Application of a systems model to a spatially complex irrigated agricultural system: a case study

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Abstract.

Although New Zealand is water-rich, many of the intensively farmed lowland areas suffer frequent summer droughts. Irrigation schemes have been developed to move water from rivers and aquifers to support agricultural production. There is therefore a need to develop tools and recommendations that consider both water dynamics and outcomes in these irrigated cropping systems. A spatial framework for an existing systems model (APSIM Next Generation) was developed that could capture the variability in soil, cropping systems and irrigation application observed under a single irrigator with constrained water and infrastructure availability. Outputs from the simulations, such as water application, crop stress, yield, drainage and water use efficiency (WUE), could then be produced. The framework was then applied to a case study site, an 80 ha irrigated cropping area in the Hawke's Bay region of New Zealand. EM and gamma surveys were used to guide a detailed soil survey and to delineate five distinct soil types, with known characteristics such as permeability and water storage. On the site there is a range of soil water storage potential, from 80 to 178 mm of plant available water (PAW), to a depth of 600 mm. A simulation of the study site was created to represent typical management of a maize grain crop. The irrigation scenarios considered were either uniform or variable rate (VRI) application, triggered by a soil water deficit of 40 or 50 % of PAW to 600 mm, and a refill of either 20, 30 or 40% of PAW to 600 mm. The actual trigger or refill point for VRI was determined on a patch basis, while for uniform was determined from the either the soil type with the smallest or greatest PAW, or mean values that proportionally represent the characteristics of the soil types present. It has shown that with the observed variability in soil properties and system constraints, managing uniform irrigation to a single soil type may result in low WUE or yield loss. It has also shown that VRI is comparable to uniform application that is managed by deficits and refill points that proportionally represent the characteristics of all of the soil types present.

Keywords. *APSIM, Irrigation, Modelling, Maize, Water use efficiency,*

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Introduction

Although New Zealand (NZ) is water-rich, many of the intensively farmed lowland areas suffer frequent summer droughts. Irrigation schemes have been developed to move water from rivers and aquifers to support agricultural production. This has seen a 70% increase, to 750,000 ha, in irrigated land over the last 8 years (Statistics NZ 2010). The production and economic benefits are substantial, and in the summer of 2011/12 irrigation contributed $NZD 2.17 billion to GDP (NZIER 2014). The NZ government is also investing a further $NZD 435 million to encourage development of additional infrastructure and this is expected irrigate a further 350,000 ha by 2035 (NZIER 2014).

To improve returns on this investment and meet freshwater protection targets, tools and recommendations to enable irrigation practices that improve water use efficiency (WUE), reduce run-off, drainage, and subsequent nutrient losses, are seen as an essential component of achieving fresh water policy goals (MFE 2013).

Lateral or centre pivot sprinklers make up 74% of irrigation systems, with many adapted for variable rate irrigation (VRI), and these consequently provide greater sophisticated control of water application. To develop tools and recommendations that consider both water dynamics and profitability of these irrigated cropping systems, a framework for an existing systems model was constructed that could capture the variability in soil, cropping systems, and irrigation application observed under a single irrigator with constrained water and infrastructure availability.

Materials and methods

Model framework development

The systems model used in this study was APSIM Next Generation (APSIM Initiative 2015), an updated version of the Agricultural Production Systems sIMulator (APSIM) (Holzworth et al. 2014). The model chosen is able to simulate systems that cover a range of plant, soil, climate and management interactions, while the software architecture in the updated application allowed faster run times for complex simulation setups, more robust software architecture, clearer and consistent code language, and multiple simulations running concurrently.

An advanced irrigation module was built to translate irrigator specifications into spatial and temporal application events. To consider the multiple layers of variability in soil, crop, landscape position and infrastructure present under a single irrigator, a multiple patch approach was required. A set of methods to create multiple patch simulations in APSIM, with many patches that were spatially aware, interconnected and could run concurrently was developed. These patches, with identifying tags, may have differing soil characteristics, crop management and position in the landscape but were controlled by overarching management routines. These routines linked into each patch and determined application depth and timing of irrigation based on irrigator specifications, soil water, infiltration capacity and irrigation application rate.

