International Journal of Plant & Soil Science
4(6): 521-534, 2015; Article no.IJPSS.2015.051
ISSN: 2320-7035

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Reaction Classes and Phosphorus and Potassium Contents of Soils in Major Potato Growing Areas of West Shoa Zone as Determined through Different Methods

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Authors' contributions

This work was carried out in collaboration between all authors. Authors TB and IH designed the study and collected soil samples from the respective study sites. Author AB. managed the literature searches. Author TB additionally did the laboratory analyses of the samples and wrote the first draft of the manuscript. Authors TB and IH further improved the manuscript to its current shape. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2015/13405
Editor(s):
(1) Marco Trevisan, Institute of Agricultural Chemistry and Environmental Research Centre BIOMASS, Faculty of Agriculture, Catholic University of the Sacred Heart, Italy.
Reviewers:
(1) Anonymous, University of Missouri Extension, USA.
(2) Anonymous, Ekiti State University, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=778&id=24&aid=7119

Original Research Article

Received 16th August 2014
Accepted 15th October 2014
Published 8th December 2014

ABSTRACT

Poor soil fertility management has been one of the major factors constraining potato productivity on farmers' field in Ethiopia, creating a wide gap between the actual yield and potential yield. A study was conducted in West Shoa Zone, Ethiopia to investigate the reaction classes as well as phosphorus and potassium contents of soils of farmers managed potato farms. Soil samples, from a depth of 0-30 cm, were collected from six districts during the *Belg* (March-June) cropping season to determine pH, phosphorus and potassium contents. Soil pH was determined using both water and 0.01 M calcium chloride solutions. Available phosphorus content in the soil was determined using both CAL and Olsen methods. Potassium content of the soil was determined both by

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extracting the potassium with Calcium Acetate Lactate (CAL) solution as well as by 1 M ammonium acetate solution. Results showed that the soil pH in all the districts was generally low, the average soil pH determined in $CaCl_2$ suspension ranged between 4.9-5.5. Most of the fields sampled in Chelia, Welmera, Ejere, Tikur-Inchini and Jibat districts had *low* and *very low* CAL-P value while all the fields sampled in Jeldu district had CAL-P only in the *target*, *high* and *very high* classes. 58.5% of the sampled fields had a CAL-K value in the *very high* class and above. 56% of the sampled fields had an ammonium acetate extractable K content in a class ranging from *moderately high* to *very high.* Nearly 70% of the fields had *low, very low* and *extremely low* according to Olsen P test. Only 9.5% of the surveyed field soil was rated as having *low* or *very low* Olsen P while 80.5% had K content of *target* value and above.

Keywords: Available phosphorus; available potassium; soil pH; West Shoa Zone.

1. INTRODUCTION

In Ethiopia, potato growers pay less attention to soil fertility management [1] and this has been one of the major factors constraining potato productivity on farmers' field, creating a huge gap between actual yield and potential yield [2]. In the central highlands of Ethiopia, where farmers grow potato twice a year, a conspicuous decline in the soil fertility status is being observed since the concept of maintenance fertilization is absent among farmers and crop residues are usually removed from the field further worsening the situation. Attempts have been made in the past as well as currently to improve Ethiopian soils productivity through encouraging the use of mineral fertilizers. However, following the government withdrawal from fertilizer subsidy, the application of fertilizer, especially by resource poor farmers has tremendously declined due to escalated fertilizer price, thus further posing a negative impact on soil fertility and hence on crop yield.

An important aspect of soil fertility management, which is often overlooked, is to decide the appropriate fertilizer type and rate to use, based on soil test results. The availability of limited number of soil testing laboratories in the country and their limited capacity could be the reason to until very recently remain with blanket fertilizer recommendations for all crops. However, it is significant to note that fertilizer response is directly related to the nature of soil, emphasizing that soil varying in fertility status results in different crop response to applied fertilizers [3]. Fertilizer recommendation should also consider textural classes of soil as nutrients can easily be lost through leaching in sand dominated soils than clay dominated ones [4]. It was with this assumption that most European countries and Americans follow soil nutrient index based fertilizer application [4] for soils of different textural classes. A sound soil fertility management programme should provide crops with an adequate amount and in balanced proportion of all essential nutrients to attain optimum crop yields and crop quality and this call for determination of soil nutrient contents and their textural classes before running into recommendations.

