Optimizing ammonium acetate procedure for determining available potassium in Iranian calcareous soils, testing the concentration and contact time

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ABSTRACT

Ammonium acetate ($NH_4C_2H_3O_2$) is the extractant mostly used by the local soil laboratories in Iran when determining available potassium (K_{ava}) in calcareous soils. To optimize the procedures for determining soil available potassium (K_{ava}), two individual experiments were carried out. For this purpose, the effect of two NH_4OAc concentrations (i.e., 1 M and 0.1 M NH_4OAc) and the efficiency of two extraction procedures (i.e., 30 min shaking on the orbital shaker and keeping the mixture overnight (12 h) without shaking) were investigated. Calcareous soils (1234 samples) from different parts of Iranian provinces were collected. The results revealed that in most soils, the decrease in the NH_4OAc concentration from 1 to 0.1 M had no significant effect on the K_{ava} concentration. There was a significant and positive correlation between potassium concentrations of 1 and 0.1 M NH_4OAc extractants, although, a significant deviation was observed for some soils. The regression equation between the two extractants was y = 0.97 x + 8.43 (R^2 = 0.97 and SEE = 36.5), which overlaps with the 1:1 line. Therefore, to save the chemicals and reduce analysis costs, 0.1 M NH_4OAc can be used instead of 1 M NH_4OAc. Results obtained from the second experiment clearly showed that shaking the mixture for 30 min was as effective as keeping it overnight without shaking to 30 min with shaking in extracting soil available potassium.

Keywords: Ammonium Acetate, Arid and Semi-Arid Areas, Available Potassium, Extraction, Fertilizer Recommendation, Soil Test.

1. Introduction

The most important purpose of soil testing is to provide a simple, fast, and inexpensive method for chemical analysis to measure the concentration of available nutrients in calcareous soils, accurately. Potassium (K) is an essential nutrient for plant growth and is one of the three main macronutrients (along with N and P) that limits plant growth (Barbagelata, 2006). Determining the available potassium (K_{ava}) concentration using a viable extractant and applicable to various soil types is essential for soil and crop management practices such as fertilizer recommendation. For rapidly choosing an extractant to determine the available concentration of nutrients, three parameters are essential including; (i) extraction of the labile forms; (ii) easy to operate, fast, and economic expenses; and (iii) applicable to a wide range of soils, crops, and climates (Hosseinpur & Zarenia, 2012; Sardi & Füleky, 2002; Zarrabi & Jalali, 2008). To determine the different fractions of an element in the soil, two critical steps, including; 1) extraction and 2)

measurement with a proper analytical instrument, are crucial. For example to extract the available form of a nutrient, in the extraction step, a chemical reagent is used to separate all or a fraction of the nutrients from the soil which is available to the plant. The quantity of extracted available form of an element by a specific extractant depends on soil, plant, and climatic factors. Determining the availability of nutrients is a key factor for nutrient management and provides a guideline for fertilizer recommendation and also improves the quality of soil and water resources (Ferrando, Barbazán, García, & Mallarino, 2020). There is a wide range of extractants to estimate K_{ava}, but the neutral NH_4OAc 1 M, has been universally accepted as an efficient extractant for wide range of soils (Bedi, Wali, & Verma, 2002; Brown, 1998) for both soluble and exchangeable K. Basically, ammonium in NH_4OAc solution are the most effective ions for replacing the potassium on the surface sites (Bohn, McNeal, & O'Connor, 1980). Novozamsky and Houba (1987) reported that various type of extractants uses to estimate the amount of K_{ava} including the

solutions such as NH_4OAc, sodium nitrate ($NaNO_3$), ammonium nitrate (NH_4NO_3), calcium chloride ($CaCl_2$), Bray solution, sodium bicarbonate ($NaHCO_3$), buffered and unbuffered ammonium oxalate (($NH_4)_2C_2O_4$), ammonium lactate ($C_3H_9O_3N$), calcium lactate ($C_6H_{10}CaO_6$), two acids (hydrochloric acid (HCl) and sulfuric acid (H_2SO_4), Morgan extractant (sodium acetate-acetic acid ($C_2H_3NaO_2.CH_3COOH$)), dilute sulfuric acid, 0.2 M oxalic acid ($C_2H_2O_4$) + 0.1 M hydrochloric acid (HCl), sodium tetraphenylborate (($C_6H_5)_4BNa$), and boiling nitric acid (HNO_3). These extractants are usually used in different concentrations and procedures. Considering the different compositions of the minerals in the different soils, plant types, and climatic conditions, it seems that the method of determining the K_{ava} is specific for each geographical region. However, it may apply to the similar soils and climates. Some studies have compared the different extractants in a specific soil type and climatic region and introduced the best extractant for their studied soils. For example, Amorim, Rogeri, and Gianello (2021) tested ammonium acetate, Mehlich 1, Mehlich 3, and ammonium chloride extractants to determine the amount of K_{ava} in some Brazilian soils and showed that Mahlich 1 extracted a higher K_{ava} for corn plants. Ferrando et al. (2020) compared three extractants, namely ammonium acetate, Mehlich 3, and sodium tetraphenylborate, and the results revealed that the ammonium acetate and Mehlich 3 overlaps with each other (however, ammonium acetate extracted relatively higher amounts of potassium). In Iran, for the first time, Manteghi (1976) used 1 M ammonium acetate (pH=7) and overnight contact time (12 hours) for the extraction of K_{ava} from the soils of Iran (Ali-Ehyaei & Behbahanizadeh, 1993) and currently this is the most dominant method for extracting K_{ava} in soil laboratories in Iran.

