Simulating spatial issues in farming systems with APSIM

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Abstract

The Agricultural Production Systems Simulator (APSIM) has long been used in the simulation of discrete management units within production systems. Recent developments now allow for the inclusion of multiple instances of the point-based modelling capability within a single simulation. This allows the user to explore the behaviour of management systems where individual land units can be influenced by other points in space. This paper provides three hypothetical case studies to illustrate both the need for such a capability, and the possibilities provided by the developments to the APSIM framework.

Media summary

The APSIM farming systems model is now capable of exploring issues relevant to sustainable agriculture e.g. whole farm resource management and catchment hydrology.

Key words

APSIM, farming systems , spatial modelling, agroforestry.

Introduction

The Agricultural Production Systems Simulator (APSIM) is a modelling framework that is used extensively in Australia and internationally. It allows components to be ‘plugged’ together to build simulations of farming systems (Keating et al., 2003; McCown et al., 1996). It has traditionally been a single point simulation model that could simulate a paddock in great detail, but lacked the ability to deal with interactions between points in space. In some cases, such a capability is required for investigating whole farm resource management, farm design, catchment hydrology, or other issues relevant to research on sustainable agriculture.

Historically, the use of point-based models in addressing spatial problems has relied upon post simulation combination of results from a series of simulations (e.g. Ringrose-Voase et al., 2001), sometimes with appropriate corrections or assumptions for possible interactions between the individual simulations (e.g. Brennan et al., 2002). Alternatively, where information flow between spatial units occurs in only one direction (i.e. no feedbacks through space) simulations are applied in series with the output from one simulation providing impact on the subsequent simulation of other spatial units (e.g. Paydar and Gallant, 2003). These restrictions can be removed if discrete land units are simulated within the one model execution with defined and appropriate information flows between points in space.

Recent developments on the inter-module communications protocol employed by APSIM (Wright et al., 1997; Moore et al., 2001) now allow the application of the model to issues that contain a spatial component. The new protocol allows multiple instances of the point-based model within a single simulation with communication of data between each discrete point in space. An abstraction of any system into functional units can thus be represented by a series of these instances with clearly defined data flows between each unit.

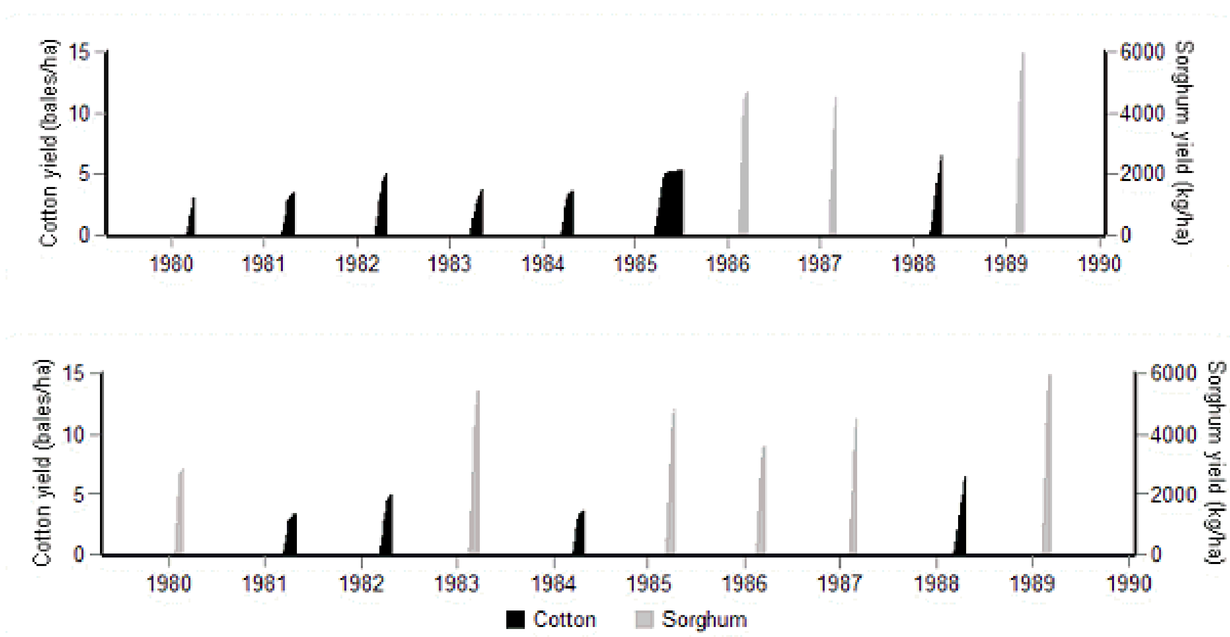
This new capability has greatly broadened the types of applications that APSIM can explore. This paper doesn’t describe the details of how this technology came about, but rather presents three very different case studies that use the multi-point capability within APSIM.

