Agricultural Water Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems

P.S. Minhas[a,*,1], Khajanchi-Lal[a,2], R.K. Yadav[a], S.K. Dubey[b], R.K. Chaturvedi[a]

[a] *Central Soil Salinity Research Institute, Karnal 132001, Haryana, India*
[b] *Central Soil and Water Conservation Research & Training Institute, RRS, Agra 282 002, India*

ARTICLE INFO

Article history:
Received 31 August 2014
Accepted 15 March 2015
Available online xxx

Keywords:
Wastewater irrigation
Cropping systems
Sustainability
Fertilizer saving
Produce quality
Peri-urban agriculture

ABSTRACT

Farmers in peri-urban areas of developing countries depend on wastewaters for their livelihood but with grave health and environmental risks. An 8-year field experiment compared food grain (FGPS), agro-forestry (AFS), fodder (FPS) and vegetable (VPS) production systems and quantified responses to fertilizers (NP 25–100%) when irrigated with sewage (SW; EC 1.3 ± 0.3 dS m^{-1} BOD 82 ± 11, NO_3–N 3.2 ± 0.4, NH_4–N 9.6 ± 0.5, P 1.8 ± 0.3, K 6.4 ± 0.4 mg L^{-1}) vis-à-vis groundwater (GW). Productivity improved with SW by 14–28% while trends were negative with sub-optimal NP under GW. Partial factor productivity (PFP) averaged 18.0, 11.1, 157 and 149 kg kg^{-1} NP with GW in FGPS, AFS, FPS and VPS, respectively. Counter figures were 13.8, 8.8, 96 and 56 kg kg^{-1} NP with SW. Paddy-wheat equivalent yields were 5.5, 1.8 and 19.9 fold under AFS, FPS and VPS with SW. About 40, 33, 75 and 20% of fertilizer NP with SW was sufficient for similar production as with recommended NP and GW in FGPS, AFS, FPS and VPS, respectively. Quality of produce improved in terms of crude protein and the micronutrients in edible parts with SW while toxic metals were within the permissible limits. However, the keeping quality of vegetables was lowered due to faster decay with pathogens contamination (Aerobic bacterial plate counts 5×10^5–4.2×10^8 cfu g^{-1} and *Escherichia coli* $<2 \times 10^2$–7×10^5). Thus, the sewage proved as a vital resource in improving productivity, sustainability and saving fertiliser costs but this may pose health risks because of pathogenic infestation that need to be regulated.

1. Introduction

Disposal of increasing volumes of wastewater, due to rapidly growing urban agglomerations, escalating industrialization and economic development, is becoming a major problem, which the developing countries are now struggling to address (Minhas and Samra, 2004; Corcoran et al., 2010). It is since the technologies for treating wastewaters are often considered as unaffordable luxuries suited only to affluent countries (Paranychianakis et al., 2006; Levy et al., 2011). Thus the safe and sustainable use of wastewaters in agriculture serves as a low cost alternative to treatment and helps in preventing uncontrolled dumping of wastewaters into lakes and streams (Drechel et al., 2010). In fact the use of raw, diluted or partially treated wastewater in agriculture creates both the opportunities and problems. Opportunities exist in terms of disposal of wastewaters, reliable irrigation resource in water scarce conditions and addition of valuable nutrients and organic matter to soils and therefore millions of urban and peri-urban farmers depend on these waters for their livelihood (Hoeks et al., 2002; Qadir et al., 2007). On the other hand, the irrigation practices being primitive, unscientific and more of disposal oriented, these pose threat to farmer's/consumer's health and the environment through transmission of diseases from excreta related pathogens and vectors, skin irritants and irreversible accumulation of toxic chemical like heavy metals, pesticides etc. in soils and groundwater (Yadav et al., 2002; Rattan et al., 2005; Qadir et al., 2007, 2010; Minhas and Lal, 2010; Murtaza et al., 2010).

In addition to their irrigation potential for high value vegetable, food and fodder crops, the interests of farmers in the peri-urban areas are to utilize sewage water for supplementing nutrients. Benefits of these nutrients depend on their concentrations in sewage

---

* Corresponding author. Tel.: +91 211 225 4055; fax: +91 211 225 4056; mobile: +91 940 368 2923.
E-mail address: minhas_54@yahoo.co.in (P.S. Minhas).

[1] Present address: National Institute of Abiotic Stress Management, Baramati 413 115, Pune, India.

[2] Present address: Water Technology Centre, Indian Agricultural Research Institute, New Delhi 110012, India.

http://dx.doi.org/10.1016/j.agwat.2015.03.012
0378-3774/

waters, the quantities of water applied, the time of its application, the type and target yields of crops grown, and the inherent fertility of the soil (Minhas and Samra, 2004). Though the nutrient supplying capacity is considered to be the major driver for sewage irrigation, maintaining adequate levels is also a major task because of possible negative effects by overuse through inducement of succulence, lodging and the resultant loss of crop yields. Since the fertilization is inseparable from irrigation with sewage; the farmers using sewage do loose freedom with respect to rate, proportions and timing of nutrient application. It is since the irrigation frequency with wastewaters usually depends on crop water requirements and not the nutrient needs (Janssen et al., 2005; Gog-Raj et al., 2006; Erni et al., 2010). Therefore, deciding about the correct doses of fertilizers and their timing is an important issue and the recommendations to the farmers concerning the use of fertilizers especially nitrogen and phosphorus have to be different for wastewater irrigated crops. Additionally, the organic loads in sewage results in accumulations of organic matter vis-à-vis nutrient supplying capacity of soils, its contents become a critical factor for deciding on the quantities of nitrogenous fertilizers (Friedel et al., 2000; Gog-Raj et al., 2006; Simmons et al., 2010). Considering these facts, the objectives of the present experiment were to evaluate the sustainability of the most common cropping systems in peri-urban areas viz. food grain, vegetable, fodder based systems with sewage irrigation and quantifying the nutrient savings (N and P) with long term usage of sewage. Since almost all the crops in peri-urban agriculture are the water profligate but shallow rooted the consequence risks of groundwater contamination especially with nitrates always exist. Therefore, an agroforestry systems having deeper rooted tree component was also included for comparisons.

2. Materials and methods

2.1. Location, soil and climate

The experiment was conducted at Research Farm of Central Soil Salinity Research Institute, Karnal, India located at 75°57′E longitude and 29°43′N latitude and 243 m above mean sea level during October 2000 to April 2008. The climate at the site is subtropical semi-arid monsoonal type with about 80% of rainfall occurring during the months of July to September. In general the evaporation is high during April to June and low during November to February. The mean monthly maximum temperature is recorded in May or June and the minimum during January. Open pan evaporation of the area generally exceeds rainfall except during rainy season (Fig. 1). The soil at the site, silt-loam at the surface, is an ex-improved sodic land still having high pH (8.7–9.2) in sub-surface layers and calcareous hard pan layer of variable thickness at a depth of 0.9–1.2 m. Some of the physico-chemical characteristics for different depths of the initial soil are included in Table 1.

2.2. Treatments and crop culture

The experiment was laid out in a double-split plot design with four replications. The 32 treatments comprised of combinations of; (A) four of the most prevalent cropping sequences of peri-urban areas of north-west India in main-plot, viz. (i) food grain production system (FGPS, paddy-wheat), (ii) vegetable production system (VPS, okra/gourds during summer and cabbage/cauliflower during winter), (iii) fodder production system (FPS, sorghum-Egyptian clover) and (iv) agroforestry system (AFS, poplar–paddy–wheat); (B) two qualities of irrigation water in sub-plots, viz. (i) sewage effluent (SW) and ii) good quality ground water (GW) and C) four fertilizer levels in sub-subplots viz. (i) 25, 50, 75 and 100% dose of recommended fertilizer nitrogen (N) and phosphorus (P). The plot size was 7.5 m × 4.0 m. To avoid the side effects on the adjoining annual crops, a separate block was assigned to agro-forestry system. Only the recommended doses of NP were applied to the first year crops i.e. during 2000–2001 and thereafter the fertilizer (N:P) doses were; 50:50, 100:50, 50:100 and 100:100% of recommended until winter season of 2003–2004. Due to low use efficiency of added nutrients particularly P, the effects of various fertilizer treatments were not conspicuous during 2001–2002 and 2002–2003. Therefore, the NP 50:100, 100:50 treatments were changed to 25:25 and 75:75. The recommended doses of fertilizer N, P and K were 120, 26 and 33 kg ha^{-1} for both paddy and wheat. One-third of N and total P and K were applied as basal dose in both paddy and wheat while the rest of N was top-dressed in two equal splits at 30 and 50 days after transplanting in paddy and 25 and 55 days after sowing in wheat crop. The recommended doses of N, P and K for sorghum fodder were also 120, 26 and 33 kg ha^{-1}, whereas these were 20, 31 and 33 kg ha^{-1} for Egyptian clover. Similarly the recommended doses of N, P and K for winter vegetables (cabbage/cauliflower) were 150, 35 and 50 kg ha^{-1} while for summer vegetables, these were 120, 26, and 33 kg ha^{-1} in okra, 80, 26 and 42 kg ha^{-1} in bottle gourd, sponge gourd and ridge gourd.

