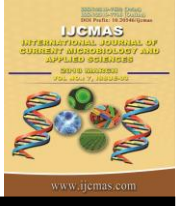
Int.J.Curr.Microbiol.App.Sci (2018) 7(3): 1192-1205

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 Volume 7 Number 03 (2018)
Journal homepage: http://www.ijcmas.com



Original Research Article https://doi.org/10.20546/ijcmas.2018.703.141

Evaluation of AB - DTPA Extractant for Multinutrients Extraction in Soils

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ABSTRACT

To evaluate ABDTPA, a multi nutrient extractant for simultaneous assessment of available P, K, S, Fe, Mn, Zn and Cu, 50 soil samples with wide range of pH were collected and analysed with ABDTPA and established standard methods. A pot culture experiment with maize crop was conducted to correlate the nutrients extracted by extractants with plant uptake. Correlation and regression analysis were carried out separately for each nutrient for acid, alkaline, neutral and all soils to obtain the relationship between amount of nutrients extracted by different methods and also with plant uptake. The results revealed that ABDTPA extractant is suitable for determination of available P in neutral (r=0.946*** with Olsen-P) and alkaline soils (r=0.607*** with Olsen-P) than acid soils (r=0.450^{NS} with Bray-P). Regarding available S, ABDTPA extractant is suitable only for alkaline soils (r=0.870*** with $CaCl_2$-S). ABDTPA extractant can be used for the determination of available K (r=0.865*** with NH_4OAc – K), Fe (r=0.982*** with DTPA-Fe), Mn (r=0.832*** with DTPA-Mn), Zn (r=0.952*** with DTPA-Zn) and Cu (r=0.918*** with DTPA-Cu) content of soils in all the pH ranges. Further, correlation of nutrients extracted by extractants with that of plant uptake showed ABDTPA method is suitable for the determination of available P and S content of alkaline soils (r=0.723* and 0.739* respectively) and not a reliable method for acid soils (r=0.464^{NS} and -0.111 ^{NS} respectively). For K and micronutrients (Fe, Mn and Zn), ABDTPA and standard methods correlated in a similar manner with plant uptake. Hence, it can be concluded that ABDTPA can be used as a multinutrient extractant for the simultaneous extraction of P, K, S, Fe, Mn, Zn and Cu in alkaline soils.

Keywords

ABDTPA, Multinutrient extractant, Soil available nutrients, Estimation

Article Info

Accepted:
10 February 2018
Available Online:
10 March 2018

Introduction

Escalating price of fertilizers and their effect on environment increased the need for the efficient use of fertilizers. For the diagnosis of the nutrient status of soil and deciding the need of fertilizer application, chemical methods of soil testing are widely used. Accurate determination of available nutrients by soil testing methods will pave the way for precise fertilizer recommendation and increased use efficiency of fertilizers. Besides, soil testing provides information for research and enriching scientific knowledge. Several methods of chemical soil testing are currently used for determining the plant available macro, secondary and micro nutrients in soils. Most of these methods/extractants are specific for few or one of the plant nutrients. For analyzing a soil sample for all plant available nutrients, separate extraction with different extractants are required which increases the time and cost of analysis.

Multielement extractant that allows the simultaneous extraction of plant available macro, secondary and micro nutrients in soils will be highly useful for soil testing laboratories (Alva 1993). Single multinutrient extractant / Universal extraction reagents will increase laboratory productivity and decrease analytical cost. Universal extraction reagents are defined as a single extractant for use on a range of soils for the determination of both major elements and micronutrients. The nutrients can be estimated using a multielement analyzer such as the inductively coupled plasma emission spectrometer or atomic absorption spectrophotometer. Without the need for manipulation of the obtained extract, with one pass through the analyzer the concentration of the elements can be obtained. Therefore, the universal extraction reagents offer two advantages, multi-element determinations both by means of the extraction and the assay of the obtained extract (Jones, 1990).

The Ammonium Bicarbonate - DTPA is a multi - element soil test for alkaline soils developed by Soltanpour and Schwab (1977) and later modified by Soltanpour and Workman (1979) to omit the use of carbon black which adsorbed metal DTPA complexes. The NH_4^+ ion replaces the exchangeable cations, Na, K, Ca and Mg as well as the trace metals. Di ethylene tri amine penta acetic acid (DTPA) will chelate cations such as Zn, Fe, Cu, Mn, Pb, Ni and Cd thus provide availability or toxicity indices for these elements. During the shaking process, CO_2 evolves from the open flask and the pH rise from its original value of 7.6 to about 8.5. The Ca and in some cases Mg, are precipitated as carbonate salts, therefore, these two elements are not determinable. Bicarbonate will change to carbonate as the pH raises precipitating Ca from labile calcium phosphates as calcium carbonate, thus bringing labile P into solution. The HCO_3^- ion will also desorb the sorbed P. The high pH (8.5) will precipitate Fe and Al as their hydroxides and bring labile iron and aluminium phosphates into solution. Apparently, the stability of the DTPA Fe complex in the AB-DTPA extracting reagent is high enough to produce results comparable to the DTPA soil test of Lindsay and Norvell although the pH of AB-DTPA reaches about 8.5. Bicarbonate also can desorb sulphate, molybdate, selenate (or selenite) and arsenate. In addition Ca and other alkaline earth minerals of these anions can be solubilised as explained for calcium phosphate. Therefore, the NH_4HCO_3- DTPA extracting reagent has a chemistry that is suitable for both cation and anion extraction. Species, such as nitrate and borate are water soluble and determinable in the extract (Soltanpour, 1985).