Although, the application of mineral fertilizers has been reported to tremendously increase potato growth and yield [5], the type and quantity of fertilizer to be applied for economically acceptable yield cannot be known unless the initial soil fertility regime of a specific area is determined through soil testing. Moreover, the national blanket recommendation for the crop which is currently being used throughout the country is not based on local soil conditions and so undermines the concept of economics of fertilizer application. This study was undertaken to partly address some of these gaps at least in some field sites of selected districts of West Shoa Zone. The objective of the study was, therefore, to evaluate the nutrient status of soils in the major potato growing areas of Western Shoa Zone to lay a baseline information for soil nutrient index based suitable fertilizer recommendations for higher and sustainable crop yield in the sub-region.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted during the *Belg* cropping season (March-June) of 2012. The study districts were all located in the highland parts of West Shoa Zone (Fig. 1). In terms of climatic condition, the study area is characterized as given in Table 1.

2.2 Soil Sample Collection

Soil samples were collected from six purposively selected major potato growing districts of West Shoa Zone, Ethiopia namely Jeldu, Tikur Inchini, Jibat, Cheliya, Welmera and Ejere districts during the *Belg* (March-June) cropping season of 2012. From each district 10 to 11 field sites were sampled except for Tikur-Inchini and Jibat as well as Womera and Ejere, where 10 samples were collected for the two districts altogether. The soil samples (0-30 cm depth) were taken into polyethylene bags in a zig-zag manner from 10-15 spots per field site using auger and later on made into one composite sample. The soil samples were immediately air dried and sieved through a 2 mm sieve.

2.3 Determination of Soil Parameters

2.3.1 Determination of soil pH

Soil pH was determined using both water and 0.01 M calcium chloride solutions. The ratio between the soil and the water/calcium chloride solution was mainatained at 1: 2.5. With both methods 20 g of soil was mixed with 50 mL of the respective solution.The content was stirred for few minutes and the solution was allowed to stand for about 2 hrs. After clear suspension was obtained the pH was measured using pre-calibirated portable pH meter.

