Climate conditions affected the simulated soil water balance of an irrigated vegetable rotation in the Lockyer Valley, Australia

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Abstract
The Lockyer Valley in south-east Queensland is a highly productive agricultural area. High-value crops are produced year-round in this region as there is adequate warmth for growth and historically a generous supply of groundwater for irrigation. However, intensive cropping, an extended drought and continued extraction of groundwater have led to depletion of groundwater resources. This has reduced the irrigation supply for cropping. Recent wet spells eased this situation, but the associations between the soil water balance, groundwater recharge and climate conditions in a vegetable crop rotation system are not fully understood. Using the HowLeaky model, we studied the changes to the soil water balance from 1961 to 2011 for a vegetable crop rotation system grown on a Black Vertosol. We compared this with a recent but relatively dry period (1991 to 2007) to understand the impacts of dry periods on soil water. During the drier period (151 mm/year less rainfall), simulated irrigation increased by 94 mm/year and simulated deep drainage decreased by 64 mm/year. Inter-decadal comparison of the soil water balance from 1980s to 2000s shows lower rainfall and higher irrigation demand during the 1990s and 2000s compared with the 1980s. The study suggests that irrigation demand and deep drainage are variable on decadal and longer timescales and highlights the need for efficient water management practices to meet possible increases in irrigation demand in the future.

Key Words
Deep drainage, transpiration, irrigation, dry, wet, HowLeaky modelling

Introduction
The Lockyer Valley in south-east Queensland is an important cropping region that produces high value vegetables. However, cropping in the last two decades has undergone multi-year drier-periods affecting the soil water balance. This situation has prompted further consideration of climate variability, rainfall in particular, for sustainable land and water management. Significant areas of the Valley also have salinity issues (White 1980, Bajracharya and Ellis 1999) and changes to the soil water balance are of important concern.

Soil water balance is an account of water added, removed or stored in a given volume of soil during a given period. Rainfall and irrigation are the major water inputs, whereas runoff, deep drainage, evaporation and transpiration are the major water outputs. Changes to any of these components, rainfall in particular, will affect the water balance. The extent of impact of climate variability on the soil water balance is not well known for the Lockyer Valley.

The objective of current study is to examine how climate variability affects the soil water balance of a vegetable rotation under long-term average climate and a drier-period. This knowledge helps to understand the potential impacts of climate conditions on soil water balance and in turn, to take appropriate action to minimise the risk associated with such changes.

Methods
The Howleaky model (Rattray et al. 2004) was used to integrate climate, soil, vegetation and other data into estimates of soil water balance. Howleaky is a daily time-step model which simulates a one dimensional water balance. The simulations were for an irrigated vegetable rotation (sweet corn, broccoli and bean) grown every year on a Black Vertosol (Isbell 1996). The climate data were for Gatton (27°32′ S 152°19′ E, 90 km west of Brisbane) obtained from a patched point data set (www.bom.gov.au/silo). Climate data included a time series of daily rainfall, temperature, potential evaporation and solar radiation. Vegetation data for each crop were developed using a crop cover model that has inputs of green, residue and total cover (%) and root depth (mm) for various times of the year. These values were set according to the local knowledge of the average cropping conditions (e.g. crop duration, tillage pattern). The root growth was

assumed to grow linearly at a rate of 15 mm/day to a maximum depth and was reset to zero at harvest. Crops were irrigated to drained upper limit (DUL) when soil water deficit reached 25 mm. This practice represented an ideal (efficient) irrigation. Runoff was calculated using the modified USDA runoff model where curve number properties were set according to Robinson et al. (2010) and data from Littleboy et al. (1996). Fallow periods between crops were simulated as bare soil.

The model was run for the period 1961 to 2011. This represented the longer-term average climate, whereas 1991 to 2007 represented the drier-period average climate. Comparison between these two periods provided the changes in soil water balance during the drier-period relative to long-term average. Decadal comparison was made from 1980s to 2000s to understand the affect of decadal climate variability on soil water balance. The soil water balance of the ten year rolling average between 1991 and 2007 was also estimated to understand the affect of climate variability within the drier-period.

