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Water Saving Potential of Irrigation Water Recycling System and Kapillary Irrigation Sub-Surface System on Vegetable Farms

Harsharn Singh Grewal[1], Basant L. Maheshwari[1], William Yiasoumi[2] and Bruce Simmons[1]

[1]University of Western Sydney, School of Natural Sciences,
Locked Bag 1797, Penrith South DC, NSW 1797, Australia
[2]Industry and Investment NSW, Locked Bag 4, Richmond NSW 2756, Australia

Abstract: Prolonged droughts and increased water demands have put enormous pressure on water resources in Australia and irrigated agriculture/horticulture has been the most impacted. There is a growing concern to promote water conservation practices including rainfall/irrigation runoff harvesting and improve water use efficiency to sustain irrigated agriculture. Rainfall/irrigation runoff is a serious challenge that leads to not only water and nutrient losses but also contributes to degradation of waterways and underground water quality. Vegetable farmers in the peri-urban areas of Sydney intensively use potable water, mostly with overhead sprinkler systems resulting in a marked wastage of water due to evaporation, runoff and deep drainage. To conserve water and protect the environment, two innovative technologies namely the Irrigation Water Recycling System (IWRS) and the Kapillary Irrigation Sub-Surface System (KISSS) were evaluated under farmers' field situations. The IWRS collects irrigation and rainwater runoff from cropped areas during sprinkler irrigation and rainfall and stores this within the farm to reuse for irrigation of crops. The KISSS applies water directly to the root zone of plants with a minimum of water loss through runoff, evaporation and deep drainage. A participatory approach was used and 8 farmers (7 vegetable growers and 1 nursery grower) were involved in this study to quantify the water saving and understand the farmer's concerns/issues about these two innovative technologies. The water conservation varied among 5 KISSS and 3 IWRS sites and also from one year to another depending upon rainfall, dry spells and farmer's management skills. On an average of 5 sites, KISSS saved 17.3% potable water in 2006-07, 18.2% in 2007-08 and 5.2% in 2008-09. A number of operational issues were observed to affect the farmers adoption of KISSS. These concerns included breakage and subsequent leakage of underground KISSS pipes while cultivating the soil for sowing further crops, the surface water requirement during germination and establishment stage and farmers perception to continue the use of sprinklers to avoid wilting of leafy vegetables during hot weather. The water saved at 3 sites by IWRS was 580 kL, 496 kL and 2,197 kL respectively in 2006-07, 2007-08 and 2008-09. The water savings varied at 3 sites with the maximum volume of water saved at nursery site (805 kL) followed by a vegetable farm (886 kL) with a normal slope and another vegetable farm (582 kL) with steep topography. Sedimentation of rainwater collection tanks due to soil erosion during heavy storms particularly due to steep topography was identified as a major issue for IWRS adoption. The study reveals that IWRS and KISSS are important technologies for water conservation, but their adoption on a wider scale depends on acceptability by farmers and some operational issues while using these technologies.

Key words: Potable water • Subsurface irrigation • Rainwater harvesting • Peri-urban agriculture • Water conservation

INTRODUCTION

Peri-urban regions in the five mainland states of Australia produce about 25% of Australia's total gross value of agriculture production [1]. Vegetable production is the most common enterprise in the peri-urban zones and vegetables produced in Sydney's peri-urban region contributes significantly to meet the fresh vegetable requirements of Sydney's more than 4 million people [2,3]. There is an increasing and continuous demand for high

Corresponding Author: Harsharn Singh Grewal, University of Western Sydney,
School of Natural Sciences, Locked Bag 1797, Penrith South DC, NSW 1797, Australia

quality fresh vegetables and fruits [4]. Moreover, locally grown food is becoming quite popular and has the great potential for economic, social and environmental benefits [5] as consumers become more aware of issues such as "food miles".

