Simulated soil water balance is affected by crop rotation/irrigation systems in the irrigated Lockyer Valley, Queensland, Australia

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Abstract
The Lockyer Valley in south east Queensland is a highly productive agricultural region, growing substantial quantities of irrigated horticultural crops. However, long droughts and over-extraction of groundwater have reduced water supply from a major source of irrigation water. Previous groundwater studies suggest judicious irrigation management can prevent the depletion and salinization of groundwater. As part of a whole-of-catchment modelling assessment, the soil water balance of two representative but contrasting crop rotation systems were assessed from 1997 to 2010 using the HowLeaky model to understand deep drainage ranges in particular, for the Lockyer Valley. These simulations led to varying rates of deep drainage due to the differences in the crop characteristics and irrigation strategy. A forage–grain–pasture system had 100 mm/year higher transpiration and 110 mm/year lower deep drainage than a vegetable system. The high rates of deep drainage due to need for consistent moist conditions and potential for salt migration under vegetable crop rotation systems could be reduced by selectively incorporating deep rooted plants such as lucerne, sorghum and sub-tropical pastures that suit moisture limited conditions.

Key Words
Transpiration, irrigation, crop type, root depth, HowLeaky modelling

Introduction
The Lockyer Valley in south east Queensland is an important horticultural area that produces substantial quantities of vegetables (Cox and Wilson 2005). Grain, forage and pasture are also grown depending on the grower's choice and are often part of crop rotations. Intensive irrigation and drought conditions have led to increased exploitation of ground water resources in this region. Importing water from an external source (purified recycled water) is being proposed to supplement future water demands and assist in the long-term recovery and maintenance of existing groundwater resources (Wolf et al. 2011). However, the resulting impacts this additional water may have on the soil water balance and the underlying groundwater system are poorly understood. Significant areas of the Lockyer Valley are affected by salinity (White 1980) with large stores of salts in the regolith that could be potentially mobilized by an increase in water inputs. Therefore, deep drainage estimates under varying cropping systems, ranging from high irrigation input high deep drainage scenarios to low input low deep drainage scenarios are needed to better understand the range of deep drainage behavior in this region.

Models are useful tools in understanding the soil water balance. They are cost effective, can easily assess various scenarios and can predict the likely trends in water balance for various growing conditions. They are suitable to simulate long-term crop rotations and also useful where limited field data is available, as is the case in much of the Lockyer Valley. In this study, two contrasting crop rotation systems were simulated using the Howleaky soil water balance model. The crop rotation systems varied with respect to both crop characteristics and irrigation strategy. These cropping systems may represent extremes, in terms of crop characteristics and irrigation strategies used by growers in the Lockyer Valley (Craig Henderson, personal communication) and they provide a low-to-high range of deep drainage estimates for the soil type modelled. These simulations also provide insight into soil water balance behavior, which is useful when developing crop rotation/irrigation systems to minimise deep drainage and maximise water use efficiency.

Methods
The HowLeaky model (Rattray et al. 2004) was used to estimate irrigation demand, transpiration and deep drainage. HowLeaky is a daily-time step, 1-dimensional model which uses rainfall and irrigation as water inputs and runoff, soil evaporation, transpiration and deep drainage as water outputs.

Climate data for Gatton (27°32′ S 152°19′ E, about 90 km west of Brisbane) were obtained from a patched point data set (Jeffrey et al. 2001). The soil studied was a Black Vertosol (Isbell 1996). Two crop rotation systems were studied, i) forage–grain–pasture, and ii) vegetable. The soil water balance was determined from 1997 to 2010, comprising a drier than average period followed by several wetter than average years. The forage–grain–pasture system consisted of forage sorghum, wheat and lucerne, while the vegetable system included sweet corn, broccoli, lettuce and beans. Vegetation data for each crop were developed using either a crop cover module with inputs of green, residue and total cover (%) and root depth (mm) or, a dynamic crop module that has detailed management and biophysical parameters concerning phenology, growth and other processes.