All the crops were grown under irrigated conditions as per quality of water. The composition of both SW and GW was analyzed at monthly interval. Measurements for biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) were carried by using standard methods as proposed by APHA (1988). Nitrogen content in water samples was determined through nitrogen analyser. The P content was measured by ascorbic acid method using colorimeter, whereas K was measured using flame photometer. Besides this, total trace metal (Fe, Mn, Zn, Cu, Cd, Cr, Ni, and Pb) concentrations in di-acid (HNO_3 and $HClO_4$) digested water samples were estimated with atomic absorption spectrophotometer. The SW had BOD 82 ± 11 mg L^{-1} and COD 136 ± 14 mg L^{-1} while these were below detectable levels in GW. Faecal coliforms in sewage were $1.5 \pm 0.3 \times 10^6$ cfu mL^{-1}. The EC of SW was 1.3 ± 0.3 dS m^{-1} while NO_3–N, NH_4–N, P and K contents averaged 3.2 ± 0.4, 9.6 ± 0.5, 1.8 ± 0.3 and 6.4 ± 0.4 mg L^{-1}, respectively. EC of GW was 0.6 ± 0.2 dS m^{-1} and its P and K contents were 0.03 and 3.5 ± 0.3 mg L^{-1}. Fe, Zn and Cu contents in sewage averaged 0.9, 0.2 and 0.1 mg L^{-1}, respectively whereas contents of Cd, Ni, Pb and Cr were in traces.

Each year, paddy (cv. Pusa 44) was transplanted during the first week of July using two seedlings per hill at 0.20 m × 0.15 m spacing in puddled plot. For subsequent irrigations, plots were flooded with 40 mm deep standing water when surface soil reached the saturation level i.e. no standing water. The crop required 28 to 33 irrigations for maturity (882 cm for 7 crops). After harvest of paddy during October, wheat (cv. PBW 343) was sown during the first fortnight of November using a seed rate of 100 kg ha^{-1} in rows 25 cm apart. In addition to a pre-plant irrigation, wheat was irrigated five times (7.0 cm water) at crown root initiation (21 days after sowing, DAS), maximum tillering (55 DAS), jointing (75 DAS) ear emergence (100 DAS) and milking (130 DAS) stages (273 cm for 8 crops). Crops were harvested manually by sickle. The net plot size was 6.4 m × 2.2 m in paddy and 6.0 m × 2.0 m in wheat. The grains were separated from straw using a plot thresher. Similarly, fodder sorghum (cv. PC-23) was planted during June in rows 0.30 m apart and harvested at about 65 days after planting. Multi-cut sorghum (cv. MFSH-4) was sown during 2003 onwards. Egyptian clover (cv. Muscavi) was planted during second week of October through broadcasting seed (25 kg ha^{-1}) in standing water. Egyptian clover received 8–9 irrigations (480 cm for 8 crops) while the sorghum required 5 irrigations (168 cm for 7 crops). Fodder crops were also cut manually with sickles and above ground biomass were recorded for each plot as fresh fodder yield. Samples were drawn for drying in oven at 60 °C to a constant weight for

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012

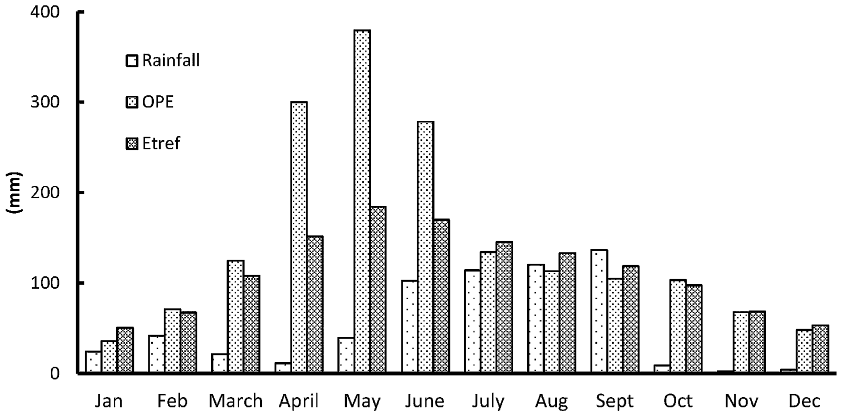

Fig. 1. Mean monthly rainfall (mm), annual open pan evaporation (OPE, mm) and reference evapo-transpiration (ETref Penman-Montieth, mm) for the experimental period (September 2000–August 2008).

conversion into dry forage yield. Summer vegetables (cv. Pusa Summer Prolific Long for bottle gourd, Pusa A-4 in case of okra and Pusa Supriya of sponge gourd, Pusa Nasdar of ridge gourd) were seeded mostly during March–April while in case of winter vegetables, 4 week old seedlings of cauliflower (cv. Snow ball) were transplanted during the during second week of October keeping spacing of 0.45 m × 0.30 m while cabbage (cv. Pride of India) was transplanted during first week of December with spacing of 0.40 m × 0.25 m. The appropriately matured vegetables were picked up/harvested manually. The lots were weighed individually and then pooled for total yields. In case of winter vegetables, cabbage and cauliflower required 5 and 4 irrigations (350 cm for 8 crops), respectively while among the summer vegetable, okra required 10 irrigations and 4–5 irrigations (255 cm for 7 crops) were sufficient for gourds (bottle gourd, ridge gourd and sponge gourd). Data on production of different crops were subjected to analysis of variance for judging the significance of differences between means of different treatments using least significant difference (LSD) computed at 5% level of Tukey's adjustment as per procedures given by Gomez and Gomez (1984).

2.3. Sustainability indices

The sustainability of sewage irrigation and nutrient doses was measured using five indices namely, yield trends, sustainable yield index (SYI), equivalent yield, partial factor productivity (PFP), and the produce quality parameters (protein content, micronutrient and metal accumulation, pathogen load and average daily decay and physiological weight loss). Sustainable production systems are characterized by non-negative trends in yield over an extended period, so the linear regression of yield (Y) with time (t): $Y = \alpha + \beta t$ was taken as an appropriate measure of sustainability of the system where β is slope or magnitude of yield trend (yield changes per year). The SYI suggested by Singh et al. (1990) was also used for defining sustainability of a cropping system i.e. $\mathrm{SYI} = (-1/\bar{y} - \sigma_{n-1})Ym^{-1}$; where $(-1/\bar{y})$ is mean yield, σ_{n-1} the standard deviation, and Ym the maximum yield obtained under a set of management practices. Since the sustainable management practices imply more than maintaining yields, partial factor productivity (PFP) that provide useful information on the efficiency of the inputs used was also computed. The PFP of applied fertilizer is the ratio of the grain yield to applied fertilizer (Dawe and Dobermann, 1999) i.e. $\mathrm{PFP} = YF_n{}^{-1}$; where Y is the grain yield and F_n is the amount of fertilizer (NP) applied, both expressed in the same units. In long-term fertilizer experiments, the grain yield of a fertilized plot at a given time represents the sum of the yield without fertilizer input (Y_0) plus the incremental increase in yield that results from fertilizer application (ΔY): $Y = Y_0 + \Delta Y$, where Y is the grain yield of a fertilized plot, Y_0 the grain yield in unfertilized (control) plots, and ΔY the yield increment due to fertilizer. By substituting Y in above equation from the equation ($Y = Y + \Delta Y$); $\mathrm{PFP} = \{Y_0 + \Delta Y\}F_n{}^{-1}$ or $\mathrm{PFP} = \{Y_0\ F_n{}^{-1}\} + \{\Delta YF_n{}^{-1}\}$. Since the experiment did not include the treatment without fertilizer input, the grain yield for zero fertilizer input was back calculated from the second degree polynomials fitted to the data. PFP is a useful measure of nutrient-use efficiency providing an integrative index that quantifies total economic output relative to the utilization of indigenous and applied nutrients. However, farmers are concerned mostly with overall returns. Therefore, the produce (grain/fodder/fruit) under different cropping systems was converted into paddy-wheat equivalent yields (PWEY) on the economic value basis. $\mathrm{PEY} = [(Yk \times Pk/Pp)$ and $\mathrm{WEY} = (Yr \times Pr/Pw)]$ where Yk and Yr refer to the yield of *kharif* (summer) and *rabi* (winter) season crops, respectively while Pk, Pr, Pp and Pw refer to unit price of produce from *kharif* (summer), *rabi* (winter), paddy and wheat crop, respectively. The market value of produce (per 100 kg) of different crops used for computations was: INR 1056 and 1174 for grains of paddy and wheat; INR 137 and 158 for green fodder of sorghum and Egyptian clover; INR 1178, 906, 689, 607, 327 and 277 for okra, ridge gourd, bottle gourd, sponge gourd, cabbage and cauliflower; INR 630 and 190 for poplar timber

Table 1
Physico-chemical characteristics using standard techniques.