Results

The soil water balance for 1961 to 2011 (longer-term) and 1991 to 2007 (drier-period) is presented in Figure 1. During 1991 to 2007, rainfall and deep drainage were respectively 151 mm and 64 mm lower while irrigation and transpiration were respectively 94 mm and 53 mm higher than 1961 to 2011.

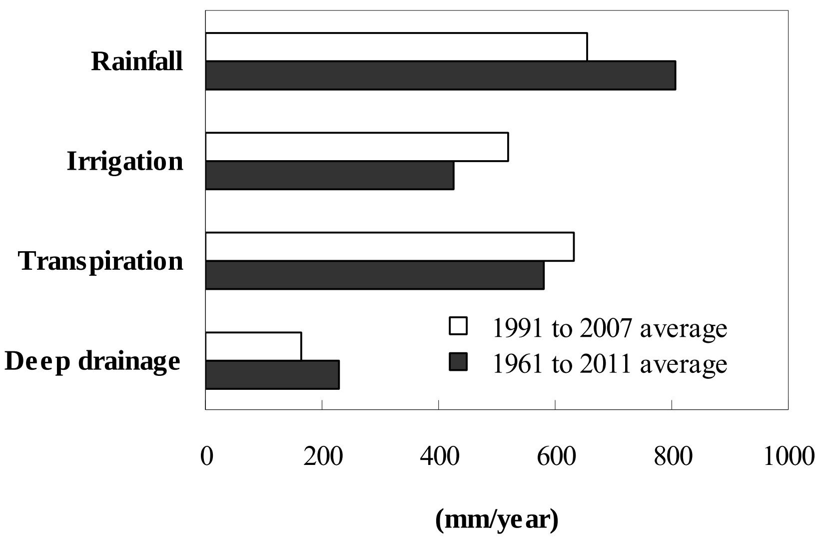

Figure 1. Soil water balance components for 1961 to 2011 (longer-term average) and 1991 to 2007 (drier-period average) for a vegetable rotation in the Lockyer Valley, Queensland.

Decadal comparison of soil water balance from the 1980s to the 2000s is presented in Figure 2. Rainfall was highest in the 1980s but diminished from then onwards and was lowest in the 2000s. There was 15% lower rainfall in the 1990s compared with the 1980s and this was reduced by a further 8% in the 2000s. Deep drainage followed a similar trend to that of rainfall. In contrast, irrigation requirement was 24% higher in the 1990s compared with the 1980s and increased by a further 11% in the 2000s. Transpiration followed the irrigation trend.

The soil water balance of the ten year rolling average for the drier-period shows that rainfall and deep drainage varied respectively by up to 71 mm and 24 mm, whereas irrigation and transpiration varied respectively by up to 32 mm and 20 mm (Figure 2).

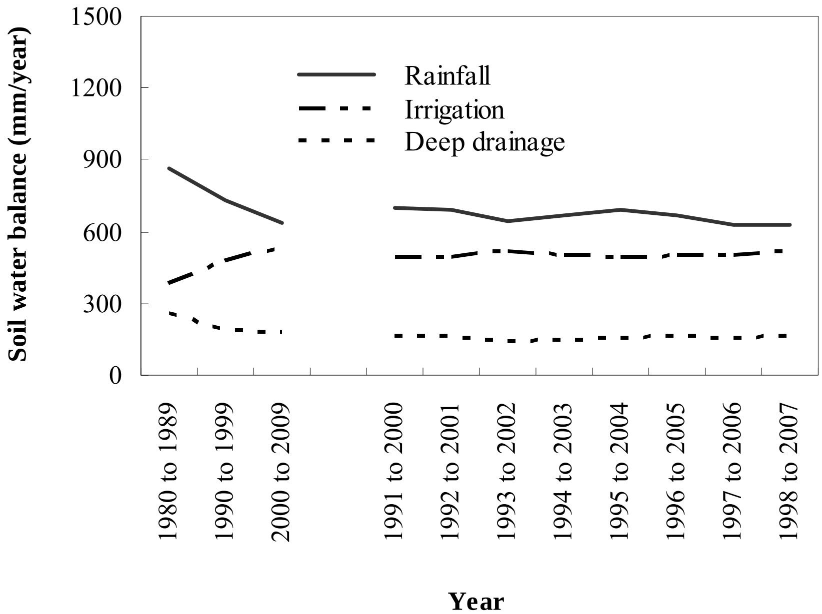

Figure 2. Average annual soil water balance for a vegetable rotation in the Lockyer Valley, Queensland. Note: average values for1980s, 1990s and 2000s (left), rolling average values from 1991 to 2007 (right).

