Modelling wheat production on farms in southwestern Queensland

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Abstract Wheat-growing in southwestern Queensland is risky due to the low and variable rainfall, and high rates of evaporation. Nitrogen (N) fertilisers benefit wheat crops when soil moisture is in good supply and soil nitrate is low, but these factors vary from year to year. A trial in 1996 showed that it was most profitable to apply a high rate of fertiliser (90 kg N/ha). However, modelling the wheat crop and comparing the conditions that occured in 1996 with those from 1960 to 1993 showed that the benefits found in 1996 were due to the abundant soil moisture available when the crop was sown. Modelling crops sown onto less soil moisture showed that N fertilisers will often be uneconomic. The results from the trial need to be viewed in the context that the conditions at sowing were historically exceptional.

1. INTRODUCTION

1.1 Wheat farming and research in Australia

In 1993, about 7.2 million hectares of wheat was grown in Australia, with a gross value of about $1,950 million. Wheat valued at more than $1,500 million was exported [Malcolm et al. 1996]. Wheat is one of Australia's most valuable export products.

Wheat production in Australia has advanced through a range of science-based technological advances, and agricultural science is an integral part of the business of wheat-production.

1.2 The risky, difficult business of farming

Australian farmers deal with a wide range of adversities. Few things in farming are as certain as the occurrence of floods, droughts, plagues and pestilence. Adverse seasonal conditions greatly reduce wheat production. Yields fluctuate over a wide range, even in the heartland of Australia's wheat belt. Figure 1 shows data from an experiment at Wagga Wagga in New South Wales, a location known for its reliability [Heenan, pers. comm.]. This graph shows how unreliable wheat production can be in such an area.

As well as poor seasons, Scott [1994] found that farmers were concerned about costs of production, lack of price control, indirect costs, market variability, lack of government understanding and taxation.

Price and marketability of wheat are risky because most of Australia's wheat is sold into markets against strong competition from much larger producers, such as the USA.

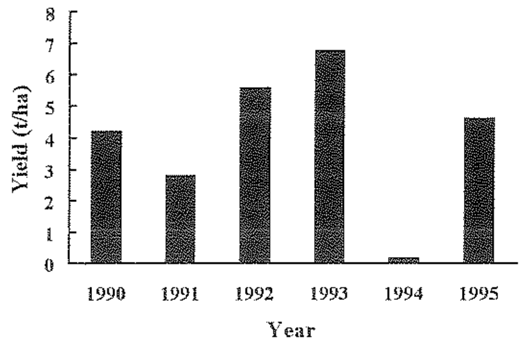

Figure 1. Wheat yields from an experiment at Wagga Wagga, showing the extreme variations that may occur from year to year. Data from Heenan, pers. comm.

Farmers are therefore faced with adversities that make their businesses difficult to manage. This study determines the effects of seasonal variablility on the optimum use of fertiliser. Fertilisers are a major cost of production for wheat growers in the northern wheatbelt.

1.3 Where is southwestern Queensland?

The southwest of Queensland's grain-growing region is mainly located in the catchments of the Maranoa and Warrego rivers. St George and Roma are major centres of grain production. Figure 2 shows annual rainfall isohyets and towns in theWarrego and Maranoa.

