IMPACTS OF INORGANIC NITROGEN FERTILISER ON SOIL FERTILITY AND GROUNDWATER QUALITY IN WESTERN IRAN

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Abstract. Input of nitrogen (N) fertilizer in agricultural systems is important for their sustainability. However, when N inputs are very high, the excess can contribute to environmental problems such as loss of soil fertility and groundwater pollution. Based on this hypothesis, a field trial was carried out in Touba orchards of Kurdistan province (Western Iran) in 2009, which aimed at evaluation of soil and groundwater quality of the mentioned orchards. Soil samples were analyzed to measure quality parameters including soil organic carbon (SOC), total nitrogen (TN), available phosphorous (P_{av}) and available potassium (K_{av}). Moreover, nitrate (NO_3^-) concentration was measured in water samples and compared with WHO standards of drinking water (50 mg l^{-1}). The obtained results of soil analysis showed that SOC is significantly higher (1.55 g kg^{-1}) and lower (0.71) in the orchards of Sanandaj and Qorveh counties, respectively. In addition, the results of hydro-chemical analysis showed that NO_3^- concentration was in the range of 21-95 mg l^{-1}. Moreover, 90% of groundwater samples collected from the orchards of the Qorveh county, exceeded WHO standard level which is a reflection of N-fertilizer application at high rate (340 kg ha^{-1}).

Keywords: fertility, inorganic fertilizer, nitrate, organic carbon, Touba orchards.

AIMS AND BACKGROUND

The present research is intended to determine the impacts of inorganic nitrogen fertilizer application on soil fertility parameters and nitrate pollution in groundwater resources of Touba orchards in Kurdistan province, western Iran.

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Improper agricultural activities cause apparent ecosystem vulnerability[1]. Agriculture and environment are intimately linked and much debate has been taken place in recent years about the sustainability of some farming practices. Farmers usually apply large amounts of nitrogen (N) fertilizer in order to ensure high crop or fruit yields. Related researches on fertilizer practices have shown that when N is applied at rates $\geq$90 kg ha^{-1}, the content of soil organic carbon (SOC) in surface soil (0-30 cm) is either equal to that of the check (no N applied) or slightly greater[2,3]. Nitrogen input for agricultural systems is important for their sustainability. However, when N inputs are very high, the excess can contribute to greater agricultural N losses that impact soil and groundwater quality. Based on this hypothesis, several studies have been conducted and they have found that high nitrate (NO_3^-) concentration (12-60 mg l^{-1}) in groundwater resources is the output of N fertilizer application at high rates[4-7]. In irrigated horticulture, excessive N fertilizer application (as high as 600-900 kg h^{-1}) is very common and it leads to NO_3 pollution[4]. In addition, of the land use systems (e.g. forest, grassland, market garden and cropland), the potential for causing NO_3 leaching is the highest in market gardens[6].

Over the last two decades, there has been a strongly increasing trend towards the growth of trees of high economic value in the Kurdistan province (Western Iran). From 1995 to 2008, land areas under market gardens increased from 34 582 to 90 738 ha[8]. However, there has been poor development of rational fertilizer recommendations in areas with rapidly expanding horticultural systems. Fruit orchards of Kurdistan province were under cultivation of rainfed wheat in the past. After cultivation of orchards, high rates of N fertilizer is applied to gain high yield. In the study area, nitrogen is applied both in organic and inorganic forms with enormous difference in amount. Application of inorganic N fertilizer in Touba orchards of Kurdistan is based on excessive amounts often being supplied late in winter. Therefore, the risk of NO_3^- leaching increases, following heavy rainfalls in spring. That may result in NO_3^- concentrations in groundwater exceeding WHO-drinking water standard (50 mg l^{-1})[9].

EXPERIMENTAL

The experimental fields are located in Kurdistan province in western Iran. The study was conducted in market gardens of a national development plan (Touba plan) between March and September 2009. Soil and water resources are the main environmental compartments exploited towards the aims of this plan. Sanandaj, Kamyaran, Qorveh, Saqez, Bijar and Divandareh are the top six counties, contributing to 99.64% of the total orchard area of Touba plan within the

Kurdistan province. Therefore, the impact assessment of Touba plan was done based on the data collected from those counties. Soil and groundwater quality data of Touba orchards were collected in 2009. Geographic location and the data on annual average application of N, P and K-containing fertilizers in the Touba orchards was collected from Jihad of Agriculture Organization and presented in Table 1.