The system developed also allowed limitations to be placed on fixed resources, such as water and infrastructure, to enable scenario analysis to be undertaken in a constrained system. Outputs from the simulations, such as water application, yield, drainage and WUE, were then produced.

Case study site description

The selected case study site was a commercially owned, run and operated 80 ha irrigated cropping area near Otane in the Hawke’s Bay region of New Zealand (S 39°53′, E 176°40′) and had a long history of crop production (> 10 years). This included wheat (*Triticum aestivum* L.), peas (*Pisum sativum* L.), squash (*Cucurbita maxima* L.), maize (*Zea mays* L.), barley (*Hordeum vulgare* L.) and Italian ryegrass (*Lolium multiflorum* L.) in rotation since 2006. The area was irrigated by a 552 m centre pivot, with revolution time of 18.76 hours and total possible flow rate of 5,266 m^3/day.

The majority of soils at this site developed in an alluvial floodplain where there is limited soil development due to recent historical flooding. To the east of this surface is an older remnant terrace with reworked loessial deposits on top of sand and sandy clay deposits, with a ridge of weathered gravels in the northeast corner. EM and gamma surveys were used to guide a detailed soil survey and to delineate five distinct zones (Figure 1, Table 1). These zones were then related to siblings in S-Map, the New Zealand soil map which provides quantitative soil information, including characteristics relating to permeability and water storage. On this site there are two zones with lower plant available water (PAW) (80 and 85 mm to a depth of 600 mm), one with intermediate PAW (107 mm to a depth of 600 mm) and two with greater PAW (159 and 178 mm to a depth of 600 mm). Wilting point, field capacity and saturation by depth for each of the soil types is shown in Figure 2.

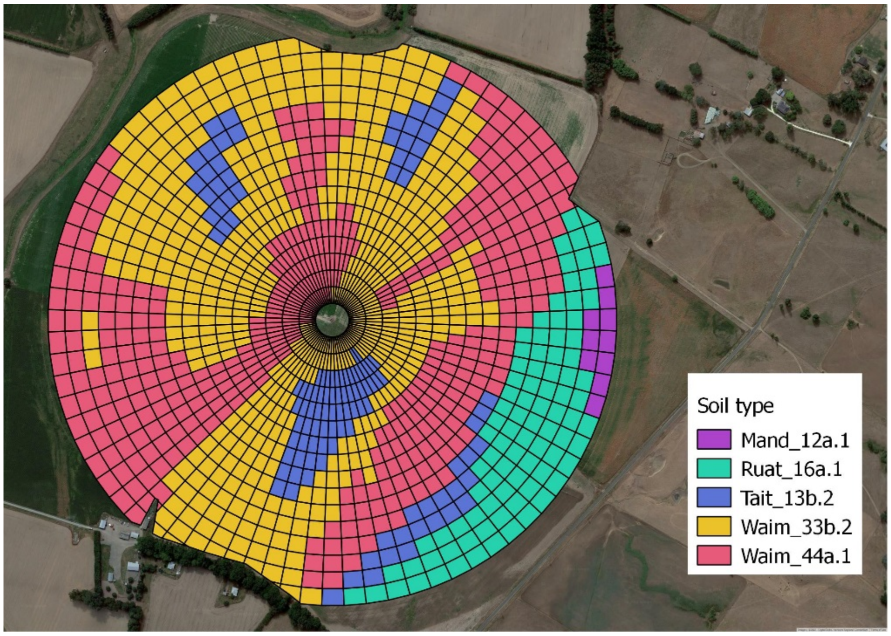

Figure 1 Map of the patches present at the study site, classified by soil type.