Runoff was calculated using a modified USDA runoff method (Littleboy et al. 1996) and a runoff curve number. Fallow periods were simulated between two crops as bare soil. The forage–grain–pasture system was irrigated with 60 mm when the soil water deficit reached 140 mm to represent the farmer's practice of supplementary irrigation with crops such as sorghum. The vegetable system was irrigated to drained upper limit (DUL) when the soil water deficit reached 25 to 100 mm, depending on the crop. Irrigation to DUL represented ideal irrigation where deep drainage was only initiated when rain fell soon after an irrigation (i.e. wetting the profile to above DUL).

Results

The simulated soil water balance for the two contrasting rotation systems is presented in Figure 1. Irrigation and deep drainage were respectively 272 mm and 110 mm/year lower and transpiration 101 mm higher under the forage–grain–pasture system than the vegetable system.

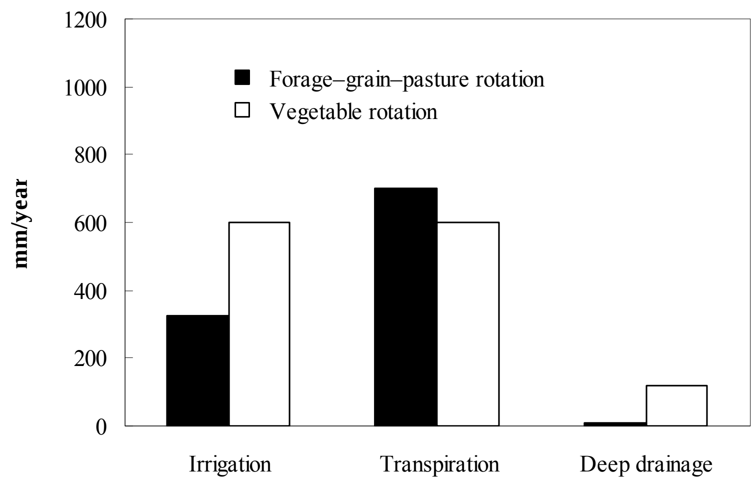

Figure 1. Simulated irrigation, transpiration and deep drainage (average annual) from 1997 to 2010 for two rotation systems in the Lockyer Valley (average annual rainfall, 701 mm).

Soil water balance trends from 1997 to 2010 for two crop rotation systems are presented in Figure 2. The forage–grain–pasture system had only three years with deep drainage, whereas the vegetable system had deep drainage every year. In both systems, deep drainage was highest during the late 2000s (2009 and 2010 for the forage–grain–pasture system and 2008 to 2010 for the vegetable system). Under the vegetable system, the lowest deep drainage was in 2002 and 2003.

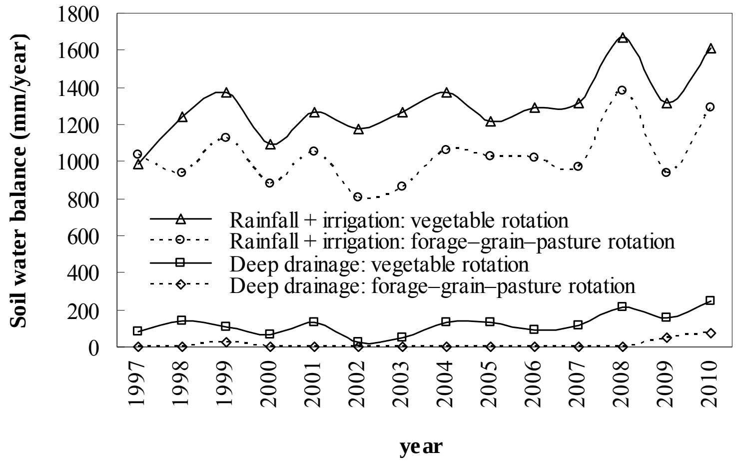

Figure 2. Simulated deep drainage and rainfall + irrigation (average annual) from 1997 to 2010 for two rotation systems in the Lockyer Valley.