Table 1. Geographic location and fertilizer practices of six counties with highest area under cultivation of Touba orchards in the Kurdistan province (J. A. O., 2008)

County	Geographic location	N fertilizer	P and K fertilizers	Farmyard manure (FMY) dung and urine
Sanandaj	35°20' N-47°0' E	188	55	390
Kamyaran	34°43' N-46°40' E	202	76	430
Divandareh	36°4' N-46°55' E	86	64	340
Saqez	36°15' N-46°16' E	210	160	310
Bijar	35°53' N-47°37' E	276	132	240
Qorveh	35°10' N-47°48' E	340	82	220

A multistage sampling technique was used to select representative fields for sampling soil and water in Touba orchards of the Kurdistan province. Out of the total of 9 counties in the province, 6 counties with the highest area under cultivation of market gardens were purposefully, selected. In each county, 10 villages were randomly selected for soil and groundwater data collection. Then, in each village, a certain orchard was purposefully selected. Soil samples were collected from 3 random sites of each orchard at 15 cm depth of the soil profile. Samples from all the three sites of the same orchard were mixed thoroughly to obtain composite samples. Soil samples were collected in the experimental field after harvesting season of gardens. The samples then passed from 2-mm sieve. Composite surface soil samples collected from each garden and analyzed to determine soil fertility parameters. Organic carbon content of soil (SOC) was determined using titration method[11]. The total nitrogen (TN) of soil samples was measured according to the Kjeldahl method[12]. Soil available phosphorous (P_{av}) was measured using the Bray extracting solution procedure[13]. Phenyl boride extraction method was applied to determine available potassium (K_{av}) [14].

In addition, a total of 60 wells were selected in the province, based on three criteria: (a) each well had to be located within one of the planted areas in order to reflect the effects of above-ground agricultural management on groundwater nitrate concentrations; (b) wells of different depths in the same county were selected to collect groundwater samples from different depths, and (c) the wells were located in the same fields where soil samples were collected. Water samples were immediately placed in 150-ml polyethylene bottles sealed and transferred to the laboratory for NO_3^- analysis. NO_3^- content of well samples was measured based on USEPA standard method[15].

Basic statistics was carried out in order to interpret obtained results on soil and water quality data. Data were subjected to analysis of variance (ANOVA) following the Fisher Duncan *post hoc* test with p=0.05 using SPSS 16 (SPSS Inc., Chicago, IL, USA) statistical package. Data were reported as mean ± standard deviation of the mean. Correlation technique was applied to know relationship between the variables.

RESULTS AND DISCUSSION

Statistical analysis of soil fertility parameters was done and the results are presented in Table 2. Organic carbon content is an indication of health and production potentials of a soil profile[16]. SOC, which is a symptom of soil fertility, was significantly higher (1.55 g kg^{-1}) in soil samples of Sanandaj than the other counties. Reflection of N fertilizer over-use is observed in low organic carbon content of soil in these counties. Concentration of SOC in soil samples of the Sanandaj county revealed that using NPK and farmyard manure (FMY) at a rate of 533 kg ha^{-1}, results in the highest SOC content, when compared to that of other counties. The amount of SOC derived from soil samples of Qorveh and Bijar counties were even less than half of that in the orchards of Sanandaj. The second rank of SOC is related to the soil samples of Kamyaran (1.25 g kg^{-1}) on which NPK+FYM is annually applied as 618 kg ha^{-1}. Inorganic fertilization of the orchards in Kamyaran, with 35 kg ha^{-1} more than Sanadaj, resulted in less SOC content (0.25 g kg^{-1}) compare to that of Sanandaj. According to the higher rate of inorganic NPK fertilizer application in Kamyaran than Sanandaj and the highest rate of FYM application in this county, it is concluded, that this type of fertilizer can halt the loss of SOC. A decreasing trend is seen in SOC concentration of soil samples of the Saqez, Bijar and Qorveh counties. The beneficial effects of FYM on physical and chemical properties of soil had long been recognised[17]. However, because of the availability of and the high governmental subsidy on inorganic fertilizers in Iran, the use of FYM to improve soil fertility is not widespread in this country.

