Pak. J. Bot., 51(5): 1753-1759, 2019. DOI: http://dx.doi.org/10.30848/PJB2019-5(18)

MAJOR NUTRIENT FLUXES AND WATER USE EFFICIENCY OF WINTER VEGETABLES UNDER PERI-URBAN FARMING OF NORTH-WESTERN PUNJAB, PAKISTAN

SHOAIB UR REHMAN[1,2*]

[1]*Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics, University of Kassel, Steinstr. 19, D-37213 Witzenhausen, Germany*
[2*] *Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan*
[*]*Corresponding author's email: shoaib.ur.rehman@outlook.com*

Abstract

Major nutrient fluxes in urban and peri-urban agriculture (UPA) under semi-arid conditions in north-west of Pakistan are not fully known. To envisage it, a field study was carried out in Faisalabad, Pakistan. Three fertilizers treatments (an unfertilized Control, F0; farm yard manure, FYM (F1) at 14.2 t dry matter (DM) ha^{-1} containing 108 kg Nitrogen (N), 27kg Phosphorus (P) and a mineral fertilizer treatment (F2) containing the same amount of N and P as in F1 were established during 2011-12. Fertilizer treatments were factorally combined with two irrigation levels i.e. RI; recommended irrigation when irrigation was applied weekly and HRI; half than recommended irrigation where irrigation was applied fortnightly. Subplots randomized within each main plot were assigned to either of the two vegetable species pea (*Pisum sativum* L.), cauliflower (*Brassica oleracea* L.). Highest crop dry matter yields (p>0.05) were recorded for pea (12 t ha^{-1}) under F2 and lowest for cauliflower in RI (6.2 t ha^{-1}) under F1 treatment, respectively. Dry matter yields of both crops were reduced to 11-18% by reducing applying half of the HRI presumably due to water stress. Contrarily, water use efficiencies of both crops were significantly (32-36%) higher under HRI treatment than under RI. Apparent nutrient use efficiencies for C, N, P and K varied widely ranged from 27- 34%. However partial nutrient balances of major nutrients specially for K, remained negative. These results indicate large K mining in the soil which required proper balancing.

Key words: Nutrient balance, Fertilizers, Irrigation agriculture, Urban farming, Vegetable production.

Introduction

Despite its vast arid and semi-arid zones Pakistan's agriculture contributes 21% to the GDP of the country and employs a major part (45%) of labor force. About 25% of the country's total surface of 796,000 km^2 belongs to the largely irrigated Indus Plain and the Punjab (Government of Pakistan, 2002). Available water totals 164920 Mio m^3 which 95% is utilized for irrigation, contributing 80% to the agricultural outputs (Lipton *et al.*, 2003; Government of Pakistan, 2002a, 2010). Vegetable production is a common practice for most of the households that are related to farming in urban and peri-urban agriculture (UPA) systems because UPA is a major food provider to the cities, especially in the developing world (Eriksen-Hamel & Danso, 2010). The short duration of vegetable cultivation makes it an attractive enterprise for smallholders who are can sell their products on spot thereby saving processing and transportation cost. High profits per unit area of UPA encourage growers to invest even with high cost of water and nutrient inputs. To meet the increasing water demands due to insufficient canal water (Malik, 1994; Palada *et al.*, 2006), over a large amount of tube wells has been installed during the past three decades resulting in widespread accumulation of salts in agricultural lands (Sharif, 2011). The use of organic and inorganic fertilizers to enrich soil with nutrients remained common among growers. In UPA systems, availability of manure from intensive livestock systems has decreased the dependency of synthetic fertilizers (Zhao, *et al.,* 2016). In this scenario, determination of nutrient-use efficiencies in UPA systems may be very helpful to formulate policies for environmentally safe food production (Oborn *et al.,* 2003; Safi *et al.,* 2011). In an effort to contribute to more informed management decisions in UPA of Faisalabad, a major city in Pakistan's Punjab, the present study was conducted to investigate the effects of different soil amendments and irrigation levels on the dry matter yields and partial nutrient balances of representative vegetables. The key reason of focusing on Pea and Cauliflower in current study is the socio-economic factors of local farmers who prefer to grow pea and cauliflower for getting high profit during winter (Rehman *et al.,* 2013).

Materials and Methods

Site description: The controlled experiment was conducted on the research farm of the University of Agriculture, Faisalabad in two consecutive growing seasons of 2010 and 2011. The site is located at 31°26'29'' N, 73°04'34''E and an elevation of 182 m asl, characterized by an arid subtropical climate. The monsoon-driven, unimodally distributed mean annual rainfall is 407 mm with daily mean temperatures ranging from 37°C to 24°C (maximum and minimum) in summer and 25°C to 10°C (maximum and minimum) in winter (Fig. 1) (Cheema *et al.,* 2006). The soil has been characterized as aridisol (Chaudhry *et al.,* 2003) derived from alluvial river deposits of silt loamy texture. Fresh irrigation water was applied from canals.