For using this multielement extractant routinely in soil testing laboratories, it must be compared to extractants calibrated in field experiments. Hence, this work was carried out to evaluate the suitability of AB-DTPA (Ammonium Bicarbonate- Diethylene Triamine Penta Acetic acid) as a multinutrient extractant for simultaneous extraction of available P, K, S, Fe, Mn, Zn and Cu in soils.

Materials and Methods

Fifty georeferenced soil samples were collected from Coimbatore and Nilgiris districts of Tamil Nadu for analysis with AB – DTPA and other extractants. Soil samples with wide pH range were collected because soil pH is one of the parameters which influences the nutrient availability. Soil samples were processed, passed through 2 mm sieve and used for analysis. Soil reaction (pH) and electrical conductivity (EC) values of the soil samples were determined. ABDTPA, a multi nutrient extractant was used for analysis of P, K, S, Fe, Mn, Zn and Cu. The extracting solution is 1 M ammonium bicarbonate (NH_4HCO_3) and 0.005 M DTPA adjusted to pH 7.6.

Preparation of AB - DTPA extractant

A 0.005 M DTPA solution is obtained by adding 1.97g DTPA to 800 ml dilute water. Approximately 2 ml 1:1 ammonium hydroxide (NH_4OH) is added to facilitate dissolution and to prevent effervescence when bicarbonate is added. When most of the DTPA is dissolved, 79.06 g ammonium bicarbonate (NH_4HCO_3) is added and stirred gently until dissolved. The pH is adjusted to 7.6 with ammonium hydroxide and dilute HCl. The solution is diluted to 1 litre volume with distilled water and used immediately.

Extraction method

Accurately 10 g soil + 20 ml AB - DTPA shaken for 15 minutes, filtered and analysed in AAS for Fe, Mn, Zn and Cu. Phosphorus and S in the extract estimated colorimetrically and K by flame emission spectroscopy. The analysis for the above said nutrients was also performed with established standard methods for comparison with AB - DTPA. The details of the standard methods used for comparison are given below.

Pot culture experiment

The comparative efficiency of different extractants was further confirmed by carrying out a pot culture study to correlate nutrients extracted with their plant uptake. Of the 50 soils, 20 soils with wide pH range of 4.29 to 9.13 were used for the pot culture experiment. Among the soils selected, 8 were acidic, 2 were neutral and 10 were alkaline. The pot culture experiment was conducted in CRD with three replications. N alone in the form of urea solution (25% of recommended N as basal and 50% N on 25 days after sowing) was applied to the maize hybrid NK 6240. The crop was irrigated with deionized water as and when required. The crop was grown up to 50 DAS and above ground parts were harvested. Harvested plants samples were analysed for P, K, S, Fe, Mn, Zn and Cu content and nutrient uptake was calculated.

Statistical analysis

Correlation and regression analysis were carried out separately for each nutrient for acid, alkaline, neutral and all soils to obtain the relationship between amounts extracted by AB - DTPA method with that of standard method. The correlation coefficient (r) and slope of the regression equation were used to appraise the efficiency of the extractants. Correlation analysis was also carried out separately for each nutrient for acid, alkaline and all soils to obtain the relationship between the amounts extracted by AB-DTPA method and standard method with that of plant uptake.

Results and Discussion

Soil reaction (pH) and electrical conductivity (EC) (Table 1)

Soil pH ranged from 3.74 to 9.13 and EC ranged from 0.03 to 1.28 dSm^{-1}. Of the 50 soil samples collected, 15 were acidic, 9 were neutral and 26 were alkaline. Soil pH and EC of the acid soils ranged from 3.74 to 6.44 and 0.03 to 0.23 dSm^{-1} with the mean values of 4.80 and 0.10 dSm^{-1} respectively. For neutral soils, pH and EC values ranged from 6.71 to 7.50 and 0.05 to 0.14 dSm^{-1} with the mean values of 7.14 and 0.09 dSm^{-1} respectively. The pH and EC values of alkaline soils ranged from 7.60 to 9.13 and 0.05 to 1.28 dSm^{-1} with the mean values of 8.21 and 0.21 dSm^{-1} respectively.

Dry matter yield, content and uptake of nutrients by Maize plant (Tables 6 and 7)

The dry matter yield of the maize plant ranged from 2.59 to 13.15 g/plant. In extremely acidic and alkaline condition, marked reduction in dry matter yield was observed. The concentration of nutrients in maize plant ranged from 0.15 to 0.44% for P, 1.08 to 4.81% for K, 490 to 856 mg kg^{-1} for S, 32.7 to 75.0 mg kg^{-1} for Fe, 33.1 to 324.4 mg kg^{-1} for Mn, 19.4 to 46.9 mg kg^{-1} for Zn. The plant uptake values varied from 7.5 to 31.1, 72 to 434, 1.36 to 9.51, 0.11 to 0.76, 0.15 to 1.97 and 0.12 to 0.38 mg/plant for P, K, S, Fe, Mn and Zn respectively. Plant Cu concentrations were not in the detectable range and hence Cu uptake could not be determined.

