Improving reliability of maize production in variable rainfall environments of the North East Region.

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Abstract
Opportunities for expanded raingrown maize production in marginal rainfall areas (<600 mm annual rainfall) in north-eastern Australia have been studied experimentally and using crop modelling. These areas are characterised by high inter- and intra-seasonal variation in timing and amount of rainfall and periodic water stress. This study used APSIM-Maize to assess impacts of soil, climate and selected agronomic practices on predicted maize yield for early (late July - September) to late (January-February) planting in 7 day intervals, phenotypes (14, 16, 18, 20 and 22 leaves), initial fraction of extractable water at planting (IFESW) (50, 65, 80 and 100%) of plant available water content, typical soils and plant population (1.2 to 4.2 plants m^{-2}) across 29 widely distributed locations in NE Australia using around 100 years of weather data. Risk to crop production was assessed in terms of factors that contributed most to yield variability. Assessment of these factors using a simple ANOVA model showed site, IFESW, plant population, planting date, phenotype, plant population x IFESW, site x planting date and soil within site to be the major contributors to variation in predicted yield. Here we present an approach to analysis of the yield predictions as a way of identifying similar sites where similar cultivar selection and agronomic practices would be appropriate.

KeyWords
Maize, modelling, risk, density, maturity, soil water

Introduction
Maize production in areas of marginal rainfall (<600 mm annual rainfall) is considered less reliable (‘riskier’) than grain sorghum which is more drought and heat tolerant - consequently farmers, who are generally ‘risk averse’, prefer grain sorghum (Routley and Robertson 2003). Opportunities for increasing maize production have been assessed using both field experimentation and modelling (Robertson et al. 2003, Routley and Robertson 2003, Birch et al 2007), as increasing demand for feed grains, silage and increasing demand for GM free maize for food in some Asian countries (Pickmere 2011) means reliable supplies for all end users are required. Opportunities for expansion are mostly in areas of high intra-seasonal variation in timing and amount of rainfall, so moisture stress is a major risk. In many potential production areas, soils have moderate to high plant available water holding capacity (PAWC), and thermal conditions are favourable for an extended period, providing a number of planting options in any one year, but high temperatures at critical times e.g. anthesis may reduce grain yield (Madhiyazhagan 2005). Variability in weather and associated risks and uncertainty influence farmers, agribusiness managers and governments when considering production, financial and policy decisions. Availability of quick maturing cultivars of maize with comparative relative maturity (CRM) ratings as low as 95-97 days means that reassessment of options for maize production is appropriate, as these may be able to be grown during periods of suitable thermal and water supply conditions, while minimising exposure to high temperatures and/or water stress. This paper extends application of concepts explored in Robertson et al. (2003), Routley and Robertson (2003) and Birch et al. (2007). For example, modelling by Birch et al. (2007) indicated that improving reliability of maize in marginal environments depended on using suitable phenotypes planted at low to moderate populations into soil containing up to 300 mm PAWC, and using early or late planting to control water use and avoid high temperature and water stress during vulnerable crop development stages. The objectives of this study are to further explore and quantify the options for maize production, focusing on yield and yield variability using APSIM-Maize for planting dates (PLD) from 15th July to 15th February and a range of key agronomic practices, including phenotype of varying maturity (Phen), initial fraction of extractable soil water at planting (IFESW) and plant population density (Density).

Materials and Methods
The APSIM model (Keating et al. 2003) configured for maize was run for 29 locations East and West of the