Experimental design: The experiment was carried out as a split plot design. Main plots consisted of a randomized factorial with three rates of fertilization (unfertilized control, F_0; farmyard manure FYM at 14.2 kg DM ha^{-1}, F_1; and mineral fertilizer F_2 applied at 108 kg ha^{-1} N and 27 kg P ha^{-1}, rates equivalent to the total N and P content contained in the manure. The amount of K from mineral fertilizer was not applied as soil fertility reports indicated its rich content in the soil. These were combined with two irrigation intervals: a recommended irrigation interval of two weeks in winter and one week in summer; and half the recommended interval. The 3 x 2 (fertilizer and irrigation treatments) main plot treatments were replicated four times yielding a total of 24 plots of 51.90 m^2 each divided into four equal subplots of 11.74 m^2 of which two were used for forages (Ul-Allah *et al.,* 2014 & 2015) and the remaining two for vegetables. Only the latter are of relevance for this study. The two plots were randomly assigned to the two winter vegetables peas and cauliflower, sown on 16^{th} and 18^{th} of October 2011and 2012 respectively. The sowing of pea and cauliflower was done on ridges with plant to plant distance (PxP) 8 cm, and row to row distance (RxR) 20 cm. The amount of irrigation water was calculated with a cutthroat flume meter (Saddiqui *et al.,* 1996) installed at the entry point of the field to monitor inflow and outflow. Subplots consisted of two flat ridges of 60 cm top width and three furrows 40cm wide and 12 cm deep. At harvest an area of 1 m^2 having plant density 2.5, 24 for cauliflower, pea respectively, was used to determine above ground fresh weight of the respective vegetable out of which 300 g was taken after oven drying at 60°C for 72 hours to constant weight for DM assessment. Plots were weeded as necessary.

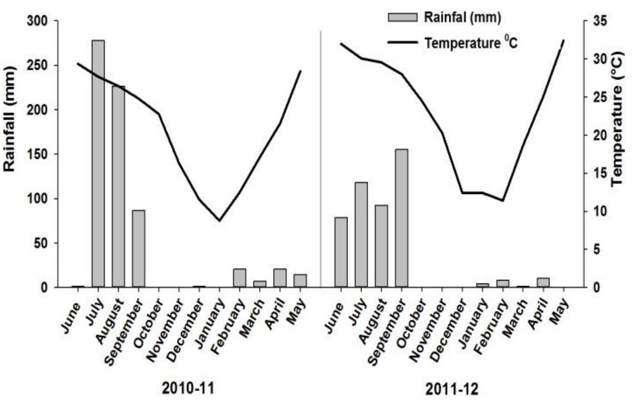

Fig. 1. Monthly average temperature and rainfall in 2010-11 and 2011-12 in Faisalabad, Pakistan.

Soil, manure, water and plant sampling: Before planting and at harvest of each season, five subsamples of soil were randomly taken at 0-20cm and 20-40cm from each plot using an auger. The samples were pooled for each plot air-dried before grinding, passed through a 2-mm mesh sieve and stored until analysis. To determine soil moisture content, separate samples were collected with a 7cm x 7cm auger below 60 cm the soil surface and soil moisture contents were measure. Subsamples of dried plant components were ground with a grinding mill (T-Tecator Cyclotec 1093, Höganäs, Sweden) to a size of 1 mm, and stored in sealed polyethylene bags. All plant samples were subjected to NIRS and reference samples were selected according to the Biewer *et al.,* (2009) and Ul-Allah *et al.,* (2014). Reference samples were analyzed in the laboratory as described in next paragraph. In 2011 the number of reference samples differed between experimental years with n = 46 for 2011 and n = 80 for 2012 due to a greater spectral heterogeneity in the second year. Furthermore, annual spectral data sets were not congruent between years. Hence, two independent calibrations were established.

Five sub-samples of manure were also sampled from the manure heap with a soil sampler at the depth of about 0.5 m depth, dried at room temperature followed by in oven at 60°C and ground with a grinding mill (Model MM 301, Retsch GmbH, Haan, Germany).

For analyses of irrigation water, samples from each site with a frequency of three times per month. Rainwater was sampled (100mL) during each significant precipitation event during the experiment and was pooled before analyses. One drop of concentrated (32%) HCl was mixed to each sample before storage to avoid any chemical degradation.

Chemical analysis: All collected soil samples were analyzed for bulk density, pH, cation exchange capacity (CEC), organic carbon (OC), exchangeable K, available P and total N. Soil pH was measured with a pH meter Ohaus, USA in a 2.5:1 water soil suspension. Total OC was measure following the method of Walkley and Black. The CEC was determined after sample extraction with ammonium acetate at pH 7. Total N was measured by Kjeldahl Method and available P by Olsen P method. Exchangeable K was measured by flame photometry.

For those reference samples for which wet analysis needed to be performed total N was calculated using a LECO FP-328 (Leco Corp., St. Joseph, MI, USA) and OC as elaborated by Close & Menke (1986). OC content were multiplied with a factor of 1.724 to calculate the organic matter contents. All plant samples were burned at 550°C to get ash, dissolved in HCl, and analyzed for K by flame photometry and P by spectrophotometry.

HCl-insoluble ash method was used to determine the adherent sand particles in manure. Total harvested dry matter was multiplied by a factor of 1.4 to calculate total photosynthetic derived C on the assumption that about 30% of total assimilated C goes to root dry matter and net exudation (Kuzyakov & Domanski, 2002). Irrigation and rain water samples were subjected to N and P analyses using a Dimatec 100 automatic analyzer (Dimatec GmbH, Essen, Germany) and concentration of K and P were determind by spectrophotometry (Hitachi U-2000, Hitachi Ltd., Tokyo, Japan).

Calculation of nutrient fluxes and apparent nutrient use efficiencies: Partial horizontal nutrients balances were determined for each plot based on the nutrient inputs (inorganic and organic fertilizer, rain water and irrigation water applied) and outputs (harvested crop biomass) per hectare. Nutrient fluxes were calculated according to following equation (EQ. 1; Khai *et al.,* 2007).

$$\mathrm{F} = \sum_{i=1}^{n} \mathrm{QiCi} \quad (1)$$

where F is the total amount of element flow (input or output) during measurement period, n is the number of events (rain, irrigation and fertilizer application, and crop harvest), Qi is the plant dry matter measured at event i, and Ci is the elemental concentration in the plant dry matter measured at event i.

