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Evaluation of suitable extractant for estimating soil available potassium in soils of Tamil Nadu

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Abstract

The assessment of soil available potassium (K) using a suitable extractant under various soil types is essential for making sound fertilizer recommendations. In the present study, suitability of six chemical extractants was evaluated using 50 georeferenced soils of Tamil Nadu for prediction of plant available K in maize (var CO-6) grown in Neubauer technique. Mean of soil K by different extractants were in the following order: Kelowna II (136.58 mg kg⁻¹) > Ammonium Acetate (121.86 mg kg⁻¹) > AB-DTPA (107.46 mg kg⁻¹) > Mehlich 3 (91.23 mg kg⁻¹) > 0.01 M CaCl₂ (40.85 mg kg⁻¹) > Distilled water (20.33 mg kg⁻¹). The highest simple correlation with plant K uptake was obtained with Kelowna II (r = 0.74**) and lowest with 0.01M CaCl₂ (r = 0.62**). Based on the R² value, the Kelowna II extractant was found to be the most suitable one followed by 1 N NH₄OAc irrespective of soil variables.

Keywords: kelowna II, neubauer seedling method, plant k uptake, soil available K

1. Introduction

Potassium (K) is an essential nutrient for plant growth, and one of the three main macronutrients together with N and P (Barbagelata, 2006) [3]. The different pools of K in soils are solution, exchangeable, non-exchangeable (slowly exchangeable) and lattice or mineral potassium (Sparks, 1987) [26] and the K present in these pools are in equilibrium with each other (Barber, 1995) [4]. Plant available K refers mainly to soluble K and exchangeable K (Lean and Watson, 1985), although some non-exchangeable potassium (held in the interlayers of expandable 2:1 type clay minerals such as illite and vermiculite) and mineral K can become soluble or exchangeable during a plant growing season when the former is depleted by crop removal or leaching (Huang *et al.*, 2012) [13].

A soil test on potassium availability measures the solution and a fraction of non-exchangeable K readily available during the crop growing season. Rapid chemical soil testing has now been universally accepted as an important tool to predict the amount of plant-available K as well as fertilizer responsiveness of plant on wide range of soils, crops, and climates. In rapid soil tests, three parameters are very important while selecting a particular extractant for determination of soil K: (i) evaluating the K nutrient in labile form; (ii) extracting methods that are simple, fast, and economic; and (iii) adapting to a wide range of soils, crops, and climates (Hosseinpur and Zarenia, 2012; Sardi and Fuleky, 2002; Zarrabi and Jalali, 2008) [11, 24, 36].

The neutral normal ammonium acetate, which extracts both solution and exchangeable K (surface and edge sites), has been used as the most widely accepted extractant for evaluating plant-available soil K in most soil testing laboratories (Bedi *et al.*, 2002; Aramrak *et al.*, 2007) [5, 1]. Many researchers alternatively suggested the non-exchangeable K as the index of long-term K supplying ability of many soils (Laxminarayana *et al.*, 2011; Tafaroji *et al.*, 2005) [17, 31] and boiling 1 N nitric acid (HNO₃) method, has been advocated (Bhatt and Meisheri, 2007; Tiwari *et al.*, 1996) [6, 32].

Hence, the greatest research challenge lies with selecting a suitable chemical extractant for determining the K availability under a particular set of soil, crop, and climatic condition (Jones, 1998) [15] and the suitability of the method needs to be further evaluated by comparing the soil test results with some universally accepted standard values. Generally, Neubauer seedling technique (Chiriak, 1964; Stanton and Orchard, 1963) [8, 28] is considered a very useful standard method in predicting K availability of soils in view of its simplicity, rapidity, low-cost implication, and involvement of biological system. This in turn would not only assess the plant availability index of soil K for making sound fertilizer recommendation, but also avoid

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long term K depletion of fertile farm lands (Sanyal, 2000) [23]. With this background, the present research study has been conducted with an aim of comparing different chemical extractions for estimating soil available K and selecting a suitable methods to estimate available K in the soils of Tamil Nadu by comparing these chemical methods with Neubauer test values as a standard biological method.

2. Materials and Methods

2.1 Soil sample collection and processing

Fifty geo referenced surface soil samples were collected at 0-15 cm depth representing various agro climatic regions and soil types of Tamil Nadu. The latitude coordinates of sampled locations, ranged from 11.1271° N and 78.6569° E. The collected soils were air dried, processed and passed through 2 mm sieve and subjected to routine chemical analysis.

