Using industry information to obtain insight into the use of crop rotations in the Western Australian wheat belt and quantifying their effect on wheat yields

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Abstract

In the last decade, data management systems have become increasingly prevalent in agricultural sectors. Information can now be sourced from consultants or similar agencies about farms and farmers. Data is routinely collected on factors such as field management, crop yield, livestock numbers, soil type, farm size and enterprise mix. In some situations these data can be combined with information on climatic, social and economic factors and used to explain the basis behind an observation. However, these analyses are generally conducted on data that were not collected for the specific purpose. In this study I discuss an analysis targeting the crop sequences used by farmers and performed on a consultant's database containing 971 farmer's fields that were monitored for at least 3 years. A 3 year sequence of continuous wheat yielded 0.2 t/ha less than a wheat crop grown after a break crop such as lupins or canola. In1997 just 5% of wheat crops were sown into a wheat stubble. By 2007 this had increased to 32%. This project is used as a case study to explore the strengths and weaknesses of the analysis of industry data with respect to rotation practices in the Western Australian wheatbelt.

Introduction

Data have long been collected on or about production levels in agriculture by the statutory bodies. Summary analyses of these data have been used to discern industry wide trends and provide insight into the progress or decline of a particular industry (ABS 2008). Local industry information on agricultural production has also been collected by other bodies like agricultural consultants, catchment management authorities and research agencies funded by national RDCs. For example, this information has been used recently to highlight the decline in lupin production in Western Australia (WA) from over 1 million hectares to under half a million hectares (Robertson et al. 2010). In general, such analyses are data driven where a response is observed in the data at a macro level at regional, state or national scales. Analyses of industry data have strengths and weaknesses. These studies aggregate data that has originated from a wide range of agro-environments. It is possible that this richness of information may provide insights into production that cannot normally be distilled from conventional agronomic or simulation modelling studies.

The use of this rich source of industry data does have its limitations, and once a trend has been identified researchers have a natural tendency to explain or understand the trend. Invariably climate plays a role and various attempts have been made to incorporate climate into an interpretation of the data from the grains industry (Cornish et al. 1999, Hamblin and Kyneur 1992). However, agronomists invariably face a problem in deciding how to combine data that has originated from different scales and this problem complicates the ability of scientists to make strong inferences about the observed trend. For example, to explain the basis for a decline (or increase) in wheat production from silo receivals, climate would need to be aggregated regionally. Influences such as soil type would be difficult to accommodate as many soil classifications are too coarse.

Nevertheless, industry information can be useful and I present an analysis of field level data from a subset of growers in the Western Australian wheatbelt. These data are used to characterise the rotations farmers are using, and explore how rotation choices have changed through time. In addition, linear mixed models are employed to assess what impact rotation choice has on wheat yield in the industry.

Methods

Fields from 49 farms owned by 12 different farmers were monitored at least 3 years between 1997 and 2007. These data were extracted from a database maintained by agricultural consultants in WA. Individual fields could be tracked for 3 years. Data were not spatially referenced and field name changes and other inconsistencies in the data prevented fields from being monitored continuously. Nevertheless, a three year rotation could be defined for 971 fields, where the last crop in the rotation was wheat. The data includes the farm of origin, the field name, the year of harvest, the crop species and the rainfall received during the growing season on the farm of origin. Because fields could be tracked through time, the crop grown in the previous two years could also be identified. As a result, these data could be used to estimate the size of the break crop effect on the yield of the subsequent cereal crop. The objective was to estimate the effect of different crop rotations on the yield of the final wheat crop grown in that rotation. Thus, there was a need to define various crop rotations from the database and explore the temporal trends for the crop grown prior to wheat. Each farm recorded rainfall and the consultants calculated a growing season (April – November) rainfall for each farm. Rainfall information was not available at the field scale.