Choosing a suitable extractant to determine K_{ava} to be applicable to different soil types, crops, and climatic conditions is one of the big challenges for Iranian researchers. For instance, Tafaroji, Haghparast-Tanha, and Vasse-Mosalla (2005) reported that using 1:20 NH_4OAc (lower concentration compared to 1 M NH_4OAc) was an acceptable method to extract the K_{ava} in Guilan soils (one of the provinces of Iran). Hosseinpur and Zarenia (2012) reported that the boiling 1 M HNO_3 extracted the highest concentration of K_{ava} among different extractants including acidic extractants, boiling 1 M HNO_3, 0.1 M HNO_3, 0.1 M HCl, Mehlich 1, 0.1 M $BaCl_2$, 0.01 M $CaCl_2$, 1 M NH_4OAc, ammonium-bicarbonate-DTPA, and distilled water. Karim Shahbazi, Cheraghi, Marzi, and Hasheminasab Zavareh (2022), compared three extractants, including ammonium acetate 1 M, Mehlich 3, and ammonium-bicarbonate-DTPA, for extracting the available amount of soil potassium and reported a high correlation between ammonium acetate and Mehlich 3.

According to recent studies, it is possible to optimize the concentration of ammonium acetate and reduce its concentration according to climatic conditions and soil characteristics. Moreover, according to the different validated methods, the extraction time can be reduced by shaking the mixture instead of settling down the mixture for a longer time. Therefore, this study was designed to compare 0.1 M and 1 M ammonium acetate extractants and determine the appropriate contact time for extracting K_{ava} from some of the Iranian soils types. Moreover, two separate sets of experiments were conducted to designate the effect of shaking and keeping the mixtures (without shaking) overnight.

2. Materials and Methods

2.1. Sampling

Sum of 1234 surface soil samples were collected from 28 provinces around Iran (Kerman, Lorestan, Yazd, Fars, Isfahan, Zanjan, Mazandaran, North and South Khuzestan (Dezful and Ahvaz cities), East Azerbaijan, West Azerbaijan, Khorasan Razavi, Golestan, Bushehr, Sistan and Baluchistan (Zabol city), Hormozgan, Kermanshah, Kurdistan, Kohgiluyeh and Boyer Ahmad, Jiroft, Chaharmahal and Bakhtiari, Markazi, Ardabil, and Alborz) with different climatic and physicochemical properties. For this purpose, about 30-50 soil samples were taken from each province, with a wide variations in physiochemical characteristics such as electrical conductivity (EC), pH, clay, K_{ava}, cation exchange capacity (CEC).

2.2. Extraction of available potassium

For the extraction procedures, 2.5 g of air-dried soil was transferred into a 250 ml plastic Erlenmeyer flask, and 50 mL of the extractants (1 M and 0.1 M NH_4OAc) were added (1:20 ratio of soil-to-extractant). The mixture was shaken for 30 min using an orbital shaker at 180-200 rpm. Then, the supernatant was filtered. To study the effect of contact time and shaking, the two experiments were treated as; for the first experiment, the mixture was agitated on an orbital shaker for 30 min (at 180-200 rpm) and then filtered. For the second experiment, the mixture of soil and extractant was left overnight at the room temperature. In both experiments, the supernatant was filtered through suitable chm filter paper, and the potassium concentration was determined using a flame photometer. Both experiments were performed in four replicates.

2.3. Data analysis

All of the calculations and graph drawings were carried out using Excel 2013. The mean comparison test was conducted using the paired t-student analysis by SAS (version 9.4, SAS Institute Inc., Cary, NC). The standard error of the estimates were obtained using the Sigma Plot 12.0, by employing the following equation, where X_i

stands for data values, $\overline{X}$ is the mean value and n is the sample size.

$$SEE = \sqrt{\frac{\sum \left(X_i - \overline{x}\right)}{n-2}} \qquad [1]$$

The confidence interval (CI) was calculated through the following equation;

$$CI = t_{0.99} \times SEE \times \sqrt{\frac{1}{n} + \frac{\left(x_i - \overline{x}\right)^2}{\sum_{i-1}^{n}\left(x_i - \overline{x}\right)^2}} \qquad [2]$$

where $t_{0.99}$ is obtained from the t-student tables, n represents the number of samples, x is observation (for each point), $\overline{x}$ represents the average value of the experimental data. The upper and lower limits of confidence intervals were calculated using equations 3 and 4.

Upper limit=(m×x_i+b)+CI   [3]

Lower limit=(m×x_i+b)-CI   [4]

where m and b are the slope and intercept of the regression line.