Water scarcity has become one of the major challenges to sustaining agriculture production in many countries [6]. In Australia, peri-urban horticultural industry has been most impacted by the water crisis [7]. Vegetable production in the Sydney region consumes significant volumes of water and farmers mostly use potable water and inefficient overhead sprinkler irrigation systems. In addition these sprinkler systems lead to significant wastage of water due to evaporation, runoff and deep drainage. There are generally marked losses of nutrients though runoff resulting in water quality degradation in waterways. In water scarcity situations, the use of water for agricultural production systems needs innovative and sustainable research and appropriate transfer of technologies [6]. Continuous drought and the severe water scarcity in Australia in the recent past forced the researchers, water planners and water management bodies to examine and develop environmentally friendly irrigation and water harvesting systems that improve water use efficiency and help to conserve potable water supplies. Consequently we commenced the evaluation of two innovative technologies, viz., Kapillary Irrigation Sub-Surface System (KISSS) and the Irrigation Water Recycling System (IWRS) in 2006 and their potential to save potable water in vegetable farming situations in Sydney's peri-urban region.

KISSS was developed by an Australian company, Irrigation and Water Technologies Pty Limited (IWT) and applies water directly to the root zone of plants with a minimum of water loss through runoff, evaporation and deep drainage. The system delivers a significant improvement in water application efficiency over sprinkler irrigation systems and traditional drip irrigation systems. Also, since the water is applied below the surface, the water wastage due to evaporation is almost eliminated. Experience has shown that the KISSS system has the potential to save up to 50% of the water used by overhead sprinkler systems. Irrigation water use for corn with another subsurface drip irrigation system similar to KISSS has been reported to reduce water use by 35-55% besides providing high efficiencies of nitrogen use through fertigation [8].

The IWRS collects irrigation and rainwater runoff from cropped areas during sprinkler irrigation and rain events and stores this within the farm in an existing water storage facility for recycling for the next irrigation. The IWRS is designed to improve the availability of the farm's irrigation water supplies and, at the same time, reduce nutrient runoff from the farm.

The main objectives of this study were (a) to have a better understanding and insight of farmers concerns and issues while adapting to KISSS and IWRS and (b) to evaluate KISSS and IWRS under field situations to quantify any benefits that may arise in potable water savings and long-term benefits to environment.

Methodology: In this study, we used a participatory approach involving farmers, staff from University of Western Sydney, Industry and Investment NSW, Irrigation and Water Technologies Ltd (IWT) and farmer associations. There were a total of eight sites, five for KISSS and three for IWRS, included in this study. All of the five KISSS sites were located in the Western Sydney region (Dural, Glenorie, Shanes Park, Austral and Schofield) – a major peri-urban region of the Sydney Metropolitan area. All the five farmers at these five sites mostly grew English spinach, coriander, beet roots, rocket, baby bok choi and leeks. Four of these five farmers were of Chinese origin, so we had to use interpreter for language translation. The fifth farmer was of Maltese origin and was able to speak good English. Two of the three IWRS sites were also in Western Sydney region (Catherine Field and Glenorie) and vegetable growing was the main enterprise of these two farmers. The third IWRS site was about 170 km from Sydney at Dapto and was a palms seedling nursery.

All the eight sites were selected after preliminary meetings with farmers to discuss the major benefits of KISSS and IWRS to save water and minimise offsite environmental impacts. We involved a bilingual officer from Industry and Investment NSW to speak to farmers of Chinese origin. Initially a survey was conducted to gain an insight of farmer concerns about the current water crisis, land degradation issues and possible strategies to improve their water management skills. As the farmers were initially reluctant to evaluate the KISSS system over their existing practices of sprinkler irrigation we organized demonstrations to show the impact of KISSS on the soil wetting zone, soil moisture movement and water use at the farmer's individual fields. Finally when the farmers were convinced about the potential of the KISSS irrigation system, we installed the KISSS at the 5 sites to evaluate its working and water saving potential. The IWRS system was installed at 3 sites after initial discussions about the advantages and disadvantages of this system with the owners of these 3 sites. Water flow meters were installed both on KISSS and IWRS to record the volume of water used by KISSS and volume of water harvested by IWRS system.

The Farms with KISSS and IWRS systems were monitored for water use and water saving over two year period. Field days were organized to share the experience of collaborator farmers with other farmers about water saving potential of KISSS and IWRS.

