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

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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

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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 ± 0.3 × 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