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Plant-soil-nutrient status of vegetables and wheat grown on calcareous soil

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ABSTRACT

Calcareous soil is extremely important in determining nutrient status and availability when applying different fertilizers to different crops associated with or without irrigation. The objective of this study was to investigate the nutritional status (nutrient availability) of different plants grown in two different ecosystems dominated with calcareous soil : Ghor Alsafi (eggplants, tomato and beans) as an example of irrigated area and the Karak Mountain Area (wheat) as an example for non-irrigated area. Physiochemical properties in soils and nutrients concentrations (C, Fe, Mn, Zn, available P, available and non-available K) in soil and plant leaves were analyzed. This study showed that N concentration in soil from both Ghor Alsafi (ranged from 4.4-5.1 mg/g) and the Karak Mountain Area (1.9-3.2 mg/g) was relatively low. This study showed that Fe content in vegetables grown in Ghor Alsafi was about 3 to 5 fold higher than the recommended maximum Fe concentration. The concentration of other nutrients (N, K, Zn and Mn) in investigated vegetables fell within the recommended concentrations range (38.3-39.7 mg/g, 36.6-39.5 mg/g, 21.7-27.3 ppm and 49.2-102.6 ppm, respectively). Phosphorus content in vegetables grown in Ghor Alsafi and in wheat grown in different locations in the Karak Mountain Area was about 5?6 fold higher than the recommended P concentration. Our results indicated that the high levels of P (ranged from 3.28-3.43 mg/g) and Fe (ranged from 340.4-551.3 ppm) in vegetables grown in Ghor Alsafi and high levels of P (ranged from 2.2-2.52 mg/g) in wheat in the Karak Mountain Area can be attributed to high levels of fertilizer application.

Key words : Calcareous soil, crops, ecosystems, nutrient availability, soil fertility

INTRODUCTION

In any crop production system, water availability and nutrient supply (mainly N, K and P) are considered the main elements that affect crop production yield (Gong *et al.,* 2011; Grzebisz *et al.,* 2013). Differences in the form and level of fertilizer application, crop cultivars and physical properties of soils have been shown to significantly influence crop production and yield (Cabeza *et al.,* 2013; Serrano *et al.,* 2014).

Karak governorate is located in the western part of Jordan near the southern end of the Dead Sea, and has mainly calcareous soils. Calcareous soil is known to affect mineral stability and availability to plants after fertilizers application. Farmers in Jordan apply N fertilizers in the form of ammonium compounds and urea. When N fertilizers are applied to calcareous soils, a high proportion of the N is volatilized (as NH_3), which reduces its availability to plants (Campana *et al.,* 2015). Phosphorus is present in different phases in soil, such as soil solution and exchangeable phase, organic matter phase, and Fe-, Al- and

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Ca-bound phases. Phosphorus in these different phases differs in its mobility, bioavailability and chemical behaviour in soil. Calcareous soils have also been reported to enhance P adsorption and precipitation in the form of calcium phosphate which is considered as one of the most stable forms (Halajnia *et al.,* 2009).

On the other hand, K is present in soluble, exchangeable and non-exchangeable forms, and as part of the mineral structure in soil. K is usually present in equilibrium between the soluble, exchangeable and non-exchangeable forms. The first two forms of K (soluble and exchangeable forms) are known to be readily available to the plants, and are generally referred to as available K. The non-exchangeable and structural forms are only slowly available to plants and are generally referred to as non-available K. The most influential factors in determining the equilibrium dynamics of K are the presence of ammonium ions and the type of clay minerals in soil.

The objective of this study was to investigate the nutritional status (nutrients availability) to different plants grown in two different ecosystems (Ghor Alsafi and the Karak Mountain Area in the Karak governorate). In addition, this study aims at comparing different methods to measure phosphorus and potassium availability for plants in calcareous soil.