Estimation of Potable Water Savings

KISSS: The water meter data of all five KISSS sites were recorded to measure the total water use. The data was then used to estimate savings in potable water use with KISSS from 2006 – 2009 when compared with the base year (2005 - 2006) water use. We also analysed the rainfall and evapotranspiration (ET) data for each site since the installation of KISSS to make allowance in the water savings for the effects of the variation in rainfall and ET amounts. In addition, we also accounted for the extent of the cropped area when compared with the base year (2005-06).

The change in water use from one year to the next is influenced by changes in rainfall, ET, cropped area and the installation of the KISSS. In other words, the change in water use in the current year compared with the benchmark year is a function of changes in the amounts of rainfall, ET and cropped area values and water saving due to KISSS. Mathematically, this can be expressed as follows:

$$\Delta WU = f(\Delta R, \Delta ET, \Delta A, WS) \tag{1}$$

Where ΔWU = Change in water use between the benchmark year (2005-06) and the current year (2006-07 or 2007-08 or 2008-09),

ΔR = Change in water use between the benchmark year and the current year due to rainfall

ΔET = Change in water use between the benchmark year and the current year due to ET

ΔA = Change in water use between the benchmark year and the current year due to cropped area and

WS = water saving due to the installation of the KISSS.

For the calculation of water saving due to the installation of the KISSS, we make the following assumptions:

- The effects of changes in rainfall, ET and cropped area are accounted by proportionately adjusting the water use in the current year.
- The irrigation practice of the farmer does not change except the installation and use of KISSS.
- The effective rainfall generated has a similar trend from one year to the next.
- The cropped area under KISSS does not change during the period of calculation.

The benchmark period for the calculation in this report is November 2005 – October 2006 and water saving calculation period (referred here to current year) is November 2006 – October 2007 or November 2007- October 2008 or November 2008- October 09.

As per volume balance for the two periods, the volume of water used in the benchmark year is related to the water used in the current year by the following equation:

$$V_b = V_c + \frac{(R_c - R_b)}{R_b} \cdot (V_b - V_c) - \frac{(ET_c - ET_b)}{ET_b} \cdot (V_b - V_c) - \frac{(A_c - A_b)}{A_b} \cdot (V_b - V_c) + WS_c \tag{2}$$

Where:

V_b = The volume of potable water used (kL) during the benchmark year (November 2005 – October 2006),

V_c = The volume of potable water used (kL) during the current year (November 2006 – October 2007 or November 2007- October 2008 or November 2008- October 09)

R_b = Total rainfall (mm) during the during the benchmark year,

R_c = Total rainfall (mm) during the during the current year,

ET_b = Total ET (mm) during the during the benchmark year,

ET_c = Total ET (mm) during the during the current year,

A_b = Total cropped area (ha) during the during the benchmark year,

A_c = Total cropped (ha) during the during the current year and

Ws_c = Water saving (kL) due to the installation of the KISSS in the current year.

By rearranging the terms in Equation 2, the water saving due to the installation of the KISSS can be calculated as

$$WS_c = (V_b - V_c) - \frac{(R_c - R_b)}{R_b} \cdot (V_b - V_c) + \frac{(ET_c - ET_b)}{ET_b} \cdot (V_b - V_c) + \frac{(A_c - A_b)}{A_b} \cdot (V_b - V_c) \tag{3}$$

Equation 3 was used for calculating potable water savings for KISSS in this study.

The rainfall and pan evaporation values for the various field sites were obtained from the Bureau of Meteorology, Australia while the cropped area was provided by the individual farmer. The ET for the sites was calculated by multiplying the pan evaporation values by a factor of 0.8.

It can be seen from Equation 3 that if rainfall in the current year is more than the benchmark year, then there will be additional water input to the irrigated area due to rain and will reduce the irrigation water requirement. This means the change in water use needs to be proportionately reduced to give correct savings in potable water use.

Similar interpretation can also be made for ET and cropped area. Equation 3 also indicates that the difference between the effect of increased rainfall and increased ET and cropped area are in reverse direction (i.e., any increase in values of ET and cropped area will increase the total irrigation water use and therefore will proportionately increase the water savings).

