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Evaluation of a new cropping option using a participatory approach with on-farm monitoring and simulation: a case study of spring-sown mungbeans

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Abstract. In the northern Australian cropping region, mungbean is commonly sown as an opportunity crop, usually on low soil water after a winter cereal, and consequently has a reputation for being a low yielding, high risk crop. Yield prospects could be improved and risks reduced if it was sown on soils with a higher soil water content, for instance in spring after a winter fallow. However, there is a lack of experience and confidence in alternative roles for mungbean in the farming system. This paper describes a research approach involving researchers, farmers, advisers, and grain traders in which on-farm monitoring of spring-sown commercial crops and cropping systems simulation with APSIM were used to explore yield prospects for a spring-sown crop after a winter fallow. The key elements of the approach are: (1) identification of possible options through simulation of scenarios, (2) testing the new practice with innovative farmers, and (3) monitoring of the management and performance of commercial crops and comparing yields with benchmarks estimated with a model. In this case, after 2 years of on-farm testing, spring-sown mungbean has been shown to have a potential for high returns in the northern cropping systems.

Additional keywords: mungbean, modelling, participatory action research.

Introduction

Mungbean [*Vigna radiata* (L.) Wilczek] is a warm-season grain legume grown in the tropics and subtropics of north-eastern Australia, mostly under dryland conditions, with a current production of about 30000 t (Sykes and Siddique 1997). Mungbean as a dryland cropping option suffers from poor farmer perception as a low yielding, high risk crop, due to the fact that it is commonly sown in December–January on low soil water, doubled-cropped after winter cereals (Lawn and Russell 1978) (Fig. 1). We suggest that an alternative perception for the crop could be promoted by considering mungbean as an option for sowing in spring after a 6–10-month winter fallow (Fig. 1). Shifting to this type of system would involve moving the sowing window forward to the opening rain of the spring, usually during October–early November. Higher levels of starting soil water may improve the yield prospects and decrease the riskiness of returns from the crop. A spring sowing allows the possibility of double-cropping back to a winter cereal through the extra soil water accumulated after the early mungbean harvest.

Traditionally, spring-sown mungbean has not been recommended, as early sowing delays the onset of flowering and prolongs the duration of flowering (Lawn 1979), resulting in uneven maturity at harvest. Although this recommendation has been followed by the industry, it was developed from on-station trials, and has had only limited evaluation under commercial conditions. In addition, spring sowing has been discouraged because the ripening period for spring-sown crops is traditionally during the wettest months (January–February), which can lead to weather damage of grain (Williams *et al*. 1995) and down-grading of the price received by the grower.

However, there are a number of factors that may warrant a re-think of spring sowing. The impact of weather damage on grower returns is potentially not as great as it once was when varieties were weathering-susceptible and the only

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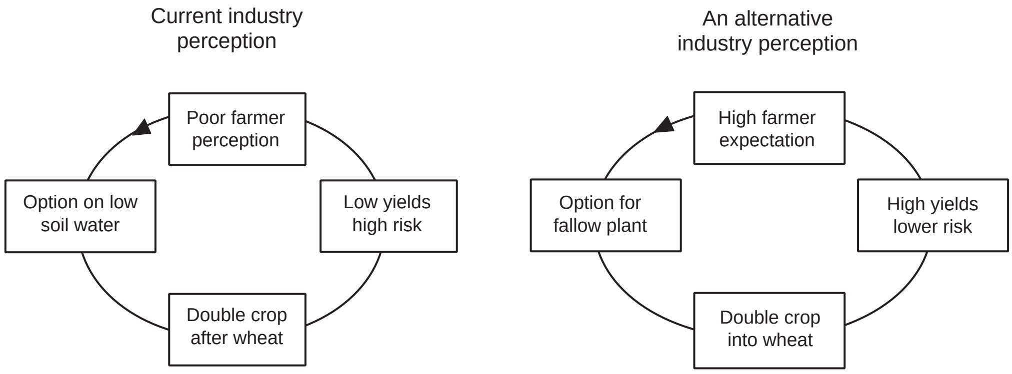

Fig. 1. Perceptions of mungbean as a cropping option in the north-eastern cropping zone of Australia.

markets were either high quality sprouting ($AU600/t) or weather-damaged stockfeed grain ($120/t). Now weathering-resistant varieties and the opening up of the processing grade markets during the 1990s have effectively put in a floor price of $450/t for weather damaged grain. In addition to the possibility of improving the yield prospects and lowering the risks of mungbean production, spring sowing also offers the opportunity to expand the role for the crop in the farming system and spread grain receipts more evenly through the harvesting season. There is also the possibility that early sowings may attract a price premium if grain quality is comparable with that from summer sowings.

In a traditional mode of research and development, this feasibility of spring sowings would be tackled by conducting a program of experiments on research stations, manipulating the main agronomic variables of interest (e.g. sowing date, variety), and then extending the results to farmers as recommendations. This paper describes an alternative process where a participatory research approach, involving researchers, farmers, grain traders, and commercial agronomists, explored prospects for spring-sown mungbean after a winter fallow. The advantage of this approach was that the common lag period for adoption may be reduced by testing the new practice in relevant commercial situations. Cast in a farming systems research perspective, this approach can be thought of as the planning phase of on-farm testing of new technology with the associated diagnosis of problems, preferences, and opportunities (McCown *et al.* 1994).

Materials and methods

Overview

The key elements of the research approach are outlined in Fig. 2. In line with the participatory theme of the approach, different participants were involved in each step.

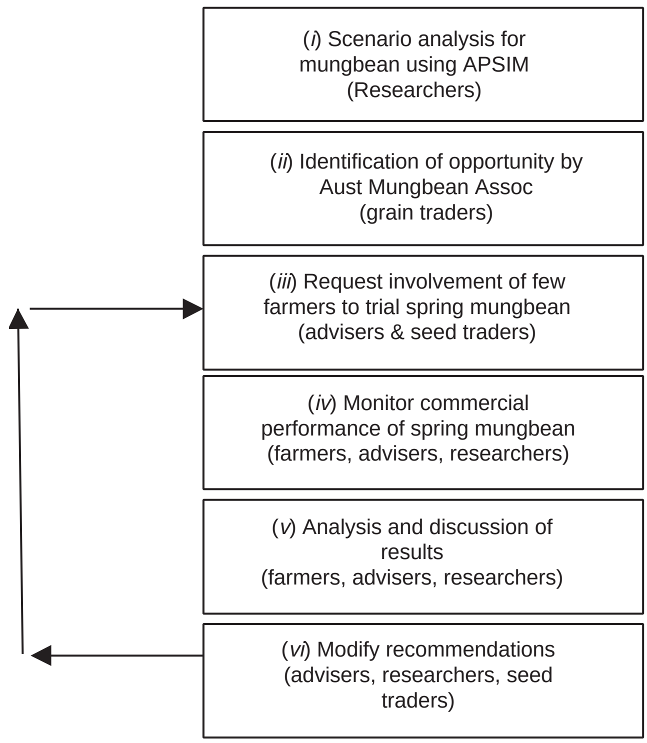

Fig. 2. Flow diagram of the steps involved in evaluation of spring-sown mungbeans with researchers, grain traders, advisers, and farmers. The key participants involved at each step are listed in parentheses.