MATERIALS AND METHODS

Studied Locations

This study was carried out at two locations in the Karak governorate those differed in climate, environment and the agricultural systems adopted during the year 2015-16. The first location was Ghor Alsafi which possesses sub-tropical climate conditions with an average temperature ranging from 19.8-31.3°C, annual rainfall around 73.6 mm and located approximately 398 meter below sea level. Soil, in this area, is dominated by alluvial soils and the agricultural system adopted in this area is dependent on irrigation. Farmers usually grow vegetables (mainly tomato, beans and eggplant). The amount of N, P and K used for growing these crops is as follows :

Tomato : 120 kg N/ha, 98 kg P/ha and 50 kg K/ha

Eggplant : 108 kg N/ha, 80 kg P/ha and 32 kg K/ha

Beans : 52 kg N/ha, 59 kg P/ha and 22 kg K/ha

The second location was the Karak Mountain Area which was located near what is well known for local people as "Mulook Street". This area has a Mediterranean climate with an average temperature ranging from 10.5-22.5°C, annual rainfall from 300-370 mm and located at 850-1100 meter above the sea level. Soil in this area is dominated by vertisol soil and the agricultural system adopted in this area is dependent on rains. Farmers usually grow cereals (mainly wheat). Fertilizer (diammonium phosphate) is usually applied with seeds at a rate of 50 kg/ha. In order to obtain a representative sample (for both soil and plant tissue), the Karak Mountain Area was divided into three sub-locations : north, middle and south.

Plant and Soil Sample Collection

Representative soil samples (2 kg) were taken from the studied locations. At each site, 10 samples were taken from soil depth 0-30 cm except for soil samples taken from locations grown with bean and eggplants (six samples each). Soil samples were air-dried at room temperature for one month and then sieved through a 2 mm screen. Material passing through the 2 mm screen was classified as soil, and the material retained on the screen was discarded.

Leaf samples were taken from Ghor Alsafi (tomato, beans and eggplant) during flowering, and from Karak Mountain Area (wheat) during the elongation stage but before spike formation. Plant samples were dried at 70°C for seven days. The sieved soils and oven-dried plant samples were then ground using a hammer mill. All samples were stored in polyethylene bottles until analyzed.

Soil Physico-chemical Measurements

Soil pH and electrical conductivity (EC) were determined to characterize soil physiochemical properties. Soil texture was determined using a hydrometer as previously described by Bouyoucos (1951).

Mineral/Nutrient Analysis

Total nitrogen and carbon concentrations for both plant and soil samples were determined by using a C : N analyzer (NA1500, Carlo Erba Instruments, Milan, Italy). Available phosphorus was extracted by using three different protocols : Olsen-P (Olsen *et al.,* 1954), Mehlich-3 (Mehlich, 1984) and calcium acetate lactate (CAL) method (Schüller, 1969). Phosphorus concentration was measured according to the procedure described by Watanabe and Olsen (1965).

Available potassium was extracted by using two different extraction solvents : NaH_4OA according to the procedure described by Rowell (1994), and calcium acetate lactate (CAL) as previously described by (Schüller, 1969). Non-available potassium was determined according to the procedure described by Cox *et al.* (1999). Potassium concentration was measured by using flame photometer (Elex 6361, Eppendorf, Hamburg, Germany).The gas-volumetric determination of calcium carbonate (Scheibler method) was performed as described by Tatzber *et al.* (2010). Cation-exchange capacity (CEC) was determined according to the procedure of Al-Nasir (2009).

Plant samples were digested using concentrated nitric acid in a microwave digestion system (Multiwave 3000, Anton Parr, USA). Mineral concentrations (P, K, Zn, Fe, Mn and Cu) in plant samples were analyzed using Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS, Elan DRC II, PerkinElmer, USA).

Statistical Analysis

To compare the mineral contents for different elements over crops (tomato, beans and eggplant) and Karak Mountain Area (south, middle and north), one way analysis of variance (ANOVA) was used to test the crops and Karak Mountain Area effects and also to compare phosphorus concentration derived by different extraction methods (CAL, Mehlich-3 and Olsen-P) by applying the following mathematical model (Steel and Torre, 1980) : $y_{ij} = \mu + \tau_i + \varepsilon_{ij}$, where, μ represents the ground mean over all observations, τ_i represents the effect of treatment i (crop or mountain area or phosphorus extraction method), and ε_{ij} are the residuals. Fisher's LSD was used as a method for comparing means after the ANOVA F-test null hypothesis of equal means has been rejected at $P \leq 0.05$. Unpaired t-test was used to compare mineral concentration in Ghor Alsafi and Karak Mountain Area and also to compare potassium content derived from the CAL and $K\text{-}NH_4OAc$ methods at a probability level of $P \leq 0.05$.