2.2 Initial soil properties and forms of Potassium

Among physical properties of soil, particle size analysis was carried out by international pipette method (Piper, 1966). The bulk density (BD) and water holding capacity (WHC) was measured by Keen's cup method (Keen and Raczowski, 1921). Soil pH and electrical conductivity (EC) was measured in 1:2.5 soil-water suspensions (Jackson, 1973). Cation exchange capacity (CEC) was determined by extracting soil with 1 N Ammonium Acetate (NH₄OAc) at pH 7.0 (Schollenberger and Simon, 1945). Soil organic carbon was estimated by wet digestion method (Walkley and Black, 1934). The soil available N and K were estimated using

alkaline KMnO₄ oxidation method by Subbiah and Asija (1956) [30] and Neutral N NH₄OAc (pH 7.0) by Stanford and English (1949) respectively. The available soil P was estimated using 0.5 M NaHCO₃ (pH 8.5) as given by Olsen *et al.* (1954) [21] for neutral and alkaline soils and Bray and Kurtz No.1 extractant (Bray and Kurtz, 1945) for acidic soils. Among soil K fractions, water soluble K was quantified using 1:2 soil: water extraction (Mac Lean, 1960) [18]; where in exchangeable K was assessed using neutral normal NH₄OAc at soil: extract ant ratio of 1:2.5 by flame photometry (Stanford and English, 1949). The non-exchangeable K was estimated by 1N HNO₃ boiling method (Wood and Deturk, 1940). The difference between total K (HCl extraction method by Jackson, 1973) and sum of water soluble, exchangeable and non-exchangeable K was computed to quantify the amount of lattice K (Wiklander, 1955).

2.3 Assessment of suitable extraction methods for soil available K

In order to assess the most suitable extraction method for determination of the soil available K in the soils of Tamil Nadu, six chemical extractants, *viz.*, Distilled water, Neutral Normal NH₄OAc, 0.01 M CaCl₂, Mehlich 3, AB-DTPA, Kelowna II were evaluated for their comparative suitability. The details of the composition of each extractants, soil: solution ratio and time of equilibration are specified in Table 1. The collected fifty geo referenced soil samples were subjected to extraction by using these six extractants followed by available K estimation by flame photometry.

Table 1: Details of chemical extractants used for estimation of soil available potassium

Method	Composition of Extractant	Soil: Extractant ratio (w/v)	Shaking Time (min)	Reference	
M ₁ :	Distilled water	Distilled water	1:10	60	Grewal and Kanwar (1966)
M ₂ :	1 N NH ₄ OAc	1 N Ammonium Acetate at pH (7.0)	1:5	5	Stanford and English (1949)
M ₃ :	0.01 M CaCl ₂	0.01 M CaCl ₂	1:10	120	Houba <i>et al.</i> (1990)
M ₄ :	Mehlich 3	0.2NCH ₃ COOH+0.25NNH ₄ NO ₃ + 0.015N NH ₄ F + 0.013NHNO ₃ - 0.001 M EDTA	1:10	15	Adolf Mehlich (1984)
M ₅ :	AB-DTPA	1 M NH ₄ HCO ₃ + 0.005 M DTPA	1:2	15	Soltanpour and Schwab (1977)
M ₆ :	Kelowna II	0.015MNH ₄ F+0.5MHOAc + 1M NH ₄ Oac	1:10	30	Ashworth and Mrazek (1995)

2.4. Neubauer seedling experiment

In the modified neubauer seedling technique 100 g of well pulverized and processed soil was thoroughly mixed with 80 g of nutrient free quartz sand and was kept in 350 g plastic dishes (7.5 cm depth and 12 cm diameter) then well sprouted maize (*Zea maize*, var CO-6) seeds were sown uniformly and moistened with distilled water to ensure 70% of water holding capacity of the soil and kept overnight till the seedlings emerged. Triplicate plastic dishes were maintained for each soil. After emergence of seedlings, the loss of water by evapo-transpiration was compensated by adding distilled water in every alternate day following differences in weight technique. A blank was also run in which 30 maize seedlings were grown in nutrient-free quartz. The seedlings were allowed to grow for 21 days and harvested carefully along with roots. The root and shoot portions of plants were first washed with deionized water and then with distilled water to remove excess of soil or sand particles.