Depth (m)	Sand(%)	Silt(%)	Clay(%)	BD[a] ($\mathrm{cm^3 cm^{-3}}$)	WHC[a] (%)	pHs	ECe ($\mathrm{dSm^{-1}}$)	Avail-N ($\mathrm{kg\ ha^{-1}}$)	Org-C(%)
0–0.15	40.5	46.3	13.2	1.48	19.17	8.27	1.28	167	0.43
0.15–0.30	41.0	45.4	13.6	1.47	19.43	8.34	1.09	148	0.34
0.30–0.60	41.4	45.8	14.3	1.45	19.58	8.41	1.13	114	0.24
0.60–0.90	40.2	44.9	14.9	1.44	18.92	8.68	1.21	98	0.18
0.90–1.20	39.3	44.3	16.4	1.42	20.12	9.12	0.63	74	0.18
1.20–1.50	44.5	45.8	9.7	1.55	16.38	9.23	0.58	63	0.12
1.50–1.80	45.2	43.0	11.8	1.52	17.94	9.37	0.61	47	0.14

[a] BD and WHC denote bulk density and water holding capacity, respectively.

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012

and twigs for fuel, respectively. The PEY and WEY for each system were added to determine total system productivity (TSP). For agroforestry system, the financial value of timber and other economic parts at final harvest was also considered for computing TSP.

2.4. *Produce quality indices*

At the crop harvest, samples were drawn from the edible parts of the produce of crops i.e. bolls of cabbage, curd of cauliflower, fruits of okra and gourds, grains of paddy and wheat, plants of Egyptian clover and sorghum. These were analyzed for total bacterial counts, Faecal coliform and fungi. The determinations for coliform were initiated within 2 h of collection. The plate counts for aerobic bacteria were analyzed using standard nutrient agar medium while fungi were monitored by Martin rose Bengal medium as described by Subba-Rao (1986). Total and Faecal coliforms were tested using 10-fold serial dilution by multiple tube fermentation procedure using lauryl tryptose broth, brilliant green lactose bile broth (BGLB) and EC medium tubes. The density of total and faecal coliform was reported as most probable number (MPN 100 g^{-1}). Compactness was computed by recording the volume of water displaced by known fresh weight of the produce and expressed as g cm^{-3}. Physiological loss of weight (PLW) was calculated by subtracting the final weight of the vegetables (Wf) from that monitored at regular intervals ($Wt_{1..n}$) and dividing by the initial fresh weight at harvest (Wi) as: PLW (%) = $[(Wt_{1..n} - Wf)/Wi] \times 100$. Similarly, decay loss (%) of fresh weight was recorded by discarding the decaying part every day for 5 days. Sub-samples were also drawn from fresh biomass and dried to a constant weight (60 °C) for determining dry matter (DM). Dried samples were finely ground and a known amount (0.5 g) of different plant parts was digested in nitric acid and subjected to metal (Fe, Mn, Zn, Cu, Cd, Cr, Ni and Pb) ion determinations using atomic absorption spectrophotometer. Similarly, dried and finely ground economic parts of each crop (grain in rice and wheat, above ground part of sorghum and Egyptian clover, cabbage boll, curd of cauliflower, fruits of okra and gourds) were digested in H_2SO_4 and subjected to nitrogen analysis using nitrogen analyser. Nitrogen content was converted into crude protein by multiplying it by 6.25 and expressing it on fresh weight basis.

3. Results

3.1. *Crop yields*

3.1.1. *Food grain production system (FGPS)*

The grain yields of wheat and paddy over the 8 years are given in Table 2. On the whole, the yields of wheat were considerably improved both with SW and NP doses. The average yield obtained with SW and GW was 4.9 and 4.0 Mg ha^{-1}, respectively. Both with GW and SW, the maximum yield was obtained with recommended dose of N and P. The increment in grain production decreased with NP levels but the yields obtained with SW and 50% NP were almost equal to GW and 100% NP. Similarly the yields of paddy were almost sustained with SW and averaged 6.0 Mg ha^{-1} as compared with 4.9 Mg ha^{-1} for GW. Initially wheat and paddy responded to graded levels of NP fertiliser applied in conjunction with SW but from 4th year onwards, the NP levels above 50% showed little advantage. The highest yields of 6.9 and 5.8 Mg ha^{-1} were recorded during 3rd year with SW and GW, respectively and thereafter, these declined especially when irrigated with GW. The rate of annual decline with GW equalled −0.22, −0.14, −0.14 and −0.08 Mg ha^{-1} when the NP applied was 25, 50, 75 and 100% of the recommended whereas the figures ranged between −0.01 to −0.05 Mg ha^{-1} with SW. The rate of decline was higher in yields of wheat that ranged between −0.28 to −0.34 and −0.07 to −0.12 Mg ha^{-1} under GW and SW, respectively. The interactive effects of water quality and fertilizer levels were non-significant except during later years (5th and 6th year) when the crop response to added NP was higher with GW than SW.

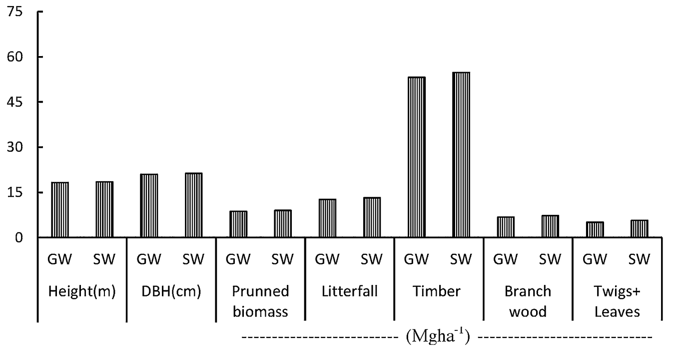

Fig. 2. Growth and yield of Poplar under agroforestry system (GW and SW denote irrigation with groundwater and sewage water).

3.1.2. *Agro-forestry system (AFS)*

Due to competition for radiation, nutrients and water, the yields of wheat and paddy were lower under agro-forestry in comparison with sole crops. Moreover, the planted area under annual crops in agro-forestry system was 82% of the sole crops. The overall grain yields of wheat and paddy under the agro-forestry system averaged 61 and 33% of those under sole crops (Table 3). The drop in production increased with age of Poplar trees and became severe after 3 years when the yields of paddy and wheat ranged between 1.1–1.4 and 1.7–2.4 Mg ha^{-1}, respectively. Even the increased doses of fertilizer NP did not show benefit though about 12% higher yields were obtained with SW when compared with GW. The progressive reduction in paddy and wheat yields with advancement in poplar age was mainly ascribed to the increased canopy and root competition for light, moisture and nutrients. The yield trends showed higher decline rates in both paddy and wheat under agroforestry than their sole crops. These averaged −0.577 and −0.695 Mg ha^{-1} yr^{-1} in paddy with GW and SW whereas the counter figures for wheat were −0.394 and −0.454 Mg ha^{-1} yr^{-1}, respectively indicating a higher impact of Poplar trees on paddy. Latter was obviously due to deciduous nature of Poplar trees those shed their leaves during winter and the new leaves emerged during late February-early March. By that time wheat was in the reproductive stage and heading towards the completion of growth cycle. Therefore, wheat could escape the shade effects though the litter fall at its sowing did interfere with seedling emergence and their initial growth. The growth and biomass production by Poplar trees was almost similar with GW and SW (Fig. 2) and even the differential fertilization (NP) to the understory paddy and wheat crops did not show any effect.

