Integrated analysis for a carbon- and water-constrained future: An assessment of drip irrigation in a lettuce production system in eastern Australia[1]

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ABSTRACT

The Australian Government is meeting the challenge of water scarcity and climate change through significant on-farm infrastructure investment to increase water use efficiency and productivity, and secure longer term water supplies. However, it is likely that on-farm infrastructure investment will alter energy consumption and therefore generate considerable greenhouse gas (GHG) emissions, suggesting potential conflicts in terms of mitigation and adaptation policies. In particular, the introduction of a price on carbon may influence the extent to which new irrigation technologies are adopted.

This study evaluated trade-offs between water savings, GHG emissions and economic gain associated with the conversion of a sprinkler (hand shift) irrigation system to a drip (trickle) irrigation system for a lettuce production system in the Lockyer Valley, one of the major vegetable producing regions in Australia. Surprisingly, instead of trade-offs, this study found positive synergies - a win-win situation. The conversion of the old hand-shift sprinkler irrigation system to a drip irrigation system resulted in significant water savings of almost 2 ML/ha, as well as an overall reduction in GHG emissions. Economic modelling, at a carbon price of $ 30/t CO2e, indicated that there was a net benefit of adoption of the drip irrigation system of about $ 4620/ML/year.

We suggest priority should be given, in the implementation of on-farm infrastructure investment policy, to replacing older inefficient and energy-intensive sprinkler irrigation systems such as hand shift and roll-line. The findings of the study support the use of an integrated approach to avoid possible conflicts in designing national climate change mitigation and adaptation policies, both of which are being developed in Australia.

Managing water more effectively is one of the most important and urgent challenges for the global community. This is an important consideration in Australia, which is highly vulnerable to climate change and climate variability. The agricultural sector is the largest consumer of water in Australia, accounting for 65% of total water use (2004e05 figures; ABS, 2008); however, due to prolonged drought and reduced water availability, Australian irrigated farming enterprises applied 31% (7286 GL) less irrigation water to agricultural land in 2008-09 compared with 2004-05 (11,147 GL) water use (ABS, 2010). Despite this reduction in water use, the gross value of irrigated agricultural production rose from an estimated $ 13.97 billion in 2000e01 (in 2005e06 dollars) to $ 14.99 billion in 2005-06 (Mackinnon et al., 2009), mainly due to the use of more water efficient irrigation technologies.

The conversion to more efficient pressurised systems has been heralded as an integral way of increasing water use efficiency and creating water savings in irrigation systems (Green et al., 1996;

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Zehnder et al., 2003; Lal, 2004; Jackson et al., 2010). Two-thirds of irrigators in the Murray Darling Basin (MDB) changed their water management practices during 2004e05 (ABS, 2008), and of these, 35% adopted more efficient irrigation techniques. Recently, Mackinnon et al. (2009) examined investment patterns on irrigated farms in the MDB during 2006e07 and found that, despite the effects of the drought on farm profitability, around 7% of irrigation farms made new investments in on-farm irrigation infrastructure during 2006-07. They suggested that investment patterns over this period were influenced by the extended drought conditions and widespread water scarcity, and that future climate change and ongoing water and environmental reforms would continue to play a part in driving investment decisions on irrigated farms.

Conventional irrigation practices are generally characterized by low water use efficiencies. The conversion to pressurised systems is a valid option for water savings (Baillie et al., 2007), but will change patterns of on-farm energy consumption and could potentially increase GHG emissions. The decision to invest in irrigation technology traditionally depends on the water conservation benefits of the new technologies, and the costs associated with implementing the technology change (Qureshi et al., 2001; Pratt Water, 2004; Mackinnon et al., 2009). Increasing concerns about energy dependency and levels of GHG emissions (Zillman et al., 2008; Jackson et al., 2010) have been largely ignored in irrigation technology adoption decisions. Analysis of trade-offs is critical to ensuring that the economic efficiency of agricultural production is maintained, while environmental impacts are minimized.

This study uses an integrated assessment framework to evaluate trade-offs between water savings, greenhouse gas emissions and economic gain associated with conversion from an old hand shift sprinkler irrigation system to drip irrigation in a lettuce cropping system in the Lockyer Valley in southeast Queensland, Australia.

2. Study area

This study is based on an 80 ha irrigated lettuce cropping farm in the Lockyer Valley, south-eastern Queensland. Data was obtained from farm records and through a semi-structured interview processes.

Rainfall patterns in this area can be highly variable, and water scarcity is a significant concern. In response, the entire property was converted over several years from overhead sprinklers (manual shift) to a drip irrigation system. Water use under drip (trickle) irrigation has resulted in greater than 100% water savings, with 1.79 ML/ha of water used with the new system compared to 3.75 ML/ha under the old hand shift sprinkler system. The drip system also allows for significant flexibility and multi-tasking. With the completely automated system, each 2 ha block is watered for 1.5 h per week and the entire farm can now be watered in a single day, allowing for increased flexibility when rain is predicted. By comparison, under the old hand shift system, watering was continuous as the system had to be kept moving around the farm.