3. Results and discussion
3.1. Physiochemical characteristics of soils

Some physiochemical characteristics of soil samples, including EC, pH, clay content, and K_{ava}, are presented separately for different provinces in Table 1. Due to the random selection, the range of changes in the physiochemical properties could be considered as a proper representative of soils in Iran. The EC of the soils varied from 0.94 to 14.58 dS/m, which covers a wide range of saline soils. The clay content of samples varied from 8.40 to 35.40 %. Considering the importance of clay content influencing potassium availability (due to different reactions such as adsorption, fixation, and release), these characteristics can be effective in terms of K_{ava} content. The CEC was varied between 3.25 to 31 $cmol_c$/kg, representing a wide variation in soil holding capacity for cations. Changes in the K_{ava} concentration were from 142.4 to 396.2 mg/kg, which indicates a significant variation in the amount of K_{ava} in the soils of Iran. The results of K_{ava} concentration were consistent with the researchers (Roozitalab, Siadat, & Farshad, 2018; Tehrani, 2013). According to the recommended critical level of K for the soils of Iran (250- 300 mg/kg), these soils have wide distribution, ranked from low to high K_{ava}, which represents the soils of Iran very well (Roozitalab et al., 2018). Tehrani (2013) reported that the concentration of K_{ava} in 33.60% of soils of Iran is less than 200 mg/kg. The reported results were consistent with the current study.

3.2. Correlation between the extraction methods
3.2.1. Extracting soil K with 1 and 0.1 M NH₄OAc solutions

The NH₄OAc is an excellent universal solution that replaces the exchangeable potassium (and also other exchangeable cations such as Na^+, Ca^{2+}, and Mg^{2+}) in the soil surfaces while keeping the pH constant. Potassium ions are released into the solution and extracted (or separated) during the filtration. A linear relationship between the K extracted using 0.1 and 1 M NH₄OAc solutions was found (Fig. 1, the regression parameters are provided in Table 2). The amount of K extracted with either 0.1 or 1 M NH₄OAc solutions fluctuated in different provinces (depending on the soils and their K_{ava} content). In Ardabil province, the amount of K extracted ranged from less than 62 mg/kg to more than 800 mg/kg and the amount of K extracted with 1 M NH₄OAc was higher when 0.1 M NH₄OAc was utilized. Similarly, in most provinces such as Tehran, Yazd, Isfahan, Kurdistan, Zanjan, Mazandaran, Khorasan, Golestan, and Kermanshah the amount of K extracted with 1 M NH₄OAc was higher than that extracted with 0.1 M NH₄OAc, while in some provinces such as Kerman, Sistan and Baluchestan (Zabol), Khuzestan (Ahvaz), Hormozgan, and Bushehr higher extracted potassium was obtained by 0.1 M NH₄OAc (Table 2). However, this higher extraction was insignificant in most cases, but this finding is against the normal expectation for extraction of K_{ava}, and therefore, more concentration is required on these soils to find out the reason behind the higher extraction of soil potassium by 0.1 M NH₄OAc.

According to Table 3, the minimum, maximum, and mean concentrations of the soil K_{ava} extracted by both extractants were close to each other. The correlation coefficient (r) obtained between the 0.1 and 1 M NH₄OAc extractants (0.981-1.00) showed a significant positive correlation. The comparison of means tests between the amounts of K_{ava} extracted by 0.1 and 1 M NH₄OAc extractants showed that in all provinces, there were no significant differences at the 5% level of significance.

As shown in Fig. 2, the simple regression equation between the two extractants was y = 0.976x + 8.43 (SEE = 36.5). The slope of the equation (0.976) is very close to one, indicating good consistency in the wide ranges of soils and potassium concentrations (Fig. 2a). The confidence interval of the regression line was very narrow, which indicates the precision of the regression equation for estimating K_{ava} using 0.1 M NH₄OAc. Moreover, the confidence interval get wider at the higher K_{ava} concentrations, indicating the lower precision at higher concentrations. Line intercept was 8.43, which is insignificant compared to the normal soil K_{ava} concentrations (the mean concentration of K_{ava} was varied between 140 and 396 mg/kg). Therefore, the regression line established between the amounts of K_{ava}

Table 1. Distribution status of some physiochemical properties of the soil samples in different provinces/cities.