The element-balance equation is expressed as for any system:

$$\Delta P_E = I_E - O_E \quad (2)$$

where ΔP_E, O_E and I_E, stand for each change in the pool, the output and the input of element $_E$ respectively (Khai *et al.*, 2007).

With the application of Eq. 2 the input flows for C, N, P, and K were calculated for fertilizer (F_E), irrigation water (IW_E), and rainwater (RW_E). The output flows were computed from the harvested DM of the crop (H_E). If ΔP_E is the net change in the soil storage of element E ($\Delta Soil_E$), Eq. 2 can be rewritten as:

$$\Delta Soil_E = F_E + IW_E + RW_E - H_E \quad (3)$$

In the study runoff on well leveled field, atmospheric deposition by dust and smoke, N_2 fixation in symbiotic and non-symbiotic crops that may range from 2 to 5 kg N ha^{-1} y^{-1} (Roy *et al.*, 2003) and the likely large volatilization of C and N were neglected during the study period. All calculations were made for each growing seasons from planting to harvest.

Apparent use efficiencies for C, N, P, and K were accessed according to Wang *et al.*, 2008, as:

$$UE = \frac{\Sigma O}{\Sigma I} X100' \quad (4)$$

where UE stands for apparent nutrient –use efficiency, O denotes the nutrient output and I denotes nutrient inputs. Water use efficiency (WUE) was calculated according to Hussein *et al*., (2011) as:

$$\text{WUE} = \frac{\text{Y}}{\text{I}} \quad (5)$$

where 'Y' stands for dry matter yield (DM) in kg while 'I' denotes for irrigation water applied in $m^{3.}$

Statistical analysis

All collected data for nutrient inputs, outputs, and horizontal fluxes of total N, OC, plant available K and P data were analyzed for analyses of variance using software package MSTAT-C (Russell, 1994), considering the treatments arranged in a split-plot design. Tukey test was used to compare the means of significant treatment/ variables.

Results

Soil nutrient status: The soil of experimental site was slightly alkaline, non-sodic and silt loam in texture with an electrical conductivity (EC) of 0.56 mS/m of 0.62 % respectively (Table 1). After two years the concentration of C was higher in F_1 and F_2 than in F_0, whereas N remained almost unchanged in F_1, but was lower in F_0 and F_2. Phosphorus and K concentration decreased in F_0, F_1 and F_2 except for K which increased in F_1. pH and bulk density slightly increased in F_0 and F_2 while they decreased in F_1 (Table 1).

Nutrient inputs: During the 2-year study, average seasonal amounts of irrigation water applied for each winter crop were 3,429 m^3 for RI and 1,905 m^3 ha^{-1} for HRI respectively. These contained 44 kg N ha^{-1}, 10 kg ha^{-1}each of P and K for RI and half of this amount was applied in HRI treatments.

The 14.2 t FYM ha^{-1} applied to each crop per season in F_1 added a total of 6,000 kg C ha^{-1}, 108 kg N ha^{-1}, 27 kg P ha^{-1} and 88 kg K ha^{-1}. In F_2, application of 131 kg Di-Ammonium Phosphate (DAP) and 183 kg Urea ha^{-1} added on the average 108 kg ha^{-1} N, and 27 kg ha^{-1} for each crop throughout the study period. On a biennial average, the photosynthetic and FYM oriented carbon addition was 4 to 12 t ha^{-1} in both crops.

Horizontal balances: Partial C balances were positive in all treatments and with both irrigations. The lowest and highest surpluses were 0.6 t C ha^{-1} for F_0 and 9.6 t C ha^{-1} for F_1 with HRI. In the first year of study (2010), total C surpluses were 9 t, 2.9 t and 2.6 t while in the second year (2011) they amounted to 7.1 t, 1.4 t and 0.9 t for F_0, F_1 and F_2 in RI, respectively. For both years, cumulative cauliflower partial N balances were negative in all treatments ranging from -54 kg N ha^{-1} to -141 kg N ha^{-1} (p<0.05). Averaged across treatments and crops cumulative cauliflower P balances were negative for F_0 (-15 kg P ha^{-1}), but positive for F_1 (9.3 kg P ha^{-1}) and F_2 (1.2 kg P ha^{-1}) over the two years of study period. For K throughout the study period deficits ranged from -421 kg ha^{-1} for F_2 to -176 kg ha^{-1} for F_1 with RI (Fig. 2).

For pea as a whole, C balances were positive for all treatments and both years with the highest surplus of 8 t C ha^{-1} in F_1 under RI, whereas the lowest surplus of 1 t C ha^{-1} was recorded in F_0 under HRI. Nitrogen balances were negative for all treatments and seasons. Phosphorus deficits amounted to -23 kg ha^{-1} in F_0 and -9 kg ha^{-1} in F_1 for RI and to -20 kg ha^{-1} and -13 kg ha^{-1} in HRI while -9 kg P ha^{-1} and -13 kg P ha^{-1} were observed in F_2. For K, deficits were high in all treatments (Fig. 3).