Table 1 Description, classification, area and plant available water to 600 mm for each soil type

S-Map sibling	Soil Type	NZ Soil Classification	Area (ha)	Plant available water to 600 mm (mm)
Mand_12a.1	Unnamed brown stony soil + Matapiro st sl	Typic Orthic Brown (BOT)	1.1	80
Ruat_16a.1	Okawa hsl + Okawa sl on st and disturbed phase	Duric Perch-gley Pallic (PPU)	9.1	85
Tait_13b.2	Kaiapo zl + hzl +buried soils	Typic Recent Gley [GRT]	7.3	178
Waim_33b.2	Twyford zl +mzl	Weathered Fluvial Recent [RFW]	33.5	159
Waim_44a.1	Twyford sl + fsl +mfsl	Weathered Fluvial Recent [RFW]	28.8	107

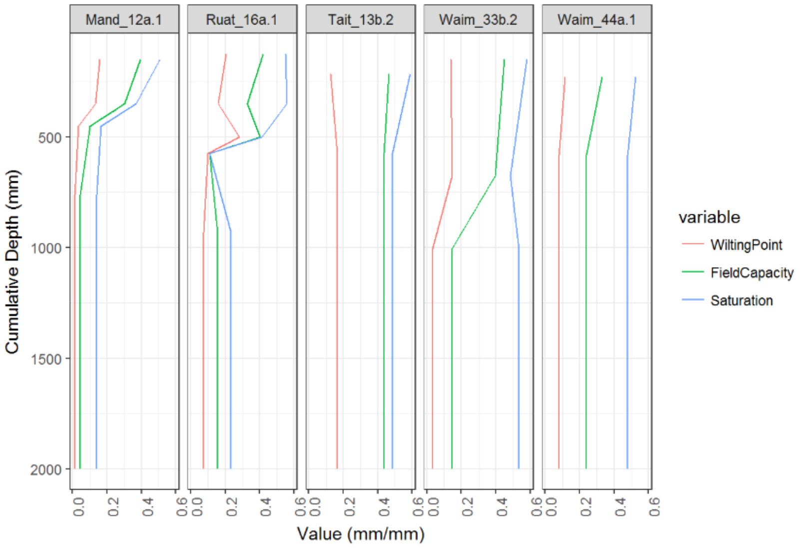

Figure 2 Wilting, field capacity and saturation points (mm/mm) for each soil type by depth

The site has a mean annual temperature of 13°C, with a monthly mean maximum temperature of 23°C in January and monthly mean minimum of 4°C in July (Figure 3). It has mean annual rainfall of 753 mm, with the extremes in annual rainfall within the study period being 421 mm in 1998 and 1067 mm in 1980.

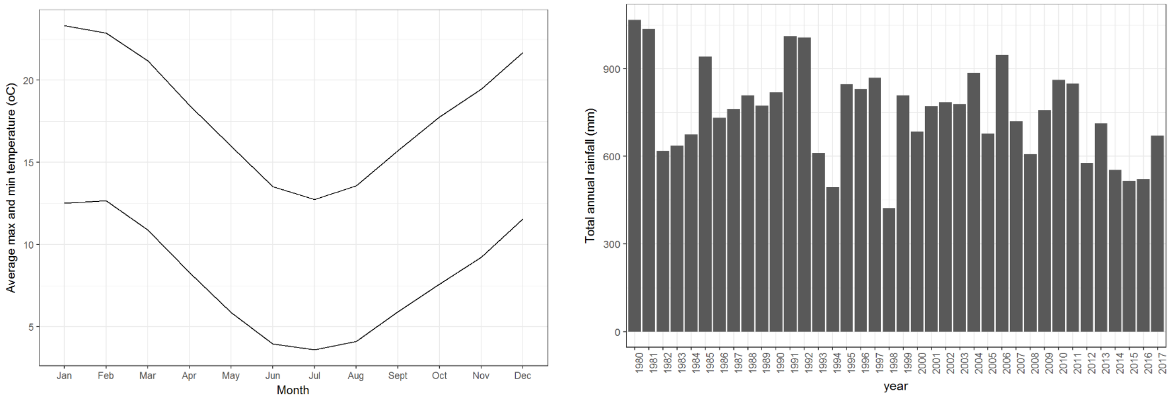

Figure 3 Average maximum and minimum temperature (°C), and total annual rainfall (mm) for the study site

Scenarios

The framework was applied to the above case study site to investigate the impact that spatial variability in soil water properties had on production and water use efficiency outcomes, and a range of irrigation strategies were also applied to the system.