| Province/City	EC (dS/m)				pH				Clay (%)				K$_{ava}$ (mg/kg)			
	Max	Min	SD*	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean
Ardabil	3.30	0.52	0.57	1.19	8.80	7.40	0.22	7.90	57.0	9.00	12.5	32.6	882	62.0	195	346
Ahvaz	21.6	0.50	4.96	4.90	7.90	7.00	0.21	7.58	52.0	6.00	9.80	21.7	384	64.0	73.9	142
Bushehr	91.0	0.90	16.9	11.3	8.40	6.90	0.26	7.64	-	-	-	-	800	35.0	151	193
Chaharmahal and Bakhtiari	-	-	-	-	-	-	-	-	-	-	-	-	756	88.0	185	364
East Azerbaijan	-	-	-	-	-	-	-	-	-	-	-	-	1500	100	230	297
Isfahan	60.0	0.40	12.5	8.60	8.20	7.40	0.19	7.70	36.0	11.6	6.10	26.0	471	100	101	287
Fars	11.6	0.58	3.00	3.60	8.50	7.10	0.34	7.80	50.3	12.0	8.88	30.4	800	152	113	319
Golestan	37.5	0.50	77.0	6.50	-	-	-	-	68.0	10.0	15.2	25.2	770	48.0	174	258
Hormozgan	163	0.17	28.9	14.6	9.70	7.40	0.56	8.18	36.0	2.00	6.68	14.7	740	56.0	145	203
Jiroft	159	0.36	22.8	7.90	8.90	7.10	0.35	7.90	24.0	2.00	5.86	8.40	1859	58.0	301	380
Karaj	13.9	0.44	2.52	2.70	8.30	7.30	0.26	7.80	55.0	10.4	10.7	23.5	1600	52.0	321	396
Kerman	43.4	0.21	7.15	7.21	8.40	7.30	0.23	7.87	60.0	3.00	12.7	18.2	806	42.0	220	326
Kermanshah	332	0.23	0.51	0.94	8.50	7.10	0.30	7.80	54.0	11.0	9.16	35.4	1560	100	244	394
Khorasan	-	-	-	-	-	-	-	-	-	-	-	-	510	78.0	86.1	216
Kohgiluyeh and Boyer-Ahmad	16.7	0.31	2.45	1.94	7.80	7.00	0.18	7.50	46.0	14.0	9.55	27.5	1090	66.0	189	252
Kurdistan	40.0	0.31	5.60	1.57	8.40	7.00	0.27	7.80	-	-	-	-	1750	52.0	303	372
Lorestan	5.40	0.33	1.03	1.00	8.60	7.20	0.24	7.70	59.0	7.00	11.6	35.3	758	70.0	162	377
Markazi	36.7	0.47	7.25	5.01	9.30	7.60	0.39	8.11	35.0	3.60	8.51	17.1	910	32.0	213	277
Mazandaran	2.50	0.42	0.51	1.00	8.20	6.70	0.31	7.70	65.0	5.00	16.2	32.9	1384	89.5	262	390
Dezful	9.60	0.46	1.92	2.40	8.10	6.70	0.26	7.50	44.0	6.00	9.65	22.9	502	60.0	74.5	168
West Azerbaijan	-	-	-	-	-	-	-	-	-	-	-	-	950	115	1934	350
Yazd	-	-	-	-	-	-	-	-	-	-	-	-	657	61.6	145	314
Zabol	64.5	0.40	12.8	10.9	8.50	7.10	0.29	8.00	49.0	4.00	10.3	16.6	535	40.0	121	177
Zanjan	-	-	-	-	-	-	-	-	-	-	-	-	525	83.0	107	312
Total	159	0.21	9.50	4.36	9.30	6.70	0.31	7.77	68.0	2.00	13.4	25.2	1859	32.0	211	300

