Achieving Sustainable Agriculture with Treated Municipal Wastewater

Reshu Yadav, Himanshu Joshi, S. K.Tripathi

***Abstract*—**A pilot field study was conducted at the Jagjeetpur Municipal Sewage treatment plant situated in the Haridwar town in Uttarakhand state, India. The objectives of the present study were to study the effect of treated wastewater on the production of various paddy varieties (Sharbati, PR-114, PB-1, Menaka, PB1121 and PB 1509) and the emission of GHG gases (CO_2, CH_4 and N_2O) as compared to the same varieties grown in the control plots irrigated with fresh water. Of late, the concept of water footprint assessment has emerged, which explains enumeration of various types of water footprints of an agricultural entity from its production to processing stages. Paddy, the most water demanding staple crop of Uttarakhand state, displayed a high green water footprint value of 2474.12 m^3/ Ton. Most of the wastewater irrigated varieties displayed up to 6% increase in production, except Menaka and PB-1121, which showed a reduction in production (6% and 3% respectively), due to pest and insect infestation. The treated wastewater was observed to be rich in Nitrogen (55.94 mg/ml Nitrate), Phosphorus (54.24 mg/ml) and Potassium (9.78 mg/ml), thus rejuvenating the soil quality and not requiring any external nutritional supplements. A Percentage increase of GHG gases of irrigation with treated municipal wastewater as compared to control plots was observed as 0.4% - 8.6% (CH_4), 1.1% - 9.2% (CO_2), and 0.07% - 5.8% (N_2O). The variety, Sharbati, displayed maximum production (5.5 ton/ha) and emerged as the most resistant variety against pests and insects. The emission values of CH_4, CO_2 and N_2O were 729.31 mg/m^2/d, 322.10 mg/m^2/d and 400.21 mg/m^2/d in water stagnant condition.

This study highlighted a successful possibility of reuse of wastewater for non-potable purposes offering the potential for exploiting this resource that can replace or reduce the existing use of fresh water sources in agriculture sector.

***Keywords*—**Greenhouse gases, nutrients, water footprint, wastewater irrigation.

I. Introduction

FRESH water is a scarce resource that is essential for humans and ecosystems, but its distribution is uneven. Agricultural production accounts for 70% of all surface water supplies. It is projected that against the expansion in the area equipped for irrigation by 0.6% per year, the global potential irrigation water demand would rise by 9.5% during 2021-25 [1]. This would, on one hand, have to compete against the sharply rising urban water demand. On the other, it would also have to face the fear of climate change, as temperatures rise, and crop yields could drop from 10-30% in many large areas. The huge demand for irrigation combined with fresh water scarcity encourages to explore the reuse of wastewater as a resource [2]. However, the use of such wastewater is often linked to the safety issues when used non-judiciously or with poor safeguards while irrigating food crops. Paddy is the most widely cultivated crop and a staple food for about 3 billion people in the world [3]. It has been reported that South and South-East Asia may suffer economic water scarcity for approximately 22 million ha of irrigated dry-season paddy fields by 2025 [4] and that most countries have suffered from a limited water supply, including agricultural irrigation water, due to factors like population growth, urbanization, and economic development [5]. Considering that Paddy production requires large amounts of water, reclaimed wastewater can be thought as an alternative water source for supplementary irrigation in areas that suffer from water shortages or unsatisfactory water quality since agricultural irrigation water is not usually required to meet same high standards of water quality as the drinking water [6]-[8]. In view of this, guidelines have been developed by Ministry of Environment and Forestry (MOEF) and Central Pollution Control Board (CPCB), Govt.of India, which have now broadly been adopted for irrigating field crops in India. Few reports of practical wastewater reuse for paddy cultivation in lowland areas have been presented [6]-[10], while case studies for paddy cultivation in upland areas have been reported in many countries [8]. Reuse of treated wastewater reduces effluent discharges into receiving waters and offers a reliable water supply for applications that do not require high-quality water, thus freeing up otherwise limited potable water resources [11]. Wastewater reuse is advantageous for many reasons [12], including tackling water scarcity in arid and semi-arid areas, avoiding the high energy cost of advanced wastewater treatments, and also the surface water pollution due to direct discharge of wastewater effluents [13]. Compared with other types of water reuse, employing wastewater effluents in agriculture presents the additional benefit of nutrient recycling in crop irrigation [14]. There have been numerous examples showing successful usage of recycled agricultural wastewater over the past few decades [15]-[17]. A central theme in the planning and practice of wastewater reuse in agriculture has been an assessment of the associated risks to humans, as it is unanimously accepted that there are some elements of risk in every practice of wastewater reuse [18]. Trace elements that are potentially harmful to human health, such as heavy metals (cadmium, copper, lead, selenium, zinc), could be found in treated municipal wastewater effluents. Furthermore,