A base APSIM simulation of the study site was next created to represent typical management of a maize grain crop in the Hawke's Bay region, New Zealand. Meteorological data (solar radiation (MJ/m^2), maximum air temperature (°C), minimum air temperature (°C) and rainfall (mm)) from the nearest Virtual Climate Station Network location (50 m from field boundary) was used (NIWA 2017). The maize hybrid P38H20 (medium duration hybrid; 17/18 leaves) was sown on 10 October, with a population of 9 plants/m^2, row spacing of 762 mm and at a depth of 20 mm. It was harvested on 15 May, responding to an expected grain maturity (i.e. post black layer). A script was developed that applied nitrogen as required to ensure that yield was not constrained by nitrogen.

Using this base simulation, patches in the landscape under the irrigator were propagated, as described above, that reflected their spatial position and soil type. A factorial of 35 years of meteorological information, one per year from 1980 to 2016, was then applied to the spatial simulation to consider inter-annual variability in weather.

The irrigation scenarios considered were either uniform or variable rate (VRI) application, triggered by a soil water deficit of 40 or 50 % of PAW to 600 mm, and a refill of either 20, 30 or 40% of PAW to 600 mm. For VRI scenarios, the PAW to 600 mm of each patch was used to trigger the irrigation of that patch and the depth of irrigation applied. For the uniform scenarios, the trigger for irrigation and depth of uniform application to all patches came from the either the soil type with the lowest (Mand_12a.1) or highest (Tait_13b.2) PAW to 600 mm, or mean values that proportionally represented all of the characteristics of the soil types present.

Results and Discussion

Uniform Application

Results of the scenario modelling exercise for the uniform application of irrigation show that there is little difference in yield as a result of treatment, with the greatest source of variability resulting from inter-annual variability in weather (Figure 4). There were however larger differences between other outcomes such as water applied, distance travelled by the irrigator (at the furthest point from the centre of the pivot), crop stress, WUE and drainage.

Across all of the refill points, using a trigger deficit of 50% PAW compared to 60% generally resulted in lower irrigation application over the season, shorter distance travelled by the irrigator and slightly higher WUE (Figure 4). However it also resulted in some crop stress which caused marginally lower yield. This effect was greatest when irrigation was triggered and managed to areas with the greatest water storage and resulted in areas with lower water storage experiencing water stress before irrigation was triggered.

Between different refill points, resulting from an application of 20, 30 or 40 % of PAW, increasing the applications generally resulted in greater total irrigation over the irrigation season, shorter distances covered by the irrigator and a slight decrease in WUE (Figure 4). In the case of treatments where irrigation was triggered and managed to areas with the lowest water storage, there was greater drainage with larger applications. There was little impact on crop stress or yield as a result of application.

The largest differences between outcomes were seen between the soil types that were used to inform the trigger deficit and refill treatments, namely the soil type with the lowest (Mand_12a.1) or highest (Tait_13b.2) PAW to 600 mm, or mean values that proportionally represented the characteristics of all of the soil types present (Figure 4). As previously discussed, crop stress causing yield penalty was seen when irrigation was triggered and managed to areas with the greatest water storage, and to a small extent in the mean treatment. This is due to the areas with lower water storage experiencing water stress before irrigation is triggered. Seasonal application of water and distance travelled by the irrigator increased from the highest PAW treatment, through the mean PAE treatment to the lowest PAW treatment. This is as might be expected and due to increasingly smaller PAW being considered and refilled more frequently. An addition, the entire area remained at a smaller soil water deficit for the entire irrigation season, which led to increased drainage resulting from rainfall.