Case study one – Irrigation management

Scenario: A 400ha farm at Dalby Qld includes a 250ha catchment with native vegetation feeding runoff into a dam with 300Ml capacity, and 2 fields used for cropping (100 ha and 50 ha). Irrigated cotton or dryland sorghum are considered for sowing in either paddock depending on the amount of water in the dam, with a preference for irrigated cotton. Cotton is sown in October in the larger paddock (Paddock1) if the dam is at least 50% full, otherwise dryland sorghum is grown. The smaller paddock (Paddock2) uses the same sowing conditions except that the dam must be at least 60% full.

The multi-point capability of APSIM is used to simulate three discrete land units, one for the catchment/dam and one for each paddock. Each point can be viewed as an instance of a complete simulation, having modules for soil water, soil nitrogen, residue, crops and management. The new capability allows for data to flow from one point to another. For example, each of the paddocks in our scenario needs to determine how much water is in the dam, which in turn is dependant on the irrigation of each of the paddocks. This cyclic dependency of data flows is what makes a multi-point capability crucial for these types of analyses. In APSIM, this interchange of data is completely flexible. The user building the simulation determines how the points are to interact and adds that knowledge into parameter and management files.

Figure 1 shows a 10 year simulation of the hypothetical farm. The top chart shows the cotton and sorghum yields for Paddock1. It can be seen that cotton is sown in 7 of the 10 years with sorghum filling in the other years. The second chart shows that Paddock2 sows only 4 cotton crops due to an insufficient dam water supply. This shortage of water can be seen in the bottom chart, particularly in 1985 when the dam is half full (but not 60% full) at sowing of Paddock1's cotton crop. In most cases, the dam level also reflects the drop in water level when irrigating a cotton crop, particularly in those years where cotton is sown in both Paddock1 and Paddock2 simultaneously. The exception is 1981 where significant rainfall fell.



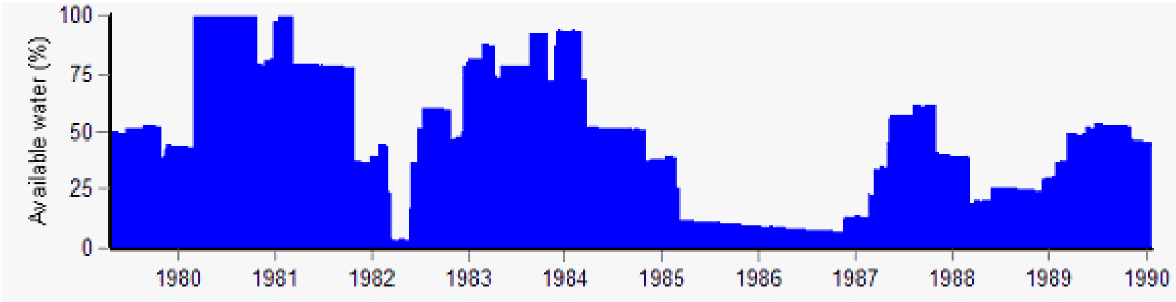


Figure 1. Cotton and sorghum yields for Paddock1 (top) and Paddock2 (middle) over time. The bottom chart shows the percentage available water in the dam for the same time period.

Such a model configuration allows the user to play resource management or farm design 'whatif' games. For example, what would be the impact of turning some of the catchment into cropping paddocks, or *vice versa*? What would happen if I put in another dam? What would happen if I adjusted my paddock management to use less water? What if I get an allocation to pump from a nearby river? Previously these types of questions where impossible, or at least very difficult, to explore with APSIM. It usually involved performing multiple simulations for each point and then somehow performing post simulation integration.

