EVALUATION OF STRATEGIES FOR INCREASING IRRIGATION WATER PRODUCTIVITY OF MAIZE USING MAIZEMAN

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Abstract
MaizeMan is Windows-based decision support software for evaluating the effect of sowing, irrigation and nitrogen management and seasonal, soil and watertable conditions on maize crop performance. Evaluation of MaizeMan for sprinkler and furrow irrigated maize showed that the model gave good predictions of yield, biomass, runoff and soil water depletion between sowing and harvest. MaizeMan simulations using Griffith weather data suggested that by far the biggest influence on yield, irrigation requirement and irrigation water productivity is seasonal weather conditions. The optimum sowing window for maximising yield and irrigation water productivity is wide, ranging from late September to mid November. The simplest management strategy for maximising yield and irrigation water productivity is irrigation scheduling tailored to soil type. This can be assisted by real time irrigation scheduling using MaizeMan, provided soil hydraulic properties are accurately characterised. One to two irrigations can also be saved by growing short duration hybrids, but the tradeoff is lower yield, while irrigation water productivity is maintained. Sprinkler irrigation appears to have the potential to increase yield and irrigation water productivity through improved soil water and aeration status, and with reduced deep drainage loss.

Introduction
Australian irrigation farmers need to increase irrigation water productivity in the face of reduced water availability and increasing prices. The ability to predict likely irrigation water requirement and yield, as affected by management, can assist farmers to develop water budgets and identify management strategies to get the best returns to water. Management factors which can affect irrigation amount and yield include irrigation method, varietal duration, sowing date, irrigation scheduling and mulching. Non-management factors include weather, soil and watertable conditions.

MaizeMan is Windows-based decision support software that provides the capability of evaluating the effect of management and seasonal, soil and watertable conditions on irrigation water productivity and yield of maize (Humphreys et al. 2003). The model can be run strategically, or in real time for irrigation scheduling and predicting likely water requirement and yield as affected by management. MaizeMan combines the CERES Maize v.3.5 crop growth model (Jones and Kiniry1986; Hoogenboom et al. 1999) with the salt, water balance and regional piezometric head processes of SWAGMAN® Destiny (Meyer et al. 1996; Xevi et al. 2006). The combination with the Destiny routines assists simulation of flood irrigated situations where transient waterlogging is likely to be common, and where shallow watertables and salinity are often present. The CERES Maize model has been widely evaluated and applied around the world (Jones and Kiniry 1986), with limited evaluation in southern NSW (Smith et al. 1993). SWAGMAN® Destiny has been evaluated in a range of crops in southern NSW (Smith et al. 2006, Xevi et al. 2006). However, evaluation of MaizeMan has been limited to date. This paper reports results of evaluation of MaizeMan for irrigated maize in southern NSW, and its application to identify strategies for optimising irrigation water productivity and yield.

Methods

Model evaluation
MaizeMan was evaluated using data from furrow and sprinkler irrigated Pioneer 3153 sown on 8 October 2004 in the Coleambally Irrigation Area, about 50 km south of Griffith, NSW. The sprinkler irrigated maize received 38 irrigations (usually ~15 mm per irrigation, total 6.2 ML/ha), compared with 13 irrigations of about 45 mm (total 6.0 ML/ha) for furrow irrigation.
At the time of sowing, the soil profile in the sprinkler block was dry to depth, while it was wet in the furrow block. Details of management and observations are provided in Humphreys et al. (2006). The soil described in MaizeMan as Mundiwa clay loam was selected for model inputs, being the most similar to the soil at the site, based on observed properties of the soil profile. The soil lower limit (LL), drained upper limit (DUL) and saturation water content (SAT) were adjusted to match values estimated from observations. The plant available water (PAW) content of the full profile (0-1 m) was relatively low (96 mm). The default genetic coefficients for Pioneer 3153 were used in the evaluation. The model was run using Griffith weather data except for rain which was measured at the site. Griffith is about 50 km north of the experimental site, with very similar weather data to the experimental site (D. Smith, unpublished data).