Soil available phosphorus

Acid soils

For acid soils, the mean soil available phosphorus extracted by Bray method (96.5 kg ha^{-1}) was higher than ABDTPA method (3.67 kg ha^{-1}) (Table 2). Correlation between Bray – P and ABDTPA – P for acid soils was non-significant (r=0.450^{NS}) (Table 8). Contradictory to this, highly significant correlation between Bray - P and ABDTPA - P have been reported by Madurapperuma and Kumaragamage (2008) with acidic low land rice soils. Slope of regression line between Bray – P and ABDTPA – P in acid soils was less than 1.0, indicating the lower extractability of phosphorus by ABDTPA extractant when compared to Bray extractant (Fig. 1) This is in line with the findings of Elrashidi *et al.,* (2003) and Madurapperuma and Kumaragamage, (2008).

Neutral soils

The mean soil available phosphorus for neutral soils extracted by Olsen method (33.1 kg ha^{-1}) was higher than ABDTPA method (13.8 kg ha^{-1}) (Table 3). Highly significant correlation (r = 0.946***) was observed between Olsen – P and ABDTPA – P for neutral soils (Table 8). Slope of regression line between Olsen – P and ABDTPA – P in neutral soils was less than 1.0 which indicate the lower extractability of phosphorus by ABDTPA extractant when compared to Olsen extractant (Fig. 1).

Alkaline soils

In alkaline soils, the mean soil available phosphorus extracted by Olsen method (34.3 kg ha^{-1}) was higher than ABDTPA method (14.8 kg ha^{-1}) (Table 4). Highly significant correlation (r = 0.607***) was observed between Olsen – P and ABDTPA – P for alkaline soils (Table 8). Maftoun *et al.,* (2003a) reported significant correlation between Olsen P and ABDTPA extractable P in calcareous soils. Slope of regression line between Olsen – P and ABDTPA – P in alkaline soils was less than 1.0, indicating the lower extractability of phosphorus by ABDTPA extractant when compared to Olsen extractant (Fig. 1). The correlation coefficient observed between P extracted by standard method and ABDTPA method was highly significant for neutral soils (r = 0.946***) followed by alkaline soils (r = 0.607***) and it was non-significant for acid soils (r = 0.450^{NS}). However, Madurapperuma and Kumaragamage (2008) observed significant correlation between Bray – P and plant P uptake in acidic low land rice soils. P extracted by standard methods significantly correlated with plant uptake (r= 0.805* for Bray method and 0.808** for Olsen method) (Table 9). P extracted by ABDTPA showed a poor relationship with plant uptake in acid soils (r=0.464^{NS}). Whereas, significant positive correlation was observed between ABDTPA-P and plant uptake in alkaline soils (r=0.723*). The results showed that ABDTPA method is suitable for the determination of available P content of alkaline soils and not a reliable method for acid soils.

Soil available potassium

Amount of soil available potassium determined by neutral normal ammonium acetate method (standard method) was in the range of 157 to 961 kg ha^{-1} with a mean value of 501 kg ha^{-1}. Soil available K determined by ABDTPA method ranged from 71 to 539 kg ha^{-1} with a mean value of 307 kg ha^{-1} (Table 5). Highly significant positive correlation was noticed between the K extracted by neutral normal ammonium acetate method (standard method) and ABDTPA method for acid (r = 0.866***), neutral (r = 0.825**), alkaline (r = 0.882***) and all the soils put together (r = 0.865***) (Table 8). Similar results have been reported by Madurapperuma and Kumaragamage (2008) for acidic lowland rice soils and by Elrashidi *et al.*, (2003) for acidic and alkaline upland soils. Slope of regression line between 1 N NH_4OAC- K and ABDTPA – K was less than 1.0. This indicate the lower extractability of potassium by ABDTPA extractant when compared to neutral normal ammonium acetate (Fig. 1). ABDTPA extractant has lower extractability of potassium when compared to neutral normal ammonium acetate which was pointed out by the slope of regression line between 1 N NH_4OAC- K and ABDTPA – K (less than 1) (Fig. 1). Madurapperuma and Kumaragamage (2008) also observed similar results in acidic lowland rice soils. Highly significant correlations were observed between K extracted by neutral normal ammonium acetate method and plant uptake in alkaline soils (r=0.887**) and all soils put together (r=0.661**) (Table 9). This is in line with the findings of Madurapperuma and Kumaragamage (2008). Though positive correlation was observed between NH_4OAc-K and plant uptake in acid soils (r=0.540^{NS}), it was not significant. The same trend was observed between ABDTPA-K and plant uptake (r=0.684***, 0.766** and 0.626^{NS} for all soils put together, alkaline soils and acid soils respectively). This indicated that there is scope to use ABDTPA extractant instead of neutral normal ammonium acetate for available K estimation irrespective of soil type.