2.4.1 Plant analysis

The plant samples were shade dried at room temperature followed by oven drying at 70°C to get constant weight and the oven dry weight was recorded. The root and shoot portions were separately ground to fine powder and then wet

digested by tri-acid extraction method (Jackson, 1973) [14]. The potassium content in the acid extract of both root and shoot samples were determined by flame photometer and expressed as percentage on oven dry weight basis.

2.4.2 Computation of K uptake

Potassium uptake by maize plant was calculated by the following equations:

$$\text{Nutrient uptake (mg pot}^{-1}\text{)} = \text{Yield of dry matter} \times \text{K content}$$

$$\text{K uptake by plant (mg pot}^{-1}\text{)} = \text{K uptake of soil pot} - \text{K uptake of blank pot}$$

The latter value is designated as the Neubauer test value.

2.5 Statistical analysis

Two procedures were employed for statistical investigation. First, the coefficients of correlation between the quantities of K removed by six extractants with the Neubauer test values and soil parameters as well as their interrelationships were determined. Second, in the step-down regression equations, total K uptake by maize plants in modified Neubauer seedling technique was used as the dependent variable. Potential independent variables were variable soil parameters and K removal by one of the six extractants. The regression equation was generated and tested at 1 and 5 % levels of significance.

The correlation coefficient (r) and coefficient of determination (R^2) were worked out for determination of suitability of different extractant in extracting soil available K (Gomez and Gomez, 1983) [9].

3. Results and Discussion

3.1 Initial soil characteristics and K forms

The results on initial soil characteristics (Table 2) showed that there were a large variation in soil types, physical, chemical properties and K forms in soils under study. The soil separates of sand, silt and clay were ranged from 12.90 to 72.90, 9.30 to 60.40, and 5.31 to 56.00 per cent with a mean value of 4.97, 30.27 and 27.44 per cent, respectively. The BD and WHC of the samples varied from 1.22 to 1.67 Mg m^{-3} and 39.20 to 65.90 per cent respectively.

Table 2: Descriptive statistics of initial properties of soil

Parameters	Max	Min	Mean	SE	CV %
Sand %	12.90	72.90	40.97	2.05	0.35
Silt %	9.30	48.90	30.27	1.59	0.37
Clay %	5.31	56.00	27.44	1.72	0.44
Bulk Density (Mg m^{-3})	1.22	1.67	1.48	0.02	0.09
Water Holding Capacity (%)	39.20	65.90	53.90	0.96	0.13
pH	4.06	10.02	7.80	0.20	0.18
EC (dSm^{-1})	0.01	2.34	0.27	0.06	1.68
CEC ($\text{cmol (p}^+) \text{ kg}^{-1}$)	4.77	43.08	19.86	1.33	0.47
OC (g kg^{-1})	5.33	53.49	20.05	2.53	0.63
Available N (kg ha^{-1})	106	512	242	20.88	0.35
Available P (kg ha^{-1})	5.62	78.94	19.00	1.34	0.48
Available K (kg ha^{-1})	47.00	1263	274	33.23	0.48
Free CaCO_3 (%)	0.00	4.70	0.96	0.23	1.18
K fractions: Water soluble K (ppm)	2.80	99.50	20.34	2.66	0.93
	16.40	464.30	100.83	12.61	0.88
	59.60	1509.00	411.11	40.57	0.70
	479.00	8392.10	3222.43	268.43	0.59
Lattice K Total K	559.50	9707.90	3754.69	320.61	0.60

About 22 per cent of the samples were acidic (\leq pH 6.5), 16 per cent were neutral (pH 6.6 to 7.3) and 62 per cent were alkaline (\geq pH 7.4) in reaction with the mean of 7.80 (mildly alkaline). The CEC ranged from 4.77 to 43.08 $\text{cmol (p}^+) \text{ kg}^{-1}$ with a mean value of 19.86 $\text{cmol (p}^+) \text{ kg}^{-1}$. Wherein, the organic content of the study area ranged from 5.33 to 53.49 g kg^{-1} with a mean of 20.05 g kg^{-1} . The soil available N, P and K ranged from 106 to 512, 5.62 and 78.94 and 47.00 to 1263 kg ha^{-1} respectively. The free CaCO_3 per cent ranged from nil to 4.70 per cent showed that all the samples under study were non calcareous. The water soluble, exchangeable, non-exchangeable and lattice K contents of the soils ranged from 2.8 to 99.50, 16.40 to 464.30, 59.60 to 1509 and 476 to 8392.10 mg kg^{-1} respectively.