The first step was the identification by researchers of possible options for sowing mungbean, through simulation of scenarios with the Agricultural Production Systems Simulator (APSIM) cropping systems model. This occurred in 1996. The results of the scenario analysis stimulated the interest of commercial grain traders. Once promising scenarios were identified, it was decided to test the new practice with innovative farmers that were identified by seed traders, during the 1996–97 season. Grain traders are ideally placed to identify collaborating farmers, as it is

Table 1. Details of commercial paddocks monitored in 1996–97 and 1997–98
Values in parentheses for starting soil water are the percentage of the full plant-available soil water store

Locality	Area (ha)	Variety	Sowing date	Starting soil water (mm)	In-crop rain (mm)
			1996–97		
Dalby	160	Emerald/Celera	Early Oct.	n.a.	150
Jandowae	160	Berken	14 Oct.	n.a.	100
Dalby	80	Satin	17 Oct.	n.a.	178
Gatton	9	Emerald	5 Oct.	n.a.	Irrigated
Brookstead	20	Satin	14 Sept.	n.a.	275
Warwick	8	Emerald	15 Nov	n.a.	260
Dalby	100	Emerald	20 Oct.	n.a.	212
Nobby	36	Berken	24 Oct.	n.a.	117
Dalby	n.a.	Emerald	24 Oct.	45 (32)	139
Pittsworth	9	Emerald	22 Oct.	136 (94)	182
Brigalow	40	Emerald	29 Nov.	116 (90)	52
Millmerran	40	Emerald	24 Oct.	48 (36)	199
Millmerran	40	Emerald	23 Oct.	48 (36)	211
Bowenville	44	Celera	14 Oct.	29 (25)	50
			1997–98		
Westbrook	46	Satin	10 Nov.	31 (20)	258
Dalby	15	Various	19 Oct.	47 (32)	331
Gatton	8	Emerald	14 Oct.	126 (98)	295
Pittsworth	60	Emerald	14 Oct.	73 (51)	110
Warra	63	Emerald	25 Sept.	77 (63)	208
Brookstead	16	Satin	27 Sept.	58 (45)	206
Moonie	150	Emerald	1 Oct.	50 (39)	347
Moonie	n.a.	Emerald	30 Oct.	50 (39)	354
Wyreema	27	Emerald	5 Oct.	80 (54)	277
Millmerran	72	Emerald	23 Oct.	32 (25)	223
Irongate	34	Emerald	15 Oct.	113 (68)	166
Grays' Gate	25	Emerald	16 Oct.	78 (62)	101
Kupunn	32	Satin	2 Oct.	108 (68)	311
Bongeen	90	Celera	20 Oct.	133 (84)	203
Felton	30	Emerald	28 Oct.	81 (57)	254
Thanes Ck	29	Emerald	26 Oct.	68 (48)	263
Gatton	n.a.	Emerald	20 Oct.	166 (100)	263
Gatton	n.a.	Emerald	20 Oct.	182 (100)	263
Kingaroy	16	Delta	18 Oct.	n.a.	261
Brookstead	n.a.	Did not sow	n.a.	20 (15)	n.a.
Bongeen	n.a.	Did not sow	n.a.	48 (30)	n.a.

n.a., not available.

from the traders that the farmers purchase seed and market grain. In order to evaluate the success of spring-sown crops, as well as identify issues and problems, the researchers and advisers then monitored the management and performance of commercial crops. This monitoring occurred over the 1996–97 and 1997–98 summer growing seasons on the Darling Downs, south-east Queensland.

Identifying the opportunity through scenario analysis

The prospects and opportunities for spring-sown mungbeans in the dryland subtropics were analysed through simulation with the mungbean module of APSIM (Carberry 1996; McCown *et al*. 1996). The module gave reasonable predictive ability when tested against 63 commercial and research station crops from the Darling Downs, Northern Territory, and Ord River, spanning grain yields (oven dry) of 334–2560 kg/ha, with 75% of variation explained (Carberry 1996). Robertson *et al*. (1998) predicted the declining trend of grain yield with delayed sowing date, observed by Lawn (1983). However, none of the datasets used in the testing was from sowings earlier than mid-November. Spring sowings in a commercial setting would be expected to occur in the September–October period.

The quantity of stored soil water at sowing is a large determinant of crop productivity in the semi-arid subtropics. To explore the impact of sowing date and starting soil water on yield prospects, simulation was conducted with the mungbean module using climate data for the years 1955–95 at Dalby, Qld (27.09°S). In the simulations, dryland crops of cv. Emerald were sown on the 15 October, November, December, and January, using a plant population density of 20 plants/m^2 and a row spacing of 50 cm. The soil water at sowing was initialised at 54, 103, or 143 mm of plant-available water, representing 25, 50, or 75% full profile for a brigalow soil type (Dalgleish and Foale 1998). Output from the simulation was analysed in terms of grain yield and its variability across the 40 years simulated. The risk of weathering damage was quantified as the number of rainfall events during pod-filling, as this is strongly related to the degree of weathering damage in mungbean (Williams *et al*. 1995). The opportunity of being able to fallow a paddock after mungbean harvest over the summer–autumn period before returning it to a winter cereal was quantified in terms of the amount of plant–available water at the occurrence of the first sowing opportunity for a winter cereal. This was defined as occurring when a total of 25 mm of rain fell over 5 days between 1 May and 29 July.