Exploratory data analysis was initially used to determine how the frequency distribution of the crop grown immediately prior to wheat changed over time. Data were subsequently analysed using a linear mixed effects model fitted using the lme4 package from the R statistical library. Then, a statistical model was constructed that explained and accounted for the dominant effects in the data (year, farm of origin and rainfall); it could be used to deduce what affect crop rotation had on the yield of the wheat crop. In addition, it was possible to explore whether rainfall interacted with the other two variables, farm and crop rotation, to see if further insights into wheat crop yield could be extracted from this particular dataset. To achieve aim, this several mixed effects models were fitted to the data. Rainfall was fixed and fitted as a continuous variable, all other explanatory variables were categorical and considered random.

From the data the following rotations were defined for each wheat crop. The wheat crop was the final crop in the rotation for a particular paddock, and could have been grown in any year. The five possible rotations were:

wheat, wheat, wheat (www)
wheat, wheat, not wheat (wwo)
wheat, lupins (wl)
wheat, pasture (wp)
wheat, not wheat, lupins or pasture (wo)

The linear mixed effects models fitted to wheat yield were:

Wheat yield = Growing Season Rainfall + Crop Rotation + Farm + Year + error
Wheat yield = Growing Season Rainfall + Crop Rotation + Growing Season Rainfall*Farm + Year + error

Wheat yield = Growing Season Rainfall + Growing Season Rainfall*Crop Rotation + Growing Season Rainfall *Farm + Year + error

Model selection, using the AIC (Akaike Information Criterion) was employed to select the most appropriate statistical model.

Results

Trends in rotation choice

At the field level, there has been a dramatic change in crop rotation through time (Figure 1). In 1997, 47.5% of wheat crops were grown following lupins, 32% of wheat crops were grown after a pasture and a further 2.4% were grown after a canola. In total, more than 80% of wheat crops were grown after a break of some description, although the previous crop could not be defined for 11.2% of wheat crops. Only 6.1% of wheat crops were grown following another wheat crop. By 2007, these proportions had changed dramatically. Lupins had dropped out of favour and only 16.1% of wheat crops were grown following a lupin crop. The number of wheat crops grown after canola was just 6.2% after reaching a peak of 18.2% in 2000. Lupins and canola had largely been replaced by wheat, with 32% of wheat crops sown following a wheat crop and another 2.0% of wheat crops sown following barley. Only 26% of 2007 wheat crops were grown following a pasture. These trends occurred progressively (Figure 1).

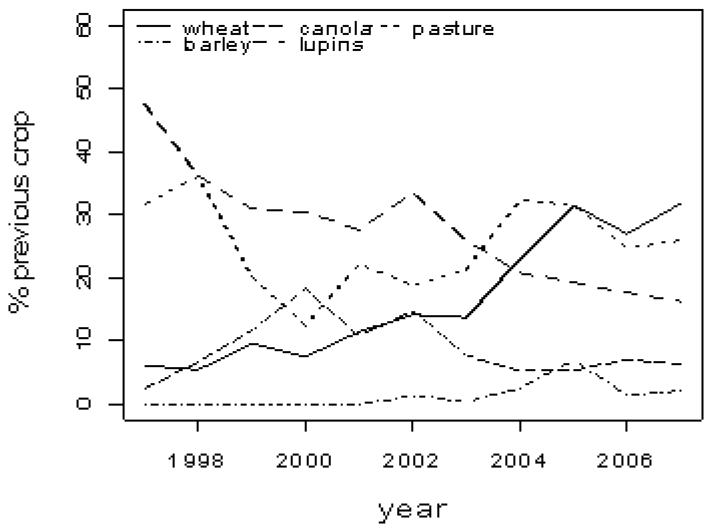

Figure 1. Trends in previous crop grown prior to wheat.

Model selection and rotation effect on wheat yield

The data were best characterized by the second model:

Wheat yield = Growing Season Rainfall + Crop Rotation + Growing Season Rainfall*Farm + Year + error

In summary, rainfall, crop rotation, farm, the response of the farm to rainfall, and the year that the crop was harvested were all important. This finding implies that the water use efficiency varies with farm. The interaction between crop rotation and rainfall was tested but no significant impact on wheat yield emerged. The analysis suggests the rotation effects on wheat yield in this data set were relatively stable in response to growing season rainfall. Alternatively, the interaction between rotation and growing season rainfall was too variable to capture with these data. Overall the fitted model accounted for 30% of the variation in yield.