RESULTS AND DISCUSSION

Physiochemical Properties of Soil in Examined Locations

Table 1 shows the physical and chemical characteristics of soil from the sites studied (Ghor Alsafi and Karak Mountain Area) in the Karak governorate. In Ghor Alsafi, it can be clearly seen that sand fraction (32.0 to 80.0%) is the major fraction of the soil. The percentage of clay (14.0 to 30.0%) and silt (7.0 to 40.0%) were similar (Table 1). The texture of soils in Ghor Alsafi can be described as sandy loam (tomato), sandy-clay loam (for both beans and eggplants). Similar soil texture profiles were observed at the three sampling sites (north, middle and south) in the Karak Mountain Area. Sand made up the largest fraction (42.0 to 77.0%) of the soil, with similar levels for silt (6.0 to 32.0%) and clay (14.0 to 37.0%) fractions

Table 1. Physical and chemical properties of soils from sampling sites in Ghor Alsafi and the Karak Mountain Area[a]

	Ghor Alsafi			Karak Mountain Area		
	Tomato=10	Beans=6	Eggplant=6	South=10	Middle=10	North=10
Sand (%)	58-80 (67.2)	32-71 (54.3)	36-71 (57)	42.0-76 (61.2)	50-73 (64.3)	44-77 (60.3)
Silt (%)	7-24 (16.5)	11-40 (23.0)	11-40 (21.0)	6.0-25 (17.4)	9-24 (17.0)	7-32 (19.0)
Clay (%)	14-20 (16.6	17--30 (22.7)	18-30 (22.0)	16-37 (22.4)	14-26 (18.6)	16-31 (21.3)
EC 1 : 1 dS/m	0.67-9.84 (3.1)	0.84-9.7 (3.9)	0.50-4.3 (1.9)	0.53-0.64 (0.58)	0.50-0.80 (0.60)	0.50-0.64 (0.60)
$CaCO_3$ (%)	22.0-42.80 (33.4)	26.6-38.2 (32.9)	6.0-43.6 (32.4)	5.3-27.6 (13.8)	8.5-35.1 (18.6)	5.4-38.2 (18.7)
CEC Meq.100/g	4.8-9.7 (7.2)	4.5-9.5 (5.9)	4-14 (11.5)	21.5-42.0 (33.6)	20.6-53.7 (35.9)	28.5-56.0 (36.5)
Organic matter (%)	0.46-2.8 (1.35)	0.5-1.9 (1.2)	0.54-3.5 (1.52)	0.56-1.1 (0.92)	0.58-2.6 (1.34)	0.61-2.8 (1.24)
Soil pH 1 : 1	7.07-8.07 (7.66)	7.60-7.97 (7.74)	7.54-7.97 (7.71)	7.78-7.87 (7.83)	7.8-8.0 (7.90)	7.66-7.98 (7.81)

[a]Data are presented as minimum-maximum values. Values in parentheses are averages.

(Table 1). Similar soil fractions were previously reported for soils in Ghor Alsafi (Bani Hani and Shatanawi, 2013) and in Karak governorate (Al-Nasir, 2010).

Soil pH, electrical conductivity (EC), $CaCO_3$ concentration, organic matter and cation exchange capacity (CEC) are shown in Table 1. Compared to the Karak Mountain Area sampling sites, the Ghor Alsafi sampling sites had higher EC and $CaCO_3$ concentration, lower CEC, and similar organic matter concentration. The higher physical and chemical measurements in Ghor Alsafi could be attributed to the intensive cultivation practices (including the frequent addition of organic and inorganic fertilizers) associated with irrigation.

The soil was slightly alkaline in both the regions, and at all sample sites. For Ghor Alsafi the soil pH range was 7.07–8.07 and for the Karak Mountain Area the soil pH range was 7.66-8.0. The alkaline soil in both the sites was attributed to the presence of high levels of $CaCO_3$. In this study, $CaCO_3$ concentration was higher in Ghor Alsafi (22.0 to 42.8%) compared to $CaCO_3$ concentration in the Karak Mountain Area (5.3 to 38.5%). However, active $CaCO_3$ is considered the primary factor that affects soil pH (Halajnia *et al.,* 2009) and could be higher in Ghor Alsafi than the Karak Mountain Area. Ghor Alsafi soil had a higher EC measurement (0.52 to 9.84 dS/m) than the Karak Mountain Area (0.50 to 0.80 dS/m). This may be due to frequent irrigation in Ghor Alsafi resulting in increased soil salinity. Organic matter concentration was slightly higher in Ghor Alsafi compared to the Karak Mountain Area (0.46 to 3.50 and 0.56 to 2.8%, respectively). This may be due to the higher water availability and more organic matter production that is associated with more intensive cultivation practices in Ghor Alsasfi (Jarmer and Shoshany, 2016).