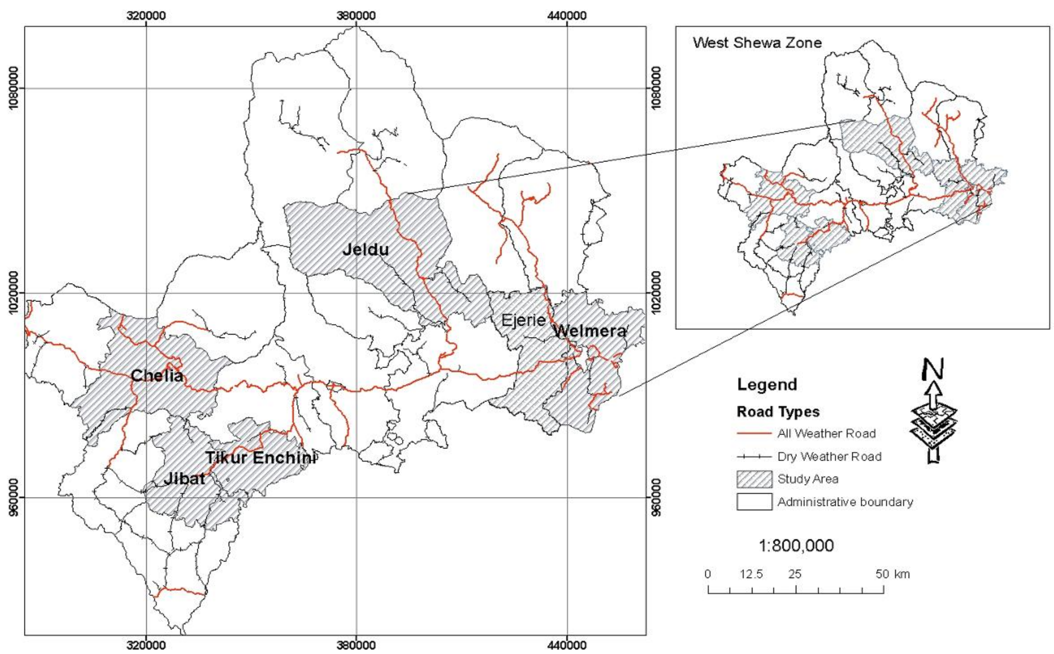

Fig. 1. Map of the study districts

Table 1. Important meteorological and other data of the study area

District	Annual Average Total Rain Fall (mm)	Annual Average Temperature (°C)	Altitude Range (masl)
Jeldu	812-699	17-25	1900-3206
Tikur-Inchini	1000-1800	6-24	2200-3023
Jibat	800-1500	18-24	1600-3200
Cheliya	900-1400	10-25	1500-3051
Ejere	900-1200	22-28	2060-3185
Welmera	760-1062	7-24	2200-2400

Source: West Shoa Zone Agriculture Office

2.3.2 Determination of soil phosphorus and potassium content

Available phosphorus content in the soil was determined using both CAL method [6] in which Calcium Acetate and Lactate (composed of calcium lactate pentahydrate, calcium acetate hydrate and acetic acid) solution was used as an extractant and the Olsen method [7] in which sodium bicarbonate (0.5 M $NaHCO_3$ at a pH=8.5) was used as an extracting solution. P concentration in the extract was measured using spectrophotometer (µQuant MQX200) at 405 and 882 nm for CAL and Olsen methods, respectively following the addition of appropriate color reagents. Likewise, the potassium content of the soil was determined both by extracting the potassium with Calcium Acetate Lactate (CAL) solution as well as by 1 M ammonium acetate solution according to [8]. Both the potassium extracted using CAL solution and 1 M ammonium acetate solution was measured using flame photometer (Eppendorf Elex 6361, Flammenphotometer).

2.4 Data Analysis

Descriptive statistics (mean, range, percentage) were used to explore the data. The data obtained were further classified in to very low, low, target, high, very high and excess based on the information described in literatures. The Pearson correlation coefficients were also determined through running correlation analysis using sigma plot version 10 in order to evaluate relationships between mineral nutrients in soil determined through different methods.

3. RESULTS

3.1 Soil pH

The results of soil pH measurements for each field site are presented in Table 2, Figs. 2 and 3. The soil pH determined using 1:2.5 soil: $CaCl_2$ suspension was generally lower (on average by 0.4) as compared to the one determined using 1:2.5 soil: water suspension. The average soil pH of the surveyed districts ranged between 5.3-5.8 in water suspension and between 4.9-5.5 in $CaCl_2$ suspension. The soil pH in all the districts was generally low except for Welmera and Ejere districts, which had relatively higher average soil pH of 5.8 in water suspension and 5.5 in $CaCl_2$ suspension. 50% of the soil in these two districts was in the moderately acidic range (Fig. 2, Table 2). The results of soil pH determined using 1:2.5 soil: $CaCl_2$ suspension, indicated that two sites (both at tullu kosoru kebele) in Cheliya district, one site at Ejere district (Ilu aga) and two site at Jeldu districts (Chilanko and Galesa qota Gesher kebeles) showed an extreme acidity (3.4-4.4). According to [9] of soil reaction classification, the soil pH results in water suspension showed that 22% of the soils surveyed were characterized as very strongly acidic, 34% as strongly acidic, 27% as moderately acidic and the rest 17% of the soil as being slightly acidic (Fig. 4a). On the other hand, according to the same classification, the soil pH results in 0.01 M calcium chloride suspension showed that 12% of the soils were extremely acidic, 41.5% were very strongly acidic, 27% were strongly acidic whereas 19.5% were moderately acidic for the whole survey area. In four of the districts, except Welmera and Ejere, 60% of the soils were either *extremely acidic* or *very strongly acidic* as measured in calcium chloride suspension (Fig. 3).