In addition to more efficient water use and ease of management, the farm manager reported that adoption of drip irrigation technology also resulted in increased yields, improved crop quality and soil health, and labour savings. Currently, this farm yields about 37,372 kg/ha while under the hand shift irrigation, yields were estimated to be 31,766 kg/ha. In addition, the newer technology has resulted in quality improvements with fewer mildews present in the crop. The drip system on this farm is now fully-automated and centrally-controlled, and the complexity of tasks has been reduced with, for example, the ability now to fertilise while irrigating (fertigate). While fertiliser use has increased under the drip system with changes in fertiliser technology over time, fertiliser efficiency is greater with trickle than sprinkler irrigation systems. Liquid fertilisers are now applied through the irrigation system (fertigation) in regular quantities adjusted to crop requirements, significantly reducing the risk of leaching over time.

3. Methods

3.1. Integrated modelling

An integrated framework was developed to assess the effectiveness of different irrigation technologies used at the farm level. This framework evaluates tradeoffs associated with the adoption of new irrigation technology in terms of irrigation requirements, water savings, energy use and GHG emission, as well as the relative costs of irrigation and associated equipment. As a general principle, trade-off analysis is based on the concept that, for a given set of resources and technology, increase in a desirable outcome will result in less of another desirable outcome (Stoorvogel et al., 2004). The integrated economic framework used has three main components - hydrological modelling, GHG modelling, and cost and benefit estimation. This framework not only provides reliable estimates of water savings and GHG implications, but also estimates tradeoffs between achieving water security and environmental security.

3.2. Greenhouse gas modelling

The GHG modelling component of the integrated framework compares emissions due to the use of energy, agrochemicals, fertilisers and farm machinery between the two different irrigation systems.

3.2.1. GHG emissions due to the use of electricity and diesel

The amount of electricity and diesel used for different farming operations was advised by the farmer. Energy content factors and GHG emissions were derived from DCC (2009) and Ozkan et al. (2004) as follows: (i) for diesel and diesel oil, energy content factor and GHG emission values used were 38.6 MJ/L and 75.2 g CO2/MJ; and (ii) for electricity, these values were 11.9 MJ/kW and 281 g CO_2/ MJ, respectively (DCC, 2009; Ozkan et al., 2004). Emissions factors for diesel include both combustion emissions factors (69.9 g CO_2e/ MJ), and indirect emissions factors related to extraction, production, transport and delivery (5.3 g CO_2e/MJ). Similarly, emissions factor for electricity include emissions due to consumption (Scope 2; DCC, 2009), and indirect emissions attributable to the extraction, production and transport of electricity and to the electricity lost in delivery in the network (Scope 3; DCC, 2009).

3.2.2. Emissions from production, packaging, storage, and transportation of agrochemicals

Agrochemicals include fertilisers and chemicals (herbicides, insecticides, fungicides and plant growth regulators). The types and amounts of agrochemicals used on the lettuce farm were recorded through a structured interview process. Four types of fertilizers (CropKing 77S^{TM}, Sulphate of Ammonia, Calcium Nitrate and Potassium Nitrate) were reported for the lettuce cropping operation. The proportions of major fertiliser elements in each fertiliser were estimated using the chemical formulae and molecular and atomic weights. For example, CropKing 77S^{TM} contains 13.3% nitrogen, 2.2% phosphorus, 13.5% potassium and 19.6% sulphur. Similarly, potassium nitrate has 13% nitrogen and 44% potassium. As suggested by Rab et al. (2008), each chemical was multiplied by a conversion factor (0.5 for herbicides and 0.25 for insecticides and plant growth regulator) to obtain the approximate active ingredients in the mix. CO2e emission factors for the production, packaging, storage and transportation of each kg of fertiliser-element (in fertiliser) and active ingredient (in herbicide, insecticide and plant regulators) were adapted from Lal (2004, Table 1).

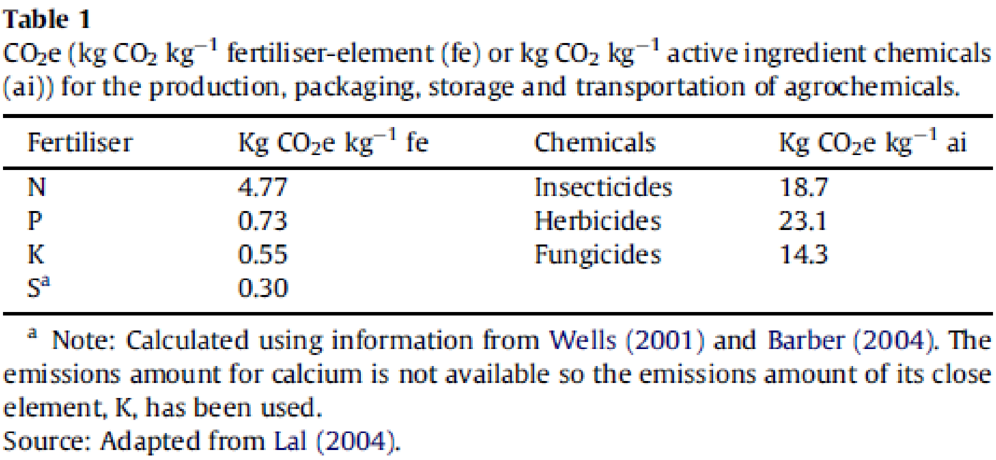


Table 1

CO_2e (kg CO_2 kg^{-1} fertiliser-element (fe) or kg CO_2 kg^{-1} active ingredient chemicals (ai)) for the production, packaging, storage and transportation of agrochemicals.