These results therefore suggest for this case study system, with the degree of variability in soil properties observed, that managing uniformly to the area of the paddock with the lowest PAW (i.e. the one that would first experience stress) can achieve consistent maximum yield for a given year, but results in significantly lower WUE. This is due to the case study system being only 13

% by area of soil types with lower plant available water (PAW) (80 and 85 mm to a depth of 600 mm). For this system, managing to values that proportionally represent the characteristics of all of the soil types present might be the preferable irrigation strategy in terms of the range of outcomes considered. However, in another system, with a different amount of variability and different soil characteristics, the same outcome might not be the case.

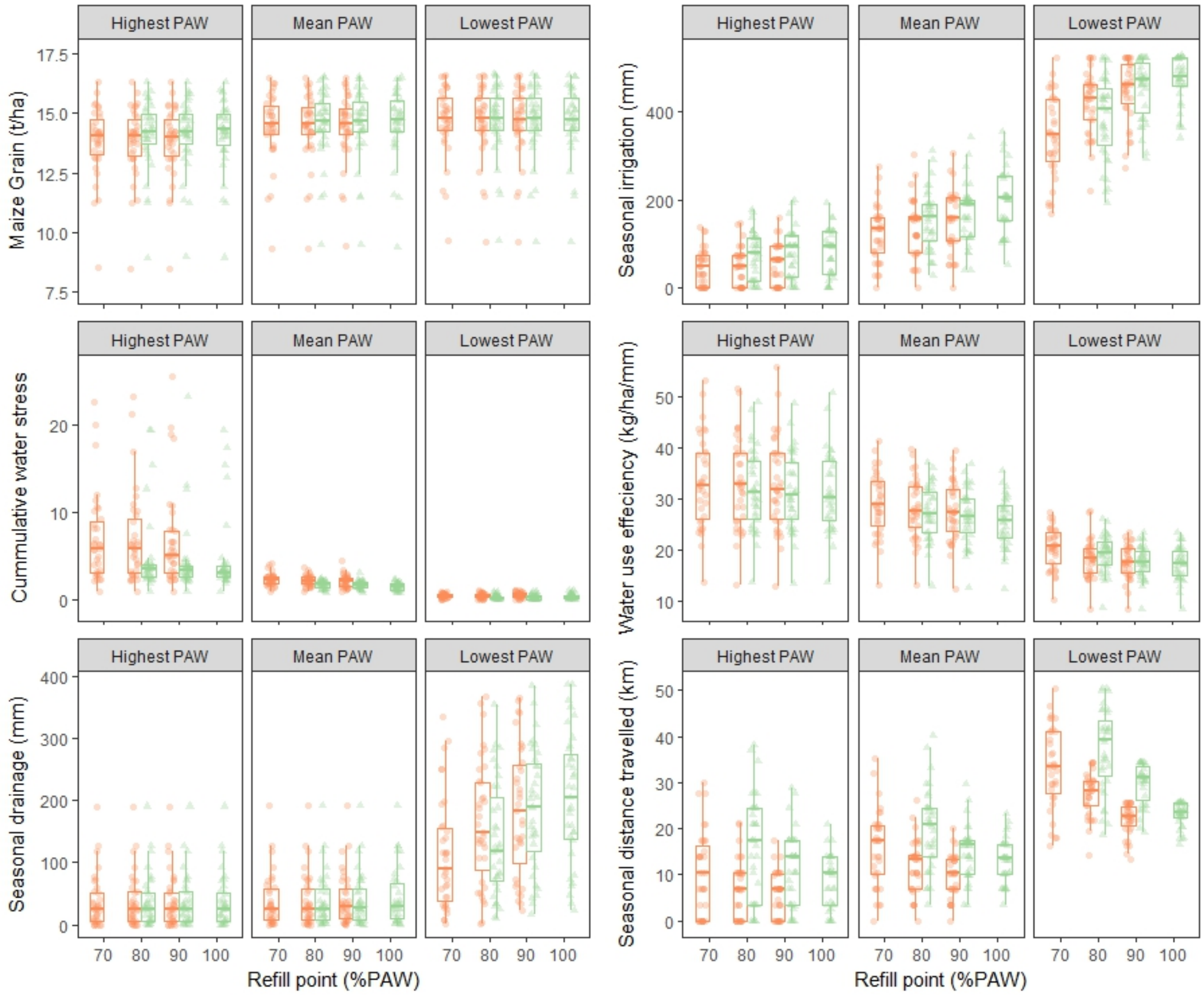

Figure 4 Outcomes for Uniform scenarios with a trigger soil water deficit of 40 % (green ▲) or 50 % (orange ●) and refill point of 70, 80 or 90 % of PAW to 600 mm using either the area with the highest, lowest or mean PAW.

VRI Application

Results of the scenario modelling exercise for the VRI application show that there is little difference in outcomes as a result of treatment, with the greatest source of variability resulting from inter-annual variability in weather (Figure 5). Perhaps unexpectedly we see a small amount of crop stress across the VRI treatments which is attributed to constraints within the system such as maximum water flow rate.

Across all of the refill points, using a trigger deficit of 50% PAW, compared to 60%, generally resulted in lower irrigation application over the season, shorter distance travelled by the irrigator and marginally higher WUE (Figure 5). However it also resulted in a small amount of crop stress which caused slightly lower yield. Again, this can be attributed to constraints within the system.

These scenarios therefore suggest that for this system, with the observed degree of variability in soil characteristics, the irrigation strategy adopted for VRI application results is very little impact on outcomes as a result of the trigger deficit or the refill point used.