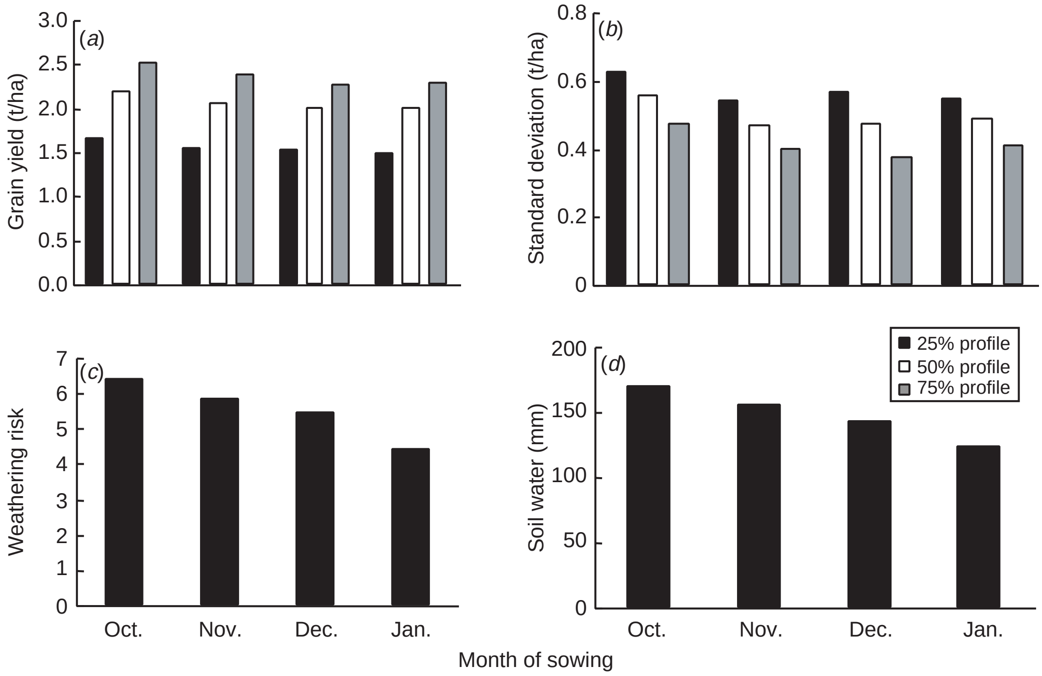

Fig. 3. Simulated response to sowing date of (*a*) oven-dry grain yield (t/ha), and (*b*) its standard deviation for 35, 50, and 75% levels of plant-available water at sowing. Also shown is (*c*) weathering risk (number of rainfall events during pod-filling) and (*d*) plant-available water (mm) at the first simulated sowing opportunity for a winter cereal after mungbean harvest.

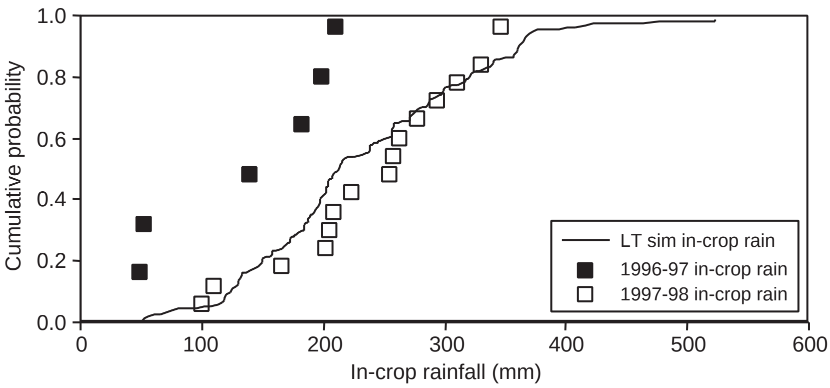

Fig. 4. Cumulative frequency distribution of long-term in-crop rainfall at Dalby (1888–1997) for a mungbean crop sown 1 November. Also shown is the cumulative frequency distribution of observed in-crop rainfall for the mungbean crops monitored in 1996–97 and 1997–98. Only those crops able to be assessed for potential yield are plotted.

Monitoring the experience on-farm

Given the lack of experience and confidence in alternative roles for mungbeans in the farming system, and absence of model validation for spring sowings, the grain traders encouraged 14 growers in 1996–97 and 22 growers in 1997–98 to trial small areas of spring-sown mungbean. (Table 1). Yields were analysed in terms of 3 levels: actual, attainable, and potential.

Actual yield was that delivered for payment by the farmer, corrected to a standard moisture content of 10%.

Attainable yield was measured using 3–6 quadrat samples, taken before commercial harvest, avoiding unrepresentative regions of the paddock that were low yielding due to obvious constraints, e.g. localised flooding, weed infestations, poor establishment. In all cases, unrepresentative portions of the paddock were minor relative to the majority of the paddock that was uniform. The difference between actual and attainable yield hence represented the impact of these unrepresentative regions of the paddock, plus grain that was not harvested due to shattering losses etc. Attainable yield was measured in 6 of the

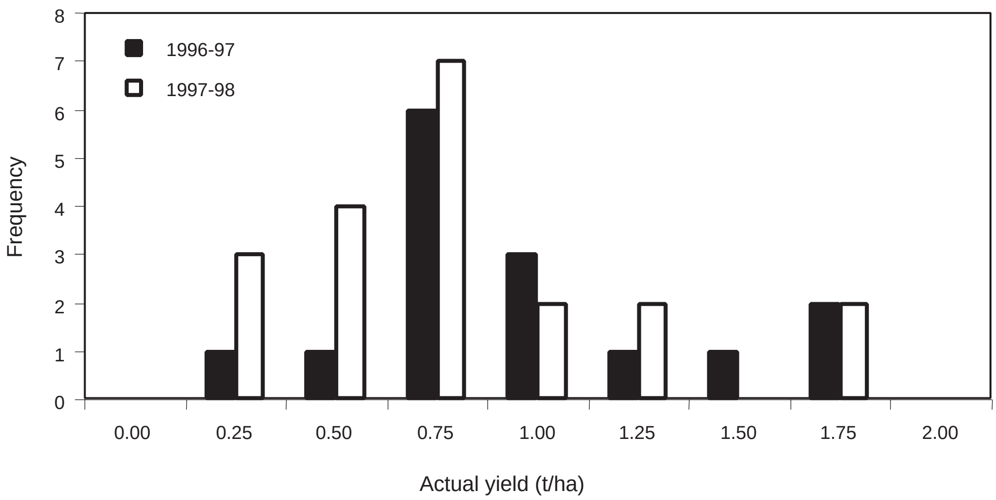

Fig. 5. Frequency histogram of actual grain yields of spring-sown mungbean crops grown in the 1996–97 (n = 14) and the 1997–98 (n = 22) seasons.