3.1.3. *Fodder production system (FPS)*

Egyptian clover being a leguminous crop, basal dose of 20 kg N ha^{-1} and two levels of P viz. 50 and 100% of the recommended dose (31 kg P ha^{-1}), were applied during 2nd and 3rd year. Fodder yield increased with P application but the overall response became non-significant from 4th year onwards though the fodder yields improved with SW (Table 5). The average yields obtained with GW and even 100% NP did not match those obtained with SW and 25% NP. Sorghum also responded to applied fertilizers and SW (Table 5). During 2003–2004 onwards, its yield obtained with 75% NP with GW was at par with that obtained with SW and 25% NP indicating 50% saving of NP with SW. The interaction effects of water quality and fertilizers were non-significant.

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012

Table 2
Grain yield (Mg ha^{-1}) of paddy and wheat as affected by sewage irrigation and NP fertilisers under food grain production system (FGPS), their trend values (β) and sustainability yield index (SYI).

Fertiliser (% NP)	Paddy during the year									Wheat during year									
	2	3	4	5	6	7	Mean	β	SYI	2	3	4	5	6	7	8	Mean	β	SYI
Groundwater irrigation (GW)																			
25	3.9	5.1	5.0	3.4	3.8	3.4	4.1	−0.22	0.65	4.0	4.0	3.2	2.4	2.8	2.2	2.2	3.0	−0.28	0.55
50	4.1	5.6	5.5	4.2	4.4	4.2	4.7	−0.14	0.71	4.9	4.7	3.8	3.0	3.7	2.8	3.1	3.7	−0.24	0.59
75	4.9	5.8	6.2	4.6	5.1	4.7	5.2	−0.14	0.79	5.3	5.2	4.1	3.9	4.1	3.7	3.9	4.3	−0.33	0.69
100	5.9	6.1	6.5	4.9	5.7	5.2	5.7	−0.08	0.84	5.8	5.5	4.5	4.7	4.5	4.5	4.7	4.9	−0.34	0.75
Mean	4.7	5.7	5.8	4.3	4.7	4.4	4.9	−0.14	0.75	5.0	4.8	3.9	3.5	3.8	3.3	3.5	4.0	−0.30	0.66
Sewage irrigation (SW)																			
25	4.8	6.0	6.1	4.8	5.6	5.5	5.5	−0.03	0.81	4.7	4.7	4.1	4.1	3.9	4.1	3.9	4.2	−0.14	0.82
50	5.3	6.1	7.0	5.3	5.9	5.9	5.9	−0.02	0.87	5.2	5.4	4.6	4.5	4.6	4.8	4.8	4.8	−0.09	0.86
75	5.7	6.2	7.2	5.7	6.2	6.4	6.2	−0.05	0.92	5.6	5.7	4.8	4.7	4.6	5.2	5.3	5.1	−0.07	0.84
100	6.1	6.7	7.3	5.8	6.4	6.2	6.4	−0.01	0.88	6.0	5.9	5.1	5.1	4.8	5.3	5.4	5.4	−0.14	0.82
Mean	5.5	6.3	6.9	5.4	6.1	6.0	6.0	−0.03	0.87	5.4	5.4	4.6	4.6	4.5	4.8	4.8	4.9	−0.10	0.84
LSD(p = 0.05)																			
WQ	0.4	0.1	0.7	1.5	0.7	0.4				0.3	0.7	0.5	0.4	0.4	0.7	0.5			
Fert.	0.6	0.4	0.4	0.6	0.4	0.6				0.6	0.6	0.4	0.4	0.3	0.4	0.6			
WQxFert	NS	NS	NS	0.7	0.6	NS				NS	0.6	0.4	0.6	NS	NS	NS			

3.1.4. *Vegetables production system (VPS)*

Vegetable crops showed similar trends in response to SW and the fertilizer NP as were noticed in paddy–wheat but the overall improvements in productivity were higher. The improvement in the yields with SW was about 28% both in winter and summer vegetables (Table 4). The vegetable crops also responded to increased doses of fertilizer NP though to a lesser extent when irrigated with SW. The successive increments in the production of summer vegetables irrigated with GW were 3.0, 1.5 and 1.8 Mg ha^{-1} with addition of 50, 75 and 100% NP while the counter figures were 1.7, 0.9 and 0.6 Mg ha^{-1} with SW, respectively. Similarly in case of winter vegetables, the increments in yields with GW were 5.8, 1.6 and 4.3 Mg ha^{-1} with 50, 75 and 100% NP while the counter figures with SW were 4.2, 1.1 and 1.4 Mg ha^{-1}, respectively. The vegetable production obtained with SW and 50% NP was even more than that obtained with GW and 100% NP. The interaction between water quality and fertilizer levels was non-significant for all the vegetables and years.

3.2. *Yield sustainability and response functions*

The sustainable yield index (SYI) is a quantitative measure of sustainability that helps to establish minimum guaranteed yield that can be obtained relative to the maximum observed yield. The SYI differed considerably between the cropping systems, water quality and with fertilizer rates (Tables 2–5). Amongst the crops, the highest SYI was recorded in Egyptian clover (0.90) with SW while it was lowest for paddy (0.17) with GW in AFS. As of variable vegetables grown during summer i.e. okra-ridge gourd-smooth gourd-bottle gourd each for two years, their SYI could not be computed. Nevertheless, SYI for winter vegetables was quit high (0.78). On the whole, the SYI improved with SW; figures being 0.86, 0.33 and 0.75 under FGPS, AFS and FPS against 0.71, 0.31 and 0.72 under respective production systems with GW. SYI also improved consistently with application of NP with GW whereas with SW, improvements occurred only with increasing fertilizer from 25 to 50% NP with SW and thereafter SYI was almost at par.

The second degree polynomials were fitted for developing production functions of different crops with applied NP (Fig. 3). The partial factor productivity (PFP) computed using zero fertilizer yields differed markedly amongst the cropping systems and also crops within the cropping systems (Table 6). Specifically the FPS and VPS showed very high PFP. The values averaged 16.5, 8.1, 152 and 197 kg kg^{-1} NP with GW in summer crops of FGPS, AFS, FPS and VPS, respectively while the counter figures were 19.4, 14.1, 159 and 102 kg kg^{-1} NP for the winter season crops. However, the PFP was

Table 3
Grain yield (Mg ha^{-1}) of paddy and wheat as affected by sewage irrigation and NP fertilizers under agroforestry system (AFS), their trend values (β) and sustainability yield index [SYI].

Fertiliser (% NP)	Paddy during year									Wheat during year									
	2	3	4	5	6	7	Mean	β	SYI	2	3	4	5	6	7	8	Mean	β	SYI
Groundwater irrigation (GW)																			
25	3.1	2.5	1.1	0.8	0.9	0.9	1.5	−0.66	0.17	3.6	3.1	2.5	1.6	1.7	1.8	1.7	2.3	−0.33	0.41
50	3.7	3.0	1.3	0.9	1.1	1.1	1.9	−0.64	0.18	4.1	4.1	2.9	2.1	1.9	2.3	2.2	2.8	−0.37	0.46
75	4.2	3.2	1.6	0.9	1.2	1.1	2.0	−0.55	0.16	4.5	4.5	3.2	2.5	2.3	2.5	2.3	3.1	−0.41	0.47
100	4.5	3.2	1.8	1.0	1.3	1.2	2.2	−0.46	0.17	4.9	4.6	3.2	2.8	2.5	2.4	2.3	3.3	−0.46	0.44
Mean	3.9	3.0	1.4	0.9	1.1	1.1	1.9	−0.58	0.17	4.3	4.1	2.9	2.3	2.1	2.2	2.1	2.9	−0.39	0.45
Sewage irrigation (SW)																			
25	4.1	3.2	1.4	1.0	1.2	1.2	2.0	−0.60	0.17	4.3	4.1	3.2	1.8	1.9	2.2	2.0	2.8	−0.44	0.39
50	4.5	3.8	1.6	1.3	1.4	1.3	2.3	−0.67	0.19	4.6	4.5	3.5	2.4	2.5	2.5	2.3	3.2	−0.42	0.47
75	4.9	3.4	2.4	1.3	1.4	1.6	2.5	−0.68	0.22	4.8	4.8	3.4	2.9	2.8	2.5	2.4	3.4	−0.44	0.49
100	5.3	4.2	2.5	1.3	1.5	1.4	2.7	−0.83	0.19	5.1	5.1	4.2	3.1	2.9	2.5	2.4	3.6	−0.52	0.48
Mean	4.7	3.6	1.9	1.2	1.4	1.3	2.4	−0.70	0.19	4.7	4.6	3.6	2.5	2.5	2.4	2.3	3.2	−0.45	0.46
LSD(p = 0.05)																			
WQ	0.4	0.5	0.5	0.2	0.2	0.1				0.9	0.3	0.5	0.4	0.2	0.4	0.3			
Fert.	0.5	0.4	0.7	0.2	0.2	0.3				0.5	0.2	0.7	0.3	0.2	0.3	0.4			
WQxFert	NS	NS	NS	NS	NS	NS				NS	NS	NS	NS	NS	NS	NS			

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012

Table 4
Fresh yield (Mg ha^{-1}) of vegetables as affected by sewage irrigation and NP fertilizers under vegetable production system (VPS).