Soil available sulphur

Acid soils

For acid soils, the mean soil available sulphur extracted by ABDTPA method (100 mg kg^{-1}) was higher than 0.15% $CaCl_2$ (13.4 mg kg^{-1}) (Table 2 and Fig. 2). Non-significant and negative correlation (r = -0.051^{NS}) was observed between 0.15% $CaCl_2$ – S and ABDTPA – S for acid soils (Table 8).

Neutral soils

The mean soil available sulphur for neutral soils extracted by ABDTPA method (16.11 mg kg^{-1}) was higher than 0.15% $CaCl_2$ (13.00 mg kg^{-1}) (Table 3 and Fig. 2). Non-significant was observed between 0.15% $CaCl_2$ – S and ABDTPA – S for neutral soils (r = 0.016 ^{NS}) (Table 8).

Alkaline soils

In alkaline soils, the mean soil available sulphur extracted by 0.15% $CaCl_2$ (19.0 mg kg^{-1}) was higher than ABDTPA method (15.6 mg kg^{-1}) (Table 4 and Fig. 2). Highly significant positive correlation (r = 0.870***) was observed between 0.15% $CaCl_2$ – S and ABDTPA – S for alkaline soils (Table 8). Slope of regression line between 0.15% $CaCl_2$ – S and ABDTPA – S in alkaline soils was nearer to 1.0, showing almost same extractability of sulphur by ABDTPA extractant and 0.15% $CaCl_2$ in alkaline soils (Fig. 3).

Standard methods used for comparison with AB – DTPA

Element	Method used	Reference
P	Bray method – Acid soils Olsen method – Neutral and alkaline soils	Bray and Kurtz (1945) Olsen *et al.*, (1954)
K	Neutral normal ammonium acetate method	Stanford and English (1949)
S	$CaCl_2$ extractable S	Williams and Steinbergs (1959)
Fe, Mn, Zn and Cu	DTPA method	Lindsay and Norvell (1978)

Table.1 Soil reaction (pH) and electrical conductivity

Soil type	pH			EC (dSm^{-1})		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
Acid soil (n=15)	3.74	6.44	4.80	0.03	0.23	0.10
Neutral soil (n=9)	6.71	7.50	7.14	0.05	0.14	0.09
Alkaline soil (n=26)	7.60	9.13	8.21	0.05	1.28	0.21

Table.2 Range and mean of available nutrients extracted by ABDTPA and standard methods in acid soils (n=15)

Nutrient	Standard method			ABDTPA method		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
P	33.4	278	96.5	1.19	7.40	3.67
K	171	867	545	115	514	306
S	6.42	20.8	13.4	15.8	270	100
Fe	31.9	132	89.3	24.0	105	86.0
Mn	5.06	159	49.8	10.7	181	43.3
Zn	0.78	18.7	5.42	0.58	15.8	6.45
Cu	0.98	13.0	3.93	1.72	16.2	5.85

Table.3 Range and mean of available nutrients extracted by ABDTPA and standard methods in neutral soils (n=9)

Nutrient	Standard method			ABDTPA method		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
P	12.6	60.7	33.1	2.93	34.7	13.8
K	157	707	423	71	457	280
S	10.2	19.3	13.0	9.70	41.6	16.1
Fe	6.38	31.4	18.3	8.93	35.2	21.8
Mn	24.4	58.4	38.4	18.5	58.7	30.1
Zn	0.81	8.39	2.82	1.00	8.62	2.96
Cu	1.52	4.95	2.91	1.69	5.30	3.46

Table.4 Range and mean of available nutrients extracted by ABDTPA and standard methods in alkaline soils (n=26)

Nutrient	Standard method			ABDTPA method		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
P	8.43	56.0	34.3	2.10	47.3	14.8
K	178	961	503	118	539	317
S	9.54	64.3	19.0	6.77	71.4	15.6
Fe	3.53	15.8	7.46	5.38	23.5	11.5
Mn	8.17	30.0	16.5	6.16	28.4	13.6
Zn	0.49	3.10	1.14	0.62	4.68	1.47
Cu	0.78	3.51	2.08	1.30	7.15	3.15

Table.5 Range and mean of available nutrients extracted by ABDTPA and standard methods - overall (n=50)

Nutrient	Standard method			ABDTPA method		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
K	157	961	501	71	539	307
S	6.42	64.3	16.2	6.77	270.8	41.0
Fe	3.53	131.8	34.0	5.38	105.4	35.7
Mn	5.06	159	30.5	6.16	181	25.5
Zn	0.49	18.7	2.72	0.58	15.8	3.23
Cu	0.78	13.0	2.79	1.30	16.2	4.02

*- P extracted by Bray and Olsen methods based on soil pH and hence overall values not given