Table 2. The soil pH of the different districts in West Shoa Zone as determined by 1:2.5 soil: water and 1:2.5 soil: $CaCl_2$ suspensions

Sl. No	Name of Districts	No. of field sites sampled per district	Soil pH (1:2.5 soil water suspension)		Soil pH (1:2.5 soil $CaCl_2$ suspension)	
			Range	Average	Range	Average
1	Jeldu	11	4.8-5.9	5.3	4.4-5.5	4.9
2	Tikur Inchini and Jibat	10	5.0-6.1	5.4	4.5-5.7	4.9
3	Cheliya	10	4.7-6.3	5.5	4.2-5.9	5.0
4	Welmera and Ejere	10	4.9-6.3	5.8	4.4-5.9	5.5

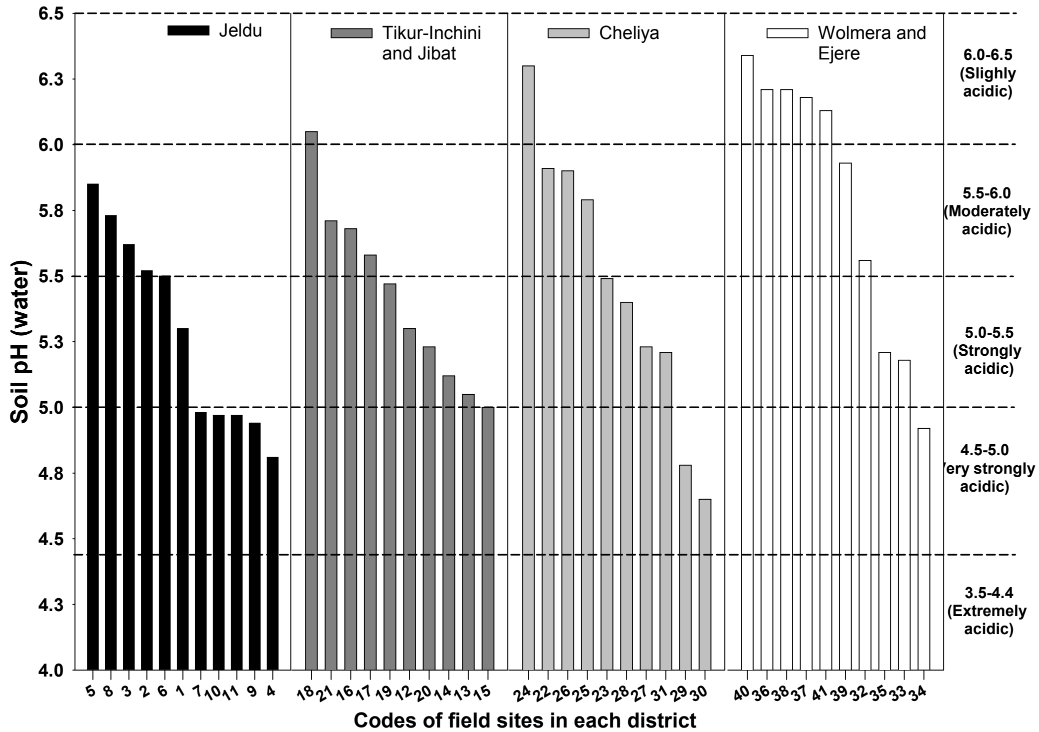

Fig. 2. pH (H_2O) of soils in different districts of West Shoa Zone

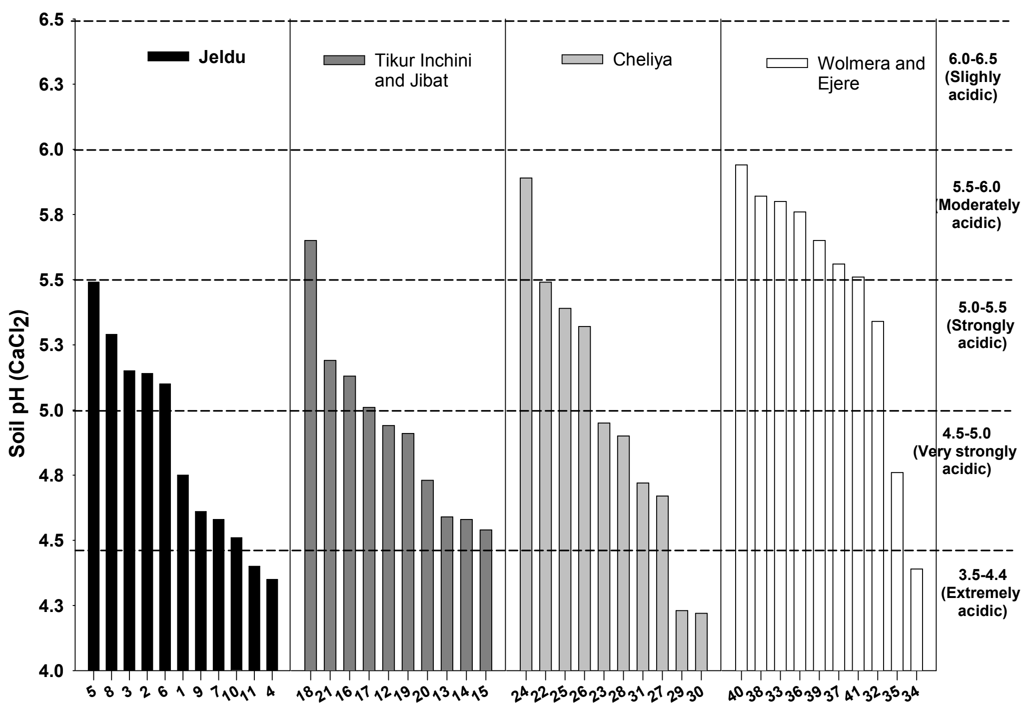

Fig. 3. pH ($CaCl_2$) of soils in the different districts in West Shoa Zone

3.2 Soil Available Phosphorus

Available phosphorus (P) content in the soil determined through both Calcium Acetate and Lactate (CAL) and Olsen methods are presented in Figs. 5, 6 and 7 and Table 3. The results showed that the available P value was clearly higher for the calcium acetate lactate extracted soils (CAL-P) method than for the sodium bicarbonate extracted soils (Olsen P). At Jeldu district the average CAL-extractable P value was 5-fold higher than that of Olsen-P value while the average CAL-extractable P values at Tikur Inchini-Jibat districts, Welmera-Ejere districts and Cheliya district were 2.6, 1.7 and 1.2 times higher, respectively. The average CAL extractable P value was the highest for Jeldu district and the lowest for Tikur Inchini and Jibat districts while Olsen P was the highest for Cheliya district and the lowest for Tikur Inchini and Jibat districts (Figs. 5 and 6, Table 3). Based on CAL-P soil test classification, most of the field sites sampled in Chelia, Welmera, Ejere Tikur-Inchini and Jibat districts had *low* and *very low* CAL-P value while all the field sites sampled in Jeldu district had CAL-P only in *target*, *high* and *very high* classes and not in *low/very low* classes (Fig. 5). At Cheliya an *extremely very high* CAL-P value was recorded at one site (Code 24). According to CAL-P soil class indexing, 46% of all field sites surveyed had *low/very low* CAL-P value whereas 54% had CAL-P value ranging from *target* to *very high* classes. On the other hand, according to [10] of Olsen P indexing, 70% of the field sites surveyed had Olsen P value from *low* to *extremely low* range whereas 30% of the field sites had Olsen P value from *target* to an *extremely high* range (Figs. 6, 7).