Options for increasing irrigation water productivity

All simulations were run using 43 years of Griffith weather data (1961-2004). Evapotranspiration was calculated using the algorithms used in the CERES crop models which are an adaptation of the Priestly-Taylor method (Ritchie 1972). The same sowing management was used for all scenarios (except for “irrigation method”) – 80,000 seeds/ha, 95% germination, 0.9 m row spacing, 50 mm sowing depth. Irrigation was terminated when grain filling was 80% complete, and nitrogen was “switched off” (not limiting), except for the real time irrigation scheduling example which used actual N application. The irrigation management depth (depth over which %PAW was calculated and used to trigger irrigations based on soil water deficit) varied with growth stage to reflect the likely maximum soil drying or rootzone depth for irrigated soils in southern NSW: 40 cm (sowing to emergence), 57 cm (emergence to floral initiation), 77 cm (floral initiation to silking), 100 cm (silking to maturity). Irrigation efficiencies were selected to provide slightly more than the amount of water needed to refill the rootzone to saturation. All grain yields and grain water productivity values reported are for oven dry grain unless otherwise stated. Net irrigation (irrigation minus runoff) amounts are reported rather than irrigation, as surface runoff can be captured and reused.

Irrigation method

MaizeMan was used to compare the effect of flood and sprinkler irrigation on crop performance using the same soil, initial conditions and sowing management as in the above field study used for model evaluation. Flood irrigation was simulated by irrigating when soil water content declined to 60% PAW, while sprinkler irrigation involved adding 15 mm whenever PAW declined to 70%.

Variatel duration

Three hybrids with different duration or CRM (Comparative Relative Maturity as provided by the seed companies) - Pacific Seeds DK477 (CRM 97), HC531IT (CRM 109), HC530 (CRM 109) – were sown on 1 October on a heavy clay soil (Yooroobla clay, PAW 180 mm at DUL, 0-1 m). Initial conditions were set on 1 September with 90% PAW to 0.4 m, 100% PAW below 0.4 m and a watertable at 2 m. Irrigations were applied when cumulative ETo-rain since the last irrigation reached 70 mm.

Sowing date

Sowing dates at 15 day intervals from 30 September to 31 December were compared for Pioneer 3335 (CRM 112) on Yooroobla clay. Initial conditions were set 15 d before sowing with 50% PAW to 2 m, and a watertable at 2 m. The crops were irrigated when rootzone soil water content declined to 50% PAW.

Irrigation scheduling (strategic)

Irrigations were scheduled when rootzone soil water content declined to 10, 20, 30, 40, 50, 60, 70, 80 or 90% of PAW for two soil types – Beelbangera clay loam (PAW 97 mm at DUL, 0-1 m), and Yooroobla clay (PAW 180 mm). Pioneer 3153 was sown on 30 September, with initial conditions set on 1 September at 90% PAW to 0.4 m, and 100% PAW between 0.4 m and the watertable at 2 m.
Real time irrigation scheduling and in-season water budgeting using MaizeMan

MaizeMan offers the ability to schedule irrigations in real time based on predicted soil water content in the rootzone. It also projects what future crop water use would be using an estimation of potential ET from long term average weather data. Pacific HC75 (CRM 117) was sown on 13 October 2003 on a heavy clay soil (Wunnamurra clay, PAW 189 mm at DUL, 0-1 m). Initial conditions on 9 July 2003 were 50% PAW to 2 m with a watertable at 2 m. Five irrigations (total 370 mm) and 302 kg N/ha were applied between sowing and 2 December 2003. The last day of weather data was 5 December 2003. MaizeMan was run to predict the date of the next irrigation using a threshold of 50% PAW in the rootzone. MaizeMan was also run to predict likely yield, irrigation amount and water productivity for this crop with irrigations after 5 December scheduled whenever ETo-rain accumulated to 90 mm. The effect of varying the irrigation cutoff date from half-way through grain filling to the end of grain filling was then analysed for the same scenario.