Reshu Yadav is with the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee- 247667, Uttarakhand , India (e-mail: reshudwt@iitr.ac.in).

Himanshu Joshi, is with Department of Hydrology, Indian Institute of Technology Roorkee -247667,Uttarakhand , India (Corresponding Author Phone : 91-1332-285390 Fax : 91-1332-285707; e-mail : joshifhy@iitr.ac.in).

S.K.Tripathi is with the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee - 247667, Uttarakhand, India (e-mail: sankufwt@iitr.ac.in).

wastewater irrigation may exceed the nitrogen and phosphorous requirements of many crops during the growing season. Wastewater applied in conditions when the plant nutrient needs are low or fertilizers have been added to crops, could affect ripeness, cause nitrate leaching and possible nitrate contamination of groundwater. In addition, it is necessary to consider different crops and quality of different types of recycled wastewater based on their source or treatments.

The objectives of this study were to investigate the characteristics of the treated municipal wastewater used for irrigation and the effect of treated wastewater in the production of various paddy varieties (Sharbati, PR114, PB1, Menaka, PB 1121 and PB 1509) and the emission of GHG gases (CO_2, CH_4 and N_2O) as compared to the same varieties grown in the control plots irrigated with fresh water.

II. Materials and Methods

The experimental paddy plots were located near the Jagjeetpur wastewater treatment plant in Haridwar, India (longitude 78.04 ^oE and latitude 30.19 ^oN). A randomized complete block designed plot arrangement was used for two treatments and three replicates for six rice varieties with 2m*2m plots. The two treatments indicated the different type of irrigation water used for plots (TR#1 provided treated wastewater and TR#2 provided ground water). For this experiment, 25 day old seedlings (Sharbati, PR 114, PB 1, Menaka, PB 1121 and PB 1509) were transplanted into study plots in June and harvested in October during the study period. Fertilizers are typically applied three times, during the pre-plant, tilling and panicle growing stages, but in this study, they were applied only at the pre-plant stage (N: P: K = 120:60:60 kg/ha) based on high-nutrient-concentration irrigation. Insecticides and pesticides were sprayed as and when required at various plant stages, and weeds were controlled manually. This study was conducted for three crop years from 15 June 2012 to 21 October 2014.

A. Water Footprint of Paddy

As described by Hoekstra et al, (2009), the sum of the blue (WF_{blue}), green (WF_{green}) and grey (WF_{grey}) water footprints contributes towards the total water footprint of an agricultural production process (WF_{proc}). The total water footprint is expressed in terms of volume per mass of product water so that the source and magnitude of consumption in terms of volume may be distinguished.

$$WFproc, blue = \frac{CWUblue}{Y} \quad (1)$$

$$WFproc, green = \frac{CWUgreen}{Y} \quad (2)$$

where *WFproc* is the process water footprint of growing crop (m^3/ton), *CWU* is crop water use (m^3/ton) and *Y* is the crop yield (ton /ha) as shown in (1) and (2).