3.2 Extractable soil potassium

The available K content of fifty geo referenced soil extracted by six chemical reagent varied from 2.83 to 99.54 (M_1), 19.20 to 563.84 (M_2), 4.86 to 184.04 (M_3), 12.89 to 487.72 (M_4), 15.50 to 531.62 (M_5), 28.78 to 598.14 (M_6) respectively (Data not given). The average quantities of K extracted were in the descending order as Kelowna II > Ammonium Acetate > AB-DTPA > Mehlich 3 > 0.01 M CaCl_2 > Distilled water with a mean of 136.58, 121.86, 107.46, 91.23, 40.85, 20.33 mg kg^{-1} . These showed that intensity of K extraction depends on soil type and nature of extractant as each extractant desorbs different portions of soil K. The difference of extractable K between soils was attributed to the concentration, time of

equilibration, and cationic behavior of the extractants in addition to the type of clay minerals, clay, and silt contents of soils (Hosseinpur and Zarenia, 2012) [11].

Among the extractants used, the lowest efficiency of distilled water in desorbing varying quantity of K from these soils is attributed to very low activity of H^+ ion in the neutral environment to displace exchangeable or adsorbed K from the soil colloidal phase and it extracted K mainly from the soil solution. Similar result was also evidenced in earlier studies (Hosseinpur and Zarenia, 2012) [11]. The high amount of K extracted by Kelowna II was due to higher displacement of K^+ from the exchange and edge sites by monovalent NH_4^+ (Debnath, *et al.*, 1994) and due to neutral environment (Singh *et al.*, 1986). Relatively low amounts of K extracted by 0.01 M CaCl_2 reagent were probably due to the low activity of Ca^{2+} in the extracting solution to replace exchangeable K from soil colloid matrix.

3.3 Interrelationships of soil K availability indices

The relationships of the different soil K availability indices determined by the various extraction methods were evaluated through simple correlation study (Table 3). It is evident that all the six chemical reagents as well as neubauer test values desorbed different amounts of K from the soils and have a high positive significant correlation with each other at 1% probability level. This implies that all these extractants were almost equally efficient in extracting K from the same pool or fractions of the soils but varies in magnitude of K extractability (Hosseinpur and Samavati, 2008).

The relationship between an extractant and plant K uptake by maize in Neubauer method provides an important index in the selection of a soil testing method. The results (Table 3) showed that all the extractants were positively correlated with the Neubauer test values at 1% level of significance. The coefficients of correlation ranged between 0.62 (M_3) to 0.74 (M_6) indicating that all the extractants were equally competent in determination of plant-available soil K. The overall results indicate that Kelowna II extractant seemed to be highly suitable for use as soil testing procedures for estimating available K followed by conventionally followed neutral normal ammonium acetate method.

Table 3: Coefficients of correlation between soil available K extracted by different chemical and biological methods

	Method	M_1	M_2	M_3	M_4	M_5	M_6
M_1	Distilled water	1					
M_2	1 N NH_4OAC	0.96**	1				
M_3	0.01 M CaCl_2	0.98**	0.94**	1			
M_4	Mehlich 3	0.95**	0.98**	0.95**	1		
M_5	AB-DTPA	0.95**	0.99**	0.98**	0.98**	1	
M_6	Kelowna II	0.94**	0.99**	0.97**	0.97**	0.98**	1
M_7	Neubauer test values	0.65**	0.73**	0.62**	0.66**	0.72**	0.74**

* and ** indicate significance at 5% and 1% probability levels, respectively

3.4 Relationships of K availability indices with soil parameters and K forms

The correlation of K availability indices with soil parameters and K forms (Table 4) showed that all the extractants have highly significant positive correlations with water soluble, exchangeable, non-exchangeable and lattice K. However, it was also evidenced that all the six chemical extractants is capable of extracting more K from water soluble and labile pool than lattice K with an r^2 value of more than 0.90. This

might be attributed due to the fact that such K pools are loosely held to the soil matrix (Panda and Patra, 2018).