Results and discussion

Model evaluation

MaizeMan correctly simulated the slightly later development of the flood irrigated maize (as a result of delay in the first sprinkler irrigation), but predictions of the dates of silking and maturity were out by about one week. Using the Priestly-Taylor option to calculate ET, MaizeMan gave good predictions of grain yield (within 2%), total biomass (within 14%), surface runoff (which was low in both treatments), and correctly predicted considerable drying of the soil profile in the furrow irrigated maize compared with slight wetting with the sprinkler irrigated maize. Yields and total biomass were underestimated by 20-25% using the locally calibrated modified Penman equation developed by Myer et al. (1999). Therefore the Priestly-Taylor option was selected for all simulations presented below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Furrow irrigated</th>
<th>Sprinkler irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain yield (dry - t/ha)$^a$</td>
<td>8.7</td>
<td>9.1$^b$</td>
</tr>
<tr>
<td>Total biomass (dry – t/ha)$^c$</td>
<td>19.3</td>
<td>21.2</td>
</tr>
<tr>
<td>Harvest index$^d$</td>
<td>0.49</td>
<td>0.50</td>
</tr>
<tr>
<td>Date of silking</td>
<td>7-9 Jan</td>
<td>1 Jan 05</td>
</tr>
<tr>
<td>Date of maturity</td>
<td>~7 Mar but highly variable</td>
<td>~7 Mar but highly variable</td>
</tr>
<tr>
<td>Runoff (mm)</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Change in soil water content (mm) 0-1 m, harvest minus sowing</td>
<td>-78$^e$</td>
<td>-57$^f$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Furrow irrigated</th>
<th>Sprinkler irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest index$^d$</td>
<td>0.50</td>
<td>0.52</td>
</tr>
<tr>
<td>Date of maturity</td>
<td>13 Mar 05</td>
<td>14 Mar</td>
</tr>
<tr>
<td>Runoff (mm)</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Change in soil water content (mm) 0-1 m, harvest minus sowing</td>
<td>5$^e$</td>
<td>24$^f$</td>
</tr>
</tbody>
</table>

$^a$ average yield of irrigation block; $^b$ corrected for loss of area due to wheel pads; $^c$ from 2 x 1 m rows at 3 locations in each irrigation block; $^d$ 6 weeks after maturity; $^e$ at maturity

Irrigation method

Grain yield varied from about 8 to 16 t/ha for both irrigation methods, depending on seasonal conditions, and was consistently higher with sprinkler irrigation, by an average of 0.5 t/ha (Fig. 1a). Net irrigation (irrigation minus runoff) ranged from about 6.5 to 11 ML/ha, and was always higher with flood irrigation, by an average of 0.8 ML/ha or 8% (Fig. 1b). Runoff was usually low and similar for furrow (mean 0.26 ML/ha) and sprinkler (mean 0.22 ML/ha), while deep drainage with furrow irrigation (mean 2.0 ML/ha) was double that with sprinkler (Fig. 1c). Simulated soil evaporation losses with sprinkler irrigation (mean 170 mm) were consistently, but only slightly, higher than with flood irrigation (mean 160 mm). Net irrigation water productivity ranged from 0.8 to 2.0 t/ML, and was always higher with sprinkler, by an average of 0.2 t/ML or 12% (Fig. 1d). The slightly higher yield with sprinkler irrigation may have been a result of slightly lower water deficit stress throughout the season (e.g. Fig. 1e) and slightly lower aeration (waterlogging) stress (e.g. Fig. 1e). The results suggest that yield and irrigation water productivity vary greatly, by a factor of two or more, depending on seasonal conditions.
The simulations also suggest that sprinkler irrigation can increase irrigation water productivity by increasing yield through providing a more favourable soil water/aeration status with a small saving in irrigation water and a substantial reduction in deep drainage losses.

Fig. 1a. Yield as affected by irrigation method

Fig. 1b. Net irrigation as affected by irrigation method

Fig. 1c. Deep drainage as affected by irrigation method

Fig. 1d. Net irrigation water productivity as affected by irrigation method

Fig. 1e. Water deficit stress during grain filling as affected by irrigation method

Fig. 1f. Aeration stress from silking to start of grain filling as affected by irrigation method
For the 2004 sowing, MaizeMan predicted yields of 12.6 and 12.0 t/ha for sprinkler and flood irrigation, respectively, using the scheduling in this example (irrigation threshold 60% PAW). Corresponding irrigation applications were 8.4 and 9.3 ML/ha, with irrigation water productivities of 1.5 and 1.3 t/ML, respectively. Actual dry grain yields (9.6 and 8.7 t/ha) were much lower with applications of 6.0 and 6.2 ML/ha for the sprinkler and drip, resulting in water productivities of 1.6 and 1.4 t/ML, respectively. The results of the simulations suggest that the maize sown at Coleambally in 2004 was under-irrigated in both irrigation systems.