Measured CEC values were three times higher in the Karak Mountain Area (20.6 to 56.0 Meq/100 g soil) than in Ghor Alsafi (4.0 to 14.0 Meq/100 g soil). The higher CEC values in the Karak Mountain Area could be attributed to the presence of Montmorillonite which is well known to increase CEC properties in soil.

Mineral Concentrations in Examined Soils

Table 2 shows mineral concentration (total N, available P and available K determined with using different extraction methods, and non-available K) in soils at different sites (Ghor Alsafi and the Karak Mountain Area). In Ghor Alsafi, there was no significant difference in N concentration in soils used to grow different vegetables (4.4 to 5.1 mg N/g soil) (Table 2). However, in the Karak Mountain Area, soil at the north sampling site had the lowest N concentration (1.9 mg N/g soil) and was the highest at the middle area (3.2 mg N/g soil). These results suggested that N concentrations in both Ghor Alsafi and the Karak Mountain Area were relatively low and that N deficiency was more pronounced in the Karak Mountain Area. Nitrogen concentrations in the investigated areas were approximately similar to soil in semi-arid areas reported by other studies which possessed similar soil properties (Gong *et al.,* 2011; Jalali and Tabar, 2011).

Table 2. Concentration of total nitrogen, available phosphorus, available and non-available potassium in soils at different locations in the Karak Governorate[a]

	Ghor Alsafi			Karak Mountain Area		
	Tomato	Beans	Eggplant	South	Middle	North
Total nitrogen (mg/g)	5.1[a]	4.9[a]	4.4[a]	1.9[a]	3.2[a]	3.0[ab]
Phosphorus						
Olsen P (mg/kg)	76.1[a]	60.0[ab]	41.3[b]	13.2[a]	12.8[a]	7.1[a]
Melich-3 (mg/kg)	45.2[a]	32.7[a]	7.4[b]	8.98[a]	7.2[a]	5.7[a]
CAL (mg/kg)*	207.9[a]	169.4[ab]	130.1[b]	25.4[a]	24.2[a]	21.30[a]
Potassium						
NH_4OAc (mg/kg)**	362.8[a]	448.3[a]	523.0[a]	415.8[a]	438.1[a]	451.1[a]
CAL (mg/kg)*	304.7[a]	211.5[a]	197.5[a]	214.7[a]	171.0[a]	161.4[a]
Non-available (mg/kg)	732.1[a]	696.6[a]	754.6[a]	427.8[a]	519.1[a]	502.3[a]

[a]Within a region and row, values followed by the same letter are not significantly different at P>0.05.
*Available P and K measured using the calcium acetate lactate CAL extraction method.
**Available K measured using NH_4OAc extraction method.

At the three sampling sites in the Karak Mountain Area (North, Middle and South), none of the extraction procedures showed a significant difference in the available P concentration (Table 2). However, in Ghor Alsafi, the available P concentration varied between the soils used to grow different crops. P levels were significantly higher in the soils from the site growing tomatoes, and lowest in soils used to grow eggplants. Based on the three methods used to determine available P, the concentration in soils from Ghor Alsafi was higher than in soils from Karak Mountain Area (with the exception of the tomato soil site using the Melich-3 method) (Table 2). This may be attributed to long term fertilizer application that resulted in P accumulation in the soil in Ghor Alsafi (Zhao *et al.,* 2016). The concentration of available P in the Karak Mountain Area and Ghor Alsafi was relatively low when compared with other studies similar in soil chemical properties (Qin *et al.,* 2016; Zhao *et al.,* 2016). There were no significant differences in the available and non-available K concentration in soils used to grow different crops in Ghor Alsafi, or in different locations in the Karak Mountain Area (Table 2).