Apparent use efficiencies of N, P and K: Over the 2 years of the study, apparent use efficiencies for C, N, P and (exchangeable) K varied widely range from 27% to 34% largely reflecting the amount of inputs applied during the study period. Efficiencies were highest (p< 0.05) in pea with F_0 in HRI for N (800%), P (441%) and K (38%), and remained lowest in cauliflower for N (1.3%), P (78%) and K (780%). Across crops, average NUE ranged from 292% for F_0, 122% for F_1 and 126% for F_2 in RI. For PUE it amounted to 165%, 66% and 39% and for KUE to 1505%, 252%, 2054% for F_0, F_1 and F_2, respectively.

Crop yields and nutrient export (removal): Dry matter yields differed widely between the selected crops. Highest yields (p> 0.05) were recorded for pea (12 t ha^{-1}) and remained lowest ones for cauliflower in RI (6.2 t ha^{-1}); these values were reduced by 11% and 18% for HRI (Fig. 4). Water stress reduced average yield in all crops by 17% for F_0, 9% for F_1 and11% for F_2. For cauliflower, average DM yield was the highest (p< 0.05) in F_2 (9.5 t ha^{-1}), followed by F_1 (7.7 t ha^{-1}) and F_0 (6.3 ha^{-1}) in RI, which was reduced by 13% in F_0, 6% in F_1 and 15% in F_2. For pea, average DM was highest in F_1 (p < 0.5 %), (12 t ha^{-1}) followed by F_2 (11.8 t ha^{-1}) and F_0 (8.4 t ha^{-1}) in RI with corresponding yield reductions of 5%, 7% and 20% in HRI (Fig. 4).

Table 1. Average values of selected soil properties over the 24 months experimental period at the UAF experimental research farm (n = 6).

Soil characteristics	F_0		F_1		F_2	
	Period					
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
C (g kg^{-1})	7.25 (±0.26)	6.83 (±0.16)	7.67 (±0.09)	8.68 (±0.17)	7.82 (±0.13)	7.74 (±0.13)
N (g kg kg^{-1})	0.39 (±0.02)	0.33 (±0.02)	0.42 (±0.01)	0.41 (±0.01)	0.38 (±0.01)	0.37 (±0.02)
P (mg kg^{-1})	6.26 (±0.24)	5.89 (±0.23)	9.19 (±0.40)	8.08 (±0.54)	7.70 (±0.29)	7.69 (±0.34)
K (mg kg^{-1})	144 (±5.94)	118 (±7.60)	194 (±9.96)	178 (±9.66)	167 (±10.7)	155 (±4.39)
Bulk density (g cm^{-3})	1.33 (±0.00)	1.34 (±0.01)	1.31 (±0.01)	1.30 (±0.01)	1.33 (±0.01)	1.34 (±0.01)
pH	8.23 (±0.03)	8.30 (±0.03)	8.05 (±0.04)	8.02 (±0.03)	8.19 (±0.03)	8.21 (±0.02)

Numbers inside parentheses represent ± standard error (SE) of the mean

Table 2. Average water use efficiency (WUE) values represented in kg DM m^{-3} over the 24 months experimental period at the UAF experimental research farm (n = 4).

Crop	Treatment	Recommended irrigation (RI)				Half of recommended irrigation (HRI)			
		Year 2010-11		Year 2011-12		Year 2010-11		Year 2011-12	
		WUE	SE	WUE	SE	WUE	SE	WUE	SE
Cauliflower	F_0	1.88^c	(±0.04)	1.63^b	(±0.04)	3.41^c	(±0.05)	1.88^b	(±0.03)
	F_1	2.18^b	(±0.04)	2.13^a	(±0.03)	3.76^b	(±0.06)	3.31^a	(±0.07)
	F_2	2.74^a	(±0.06)	2.58^a	(±0.08)	4.69^a	(±0.05)	3.11^a	(±0.05)
Pea	F_0	2.51^b	(±0.05)	2.21^c	(±0.02)	3.35^b	(±0.03)	3.18^b	(±0.02)
	F_1	3.14^a	(±0.02)	3.59^a	(±0.03)	5.61^a	(±0.05)	5.44^a	(±0.09)
	F_2	3.33^a	(±0.04)	3.29^b	(±0.03)	5.45^a	(±0.10)	5.20^a	(±0.14)

Numbers inside parentheses represent ± standard error (SE) of the mean
Superscripted small alphabets are statistically assigned, according significant differences among varying treatment levels