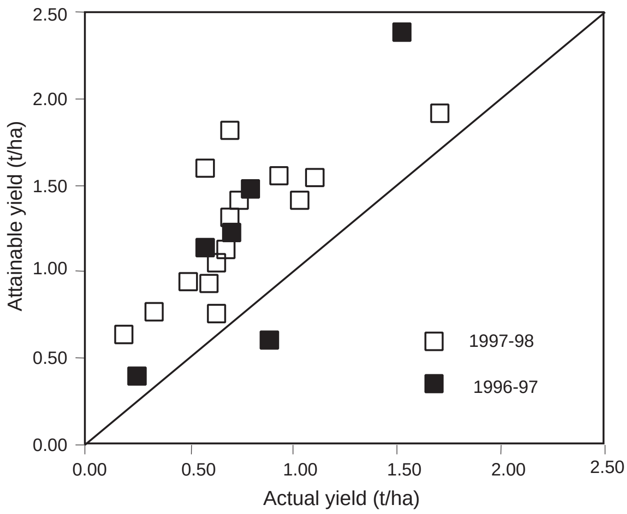

Fig. 6. Attainable (quadrat sampling) *v.* actual (paddock) yield for the spring-sown mungbean crops monitored in 1996–97 (n = 6) and 1997–98 (n = 19). Also shown is the 1 : 1 line. Attainable yields are expressed as oven-dry weight, whereas actual yields are expressed at 10% moisture.

14 crops in 1996–97 and in 18 crops in 1997–98. Measurements recorded on the quadrat samples were: number of plants, green leaf area index, and net above-ground biomass, which was partitioned into green leaf, senesced leaf, stem, grain, and pod wall. In a subset of crops, quadrat samples were also taken at intervals prior to harvest to monitor the growth and development of the crop over the season.

Potential yield in each paddock was estimated using the APSIM model, and hence represented the yield determined by climatic limitations only. The difference between attainable yield and potential yield can be interpreted as being due to constraints not accounted for by the model, e.g. insect and disease damage, waterlogging, inoculation failure. As such, the discrepancy between attainable and potential yield is a partial quantification of suboptimal management. Inputs required by the model for the calculation of potential yield were: plant population density, row spacing, variety, date of sowing, date of harvest, and fertiliser nitrogen (if any) applied. APSIM does not account for nutrient constraints other than N. In most situations, farmers would apply sufficient quantities of P, S, and Zn to meet anticipated crop needs. Daily minimum and maximum temperature and solar radiation were measured at automatic weather stations within 5 km of each paddock. Daily rainfall was recorded by the farmer as close as possible to the paddock. The amounts of plant-available water and mineral nitrogen at sowing, by soil layer, were also required by the model. This was obtained by taking 10 soil cores (37 mm diameter) at regular spacings across the paddock, to a depth of 150 cm. Cores were partitioned into layers 0–15, 15–30, 30–60, 60–90, 90–120, 120–150 cm, bulked across the 10 cores, and subsampled. Subsamples were analysed for gravimetric soil water content, and nitrate using Kjeldahl digestion followed by ammonium determination by the indophenol-blue colorimetric procedure. Volumetric water content was calculated from gravimetric water content using bulk densities obtained on the same soil type at another location (Dalgleish and Foale 1998). Likewise, plant-available water capacity for each paddock, defined as the water held between the lower limit and drained upper limit (Ritchie 1981), was determined for the same soil type elsewhere (Dalgleish and Foale 1998). In a small number of cases the lower limit could be obtained *in situ* by soil coring after harvest, where a dry finish to the season meant that the crop ceased growing before maturity and it was assumed had therefore exhausted all plant-available water in the root-zone. Unless otherwise stated, actual yields are quoted at 10% moisture content, whereas attainable and potential are expressed on an oven-dry basis.

Gross margins were calculated for each crop using the commercial yields, the prices received for the graded grain and gradings, and assuming a standard set of growing costs of \$120/ha (Lucy *et al*. 1997).

In addition to gathering 'hard' data on the performance of the commercial crops, 'soft' information on agronomic constraints encountered by growers, and perceptions of the suitability of the crop for their cropping system, was also documented. Management was documented using the GRDC TOPCROP Queensland check cards. These are cards with a checklist for agronomic management, and enable the management operations imposed on the crop to be documented and any observations affecting growth and development of the crop (e.g. insect damage) to be recorded. Open-ended questions on the TOPCROP check cards, such as 'Possible reasons for lower yield than expected?', were used to explore with farmers, in an un-prompted manner, reasons for differences between actual, attainable, and potential yield. In addition,