Fertiliser	Kg CO_2e kg^{-1} fe	Chemicals	Kg CO_2e kg^{-1} ai
N	4.77	Insecticides	18.7
P	0.73	Herbicides	23.1
K	0.55	Fungicides	14.3
S[a]	0.30		

[a] Note: Calculated using information from Wells (2001) and Barber (2004). The emissions amount for calcium is not available so the emissions amount of its close element, K, has been used.

Source: Adapted from Lal (2004).

3.2.3. *Emissions of N2O from soils due to N-fertiliser application*

In Australia, the Cooperative Research Centre (CRC) for Greenhouse Accounting has established a set of emissions factors suitable for Australian agricultural systems. As per their recommendation, an emissions factor of 2.1% (2.1 kg N_2O-N/100 kg-N) was used in this study (DCC, 2005 cited in O'Halloran et al., 2008); evidence that N2O emissions from soils may vary under different irrigation systems is yet to be verified in Australia. The total amount of N_2O-N was calculated and converted into N_2O (by multiplying by 1.57, the molecular wt of N_2O/mole wt of N2) and then into CO_2e.

3.2.4. Emissions due to the production of farm machinery

Several studies have estimated GHG emissions due to the production of a kilogramme of farm machinery (Stout, 1990; Helsel, 1992; Maraseni et al., 2007, 2009b). Maraseni et al. (2007, 2009b, 2010a) found that GHG emissions due to farm machinery used are directly related to fossil fuel consumption. For example, Maraseni et al. (2007) estimate that GHG emissions associated with the production of farm machinery and accessories used in peanut maize cultivation systems are 14.4% of the emissions associated with fossil fuels use. Due to lack of data for other farming systems, we have followed them for the estimation of GHG emissions for the production of farm machinery.

3.3. Hydrological modelling

Water savings can be quantified through field experiments and crop models (Wood and Finger, 2006; Khan et al., 2004, 2008a,b; Peter DeVoil, pers. comm.). Field experiments are usually the most accurate method of determining potential water savings, but require time and costs. Alternatively, crop models such as Soil, Water, Atmosphere and Plant (SWAP) and Agricultural Production Systems sIMulator (APSIM) are often applied to estimate potential water savings (Khan et al., 2004, 2008a,b). Khan et al. (2004; 2008a,b) and Khan and Abbas (2007) have effectively employed SWAP models to estimate potential water savings resulting from improved water management and new technologies (drip and sprinkler irrigation systems) under a range of soil and climatic conditions.

The SWAP model was applied to estimate potential water savings for the lettuce farm under consideration in this study. The irrigation technology on the farm was grouped under two broad system types: drip and sprinkler irrigation systems. This farm harvests two lettuce crops (autumn and winter) during the cropping year. However, water savings were estimated for winter lettuce only. Winter lettuce is transplanted early August and harvest starts during early October (about 55-60 days after transplantation). Lettuce is grown on a wide range of soil types ranging from light sandy to heavy clay loams in the Lockyer Valley (Amjed, 2010). However, for the SWAP model, the sandy loam soil type, the main soil type at the farm, was used. Lettuce is a shallow rooted crop, with 85% of water uptake occurring from the top 20 cm of the soil profile. It is susceptible to water stress, and uniform distribution of irrigation water is necessary to ensure the crop is not over- or under-irrigated.

Bureau of Meteorology (BoM) climatic data for the Gatton weather station were used in the SWAP model. The average annual rainfall is 770 mm, with a large variation in annual rainfall distribution. The mean minimum and maximum temperatures during the cropping period are 9.8 ^{o}C and 25 ^{o}C, respectively. The potential evapotranspiration (ETo) during the growing season ranges from 3.2 to 5.5 mm/day. The timing of irrigation applications throughout the season was determined by the grower using visual observations of the crop and soil, and based on his experience and the use of Enviroscan meters. Approximately 25 mm was applied in each irrigation event using three different irrigation practices. The SWAP model was simulated for the period between Jan 1980 to DCC, 2009.

3.4. Economic modelling

A key component of the integrated framework was to undertake Benefit-Cost Analysis (BCA). A number of key economic evaluation indices, Net Present Value (NPV), Internal Rate of Return (IRR), Benefit Cost Ratio (BCR), and Payback Period year, were used to assess the economic feasibility of the conversion from the less efficient and more energy intensive sprinkler (hand shift) irrigation system, to the new, more efficient drip irrigation system.

Modern irrigation systems are sophisticated and capital intensive, and require significant initial capital investment. The stream of benefits flow over the life of a system, usually 15-25 years, depending on the type of system used. To measure economic returns from the on-farm investment in such technologies, the benefits from the new system were measured, taking into account the total impacts of the option: improvement in yield and quality, shifts in cropping rotation, reductions in input costs, labour savings, water savings, and the benefits (or costs) of GHG emissions reduction and other factors.

Sensitivity analysis was also carried out to validate the robustness of the economic analysis by systematically changing the values of key benefit parameters. Variables in the sensitivity analysis included water savings, labour and yield benefits, water sharing, GHG emission prices, sprinkler irrigation technology life, and interest rates. However, sensitivity analysis results are mainly discussed using NPV as an evaluation criterion.