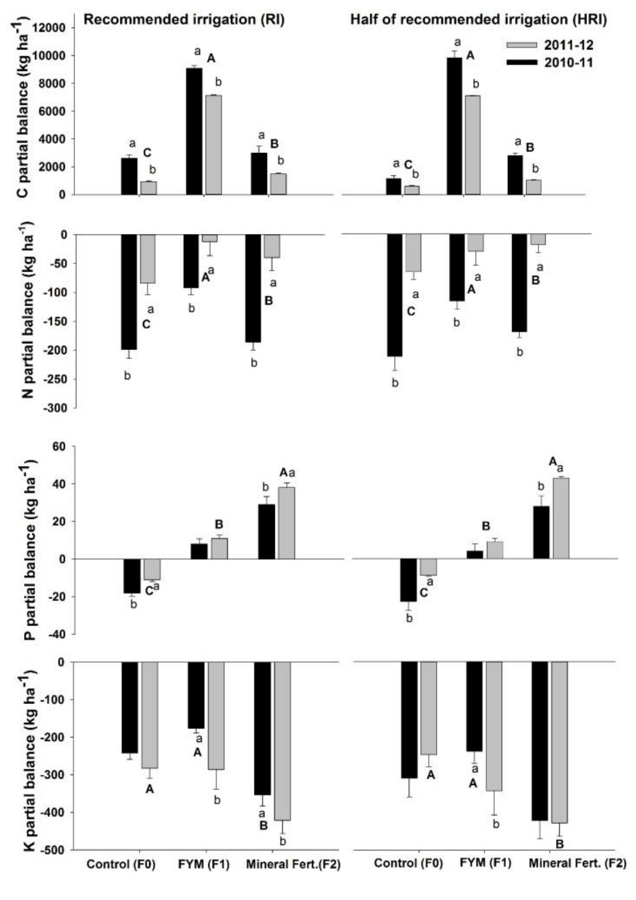

Fig. 2. Partial balances for nitrogen (N), phosphorus (P) and potassium (K) in cauliflower production over a 24 months research period at the research station of University of Agriculture, Faisalabad, Pakistan. Data show means ± standard error, (n = 4). Capital letters indicate significant differences between fertilizer treatments and small letters significant inter-annual differences using Tukey's mean separation test at $p < 0.05$.

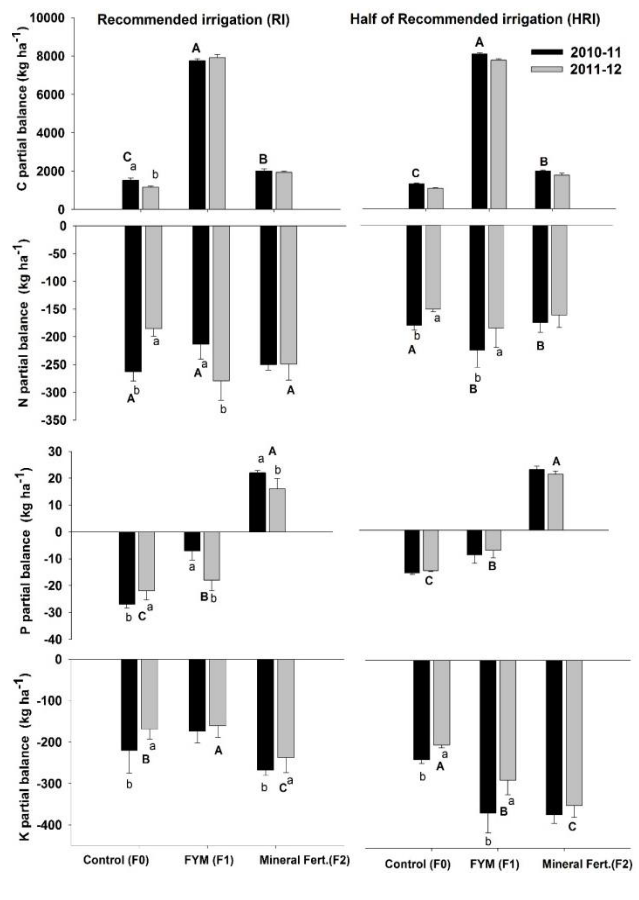

Fig. 3. Partial balances for nitrogen (N), phosphorus (P) and potassium (K) in pea production over a 24 months research period at the research station of University of Agriculture, Faisalabad, Pakistan. Data show means ± standard error, (n = 4). Capital letters indicate significant differences between fertilizer treatments and small letters significant inter-annual differences using Tukey's mean separation test at $p < 0.05$.

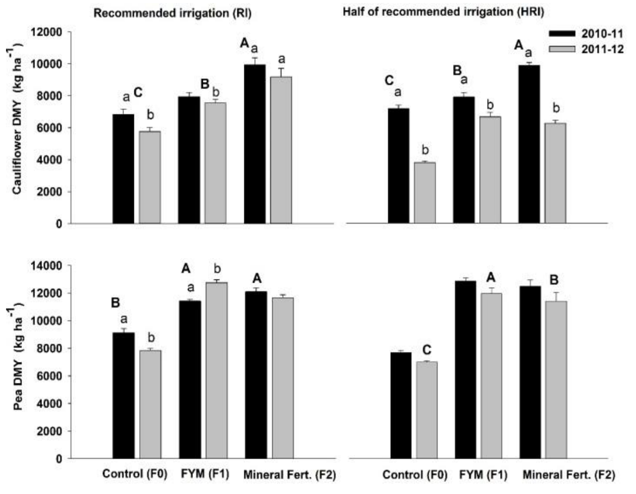

Fig. 4. Dry matter yields of cauliflower and pea during the 24 months experimental period at the research station of University of Agriculture, Faisalabad, Pakistan. Data show means ± standard error, (n = 4). Capital letters indicate significant differences between fertilizer treatments and small letters significant inter-annual differences using Tukey's mean separation test at $p< 0.05$.

Water use efficiency: On biennial study, an average water use efficiency (WUE) for cauliflower was 1.8, 2.2 and 2.7 kg DM m^{-3} with RI while 2.6, 3.5 and 4 kg DM m^{-3} with HRI for F_0, F_1 and F_2 respectively. The highest WUE was recorded with HRI (5.5 kg DM m^{-3}) for pea. Overall WUE with F_0, F_1, F_2 treatments amounted to 32-36% higher with HRI than RI in all crops (Table 2).

Discussion

Soil nutrient status: Changes in soil bulk density and pH of similar magnitude than those determined in our study were previously reported by Ishaq *et al*., (2002) and Muhammad *et al*., (2008) for arable soils of Faisalabad. These authors attributed such changes to prolonged effects of tillage, fertilizer application and crop residue application. The decline in pH and bulk density seemed closely related to the application of organic carbon to the soil. Current soil OC and N losses occurred due soil moisture and OM loss coupled with high temperature-related turnover (Kirschbaum, 2013) particularly in sandy soil (Russow *et al.*, 2008). In a similar study, Predotova *et al*., (2010) reported that under irrigated UPA vegetable production gardens in semi-arid Niamey, Niger, the high temperatures coupled with low soil moisture probably reduced soil C_{org}.