Discussion

Climate variability affected the simulated soil water balance. Reduction in the rainfall during the drier-period corresponded to an increase in the irrigation requirement (Figure 1). This could explain the greater exploitation of groundwater in the Lockyer Valley during the drier-period as groundwater is the main source for irrigation. Though higher irrigation during the drier-period is inevitable, it increases transpiration if the crops water requirements are met. Water is a costly input and is becoming limiting in the Lockyer Valley and hence, profitable and sustainable vegetable cropping under these circumstances is subject to continued water availability.

Reduction in simulated deep drainage was as expected for the drier-period. Deep drainage depends on other components of soil water balance, rainfall and irrigation in particular. Our study adopted ideal irrigation management where deep drainage is mainly due to rainfall following irrigation. Therefore, lower rainfall corresponded to lower deep drainage even under irrigated conditions. Irrigated land salinity and dryland salinity are major concerns for the alluvial plains of the Lockyer Valley which are related to an expansion of cropping and irrigation (Powell et al. 2002). Therefore, reduction in rainfall and in turn deep drainage may further increase the salinity in the root zone, depending on the irrigation practices adopted and the salinity of the soil and water. Salinity problems would be worsened where irrigation water is already saline and in saline areas with shallow groundwater tables.

Irrigation management and crop choice play an important role in determining the soil water balance. Irrigation is essential for profitable vegetable cropping. If irrigation inefficiencies and leaching requirements were accounted for and water was not a limiting factor, deep drainage for the drier-period would have been higher than reported here (Figure 1). Up to three times increase in simulated deep drainage was reported for a vegetable dominated cropping sequence in the Lockyer Valley when irrigation application level was increased from ‘DUL’ to ‘up to 50% above DUL’ (data not shown). Deep rooted crops such as sorghum and lucerne on the other hand can tolerate considerable moisture stress and suit moisture limited conditions. Longer cropping duration associated with these crops can also minimise the fallow period. Therefore, lower deep drainage may be expected under farming systems that comprise of crops such as lucerne and sorghum.

Decadal comparison of the soil water balance trends suggests an increasing water requirement for the future. If the decreasing rainfall trend continues, over-exploitation of ground water is likely. Less evident variability in the soil water balance within the drier-period (Figure 2) may be an indication of the persistent nature of the drier-period. These conditions limit the water resource for sustainable cropping and necessitate improved water management practices. Alternative water supplies may also become necessary as has already been proposed for the Lockyer Valley (Wolf et al. 2011). In contrast, wet spells, as seen in the late 2000s and flooding in the early 2011 (data not shown), may ease this situation to some extent. These wet spells were promising in terms of meeting the crops' water needs. However, the changes to the soil water balance brought about by climate variability and the consequences on the underlying groundwater system, especially in the longer-term are largely unknown and require further attention.

Conclusion

The study explains the simulated changes in the soil water balance brought about by climate conditions in an irrigated vegetable rotation in the Lockyer Valley. Irrigation demand was increased by 94 mm/year during the drier-period (1997 to 2007) which had 151 mm/year less rainfall than the longer-term (1961-2011). Increase in transpiration due to timely and adequate supply of water and decreases in deep drainage occurred during the drier-period. However, increase in irrigation requirements may deplete groundwater supplies and would increase the cost of production. Irrigation inefficiencies and leaching requirements would further increase the irrigation demand. Wet spells at the end of the 2000s and early 2011 have shown promise in meeting the irrigation demand. However, inter-decadal comparison of the soil water balance suggests a lower rainfall and higher irrigation demand during the 1990s and 2000s than the 1980s. This highlights the need for efficient water management practices to meet possible increases in irrigation demand in the future.

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