Filter Technology: Integrated Wastewater Irrigation and Treatment, a Way of Water Scarcity Alleviation, Pollution Elimination and Health Risk Prevention

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Abstract

The use of urban wastewater in agriculture is a widely established practice for alleviating water scarcity situations and reducing or even eliminating the purchase of chemical fertilizers. However, unregulated irrigation with untreated wastewater poses serious public health risks, as sewage is a major source of excreted pathogens that cause gastro-intestinal infections in human beings. Wastewater may also contain highly poisonous chemical toxins from industrial sources that may cause much more serious long-term health risks. Reuse after proper treatment is normally recommended as the main solution of preventing health risks. Unfortunately, because of the high cost of engineering plants, most cities in developing countries do not have sufficient wastewater treatment capacity, and the perspectives of the capacity increasing in these cities are bleak. Planned and regulated wastewater irrigation with crop limitations and proper irrigation methods (for example local irrigation) may to some extent, prevent health risks. But for a given territory, it is often impossible to limit the type of crops to be grown.

This paper introduces the FILTER (Filtration and Irrigated cropping for Land Treatment and Effluent Re-use) technique, an improved land treatment technique developed at CSIRO, Australia and tested both in Australia and China. FILTER combines the use of nutrient-rich wastewater for intensive cropping with filtration through the soil to a subsurface drainage system. Therefore, FILTER has the capacity to handle high volumes of wastewater in a relatively small land area and during periods of low cropping activity or periods of high rainfall. In order to produce minimum-pollutant drainage water which meets general environmental criteria for re-use and discharge to surface water bodies, the wastewater application and subsurface drainage in the FILTER system needs to be managed to ensure adequate removal of pollutants, while maintaining required drainage flow rates. Trial results indicate that a well-managed FILTER technique can reduce pollutant levels in drainage waters below EPA limits, while maintaining crop yields and nutrient removal to potentially make it a sustainable system.

Keywords: wastewater treatment, wastewater irrigation, pollutant removal, controlled subsurface drainage.

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Background

The use of urban wastewater in agriculture is a widely established practice, particularly so in urban and peri-urban areas of arid and seasonally arid zones. Lunven (1992) estimated that one tenth or more of the world's population currently eats food produced on wastewater (but not always in a safe way).

In China, the amount of wastewater discharged every year is about 60 billion tons, approximately the same as the annual runoff of the Yellow river. Except for a few big cities, wastewater is not properly treated before being discharged into surface water bodies in most places of the country and causes water pollution thus further compounding the water scarcity problem. At the same time, agriculture and cities are consuming more and more fresh water owing to population increases and economic development. Especially in the arid and semi arid part of North China, the water scarcity situation is much more serious than in other places of the country. In these places, wastewater has been one of the important sources of irrigation water. It is estimated that the total area frequently irrigated with wastewater in China is about 4 million ha. Wastewater is an important source of irrigation water as well as a source of plant macro-nutrients (N, P and K) and trace elements (Zn, Cu, Mo, B etc). Wastewater irrigation can alleviate water scarcity situations and allows farmers to reduce or even eliminate the purchase of chemical fertilizer and organic matter that serves as soil conditioner and humus replenishment.

However, unregulated irrigation with untreated wastewater poses serious public health risks, as sewage is a major source of excreted pathogens - the bacteria, viruses, protozoa and the helminthes (worms) that cause gastro-intestinal infections in human beings. Wastewater may also contain highly poisonous chemical toxins from industrial sources. Relevant groups of chemical contaminants are heavy metals, hormone active substances (HAS) and antibiotics. The risks associated with these substances may, in the long-term turn out to constitute a greater threat to public health and be more difficult to deal with than the risks from excreted pathogens.