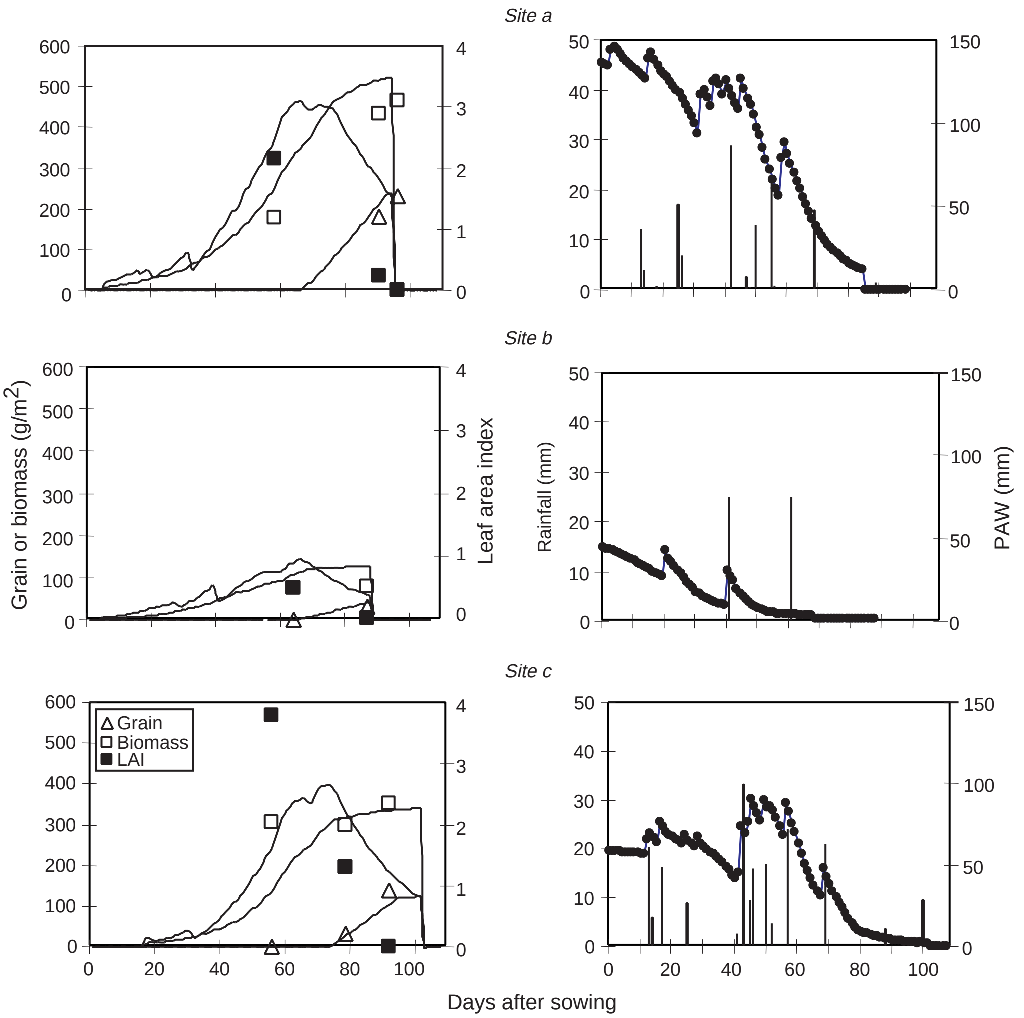

Fig. 7. Observed and simulated time-course of above-ground biomass, grain, and leaf area index (left-hand graphs) for crops at 3 independent sites (*a*, *b*, c) monitored in 1996–97, and observed rainfall and the simulated time-course of (PAW) plant-available soil water (right-hand graphs).

after the 1997–98 season, 17 growers completed a written questionnaire on their perceptions of the advantages/disadvantages and constraints of spring-sown mungbean. Respondents were asked to rate statements on a scale from 1 (of no importance) to 5 (very important).

Evaluating adoption

The rate of adoption of spring sowing by the mungbean industry was evaluated using statistics of the amounts of grain received during the harvesting period (late December–early February), compared with those received for the main summer crop. Data were collated from the main mungbean seed traders in northern NSW, southern Queensland, and central Queensland for the 1995–96 season before spring sowing was widely promoted, and the 1996–97 and 1997–98 seasons during which spring sowing was being promoted by the industry.

Results

Identifying the opportunity through scenario analysis

The simulations showed that average grain yield declined slightly with sowing date (Fig. 3*a*). The October sowing date had higher yield potential than later sowings due to a longer crop duration associated with cooler, early-season temperatures slowing development, rather than a larger amount of in-crop rainfall (data not shown). However, simulations indicated that a larger impact on potential yield was that of plant-available water at sowing (Fig. 3*a*), which increased average yield and lowered risk (Fig. 3*b*) at all sowing dates. Associated with earlier sowing was an increased risk of weathering damage (Fig. 3*c*), measured by the number of rainfall events during the pod-filling phase. The average plant-available water present at the first sowing opportunity for wheat (25 mm of rain over 5 days between 1 May and 29 July) was simulated to be higher for the early sowings (Fig. 3*d*), suggesting an improved opportunity for double-cropping back to a winter cereal. In summary, the simulations indicated that spring sowings after a fallow and on high starting soil water would yield higher, on average, than later sowings, especially when sown in summer on low soil water because of being double-cropped after a winter cereal.

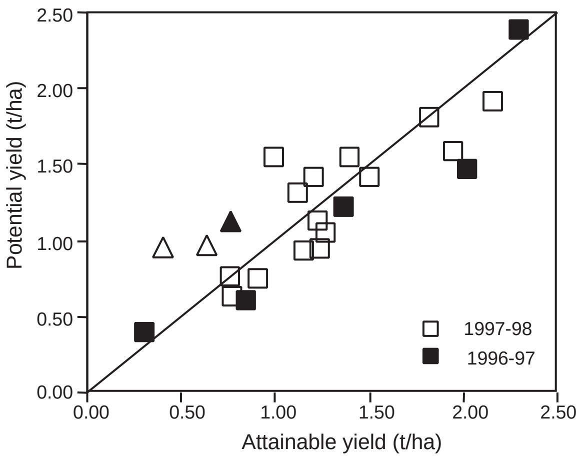

Fig. 8. Potential (simulated) yield *v.* attainable (quadrat) yield for the spring-sown crops grown in 1996–97 (*n* = 6) and 1997–98 (*n* = 19). Points with the triangle symbol had a significant discrepancy between the potential and attainable yields (see text for discussion). Also shown is the 1 : 1 line.

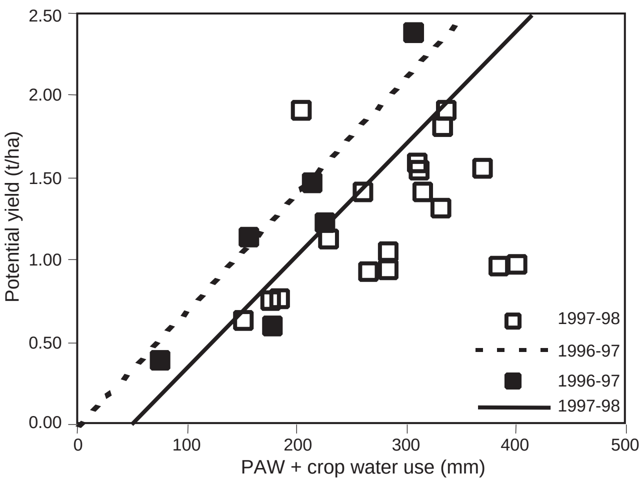

Fig. 9. Potential (simulated) grain yield *v.* plant-available soil water at sowing plus in-crop rainfall minus soil water at harvest minus runoff. The lines, fitted by eye to the outer envelope of points in each season, are $Y = 7*X/1000$ (1996–97) and $Y = 6*X/1000–0.42$ (1997–98).

Spring sowings would allow fallow re-charge before sowing a subsequent winter crop, but would be more susceptible to weathering damage.

Actual, attainable, and potential yields on-farm

A total of 14 and 22 crops were intensively monitored in 1996–97 and 1997–98, respectively. All crops were sown after a winter fallow. There was a wide range of starting plant-available soil water, varying from 15% to 100% soil water profile. Two growers in 1997–98 decided not to sow once they had observed the low levels of plant-available soil water present in their paddocks. In-crop rainfall across the 2 seasons varied from 50 to 354 mm, with one crop grown under irrigated conditions in 1996–97. The frequency distribution for in-crop rainfall is plotted in Fig. 4, along with the 109-year in-crop rainfall distribution for a representative 1 November sowing date at Dalby, which is a locality central to the study area. It can be seen that in 1996–97, rainfall was overall lower than the long-term distribution. However, in 1997–98 the frequency distribution of in-crop rainfall was remarkably similar to the long-term temporal distribution for Dalby. By sampling geographical variation in rainfall within a region it was therefore possible to re-create the temporal variation that exists within the climate record.