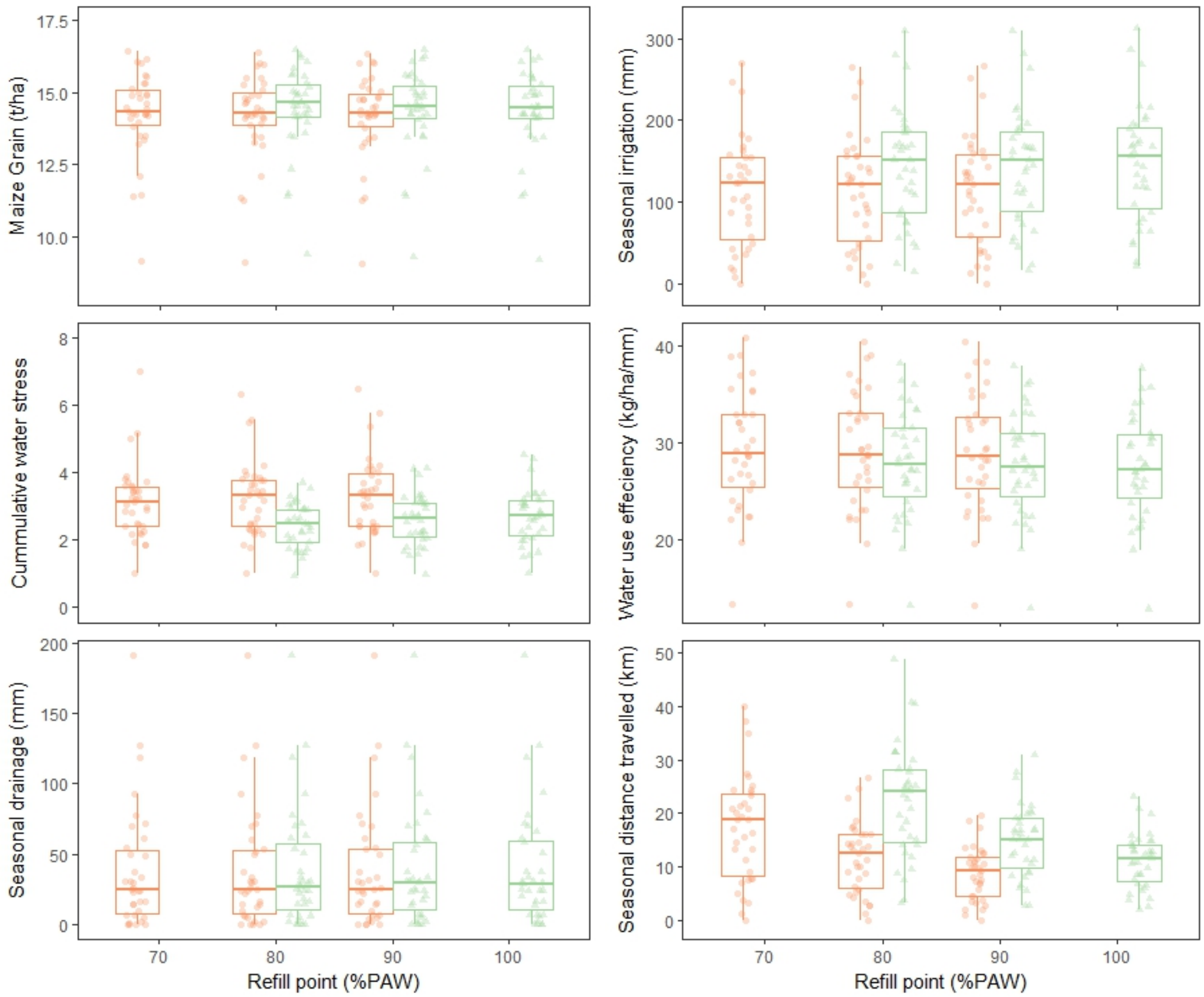

Figure 5 Outcomes for VRI scenarios with a trigger soil water deficit of 40 % (green ▲) or 50 % (orange ●) and refill point of 70, 80 or 90 % of PAW to 600 mm.

Comparing uniform and VRI application

When comparing VRI and different uniform irrigation strategies, modelled results suggest that across outcomes, for this system with the observed constraints, VRI is comparable to uniform application that is managed by deficits and refill points that proportionally represent the characteristics of all of the soil types present (Figure 6). Again this is due to the case study system being dominated by soils with greater PAW. VRI however shows benefits over uniform application that is managed to a single soil type. Results indicate that VRI has lower water application, drainage and greater WUE than managing to the soil type with the smallest PAW, and lower crop stress and slightly greater yield than managing to the soil type with the highest PAW. However, in another system, with a different amount of variability, different soil characteristics and different constraints, the same outcome might not be the case. This also does not consider any efficiency gains that might be achieved through not irrigating features that do not need irrigation such as laneways and ponds.