The evapotranspiration rate of a crop in consideration under a specific climate of the agricultural region of the study is required for calculating 'Crop water use'. CROPWAT 8.0 and CLIMWAT 2.0 developed by the Food and Agricultural Organization of the United Nations (FAO) were used to get the site-specific information. Precipitation data, crop growth inputs and general soil data were taken by CROPWAT from CLIMWAT in suitable conditions to calculate crop water requirements over a complete length of growing period of the crop. Blue and green water footprints could be obtained after incorporating all yields and variables in the CROPWAT program. The last step of accounting blue and green water foot printing was accomplished by summing up blue and green water stored in the physical harvested crop. Quantification of the grey water footprint is quite different from for blue and green water. In case of paddy production, the grey water component of the total water footprint was calculated as follows [19].

$$WFproc, grey = \frac{(\alpha * AR)/(C\max - Cnat)}{Y} \quad (3)$$

where WFproc is the process water footprint of growing crop (m^3/ton), α is dimension less factor for leaching runoff, AR chemical application rate (Kg/ha), C_{max} is the maximum acceptable concentration of chemical (Kg/m^3), C_{nat} is a natural concentration of chemical (Kg/m^3) and Y is crop yield (ton/ha) in (3).

The sum of green (WF_{green}), blue (WF_{blue}) and grey (WF_{grey}) water footprints yielded the total water footprint of an agricultural production process (WF_{proc}).

B. Crop Growth Data

The growing stages of rice were recorded by measuring the crop height, leaf area index (LAI) and dry matter. The plant height was measured from the soil surface to the top of the straightened shoot/leaf. Leaf area was measured for two plant hills in each plot. At the time of harvesting, crop cutting experiment was conducted. After manual threshing, the grain and straw weights were monitored.

C. Green House Gases Estimation

To estimate the greenhouse gas emission from different paddy varieties grown under two treatments, the gas samples were collected in tedlar bags from the acrylic gas chamber (length 40cm, width 40 cm and height 65cm) fitted over the crop grown plots after 30 days of rice transplantation on a weekly basis. Methane and nitrous oxide emission rates were determined at a 0.5 h interval for 1.0 h by measuring the changes of methane and nitrous oxide concentrations (the net change between greenhouse gas emission and sink) in the acrylic chamber. Methane and nitrous oxide were analyzed by gas chromatography using FID and ECD, respectively [20], [21].

$$F = (V/A)\ (\triangle C/\triangle t) \quad (4)$$

where *F* is the methane or nitrous oxide emission rate (mg/m^2/h), **V** is the volume of chamber above soil (m^3), *A* is the cross-section of chamber (m^2), $\triangle C$ is the concentration difference between zero time and time t (mg/m^3), and Δt is the time duration between two sampling periods (h).

III. Results and Discussion

Uttarakhand state lies in the agro ecological zone no. 4 and 11. More than 70% of the state population are involved in agriculture for its livelihood; Uttarakhand being an agricultural state. The area under cultivation is 14.02% within the total reported area, out of which more than 55% is the rain-fed land, where cropping intensity is 160.6%. However, the land holding is small and exists in patches over the slopes. The values of green, blue and grey water footprint of paddy for the Haridwar district are tabulated in Tables I and II respectively. The water footprint of paddy crop for Haridwar district clearly indicates the dependence of farmers on green water i.e., rain-fed irrigation and the total water footprint value is 3506.71m^3/ton, which supports that its irrigation demand is very high. The treated wastewater from the Jagjeetpur municipal wastewater treatment plant is a rich source of nutrients as depicted in the Table III, which fulfills all the nutrient requirements of the plants, thus restricting the use of synthetic fertilizers in agriculture. As shown in Table IV, the yield increased in all the paddy varieties with the higher values shown in Sharbati, Menaka, PR 114 and PB 1, and relatively lower values shown in PB 1121 and PB 1509. Out of all the six paddy varieties, the most stable variety came out to be Sharbati, whose yield was maximum and which was resistant to diseases and infestation caused by pests and insects. In terms of greenhouse gas emissions from various varieties under different water treatments the percentage increase of CH4, CO_2 and N_2O for all six paddy varieties is shown in Table V.