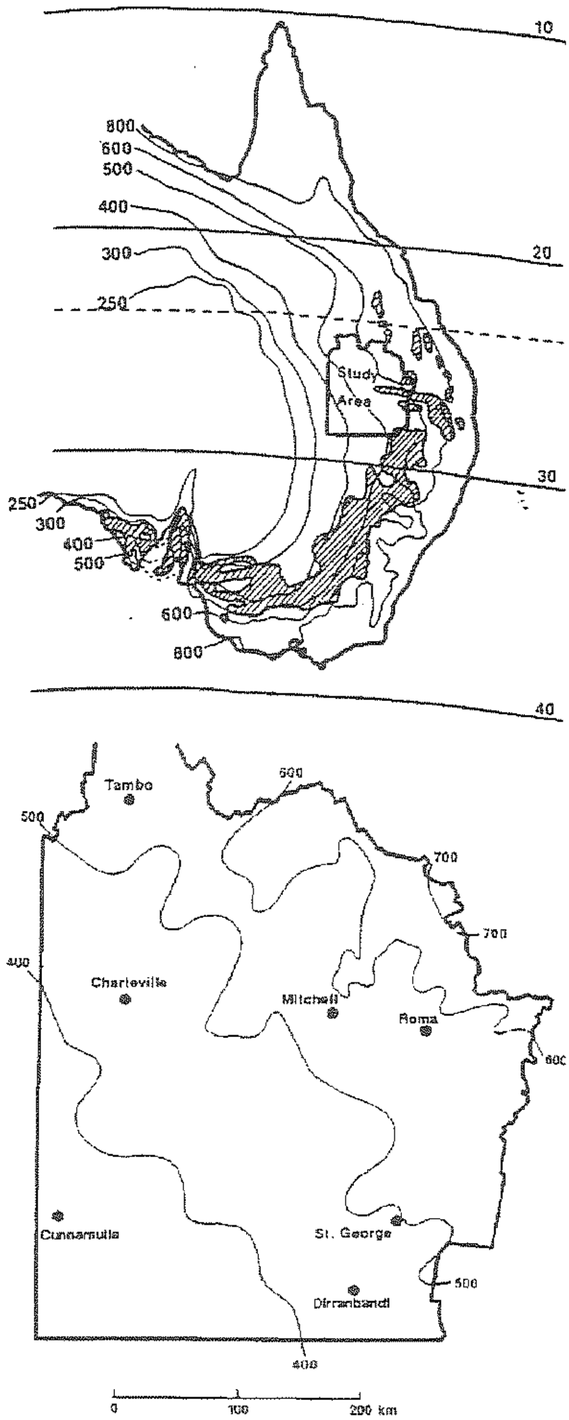

Figure 2. The wheat belt of eastern Australia (shaded) and the Warrego and Maranoa regions, showing isohyets of annual rainfall.

1.4 Farming systems in southwest Queensland

Farms on the western margin of the wheat belt of eastern Australia receive lower and more variable rainfall than farms to their east (Figure 2). This restricts their range of cropping options and limits their output.

On the western margin of the wheatbelt in Queensland, summer rainfall typically exceeds winter rainfall, but the wheat is grown in winter. This is because farmers use a fallow period (ie. without crop) to accumulate moisture in the soil for growing the crop in the cooler, more humid months. Winter rainfall alone is usually insufficient to grow a crop of wheat, so storage of summer rainfall is very important. Despite this system, crops will often fail due to lack of moisture.

In seasons with adequate moisture, crop yields are limited by soil fertility, particularly a lack of available nitrogen (N). Nitrogen makes crops leafier and heavier, which may result in more grain, except in dry years when crops grown with abundant N use more soil moisture, and may suffer severe moisture stress. So nitrogen has the potential to increase yields when rainfall and soil moisture is adequate, but decrease yields when rainfall and soil moisture are in short supply. Nitrogen supply also affects the concentration of protein in the grain. Farmers receive higher prices for wheat with higher protein, so there's a price as well as yield incentive to apply N fertilisers if soil reserves of N are low.

Managing soil moisture and nitrogen supply to the wheat crop are keys to increasing farmer's yields, profits, and sustainability.

1.5 Farming and science in southwestern Qld

Although some areas have been cropped for 40 or 50 years, it wasn't until an expansion in the area cropped in the 1960s and 1970s that these farming systems were intensively studied. There were concerns at the time that pastoralists were adopting farming during a sequence of benign seasons, and that farming would be unsustainable. However, Hammer et al. [1987] used long-term climate records and a model of wheat yields to show that this was not the case; farming had extended westward during a period that was climatically normal, and that farming was quite economic in the long-term.

More recently, investigations have focussed on improving the farming systems. Thomas et al. [1995] conducted field trials and found that different soils, tillage and fertiliser rates gave a wide range of yields and yield responses in different seasons. Results from field experiments such as these are often complicated by seasonal differences in rainall and soil nutrient status. Limits to the number of sites, soil types, agronomic practices and seasonal conditions that may be studied reduces the effectiveness of such experiments.

To overcome some of the limitations of field experiments Thomas et al. [1995] used the PERFECT model (Littleboy et al. [1993]) to simulate wheat yields. The model fitted results obtained in the field, and was used to assess the long-term sustainability, productivity and economy of cropping a range of soil types. This broadened the knowledge base available for evaluating land classes in the region.