Newell Highway (NSW) and Leichardt Highway (Qld), using the most recently available long term weather data for around 100 years (commencing early in the 20th century) in SILO (Bureau of Meteorology 2006). Soils were Vertosols and others with relatively high water holding capacity (e.g Chromosols) characterised in the APSIM soils data base and adequate plant nutrition was assumed. IFESW was set at 50, 65, 80 and 100% of PAWC for each soil, Phen (to represent cultivar types) was 'selected' by imposition of final leaf number (14 to 22 leaves in increments of 2 leaves), PLD ranged from 15th July to 15th February, in intervals of 7 days and Density was 1.2, 1.8, 2.4, 3.0, 3.6 or 4.2 plants m^{-2}. As a first step each of the 136,798 sets of simulation conditions was reduced to a set of mean figures across the (approximately) 100 year's worth of data, concentrating on predicted mean yield (rather than individual years which is computationally tedious) and yield variability, though other attributes could be examined. A simple GLM ANOVA model was used as a numerical (rather than inferential) tool to assess the sensitivity of the model to the different conditions. The model fitted to the mean yield included main effects for each of the conditions including site and soil type within site, as well as 2-way interactions. We used the variance ratio of each fitted effect relative to the residual mean-square as a way of ranking the contributions to overall variation. Although a simplistic measure, the model r^2 was 0.97, indicating that higher order interactions have relatively little impact on predicted mean yield. To focus on different sites and how they might respond, we isolated two specific combinations of conditions: IFESW =100%, Density =2.4 p/m^2, and Phen = 18 leaf (referred to as 'high PAW, long maturity'), and the second, IFESW =65%, Density = 2.4 p/m^2, and a 'quicker' Phen (14 leaf) (referred to as 'low PAW, short maturity'). We then extracted the average yields for each of the 15 PLDs for the 76 site-soil combinations. The PLDs (variables) represent successively later plantings, which should be quite strongly correlated, whereas the different soils should be less so. Using the 'high PAW, long maturity combination', a cluster analysis was carried out using Ward's method (based on the euclidean distance between each site-soil combination). Subsequently, principal components analysis (PCA) was carried out on the same 76x15 data matrix. Finally, example locations from each of the clusters identified were used to illustrate the types of responses together with the prediction of yield across all PLDs for the representative sites.

Results

The cluster analysis produced 6 groups of responses (Table 1), which were used to guide the remaining analyses. Variance ratios for main and two factor interactions showed that IFESW, Density, PLD, site and Phen were major contributors to variance, with soil and the interactions much smaller contributions. PCA revealed the first two principal components explained 97% of the variance between observations, with the 6 cluster groups indicated by differing symbols in Figure 1(a, c, d). Inspection of the loadings and vectors of the first two components (Figure 1 (a, b) that a simple summary of any location's response can be obtained by plotting mean yield (kg/ha) for early (July 15 and 30) and late season planting (Jan 30, Feb 15) against the mean yield for 'mid-season planting' (all other PLDs) (Figure 1 (c, d)).

Table 1. Cluster membership by location (site), soil and, profile number from APSIM (BV, GV, RC = Black Vertosol, Grey Vertosol, Red Chromosol respectively, other soils as shown in full).

Cluster	Site, soil and profile number
1 (●)	Cecil Plains BV001, 002, 116, Chinchilla GV021, Dalby BV027,GV010, Wandoan Brown Sodasol 064, Wandoan GV091, Warra GV019, 022
2 (×)	Bellatta GV083, 120, Chinchilla GV 029, Dalby GV012, Garah BV011, Gravesend GV078, Inglewood BV032, GV010, Inglewood RC039, Mungindi GV126, Narrabri GV124, Pallamallawa GV078, Roma GV100, The Gums GV102, Toobeah RC016, Narrabri V124, Pallamallawa GV078, Roma GV100, The Gums GV103, Toobeah RC016, TullonaGV043, 101, Wandoan GV100, WeeWaa GV120, 125
3 (◊)	Ashley BV012, , Croppa Ck GV047, Garah BV005, Garah GV059, Goondiwindi BV042, Goondiwindi GV014, Gurley BV012, Gurley GV057, Hannaford GV103, 105, Moone GV082, 091, Moree BV012, Moree GV057, 059, Narrabri Brown Clay 121, Narrabri GV097, Roma Brown, Sodasol064, StGeorge Grey, Dermosol041, StGeorge GV040, The Gums GV092, 105, Toobeah GV051, Tullona GV102, WeeWaa GV097
4 (□)	Croppa Ck BV053, Goondiwindi GV037, Gurley GV079, Moone GV081, Mungindi Brown, Chromosol 039, Mungindi GV157, North Star BV042, North Star RC041, Toobeah RC033
5 (■)	Delungra GV078, 079, Warwick BV031, 032, Warwick Brown Vertosol 033
6 (○)	Delungra BV061, Gravesend BV061, Pallamallawa BV061, Warialda BV053, 061

There is clearly a very close alignment between Figures 1(a) and 1(c), suggesting that splitting the PLDs into two groups summarises much of the difference between locations. As the second combination of conditions (‘low PAW, short maturity’) produced a similar pattern from PCA we present just the derived plot, using the groupings obtained from the earlier cluster analysis. The alignment of the locations is surprisingly similar, though the range in yields is less, due no doubt to the combined effects of lower IFESW and quicker Phen. Using ANOVA as a tool for carrying out sensitivity analysis does allow influential model parameters to be identified as a first step, but is difficult to visualise. Multivariate approaches, while focussing on subsets of simulations, lead to more tractable representations of the relationships among different cropping areas.