In order to prevent health risks, reuse after proper treatment is normally recommended as the main solution. There exists a large array of technological and process options for wastewater treatment. The most common systems of wastewater treatment in use in cities around the world are engineering plants which remove the main pollutants in the wastewater and release the treated effluent with lower concentrations of pollutants into natural water bodies for downstream reuse or as a disposal approach. A disadvantage of this engineering approach is that the engineering plants at large sewage works cost millions of dollars to build and have high operating costs, especially where a high level of nutrient and chemical removal is required to protect sensitive freshwater and marine environments. Due to low financial capacity, most cities in undeveloped countries have insufficient engineering plants and are not able to treat more than a modest percentage of urban wastewater. The perspectives regarding the increase in wastewater treatment capacity in these cities are bleak. Besides, such plants also generate waste which requires disposal.

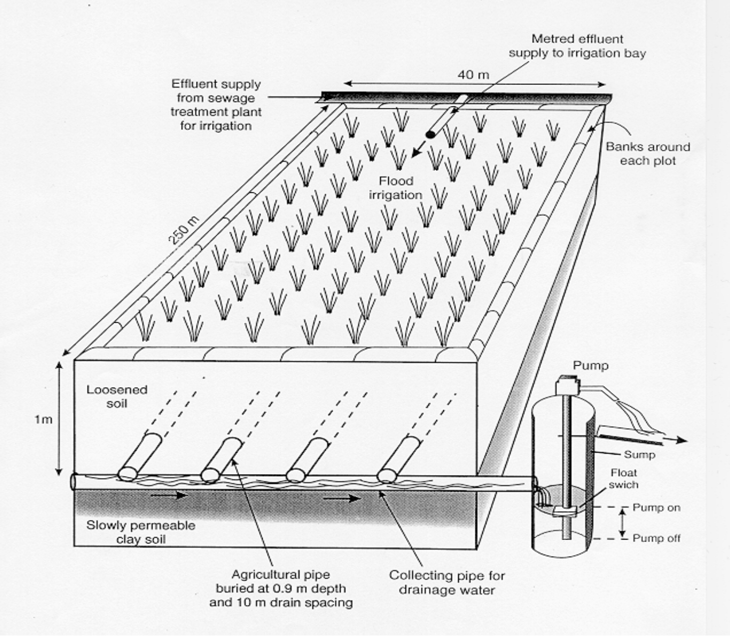
Another option to prevent the health risks is planned and regulated wastewater irrigation with crop limitations and proper irrigation methods (for example local irrigation). But for a given territory, it is not easy, often impossible, to limit the type of crops to be grown. For this reason, planned and regulated wastewater irrigation is often only a theory.

Introduction to FILTER (Filtration and Irrigated cropping for Land Treatment and Effluent Reuse)

Against this background, the FILTER (Filtration and Irrigated cropping for Land Treatment and Effluent Reuse) technique was developed in Australia (Jayawardane, 1995). By using this system, wastewater can be treated in a relatively small area of land with selected crops so that pollution of agricultural produce and health risks due to large-scale wastewater irrigation can be prevented. The FILTER technique combines using the nutrient rich effluent or wastewater for intensive annual cropping, with filtration through the soil to a sub-surface drainage system during periods of low cropping activity and high rainfall. It provides wastewater treatment throughout the year, thereby eliminating the need for expensive wastewater storage. The treated wastewater can be reused for irrigation or discharged to water bodies meeting the EPA requirements.

The FILTER technique can be categorized as a rapid, controlled flow system, which is a hybrid system that combines some of the hydraulic flow characteristics and wastewater renovation process of the slow infiltration, rapid infiltration and overland flow systems. The structure of the system is shown in Figure 1. The flow of wastewater or effluent, to the sub-surface drainage system, is controlled by regulated pumping. Wastewater or effluent application and sub-surface drainage can be regulated to ensure adequate soil conditions for crop growth and pollutant removal rates, thereby producing low-pollutant drainage waters which meet EPA criteria for reuse or discharge to surface water bodies.