Table 4: Coefficients of correlation between soil available K extracted by different chemical and biological methods, soil variables and forms of K

Soil variables	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	M ₇
	Distilled water	1 N NH ₄ OAC	0.01 M CaCl ₂	Mehlich 3	AB-DTPA	Kelowna II	Neubauer test values
Sand %	0.11	0.17	0.15	0.19	0.16	0.19	-0.16
Silt %	-0.12	-0.37**	-0.12	-0.22	-0.18	-0.28**	0.18
Clay %	0.29*	0.10	0.05	0.11	0.12	0.08	0.07
pH	0.44**	0.51**	0.43**	0.45**	0.52**	0.18	0.40
EC	0.54**	0.68**	0.53**	0.65**	0.68**	0.66**	0.64
CEC	0.31*	0.33**	0.30*	0.29*	0.33*	0.31*	0.22
CaCO ₃ %	0.31*	0.33**	0.32*	0.30*	0.74**	0.32*	0.23
WS-K	0.99**	0.98**	0.98**	0.95**	0.96**	0.94**	0.75
Ex-K	0.94**	0.99**	0.92**	0.98**	0.99**	0.99**	0.80
NEx-K	0.94**	0.96**	0.95**	0.96**	0.96**	0.96**	0.78
L-K	0.83**	0.87**	0.86**	0.84**	0.86**	0.87**	0.71
T-K	0.86**	0.90**	0.88**	0.87**	0.89**	0.90**	0.73

* and ** indicate significance at 5% and 1% probability levels, respectively

Highly significant positive correlations were observed between all the extractants and the soil pH and EC values. Kelowna II showed r value of 0.18 which was statistically non-significant indicating its suitability for a wide range of soil type independent of pH. This is in consistent with the findings of Ashworth and Mrazek (1995). A significant negative correlation was found between extractants and the silt fraction of soil.

4. Conclusion

In order to assess the suitability of K extractant in soils of Tamil Nadu, six chemical extractants were examined and compared with Neubauer method of K uptake by maize. It was found that all the extractants were equally suitable for extracting soil K. However, the extractants such as Kelowna II was found to be the most suitable extractant followed by 1 N NH₄OAc irrespective of soil variables. These methods are simple, rapid, and cost-effective. The test values of different extraction methods obtained, however, need to be calibrated separately in a wide range of soils, plants, and climatic conditions for their interpretation and effective use in making sound K fertilizer recommendation.

5. References

- Aramrak SJ, Chanchareonsook C, Suwannarat, Sarobol E. Assessment of multielement extractant for prediction of available potassium in Thai soils. *Kasetsart Journal: Natural Science*. 2007; 41(3):461-66.
- Ashworth J, Mrazek K. Modified Kelowna test for available phosphorus and potassium in soil. *Communications in soil science and plant analysis*. 1995; 26(5-6):731-739.
- Barbagelata PA. Evaluation of potassium soil tests and methods for mapping soil fertility properties in Iowa corn and soybean fields. *Retrospective Theses and Dissertations*, 2006, 1797.
- Barber SA. *Soil Nutrient Bioavailability*. John Wiley & Sons, 1995, 91
- Bedi AS, Wali P, Verma MK. Evaluation of extractants and critical levels for potassium in wheat. *Journal of the Indian Society of Soil Science*. 2002; 50(3):268-71.
- Bhatt VR, Meisheri MB. Relative efficacy of soil test methods to measure changes in K status due to uptake, addition and release of potassium in calcareous soil under continuous cropping. *Asian Journal of Soil Science*. 2007; 2(1):28-32.
- Bray RH, Kurtz L. Determination of total, organic and available forms of phosphorus in soils. *Soil Science*. 1945; 59(1):39-46.
- Chiriack A. A comparison study of some chemical methods for determining available potassium in soil. *Analytical Institute of Central CERC Agricultural Section Pedology*. 32:201-10. *Soils and Fertilizers*. 1964; 29(1):2356:1966.
- Gomez KA, Gomez AA. *Statistical procedures for agricultural research*, 2nd Edn. International Rice Research Institute, Los Banos, Philippines, 1983.
- Grewal JS, Kanwar JS. Forms of potassium in Punjab soils. *Journal of the Indian Society of Soil Science*. 1966; 14(1):63-67.
- Hosseinpur AR, Zarenia M. Evaluating chemical extractants to estimate available potassium for pinto beans (*Phaseolus vulgaris*) in some calcareous soils. *Plant Soil and Environment*. 2012; 58(1):42-48.
- Houba V, Novozamsky I, Lexmond TM, Van der Lee J. Applicability of 0.01 M CaCl₂ as a single extraction solution for the assessment of the nutrient status of soils and other diagnostic purposes. *Communications in Soil Science and Plant Analysis*. 1990.; 21(19-20):2281-2290.
- Huang PM, Li Y, Sumner ME. *Handbook of soil sciences*. 2nd Edn, CRC Taylor & Francis, 2012.
- Jackson ML. *Soil chemical analysis*. Prentice Hall of India Private Ltd., New Delhi, 1973, 56-70.
- Jones JJB. *Soil test methods: past, present, and future use of soil extractants*. *Communications in Soil Science and Plant Analysis*. 1998; 29(11-14):1543-1552.
- Keen BA, Raczkowski H. The relation between the clay content and certain physical properties of soil. *The journal of Agricultural Sciences*. 1921; 11(4):441-449.
- Laxminarayana K, Bharali S, Patiram. Evaluation of chemical extraction methods for available potassium in rice soils of Meghalaya. *Journal of the Indian Society of Soil Science*. 2011; 59:295-99.
- Mac Lean AJ. Water soluble potassium percent K saturation and pK-1/2p (Ca+Mg) as indices of management effects on K status of soils. *Trans. 7th International Congress on Soil Science, Madison III*, 1960, 86-91.
- Mc Lean EO, Watson ME. *Potassium in Agriculture*, In: D. Robert and D. Munson, Madison, Wisconsin, USA, 1985; 277-308.