Under semiarid subtropical climate conditions, Mahmood *et al.*, (1998) reported that N losses due to denitrification were higher in maize than in wheat season due to higher soil temperatures in sandy-clay loam. Under such extreme environmental conditions specially for sandy soils, the inorganic-N losses can be minimized by reducing the volume of waste applied per each irrigation turn or by plastic roofing over FYM heaps (Predotova *et al.,* 2010).

Nutrient removal: Nutrient use efficiencies varied across amendments, irrigation regimes and crops. Our data indicate that K depletion was highest in F_2 with HRI and lowest for F_1 with RI.

The soil K status in the present study represents the exchangeable K, slightly changed from the beginning to the end of the study period indicating the possible differences in the effects of manure incorporation and the application of mineral (N, P) fertilizers. Similar to our results, Safi *et al*., (2011) also reported variations in K status due to FYM and city sewage wastes in soils of Kabul under UPA farming. Wang *et al*., (2008) also reported the imbalances in NPK in vegetable farming of two contrasting peri-urban areas, close to river delta of Yangtze in China where they found imbalances in N, P and particularly negative for K. According to Wang *et al*., (2008), nutrient imbalances particularly the negative K status could be due to the deteriorated soil quality that often may mislead the farmers to apply more N and P that in turn affects nutrient balance of soil (Wang *et al.,* 2008). However, the apparent reason for negative K status in current study contrary to N&P is that no K fertilizer was applied as nutrient input throughout for current envisaged vegetables crops throughout the study period. Since cauliflower and pea are relatively high K requiring crops, consequently more K was removed from soil by the both crops without any replenishment in the form of nutrient input that consequently resulted in negative K balance. The notion behind not applying K fertilizer is that there is no trend of using K fertilizers in Pakistan since most agriculture is usually fed with canal water which is believed to sufficiently maintain the existing K status of soil (Ullah, *et al.*, 2018; Zahoor, *et al.*, 2017; Wakeel, 2014). Furthermore, the Pakistani soils are of mica origin, especially the soils of current study site Faisalabad are developed from smectite (Akhtar & Dixon, 2013). The present negative K status in our study emphasizes a careful evaluation of existing nutrient status of soil updated recommendations particularly for K, enabling effective synchrony with crop's nutrient demand.

Partial nutrient balance: In the current study, annual application of 4,572 m^3 irrigation water ha^{-1} was only slightly smaller than the 5,820 m^3 reported from UPA vegetable production in Kabul (Safi *et al.,* 2011) but almost ten-fold higher than the 573 m^3 reported by Abdalla *et al.,* (2012) from Khartoum (Sudan) where the floods of the River Nile soaked the land for 2-4 months per year which resulted in lower water requirements by the soil. The partial annual nutrient balances of 131 kg N, 37 kg P and 84 kg K ha^{-1} from irrigated vegetable production systems under hot dry conditions of Oman reported by Buerkert *et al*., (2005) and of 215 kg N, 150 kg P and -250 kg K ha^{-1} reported by Safi *et al*., (2011) at Kabul, Afghanistan are many fold larger than our findings. Such variations in partial nutrient balances under sub-tropical conditions are mainly governed by the differences in irrigation regimes and fertilizer application (Abdalla *et al.,* 2012; Safi *et al.,* 2011; Ertek *et al.,* 2006).

Dry matter yields and water use efficiency: In the present study, DM yield of both crops slightly varied among both irrigation and fertilization treatments. The highest DM yield was found in Pea (12 t ha^{-1}) than in cauliflower under FYM treatment but remained negligibly affected by both irrigation regimes. However contrary to pea, cauliflower DM yield was slightly reduced (7-16%) in FYM treatment, fed with reduced irrigation (HRI), compared to full water supply (RI) presumably due to water stress. Similar to our results, Bozkurt (2011) recorded a decline of 25- 50% in cauliflower under mediterrainen climate. The decrease in DM yields under reduced irrigation for other horticultural crops e.g. for bitter gourd (Behera *et al.,* 2010), eggplant (*Solanum melongena* L.; Kirnak *et al.,* 2002), cucumber (*Cucumis sativus* L.), and tomato (*Lycopersicon esculentum* L.; Topcu *et al.,* 2007) respectively, have also been reported. The water stress caused by reduced irrigation lowers the fertilizer use efficiency of crops (Bozkurt *et al.,* 2011; Ul-Allah *et al.,* 2018) thereby affecting DM yields. Compared to DM yields, WUE of both crops was significantly higher under HRI than in RI treatment which suggest a careful revision of existing irrigation scheduling, issued by local agriculture extension department.

Conclusions

The present study showed negative balances for N, P and particularly higher in K for both crops under different fertilization treatments, suggesting a careful crop based-soil nutrient management prior to cultivation. The high temperatures coupled with low soil moisture and poor soil structure possibly reduced the current soil OC content and induced more N losses due to leaching which inevitably influenced partial nutrient balances in soil. The higher WUE under reduced irrigation (HRI) than in full irrigation (RI) treatment raises question on the existing irrigation recommendations. Our findings suggest partial nutrient balances as a useful indicator for the sustainability assessment of vegetable production systems particularly under urban farming. However, the assessment of major nutrient losses through leaching and volatilization will give further deeper insights into the full matter fluxes thereby resulting in a more comprehensive prediction of treatment effects on long-term changes in soil quality and vegetable yields in urban vegetable gardens.