Fig 1. Schematic diagram of FILTER plots



Each fortnightly wastewater application cycle or filter event consists of four consecutive stages. These four stages are wastewater application (irrigation), followed by a post-irrigation equilibration period and by a pumping period (until drainage outflow approximately matches the net inflow) and finally a no-pumping equilibration period (leading to flattening of the water table). The manipulation of these four-stage wastewater application and drainage operations could be used to maximize the removal of nutrients, and increase the uniformity in nutrient distribution and retention in the soil across the FILTER plots. The FILTER technique was field tested in both Australia and China. This paper presents the field results on the pollutant removal and crop growth measurements, carried out to assess the pollutant removal effect of the FILTER system at the FILTER trial sites in Griffith, NSW of Australia and Wuqing county, Tianjin municipality of China.

Tests and results

In Griffith, four irrigation bays (430 m long by 82, 80, 86 and 102 m wide) with 0.4 m banks were constructed to provide good control of irrigation. A subsurface drainage system was installed within the pilot trial area, which was connected through the collector drains and the main drain to the main sump, fitted with an electric pump and flow meter. The subsurface drains were spaced 8 m apart at a depth of 1.2 m. The irrigation channels and associated structures for controlling and monitoring irrigation were installed. A dethridge wheel, MACE flow and current meters were used to measure irrigation and drainage volume.

In autumn 1998, two of the bays were sown with Coolibah Oats at a rate of 90 kg ha^{-1} and 150kg of di-ammonium phosphate (18:20) fertilizer was drilled in with the seed. The other two bays were planted with ryegrass pasture mix; 17 kg multimix ha^{-1}, 6 kg demeter fescue ha^{-1}, 8 kg Victorian rye ha^{-1} and 5 kg guard rye ha^{-1}. Eight irrigation/FILTER events, of 2 weeks duration each, were carried out during that winter cropping season.

In Wuqing, ten wastewater irrigation and filtration plots, measuring 60m x 40m each, were constructed. The site consists of two FILTER plots with drains spaced at 5m, two FILTER plots with drains spaced at 10m, two FILTER reuse plots on which the drainage water from the above four FILTER plots were reused, three irrigated plots with no drains and one plot used for soil sampling to measure the soil hydraulic properties. A sub-surface drainage system was installed in each of the FILTER plots at a depth of 1.2 m, which was connected through the collector drains to the sump of each FILTER plot. The sump was fitted with an electric pump to discharge the filtered water from the subsurface drains. A pipe for conveying irrigation water and associated structures for controlling and monitoring irrigation were installed.

In winter 1999, the trial plots were sown with a winter wheat crop. Five irrigation/filter events were used for the first cropping season during the spring 2000. Continuous irrigation and drainage water samples were collected during the trials. Samples were stored at 4 ^{o}C before pH, Electrical Conductivity (EC), Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS), ammonium, oxides of nitrogen (NOx), total kjeldahl nitrogen (TKN), total phosphorus (TP), total fecal coliforms, and oil & grease were determined.

The soil profile was sampled up to a depth of 1.4 m and the core divided into intervals of 20 cm. The samples were analyzed following the methods of Rayment and Higginson, (1992).

When the crops were harvested, dry matter and grain yields were recorded. The crops were analyzed for total N following the method of Etheridge et. al., (1998) whereas TP and micronutrients were determined following the method of Zarcinas et. al., (1987) in order to estimate nutrient removal. Results of pollutant concentration and pollutant load reduction during the filtration events in Griffith site are shown in Table 1. For the Wuqing experimental plots changes of the concentrations of TP, BOD5 and COD in the effluent and drainage water are shown in Figures 2, 3 and 4. Load reduction of pollutants and their comparison with results from Griffith site are shown in Table 2.