Actual grain yields varied widely within and across the 2 seasons (Fig. 5). The 1996–97 season had a higher average yield than in 1997–98 (0.80 *v.* 0.69 t/ha), due to fewer crops yielding less than 0.75 t/ha. The attainable yield, measured pre-harvest from hand-harvested quadrats, was in nearly all cases greater than the actual commercial yield harvested by the farmer (Fig. 6). In one case, attainable yield was less than actual, probably due to experimental error in the measurement of quadrat yields. In the majority of cases, farmers were able to identify causes of the discrepancy between actual and attainable yield. In many situations the cause was linked to poor harvesting efficiency, which was often corroborated by observation of significant amounts of shattered pods and grain on the ground after harvest and the germination of grain following rain after harvest.

In most cases, variation in attainable yield among crops was related to crop water supply. As an example, Fig. 7 shows the observed and simulated time-course of leaf area index (LAI), biomass, and grain in crops at 3 independent sites that varied widely in yield level. Also shown is the observed rainfall events over the season and the simulated total plant-available soil water (PAW). The crop in Fig. 7*a* had 136 mm of plant-available soil water at sowing, 182 mm of well distributed in-crop rainfall, and hence had a high attainable yield of 2.30 t/ha (Fig. 7a). In contrast, the lowest yielding crop (Fig. 7*b*) of 0.31 t/ha was sown on a profile containing only 32 mm of plant-available water and received 50 mm rainfall during the season. The crop in Fig. 7*c* was intermediate in attainable yield (1.37 t/ha) due to a low starting soil water of 48 mm, but reasonable in-crop rainfall of 211 mm. In the 3 examples, the model predicted satisfactorily the time-course of LAI, biomass, and yield, which implied that crops were growing to their climatic potential. Inspection of the TOPCROP check cards of these 3 growers revealed that they had minimised the impact of weeds, pests, and diseases, so that attainable yield should have been close to potential.

For the crops that were measured for attainable yield, nearly all showed close agreement with the model estimate of potential yield (Fig. 8) [root mean squared deviation (RMSD) = 0.28 t/ha, $n = 23$], given the RMSD on the model of 0.20 t/ha (Carberry 1996) and the typical experimental error associated with the measurement of attainable yield of 0.2 t/ha. Given the size of the errors in potential yield calcu-

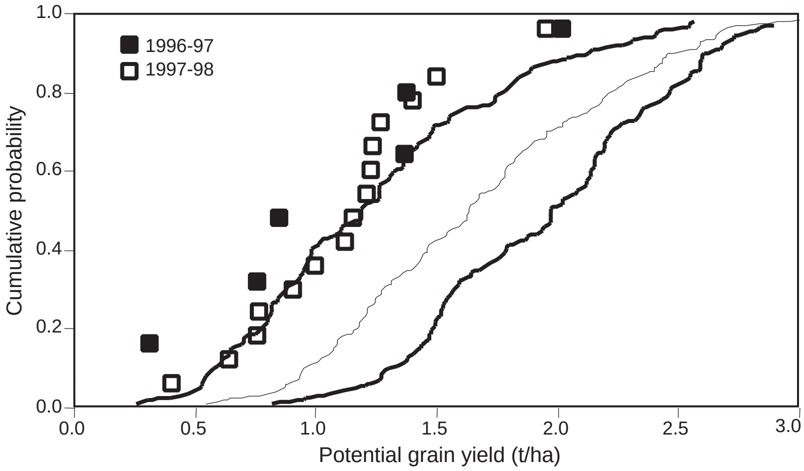

Fig. 10. Cumulative frequency distributions for simulated mungbean grain yield. The points are for the 1996–97 (closed symbol) and 1997–98 (open symbol) crops that were monitored. The 3 continuous lines are simulated long-term grain yields at Dalby for a 1 November sowing date with the starting soil water of 54 mm (left-hand line), 103 mm (middle line), or 143 mm (right-hand line).

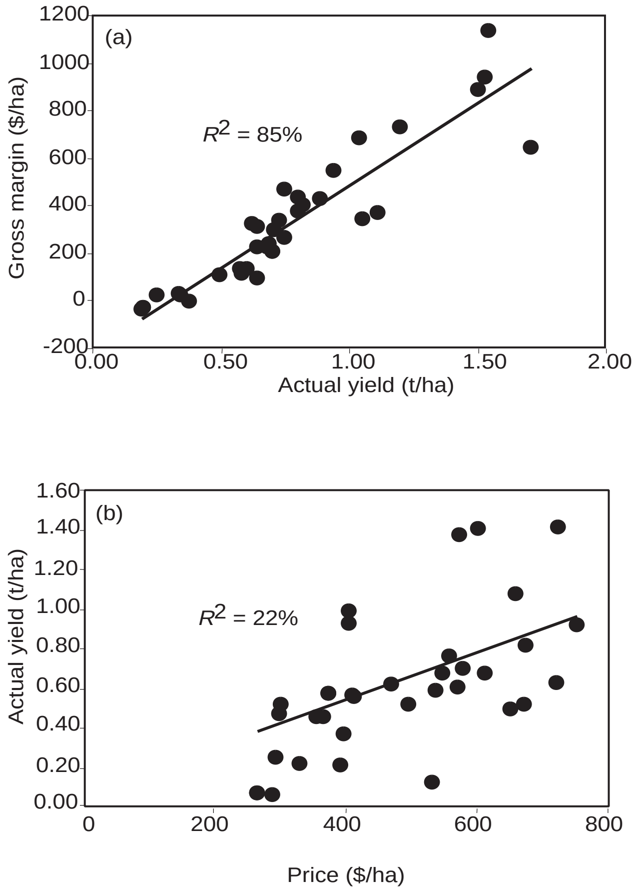

Fig. 11. Correlation between (*a*) gross margin and actual yield and (*b*) actual yield and price. Each point represents one paddock that was monitored, pooled over two seasons.

lated by the model and measured attainable yields, 3 crops exceeded an absolute deviation of 0.40 t/ha of the potential from the attainable yield. For 2 of the 3 crops, the check cards showed identifiable reasons for the discrepancy. In one case, severe insect damage during early pod-filling would have reduced yield below the potential. In another, a highly compacted soil layer at 30 cm would have restricted root development and crop access to soil water. In the third case, reasons for the discrepancy could not be identified. If these 3 crops are excluded, then the RMSD for attainable *v.* potential yield is reduced to 0.23 t/ha.