Based on an assumed growing season rainfall of 200 mm, the predicted farm yields ranged from 1.43 to 3.23 t/ha. However, the interquartile range or the difference between the first and third quartiles was just 192 kg/ha. Mean yields across years ranged from 1.7 t/ha in 2002 to 2.35 t/ha in 1997. These differences were evident even after the effects of growing season rainfall were accounted for in the model. The effect of rotation was important. Wheat yields from across the rotations ranged from 1.82 t/ha for the continuous wheat rotation (www) to 1.98 t/ha for the wheat - lupin (wl) rotation. Wheat grown after one wheat (wwo) crop averaged 1.85 t/ha. In addition, wheat grown after pasture (wp) averaged 1.98 t/ha. Wheat grown after something other than lupins, pasture or wheat (wo) also averaged 1.98 t/ha. Most of these crops were grown after a legume such as field peas or canola.

Discussion

Outcomes and strengths from the analysis of industry information.

The analyses of industry data on crop rotations offered insights that cannot be gleaned from conventional white peg agronomy studies or from simulation modeling. The study demonstrated the decline in the popularity of the wheat - lupin rotation, reducing the area of lupins. Silo receivals of lupins had declined during the period of investigation so the decline in itself was not surprising. However, these data demonstrated that the wheat - lupin rotation choice has been replaced, not by another break crop, but by an increase in the number of wheat crops grown following a wheat crop. Therefore, farmers have shown a propensity to grow wheat continuously or at least with fewer breaks. This could be because they do not believe they have a viable break crop to grow. In this study, the linear mixed model showed that wheat yields grown after a lupin crop averaged almost 200 kg/ha more than wheat yields grown in 3 years of continuous wheat. Thus, comparatively small effects of crop rotation could be detected with industry data. Industry data are variable from farm to farm and in this instance (2007) wheat crop yields ranged from less than 1 t/ha to 4.5 t/ha. By accounting for as many macro level influences as possible (year of harvest, farm of origin and rainfall), these small rotation effects could be distilled from the data. The study indicates that in 32% of wheat crops farmers are accepting a yield penalty in the order of 200 kg /ha or a penalty of around 10% of grain yield.

This analysis demonstrated that other rotation choices deliver a similar boost in wheat yield from lupins. Thus farmers, regardless of location, have the capacity to ensure that wheat is grown in a weed-free and disease-free environment and this capacity will generate a higher yield. Despite these rotation choices, farmers are choosing to grow wheat on wheat at unprecedented levels.

Analysis of industry data highlights the fact that effects like the break crop effect are real. Industry can overcome the perception that trials run on research stations or by research agencies are not real or relevant. Secondly, analysis of the frequency distributions provides insights into the management decisions of farmers. This analysis is powerful, because researchers can foresee future problems likely to beset the industry and perhaps give researchers cause to evaluate some of their prevailing assumptions about what constitutes a sustainable farming system.

Some weaknesses of industry information

It is often difficult to ascribe a process to an effect with industry information. The mechanism behind the rotation effect cannot be discerned from these data; it can simply be used to generate a series of questions. Crop rotation is an old agricultural practice and its basic principles have been widely studied (e.g., Kirkegaard et al. 2008). Factors like in-season rainfall that interact with soil born disease did not interact with rotation choice to affect crop yield. Further exploration and analyses of these data, accompanied by even more data such as soil type, are unlikely to yield further insights because the data are too variable. Since industry data are variable and complex, statistical models need to be employed to extract insights into factors such as rotation. The choice of statistical model is often subject to debate and can affect the outcome. Thus decisions about whether to fix the rainfall effects, to include the farm, year or even the field into the statistical model can be defended or disputed.

Conclusion

Industry information is best used to monitor industry trends. Complex statistical methods can be employed to extract management level effects. However these small effects will be difficult to interpret because major effects (rainfall, farm and year) can confound the signal of interest and these must be accommodated in a statistical model. The data are variable and a large number of observations are required to capture minor agronomic effects. However, the data provide valuable insights into industry practice and provide a context for more traditional methods of experimentation.

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