Fertiliser (% NP)	Summer vegetables (Okra/Gourds) during the year							Winter vegetables (Cabbage/Cauliflower) during the year							
	2	3	4	5	6	7	Mean	2	3	4	5	6	7	8	Mean
Groundwater irrigation (GW)															
25	11.9	8.2	6.0	7.1	17.3	15.5	11.0	17.4	15.5	20.1	19.3	19.1	20.0	22.5	19.1
50	13.8	8.5	7.1	8.5	24.2	22.0	14.0	28.9	24.0	21.0	24.1	22.8	25.2	28.4	24.9
75	15.0	8.8	7.9	9.8	27.0	24.7	15.5	23.8	21.0	23.2	26.3	27.5	28.6	32.6	26.1
100	20.6	9.7	8.8	10.3	27.8	26.3	17.3	35.0	30.5	23.4	28.0	30.0	31.4	34.8	30.4
Mean	15.3	8.8	7.4	8.9	24.1	22.1	14.4	26.2	22.8	21.9	24.4	24.9	26.3	29.6	25.1
Sewage irrigation (SW)															
25	16.5	8.8	8.1	10.1	29.0	26.5	16.5	26.3	22.0	25.0	26.0	29.2	30.2	34.9	27.7
50	18.9	9.1	9.4	11.0	31.9	29.0	18.2	35.3	32.5	25.2	29.7	30.2	34.5	36.1	31.9
75	21.3	9.4	11.1	11.9	31.3	29.9	19.1	30.3	36.8	28.2	31.1	34.6	33.2	36.7	33.0
100	23.8	10.8	11.3	11.8	31.0	29.5	19.7	38.2	37.3	28.9	31.6	34.0	34.3	37.5	34.5
Mean	20.1	9.5	10.0	11.2	30.8	28.7	18.4	32.5	32.1	26.8	29.6	32.0	33.1	36.3	31.8
LSD($p = 0.05$)															
WQ	2.3	2.2	1.2	1.4	6.6	5.2		3.4	1.2	5.2	5.0	6.5	9.3	3.1	
Fert.	2.1	1.3	1.2	1.6	3.0	2.8		3.4	1.0	6.5	5.9	4.2	6.4	5.0	
WQxFert.	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	

considerably reduced with SW. The PFP of summer crops under FPS and VPS were 101 and 75 37 kg kg^{-1} NP, respectively and 91 and 37 kg kg^{-1} NP for winter crops. A decline in PFP was also noticed with increments in fertilizer NP particularly with GW. Considering the yields of crops obtained with 100% NP with GW as reference, the computations show that these yields could be attained with 36 and 50% fertilizer NP in paddy and wheat as sole crop; 18 and 40% NP in paddy and wheat under agroforestry; with 0 and 63% NP in fodder crops of Egyptian clover and sorghum and 22% NP in both bottle gourd and cabbage. Thus on an average, three-fifth, one-fourth, two-third and four-fifth saving in NP could be achieved with continuous SW compared with GW in FGPS, AFS, FPS and VPS, respectively.

The paddy–wheat equivalent yield (PWEY), calculated considering the financial value of produce from paddy and wheat as unity, also differed distinctly for various cropping systems. The highest PWEY (21.6) was recorded for VPS with SW and 100% NP while the average values with GW and SW were 15.5 and 19.9, respectively. Though, the productivity of paddy and wheat was quite low under AFS, the PWEY averaged 5.3 times when the price of Poplar trees was added. Even the PWEY was about 1.7 times under FPS. Considerable improvements in PWEY were monitored with NP fertilizers especially in VPS where these increased from 12.0 to 19.0 under GW and from 17.5 to 21.6 under SW.

3.3. *Produce and soil quality*

Pathogens present in wastewaters usually adhere to the surface or penetrate in the produce and even multiply depending on prevailing conditions. Aerobic plate counts and the number of coliform bacteria for marketable parts of crops and vegetables raised on sewage irrigated soils are given in Table 7. The aerobic bacterial plate counts were highest in vegetables followed by fodders and grain crops. Similarly, the vegetables especially gourds coming in direct contact with sewage had the maximum coliform contamination (7×10^5 MPN 100 g^{-1}) followed by Egyptian clover (3.5×10^5 MPN 100 g^{-1}) and it was least in grain of food crops ($<2 \times 10^2$ MPN 100 g^{-1}). Wastewater irrigation also affected the keeping quality though other physiological parameters like compactness; weight loss etc. remained unaffected (Table 8).

Nevertheless, marked improvements in the produce quality were monitored with SW in terms of protein and micronutrient contents (Table 9). The protein content in grains of wheat irrigated with GW averaged 10.5 and 9.9% under FGP and AFP system while it was 8.4 and 8.5% in paddy grains, respectively. The contents increased to 11.5 and 10.8% in wheat and 8.9 and 9.0% in paddy irrigated with SW (Table 9). Since the protein content is being given on fresh weight basis of edible parts, its values seems to

Table 5
Fodder yield (Mg ha^{-1}) of sorghum and Egyptian clover as affected by sewage irrigation and NP fertilizers under fodder production system (FPS), their trend values (β) and their sustainability yield index (SYI).

Fertiliser (% N P)	Sorghum fodder during the year									Egyptian clover during the year							
	2	3	4	5	6	7	8	β	SYI	4	5	6	7	8	Mean	β	SYI
Groundwater irrigation (GW)																	
25	29.6	30.9	51.4	48.5	52.5	44.1	42.8	-1.81	0.64	69.5	59.7	63.0	59.6	59.5	65.6	-2.01	0.81
50	33.2	36.3	60.5	56.3	61.0	52.0	49.9	-2.07	0.62	71.3	63.7	66.5	60.8	63.1	68.9	-1.93	0.81
75	37.8	39.8	66.8	59.6	64.7	57.0	54.3	-2.40	0.63	72.3	66.9	71.7	62.7	64.9	70.3	-1.88	0.84
100	40.5	43.9	73.3	64.6	65.9	64.2	58.7	-2.59	0.62	74.0	66.8	75.4	61.1	67.2	72.8	-1.93	0.78
Mean	35.3	37.7	63.0	57.3	61.0	54.3	51.4	-2.22	0.63	71.8	64.3	69.1	61.0	63.7	69.4	-1.94	0.81
Sewage irrigation (SW)																	
25	34.0	36.4	62.4	55.9	66.2	56.1	51.8	-0.85	0.61	75.5	73.6	78.5	70.4	70.7	74.6	-1.28	0.94
50	40.0	39.0	67.8	60.0	69.7	60.8	56.2	-1.14	0.63	74.0	76.5	86.0	72.0	69.1	78.0	-1.43	0.85
75	37.3	40.9	76.3	66.0	73.0	69.6	60.5	-1.30	0.57	76.3	74.3	84.0	75.0	72.4	77.4	-0.70	0.96
100	43.3	45.8	81.0	70.3	73.4	71.3	64.2	-2.59	0.60	84.0	77.3	88.5	75.8	71.9	82.3	-2.58	0.84
Mean	38.6	40.5	71.9	63.1	70.6	64.4	58.2	-1.47	0.60	77.4	75.4	84.2	73.3	71.0	78.1	-1.50	0.90
LSD ($p = 0.05$)																	
WQ	3.2	3.7	5.2	9.7	11.2	2.9				5.2	9.2	7.2	3.2	8.5			
Fert.	4.0	4.5	6.5	5.7	3.4	7.6				6.5	NS	4.8	3.5	6.9			
WQxFet.	NS	NS	NS	NS	NS	NS				NS	NS	NS	NS	NS			