IWRS: The water meter data (installed with IWRS) were recorded for all three sites. The amount of rainwater harvested and pumped into the water storage tanks and dams was calculated directly from the water meter readings.

RESULTS AND DISCUSSION

Water Savings with KISSS and its Major Issues: The average potable water savings from the five KISSS sites was 477 kL/ha (17%) in 2006-07, 469 kL/ha (18%) in 2007-08 and 196.1 kL/ha (5%) in 2008-09 (Table 1). There was a considerable variation in water savings at the five sites. The water savings were markedly greater at sites 1 and 2 compared with sites 3, 4 and 5. This variation was mainly due to the greater use of sprinkler irrigation system at sites 3, 4 and 5 and different management practices of farmers. As four of the five farmers abandoned KISSS during 2008-09 there was no water savings in 2008-09 at those four sites. Only one of the five farmers used KISSS during 2008-09 and there was significant volume of water saving at his site. Similar to the water saving in our study, other researchers have also reported water savings in addition to greater water use efficiency and reduced risk of drainage and runoff with subsurface drip irrigation system [8-10]. Reduced nitrogen use efficiency and plant biomass was observed in Coneflower seedlings with overhead irrigation system compared with subirrigation system [11].

Despite the good water saving potential of KISSS in our study, all five farmers with KISSS experienced operational difficulties, mainly due to the damage to the underground KISSS pipes, caused by rotary hoeing to enable the farmers to sow subsequent vegetable crops. This damage to irrigation pipes resulted in leakage from the irrigation system and reduced the overall water savings.

Since KISSS applies water below the soil surface and directly in the rootzone, the soil surface tends to be drier compared to sprinkler system. For this reason, the germination and crop establishment during early vegetative stage was the major challenge with KISSS system and farmers had no option but to use their sprinkler irrigation systems during establishment stage in our study. This markedly affected the farmers' perception and had a detrimental effect on adoption of KISSS as an alternative irrigation system on a commercial scale for vegetable crops. Other researchers have also reported crop establishment as one of the greatest challenges for irrigators using subsurface drip irrigation system [8,12]. Crop establishment with these irrigation systems relies on unsaturated water movement from the buried source to the seed and/or seedlings and establishment is affected by distance to water source, soil texture, soil structure and water content [12].

During hot and very hot days, the plants tended to wilt quicker with KISSS irrigation system and all the five farmers involved in this study were concerned that the use of KISSS will cause wilting of their plants and consequently affect the price of their produce. So farmers continued to use the sprinkler system during hot weather and as a result the acceptability of the KISSS was affected.

Table 1: Water savings (kL/ha) over three years with KISSS irrigation system after adjusting the rainfall, ET and cropped area at 5 sites

Year	Site 1 (Dural)	Site 2 (Glenorie)	Site 3 (Austral)	Site 4 (Shane park)	Site 5 (Schofield)	Average	% saving
2006-07	662.0	904.5	363.3	315.1	142.0	477.4	17.3
2007-08	769.0	901.5	69.5	383.0	220.8	468.8	18.2
2008-09	980.6	0.0	0.0	0.0	0.0	196.1	5.2
Total	2411.6	1806.0	432.8	698.1	362.8		

Due to the some major operational issues and concerns of farmers described above, three farmers completely abandoned using KISSS during March – April 2008 and the monitoring at those sites was abandoned. Furthermore, one farmer had to stop farming due to his serious health problem in 2008 and as a result there was a serious setback to KISSS use at his site. Only one farmer used the KISSS system during 2009 and he was also concerned about the breakage and leakage problem of the underground KISSS pipes besides the labour and management cost to maintain two systems at the same time

It appears that the feasibility of using the KISSS irrigation system despite its water saving potential will remain impacted for leafy vegetable production systems due to some operational issues and farmers concerns. Unless farmers adopt zero-tillage or modify their tillage operations by adapting very shallow rotary hoeing, the adoption of KISSS on a commercial scale for vegetable crops will be a challenging task. Our findings are reinforced by others such as [13-15] who stated that any irrigation scheduling system to be successful must be simple to understand, easy to manage and acceptable to the farmers.