**Varietal duration**

Crop duration varied considerably with seasonal conditions for all hybrids, and increased as CRM increased from 97 to 118 (Fig. 2a). Duration was very short for all hybrids in a couple of extreme years (1997 and 1967). This appeared to be due to a very short grain filling period (10-16 days) associated with unusually high temperatures, especially high minimum night temperatures (mean 18-19°C in 1997) compared with the highest yielding year for each hybrid (mean minimum 13-15°C). Yield ranged from 3-4 t/ha for all hybrids in 1997 to 14-16 t/ha in the highest yielding years (Fig. 2b). Yield increased as CRM increased, by an average of about 8% for each increase in CRM of 10-11. Net irrigation ranged from 3.3 to 9.6 ML/ha (Fig. 2c), and increased by an average of 1.2 ML/ha as CRM increased from 97 to 118. Net irrigation water productivity was in the range of 1.2 to 2.4 t/ML in 90% of years, and was generally similar for all hybrids (means 1.66, 1.56 and 1.60 t/ML for DK477, HC531IT and HC675, respectively) (Fig. 2d). The results suggest that while some irrigation water can be saved by growing shorter duration hybrids, there is little effect on irrigation water productivity due to a proportionate loss in yield as duration and irrigation amount are reduced.

![Fig. 2a. Duration of varieties as affected by CRM](image-url)

![Fig. 2b. Yield as affected by varietal duration](image-url)

![Fig. 2c. Net irrigation as affected by varietal duration](image-url)

![Fig. 2d. Net irrigation water productivity as affected by varietal duration](image-url)
**Sowing date**

Crop duration was least for sowings from 30 Sep. to 30 Nov. (range 114 to 144 days). Crop maturity was delayed as the date of sowing was delayed, with maturity of crops sown in Dec./Jan. delayed until May to July (Fig. 3a). Yields were highest with 15 December sowing, however maturity date (mid-April to early July) would be impractical in the field because of issues of high grain moisture content and wet soil conditions preventing harvest. Therefore the 15 December sowing was omitted from further analysis. Yields of 30 September to 15 November sowings were generally similar (mean 11.8 to 12.0 t/ha), while yields with 30 Nov. sowing (mean 13.0 t/ha) were higher (Fig. 3b). Irrigation applications were least with 30 November sowing (mean net irrigation 7.4 ML/ha) and highest for 30 September sowing (mean net irrigation 8.3 ML/ha) (Fig. 3c). Net irrigation water productivity was usually similar for 30 September to 31 October sowings, and increased as sowing was delayed to 30 November (Fig. 3d). Mean net irrigation water productivity for 30 September to 15 November sowings was around 1.6 t/ML compared with 1.8 t/ML for 30 November sowing.

The results suggest similar yield and irrigation water productivity for a wide sowing window for Pioneer 3335 from the end of September to mid-November, with maturity from mid-February to late March in time for grain dry down in the field and harvesting before winter. The results also suggest that almost 1 ML/ha of irrigation water can be saved while increasing yield by 1 t/ha by delaying sowing of Pioneer 3335 to late November. However, factors other than climatically determined yield potential can disadvantage later sowings, such as increased insect pest pressures (Duffield 2000) and increased likelihood of slower grain dry down and wet soil conditions delaying harvest.

**Fig. 3a. Maturity day as affected by sowing date**  
**Fig. 3b. Yield as affected by sowing date**  
**Fig. 3c. Net irrigation as affected by sowing date**  
**Fig. 3d. Net irrigation water productivity as affected by sowing date**
**Irrigation scheduling**

**Clay loam**

Grain yield increased as the threshold for irrigation increased from 10% to 50% PAW (Fig. 4a). Yields were similar for irrigation thresholds of 50 to 90% PAW, with the mean number of irrigations increasing from 20 at 50% PAW to 53 at 90% PAW. The high irrigation frequency even at 50% PAW reflects the relatively low PAW (97 mm over 0-1 m) on this soil. Net irrigation amount (irrigation minus runoff) also increased as the irrigation threshold increased up to 70% PAW (Fig. 4b). The low irrigation amounts for low thresholds were probably a consequence of poor crop growth and therefore reduced soil water extraction. Net irrigation water productivity was highest for irrigation thresholds of 50-60% PAW, and declined as the threshold increased to 90% (Fig. 4c). The results suggest that on soil with a relatively low soil water holding capacity, both yield and irrigation water productivity are maximised by irrigating when soil water content falls to ~50% of PAW in the rootzone.