TABLE I
Overview of All Major 'Green' and 'Blue' Components of the Water Footprint of Haridwar District of Uttarakhand

Parameters	Values
Product	Paddy
ET_{Green} (mm/decade)	473.3
ET_{Blue} (mm/decade)	68.6
ET_{Total} (mm/decade)	541.9
CWU_{Green} (m^3/ha)	4733
CWU_{Blue} (m^3/ha)	686
CWU_{Total} (m^3/ha)	5419
Yield (Ton/ha)	1.913
WF_{Green} (m^3/ton)	2474.12
WF_{Blue} (m^3/ton)	358.59

TABLE II
Data and Calculation of the Grey Water Component of Paddy in Haridwar District, Uttarakhand, India

Crop	Average fertilizer application rate (kg/ha)	N leaching fraction	US EPA N ambient water quality standard (mg/L)	Yield (Ton/ha)	Total WF_{grey} (m^3/ton)
Rice	129	0.10	10	1.913	674

TABLE III
Characteristics of Treated Wastewater from the Treatment Plant

Parameters	Value
Total Solids	0.0436 gm
Total Dissolved Solids	0.0412 gm
Total Hardness	164mg $CaCo_3$/l
Total Alkalinity	242 mg/l
Total Carbon	73.4 mg/l
Total Inorganic Carbon	71.38 mg/l
TOC	2.02 mg/l
NPOC	54.24 g/l
Na	47.44 g/ml
K	9.781 /ml
Ca	109.742 /ml
Mg	25.426 mg/ml
Chloride	49.019 mg/ml
Sulfate	47.406 mg/ml
Nitrate	55.935 / ml
pH	7.35
Conductivity	620µs/cm
Temperature	21.8
TDS	374 mg/l
Turbidity	1.42 TU

TABLE IV
Percentage Increase in Yield of Paddy Varieties Under Different Treatments

Rice varieties	Percentage increase
Sharbati	5.7
Menaka	(-) 6.2
PR 114	6.0
PB 1	4.8
PB 1121	(-) 2.9
PB 1509	2.0

TABLE V
GHG Gas Percentage Increase Values Emitted from Different Paddy Varieties in Different Water Treatments

Rice varieties	CH_4	CO_2	N_2O
Sharbati	3.8	7.3	4.3
Menaka	8.6	3.1	5.1
PR 114	1.1	3.4	5.8
PB 1	2.5	5.3	3.2
PB1121	4.4	9.2	3.2
PB1509	0.4	1.1	0.2

IV. Conclusion

It was observed that treated municipal wastewater may be used effectively for growing major cereal crops like paddy that are considered a high water consuming crop, without any adverse effect on the ground water and soil. Treated wastewater served as an excellent source of plant nutrients which reduced the need of adding synthetic fertilizers, which otherwise pose harm to the environment and in the long term reduce the soil fertility. The use of treated wastewater was also observed to improve the soil fertility by increasing organic content and the water holding capacity. It could be concluded that the productivity of crop could be improved, and the emission of greenhouse gases could be reduced by proper management of treated wastewater irrigation, fertilizer application and ameliorant applications.

REFERENCES

[1] IWMI.,World's water supply and demand 1995–2025. International Water Management Institute, Colombo, Sri Lanka, 2000.

[2] Drechsel P, Keraita B, Amoah P, Abaidoo RC, Raschid-Sally L, Bahri A., Reducing health risks from wastewater use in urban and peri-urban sub-Saharan Africa: applying the 2006 WHO guidelines. Water Science & Technology 57 (9), 2008.

[3] Govindarajan, S., N. K. Ambujam, and K. Karunakaran, Estimation of paddy water productivity (WP) using hydrological model: an experimental study. Paddy and Water Environment, 6: 327-339, 2008.

