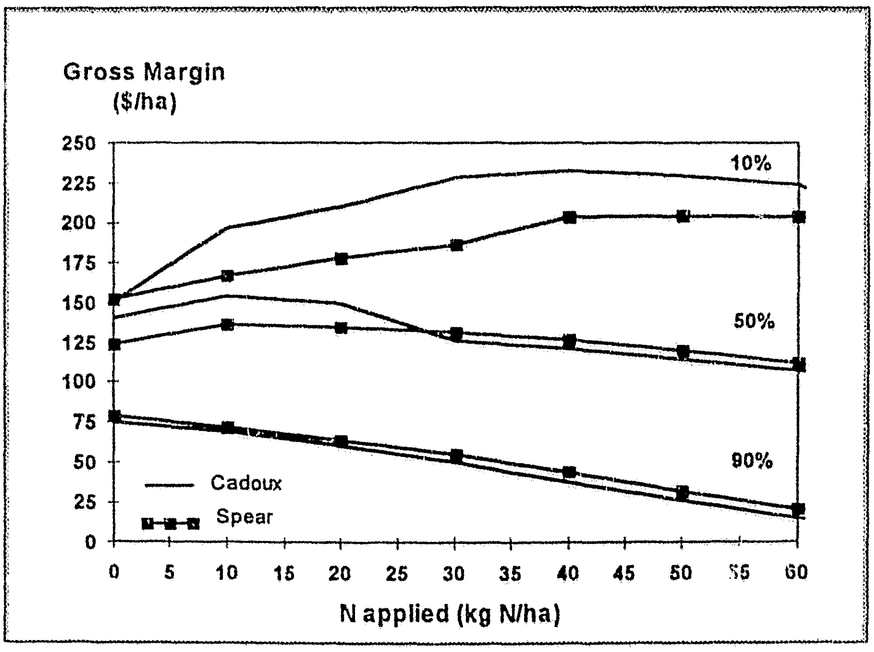


Figure 9 allows a comparison between varieties. The returns associated with nitrogen application rates are shown for each variety along the iso-season curves. In addition, the opportunity cost of planting a variety at a given nitrogen application rate is shown as the difference between the iso-season curves of each variety at the required level of probability.

For the sowing date assumed in Figure 9, Spear is slightly higher yielding than Cadoux (and therefore slightly lower protein at a given nitrogen application rate).

The 90% probability curve (indicating the worst 10 % of seasonal outcomes) shows that Cadoux returns slightly less than Spear for all nitrogen application rates. The reason in this case is that at all rates of nitrogen the protein percent achieved by Cadoux is greater than the 11.5% upper limit for noodles, hence the grain goes into ASW with Spear.

However, if the season finish is the median or better then the maximum gross margin returned by Cadoux is substantially greater than that of Spear as the noodle grade is made (current protein limit of 9.5% – 11.5%) and a premium of approximately $17/tonne achieved for a range of nitrogen application rates. This difference analysis indicates the opportunity costs of selecting one variety over another, and the opportunity cost of selecting one application rate of nitrogen over another. This type of decision is typical of decisions faced by farmers in an uncertain environment The difference in returns over a range of possible outcomes (in this case, seasonal outcomes) represents the true risk and opportunity cost of one strategy versus another.

Again, to the analytically adept, a cumulative frequency distribution of the differences between two courses of action may more succinctly demonstrate opportunity cost. An example is shown in Figure 10.

Figure 10. Cumulative Distribution of the Differences in Gross margin Between Spear and Cadoux

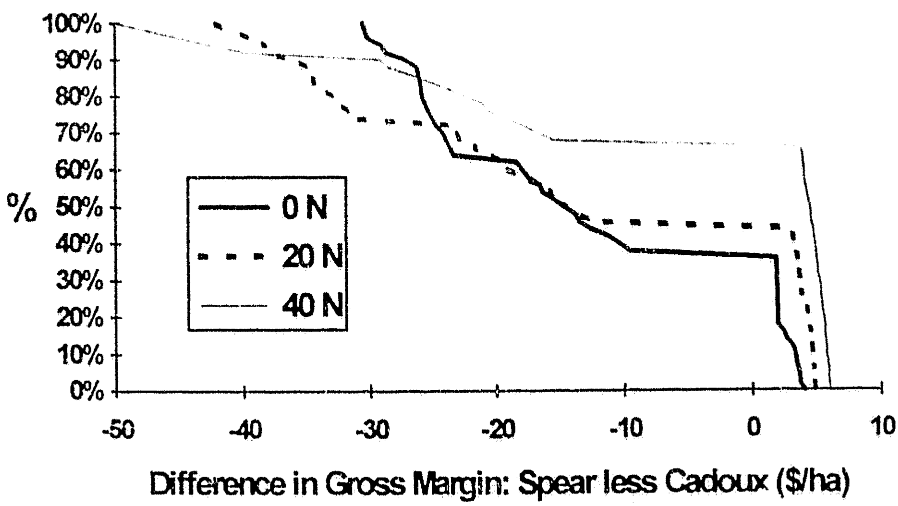


Figure 10 demonstrates that at a nitrogen application rate of 40 kg N /ha, the majority of seasonal outcomes (approximately 70%) would result in Spear returning a greater gross margin than Cadoux. However, the difference in gross margin is, at most, $6 per ha. Yet if the seasonal outcome results in Cadoux returning a greater gross margin (approximately 30% chance), the cost of planting Spear instead in terms of foregone returns could amount to $50 per ha.

However, it is the author's experience that output of the type in Figure 10 is seldom understood by the targeted user group. Output is better presented as gross margin versus nitrogen rate, as in Figure 9, and the intermediary marketeer of the information (consultants and advisers) taught to how to use the graph to extract information in the different ways described. Of course, the 90%, 50% and 10% seasonal outcomes were chosen purely for the example in Figure 9. SPLAT allows any levels of probability to be selected which would allow a more accurate difference analysis.

Conclusions

Graphical output is the most complete way of presenting information from SPLAT to consultants and advisers. It is intended that these extension specialists using SPLAT be trained in the use of graphs to facilitate the interpretation of the analyses indicated above. The next level of resolution will depend upon individual circumstances of farmers. It is not intended to present the majority of farmers with graphical information.

The only two representations of varietal and nitrogen information will be those shown in Figure 7 and Figure 9. These contain all the information provided by SPLAT for varietal and nitrogen decisions. Other output can be generated, such as iso-protein yield curves and protein yield versus season curves but these are intended for the crop modellers producing the protein, yield and season relationships described in this paper.

The uses and abuses of probabilistic information presented to farmers has been well documented. Farmers generally face too tew seasonal events for expected values to be of much use (Makeham and Malcolm 1993). The paddock specific decisions faced by farmers change from year to year. The use of expected values at the farmer decision making level is therefore of little use.

Rather than formally including probabilities in a decision analysis, the possible outcomes are presented with probabilities and the farmer weighs these up with his risk attitude, preferences, personal make-up and situation and makes a decision. This approach is consistent with ideas suggested by Malcolm (1994). The choice of seasonal outcome and level of risk on which a decision is based is entirely at the discretion of the decision maker. The seasonal outcome is, of course, unknown at the time the decision is made. However, by weighing up the consequences of a range of outcomes, and extracting information about the risks associated with these outcomes from SPLAT output, the decision maker can make a more informed choice of wheat variety and nitrogen application rate.

The purpose of providing stochastic varietal decision aids is to help farmers make more informed judgements. It is not the intention to take away the decision. The process of weighing up the odds in a more formal manner, with concise specification of assumptions, should lead to more informed decisions.

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