*SD; Standard deviation
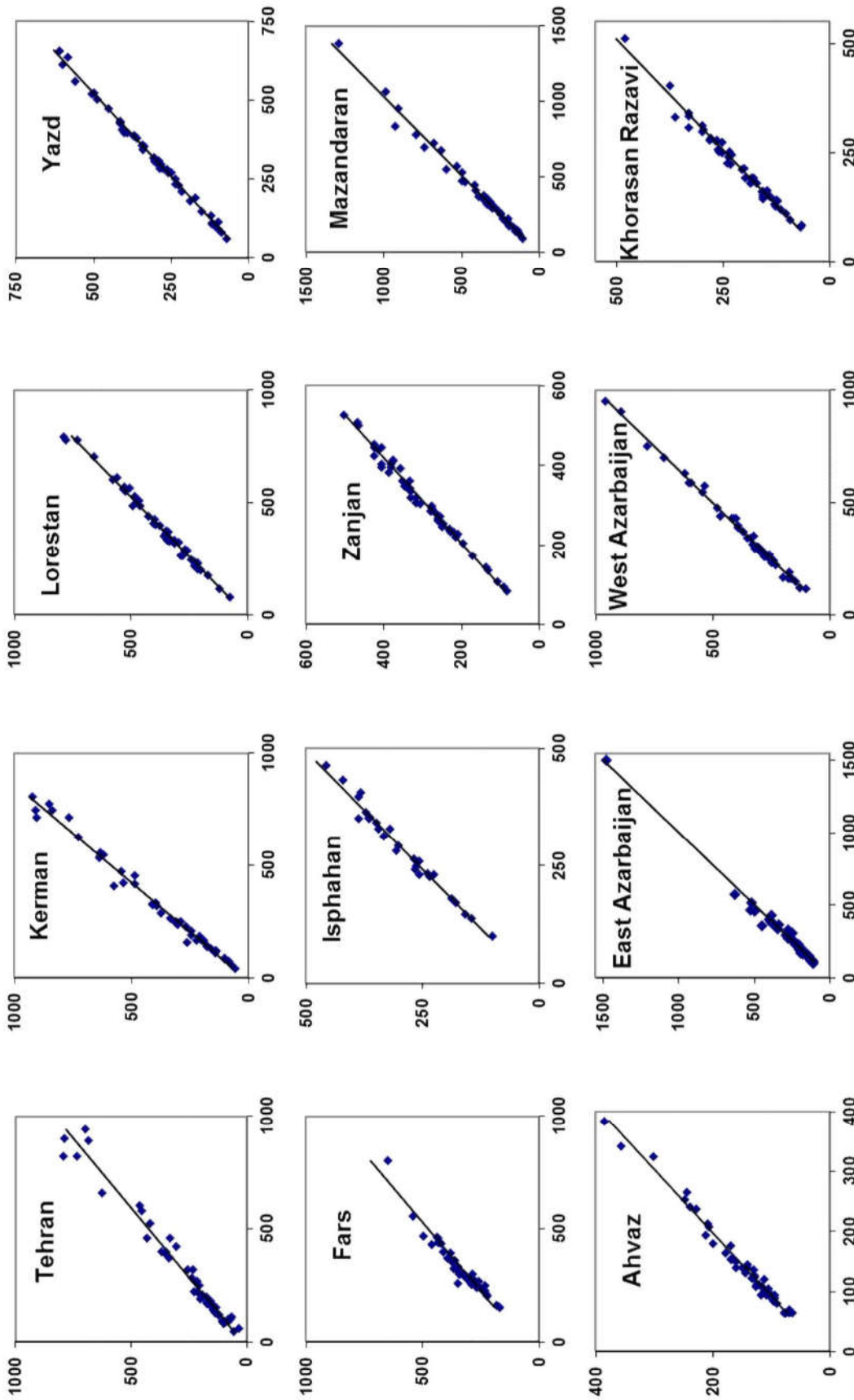
Fig. 1. The relationship between the amounts of K_{ava} extracted by 0.1 M and 1 M ammonium acetate solutions in the soil samples of different provinces of Iran. In all figures, the x-axis stands for the amount of available potassium extracted by ammonium acetate 1 M and the y-axis stands for the amount of available potassium extracted by ammonium acetate 0.1 M.
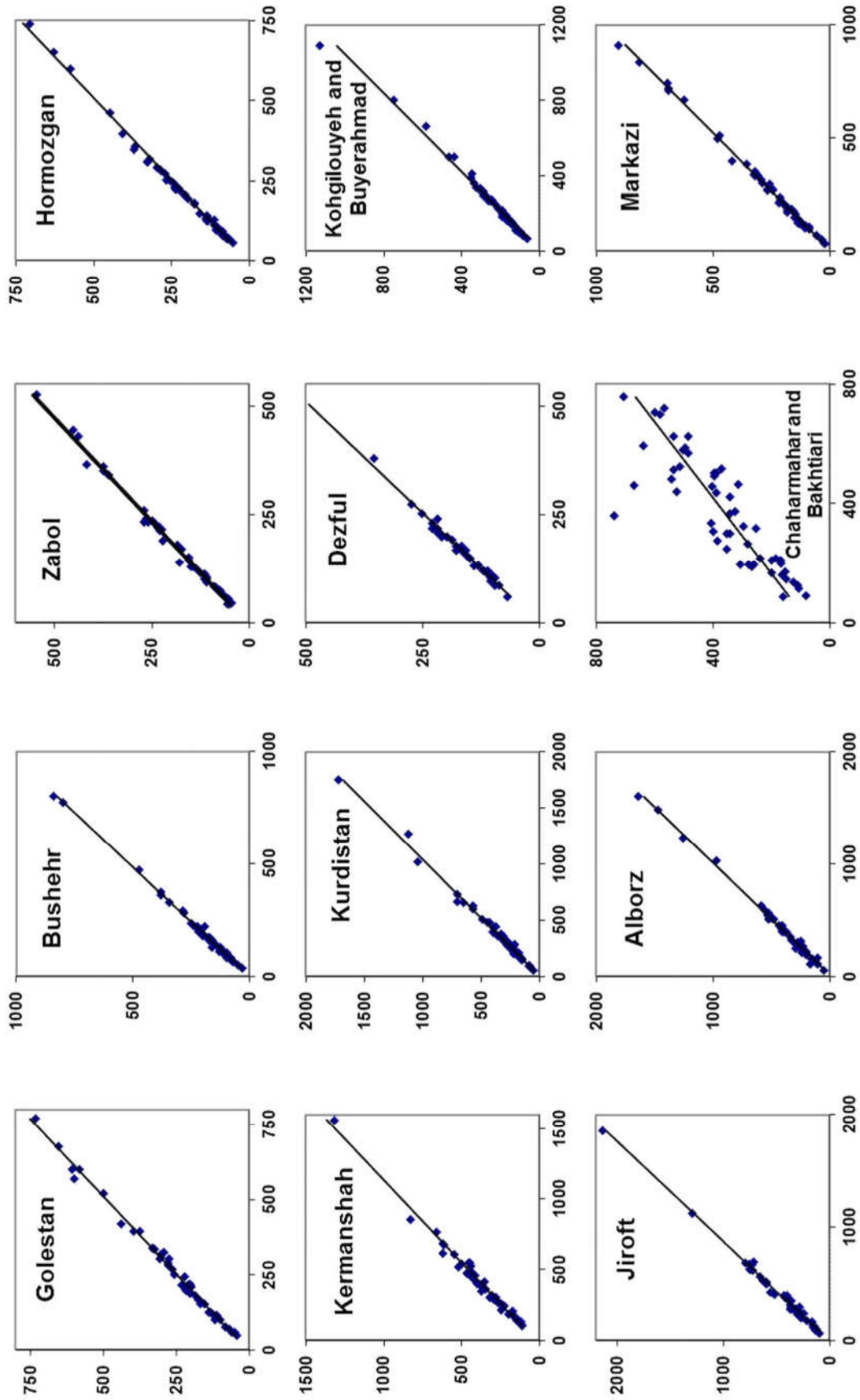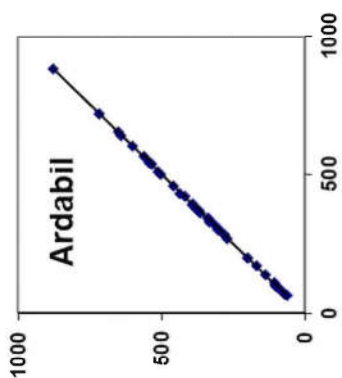
Fig. 1. (continued)

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Ardabil

Fig. 1. (continued)

Table 2. The regression parameters of the line fitted to the results of potassium extracted by 0.1 and 1 M NH_4OAc for different provinces.