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012

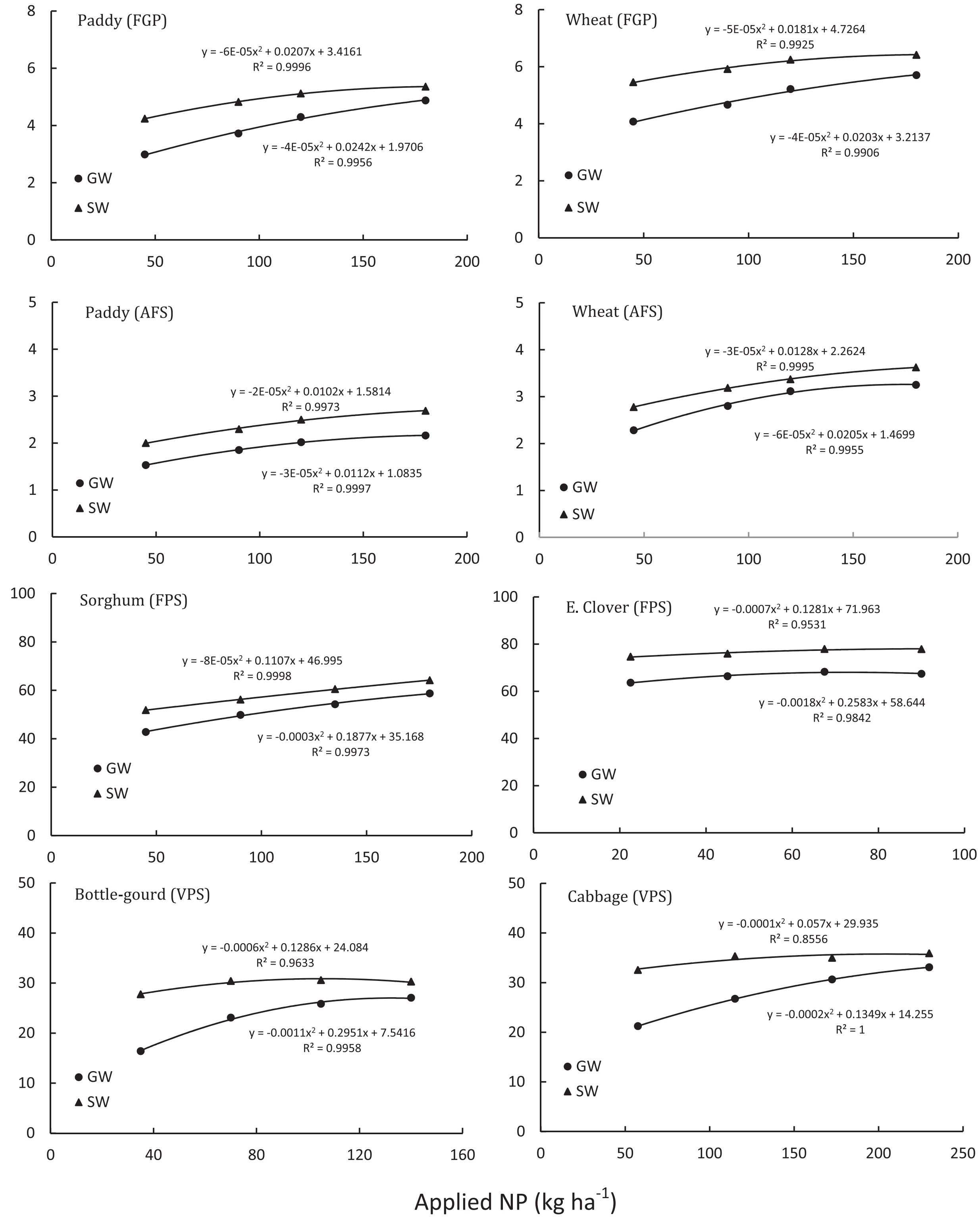

Fig. 3. Average response of crops (Mg ha^{-1}; 2000–2008) to fertilizer NP rates.

be low and these ranged between 2.59 and 2.80, 1.68 and 1.85, 1.70 and 1.87, 0.74 and 0.85% in Egyptian clover, sorghum, winter and summer vegetables, respectively but the contents were relatively higher with SW. Crude protein in wheat and paddy grains also improved with fertilizer doses and was the maximum with 100% recommended doses of NP under SW while it was not affected in fodder and vegetable crops. The contents of Zn, Cu, Fe and Mn also improved with sewage irrigation (Table 10). But being domestic sewage, the contents of toxic metals like Cd, Pb, Ni, Cr were very low and also remained below traceable levels in the produce.

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012

Table 6
Partial factor productivity (PFP, kg kg^{-1} NP) and paddy-wheat equivalent yields (PWEY) for different cropping sequences and nutrient rates.

Fertilizer (% NP)	PFP (kg kg^{-1} fertilizer)				PWEY	
	Summer crop		Winter crop		GW	SW
	GW	SW	GW	SW		
Food grain production system (FGPS)						
	Paddy		Wheat			
25	19.2	16.2	22.6	18.3	0.7	0.9
50	16.2	13.3	19.4	15.6	0.8	1.0
75	16.7	12.7	19.4	14.2	0.9	1.1
100	13.8	9.4	16.2	10.8	1.0	1.1
Mean	16.5	12.9	19.4	14.7	0.8	1.0
Agroforestry system (AFS)						
	Paddy		Wheat			
25	9.9	9.3	18.1	11.5	5.2	5.4
50	8.5	8.0	14.8	10.3	5.2	5.5
75	7.8	7.7	13.7	9.3	5.3	5.5
100	6.0	6.2	9.9	7.6	5.3	5.5
Mean	8.1	7.8	14.1	9.7	5.2	5.5
Fodder production system (FPS)						
	Sorghum		Clover			
25	170	107	223	119	1.4	1.6
50	164	102	172	89	1.5	1.7
75	141	100	143	89	1.6	1.8
100	131	95	98	66	1.7	1.9
Mean	152	101	159	91	1.6	1.8
Vegetable production system (VPS)						
	Gourd		Cabbage			
25	253	105	121	45	12.0	17.5
50	222	90	109	47	15.3	19.8
75	174	62	95	29	16.5	20.7
100	139	44	82	26	19.0	21.6
Mean	197	75	102	37	15.7	19.9

4. Discussion

Wastewater irrigation by the small holders of peri-urban areas of developing countries is increasing with their volumes, but the assessment of the livelihood benefits and the losses continue to be complex. Ideally sustainable irrigation with wastewaters, in addition to their effluent quality, requires information on a number of parameters like crop types, soil quality and climatic considerations.

Table 7
Mean values of micro flora on marketable produce of sewage irrigated crops.

Cropping system	Crop	Bacteria (cfu g^{-1})	Faecal Coliforms (MPN 100 g^{-1})	Fungi (cfu g^{-1})
Food grain				
	Wheat	5×10^5	$<2 \times 10^2$	Nil
	Paddy	7×10^5	$<2 \times 10^2$	Nil
Fodder				
	Egyptian clover	3×10^7	3.5×10^5	3×10^5
	Sorghum	2×10^7	7×10^2	2×10^3
Vegetables				
	Cauliflower	7×10^7	3×10^4	2.4×10^4
	Cabbage	4.2×10^8	3.2×10^3	Nil
	Okra	5.8×10^6	$<2 \times 10^2$	3.8×10^5
	Ridge-gourd	3×10^7	7×10^5	3.7×10^7

Table 8
Physiological parameters for crop quality as affected by sewage irrigation.

Crops	Compactness (g cm^{-3})		ADPWL (%)		ADDL (%)	
	SW	GW	SW	GW	SW	GW
Cabbage	0.98	0.89	9.92	10.38	7.46	6.88
Cauliflower	1.08	1.12	9.48	8.84	9.18	8.56
Okra	0.84	0.88	6.37	7.12	5.69	5.28
Ridge gourd	0.93	0.91	9.95	10.14	9.72	9.41
Bottle gourd	1.18	1.07	7.82	8.17	8.98	8.12
Spinach	1.23	1.28	14.35	13.28	16.38	15.06
Sorghum	–	–	12.79	11.91	14.24	12.32
Clover	–	–	15.64	14.88	19.12	16.21
Mean	1.04	1.03	10.79	10.59	11.35	10.23

ADPWL: Average daily physiological weight loss for 10 days; ADDL: Average daily decay loss (%) of fresh weight for 5 days.

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012

Table 9
Protein content (%) of economic parts of crops as affected by sewage irrigation and nutrient rates.