The estimates of these parameters were obtained through a detailed structured interview with the lettuce farmer. The farm level irrigation technology modernisation model ‘Waterwork’ (Khan et al., 2010) was used to evaluate the economics (costs and benefits) of technology adoption. The model was simulated for 25 years with an interest rate of 5%. The current temporary and permanent water trading price of $ 300/ML and $ 1500/ML (www.waterexchange.com.au/) were used in the modelling as a substitute for a water price through the water sharing and buyback program.

3.4.1. Economic model parameters and assumptions

The following parameters and assumptions were used in the analysis:

- The 80 ha farm consists of multiple blocks of 2 ha, therefore a 2 ha block converted to sprinkler irrigation during 2005-06 was selected for detailed economic analysis.
- The cropping pattern included mainly autumn and winter lettuce, with replacement with broccoli, cauliflower, depending on the market conditions. We used the winter lettuce crop in the analysis. Barley, wheat and/or oats are grown during summer, but are mainly rain-fed, and were not included in the analysis.
- A yield improvement of about 18% (over 5.6 t/ha), as reported by farmer, was used in the model.
- All of the saved water is used to increase the cropping area.
- Water use efficiency of 92%, as reported by the farmer, was used in the analysis.

- Drip irrigation led to significant labour savings (about 50%). Further reductions have been achieved through full-automation and centralised-controlled at the farm, but were not included in the analysis.
- Quality improvements were modelled through higher market prices. Based on the farmer's assessment, drip irrigation results in 10% higher market prices.
- Tax savings are possible but were not included in the analysis. Similarly, no water trading occurs at this property due to physical constraints, therefore no permanent or temporary
- water trading was considered in the analysis. However, in the sensitivity analysis a 50:50 water sharing plan was considered.
- The model did not include carbon prices in the base case economic model. However, two prices, \$ 10/t CO2e and \$ 30/t CO2e, were used in the sensitivity analysis.
- Water saving estimates were obtained through SWAP models and the farmer's assessment; however, only the farmer's assessment was used in the economic model.

4. Results

4.1. Greenhouse gas emission estimation

4.1.1. GHG emissions due to the use of fossil fuels (electricity and diesel)

Energy consumption and GHG emissions due to the use of fuels (diesel and electricity) for farm operations in the two different lettuce-cropping irrigation systems are given in Table 2. Overall, fuel-related GHG emissions in the trickle and hand shift irrigation systems were 3134 kg CO_2e/ha and 4968 kg CO_2e/ha, respectively. Both the farm machinery operation and irrigation related emissions were higher in the hand shift irrigation system which used higher amounts of diesel and electricity. Farm machinery operation related emissions in the hand shift system were 1.3 times the emissions from trickle irrigation, and the amount was double in the case of irrigation related emissions.

4.1.2. GHG emissions due to use of agrochemicals

In total, the production, packing, storage and transportation of agrochemicals used in the trickle and hand shift irrigation systems released 1210 kg CO_2e/ha and 677 kg CO_2e/ha emissions, respectively (Table 3). Lettuce farming under the hand shift irrigation system used higher quantities of CropKing fertiliser than trickle irrigation. The hand shift irrigation system used 200 kg of sulphate of ammonia but did not use potassium nitrate and calcium nitrate. On the other hand, lettuce farming under trickle irrigation did not use sulphate of ammonia but used 800 kg/ha of calcium nitrate and 200 kg/ha of potassium nitrate. However, much of this difference can be attributed to changes in fertilisation practices over recent years and to the farmer's experience in precision farming rather than differences due to irrigation technology.

4.1.3. Emissions of N2O from soils due to N-fertilizer application

Cropping under the trickle and hand shift irrigation systems emitted around 1827 kg CO_2e and 935 kg CO_2e GHGs per hectare, respectively, into the atmosphere from the de-nitrification of applied N fertilizer (Table 4). These emissions were directly related to N fertilizer amounts: the higher the N fertilizer use, the greater the emissions of N_2O and thus the higher the CO_2e. All fertilisers used for lettuce cropping in both irrigation systems contain some amount of nitrogen. However, in total, higher amounts of fertilisers were used in the present-day trickle irrigation system. Therefore, almost two times more GHG emissions were emitted per hectare by the trickle-irrigated lettuce cropping systems than by the former hand-shift-irrigated lettuce cropping system.

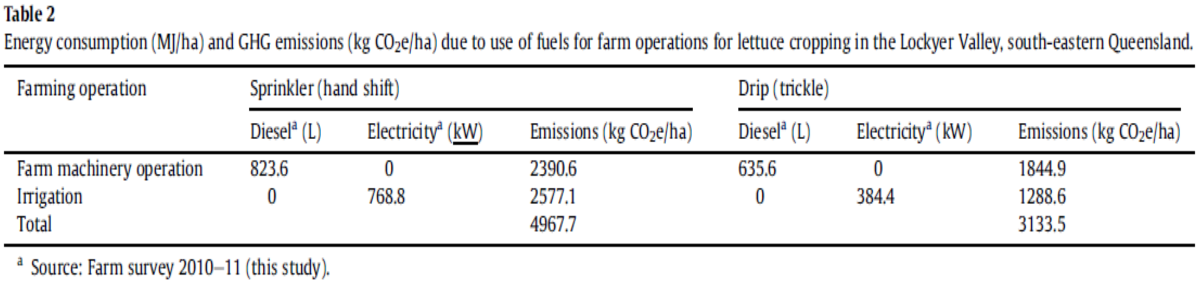


Table 2
Energy consumption (MJ/ha) and GHG emissions (kg CO_2e/ha) due to use of fuels for farm operations for lettuce cropping in the Lockyer Valley, south-eastern Queensland.