Table.6 Dry matter yield, nutrient concentration in maize plant

S. No.	Soil type	Soil pH	Dry weight	P	K	S	Fe	Mn	Zn
			g/plant	**%**		**mg kg^{-1}**			
1	Acid soil	4.29	6.63	0.29	1.25	787	43.7	296	33.1
2		4.43	2.84	0.26	3.02	727	59.5	324	45.6
3		4.44	5.72	0.23	3.53	655	40.0	259	44.2
4		4.77	5.84	0.23	3.97	585	63.2	230	45.1
5		4.84	6.60	0.24	4.81	628	51.7	123	46.5
6		4.94	11.78	0.44	3.44	582	64.3	103	24.2
7		5.32	8.59	0.26	3.67	812	75.0	101	31.0
8		6.44	6.71	0.21	1.08	490	50.4	38.9	24.6
9	Neutral soil	6.72	10.02	0.23	2.57	717	60.7	33.2	24.3
10		7.35	8.91	0.21	2.44	566	41.0	38.2	20.2
11	Alkaline soil	7.99	13.15	0.24	3.29	716	32.7	33.1	19.4
12		8.12	7.15	0.23	2.55	704	42.6	42.4	21.9
13		8.14	8.01	0.29	1.60	520	46.6	38.3	27.7
14		8.18	8.97	0.15	3.55	567	48.8	38.6	24.4
15		8.22	7.57	0.35	2.61	516	42.3	43.0	22.6
16		8.26	7.66	0.17	3.12	802	48.0	52.1	21.5
17		8.39	6.17	0.23	2.41	672	42.4	54.2	36.5
18		8.49	8.10	0.20	2.96	494	45.5	52.9	46.9
19		8.56	6.74	0.25	2.17	652	36.6	61.6	20.7
20		9.13	2.59	0.31	2.99	856	40.8	56.4	45.4
Min		**4.29**	**2.59**	**0.15**	**1.08**	**490**	**32.7**	**33.1**	**19.4**
Max		**9.13**	**13.15**	**0.44**	**4.81**	**856**	**75.0**	**324**	**46.9**
Mean		**6.85**	**7.49**	**0.25**	**2.85**	**652**	**48.8**	**101**	**31.3**

Table.7 Nutrient uptake by maize plant (mg/plant)

S. No.	P	K	S	Fe	Mn	Zn
1	19.6	83	5.21	0.29	1.97	0.22
2	7.52	86	2.06	0.17	0.92	0.13
3	13.2	202	3.74	0.23	1.47	0.25
4	13.5	232	3.42	0.37	1.35	0.27
5	16.1	318	4.14	0.34	0.81	0.31
6	51.2	404	6.84	0.76	1.21	0.35
7	22.5	316	6.96	0.65	0.87	0.27
8	14.1	72	3.30	0.34	0.26	0.16
9	23.1	257	7.18	0.61	0.33	0.24
10	18.8	217	5.04	0.37	0.34	0.18
11	31.1	434	9.38	0.43	0.43	0.25
12	16.7	182	3.67	0.30	0.30	0.16
13	22.9	128	4.15	0.37	0.31	0.22
14	13.9	317	5.07	0.44	0.35	0.22
15	26.6	198	3.90	0.32	0.33	0.17
16	13.3	239	6.14	0.37	0.40	0.17
17	14.1	149	4.15	0.26	0.33	0.22
18	16.4	240	4.00	0.37	0.43	0.38
19	16.6	146	4.39	0.25	0.42	0.14
20	7.93	77	2.09	0.11	0.15	0.12
Min	**7.52**	**72**	**1.36**	**0.11**	**0.15**	**0.12**
Max	**51.2**	**434**	**9.51**	**0.76**	**1.97**	**0.38**
Mean	**19.0**	**215**	**4.6**	**0.37**	**0.65**	**0.22**

Table.8 Correlation coefficients for nutrients extracted by ABDTPA method and standard methods (Bray – P, Olsen – P, NH_4OAc – K, $CaCl_2$ – S and DTPA – Fe, Mn, Zn and Cu)

Elements	All soils (n=50)	Acid soils (n=15 ; 11 for Bray-P)	Neutral soils (n=9)	Alkaline soils (n=26)
P	-	0.450^{NS}	0.946***	0.607***
K	0.865***	0.866***	0.825**	0.882***
S	-0.055^{NS}	-0.051^{NS}	0.016^{NS}	0.870***
Fe	0.982***	0.890***	0.934***	0.778***
Mn	0.832***	0.783***	0.795*	0.813***
Zn	0.952***	0.950***	0.995***	0.960***
Cu	0.918***	0.946***	0.884**	0.761***

*** - significant at $p \leq 0.001$
** - significant at $p \leq 0.01$
* - significant at $p \leq 0.05$
^{NS} – Non significant

Table.9 Correlation of nutrients extracted by different methods with plant uptake

Elements	Standard method			ABDTPA method		
	All soils (n= 20)	Acid soils (n= 8)	Alkaline soils (n= 10)	All soils (n= 20)	Acid soils (n= 8)	Alkaline soils (n= 10)
P	-	0.805*(n=7)	0.808**	-	0.464^{NS} (n=7)	0.723*
K	0.661**	0.540^{NS}	0.887**	0.684***	0.626^{NS}	0.766**
S	0.184^{NS}	0.511^{NS}	0.157^{NS}	-0.111^{NS}	-0.127^{NS}	0.739*
Fe	0.322^{NS}	0.425^{NS}	0.777**	0.250^{NS}	0.236^{NS}	0.670*
Mn	0.526*	0.231^{NS}	0.296^{NS}	0.595**	0.396^{NS}	0.424^{NS}
Zn	0.583**	0.595^{NS}	0.846**	0.601**	0.485^{NS}	0.883**