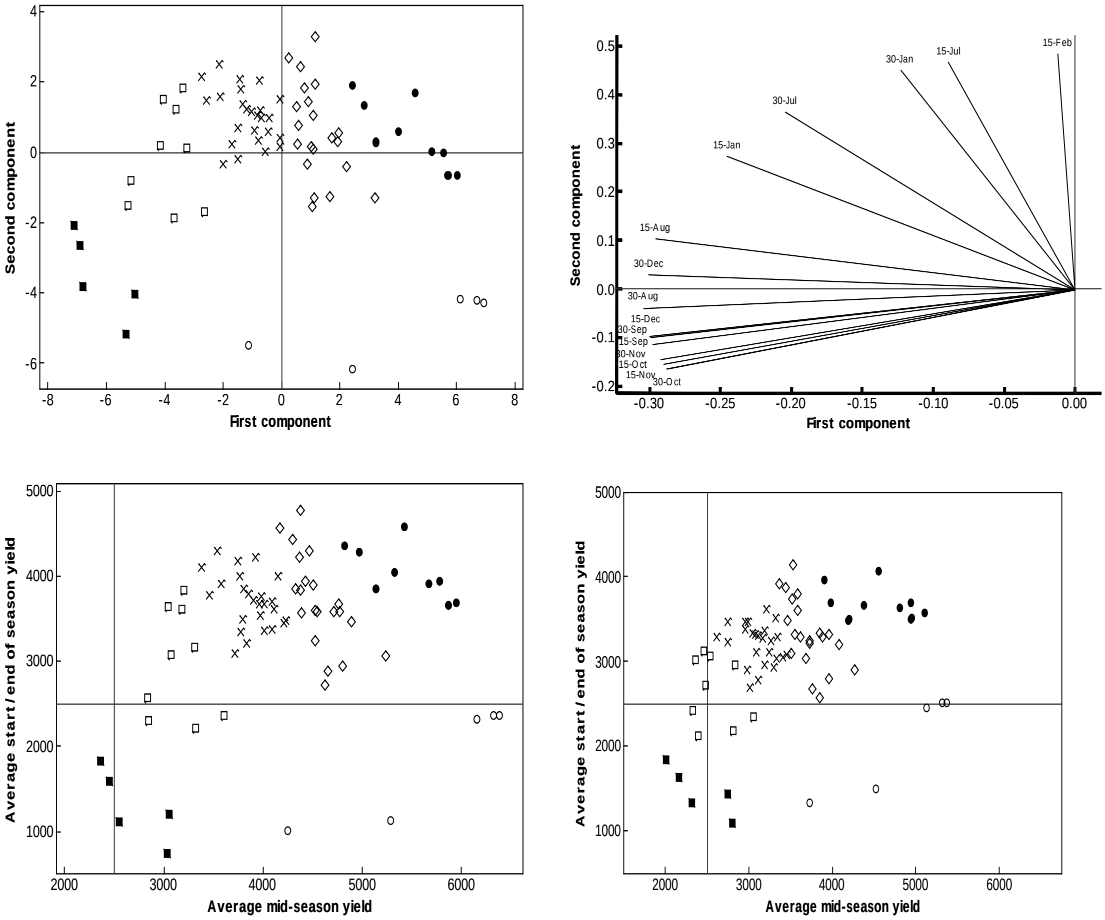

Figure 1. (a, top left) Cluster groupings. and (b, top right) vectors in a modelling study of maize yield in croplands in NE Australia and score plots for average early and late season planting (Jul 15 and 30, Jan 30, Feb 15) against the mean yield for ‘mid-season planting’ (all other PLDs) for (c, lower left) IEFSW = 100%, DENSITY = 2.4, Phen = 18 leaves and (d, lower right) IEFSW = 65%, DENSITY = 2.4, Phen = 14 leaves (b, right). (For symbols, see Table 1). Vertical and horizontal lines at 2500 kg/ha represent an approximate break even yield.