Table 1. Pollutant concentration and pollutant load reduction during the Filtration events in Griffith site

Pollutant	Pollutant concentration (mg l^{-1})*		Pollutant loads (kg ha^{-1})		%Removal
	Incoming effluent	FILTER drainage	Effluent	Drainage	
Total phosphorus	6.1	0.39	46.7	1.7	96
Total nitrogen	19	15	131.4	55.9	57
Organic nitrogen	6.3	1.5	46.3	6	87
Ammonium-N	12.5	0.2	19.2	6.1	99
Nitrate-N	0.4	13.3	1.7	49.2	Increase
BOD_5	10.3	0.6	80.1	3.9	95
Oil & grease	1.8	0	15.9	0	100
Total suspended solids	71	16.9	70.8	16.9	76
*E.coli (CFU/100 mL)	170	4		0	98

**E.coli* is expressed as colony forming unit (CFU) per 100 ml of effluent

Figure 2. The Total-P concentration (mg l^{-1}) in the effluent applied and drainage waters from Wuqing FILTER 5m and FILTER 10m plots.

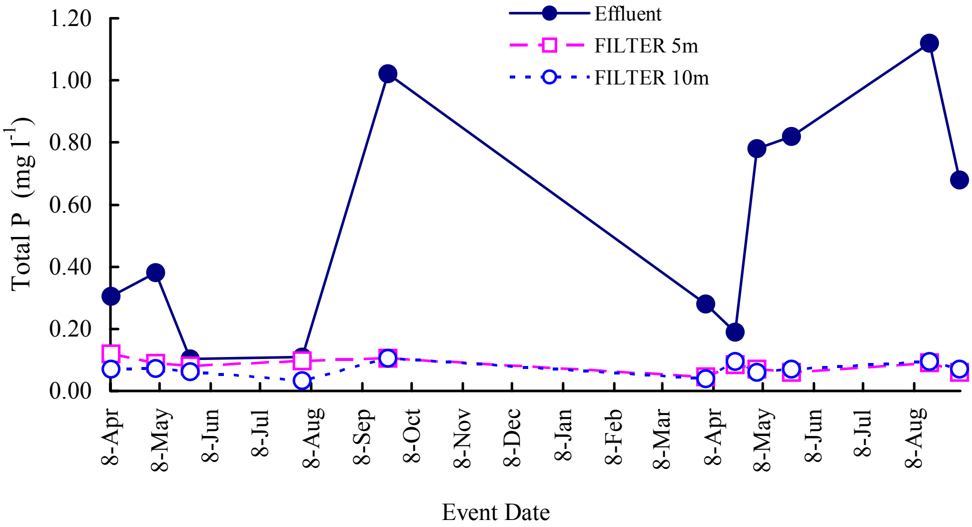


Figure 3. The BOD_5 concentration in the effluent applied and drainage waters from Wuqing FILTER 5m and FILTER 10m plots.