Province/City	Regression equation				Province/City	Regression equation			
	Slope	Intercept	R^2	SEE		Slope	Intercept	R^2	SEE
Ahvaz	0.945	13.76**	0.984	9.04	Kermanshah	0.850	34.3**	0.985	26.3
Ardabil	0.996	1.70	0.999	2.50	Khorasan	0.980	-1.29	0.982	17.0
Bushehr	1.03	2.95	0.995	10.1	Kohgilouyeh and Boyer Ahmad	0.960	0.460	0.989	18.8
Chaharmahal and Bakhtiari	0.780	73.3	0.736	87.2	Kurdistan	0.960	-4.29	0.992	26.9
East Azarbaijan	1.00	1.69	0.986	28.6	Lorestan	1.05	0.497	0.993	13.8
Isphahan	0.990	10.01	0.982	13.6	Markazi	0.970	-2.57	0.996	12.6
Fars	0.820	69.4**	0.942	23.1	Mazandaran	0.950	18.6	0.988	26.9
Golestan	0.960	6.40	0.994	13.2	Dezful	0.980	4.34	0.988	7.86
Hormozgan	0.970	8.02**	0.996	8.98	West Azarbaijan	0.990	8.78	0.994	14.9
Jiroft	1.13	18.3*	0.992	30.7	Yazd	0.940	8.01	0.995	14.9
Karaj	1.00	-8.94	0.994	24.7	Zabol	1.05	4.30	0.994	9.71
Kerman	1.13	22.7**	0.987	24.1	Zanjan	0.930	9.68	0.987	11.5
Total	0.970	8.43	0.968	32.6	-	-	-	-	-

Table 3. The minimum, maximum, and mean values of K_{ava} (mg/kg) extracted by NH₄OAc 1 and 0.1 M.

Province/City	K_{ava} extracted (min)		K_{ava} extracted (max)		K_{ava} extracted (mean)		Pearson correlation
	0.1 M NH₄OAc	1 M NH₄OAc	0.1 M NH₄OAc	1 M NH₄OAc	0.1 M NH₄OAc	1 M NH₄OAc	
Ahvaz	64	64	385	384	148	142	0.993**
Ardabil	62	62	880	882	347	346	1.00**
Bushehr	30	35	840	800	202	193	0.998**
Zanjan	82	83	504	525	301	312	0.994**
East Azarbaijan	110	100	1480	1500	297	297	0.993**
Zabol	50	43	545	525	186	174	0.997**
Yazd	69	61	608	657	305	314	0.998**
West Azarbaijan	100	115	950	960	354	350	0.997**
Dezful	69	60	502	502	158	157	0.994**
Mazandaran	103	89	1288	1384	389	390	0.994**
Markazi	22	32	905	910	265	274	0.998**
Lorestan	75	70	780	758	382	378	0.996**
Kordestan	55	52	1720	1750	355	373	0.996**
Khorasan	68	78	480	510	210	216	0.981**
Kermanshah	110	100	1320	1560	371	394	0.992**
Kerman	56	42	924	806	391	326	0.993**
Alborz	56	52	1650	1600	388	396	0.997**
Jiroft	96	58	2141	1859	447	380	0.996**
Hormozgan	54	56	705	740	205	203	0.998**
Golestan	44	48	730	770	256	258	0.997**
Fars	172	152	650	800	331	319	0.971**
Kohgiluyeh and Boyer-Ahmad	66	66	1130	1090	242	253	0.995**
Isfahan	100	100	505	471	295	287	0.991**
Tehran	57	44	701	940	259	297	0.986**

extracted with 1 M and 0.1 M NH₄OAc showed a good agreement with the 1:1 line, which means that both methods have a similar capability to extract K_{ava} from the soils (Fig. 2b).

The results of this study were similar to the other reports (Tafaroji et al., 2005; Zarenia, Hosseinpur, Zarbizadeh, & Kiani, 2013). NH₄OAc extracts a fraction of exchangeable and whole of the soluble potassium from soil (Sparks, 1987). Other cations in soils, such as Ca^{2+}, Mg^{2+}, and Na^+ can affect the efficiency of NH₄OAc in the extraction of available potassium. Because calcium carbonate is dominant in the soils of arid and semi-arid regions (Durand, Monger, Canti, & Verrecchia, 2018), therefore, in these soils, a significant part of the cation

exchange capacity (CEC) is saturated by calcium ions. Due to the lower valence and concentration of K compared to Ca, it is held with weaker force by charged soil colloids (Bohn et al., 1980). Therefore, K_{ava} extraction in these conditions requires less energy, and extraction with NH₄OAc with a concentration of 0.1 M is similar to 1 M NH₄OAc (in most cases).