*** - significant at $p \leq 0.001$
** - significant at $p \leq 0.01$
* - significant at $p \leq 0.05$
^{NS} - Not significant

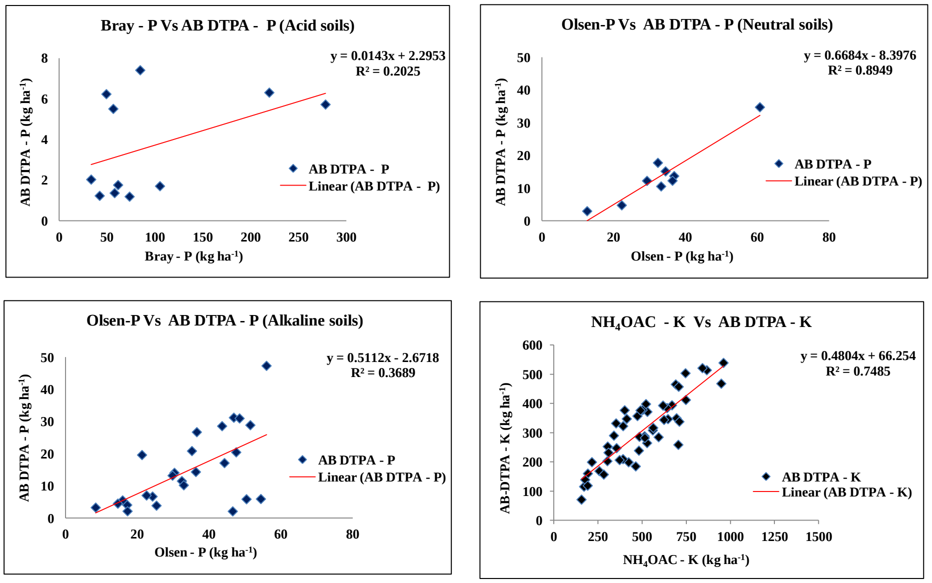


Fig.1 Relationship between soil available P and K extracted by standard methods and ABDTPA

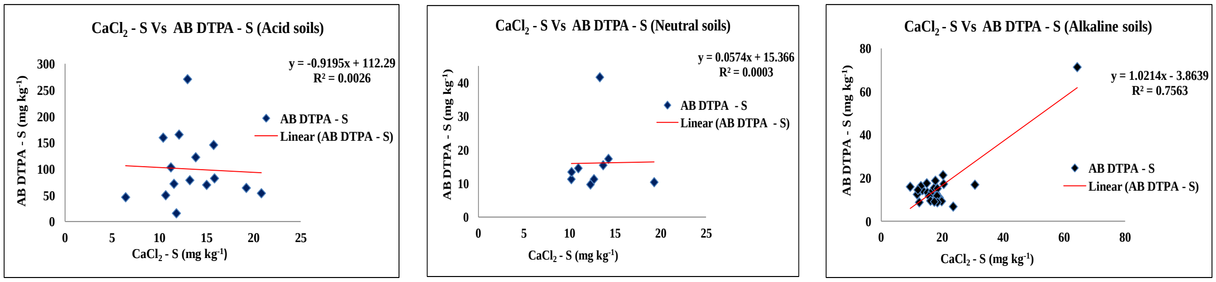
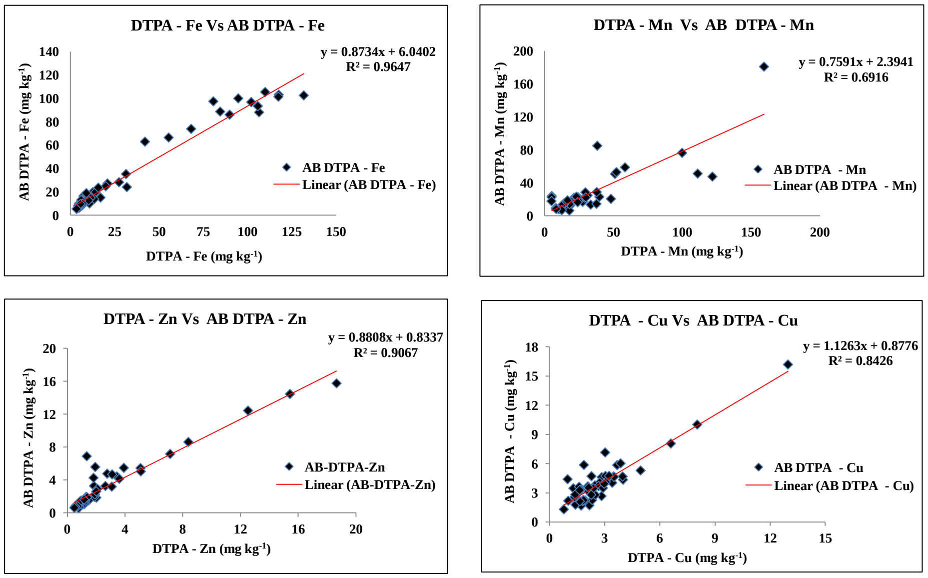


Fig.2 Relationship between soil available S extracted by standard method and ABDTPA

Fig.3 Relationship between soil available micronutrients extracted by standard method and ABDTPA



The correlation coefficient observed between S extracted by standard method and ABDTPA method was positive and highly significant for alkaline soils (r = 0. 0.870***); not significant for neutral soils (r = 0.016 ^{NS}) and negative and non-significant for acid soils (r = - 0.051^{NS}) (Table 8).