Case study two – Precision agriculture

Scenario: A hypothetical paddock in the Liverpool Plains, NSW (latitude -31.7?S, longitude 150.4?E) shows spatial variation in yield due to soil depth and transient water logging within a low point in the paddock. Soil depth and water holding capacity decreases downslope within the paddock, with the lowest point containing a restriction to rooting and water movement at 90 cm depth. To exacerbate the water logging, runoff from a large area outside of the paddock contributes extra water to the water logged area. A simple abstraction of the system in question has been developed utilising five distinct points or zones (upper catchment plus four zones within the paddock), which are similar except for their area and soil type: upper catchment (50 ha, 289mm plant available water capacity (PAWC)), point 1 (20 ha, PAWC 244 mm), point 2 (10 ha, PAWC 214 mm), point 3 (10 ha, PAWC 169mm) and point 4 (waterlogged area, 5 ha, PAWC 169 mm). The soil at points three and four is identical, except that runoff from all other points runs onto point four. Continuous wheat cropping is sown in all zones based on antecedent rainfall and stored soil moisture within the most common soil type within the paddock (point 1).

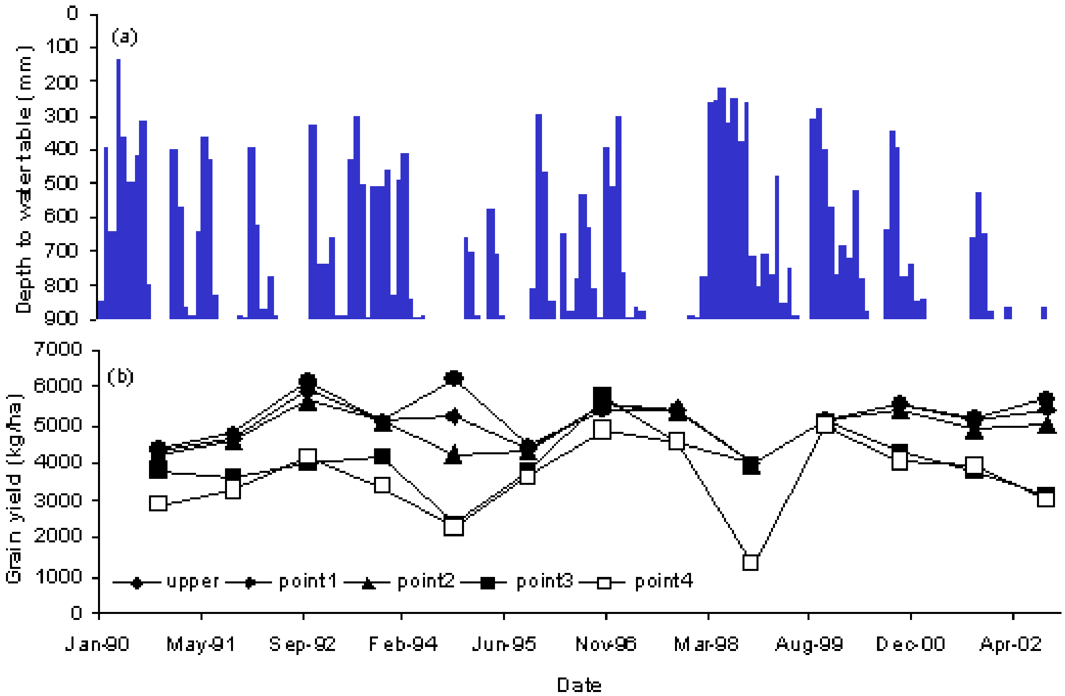


Figure 2. Time series of (a) depth to water table and (b) grain yield within each zone within the paddock and the upper catchment area.

The results illustrate the decline in production within the paddock due to changes in soil depth. The effect of water logging, however, is less persistent across seasons. The difference in yield between points three and four is entirely due to water logging (they have the same soil specification) and is greatest when there are extended periods of water logging (see figure 2a) due mostly to inflow of water elsewhere in the catchment. In fact, simple analysis of the simulation results indicate that catchment runoff could account for greater than 10% more of the variation in water logging related yield loss than rainfall alone. This highlights the importance of surface conditions in other parts of the catchment on the risk of waterlogging in this scenario.

Case study three – Agroforestry.

The multi-point capability has been used recently to investigate the effect of trees along the side of a cropping field facing the prevailing winds (Huth et al., 2002). The roots of the trees on the edge of the tree belt access the water and nutrients within the field and decrease yields near the edge. However, the belt of trees, when oriented as a windbreak, affects the crop for a significant distance down-wind by altering the micro-climate. Figure 3 graphically depicts this scenario.