Although the differences in cultivation practices (in term of extensive fertilizer applications) between Ghor Alsafi and the Karak Mountain Area, there were no significant differences in N concentrations between both the areas (Table 3). Although farmers in Ghor Alsafi make extensive use of nitrogen-rich fertilizers (mainly ammonium sulfate and urea), the N concentration is still low because of ammonia volatilization as a result of alkaline soil properties (Köster *et al.,* 2014). Earlier study showed that N loss as NH_3 could reach more than 70% and up to 90% in alkaline soil (Campana *et al.,* 2015). Furthermore, the relatively high temperature in Ghor Alsafi compared to the Karak Mountain Area may further enhance N losses.

Because of the high usage of P fertilizers in Ghor Alsafi, and to a lesser extent in the Karak Mountain Area, higher concentrations of available P were expected in the soil in Ghor Alsafi compared to the Karak Mountain Area (Table 3). This could be attributed to soil alkalinity related to the $CaCO_3$ concentration as discussed earlier. The presence $CaCO_3$ was reported to enhance P precipitation in the form of Ca-bound P (Hesterberg, 2010). Jalali and Tabar (2011) reported that Ca-bound P was the most abundant P fraction in soils under different land uses, representing an average of 71.4% (ranging from 61 to 78%) of total P.

Table 3. Effect of investigated areas Ghor Alsafi and the Karak Mountain Area on mineral concentrations in soil and in plant tissue

	Ghor Alsafi[a]	Karak Mountain Area
Mineral concentration in soil		
N (mg/g)	1.07[a]	0.84[a]
K (mg/g)	473.0[a]	439.4[b]
P (mg/g)	57.70[a]	10. 90[b]
Mineral concentration in plant		
N (mg/g)	38.8[a]	29.0[b]
K (mg/g)	39.15[a]	30.05[b]
P (mg/g)	3.37[a]	2.38[b]
C (%)	37.19[b]	42.16[a]

[a]Within a row, values followed by the same letter are not significantly different at P>0.05.

As expected, there was a significant difference in available K in Ghor Alsafi (472.99 mg/kg) compared to the Karak Mountain Area (439.4 mg/kg) (Table 3) as a result of higher levels of fertilizer application in Ghor Alsafi. Available and non-available K levels in the soils in this study were similar to (Bani Hani and Shatanawi, 2013; Qin *et al.,* 2016) or higher than (Gong *et al.,* 2011) the levels reported in other studies.

The N, P and K concentrations in plant material grown in Ghor Alsfai and the Karak Mountain Area are shown in Table 3. The concentrations of N, P and K were significantly higher in plants grown at Ghor Alsafi, but the concentration of C was significantly higher in plants grown in the Karak Mountain Area. Higher concentrations of N, P and K were attributed to more intensive fertilizer application in Ghor Alsafi. There were differences in the level of nutrients detected in different plant samples. Differences in nutrient contents may be attributed to plant species. Higher nutrient contents (N, P and K) in tomato, bean and eggplants were reported (Hochmuth *et al.,* 2015) when compared to wheat (Bergmann, 1993). Carbon percentage in grasses (such as wheat) was reported to be higher than carbon percentage in vegetables and legumes (Whalen and Sampedrol, 2009).

Effect of Extraction Method on Available P and Available K

Table 4 shows the effect of extraction

methods on both available P and available K concentrations in the examined soils. There were no significant differences among the three methods used to measure the available P concentration. By contrast, for K the extraction method had a significant effect on the measured available K concentration. The NH_4OAc extraction method (453.89 mg/kg) gave a significantly higher available K concentration compared to the CAL extraction method (220.56 mg/kg) (Table 4).

Table 4. Effect of different extraction methods on available P and K concentrations in soil[a]

Extraction method	P (mg/kg)	Extraction method	K (mg/kg)
CAL	98.1[a]	CAL	220.56[b]
Mehlich-3	15.7[a]	K-NH_4OAc	453.89[a]
Olsen P	31.1[a]		

[a]Within a column, values followed by the same letter are not significantly different at P>0.05.

Nutrients Concentration in Examined Plants

Table 5 shows nutrients concentration (N, P, K, Fe, Mn, Zn and C) in vegetables (grown in Ghor Alsafi) and wheat plant (grown in the Karak Mountain Area) tissues collected during the flowering stage and before the spike formation, respectively. Measurement of the plant composition during the above mentioned stages of plant growth was performed to evaluate the nutritional status of the plants when nutrient demand was at its highest. There were no significant differences in nutrient concentration in plants grown in different soils in Ghor Alsafi except for C, which was significantly lower in tomato plant samples. In the Karak Mountain Area, there were significant differences in N, Fe, and Zn concentrations and were highest in the southern sampling site.