Farming operation	Sprinkler (hand shift)			Drip (trickle)		
	Diesel[a] (L)	Electricity[a] (kW)	Emissions (kg CO_2e/ha)	Diesel[a] (L)	Electricity[a] (kW)	Emissions (kg CO_2e/ha)
Farm machinery operation	823.6	0	2390.6	635.6	0	1844.9
Irrigation	0	768.8	2577.1	0	384.4	1288.6
Total			4967.7			3133.5

[a] Source: Farm survey 2010–11 (this study).

4.1.4. GHG emissions due to the production of farm machinery

As noted, the operation of lettuce farm machinery (other than irrigation machinery) in the hand-shift irrigation system required larger quantities of diesel than the trickle irrigation system. As the quantity of GHG emissions due to the use of farm machinery was directly related to diesel-related emissions, the hand-shift irrigation lettuce farming system had higher amounts of machinery related emissions (344.3 kg CO_2e/ha) than did trickle irrigation (265.7 kg CO_2e/ha).

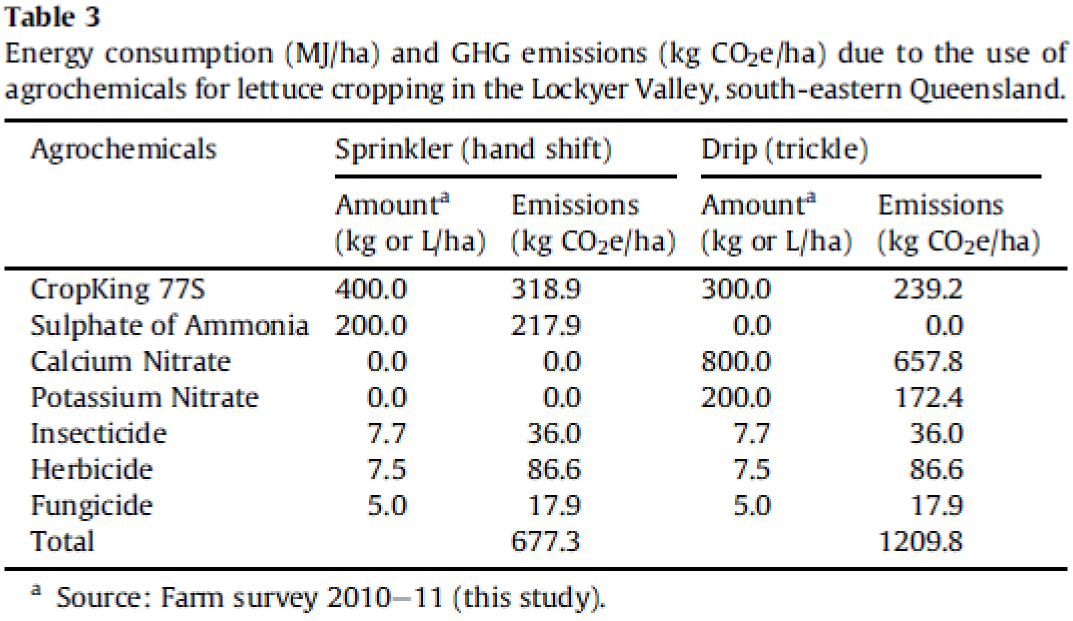


Table 3
Energy consumption (MJ/ha) and GHG emissions (kg CO_2e/ha) due to the use of agrochemicals for lettuce cropping in the Lockyer Valley, south-eastern Queensland.

Agrochemicals	Sprinkler (hand shift)		Drip (trickle)	
	Amount[a] (kg or L/ha)	Emissions (kg CO_2e/ha)	Amount[a] (kg or L/ha)	Emissions (kg CO_2e/ha)
CropKing 77S	400.0	318.9	300.0	239.2
Sulphate of Ammonia	200.0	217.9	0.0	0.0
Calcium Nitrate	0.0	0.0	800.0	657.8
Potassium Nitrate	0.0	0.0	200.0	172.4
Insecticide	7.7	36.0	7.7	36.0
Herbicide	7.5	86.6	7.5	86.6
Fungicide	5.0	17.9	5.0	17.9
Total		677.3		1209.8

[a] Source: Farm survey 2010–11 (this study).

4.2. Water saving estimates

The SWAP model was applied to estimate the potential water savings. The farmer's estimates were used to validate the water savings obtained through the SWAP model. The model simulation results showed that, from the reported water use of 4 ML/ha for the old overhead sprinkler system, an average of 1.6 ML/ha of water savings (range: 1.4 ML/hae2.0 ML/ha) was possible for winter lettuce with conversion to the drip irrigation system. Based on the farmer's assessment, water savings of 1.96 ML/ha (52.4%) were achieved for lettuce grown under drip irrigation compared to overhead sprinklers, which indicated that the farmer was achieving at the higher level of water savings indicated through SWAP modelling. This is not surprising given the fact that farmers often use deficit irrigation practices, especially during periods of low water availability.