In 1996, a large experiment was established near Nindigully (44 km south of St George) to compare several cropping systems. This experiment, known as the core trial, has provided information on the yields of wheat, responses of wheat to various rates of N fertilisers, and the yields of other crops. In the future the core trial will provide information on carryover effects of crops.

The aim of this study is to use data from the core trial to calibrate a model of cropping systems, and to use the model to assess the use of N fertilisers under a wide range of seasonal, soil and management conditions.

2. METHODS

2.1 The core trial and the APSIM model

The relevant part of the trial at Nindigully measured wheat yields and grain N concentrations in wheat crops that had either 0, 30, 60 or 90 kg N/ha of N fertiliser applied at sowing. Grain N concentration is a *de facto* for grain protein concentration (protein = 5.7 x N).

Wheat of variety Hartog was sown at 38kg/ha on 25 May. Nitrate in the soil profile (0 to 120 cm depth) immediately before sowing was equal to 69 kg N/ha.

APSIM (the Agricultural Production systems SIMulator, McCown et al. [1995]) was used to simulate wheat production in the core trial. APSIM is a collection of software that allows a wide range of partial models to be run together to simulate a limited agricultural system. The partial models include crops, pastures, soil water, soil nutrients, soil erosion and crop residues. Together, they can represent a small area with uniform resources and agronomic management, such as a paddock.

Data collected from the core trial was used to calibrate APSIM for this study.

2.2 Experiments with APSIM

Weather, starting plant-available soil moisture (PAW) and soil nitrate data were used in the APSIM model to estimate yields for the same 4 levels of N fertiliser applied in the trial; 0, 30, 60 and 90 kg N/ha.

The model was run for 1996, and the results compared subjectively with the measured values. Next, the model was run using an historical climate record for St George (1960-1993). To differentiate the effects of different seasonal conditions in-crop from preceding conditions, the available soil moisture and soil nutrient levels were set at the time of sowing (which was also fixed each year). Therefore, the results from the modelling experiments that varied soil moisture and N fertiliser rates are useful for answering questions such as; "How much yield can I expect from these rates of fertiliser, *GIVEN* that I am sowing on date X, with Y amount of PAW, and Z amount of soil nitrate?"

The effects of sowing date on responses to N fertilisers were similarly examined by simulating 3 sowing dates (25 April, 25 May and 25 June). The sowing date in 1996 was 25 May (which is fairly typical). Available soil moisture at sowing and soil nitrate levels were set at 108 mm and 69 kg N/ha, respectively, at sowing.

Simulated yields and grain N concentrations were used to calculate gross margins ($/ha) for each year. Thallon is the nearest wheat silo to Nindigully, so prices at the Thallon silo were used to calculate gross annual income. N fertiliser was assumed to cost $1/kg N applied. Other variable costs of production were estimated to be $80/ha.

3. RESULTS AND DISCUSSION

3.1 What happened in the core trial in 1996?

It was an excellent year for growing wheat. Yields from most crops in the district were very good, though frosts affected a few crops. PAW at sowing was 204 mm, equal to 95% of the capacity of the soil profile.

Rainfall received between sowing and harvest was excellent (201 mm), with a useful spread between early crop growth (131 mm before anthesis) and during grain filling (70 mm after anthesis).

3.2 Modelling the fertiliser N responses in the trial

Comparison of the measured and modelled yields (Figure 3) shows that APSIM did a useful job of estimating both the yields and fertiliser N yield responses.

Comparisons of the measured and modelled grain N concentrations (Figure 4) are also favourable. This is important because the price received for grain depends on the concentration of protein in the grain.

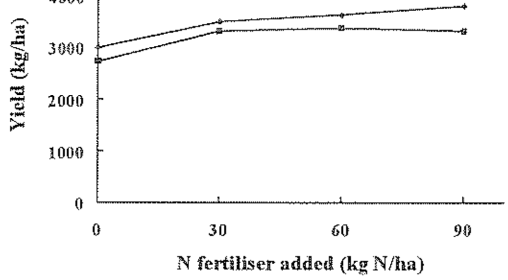

Figure 3. Measured and modelled yields at Nindigully.