Potential yield and crop water supply

The good agreement between attainable and potential yield indicated that yield variation among the crops could be accounted for by variation in crop water supply. A gross indicator of seasonal crop water supply is the net change in the plant-available soil water store from sowing to harvest, plus the effective in-crop rain. Seasonal crop water supply was calculated for each crop by adding net change in the plant-available soil water store from sowing to harvest to in-crop rainfall minus simulated runoff. Although there was no direct validation of the model estimates of deep drainage or runoff, the soil water balance, SOILWAT, in APSIM has been extensively validated on similar clay soils in the region by Probert *et al.* (1998). In none of the crops was simulated deep drainage beyond the root-zone greater that 5 mm over the season; hence, it could be effectively ignored from the calculation of effective rainfall. Fig. 9 shows a scatter diagram of simulated grain yield *v.* seasonal water supply, calculated as described above. For each season an outer envelope of points follows a linear trend, as observed by French and Schultz (1984) for wheat in southern Australia. This envelope represents the maximum water use efficiency of the crop in the 2 seasons, where grain yield is highest for each level of crop water supply. Values below the envelope have lowered water use efficiency. Lines fitted by eye to the outer envelope give slopes of 0.007 and 0.006 t/ha.mm for 1996–97 and 1997–98, respectively, with an apparent positive intercept on the abscissa for 1997–98 of *c.* 50 mm. There was no apparent intercept for the 1996–97 outer envelope of points, an issue to be discussed in the next section.

The range of potential yield achieved in the monitoring exercise agreed well with the long-term (40 years) frequency distribution of simulated yields at Dalby for a 1 November sowing date and a starting soil water of 54 mm (Fig. 10). Observed mean starting soil water was actually slightly higher than the 54 mm used in the long-term simulation, at 70 and 86 mm in the 1996–97 and 1997–98 seasons, respectively. Nonetheless, this demonstrates that the monitoring exercise over 2 seasons sampled a range in yield variation that was similar to the temporal variation expected at a single location.

Gross margins

Profitability of each crop was not simply a function of yield, as price per tonne varied significantly among crops. In 1996–97, price varied from $AU360/t to $715/t (mean = $542/t), whereas in 1997–98 it varied from $260 to $747/t (mean = $405/t), associated with variation in grain quality. The respective gross margins were $–2 to $941/ha (mean, $378/ha) for 1996–97, and $–35 to $732/ha (mean, $237/ha) for 1997–98. Yield explained 85% of the variation in gross margin (Fig. 11*a*), whereas price explained only 50%. This occurred because price was significantly related to yield (Fig. 11*b*) (R^2 = 22%, $P < 0.05$). Clearly, although price for mungbean grain may vary hugely, achieving high yields ensured a reasonable economic return.

Grower perceptions

Survey responses were obtained from 17 growers as to their perceptions of the advantages and constraints of spring-sown mungbeans (Table 2). In response to the question ‘Rate the following as a list of the possible advantages of spring *v.* summer-sown mungbeans’, respondents rated, on average, highest the need to avoid severe heliothis pressure in mid-summer and enabling a switch from a summer cropping to a winter phase. Less important were the potential for higher price, reliability of yields, and early-season ground cover for erosion control. In response to the question ‘Rate the factors that are holding back yield of spring-sown mungbeans on your farm’, respondents rated most important harvesting losses and weathering damage (low grain quality). Less important were the factors of varietal performance, control of heliothis, accurate determination of soil water status prior to sowing, and control of sucking insects (mirids, green vege bug). All but one farmer said that they would sow spring mungbeans again. This one farmer made a decision to not grow mungbeans at all, due to the high level of management input required.

Evaluating adoption

The 6 major mungbean grain trading companies operating in Queensland and New South Wales were surveyed for the percentage of total seasonal grain receipts coming from spring-sown crops. Fig. 12 shows that prior to the 1996–97 season, negligible spring-sown crop was grown. Since the on-farm evaluation of the crop began in 1996–97 the size of the spring-sown crop has grown, so that by the 1997–98 season, between 5 and 20% (average 10%) of the crop was grown from spring sowings. Many traders stated that they believed that the spring crop would not exceed 30% of the total mungbean industry due to their and the farmer’s desire to maintain a spread of sowing dates within a season to spread risk and grain receipts.

Discussion

Changed farming practice as a result of research is often hampered by the perception that research results do not conform with on-farm reality. The value of the research approach described in this paper is that utilising commercial situations to evaluate a new agronomic practice provides a naturally occurring range in yield levels. In the semi-arid subtropics of northern NSW and southern Queensland, crop water supply is the predominant driver of yield variation, and the set of crops evaluated here varied greatly in starting soil water and in-crop rainfall. Traditional on-station agronomic experimentation would have sampled only a limited range of conditions and yield levels.

The study used the concept of actual, attainable, and potential yield to define and analyse constraints in the spring-sown crops. This allows separation of factors constraining yield into those that are under control of the farmer and those that are not, i.e. climatic influences. By utilising a crop growth model coupled with historical climate data, it also allows the yields achieved in a particular season to be put into context against the background of climatic variability. In the present study, potential yield was strongly determined by the total amount and distribution of crop water supply, as integrated by the model simulations. Although starting soil water and in-crop rainfall were both significantly correlated with potential yield (r = 0.42 and 0.52, respectively), the former is under the control of the manager, whereas the latter is not. The experience of monitoring on-farm crops reinforced the results of the scenario analysis, which showed the over-riding importance of pre-sowing soil water on yield, in any given season.

The outer envelope of points in Fig. 9 suggests that there is a subset of crops each season, in which yield is linearly related to net soil water extraction plus effective rainfall. However, there are a significant number of crops in which yield cannot be accounted for using this simple relation, as shown by the 3 out of 7 (1996–97) and 6 out of 18 (1997–98) points falling significantly below the outer envelope. Even though Fig. 8 suggests that almost all crop yields were water-

Table 2. Advantages of spring *v.* summer-sown mungbean, and importance of factors holding back yields on farm

Rankings are the average of responses from 17 growers, who were surveyed after the second season of evaluation (1997–98)

Order of importance	Advantages of spring *v.* summer sowing	Factors holding back yield
Highest	Avoids heliothis pressure in mid summer	Harvesting losses
	Enables switch from summer to winter crop	Weathering damage (low grain quality)
Medium	Potential for higher price	Varietal performance
	Reliability of yields	Control of heliothis
		Accurate measure of soil water before planting
Lowest	Early-season ground cover for erosion control	Control of sucking insects