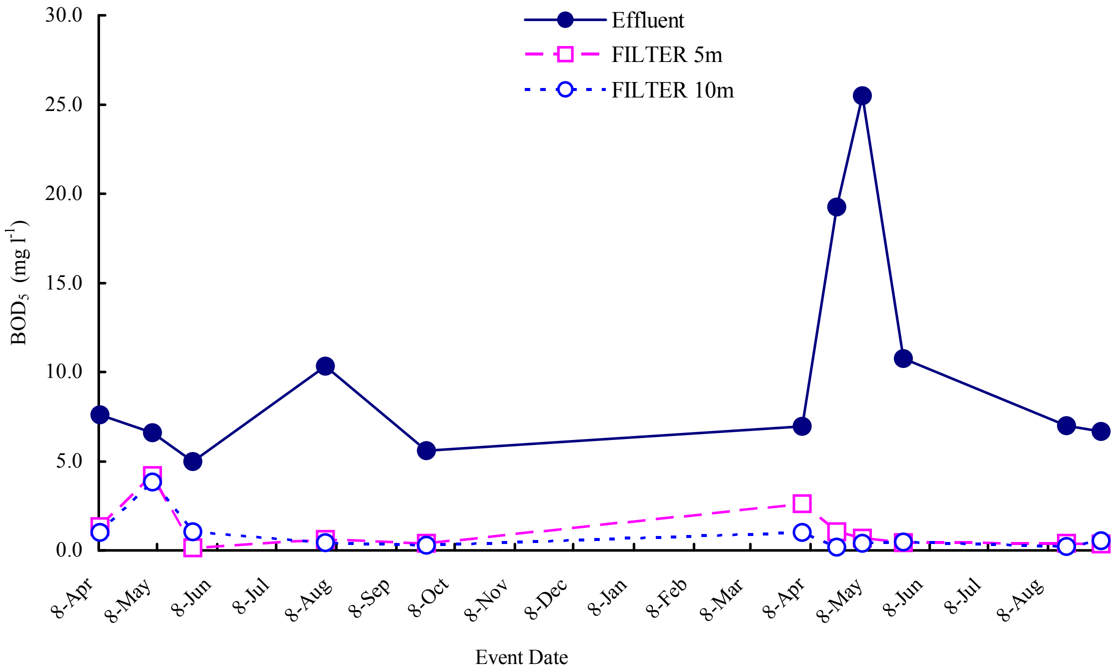


Figure 4. The COD concentration in the effluent applied and drainage waters from Wuqing FILTER 5m and FILTER 10m plots