Table 2. Means followed by standard deviations of soil fertility parameters measured in soil samples of Touba orchards of the Kurdistan province

Soil properties	Sanandaj	Kamyaran	Divandareh	Saqez	Bijar	Qorveh
SOC ($g\ kg^{-1}$)	1.55±0.63c	1.25±0.59bc	1.01±0.31ab	0.85±0.39ab	0.72±0.22a	0.71±0.27a
TN ($g\ kg^{-1}$)	0.07±0.02a	0.08±0.02a	0.06±0.01a	0.12±0.04a	0.12±0.05a	0.45±0.21b
P_{av} ($mg\ kg^{-1}$)	7.1±5.72ab	16.43±4.72cd	12.03±14.6bc	4.1±4.62a	19.5±3.86d	7.72±2.56ab
K_{av} ($mg\ kg^{-1}$)	233.65±99.3abc	329.17±234.7c	330.7±185.4bc	205.86±103.1ab	309.4±117.2abc	187.2±103.8a
SOC/TN ($g\ kg^{-1}$)	26.04±18.44c	15.32±6.21b	15.05±6.67b	7.56±5.58ab	6.97±5.73ab	2.07±1.48a

Means ± standard deviation (SD) within a row followed by a different letter are significantly different after ANOVA followed by *post-hoc* Duncan test (p=0.05). Each value represents the mean of 10 measurements.

Distribution of TN followed an increasing trend with the amount of inorganic N fertilizer application. The least amount of N fertilizer application is related to the orchards of Divandareh and interestingly, the SOC and TN contents were found to be 1.01 and 0.06 g kg^{-1}, respectively. These results of this study are consistent with those of other researchers[18], who studied the relationships of TN with the application of inorganic N fertilizers. The TN concentration which is an important soil degradation indicator is the highest (0.45 g kg^{-1}) in the orchards of Qorveh due to the highest rate of N fertilizer (340 kg ha^{-1}) consumption. Statistical analysis showed that TN concentration in soil samples of this county was significantly different from that of others.

The so-called Bray P (plant-available phosphorous) was estimated in the acidic soil samples of Touba orchards. Based on soil science reports, whenever the concentration of this element is less than 20 mg kg^{-1}, it is considered as low concentration[19]. The overall results of P_{av} in soil samples of the present study showed that this element is present at low concentrations, with the highest (19.5 mg kg^{-1}) and the lowest (4.1 mg kg^{-1}) average values related to Bijar and Saqez, respectively. P-containing fertilizer applications are generally recommended when the test's result is low or medium (20-40 mg kg^{-1})[19]. Soil acidification was likely the result of the nitrification of excessive applied N fertilizer and NO_3^- leaching[7]. The acidified condition of a soil profile lowers availability of P and K nutrients. This matter is reflected in soil samples of

Divandareh, Kamyaran and Bijar in which the K_{av} concentrations were recorded as 330.7, 329.17 and 309.4 mg kg^{-1}, respectively. Against the average concentration of TN (0.06 g kg^{-1}), the highest average value of K_{av} (330.7 mg kg^{-1}) was measured in soil samples of Divandareh county.

In the current study, the SOC:TN ratio ranged between 62.25 (Sananadaj) and 0.27 (Qorveh). The average values of SOC:TN in Sanandaj and Qorveh were significantly higher and lower than that of other counties, respectively. The average values of this parameter were not significantly different among other 4 counties. Overall, under the Touba orchards, the soil samples showed low values of SOC:TN ratio which is another environmental indicator of unwise and over-use of N fertilizer.

Table 3. Nitrate concentrations in groundwater resources of Touba orchards in the Kurdistan province

County	Well depth (m)		Average ± standard deviation of NO_3^- (mg l^{-1})	Range (mg l^{-1})	NO_3^- > 50 mg l^{-1} (No. of wells)
	>15	<15			
Qorveh	3	7	68.9±16.7	52-95	9
Bijar	1	9	60.3±17.6	35-83	7
Kamyaran	5	5	53±15.8	34-76	6
Sanandaj	2	8	49.3±14.3	23-71	4
Saqez	6	4	44±12.4	21-65	3
Divandareh	4	6	35.9±11.2	22-55	2

Table 3 shows that in 51.66% of groundwater samples, NO_3^- concentration was ranging within 51-95 mg l^{-1}, which exceeds WHO-standard for drinking water (≤50 mg l^{-1}). Sampled wells were classified as shallow or deep using a depth of 15 m as criterion. Half of the wells were severely contaminated by NO_3^- and the frequency was great among the 6 counties. Of the tested groundwater samples of Qorveh, 90% were polluted by NO_3^-, whereas only 10% of the wells in Divandareh were found to be polluted. Inorganic N fertilizer only contributes to 16.92% of the total annual fertilizer input in Touba orchards of Divandareh. Therefore, the least average value of NO_3^- was recorded in the orchards of this county, reflecting the low impact of less inorganic N fertilizer application on groundwater resources.