Table 6 shows a comparison of adequate/recommended mineral concentration profile (N, P, K, Fe, Mn and Zn) and measured mineral concentration in selected plant tissues in soils from different locations. The adequate/recommended mineral concentration for the plant types in this study is presented as minimum–maximum range (Table 6).

It can be clearly seen that P content in vegetables (eggplants, tomato and beans) grown in Ghor Alsafi and in wheat grown in different locations in Karak Mountain Area was about

Table 5. Mineral concentration on a dry matter basis of plants grown in two regions within the Karak Governorate[a]

	Ghor Alsafi			Karak Mountain Area		
	Tomato	Beans	Eggplant	South	Middle	North
N (mg/g)	38.3[a]	38.3[a]	39.7[a]	32.3[a]	29.2[ab]	25.6[b]
P (mg/g)	3.28[a]	3.43[a]	3.39[a]	2.52[a]	2.42[a]	2.20[a]
K (mg/g)	39.5[a]	38.3[a]	36.6[a]	31.1[a]	29.5[a]	29.4[a]
C (%)	35.1[b]	38.2[a]	38.5[a]	42.8[a]	45.8[b]	42.0[ab]
Fe ppm	551.3[a]	340.4[a]	487.3[a]	80.3[a]	71.6[ab]	62.1[b]
Mn ppm	89.4[a]	102.6[a]	49.2[a]	38.9[a]	38.6[a]	37.2[a]
Zn ppm	27.3[a]	24.5[a]	21.7[a]	24.0[a]	22.5[ab]	20.5[b]

[a]Within a region and row, values followed by the same letter are not significantly different at P>0.05.

Table 6. Comparison of mineral concentrations measured in two different regions within the Karak Governorate, and comparison of mineral concentrations that indicate that the plant has adequate nutritional status

	Eggplant		Tomato		Bean		Wheat	
	Recommended range[a]	Measured average	Recommended range[a]	Measured average	Recommended range[a]	Measured average	Recommended range[a]	Measured average
N (mg/g)	42-60	39.7	30-50	38.3	30-41	38.3	30-50	25.6-32.3
P (mg/g)	0.3-0.6	3.39	0.3-0.6	3.28	0.3-0.5	3.43	0.3-0.6	2.20-2.52
K (mg/g)	35-50	36.6	30-50	39.5	20-31	38.3	35-55	29.4-31.1
Fe ppm	50->100	487.3	40->100	551.3	25->100	340.3	>100	62.1-80.3
Mn ppm	50-100	49.2	30-100	89.4	20-100	102.6	35-100	37.2-38.9
Zn ppm	20-30	21.7	25-40	27.3	20-40	24.3	25-70	20.5-24.1

[a]Adapted from Hochmuth *et al.* (2015); [b]Adapted from Bergmann (1993) and [c]Nutrient concentration in wheat plants is the average of samples obtained from three different locations in the Karak Mountain Area.

5-6 fold higher than the recommended maximum P concentration (Hochmuth *et al.,* 2015). The Fe content of vegetables grown in Ghor Alsafi was about 3-5 fold higher than the recommended maximum Fe concentration (Hochmuth *et al.,* 2015), while the concentration of other nutrients (N, K, Mn and Zn) fell within the recommended range (Table 6).

The K, Zn and Fe concentrations in wheat were below the recommended minimum concentration (Hochmuth *et al.,* 2015). High levels of P and Fe in vegetables grown in Ghor Alsafi and high levels of P in wheat in the Karak Mountain Area can be attributed to high fertilizers application.

CONCLUSION

It can be concluded from this study that farmers in both the areas studied (Ghor Alsafi and the Karak Mountain Area) used improper cultivation practices, which was more noticeable in Ghor Alsafi. The continual addition of P rich fertilizer increased the P content in soil above the optimum level required by crops. This study revealed that farmers in the Karak Mountain Area did not use enough K rich fertilizers. Crop rotation could be an effective approach to maintain soil fertility in the mountain area. Further research should be conducted to minimize nitrogen losses through the volatilization of NH_3 from calcareous soil.

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