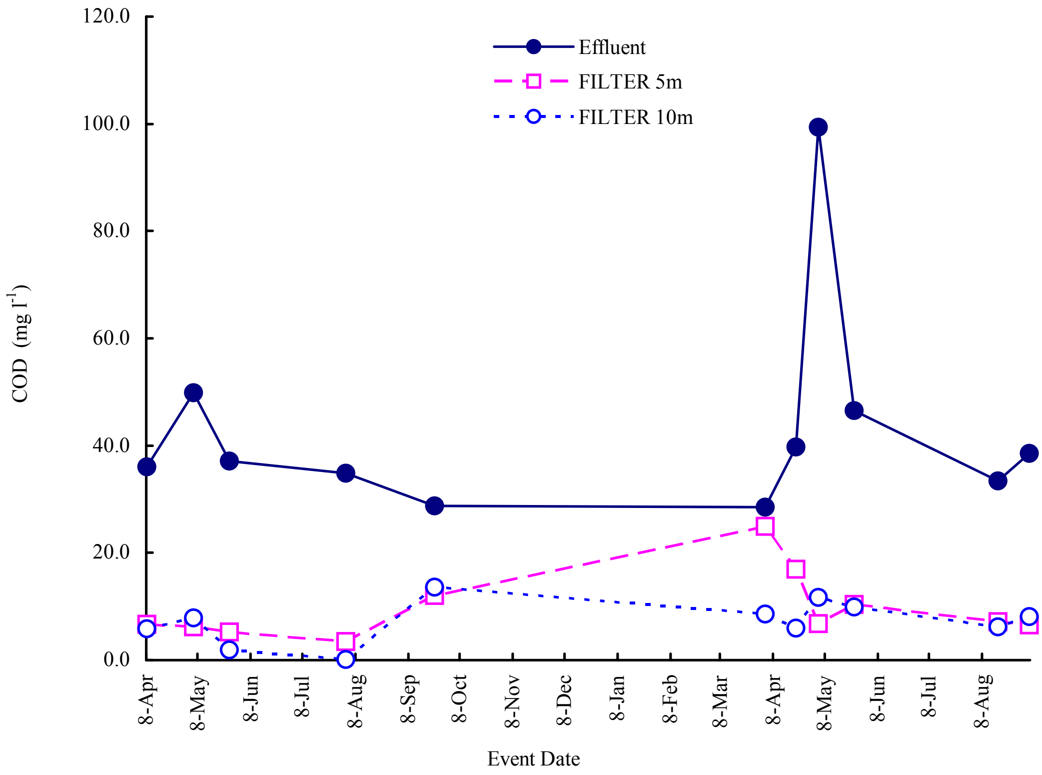


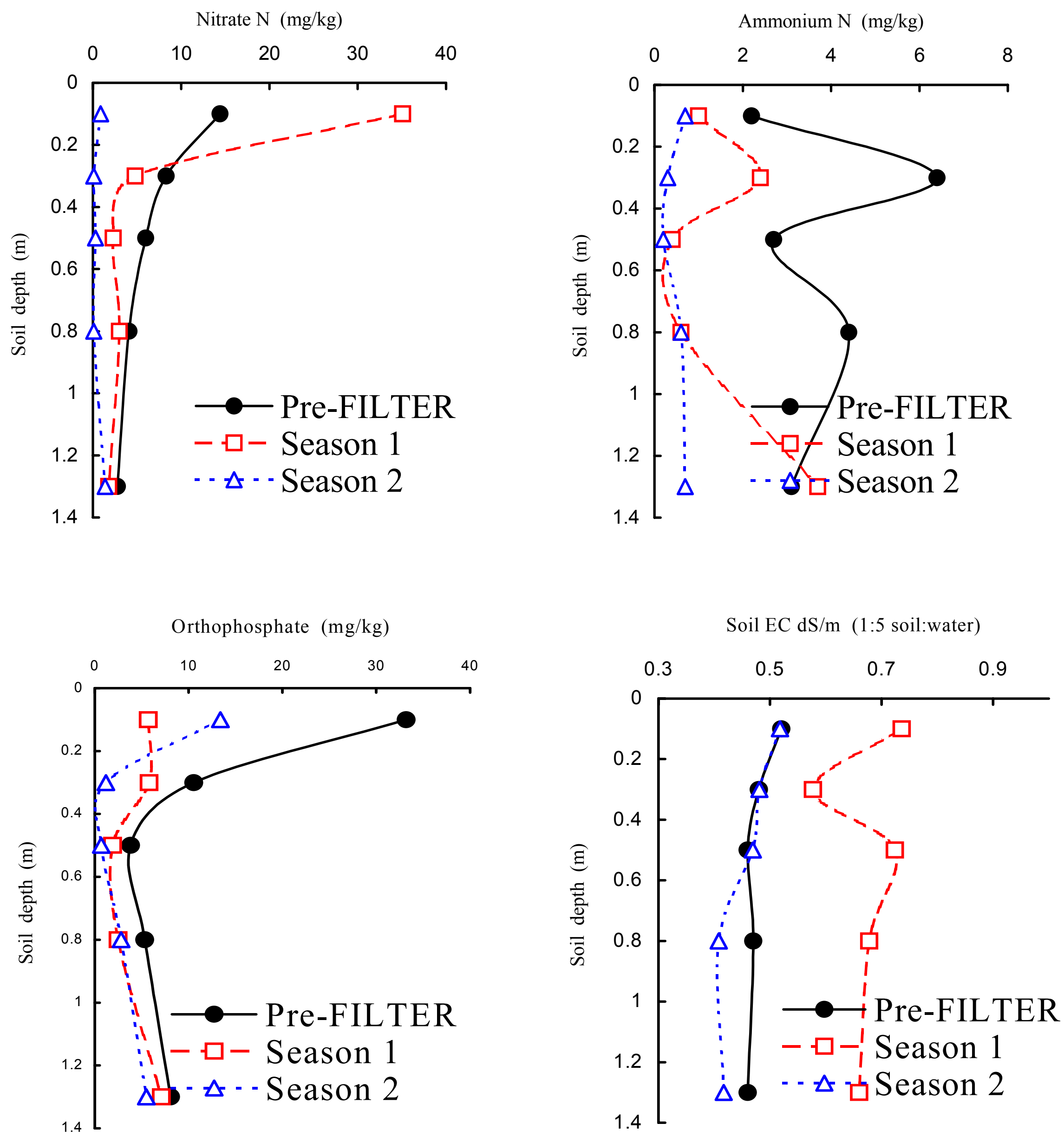
Table 2. Pollutant load reductions (%) of Wuqing and Griffith Pilot FILTER Trial sites, and reductions in mean E. coli counts

Pollutant	Total-P	Total-N	SS	BOD5	COD	E. coli
Griffith	96	58	85	95		98
Wuqing 5m	99	82	68	61	75	
Wuqing 10m	99	86	81	79	86	

From the results it can be observed that the pollutants can be substantially removed by using the FILTER technique. For the pathogens, utilizing E.coli count as the indicator parameter, can also be significantly reduced. Sampling of drainage waters from Griffith FILTER plots for E.coli during a filter events showed that the average number of E.coli in effluent water was 170 cfu /100 ml of effluent, whereas in drainage water this was reduced to 4 cfu /100 ml. The maximum total aerobic bacteria count in the effluent applied was 24,000 cfu /100ml, while the count in drainage water was 1300.