**Fig. 4a. Yield as affected by irrigation scheduling on the clay loam**

**Fig. 4b. Net irrigation as affected by irrigation scheduling on the clay loam**

**Fig. 4c. Net irrigation water productivity as affected by irrigation scheduling on the clay loam**

**Fig. 5a. Yield as affected by irrigation scheduling on the clay**

**Fig. 5b. Net irrigation as affected by irrigation scheduling on the clay**
For the same scenario but with a shallower regional watertable (1 m instead of 2 m), yields were similar with frequent irrigation (PAW thresholds of 60 to 80%) while irrigation amounts were reduced by about 50 mm in comparison with the deeper watertable situation.

**Clay**

In contrast to the clay loam, grain yield on the clay (180 mm PAW) decreased as irrigation threshold increased from 40 to 90% PAW (Fig. 5a), probably due to greater aeration stress (waterlogging) at higher irrigation thresholds (more frequent irrigation) on this heavy clay soil with low drainable porosity (e.g. Fig. 5b). The effect of very infrequent irrigation was also less on the clay. As on the clay loam, net irrigation (irrigation minus runoff) increased as the irrigation threshold increased. Yield was maximised with irrigation at 30-40% PAW (16-17 irrigations on average), while net irrigation water productivity was generally highest with an irrigation threshold of 30% PAW (mean 1.7 t/ML)(Fig. 5c).

The contrasting results on the two soil types suggest the need for more frequent irrigation at higher thresholds on soils with low water holding capacity to avoid water deficit stress, and for less frequent irrigation at lower thresholds on heavy clay soils prone to waterlogging.

**Real time irrigation scheduling using MaizeMan**

On 6 December 2003, MaizeMan predicted that PAW in the rootzone would decline to 50% on 10 December 2003 on the clay soil. At that stage, almost all the roots were in the top 0.5 m, therefore the amount of water required to refill the rootzone from 50% PAW was only 47 mm. In this example, 3.7 ML/ha had been applied prior to 6 December.

For irrigations scheduled after 6 December whenever ETo-rain accumulated to 90 mm, MaizeMan predicted that yield would exceed 8.7, 11.3 and 12.9 t/ha in 25%, 50% and 75% of years. The associated irrigation requirement from 6 December to maturity was predicted to exceed 5.0, 5.9 and 6.9 ML/ha in 25%, 50% and 75% of years. Cutting off irrigations half way through the grain filling period saved 2 irrigations or about 160 mm, on average, but at a cost of about 1.3 t/ha or 10% of yield. The effect on yield was much larger on the clay loam with lower plant available water capacity. For example, using the same scenario on the Beelbangera clay loam, cutting off irrigation half way through the grain filling period doubled the yield reduction to 20% for a smaller irrigation water saving of about 110 mm. MaizeMan simulations for a wide range of scenarios suggest that irrigations need to be continued until approximately 80% of the way through the grain filling period for maximum yield.
General discussion

MaizeMan gave good predictions of a small range of crop and soil water parameters for two crops grown with very different irrigation management. Other testing of MaizeMan has also been encouraging (Humphreys et al. 2003), however there has been no testing under shallow watertable and saline situations. Users also need to be aware that the genetic coefficients provided in MaizeMan should be used with caution, as most of them have been derived from observations from one sowing date in the Murrumbidgee Valley.

A range of potential management options for saving water were analysed, but under limited conditions. For example, irrigation scheduling was only examined for one hybrid (maturity) and sowing date, two soil types, and one irrigation method (flood) using Griffith weather data. Therefore the results of the simulations should be regarded as only indicative if attempting to extrapolate to other hybrids, sowing dates and soil types. Nonetheless, the results provide some useful generalisations for irrigated maize in southern NSW.