4.3. Economic evaluations

The main benefits of the new irrigation system include water savings, increased yield, quality improvements leading to increased output prices, labour savings and decreased input costs. The results of the economic analysis, presented in Table 5, indicate a stronger economic return at the level of water savings (1.96 ML/ha) reported for the drip irrigation technology, and that conversion was an economically viable option for this farm.

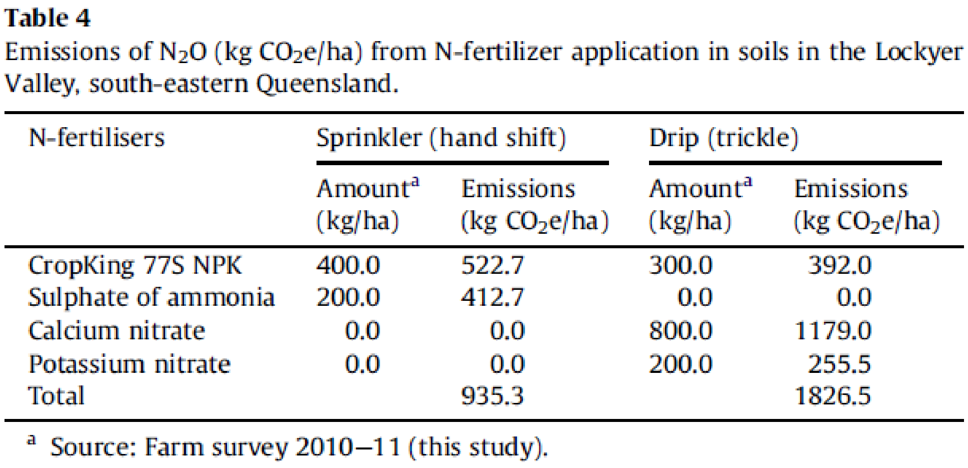


Table 4

Emissions of N_2O (kg CO_2e/ha) from N-fertilizer application in soils in the Lockyer Valley, south-eastern Queensland.

N-fertilisers	Sprinkler (hand shift)		Drip (trickle)	
	Amount[a] (kg/ha)	Emissions (kg CO_2e/ha)	Amount[a] (kg/ha)	Emissions (kg CO_2e/ha)
CropKing 77S NPK	400.0	522.7	300.0	392.0
Sulphate of ammonia	200.0	412.7	0.0	0.0
Calcium nitrate	0.0	0.0	800.0	1179.0
Potassium nitrate	0.0	0.0	200.0	255.5
Total		935.3		1826.5

[a] Source: Farm survey 2010–11 (this study).

The net benefit of adoption of the drip irrigation system was about $ 4613/ML/year. The benefit-cost ratio of 13.1 indicates that every dollar spent on the improved technology led to a $ 13.1 increase in income. The increased yield and labour savings were sufficient to recover costs within the first year of investment.

4.3.1. Sensitivity analyses

Sensitivity analysis was used to test the robustness of the economic analysis by changing the values of key benefit parameters such as water savings, labour and yield benefits, water sharing, GHG emission prices, sprinkler irrigation technology life, and interest rates. Temporary water trading was not considered for this case study, instead a water sharing scenario based on 50:50 water sharing was considered.

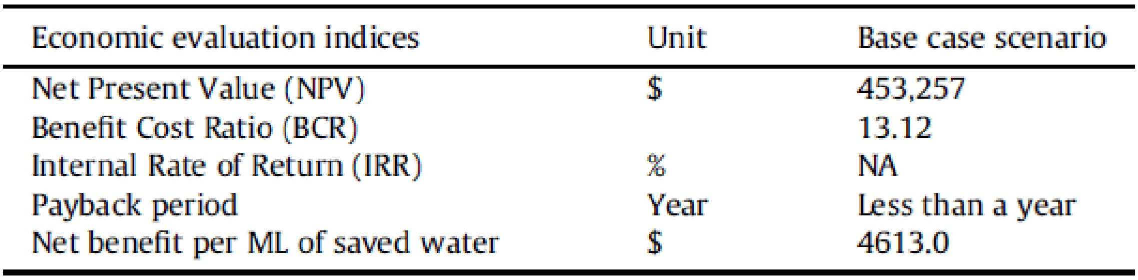
The sensitivity analysis showed that all scenarios resulted in positive NPV (Table 6), therefore investments in converting the hand shift sprinkler irrigation system to drip irrigation were viable and robust. This was mainly due to higher yield and quality benefits, and significant amounts of water and labour savings.

The results indicate that greater profits for lettuce cropping are possible under a drip irrigation system than a hand shift sprinkler irrigation system, if the estimated yield benefits, water savings and labour savings occur.