Previous studies have shown that heavy textured soils can provide an effective filter to remove microorganisms from sewage effluent, where bacteria are physically strained and the much smaller viruses are usually adsorbed. Due to soil chemical and biological activities, the FILTER system on heavy soils could effectively reduce E.coli, thereby producing drainage waters with lower risk of pathogen infestation

Figure 5. Changes in the content of extractable soil NOx-N, extractable soil NH4-N, extractable soil phosphorus and soil salinity in FILTER 5m plots



In a separate trial involving the spiking of the applied effluent with the full range of pesticides used in agriculture enterprises in the area, the pesticide loads in drainage waters were reduced by more than 98% (Data not shown). This means modified FILTER systems may thus be used to treat other industrial and commercial effluent containing chemicals which adsorb onto soil particles. The changes in extractable soil NOx-N content, extractable soil NH_4-N content, extractable soil phosphorus content and soil salinity in Wuqing FILTER 5m plots during 1999-2000 wheat cropping season and the cropping season followed are shown in Figure 5

For the 2M KCl extractable soil NOx-N (oxidized nitrogen) and extractable soil NH_4-N, there has been a considerable reduction in most of the soil layers during the first cropping season and a further reduction during the second cropping season. The extractable soil phosphorus content in the FILTER 5m plots still shows a slight decrease at the end of the winter cropping season, in spite of high phosphorus fertilizer application. The soil phosphorus content shows little change from the start to the end of the summer cropping season. This means a balance of soil phosphorus content between the addition from effluent irrigation, fertilizer applying and leaching from drainage. The changes of pollutant content in Wuqing FILTER 10m plots are very similar to the changes observed in the FILTER 5m plots.

Reasonable yields were obtained with substantial removal of N, P, K and Ca (Table 3). This data can be used to calculate the land area required to maintain nutrient balance, and to develop short-term and long-term options for nutrient management. These results emphasize not only the use of nutrients from wastewater for cropping, but also the economic benefits through crop production. Further, through the combination of FILTER design and cropping management it will be possible to avoid build up of nutrients at the reuse site.

Table 3. Removal of nutrient by crops in FILTER trial

Crops	Average Yield (t ha^{-1})		Nutrient removal (kg/ha)			
	Dry Matter	Grain	N	P	K	Ca
Pasture (Griffith)	12.5		182	21.4	142	19.8
Oats (Griffith)	13.4		76	19.9	131	12.1
Wheat (Wuqing)	12.5	3.94	139	20		

Summary and conclusions

From the results of the FILTER trials carried out in Griffith and Wuqing, it is suggested that the FILTER system can reduce pollutants, including pathogens and toxins, in drainage water to a reasonable level. This makes the technique a good option to be used separately or combined with other treatment methods for the treatment and reuse of wastewater, preventing health risks due to large-scale wastewater irrigation. In addition, during the operation of the FILTER system no accumulation of pollutants in the soil profile occurred, indicating the sustainability of the FILTER system in the treatment of wastewater and/or disposal of effluent. Further, good crop yields can offset the construction cost of the FILTER system this makes the FILTER technique more economically reasonable to be utilized for treating effluent.

In short, through the combination of an appropriate FILTER design and irrigation/drainage/cropping management, it is possible to develop a sustainable and economically reasonable system, which can reduce pollutant levels of effluent to a reasonable level, avoids build up of nutrient at the reuse site and prevents health risks due to large scale wastewater irrigation.

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