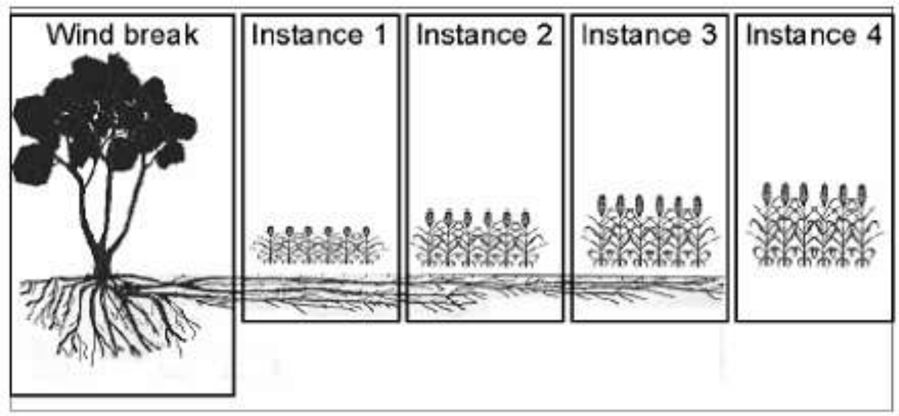


Figure 3. A graphical representation of the tree-crop competition zone

In this scenario, two points, or instances, in the tree belt (an inner and edge point) and a number of 'crop' points leading away from the trees were simulated. Each point had its own water, nitrogen and management modules. The tree points had instances of the APSIM-Forest module and the crop points each had an instance of APSIM-Chickpea. Tree roots were allowed to grow dynamically, through space and access water and nutrients from cropped areas as the trees developed. In addition the effects of the trees on the microclimate of the various cropped areas were simulated daily as a function of the size of the trees. This configuration was then used to explore the long-term benefits of planting trees on farms to protect the environment from down-stream salinity impacts. For a complete analysis, refer to Huth et al. (2002).

Conclusion

The multi-point modeling capability in APSIM is a powerful new enhancement. It brings a spatial element to APSIM which can be used in a diverse range of applications, ranging from whole of farm (e.g. scenario 1) to within paddock (e.g. scenarios 2 and 3) in their scope. Linkages between APSIM and other spatial modeling approaches, for example geographical information systems, are being investigated to facilitate greater integration with existing hydrological and ecological research efforts.

References

Brennan L.E., Lisson S.N., Khan S., Poulton P.L., Carberry P.S., Bristow K.L. (2002) An economic and environmental evaluation of the benefits and risks of recycled-water irrigated crop production on the Darling Downs. A study commissioned by the Darling Downs Vision 2000 Technical Sub-Committee. 149 pages.

Huth, N. I., Carberry, P. S., Poulton, P. L., Brennan, L. E., and Keating, B. A., A framework for simulating agroforestry options for the low rainfall areas of Australia using APSIM. Europ. J. Agronomy 18, 171-185. 2002.

Keating, B. A., Carberry, P. S., Hammer, G. L., Probert, M. E., Robertson, M. J., Holzworth, D., Huth, N. I., Hargreaves, J. N. G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J. P., Silburn, M., Wang, E., Brown, S., Bristow, K. L., Asseng, S., Chapman, S., McCown, R. L., Freebairn, D. M., and Smith, C. J. (2003) An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18[3-4], 267-288.

McCown R.L., Hammer G.L., Hargreaves J.N.G., Holzworth, D.P. and Freebairn D.M. APSIM: A novel software system for model development, model testing, and simulation in Agric. systems Res.. Agric. Systems, 50: 255-271. 1996.

Moore, A. D., Holzworth, D. P., Herrmann, N. I., Huth, N. I., Keating, B. A., and Robertson, M. J., Specification of the CSIRO Modelling Protocol. LWRRDC Project CPI 9 . 2001.

Paydar, Z and Gallant, J. C. Applying a spatial modelling framework to assess land use effects on catchment hydrology. In D. A. Post (Ed) Proceedings of the International Congress on Modelling and Simulation, Townsville, Australia, July 2003, Volume 2. pp. 491-496.

Ringrose-Voase, A.J., Young, R.R., Huth, N.I., Paydar, Z., Bernardi, A.L., Banks, R.G., Cresswell, H.P., Keating, B.A., Scott, J.F., Holland, J.F. and Daniels, I. A tool to aid development of land use strategies at a catchment scale to reduce dryland salinity risk. In F.Ghassemi, P. Whetton, R. Little and M. Littleboy (Eds) Proceedings of the International Congress on Modelling and Simulation, Canberra, Australia, December 2001, Volume 2. pp. 633-638. Modelling and Simulation Society of Australia and New Zealand. 2001.

Wright, S. L. , Veraart, V. E., Moore, A. D., and Keating, B. A., A Software Protocol for Connecting Different Crop, Soil and Pasture Simulation Models. American Society Agronomy Abstracts Anaheim CA. 21. 1997.