5. Discussion and policy implications

There is a clear difference in the quantities of GHG emissions per hectare between the two lettuce farming irrigation systems (Table 7). Major differences were noted in fuel and agrochemical related emissions. Trickle irrigation accounts for a higher amount of agrochemical-related emissions but a smaller amount of fuel related emissions. Overall, higher total quantities of GHGs were emitted from the hand shift (6925 kg CO_2e/ha) than from the trickle irrigation (6435 kg CO_2e/ha) farming system. Total emissions in the lettuce crop in this study were higher than for many other crops analysed by the researchers in Australia. For example, an irrigated cotton farming system in the Darling Down region emits 4841 kg CO_2e/ha (Maraseni et al., 2010a); a rice farming system with a surface irrigation system in the Murrumbidgee area emits 1076 kg CO_2e/ha (Maraseni et al., 2009b); a dryland peanut cropping system in the Kingaroy district emits 1076 kg CO_2e/ha (Maraseni et al., 2007); and dryland barley, chickpeas, wheat and durum cropping in Darling Down region emit 251.8 kg CO_2e/ha, 279.7 kg CO_2e/ha, 577.6 kg CO_2e/ha and 633.7 kg CO_2e/ha, respectively (Maraseni and Cockfield, 2011).

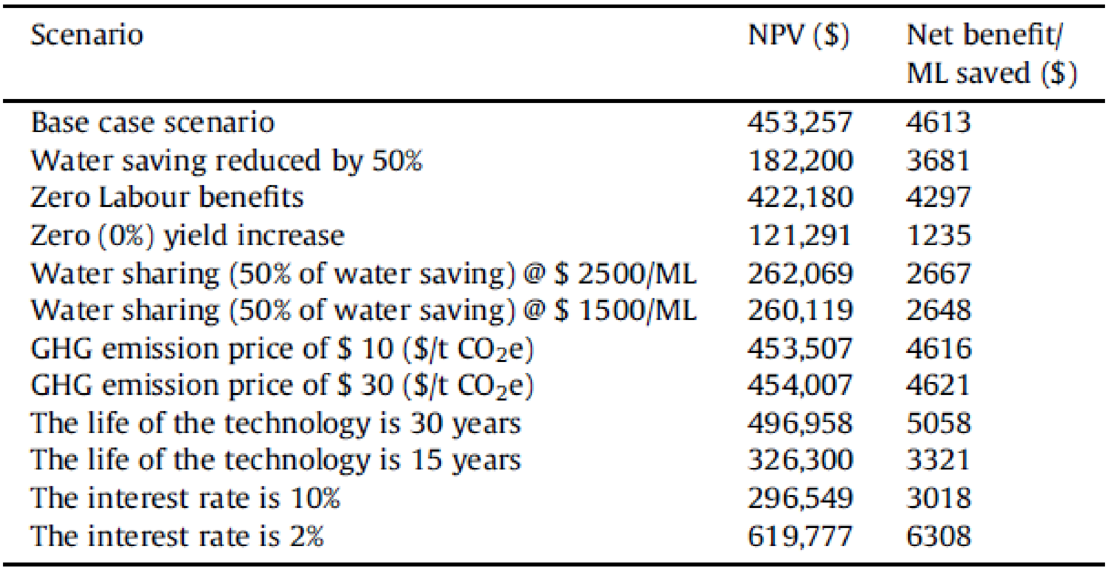
Table 5
Economic evaluation of drip irrigation technology adoption for lettuce cropping in the Lockyer Valley, south-eastern Queensland.



Economic evaluation indices	Unit	Base case scenario
Net Present Value (NPV)	$	453,257
Benefit Cost Ratio (BCR)		13.12
Internal Rate of Return (IRR)	%	NA
Payback period	Year	Less than a year
Net benefit per ML of saved water	$	4613.0

NA: Could not be calculated.

Table 6
Sensitivity analysis of drip irrigation technology adoption for lettuce cropping in the Lockyer Valley, south-eastern Queensland.



Scenario	NPV ($)	Net benefit/ ML saved ($)
Base case scenario	453,257	4613
Water saving reduced by 50%	182,200	3681
Zero Labour benefits	422,180	4297
Zero (0%) yield increase	121,291	1235
Water sharing (50% of water saving) @ $ 2500/ML	262,069	2667
Water sharing (50% of water saving) @ $ 1500/ML	260,119	2648
GHG emission price of $ 10 ($/t CO_2e)	453,507	4616
GHG emission price of $ 30 ($/t CO_2e)	454,007	4621
The life of the technology is 30 years	496,958	5058
The life of the technology is 15 years	326,300	3321
The interest rate is 10%	296,549	3018
The interest rate is 2%	619,777	6308

This was expected as preplanting and harvesting operations in lettuce cropping require large amounts of machinery operation, and thus use of fuels. The smaller amount of GHG emissions in dryland cropping systems is obvious as there are no pumping related emissions.

The results from this case study are a little lower than our previous estimate of average national level emissions for lettuce farming systems in Australia (8750 kg CO2e/ha; Maraseni et al., 2010b). This variation is inevitable as farms operate under different climatic, topographic and edaphic conditions.