Discussion

The soil water balance components were dependent on the crop rotation system simulated and the way irrigations were scheduled. Differences in the simulated deep drainage indicate sensitivity of deep drainage to rotation systems that differ in crop characteristics and irrigation management practices. In the forage–grain–pasture system (deficit irrigated) the water bucket (plant available water) was only refilled when nearly empty. Therefore, this system was less sensitive to deep drainage being triggered by rainfall soon after an irrigation event (the main trigger for the occurrence of simulated deep drainage). In the vegetable system, which is susceptible to moisture stress and hence received adequate irrigation, the bucket was refilled when only the top portion was empty. Therefore, the vegetable system was very sensitive to overfilling (resulting in deep drainage).

Differences in the simulated water balance between rotation systems were also related to crop characteristics. For example, the forage–grain–pasture system consisted of crops such as lucerne and sorghum that have deep roots. Deep roots help to explore the soil to greater depth which in turn dries the soil profile to greater depth. This increased depth of water utilisation and the resulting drier profiles provide a greater buffer against deep drainage when rainfall and irrigation temporarily exceed crop water demand. Deep rooted crops such as lucerne may also utilise the deeper stored water from previous fallow conditions (Ridley et al. 2001). The deep rooted crops tolerate considerable moisture stress and suit moisture limited conditions as simulated in this study. In contrast, most high value vegetables such as lettuce and broccoli have shallow root systems that cannot extract stored water from deeper soil layers. They are also susceptible to water stress and therefore require frequent shallow irrigations leaving the soil profile moist for most of the cropping period. The vegetable systems are therefore ‘wet’ and hydrologically volatile. In other modelling we have simulated contrasting crop characteristics with nearly similar irrigation management. Such results suggest only marginal increase in deep drainage under forage–grain–pasture and were considerably lower than sequences involving vegetables (data not shown). This emphasises the impact of crop characteristics on deep drainage.

Considerable inter-year variability in the simulated soil water balance is evident irrespective of rotation systems. Deep drainage was highly episodic under the forage–grain–pasture system where it occurred only during very wet years (the late 2000s in particular). In contrast, deep drainage was more regular under the vegetable system i.e. deep drainage took place in all years. This suggests the consistent ‘leaky’ nature of the vegetable systems.

Significant areas of the Lockyer valley have poor quality, saline groundwater (Bajracharya and Ellis 1999). In much of the intensive vegetable growing regions of the central Lockyer Valley, electrical conductivity of water is about ~0.5-2.5 dS/m and in some areas as high as 4-6 dS/m. Under vegetable system, high rates of deep drainage can lead to water recharging the local, shallow, unconfined aquifer, carrying with it considerable salts loads. Depending on the irrigation practices, frequent irrigation with salty water may build up salts in the root zone or if the leaching fraction is high enough, further salt will be exported to groundwater. There is an accompanying soil structural decline as the profile increasingly becomes saline (and often sodic).

Our deep drainage estimates compare well with those of Thorburn et al. (1990) who derived a deep drainage range of 0-554 mm/year using SODICS (Rose et al. 1979) for the Lockyer Valley. Lower irrigation and lower deep drainage values can be expected in the Howleaky simulation, as it used ‘deficit’ and ‘ideal’ irrigation, filling to DUL or less. Depending on inefficiencies in real irrigation practice, deep drainage would be higher than our estimates. For example, a 3 fold increase in deep drainage (from ~80 mm/year to ~260 mm/year) occurred for a cropping sequence in the Lockyer Valley when the irrigation application level was increased from ‘DUL’ to ‘up to 50% above DUL’ (unpublished data).

Conclusion

Components of the simulated soil water balance, deep drainage in particular, were dependent on the crop rotation system that differed with respect to crop characteristics and irrigation strategy. The soil water balance of a forage–grain–pasture system studied here was characterised by higher transpiration and lower deep drainage relative to a vegetable system. Deep drainage risk is higher under vegetables due to shallow root systems and need for consistent moist conditions compared with forage-grain-pasture system which better suits moisture limited conditions. Higher deep drainage under vegetable system may also increase the irrigation demand and salinity risk especially when irrigated with salty water and in saline areas with shallow groundwater tables. Selective incorporation of deep rooted, stress-tolerant crops in vegetable rotation systems and changes to the irrigation strategy may help to reduce these issues.

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