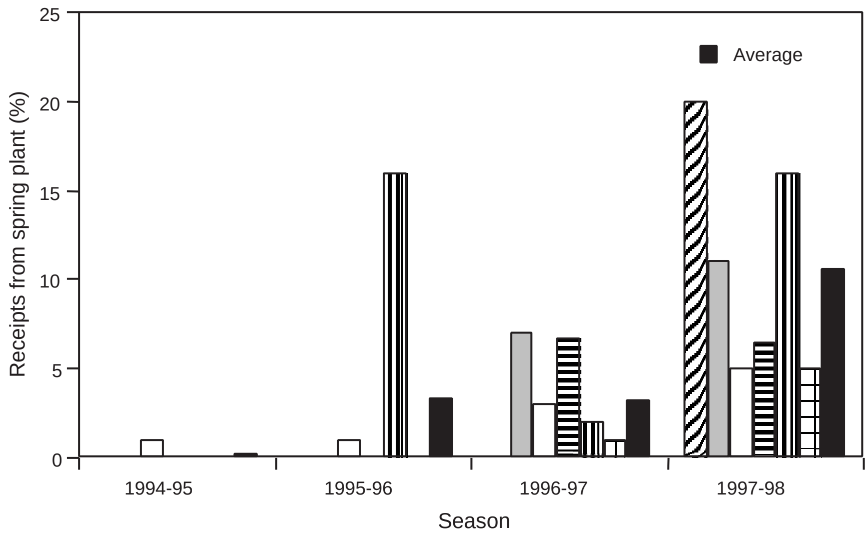

Fig. 12. The percentage of total seasonal grain receipts that came from spring-sown crops, over the 4 growing seasons from 1994–95 to 1997–98. Data are from the 6 major mungbean grain trading companies operating in Queensland and northern New South Wales. Receipts from spring-sown crops were defined as grain received prior to the first week of February in each season. Spring sowing of mungbeans was first promoted prior to the 1996–97 season.

limited (as integrated by the model simulations), from a theoretical point of view there are a number of reasons why seasonal crop water supply, expressed as a total, should be a poor predictor of grain yield in some situations (Connor and Loomis 1991), and hence water use efficiency is not a constant. Firstly, it takes no account of the timing of rainfall on yield determination. Secondly, the partitioning of water use between evaporation from soil and transpiration (which is related to biomass production) will depend upon the frequency of soil wetting, particularly before full crop cover is reached. Traditionally, the positive intercept on the abscissa shown for the 1997–98 envelope line in Fig. 9 has been interpreted as equivalent to evaporation from soil prior to full crop cover, after which time water use is linearly related to biomass production. The size of this intercept therefore may be expected to vary with early season rainfall, and this may be an explanation for the difference between 1996–97 and 1997–98 in the size of the intercept. Thirdly, the relationship between transpiration and biomass production depends upon the saturation deficit of the air. Although this may not vary greatly over a localised region, it could be expected to vary with sowing date. In summary, although the generalised relations in Fig. 9 are useful in some circumstances in defining limits to yield where water supply is the main driver of biomass production, their limitations can be significant, yet are often ignored.

Discrepancies between potential and attainable yield could be traced to known constraints, such as pest damage. However, it was notable how many crops were achieving attainable yields close to the potential, indicating satisfactory control of potential biotic constraints. A remarkable result of the study was the large gap in many crops between attainable and actual yields at harvest. Although some of the gap can be accounted for by the sampling method for determining attainable yield, a significant proportion of the gap was no doubt due to losses of grain at harvest. Easdown (1987) measured large grain losses at harvest in mungbean crops in the Callide Valley in Queensland. In his study, the average district yield was 0.75 t/ha, and average harvest loss was 0.23 t/ha, ranging from 0.09 to 0.43 t/ha. Losses occurred at both the front and back of the header. There was also a component of unharvested grain. Losses at the front of the header were the greatest source, two-thirds of which was due to losses of whole pods. Although the absolute size of this loss is difficult to quantify, and is not done in this study, these results have alerted us to the potential magnitude of the problem. At the end of the 2 seasons of evaluation, growers nominated harvesting losses as overall the greatest constraint to yields (Table 2).

The good agreement between the quadrat yields and simulated yields indicates the validity of the model, previously developed and tested on summer-sown crops, in simulating spring-sown crops. The model contains no functions dealing with the impact of early sowing on the timing and duration of flowering and any possible effects on the partitioning of biomass to grain yield. In this sense the null hypothesis, that there is nothing unique about the effect of spring sowing *v.* summer sowing on the physiology of growth and development of mungbean, can be accepted.

The analysis of gross margins highlighted the importance of yield *v.* price. Whereas yield explained 85% of the variation in gross margin, price explained only 50%. This was because there was a positive association between high yield crops and high grain quality (price). The range of gross margins achieved was stated by the farmers as competitive with alternatives such as grain sorghum or even dryland cotton. All but one farmer were willing to grow the crop again.

Benefits of spring-sown mungbeans can be quantified in terms of yield and quality (price) but when considering what information will influence grower's decision to sow the crop, it is important to document the difficult-to-quantify factors. Table 2 indicates that factors such as avoiding insect pressure in mid-summer and enabling a switch in cropping sequence are actually more important that reliability of yields and price, when ranked by growers. Clearly, in this study the more innovative or well-off farmers were sampled, so some caution must be exercised when extrapolating to the whole range of the farmer spectrum the low rating of the importance of yield and price. The survey of grower perceptions also made some attempt to assess the potential environmental impacts of a shift to spring sowing, in terms of increased erosion risk due to the absence of late summer ground cover. This was not rated highly as an issue by the growers.

A full analysis of implications of moving from summer-sown to spring-sown crops for the farming system is beyond the scope of this paper. Such an analysis would examine the opportunity costs in relation to the change in space–time occupancy of mungbeans relative to other crops that could have been grown in the paddock at the same time (e.g. sorghum, cotton). Also, the implications for winter cereal productivity should be examined. APSIM, being a cropping systems model, would be able to examine quantitatively the productivity implications of such a change to the farming system. The scenario analysis presented in Fig. 2*d* examines one aspect of the system that would be affected and suggests that spring sowing would allow more soil water accumulation for a following winter cereal than traditional summer sowing.

A feature of the research approach in this paper has been the active participation of farmers, researchers, grain traders, and advisers. Advisers were able to evaluate the relevant agronomic issues to growing spring-sown mungbean crops. Researchers were able to gain further understanding on the physiology of mungbean and test a simulation model over a wide range of situations. Grain traders provided a point of contact with growers and were able to identify innovative growers. They had an interest in expanding the role for the crop in the farming system, spreading grain receipts more evenly through the harvesting season, and benefiting from the possibility that early sowings may attract a price premium. Finally, farmers gained relevant information on the feasibility of growing spring-sown crops by having the practice trialled in a credible commercial context. The experience of this small group was transmitted to a wider audience through information brochures. The proof of the value of this approach is the relatively rapid rate of adoption since the issue first began to be publicised in 1996.

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