Acknowledgments

We thank Mrs. Eva Wiegard and Claudia Thieme from Department of Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics, University of Kassel, Germany for their practical support in laboratory work. This study was financially supported by the Faculty Development Program of the University of Agriculture, Faisalabad in collaboration with the Higher Education Commission of Pakistan through a scholarship granted to the first author.

References

Abdalla, S.B., M. Predotova, J. Gebauer and A. Buerkert. 2012. Horizontal nutrient flows and balances in irrigated urban gardens of Khartoum, Sudan. *Nutr. Cycl. Agroecosyst*., 92: 119-132.

Akhtar, M.S. and J.B. Dixon. 2013. Mineralogical Characteristics and Potassium Quantity/Intensity Relation in Three Indus River Basin Soils. *Asian. J. Chem*., 21: 3427-3442.

Behera, T.K., S. Behera, L.K. Bharathi, K.J. John, P.W. Simon and J.E. Staub. 2010. Bitter Gourd: Botany, Horticulture, Breeding, in Horticultural Reviews, Volume 37 (Ed.): J. Janick, John Wiley & Sons, Inc., Hoboken, NJ, USA. 102-120.

Biewer, S., T. Fricke and M. Wachendorf. 2009. Development of canopy reflectance models to predict forage quality of legume-grass mixtures. *Crop Sci*., 49: 1917-1926.

Bozkurt, S. 2011. Yield responses of cauliflower (*Brassica oleracea* L. var. Botrytis) to different water and nitrogen levels in a Mediterranean coastal area. Acta Agriculturae Scandinavica. *Soil Plant Sci*., 61: 183-194.

Buerkert, A., M. Najieb, S. Siebert, I.A. Khan and A. Al-Maskari. 2005. Nutrient cycling and field- based partial nutrient balance in two mountain oases of Oman. *Field Crop Res*., 94: 149-164.

Chaudhry, E.H., A.M. Ranjha, M.A. Gill and S.M. Mehdi. 2003. Phosphorus requirement of maize in relation to soil characteristics. *Int. J. Agri. Biol*., 4: 625-629.

Cheema, M.A., M. Farooq, R. Ahmad and H. Munir. 2006. Climatic trends in Faisalabad (Pakistan) over the last 60 years. *J. Agri. Soc. Sci*., 2: 42-45.

Close, W. and K.H. Menke 1986. Selected topics in animal nutrition. Deutsche Stiftung für Internationale Entwicklung (DSE), Feldafing, Germany, 85 p

Ertek, A., S. Sensoy, I. Gedik and C. Kacukymuk. 2006. Irrigation scheduling based on pan evaporation values for cucumber (*Cucumis sativus* L.) grown under field condition. *Agri Water Manag*., 81: 159-172.

Eriksen-Hamel, N. and G. Danso. 2010. Agronomic considerations for urban agriculture in southern cities. *Int. J. Agri. Sustain*., 8: 88-93.

Government of Pakistan. 2002a. Pakistan Water Sector Strategy" Volume-1. Ministry of water and power, Office of Chief Engineering Advisor/ Chairman Federal Flood Commission, Islamabad, Pakistan pp 1-12.

Government of Pakistan. 2002b. Pakistan Water Sector Strategy. Volume-4. Ministry of water and power, Office of Chief Engineering Advisor/ Chairman Federal Flood Commission, Islamabad, Pakistan. pp 1-13.

Government of Pakistan. 2010. Pakistan Economic Survey. Economic Advisor's Wing, Finance Division, Government of Pakistan, Islamabad Pakistan. pp 1-17 http://www.finance.gov.pk/survey/chapter_12/highlights.pdf. (last accessed on 12-05-2016).

Hussein, F., M. Janat and A. Yakoub. 2011. Assessment of yield and water use efficiency of drip-irrigated cotton (*Gossypium hirsutum* L.) as affected by deficit irrigation. *Turk. J. Agri. Fores*., 35: 611-621.

Ishaq, M., M. Ibrahim and R. Lal. 2002. Tillage effects on soil properties at different levels of fertilizer application in Punjab, Pakistan. *Soil Till. Res*., 68: 93-99.

Khai, N.M., P.Q. Ha and I. Öborn. 2007. Nutrient flows in small-scale peri-urban vegetable farming systems in Southeast Asia-a case study in Hanoi. Agri. Ecosyst. Environ., 122: 192-202.

Kirnak, H., I. Tas., C. Kaya and D. Higgs. 2002. Effect of deficit irrigation on growth, yield and fruit quality of eggplant under semiarid conditions. *Aust. J. Agri. Res*., 53: 1367-1373.

Kirschbaum, M.U.F. 2013. Seasonal variations in the availability of labile substrate confound the temperature dependence of organic matter decomposition. *Soil Biol. Biochem*., 57: 568-576.

Kuzyakov, Y. and G. Domanski. 2002 Carbon input by plants into the soil. *Rev. J. Plant Nutr. Soil Sci*., 163: 421-431.

Lipton, M., J. Litchfield, R. Blackman, D.D. Zoysa, L. Qureshy and H. Waddington. 2003. The impact of Irrigation on Poverty" (draft). Poverty Research Unit at University of Sussex, UK. 1-16. (http://www.sussex.ac.uk/Units/PRU/irrigation.pdf.)

Mahmood, T., K.A. Malik, S.R.A. Shami and M.I. Sajjad. 1998. Denitrification and total N losses from an irrigated sandy-clay loam under maize-wheat cropping system. *Plant Soil*, 199: 239-250.