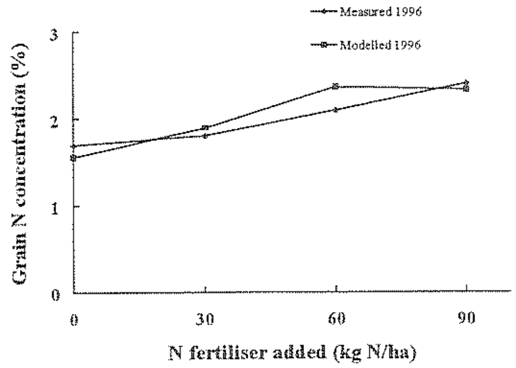

Figure 4. Measured and modelled grain N concentrations.

3.3 Results from the historical climate sequence

Figure 5 shows that the yields in 1996 were very similar to the means of the simulated yields (1960 to 1993).

Figure 6 shows the whole range of the annual yields (1960 to 1993, + 1996) for the 4 fertiliser N treatments (0 to 90N). Because the yields in these figures are based on the same sowing conditions in each simulated year (those for 1996) the differences between years are entirely caused by different seasonal conditions after sowing.

Figures 5 and 6 show that the yield responses to N fertiliser in 1996 were definitely *not* exceptional *given the excellent conditions at sowing.*

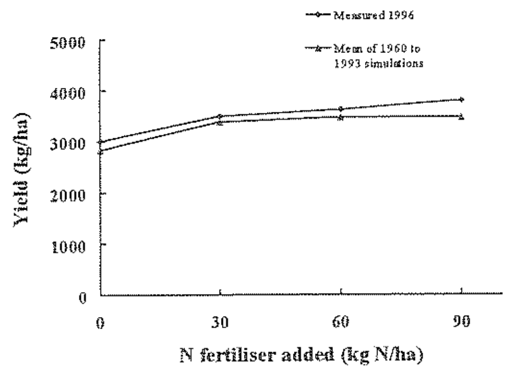

Figure 5. The measured yields in 1996 and the means of the modelled yields for 1960 to 1993.

Fertiliser responses in each year were highly variable (Figure 6), ranging from negative or no yield response (e.g. 1982, 1991) to doubling of the yield with 90 kg N/ha (1966). The variability in response implies that caution is required when interpreting 1 or 2 years' results.

3.4 Effects of different conditions at sowing

Because abundant soil moisture at sowing is not common at Nindigully, further simulations were conducted using starting conditions of 108 mm PAW (50% full, a typical condition) and 54 mm PAW (25% full, poor conditions).

Figure 7 shows that the simulated yields for 108 mm were lower and more variable than for 204 mm (Figure 6).

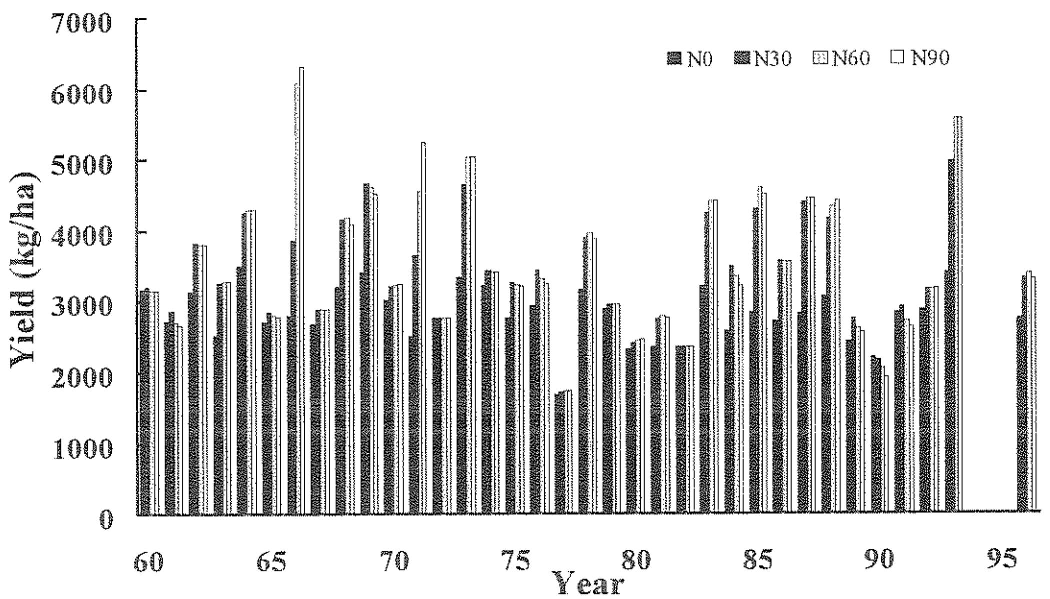

Figure 6. Simulated yields for 1960 to 1993, and 1996, given 204 mm (95% PAWC) of available soil moisture and 69 kg N/ha of soil nitrate at sowing.