Fertilizer (% NP)	Food Grains		Agro-forestry		Fodder		Vegetables	
	Wheat grain	Rice grain	Wheat grain	Rice grain	Clover (Plant)	Sorghum (Plant)	Cabbage/Cauliflower	Okra/Gourd
Groundwater (GW)								
25	9.97	8.11	9.60	8.14	2.59	1.70	1.80	0.74
50	10.45	8.22	9.79	8.35	2.62	1.68	1.79	0.76
75	10.69	8.62	10.01	8.68	2.60	1.70	1.76	0.77
100	10.84	8.75	10.18	8.78	2.59	1.73	1.70	0.79
Mean	10.49	8.43	9.90	8.49	2.60	1.70	1.76	0.77
Sewage water (SW)								
25	11.14	8.79	10.69	8.89	2.75	1.78	1.75	0.82
50	11.27	8.74	10.77	8.98	2.74	1.81	1.78	0.84
75	11.68	9.02	10.83	8.98	2.73	1.84	1.84	0.84
100	11.74	9.11	10.91	9.08	2.80	1.85	1.87	0.85
Mean	11.46	8.92	10.80	8.98	2.76	1.82	1.81	0.84
LSD ($p = 0.05$)								
WQ	0.33	0.22	0.20	0.16	0.08	0.03	NS	0.04
Fert.	0.35	0.13	0.28	0.11	NS	NS	NS	NS
WQxFert.	NS	0.18	NS	0.15	NS	NS	0.13	NS

Table 10
Metal contents (mg kg^{-1}on dry wt. basis) in crops grown with sewage (SW) and groundwater (GW).

Cropping system	Crop	Part	Zn		Cu		Fe		Mn	
			SW	GW	SW	GW	SW	GW	SW	GW
Food grain	Wheat	Grain	37 ± 5	29 ± 5	19 ± 3	17 ± 4	176 ± 20	134 ± 16	68 ± 10	62 ± 8
		Straw	46 ± 8	39 ± 6	14 ± 3	10 ± 2	123 ± 16	130 ± 14	56 ± 7	47 ± 5
	Paddy	Grain	31 ± 4	27 ± 5	22 ± 5	19 ± 3	142 ± 15	134 ± 11	76 ± 8	89 ± 11
		Straw	46 ± 7	43 ± 6	18 ± 5	12 ± 4	102 ± 10	89 ± 10	144 ± 20	121 ± 15
Agroforestry	Wheat	Grain	31 ± 6	34 ± 7	20 ± 5	16 ± 3	193 ± 21	154 ± 13	58 ± 9	55 ± 5
		Straw	51 ± 7	43 ± 5	12 ± 3	12 ± 2	138 ± 16	120 ± 25	52 ± 10	49 ± 6
	Paddy	Grain	37 ± 6	32 ± 4	18 ± 5	19 ± 3	135 ± 15	121 ± 10	80 ± 10	86 ± 12
		Straw	41 ± 8	33 ± 7	20 ± 5	15 ± 3	122 ± 10	111 ± 11	128 ± 15	125 ± 15
Fodder	Clover	Plant	38 ± 6	37 ± 8	9 ± 3	8 ± 2	590 ± 66	603 ± 50	27 ± 5	22 ± 3
	Sorghum	-do-	29 ± 4	26 ± 4	7 ± 2	7 ± 2	96 ± 15	84 ± 9	38 ± 5	33 ± 6
Vegetable	Cabbage	Boll	62 ± 8	53 ± 6	19 ± 5	15 ± 3	286 ± 52	234 ± 40	36 ± 6	26 ± 3
	Cauliflower	Curd	53 ± 10	46 ± 6	11 ± 4	9 ± 2	228 ± 25	210 ± 18	25 ± 4	24 ± 5
	Okra	Fruit	34 ± 5	28 ± 5	16 ± 4	13 ± 3	216 ± 22	194 ± 17	48 ± 9	33 ± 7
	Gourds	-do-	37 ± 7	28 ± 6	13 ± 3	10 ± 3	88 ± 15	73 ± 11	22 ± 6	19 ± 4

However, little information is available on these aspects due to general lack of systematic and long term experimental data. The worldwide inferences are usually based on surveys on wastewater-related activities which indicate that these waters, because of ready availability, are used for all types of cereal, vegetable and fodder crops, fruit orchards and floriculture (Minhas and Samra, 2004; Scott et al., 2004; Raschid-Sally and Jayakody, 2008; Murtaza et al., 2010; Qadir et al., 2010). Vegetable crops are by far the commonest, because these provide quick and high economic returns to peri-urban farmers. The long-term crop yields obtained in terms of the paddy-wheat equivalent yields (PWEY) under this experiment were also the maximum in VPS (19.9*PWEY) followed by the AFS(5.5*PWEY) and even the performance of FPS was better (1.8*PWEY) than the most prevalent FGPS in the area. Sewage enhances production of vegetables because of abundance of organic matter and nutrients. Leafy vegetables like cauliflower, cabbage, spinach, etc. show luxurious growth when irrigated with sewage water (Murtaza et al., 2010), therefore are preferred in peri-urban agriculture. A yield advantage of 20–25% in vegetable yields from wastewater irrigation at farmers' fields in Karnataka, India was recorded by Bradford et al. (2003). In another case study on wastewater use along Musi river of Hyderabad, cultivation of fodder and vegetables was more remunerative than the other crops and dairy mainly because of their shorter self-life and proximity to the market (Keremane, 2009). Market demand of the area also plays a key role in shaping the choice of crops e.g. with the influence of high industry, high labour costs and unavailability of labour caused a shift in cropping from paddy to fodder production (Mahesh et al., 2015)

Another well-established advantage of wastewater is their nutrient content and recycling of organic matter. The nutrients of major concern in recycled water are nitrogen and phosphorus. The nutrients contained in SW boosted the growth of plants and resulted in improvement in the crop productivity by 22, 14, 18, and 28% in FGPS, AFS, FPS and VPS, respectively. While the trends in productivity were negative even with optimal levels of NP with GW, the sustainability yield index (SYI) was better with SW irrigation. The overall improvements in yields of crops irrigated with sewage waters have been reported earlier (Chakrabharti, 1995; Minhas and Samra, 2004; Drechel et al., 2010). However, in a long term (25–30 years) field study from Pakistan, Simmons et al. (2010) reported no effect of wastewater irrigation on wheat yields because of elevated soil electrical conductivity. Plants irrigated with SW may also suffer due to nutrient imbalances, especially with inducement of succulence with excessive nitrogen supplies and thereby, these becoming prone to damage by lodging with wind throw and pathogens (Minhas and Samra, 2004). But such damage was not apparent during this long term experiment except that lodging of wheat did occur during second year of cropping. Almost all the crops also showed considerable response to the applied NP. The partial factor productivity (PFP) averaged 15.6, 11.1, 155.5 and 149.5 kg kg^{-1} NP with GW in FGPS, AFS, FPS and VPS, respectively. But with enrichment of soils with nutrients, PFP with SW irrigation was reduced to 13.8, 8.8, 96.0 and 56.0 kg kg^{-1} NP, respectively. The production functions developed with long term data indicate saving in NP fertilizer with SW to the extent of 80, 75, 66 and 20% of those recommended for GW irrigated soils in case of VPS,

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012

GPS, FPS and AGF, respectively. Gog-Raj et al. (2006) has earlier reported the response to N vis-a-vis saving in nitrogen to depend upon the accumulated organic carbon contents in soils as a result of sewage irrigation. However, to be on safer side, farmers often go in for fertilisers as recommended for normal water irrigated soils. This demands for proper guidelines and awareness of the growers regarding the adjustment of inorganic fertilisers considering the composition of wastewater used for irrigation.

It is also generally feared that the excessive concentrations of nutrients especially the nitrogen and some of the toxic elements lower the quality of produce with sewage irrigation (Jimenez, 2006; Qadir et al., 2007; Minhas and Lal, 2010). However, the changes in quality of the produce with SW remained non-significant; rather there were improvement in the contents of protein and the micronutrients as well. Since the sewage water was of domestic origin the toxic elements were also not traceable in produce. Nevertheless, the pathogenic contamination was recorded in produce coming in direct contact e.g. gourds, fodders. But the pathogens being exo-genic, the adaption of low cost farm based options for their reductions can be quite effective in lowering their levels within the permissible limits (Minhas et al., 2006; Keraita et al., 2007). Moreover, measures like regulating crops e.g. avoiding crops where edible portion is eaten raw, and shift to drip irrigation system have been recommended to minimize pathogenic effects (WHO, 2006; Levy et al., 2011).