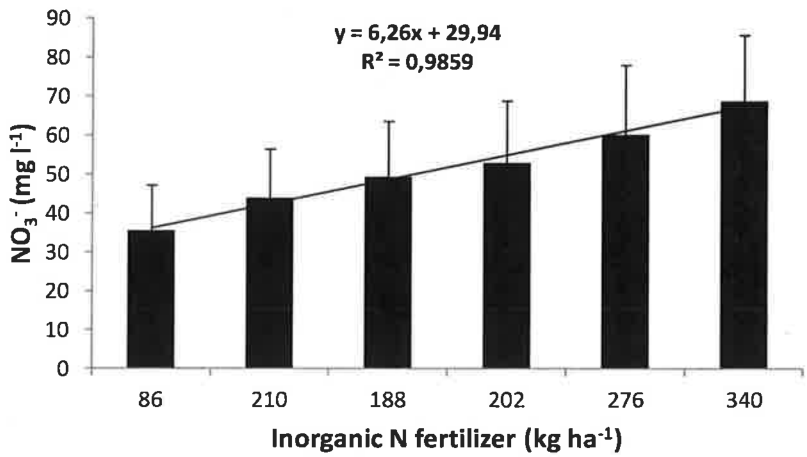

Fig. 1. Correlation between the mean values with standard deviation of nitrate (NO_3^-) concentration measured in groundwater samples and inorganic nitrogen fertilizer input of Touba orchards in the six counties of Kurdistan province, Iran. Each value of inorganic nitrogen fertilizer input is related to a certain county presented in Table 1

Additionally, Fig. 1 shows that a high correlation value (R^2=0.98) is existed between the amount of inorganic N fertilizer applied to Touba orchards and the measured NO_3^- concentration in groundwater samples of these orchards. In line with other researches on the impact assessment of inorganic fertilizers[6,7,20], in this study, it was found that determining factor of groundwater quality was agricultural activities related to nitrogenous fertilizers.

In order to deduce acidity, organic manure application is suggested as it has a positive effect on SOC stock in aggregates[17,21]. Combined application of inorganic fertilizers with organic manure should be performed to safeguard the soil fertility as well as to ensure plant productivity and food security[22].

Weaknesses in the extension services may be partly responsible for fertilizer over-use in the study area, and this is a complex institutional and economic issue. Another key factor behind N over-use is that the majorities of farmers do not take account of N inputs from manure and and from dissolved form of N in irrigation water when they decide how much N fertilizer to apply, and extension workers do not recommend that they should make such adjustments. In addition, increasing the precision in the application of both water and nutrients can potentially be achieved by simultaneous application via fertigation[23].

Fertigation offers the potential to overcome the low fertility of soils by gradual delivery of key nutrients to the main rooting zone in the irrigated horticultural systems. This has advantage of synchronising nutrient supply with plant demand, thus reducing the amount of nutrients applied and their environmental impacts[24]. Generally, while implementing an agricultural plan, further deterioration of soil and groundwater quality is expected, if no management strategies are developed concerning fertilizer practices.

CONCLUSIONS

This study revealed unbalanced use of nutrients in the commercial orchards of Kurdistan province. Organic fertilizers are insufficiently applied, whereas inorganic N fertilizer is considerably over-used. Soil fertility may deteriorate with low SOC:TN ratios estimated in Touba orchards of the province. Results obtained from the chemical analysis of soil and water samples of Touba orchards, illustrated the necessity of integrated nutrient management and harmonizing the use of inorganic and organic fertilizers as nutrient sources. If the current methods of soil fertility management are continued, groundwater and food contamination will be increased which jeopardize the sustainability of the current land use systems. Finally, research into management practices to halt the decline of soil organic matter and increase its availability is necessary and should be accorded high priority.

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