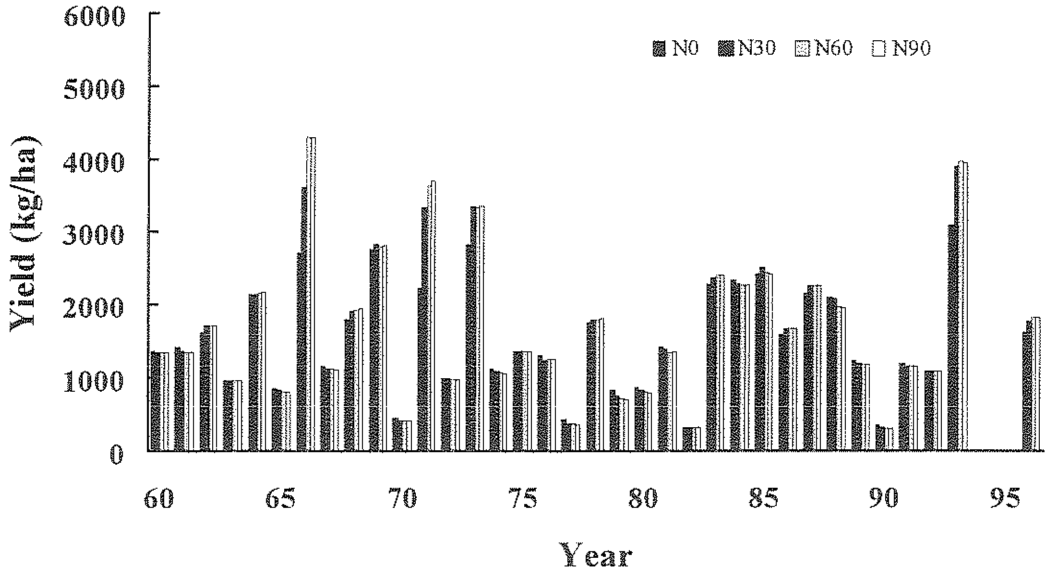

Figure 7. Simulated yields for 1960-1993, and 1996, given 108 mm (50% PAWC) of available soil moisture and 69 kg N/ha of soil nitrate at sowing.

The means of the simulated grain yields for the period are shown in Figure 8. As expected, the yields at each level of N fertiliser were substantially greater with more available soil moisture at sowing. The effect of available soil moisture at sowing on mean yield is very large even though the crop still has about 4 months to grow, and receives in-crop rainfall.

Yield responses to N fertiliser were also different at the 3 levels of PAW at sowing. This agrees with the theory that responses to N fertiliser are limited by available soil moisture. Crops with abundant N may be too leafy early in the season and use too much soil moisture and suffer stress during critical periods for grain production around anthesis and grain fill.

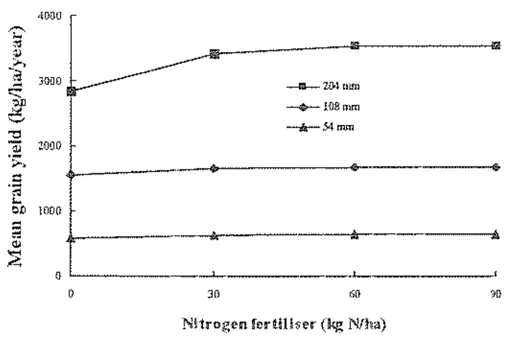

Figure 8. The means of simulated grain yields for crops with 0, 30, 60 and 90 kg N/ha applied at sowing. Available soil moisture at sowing was set to 54, 108, or 204 mm (equal to 25%, 50%, 95% PAWC).

Like grain yields, gross margins and responses of gross margins to rates of N fertiliser were very sensitive to how much soil moisture was available at sowing (Figure 9).