Though positive correlations were observed between 0.15% $CaCl_2$ extractable S and plant uptake, they were not significant for all categories of soils (r = 0.184^{NS}, 0.157^{NS} and 0.511^{NS} for all soils put together, alkaline soils and acid soils respectively) (Table 9). ABDTPA-S was negatively correlated with plant uptake for all soils put together (r=-0.111^{NS}) and acid soils (r=-0.127^{NS}). Whereas, positive and significant correlation was observed between ABDTPA-S and plant uptake for alkaline soils (r=0.739*). This showed the better performance of ABDTPA than 0.15% $CaCl_2$ for S extraction in alkaline soils. Theoretically, AB-DTPA is suitable for extraction of sulfate from soils, as most sulfate salts are soluble in aqueous solution. Furthermore, the HCO_3^- anion will desorb the sorbed SO_4^- anion if present. Bicarbonate can also solubilize labile insoluble sulfate minerals that may be found in soils (Soltanpour 1985).

Soil available iron

Amount of soil available iron determined by DTPA (standard method) was in the range of 3.53 to 131.8 mg kg^{-1} with a mean value of 34.0 mg kg^{-1}. Soil available Fe determined by ABDTPA method ranged from 5.38 to 105.4 mg kg^{-1} with a mean value of 35.7 mg kg^{-1} (Table 5). Slope of regression line between DTPA – Fe and ABDTPA – Fe was less than 1.0, showing less extractability of Fe by ABDTPA extractant when compared to DTPA. Similar results have been reported by Madurapperuma and Kumaragamage (2008) for acidic lowland rice soils. Highly significant positive correlation was observed between the Fe extracted by DTPA method (standard method) and ABDTPA method for acid (r = 0.890***), neutral (r = 0.934***), alkaline (r = 0.778***) and all the soils put together (r = 0.982***) (Table 8).

Both DTPA and ABDTPA exhibited non-significant relationship with plant uptake for all soils put together (r=0.322^{NS} and 0.250^{NS} for DTPA and ABDTPA respectively) and acid soils (r=0.425^{NS} and 0.236^{NS} for DTPA and ABDTPA respectively) (Table 9). Significant correlation was observed between DTPA Fe and ABDTPA Fe with plant uptake for alkaline soil (r=0.777** and 0.670* for DTPA and ABDTPA respectively). Highly significant correlation between ABDTPA extractable Fe and plant uptake have been reported by Al-Mustafa *et al.,* (2001) in calcareous soils. In all types of soil, positive and highly significant correlation between Fe extracted by DTPA and ABDTPA methods and also similar trend between DTPA and ABDTPA extracted Fe with plant uptake were observed. This indicated that ABDTPA can be used in the place of DTPA for available Fe estimation irrespective of soil type.

Soil available Manganese

Soil available manganese determined by DTPA (standard method) was in the range of 5.06 to 159 mg kg^{-1} with a mean value of 30.5 mg kg^{-1}. Soil available Mn determined by ABDTPA method ranged from 6.16 to 181 mg kg^{-1} with a mean value of 25.5 mg kg^{-1} (Table 5). Soil available Mn extracted by ABDTPA is lesser than DTPA extracted Fe which is indicated by the slope of the regression line (less than 1.0). Madurapperuma and Kumaragamage (2008) also reported similar findings for acidic lowland rice soils. However, Elrashidi *et al.,* (2003) reported with acidic and alkaline soils under highland conditions, extraction of substantially higher quantities of Fe and Mn by AB DTAP than DTPA extractant. Highly significant positive correlation was observed between the Mn extracted by DTPA method (standard method) and ABDTPA method for acid (r = 0.783***), neutral (r = 0.795*), alkaline (r = 0.813***) and all the soils put together (r = 0.832***) (Table 8). For soil available Mn and Fe, Madurapperuma and Kumaragamage (2008) reported similar results.

Significant correlation was observed between DTPA Mn and ABDTPA Mn with plant uptake for all soils put together (r=0.526* and 0.595** for DTPA and ABDTPA respectively) (Table 9). When correlation analysis was performed for acid and alkaline soils separately, both DTPA and ABDTPA exhibited non-significant relationship with plant uptake (r=0.231^{NS} and 0.396^{NS} for DTPA and ABDTPA respectively for acid soils; r=0.296^{NS} and 0.424^{NS} for DTPA and ABDTPA respectively for alkaline soils). The results are in contradiction with the findings of Madurapperuma and Kumaragamage (2008) who reported significant correlation between Mn and Fe extracted by DTPA and ABDTPA extractants with plant uptake. Mn extracted by DTPA and ABDTPA are highly correlated and both the methods correlated in a similar way with plant uptake. Hence, it is concluded that ABDTPA extractant can be used instead of DTPA for available Mn estimation for soils with all pH range.