Malik, M.N. 1994. Horticulture. National Book Foundations, Islamabad, Pakistan. pp. 510-535.

Muhammad, S., T. Muller and R.G. Joergensen. 2008. Relationships between soil biological and other soil properties in saline and alkaline arable soils from the Pakistani Punjab. *J. Arid Environ*., 72: 448-47.

Oborn, I., A.C. Edward, E. Witter, O. Oenema, K. Ivarsson, S.I. Nilsson and A.R. Sitinzing. 2003. Element balances as a tool for sustainable nutrient management. A critical appraisal of their merits and limitations within an agronomic and environmental context. *Eur. J. Agron*., 20: 211-225.

Oenema, O., H. Kros and W. De Varies. 2003. Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. *Eur. J. Agron*., 20: 3-16.

Palada, M.C., J.K. Thomas and A.L. Thomas. 2006. The role of AVRDC - The World Vegetable Centre in Enhancing and Promoting Vegetable Production in the Tropics. *Hort. Sci*., 41: 556-560.

Predotova, M., W.A. Bischoff and A. Buerkert. 2011. Mineral nitrogen and phosphorus leaching in vegetable gardens of Niamey, Niger. *J. Plant Nutr. Soil Sci*., 174: 47-55.

Predotova, M., J. Gebauer, E. Schlecht and A. Buerkert. 2010. Gaseous nitrogen and carbon emissions from urban gardens in Niamey, Niger. *Field Crop Res*., 115: 1-8.

Roy, R.N., R.V. Misra, J.P. Lesschen and E.M.A. Smaling. 2003. Assessment of soil nutrient balance approaches and methodologies. FAO, Rome, Italy. FAO Fertilizer and Plant Nutrition Bulletin 14. (last accessed on 20-04-2016. http://www.fao.org/docrep/006/y5066e/y5066e00.htm)

Russell, O. 1994. MSTAT-C v. 2.1 (a computer based data analysis software). Crop and Soil Science Department, Michigan State University, USA.

Russow, R., O. Spott and C.F. Stange. 2008. Evaluation of nitrate and ammonium as sources of NO and N_2O emissions from black earth soils (*Haplic Chernozem*) based on N-15 field experiments. *Soil Biol. Biochem*., 40: 380-391.

Safi, Z., M. Predotova, E. Schlecht and A. Buerkert. 2011. Horizontal matter fluxes and leaching losses in urban and peri-urban agriculture of Kabul, Afghanistan. *J. Plant Nutr. Soil Sci*., 174: 705-716.

Sharif, A. 2011. Technical adaptations for mechanized SRI production to achieve water saving and increased profitability in Punjab, Pakistan. *Paddy Water Environ*., 9: 111-119.

Topcu, S., C. Kirda, Y. Dagan, H. Kaman, M. Cetin, A. Yazici and M.A. Bacon. 2007. Yield response and N fertilizer recovery of tomato grown under deficit irrigation. *Eur. J. Agron*., 26: 64-70.

Ul-Allah, S., A.A. Khan, T. Fricke, A. Buerkert and M. Wachendorf. 2014. Fertilizer and irrigation effects on forage protein and energy production under semi-arid conditions of Pakistan". *Field Crop Res*., 159: 62-69.

Ul-Allah, S., A.A. Khan, T. Fricke, A. Buerkert and M. Wachendorf. 2015. Effect of fertiliser and irrigation on forage yield and irrigation water use efficiency in semi-arid regions of Pakistan. *Exp. Agri*., 51: 485-500.

Ul-Allah, S., M. Iqbal, S. Maqsood, M. Naeem, M. Ijaz, W. Ishfaq and M. Hussain. 2018. Improving the performance of bread wheat genotypes by managing irrigation and nitrogen under semi-arid conditions. *Arch. Agron. Soil Sci*., 64: 1678-1689.

Ullah, G., E.A. Khan and A. Khakwani. 2018. Physiological response of spring wheat to seeding and Potasium application rates. *Pak. J. Bot*., 50(3): 937-947.

Rehman, U.S., M. Predotova, I.A. Khan, E. Schlecht and A. Buerkert. 2013. Socio-economic characterization of integrated cropping systems in urban and peri-urban agriculture of Faisalabad, Pakistan. *J. Agri. Rural Dev. Trop*., 114(2): 133-143.

Wakeel, A. 2014. Critical Review of Research on Soil K and Crops' Response to K Fertilizers in Pakistan: Perspectives and Opportunities. *Int. Potash Inst*., 37: 16-31.

Wang, H.J., B. Huang, X.Z. Shi, J.L. Darilek, D.S. Yu, W.X. Sun, Y.C. Zhao and Q. Chang. 2008. Major nutrient balances in small-scale vegetable farming system in peri-urban areas in China. *Nutr. Cycl. in Agroecosyst*., 81: 203-218.

Zahoor, R., W. Zhao., M. Abid., H. Dong and Z. Zhou. 2017. Potasium application regulates nitrogen metabolism and osmotic adjustment in cotton (*Gossypium hirsutum* L). functional leaf under drought stress. *J. Plant Physiol*., 2015: 30-38.

Zhao, J., N. Tian., L. Jing., L. Qiang., F. Zhiying., H. Qiwei., Z. Ruifu., L. Rong., S. Biao and S. Qirong. 2016. Effect of organic compound fertilizer with reduced chemical fertilizer application on crop yield, soil biological activity and bacterial community structure in a rice-wheat cropping system. *Apl. Sci. Eco*., 99: 1-12.

(Received for publication 22 January 2018)