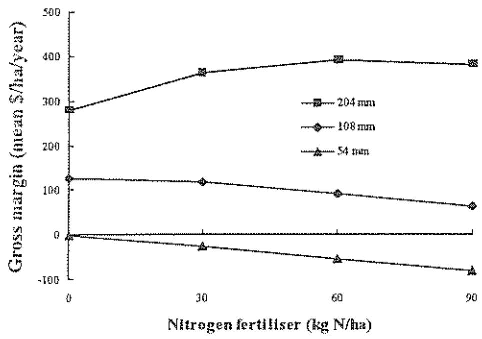

Figure 9. Gross margins from the simulated wheat crops grown with 4 rates of N fertiliser and 3 levels of available soil moisture at sowing.

3.5 Effects of sowing date on responses to N fertilisers

Wheat yields decreased with later sowing at both 0 and 60 kg N/ha of fertiliser (Figure 10). This was expected, and is due to increased moisture stress. Later sowing leads to the crop maturing later in the year, when conditions are usually hotter and dryer.

The wheat yields were increased most by 60 kg N/ha of fertiliser at the early sowing (Figure 10). Loss of yield benefits from N fertiliser at the late sowing is due to moisture stress around anthesis and during grain filling becoming more strongly limiting with later sowing. Because N fertilisers make the crop leafier, the chances of severe moisture stress increase, so the yield benefits of N for late-sown crops are less.

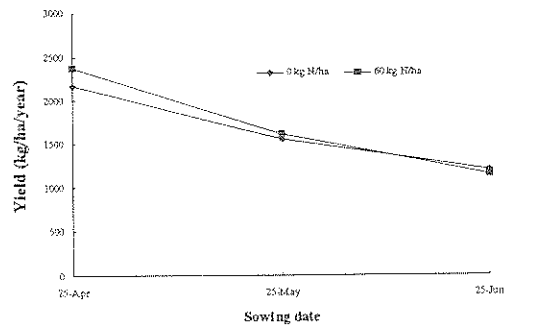

Figure 10. Yields with 108 mm of available soil moisture present at sowing (50% full).

Gross margins (Figure 11) reflects the better yield response at early sowing. However, nil fertiliser is more profitable than 60 kg N/ha at each sowing date, under these conditions (108 mm PAW, 69 kg N/ha nitrate at sowing).

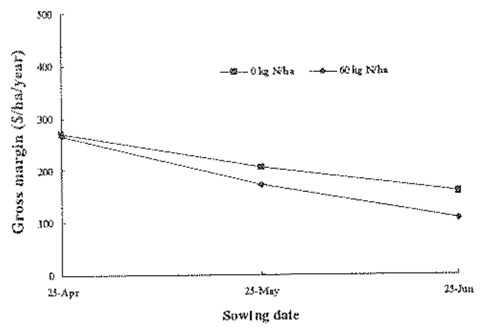

Figure 11. Gross margins for the 3 sowing dates.

4. CONCLUSIONS

The core trial provided new information concerning wheat production, measuring yields under near-ideal conditions.

The model was able to place the results from 1996 in a broader context of seasonal conditions and conditions at sowing. The profitable response to N fertiliser found in 1996 depended on the abundant soil moisture present at sowing. Modelling experiments with APSIM showed that unless soil moisture conditions at sowing are favourable (as in 1996), the yield and nitrogen responses of wheat to N fertiliser are greatly diminished. N fertiliser will usually be uneconomic when less soil moisture is available at sowing.

The reluctance of farmers in this region to apply high rates of N fertiliser has been noted for some time, and may have been misinterpreted by researchers and consultants. The results from the model show that there would be little or no yield gain in the majority of years (when the profile is only partly full). So it is a good strategy not to routinely use N fertiliser. The variable responses between years and relatively high cost of nitrogen fertilisers are also strong disincentives to their use. However, the model also strongly supported experimental results showing that high rates of N fertiliser are best when soil moisture is abundant. These 2 strategies are compatible, not contrary, and may be combined to provide a more profitable pattern of fertiliser use that is dependent on the moisture supply at sowing.

This study has bridged some perceived inconsistencies between the knowledge held by farmers, gained through vast experience, and the knowledge held by experimentalists, gained from training and precise observation. In this respect APSIM has been a useful tool for communication and increased understanding, as well as a tool for tackling the problem of matching agricultural management to seasonal conditions.

5. ACKNOWLEDGMENTS

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