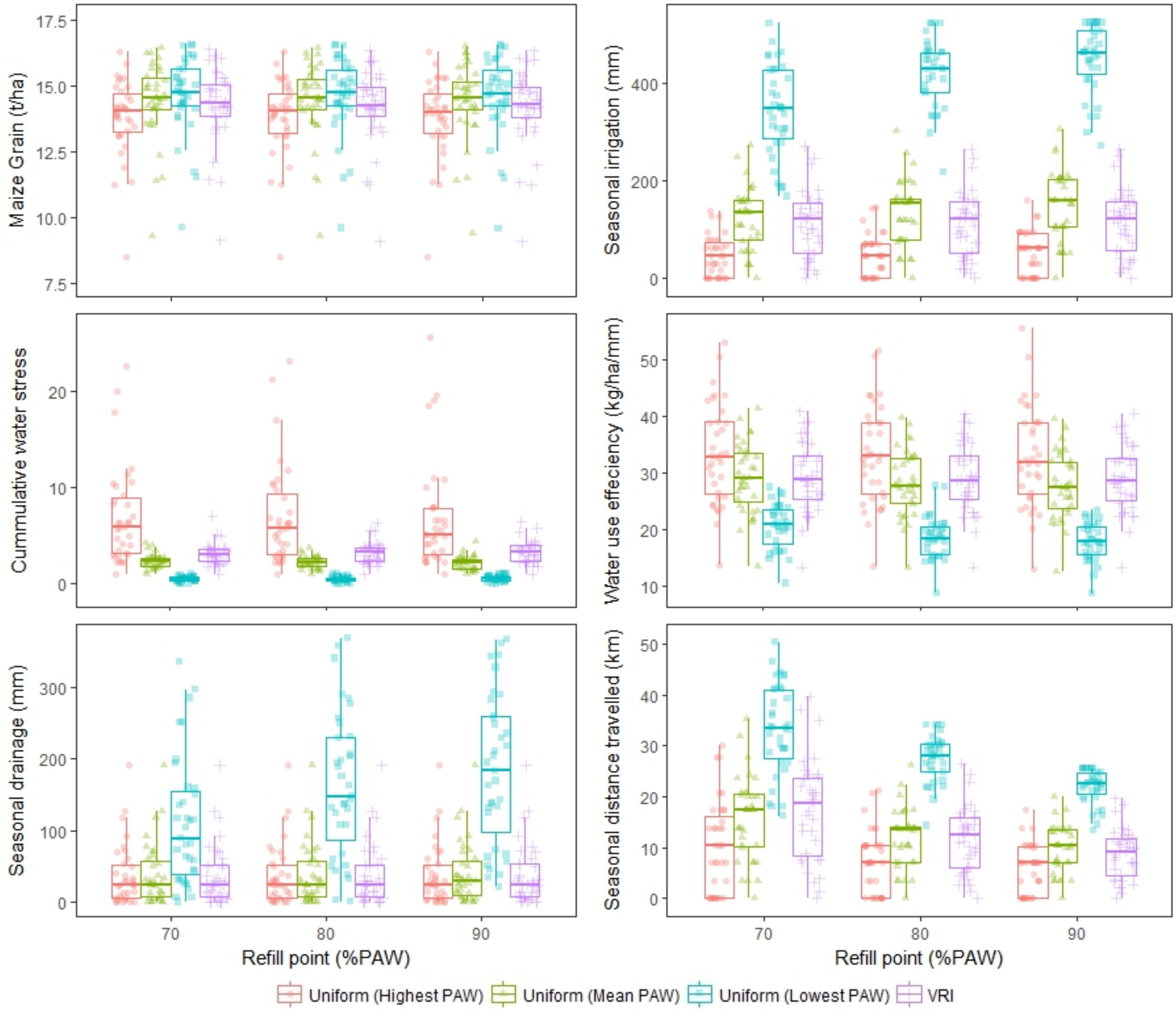

Figure 6 Outcomes for both VRI and uniform scenarios with a trigger soil water deficit of 50 % and refill point of 70, 80 or 90 % of PAW to 600 mm. For the uniform treatments using either the area with the highest, lowest or mean PAW.

Conclusion

The application of this framework has provided insights into outcomes resulting from different irrigation scenarios on this case study site. It has shown that for the observed variability in soil properties and system constraints, managing uniform irrigation to a single soil type may result in low WUE or yield loss. It has also shown that VRI is comparable to uniform application that is managed by deficits and refill points that proportionally represent the characteristics of all of the soil types present. However, in another system, with a different level of soil variability, different soil characteristics and different constraints, the outcome may be different. Further work is therefore required to look across a variety of systems and sites.

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References

APSIM Initiative (2015) APSIM (next generation). https://www.apsim.info/Documentation/APSIM(nextgeneration).aspx

Holzworth, D., Huth, N. et al. (2014) APSIM – Evolution towards a new generation of agricultural systems simulation. Environmental Modelling & Software. 62:327-350.

MFE (2013) National Policy Statement for Freshwater Management 2011 http://www.mfe.govt.nz/rma/central/nps/freshwater-management.html

NZIER (2014) Value of irrigation in New Zealand. NZIER report, Wellington.