5. Conclusions

Wastewater irrigation is now widespread and growing further in developing countries but carries varying degree of risks. The 8-year performance of various cropping sequences corroborates that due to near ness to the markets, peri-urban farmers risk for the perishable but high value vegetable production e.g. PWEY averaged 19.9. The other option can be the agro-forestry systems (5.5 × PWEY) with additional benefits of environmental sanitation and eco-restoration but the peri-urban farmers seem to prefer fodder production (1.8 × PWEY) for better returns from urban livestock. The wastewaters have considerable nutrient-supplying capacity and thereby fertilisers have to be adjusted accordingly. Experimental evidences generated further show that at least half the NP fertilisers can be saved with sewage irrigation though the proportions would vary with cropping sequence. Thus the awareness of the growers to adjust NP fertilisers would not only reduce the production costs but also the potential of environmental pollution. To make wastewater irrigation safer from pathogens, both on and off-farm interventions should be of help. Continued research and development on these aspects should further help in increasing the use of wastewater for irrigation and address the environmental concerns of the general public.

Acknowledgments

Experiment was a part of the Mission Mode Project “Use of urban and industrial effluents in agriculture’ funded under National Agricultural Technology Project by Indian Council of Agricultural Research, New Delhi. The financial help is thankfully acknowledged. The authors are also grateful for the technical help and assistance rendered by Sh. N.S. Ahalawat, Sh. Jagdish Arora, Sh. Ajay Kumar and others from CSSRI, Karnal.

References

Bradford, A., Brook, R., Hunshal, C.S., 2003. Wastewater irrigation in Hubli–Dharwad, India: implications for health and Livelihoods. Environ. Urban 15, 157–170.

Chakrabharti, C., 1995. Residual effects of long-term land application of domestic wastewater. Environ. Int. 21, 333–339.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D., Savelli, H. (Eds.), 2010. Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal.

Dawe, E., Dobermann, A., 1999. Defining Productivity and Yield, IRRI Discussion Papers, Series, No. 33, IRRI, Los Banos, Philippines.

Drechel, P., Scott, C.A., Rachid, L., Redwood, M., Bahri, A. (Eds.), 2010. Wastewater Irrigation and Health. Earthscan, London, UK, p. 404.

Erni, M., Drechsel, P., Bader, H., Scheidegger, R., Zurbruegg, C., Kipfer, R., 2010. Bad for the environment, good for the farmer? Urban sanitation and nutrient flows. Irrig. Drain. Syst. 24, 113–125.

Friedel, J.K., Langer, T., Stahr, K., 2000. Effects of long-term waste water irrigation on soil organic matter, soil microbial biomass and its activities in central Mexico. Biol. Fertil. Soils 31, 414–421.

Gog-Raj, Tiwari, S., Minhas, P.S., 2006. Response of sewage irrigated wheat (*Triticum aestivum* L.) to levels and timing of nitrogen application. Ind. J. Agron. 51, 46–48.

Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research, 2nd ed. John Willey & Sons, New York.

Hoeks, W., Hassan, vander., Ensink, U.I., Feenstra, J., Raschid-Sally, S., Munir, S., 2002. Urban Wastewater: A Valuable Resource for Agriculture. IWMI Report No. 63, Colombo, Sri Lanka.

Janssen, B.H., Boesveld, H., Rodriguez, M.J., 2005. Some theoretical considerations on evaluating wastewater as a source of N, P and K for crops. Irrig. Drain. 54 (S1), S35–S47.

Jimenez, B., 2006. Irrigation in developing countries using wastewater. Int. Rev. Environ. Strateg. 6, 22–33.

Keraita, B., Konradsen, F., Drechsel, P., Abaidoo, R.C., 2007. Reducing microbial contamination on wastewater-irrigated lettuce by cessation of irrigation before harvesting. Trop. Med. Int. Health 12 (Suppl. 2), 8–14.

Keremane, G.B., 2009. Urban wastewater use for irrigation: a case study of farmers along Musi river in Hyderabad. Karnataka J. Agric. Sci. 22, 235–237.

Levy, G.J., Pinchas, F., Bar-Tel, A., 2011. Treated Wastewater in Agriculture: Use and Impacts on Soil Environment and Crops. Wiley-Blackwell, West Sussex, UK, pp. 446.

Mahesh, J., Amersinghe, P., Pavelic, P., 2015. An integrated approach to assess the dynamics of peri-urban watershed influenced by wastewater irrigation. J. Hydrol. 523, 427–440.

Minhas, P.S., Lal, K., 2010. Urban wastewater for irrigation: contamination by heavy metals. In: Lal, R. (Ed.), Encyclopaedia of Soil Science. , 2nd ed. Taylor & Francis, New York, 1:1, 1–4.

Minhas, P.S., Samra, J.S., 2004. Wastewater Use in Peri-urban Agriculture: Impacts and Opportunities. Central Soil Salinity Research Institute, Karnal, India, pp. 75.

Minhas, P.S., Sharma, N., Yadav, R.K., Joshi, P.K., 2006. Prevalence and control of pathogenic contamination in some sewage irrigated vegetable, forage and cereal grain crops. Bioresour. Technol. 97, 1174–1178.

Murtaza, G., Gafoor, A., Qadir, M., Owenes, G., Aziz, A., Zia, M.H., Saifullah, 2010. Disposal ans use of sewage on agricultural lands in Pakistan. A review. Pedosphere 20 (1), 23–34.

Paranychianakis, N.V., Angelakis, A.N., Leverenz, H., Tchobanoglous, G., 2006. Treatment of wastewater with slow rate systems: a review of treatment processes and plant functions. Crit. Rev. Environ. Sci. Technol. 36, 187–259.

Qadir, M., Wichelns, D., Raschid, L.R., Minhas, P.S., Drechsel, P., Bahri, A., McCornick, P., 2007. Agricultural use of marginal-quality water: opportunities and challenges. In: Molden, D. (Ed.), Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan, London, UK.

Qadir, M., Wichelns, D., Sally, L.R., McCornick, P.G., Drechsel, P., Bahri, A., Minhas, P.S., 2010. The challenges of wastewater irrigation in developing countries. Agric. Water Manage. 97, 561–568.

Raschid-Sally, L., Jayakody, P., 2008. Drivers and Characteristics of Wastewater Agriculture in Developing Countries: Results From a Global Assessment. IWMI Research Report 127. International Water Management Institute, Colombo, Sri Lanka.

Rattan, R.K., Datta, S.P., Chhonkar, P.K., Suribabu, K., Singh, A.K., 2005. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater – a case study. Agric. Ecosyst. Environ. 109, 310–322.

Scott, C.A., Faruqui, N.I., Raschid-Sally, L., 2004. Wastewater use in irrigated agriculture: management challenges in developing countries. In: Scott, C.A., Faruqui, N.I., Raschid-Sally, L. (Eds.), Wastewater Use in Irrigated Agriculture. CABI Publishing, UK.

Simmons, R.W., Ahmad, W., Noble, A.D., Blummel, M., Evans, A., Weckenbrock, P., 2010. Effect of long-term un-treated domestic wastewater re-use on soil quality, wheat grain and straw yields and attributes of fodder quality. Irrig. Drain. Syst. 24, 95–112.

Singh, R.P., Das, S.K., Rao, U.M.B., Reddy, M.N., 1990. Towards Sustainable Agricultural Practices, Bulletin. Central Research Institute on Dryland Agriculture, Hyderabad, pp. 5–9.

Subba-Rao, N.S., 1986. Biofertilizers in Agriculture. Oxford and IBH Publishing Co., New Delhi, pp. 178.

WHO, 2006. Guidelines of the Safe Use of Wastewater, Excreta and Grey Water: Wastewater Use in Agriculture, vol. 2. World Health Organization, Geneva, Switzerland.

Yadav, R.K., Goyal, B., Sharma, R.K., Dubey, S.K., Minhas, P.S., 2002. Post-irrigation impact of domestic sewage effluent on composition of soils, crops grown there upon & ground water – a case study. Environ. Int. 28 (6), 481–486.

Please cite this article in press as: Minhas, P.S., et al., Long term impact of waste water irrigation and nutrient rates: I. Performance, sustainability and produce quality of peri urban cropping systems. Agric. Water Manage. (2015), http://dx.doi.org/10.1016/j.agwat.2015.03.012