Whilst interacting with farmers during the monitoring process in this study, all the farmers revealed that they preferred overhead sprinkler systems because in addition to maintaining plant turgidity and avoiding plant wilting during hot weather and some frost protection during winter, the sprinkler system is easy to use and less capital cost is involved than KISSS and subsurface drip irrigation systems. Of course, the sprinklers are inefficient due to loss of water via evaporation, runoff and deep drainage [10,16]. The nutrients removed in runoff from sprinkler irrigated areas may be 'wasted' and contaminate receiving waters resulting in environmental pollution. Maheshwari and Connellan [17] also reported overhead sprinklers as the most commonly used irrigation systems in Australia for urban irrigation including open space, parks and golf courses as well as for turf and vegetable farms.

Water Savings with IWRS and its Major Issues: There was a total of 3,273 KL potable water saved by IWRS system over a period of three years at the three sites (Table 2). The total volumes of water saved by IWRS during 2006-07, 2007-08 and 2008-09 were 580 kL, 496 kL and 2,197 kL respectively. The maximum volume of water saved was at Site 1 at Dapto (1,805 kL), followed by Site 2 at Catherine Field (886 kL) and Site 3 at Glenorie (582 kL). Significant water saving with IWRS mainly occurred in 2009 at sites 1 and 2.

The major issue with IWRS system observed in this study was severe sedimentation of the tank and blockage of pumping system in 2007 and 2008 mainly during heavy storms at all the three sites. The main source of sediment was from sloping lands that contributed to the runoff. This was a serious challenge in the success of this system under field conditions and affected the water harvesting and potable water saving during 2007 and 2008 at all three sites. Consequently, a significant volume of rainwater water was lost during this period and reduced the volume of rainwater collected for replacing potable water.

To rectify the situation, the storage tanks and pumping systems were cleaned of the sediments at all the 3 sites. In addition, to reduce further sediments entering the tanks, at one site barriers were placed in the inlet channel while the channel was concrete lined at the other site to allow deposition of sediments in the channel and thus prevent the entry of sediments into the storage tanks. However, there was a significant cost involved in fixing these problems.

The system worked well at two of the three sites during 2009. However, severe sedimentation problem continued in storage tanks, pipes and pumping system, mainly due to silt laden runoff during heavy rain periods at third site. The steep topography of this site was a major contributing factor for the on-going sedimentation problem. As a result water harvesting and potable water saving was seriously affected at this site not only in 2007 and 2008 but also in 2009.

Table 2: Water savings (kL) with Irrigation and Water Recycling System (IWRS) at three sites during 2006 to 2009

Sites	2006-07	2007-08	2008-09	Total water saved (kL)
Site 1 (Dapto)	447	207	1151	1805
Site 2 (Catherine Field)	5	145	736	886
Site 3 (Glenorie)	128	144	310	582
Total	580	496	2197	3273

We also observed marked effect of continuous heavy rains affecting the rainwater harvesting capacity of the IWRS system. As the farmers dams at the IWRS sites were full due to continuous heavy rains during May-June 2009 and the growers were compelled to turn off the pumps of their IWRS system resulting in lot of wastage of water and runoff of nutrients.

The study thus reveals that IWRS has good potential to harvest runoff/rain water, but the sedimentation and blockage of pumping system due to steep topography and exposed vegetable production fields will limit the water harvesting capacity of this system unless site-specific suitable measures are adapted to limit the impact of sedimentation.

CONCLUSIONS

- Considering the need to save every drop of water, particularly during drought situations, the study suggested that the average water savings with IWRS and KISSS was significant. The study also reveals that IWRS and KISSS are important technologies for water conservation, but their adoption on a wider scale requires further work to resolve some operational issues and extension effort on some perceptions.
- A major issue with IWRS observed in this study was sedimentation of the storage tank and blockage of pumping system. The system will not be effective or not work at all in the rainwater harvesting site where there will be sediment load with the harvested water. Furthermore, the study demonstrated that concrete lining the inlet channel and some mechanism to trap sediment will help overcome the sedimentation problem.
- Irrigation using KISSS has considerable potential to save water but damage to subsurface pipes during cultivation and the surface water requirement during germination and establishment stage and farmers perception to continue the use of sprinklers to avoid wilting of leafy vegetables during hot weather tend to restrict KISSS adoption by farmers.