The types of yield responses for representative site and soil combination in each of the 6 clusters (Table 1) are shown in (Table 2), together with the prediction of yield across all PLDs for these sites (Figure 2).

Table 2. Illustration of the types of yield responses for representative site and soil combinations in clusters.

Cluster	Site-soil	Responses
1	Dalby Black Vertosol	High yield with mid season PLD, lower with early & late PLD
2	Mungindi Grey Vertosol	Moderate yield in all PLD,, slightly higher yields than cluster 3
3	Moree Grey Vertosol	Moderate yield in all PLD,, slightly higher yields than cluster 4
4	Goondiwindi Grey Vertosol	Moderate yield with all PLD
5	Warwick Black Vertosol	Very high yields in mid season PLD, low with early & late PLD
6	Warialda Black Vertosol	Relatively low yield in all PLD

These show that with the exception of Warwick (Cluster 5) and Dalby (Cluster 1), which have low yield in early and late planting, and consistently high predicted mean yield in other PLDs, there is a pronounced reduction in yield for planting mid to late spring, with highest predicted yield in July – August and December-early January planting. Warialda and similar sites tend to have low predicted yield due to comparatively low PAWC.

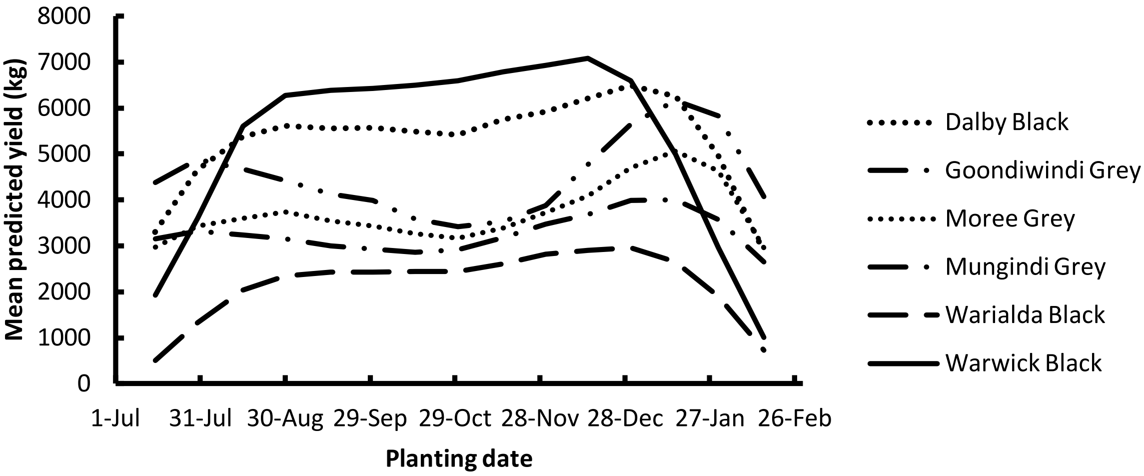

Figure 3. Predicted mean maize yield for representative sites and soils (all Vertosols) in each cluster for planting 15 July to 15 February

Discussion

The large number of simulations and approaches to interrogating and presenting the output means that this study has produced a valuable resource, which can be used to develop an agronomic package for successful maize production by location. It is clear, for instance, that planting on less than 80% IEFSW, using Density >2.4 and PLD outside the most desirable planting windows will increase risk of failure, with Phen being important under specific circumstances e.g. to avoid high or low temperatures at critical development stages. The relatively low contribution of Soil to variation is attributable to the selection of only soils already used for cropping, others being unsuitable because of low PAWC – the few with moderate PAWC e.g. at Warialda, North Star and Croppa Creek had comparatively low yield simulations and more frequent low yield years than other sites. The output provides capacity to investigate reliable planting windows, assess risk of failure (e.g. frequency not achieving an acceptable yield), and identifying which sites can be used as references for environments with similar characteristics. Overall, the simulations and detailed statistical analysis suggested that using IFESW = 100%, Density = 2.4 and Phen of 18 leaves is practicable except in the most favoured environments where Phen > 18 leaves and Density > 2.4 can be used, or the most risky environments where Phen < 18 leaves and DENSITY < 2.4 could be considered. PLD can vary quite widely in favoured areas (Clusters 1 and 5), and in others provided the high and low temperature risk periods at critical development stages are avoided.

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