20. Mehlich A. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communications in soil science and plant analysis*. 1984; 15(12):1409-1416.
21. Olsen SR, Cole CV, Watenabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S.D.A. Circ. 939, U.S. Govt. Printing Office, Washington, DC, 1954.
22. Piper CS. *Soil and plant analysis*. International Science Publishers Inc., New York, 1966.
23. Sanyal SK. Potassium availability of soils of West Bengal in relation to their mineralogy. Proceedings of the workshop on 'Potassium in Agriculture in West Bengal' under the auspices of PPIC (India Programme) and the Government of West Bengal, Kolkata, West Bengal, India, 2000.
24. Sardi K, Fuleky V. Comparisons of extractants used for evaluating the bioavailability of soil P and K. *Communications in Soil Science and Plant Analysis*. 2002; 33:2803-2812.
25. Schollenberger C, Simon R. Determination of exchange capacity and exchangeable bases in soil-ammonium acetate method. *Soil Science*. 1945; 59(1):13-24.
26. Sparks DL. Potassium dynamics in soils. *Advances in Soil Sciences*. 1987; 6:1-63.
27. Stanford S, English L. Use of flame photometer in rapid soil tests of K. *Canadian Journal of Agronomy*. 1949; 41:446-447.
28. Stanton DA, Orchard ER. Evaluation of the potassium supplying power of soils. *South African Journal of Agricultural Science*. 1963; 6(2):249-60.
29. Subba Rao A, Muralidharan Y, Lakaria BL, Singh KN. Soil testing and nutrient recommendations. *Journal of the Indian Society of Soil Science*. 2009; 57(4):559-571.
30. Subbiah BV, Asija GC. A rapid procedure for estimation of available nutrients in soils. *Current Science*. 1956; 25:259-260.
31. Tafaraji SH, Haghparast-Tanha MR, Vasse-Mosalla S. Evaluation of different extraction methods to extract available potassium in soils of Guilan province. *Journal of Agriculture Sciences*. 2005; 1(6):27-40.
32. Tiwari A, Misra SG, Tiwari R. Calibration of soil test-methods and assessment of critical limits of potassium in soils and plants of chickpea. *Indian Journal of Pulses Research*. 1996; 9(1):43-46.
33. Walkley A, Black CA. An estimation method for determining soil organic matter and a proposed modification of chromic acid titration method. *Soil Science*. 1934; 37:93-101.
34. Wiklander L. Potassium symposium, 1955, 1154:109.
35. Wood LK, Deturk EE. Adsorption of ammonium and potassium in non-replaceable form. *Proceedings of Soil Science Society of American Journal*. 1940; 25(2):101-104.
36. Zarrabi M, Jalali M. Evaluation of extractants and quantity-intensity relationship for estimation of available potassium in some calcareous soils of western Iran. *Communications in Soil Science and Plant Analysis*. 2008; 39(17/18):2663-2677.