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REFERENCES

1. Houston, P., 2005. Re-valuing the Fringe: Some findings on the value of agricultural production in Australia's peri-urban regions. Geographical Res., 43: 209-223.
2. Chan, K.Y., C.G. Dorahy, S. Tyler, A.T. Wells, P.P. Milham and I. Barchia, 2007. Phosphorus accumulation and other changes soil properties as a consequences of vegetable production, Sydney region, Australia. Australian J. Soil Res., 45: 139-146.
3. Devasirvatham, V. and P.S. Cornish, 2007. Precision application of water for peri-urban horticulture. Intl. J. Water, 3: 418-424.
4. Meyer, W.S., 2008. The future of irrigated production horticulture-World and Australian perspective. Acta Horticulturae, 792: 449-458.
5. Conner, D.S., A.D. Montri, D.N. Montri and M.W. Hamm, 2009. Consumer demand for local produce at extended season farmers' markets: guiding farmer marketing strategies. Renewable Agri. Food Sys., 24: 251-259.
6. Pereira, L.S., T. Oweis and A. Zairi, 2002. Irrigation management under water scarcity. Agri. Water Manage., 57: 175-206.
7. Hamilton, A.J., A.M. Boland, D. Stevens, J. Kelly, J. Radcliffe, A. Ziehrl, P. Dillon and B. Paulin, 2005. Position of the Australian horticultural industry with respect to the use of reclaimed water. Agri. Water Manage., 71: 181-209.
8. Lamm, F.R. and T.P. Trooien, 2003. Subsurface drip irrigation for corn production: a review of 10 years of research in Kansas. Irrigation Sci., 22: 195-200.
9. Dumroese, R.K., J.R. Pinto, D.F. Jacobs, A.S. Davis and H. Baron, 2006. Subirrigation reduces water use, nitrogen loss and more growth in a container nursery. Native Plants J., 7: 253-261.
10. Goodwin, P.B., M. Murphy, P. Melville and W. Yiasoumi, 2003. Efficiency of water and nutrient use in containerised plants irrigated by overhead, drip or capillary irrigation. Australian J. Exp. Agri., 43: 189-194.
11. Pinto, J.R., R.A. Chandler and R.K. Dumroese, 2008. Growth, nitrogen use efficiency and leachate comparison of subirrigated and overhead irrigated pale purple coneflower seedlings. HortSci., 43: 897-901.
12. Charlesworth, B.P. and A.W. Muirhead, 2003. Crop establishment using subsurface drip irrigation: a comparison of point source and area sources. Irrigation Sci., 22: 171-176.

13. Burt, C.M., 1996. Essential water delivery policies for modern on-farm irrigation management. In: Irrigation Scheduling: From Theory to Practice, Proceedings ICID/FAO Workshop, Sept. 1995, Rome, Water Report No. 8, FAO, Rome.
14. Horst, L., 1996. The discrepancy between irrigation scheduling and actual water distribution: an analysis and suggestions for possible solutions. In: Irrigation Scheduling: From Theory to Practice, Proceedings ICID/FAO Workshop, Sept. 1995, Rome, Water Report No. 8, FAO, Rome.
15. Tollefson, L.C. and M.N.J. Wahab, 1996. Better research-extension-farmer interaction can improve the impact of irrigation scheduling techniques. In: Irrigation Scheduling: From Theory to Practice, Proceedings ICID/FAO Workshop, Sept. 1995, Rome, Water Report No. 8, FAO, Rome.
16. Huett, D.O., 1997. Fertilizer use efficiency by containerised nursery plants. 1. Plant growth and nutrient uptake. Australian J. Agri. Res., 48: 251-258.
17. Maheshwari, B. and G. Connellan, 2004. Role of Irrigation in urban water conservation: Opportunities and Challenges. Proceedings of the National Workshop held at Horticulture Australia Limited, Level 1, 50 Carrington Street, Sydney from 28-29 October 2004. CRC for Irrigation Futures Publication no. 2005/1.