According to the Shahbazi and Besharati (2013) report, 63% of the soils in Iran have less than 1% organic carbon. Organic matter plays a significant role in CEC and its deficiency reduces the capacity of soils for holding cations (Marschner, 1995). The negative charged organic compounds prefer the divalent calcium rather than monovalent potassium (Sparks, 1987). Therefore,
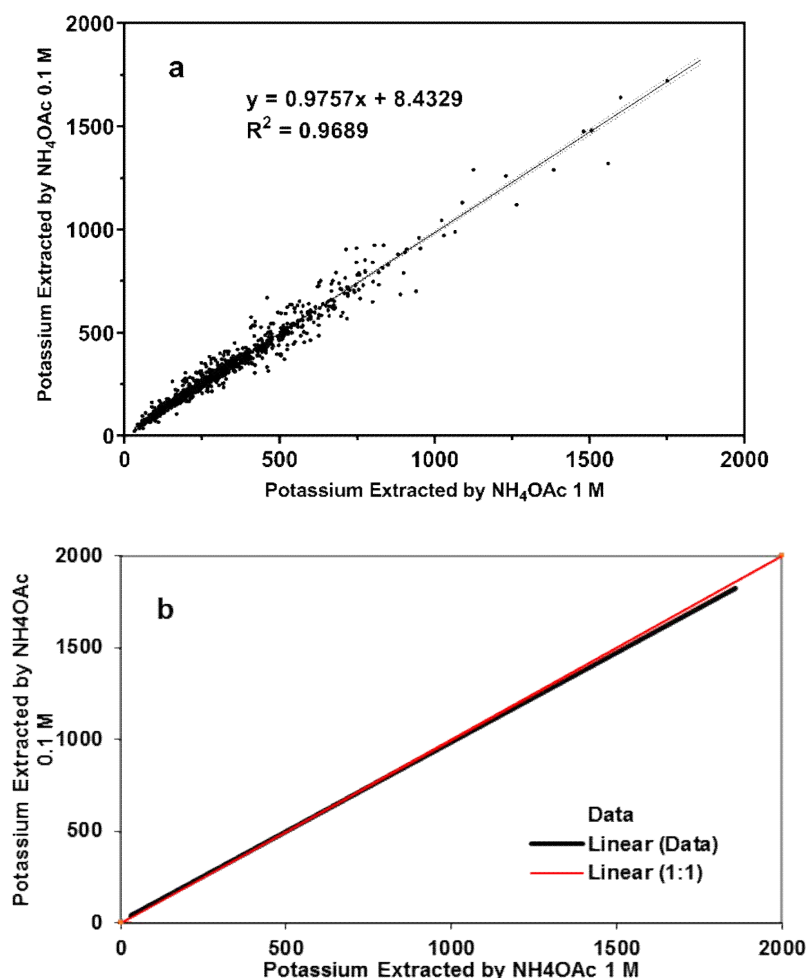
Fig. 2. The simple regression between the extracted potassium (mg/kg) by NH4OAc 1 M and NH4OAc 0.1 M in total studied soils; a) indicates the confidence intervals of the regression line and b) shows the deviation from 1:1 line.

even in the regions with a significant amount of organic matter, due to the presence of calcium, potassium is held with low energy and extracted easily with a concentration of less than 1 M NH4OAc.

Given the effect of the electric charge of the ions and their hydration radius in adsorption by soil colloids, according to Coulomb's law ($F = kq_1q_2/r^2$), K^+ is held in a further distance (than the divalent or smaller cations) of colloidal particles (Sparks, 2003). All the discussed mechanisms led to easy extraction of K from calcareous soils. Therefore, the amount of K_{ava} extracted using 0.1 M NH4OAc is not significantly different than that extracted using 1 M NH4OAc

3.2.2. The effect of extraction time on the amount of extracted potassium

According to the results in Table 4, the amount of K_{ava} extracted with 30 min and overnight (12 h) contact times was close to each other. The correlation between the two

methods was varied from 0.986 to 1.00, which is a high correlation rate, indicating an insignificant difference between the amounts of potassium extracted by methods with different extraction times. In most provinces, the mean amount of K_{ava} extracted with overnight contact time was higher than that extracted with 30 min contact time.

The results of the linear regression between the extractable potassium with 30 min and overnight (12 h) contact times are shown separately for each province and the whole of the samples (1088 samples) in Table 5. The results revealed a good correlation between the two extraction procedures. The determination coefficient (R^2) between the two procedures (30 min vs. overnight) varied from 0.915 to 0.999, which are close to one and can be concluded that there is no significant difference.

Figure 3 depicts the distribution of the points (for each sample) around the regression line for the whole of the samples. The simple regression equation between the two contact times was y = 1.0171x + 4.88. The slope of

Table 4. The effect of the contact time (30 min with shaking and overnight without shaking) on the extraction of the available potassium (mg/kg)

Province/City	K_{ava} extracted (min)		K_{ava} extracted (max)		K_{ava} extracted (mean)		Pearson correlation
	30 min	Overnight	30 min	Overnight	30 min	Overnight	
Ahvaz	64	62	384	359	142	135	0.993**
Ardabil	62	60	882	880	346	348	1.00**
Bushehr	35	35	800	790	193	202	0.998**
Zanjan	83	82	525	539	312	317	0.997**
East Azarbayjan	100	100	1500	1500	297	297	1.00**
Zabol	43	40	525	535	174	177	0.999**
Yazd	62	69	657	651	314	316	1.00**
West Azarbayjan	115	110	950	985	350	369	0.991**
Dezful	60	60	502	502	168	171	0.996**
Mazandaran	89	103	1384	1366	390	395	0.999**
Markazi	32	38	910	925	277	288	0.999**
Lorestan	70	75	758	778	378	398	0.998**
Kordestan	52	51	1750	1745	373	385	0.997**
Khorasan	78	80	510	538	216	237	0.987**
Kermanshah	100	115	1560	1630	394	414	0.987**
Kerman	56	62	806	860	359	384	0.991**
Alborz	52	64	1600	1640	396	412	0.996**
Jiroft	58	49	1859	1735	380	393	0.995**
Hormozgan	56	56	740	800	203	211	0.991**
Golestan	48	48	770	830	258	272	0.999**
Fars	152	142	800	732	319	321	0.957**
Kohgiluyeh and Boyer-Ahmad	66	67	1090	1145	253	260	0.999**
Isfahan	100	107	471	509	287	318	0.976**
Tehran	44	58	940	701	297	259	0.986**