The simulations show that by far the biggest influence on yield, irrigation requirement and irrigation water productivity is seasonal weather conditions, which can cause variation in all these parameters by a factor of up to 2. One of the major causes of yield variation is temperature during grain filling, with high temperature, especially high night temperature, decreasing the grain filling period and reducing yield. The simulations suggest that delaying sowing can delay the period of grain filling to cooler periods and increase yield and reduce irrigation amount, but this is not practical in southern NSW due to the increased likelihood of insect damage, and because maturity is delayed to the onset of winter, impairing grain drying in the field and increasing the likelihood of wet soil conditions by time the crop is ready to harvest. The simulations also suggest that maize has a very wide sowing window in southern NSW, with similar yields, irrigation water requirement and irrigation water productivity for sowings from late September to mid November.

The results suggest that sprinkler irrigation can increase yield and irrigation water productivity by 10-15% over flood irrigation through improved soil water and aeration status, with slightly reduced irrigation application and substantially reduced deep drainage losses. These yield predictions were supported by observations of maize grown under both systems at Coleambally in 2004 (Humphreys et al. 2006). Simulated soil evaporation, a non-beneficial loss, was substantial (mean 1.5-1.6 ML/ha) with both flood and sprinkler irrigation. Sub-surface drip irrigation has the potential to greatly increase irrigation water productivity through reduced soil evaporation, however at present MaizeMan does not have the capability to simulate subsurface drip. Nor does it have the capability of simulating the impact of mulching on water conservation and crop performance.

The shorter duration hybrids appear to have the ability to save 1-2 irrigations in comparison with the longer duration hybrids, but MaizeMan predicts a proportionate loss in yield, and negligible effect on irrigation water productivity.

The simulations suggest that yield and irrigation water productivity can be maximised by well-timed irrigation, but the optimum schedule varies with soil type. The soil with low water holding capacity required irrigation at higher thresholds (50-60% PAW) than the heavy clay soil with high water holding capacity (optimum 30-40% PAW) due to exacerbation of aeration stress in the heavy soil with frequent irrigation. Real time irrigation scheduling using MaizeMan provides the opportunity to tailor irrigation frequency to soil type and maximise yield and irrigation water productivity. However, this requires accurate characterisation of soil properties for the actual field, especially the lower and upper limits for plant available water, and saturation soil water content, and saturated hydraulic conductivity. The irrigation scheduling capability of MaizeMan has also had limited testing to date.

Perhaps more important than manipulating management as above, maximising returns to irrigation water requires the ability to plan plantings based on knowledge of both the likely irrigation water requirement and likely irrigation allocations. MaizeMan offers the ability to predict likely irrigation water requirement both in real time and strategically, and to evaluate tradeoffs between yield and irrigation and sowing management. A web-based tool for predicting likely allocations for the Murrumbidgee Valley, based on historic inflows, dam levels and sea surface temperature, is under development by Khan et al. (2004).
Conclusions

Evaluation of the ability of MaizeMan to predict crop and soil water parameters under furrow and sprinkler irrigation was encouraging. However, MaizeMan has undergone limited testing to date, and in particular in shallow watertable and saline environments, and further evaluation is required. While it has the capability to simulate flood and sprinkler irrigation, it is unable to simulate sub-surface drip irrigation, or the impact of mulching, currently limiting its ability to evaluate a range of potential water saving options.

MaizeMan is a useful tool for evaluating options for increasing yield and irrigation water productivity. Simulations using MaizeMan for Griffith weather suggest that by far the biggest influence on yield, irrigation requirement and irrigation water productivity is seasonal weather conditions. The optimum sowing window for maximising yield and irrigation water productivity is wide, ranging from late September to mid November. The simplest management strategy for maximising yield and irrigation water productivity is irrigation scheduling tailored to soil type. This can be assisted by real time irrigation scheduling using MaizeMan, provided soil hydraulic properties are accurately characterised. One to two irrigations can also be saved by growing short duration hybrids, but the tradeoff is lower yield, while irrigation water productivity is maintained. Sprinkler irrigation appears to have the potential to increase yield and irrigation water productivity through improved soil water and aeration status, and with reduced deep drainage loss. However, there are limited field data available to date to support all these predictions.

Acknowledgements

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References