[4] Tuong, T. P. and B. A. M. Bouman, Rice production in water-scarce environments. In J. Kinje, R. Baker and D. Molden (Eds.), Water productivity in agriculture: limits and opportunities for improvement, CABI Press, Wallingford, UK, 2003.

[5] IWMI, Urban Wastewater: A Valuable Resource for Agriculture: A Case Study from Haroonabad, Pakistan: Research Report 63: International Water Management Institute (IWMI): Colombo Sri Lanka, 21, 2002.

[6] Kang, M.S., S.M. Kim, S.W. Park, J. J. Lee, and K. H. Yoo, Assessment of reclaimed wastewater irrigation impacts on water quality, soil, and rice cultivation in paddy fields. Journal of Environmental Science and Health Part A, 42: 439-445, 2007.

[7] Jang, T. I., S. B. Lee, C. H. Sung, H. P. Lee, and S. W Park, Safe application of reclaimed water reuse for agriculture in Korea. Paddy and Water Environment, 8: 227-233, 2010.

[8] Jang, T. I., H. K. Kim, C. H. Sung, E. J. Lee, and S. W. Park, Assessing nutrient losses of reclaimed wastewater irrigation in paddy fields for sustainable agriculture. Agricultural Water Management, 104: 235-243, 2012.

[9] Jang, T. I., Environmental effects of reclaimed wastewater irrigation on paddy fields. Doctoral Dissertation, Seoul National University, Seoul, Korea (in Korean), 2009.

[10] Jang, T. I., S. W. Park, and H. K. Kim, Environmental effects analysis of a wastewater reuse system for agriculture in Korea. Water Science and Technology, 8: 37-42, 2008.

[11] Exall, K.; Marsalek, J.; Schaefer, K. A review of water reuse and recycling, with reference to Canadian practice and potential: 1. Incentives and implementation. Water Qual. Res J Can. 39(1), 1–12, 2004.

[12] Iglesias, R.; Ortega, E. Present and future of wastewater reuse in Spain. Desalination, 218, 205–119, 2008

[13] Hamilton,D.L.; Brockman, R.P.; Knipfer, J.E.,The agricultural use of municipal sewage. Can. J. Physiol. Pharm, 1984, 62, 1049–1055.

[14] V´azquez-Montiel, O.; Horan, N.J.; Mara, D.D. Management of domestic wastewater for reuse in irrigation. Water Sci. Technol. 33(10–11), 355–362, 1996.

[15] Pettygrove, G.S.; Asano, T. Irrigation with Reclaimed Municipal Wastewater. A Guidance Manual; Lewis: Chelsea, MI, 1985.

[16] Sheikh, B.; Cort, R.P.; Kirkpatrick, W.R.; Jaques, R.S.; Asano, T. Monterrey wastewater reclamation study by agriculture. Res. J. Water Pollut. (C). 62, 216–226, 1990.

[17] Castro, E.; Ma˜ nas, P.; De las Heras, J. Nitrate content in lettuce Lactuca sativa L.) after fertilization with sewage sludge and treated wastewater irrigation. Food Addit. Contam , 26 (2), 172–179, 2009

[18] Bastos, R.K.X.; Mara, D.D. The bacterial quality of salad crops drip and furrow irrigated with waste stabilization pond effluent: an evaluation of the WHO guideline. Water Sci. Technol., 31(12), 425–430, 1995.

[19] Hoekstra, A.Y., Chapagin, A.K., Aldaya, M.M., Mekonnen, M.M., Water footprint manual: state of the art 2009. Water Footprint Network, Enschede, the Netherlands, 2009.

[20] Cai, Z., Xing, G., Yan, X., Xu, H., Tsuruta, H., Yagi, K., Minami, K. , Methane and nitrous oxide emissions from rice paddy fields as affected by nitrogen fertilizers and water management. Plant Soil 196, 7–14,1997

[21] Chen ZS,Relationship between heavy metal concentrations in soils of Taiwan and uptake by crops, Department of Agricultural Chemistry, National Taiwan University, Taipei 106, Taiwan, Roc, Internet p. 15, 2000.