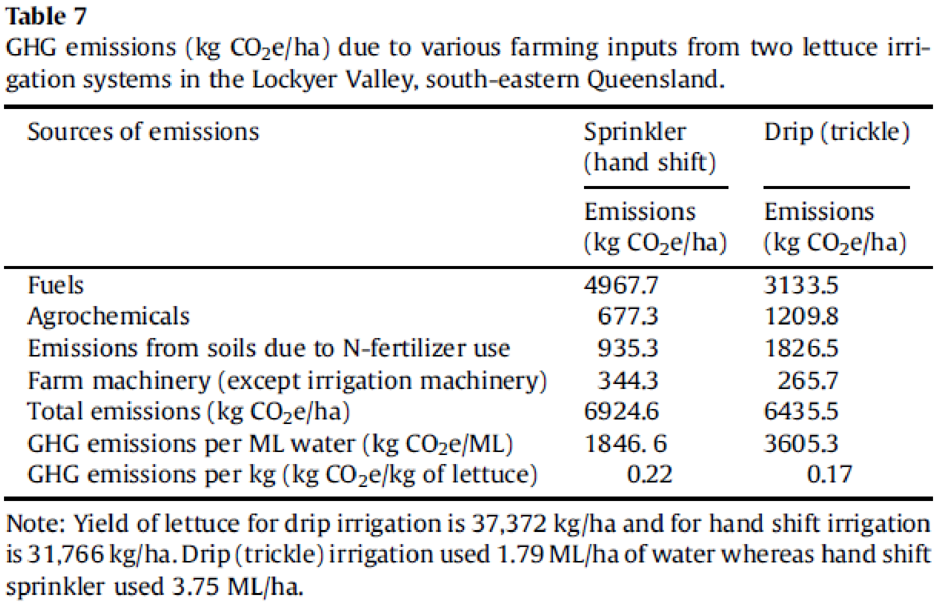


Table 7

GHG emissions (kg CO_2e/ha) due to various farming inputs from two lettuce irrigation systems in the Lockyer Valley, south-eastern Queensland.

Sources of emissions	Sprinkler (hand shift)	Drip (trickle)
	Emissions (kg CO_2e/ha)	Emissions (kg CO_2e/ha)
Fuels	4967.7	3133.5
Agrochemicals	677.3	1209.8
Emissions from soils due to N-fertilizer use	935.3	1826.5
Farm machinery (except irrigation machinery)	344.3	265.7
Total emissions (kg CO_2e/ha)	6924.6	6435.5
GHG emissions per ML water (kg CO_2e/ML)	1846. 6	3605.3
GHG emissions per kg (kg CO_2e/kg of lettuce)	0.22	0.17

Note: Yield of lettuce for drip irrigation is 37,372 kg/ha and for hand shift irrigation is 31,766 kg/ha. Drip (trickle) irrigation used 1.79 ML/ha of water whereas hand shift sprinkler used 3.75 ML/ha.

Trickle irrigation led to a 52% decrease in water use per hectare, and, consequently, almost a doubling of the GHG emissions per unit of water (GHG emissions per unit of water in the trickle-irrigated lettuce farming system were 3605 kg CO2e/ML compared to emissions of 1847 kg CO2e/ML from the hand-shift irrigation system.). However, yields for the drip irrigation systems were 1.2 times those of the older overhead sprinkler system and GHG emissions per unit of yield were 1.3 times lower than that those from the older overhead sprinkler system.

The economic analysis also concluded that drip irrigation had greater potential efficiencies for the lettuce farm under investigation. However, achieving maximum efficiencies under drip irrigation systems depends greatly on the design and management of the system (Raine et al., 2000). This was evident in this case study with the lettuce grower achieving high-end water savings (close to 2 ML/ha) through better management. In this case, drip technology delivered greater efficiencies with suitable management, and thus saved significant volumes of water, compared with the older handshift labour intensive sprinkler irrigation system. A benefit cost analysis investigating the net benefit of converting from the hand shift sprinkler irrigation to a drip irrigation system found positive net benefits despite higher investment costs; these net benefits are primarily attributed to improvements in water, production and labour efficiencies. The results are consistent with other studies conducted in Australia for lettuce (see Hickey et al., 2006). However, the BCR estimated in this case study is lower than that estimated by Hickey et al. (2006).

The conversion of older inefficient and energy-intensive sprinkler irrigation systems (hand shift) to trickle irrigation technologies saved considerable water and GHG emissions and was also economically highly competitive. Australia is the highest per-capita GHG emitting country in the world (27 t CO_2e/person) and is also highly vulnerable to the effect of climate change; hence, both climate change adaptation and mitigation are important (Maraseni et al., 2009a). Developing policies to encourage farmers to replace hand shift irrigation systems with trickle irrigation systems could help to achieve both adaptation and mitigation objectives. In addition, further innovation such as the use of agrobiogas could be helpful in reducing GHG emissions (Budzianowski, 2012).

This study highlights the complexity involved in evaluating the effectiveness of achieving on-farm water use efficiency through conversion to new water use efficient irrigation systems. The tradeoffs analysis raises a critical point, indicating that both mitigation and adaptation have to be evaluated at the same time in order to optimise economic investments in irrigation technologies while managing climate change.

6. Conclusion and recommendations

This study investigated whether the conversion of a sprinkler (hand shift) irrigation system to a drip (trickle) irrigation system resulted in water savings and reduced greenhouse gas emissions, and whether the conversion was an economically sound decision for an irrigated lettuce production system in the Lockyer Valley, one of the major vegetable producing regions in Australia. The results indicate that there are significant benefits of the trickle irrigation system compared to the old one in all these attributes, and that on farm infrastructure investment programs should give priority to replacing old hand shift irrigation systems with trickle irrigation systems. The findings of this study also support the use of an integrated approach to avoid possible conflicts in the design of national climate change mitigation and adaptation policies.

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