Table 5. The regression parameters of the line fitted to the results of potassium extracted after 30 min shaking and overnight contact time for different provinces.

| Province/City	Regression equation			Province/City	Regression equation		
	Slope	Intercept	R^2		Slope	Intercept	R^2
Ahvaz	0.897	7.40	0.986	Khorasan	1.08	4.04	0.974
Ardabil	0.997	3.02	0.999	Kohgilouyeh and Boyer Ahmad	1.04	-2.66	0.998
Bushehr	0.984	11.7	0.996	Kurdistan	1.04	-1.58	0.994
Chaharmahal and Bakhtiari	0.780	73.3	0.736	Lorestan	1.055	0.497	0.996
Isphahan	1.19	-23.5	0.953	Markazi	1.00	9.79	0.998
Fars	0.947	19.2	0.915	Mazandaran	0.982	12.0	0.998
Golestan	1.06	-2.28	0.998	Dezful	0.987	4.38	0.992
Hormozgan	1.06	-3.21	0.982	West Azarbaijan	1.055	-0.121	0.982
Jiroft	0.950	32.4	0.989	Yazd	0.992	4.77	0.999
Karaj	1.01	10.4	0.992	Zabol	1.02	-0.073	0.998
Kermanshah	1.04	2.16	0.994	Zanjan	1.04	-6.63	0.995
Total	1.02	4.88	0.989	-	-	-	-
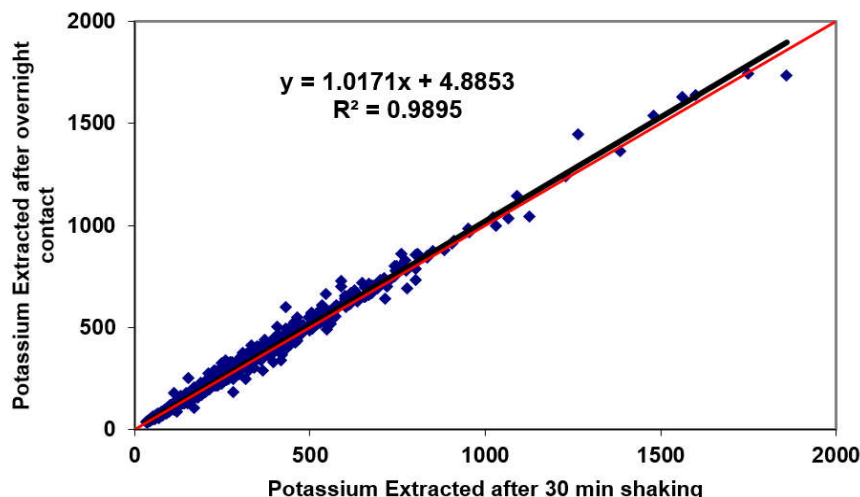
Fig. 3. The simple regression between the extracted potassium (mg/kg) by 30 min shaking and overnight contact time (the extractant was NH_4OAc 1 M.

the equation (1.017) is very close to one, indicating good consistency in the wide ranges of soils and potassium concentrations. The line intercept was 4.88, which is insignificant compared to the normal soil K_{ava} concentrations. Therefore, the regression line established between the amounts of K_{ava} extracted with two extraction procedures (30 min vs. overnight) has a good agreement with the 1:1 line, which means that both extraction procedures are able to extract K_{ava} from the soils.

The methods that are presented in the scientific literature extract the available potassium with different contact times. Depending on the extractant-to-soil ratios and contact times, different resultsobtained, therefore, the methods are modified for each region to provide a good estimation of plant available form of nutrients. For example, in the United States, extraction is performed with a contact time of 5 min and a soil-to-extractant ratio of 1:10 (Helmke & Sparks, 1996). Also, Carter and Gregorich (2007) employed the soil-to-extractant ratio of 1:10 and a contact time of 30 min to extract K_{ava} from the soils of Canada. However, various studies have reported that K_{ava} increases with increasing contact time (Bhattacharyya & Poonia, 1996; Hosseinpur, Motaghian, & Salehi, 2012; Jalali, 2006), the amount of K_{ava} extracted with different extractants should be matched with the response of the plant and its nutrient demand (Karim Shahbazi et al., 2022).

4. Conclusion

Generally, 1 M NH_4OAc solution is mostly used in all soil laboratories to extract available potassium (K_{ava}). Our results showed the possibility of using much lower concentration of NH_4OAc (0.1 M) solution instead of NH_4OAc 1 M solution which leads to a big saving of

chemicals. Additionally, successful changing of the contact times from 12 h without shaking to 30 min with shaking might be useful for saving time and efficiency of soil testing of K particularly where a rapid result is expected by farmers.

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