Soil available zinc

Soil available zinc determined by DTPA (standard method) was in the range of 0.49 to 18.7 mg kg^{-1} with a mean value of 2.72 mg kg^{-1}. Soil available Zn determined by ABDTPA method ranged from 0.58 to 15.8 mg kg^{-1} with a mean value of 3.23 mg kg^{-1} (Table 5). The correlation observed between the Zn extracted by DTPA method (standard method) and ABDTPA method for acid (r = 0.950***), neutral (r = 0.995***), alkaline (r = 0.960***) and all the soils put together (r = 0.952***) (Table 8) was positive and highly significant. Highly significant correlation between DTPA and ABDTPA extractable Zn was reported by Madurapperuma and

Kumaragamage (2008) for acidic lowland rice soils; Elrashidi *et al.*, (2003) for alkaline soils and by Natta Takrattanasaran *et al.*, (2010) for calcareous soils. Highly significant correlations were observed between Zn extracted by DTPA and plant uptake in alkaline soils (r=0.846**) and all soils put together (r=0.583**) (Table 9). Though positive correlation was observed between DTPA-Zn and plant uptake in acid soils ($r=0.595^{NS}$), it was not significant. The same trend was observed between ABDTPA-Zn and plant uptake (r=0.601**, 0.883** and 0.485^{NS} for all soils put together, alkaline soils and acid soils respectively). Similar results were observed by Abreu *et al.*, (2002), Maftoun *et al.*, (2003b) and Natta Takrattanasaran *et al.*, (2010), this showed that there is a possibility to use ABDTPA extractant instead of DTPA for available Zn estimation irrespective of soil type.

Soil available copper

Soil available copper determined by DTPA (standard method) was in the range of 0.78 to 13.0 mg kg^{-1} with a mean value of 2.79 mg kg^{-1}. Soil available Cu determined by ABDTPA method ranged from 1.30 to 16.2 mg kg^{-1} with a mean value of 4.02 mg kg^{-1} (Table 5). Higher extractability of Cu by ABDTPA than DTPA has been reported by Madurapperuma and Kumaragamage (2008). Plant Cu concentrations were not in the detectable range. Hence, Cu uptake could not be determined and correlation with the extractants was not carried out. Madurapperuma and Kumaragamage (2008) also reported Cu in non-detectable range in rice plants. The correlation observed between the Cu extracted by DTPA method (standard method) and ABDTPA method for acid (r = 0.946***), neutral (r = 0.884**), alkaline (r = 0.761***) and all the soils put together (r = 0.918***) (Table 8) was positive and highly significant. Similar results have been reported by Madurapperuma and Kumaragamage (2008) in acidic lowland rice soils and Maftoun *et al.*, (2003c) in calcareous soils. This showed that ABDTPA is a suitable extractant for the determination of available Cu content of soils in all the pH ranges.

Correlation among the nutrients extracted by ABDTPA and standard methods revealed that ABDTPA extractant is more suitable for the determination of available P in neutral and alkaline soils than acid soils. Regarding available S estimation, ABDTPA extractant is suitable only for alkaline soils. ABDTPA extractant can be used for the determination of available K, Fe, Mn, Zn and Cu content of soils in all the pH ranges. Correlation of the nutrients extracted by ABDTPA and standard methods with that of plant uptake showed that ABDTPA method is suitable for the determination of available P content of alkaline soils and not a reliable method for acid soils. Positive and significant correlation observed between ABDTPA-S and plant uptake for alkaline soils showed the better performance of ABDTPA than 0.15% $CaCl_2$ for S extraction in alkaline soils. It was found unsuitable for S estimation in acid soils. For K and micronutrients (Fe, Mn and Zn) ABDTPA method can be used in the place of neutral normal ammonium acetate and DTPA extractant respectively for soils in all pH ranges.

The overall results indicated that ABDTPA was found suitable for the estimation of available P and S in alkaline soils, available K, Fe, Mn, Zn and Cu in all the soils irrespective of pH. For using as a multinutrient extractant for the simultaneous extraction of P, K, S, Fe, Mn, Zn and Cu, it is suitable only for alkaline soils. Hence, it can be concluded that ABDTPA can be used as a multinutrient extractant for the simultaneous extraction of P, K, S, Fe, Mn, Zn and Cu in alkaline soils.

Future line of work

To use this method for fertilizer recommendations, further evaluation of ABDTPA extractant has to be performed with more number of soils varying in texture, parent material and climate. The critical limits have to be fixed for macro and micro nutrients for prescribing fertilizer recommendations using AB-DTPA extractant. So that it can be followed in soil testing laboratories for large scale analysis of soil samples which will save the time and cost of soil analysis. Also with multinutrient extractants like ABDTPA it will be possible to make full use of the multinutrient analysers like AAS and ICP.

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How to cite this article:

Malathi, P. and Stalin, P. 2018. Evaluation of AB - DTPA Extractant for Multinutrients Extraction in Soils. *Int.J.Curr.Microbiol.App.Sci.* 7(03): 1192-1205.
doi: https://doi.org/10.20546/ijcmas.2018.703.141