3.3 Soil Potassium Contents

Data on potassium content in the soil extracted with CAL and ammonium acetate solutions are presented in Table 4 and Figs. 8 and 9. The results showed that the soil potassium content was clearly higher for ammonium acetate extracted soils than for calcium acetate lactate extracted one. The average ammonium acetate extractable potassium content of the soil was 1.5-1.7 fold higher than that of calcium acetate lactate extracted ones. The average CAL as well as ammonium acetate extractable potassium content of the soil slightly varied among the districts; however, they considerably varied between sites in each district. The average K content of the surveyed areas determined using calcium acetate lactate and ammonium acetate as an extractant ranged between 475-625.6 mg kg^{-1} soil and 797.8-928 mg kg^{-1} soil, respectively. With both extraction methods, the average K content was the highest for Tikur-Inchini and Jibat districts followed by Welmera and Ejere districts. Soils from Cheliya and Jeldu districts had relatively lower potassium content with both methods. According to CAL-extractable soil potassium indexing, out of the 41 field sites surveyed only one field site (Ilu aga in Ejere district) had a *very low* potassium status (Table 5). Moreover, three of the sampled field sites, one field site in Ejere district (Ilu aga kebele) and two field sites in Cheliya district (both in Tullu kosoru kebele) had a *low* CAL-K status. All the other sampled field sites (37 sites) in all the districts showed a CAL-K status of *target value* and above. 58.5% of the sampled fields had a CAL-K value in the *very high* class or above indicating that more than half of the sampled field sites were very rich in potassium content (Fig. 10a). In 9 of the sampled field sites, the CAL-K status was even far beyond the very high class may be classified as *extremely very high* (Fig. 8). According to [10] ammonium acetate extractable soil potassium indexing, 9.8% of the sampled field sites had *very low* to *low* ammonium acetate extractable K content (Fig. 10b). Another 9.8% of the sampled field sites had ammonium acetate extractable K content of a *target* class whereas 56% of the sampled field sites had an ammonium acetate extractable K content in a class ranging from *moderately high* to *very high* (Figs. 8 and 10b).

4. DISCUSSION

4.1 Soil pH

The soil pH of all the surveyed districts except Welmera and Ejere districts were very low (Table 2, Figs. 2 and 3). In such lower soil pH, availability of nutrients such as phosphorus can negatively be influenced unless the soils are reclaimed through lime application. Lower soil pH reduces availability of phosphorus for plant uptake since phosphorus precipitate as Al or Fe phosphates. Such lower pH can also result in toxicity of micronutrients such as manganese. In the current study, very low soil pH (4.2) resulted in excessive manganese uptake and accumulation in plant tissue (350 mg/kg d.m), which was nearly twice the optimum range (21-200 mg/kg d.m) for potato according to [11]. Such higher manganese concentration can potentially result in manganese toxicity in potato crop. The results observed in the current study showed a significant negative relationship between Manganese (Mn) concentration in plants tissue and soil pH (Fig. 11) demonstrating the association of lower soil pH with manganese toxicity.

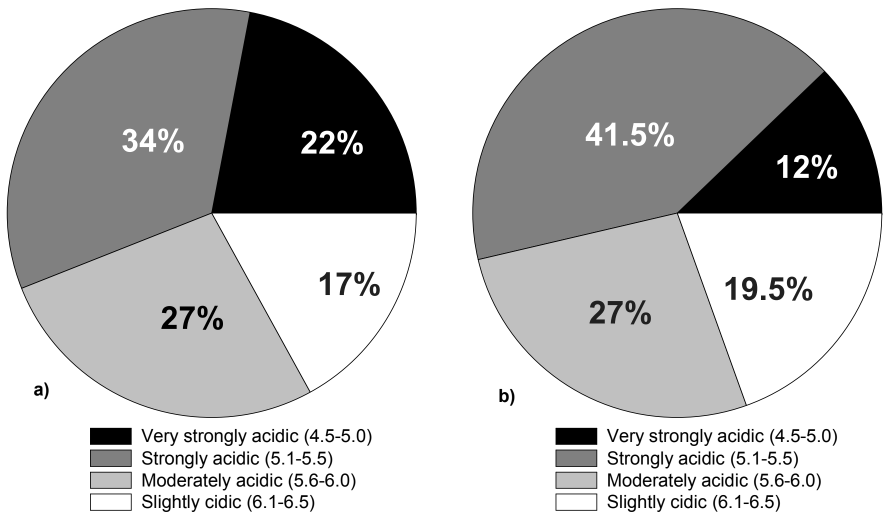

Fig. 4. Reaction of soils in pH classes in the major potato growing areas of West Shoa Zone (n=41). ((*a) in water suspension and (b) in 0.01 M calcium chloride*)

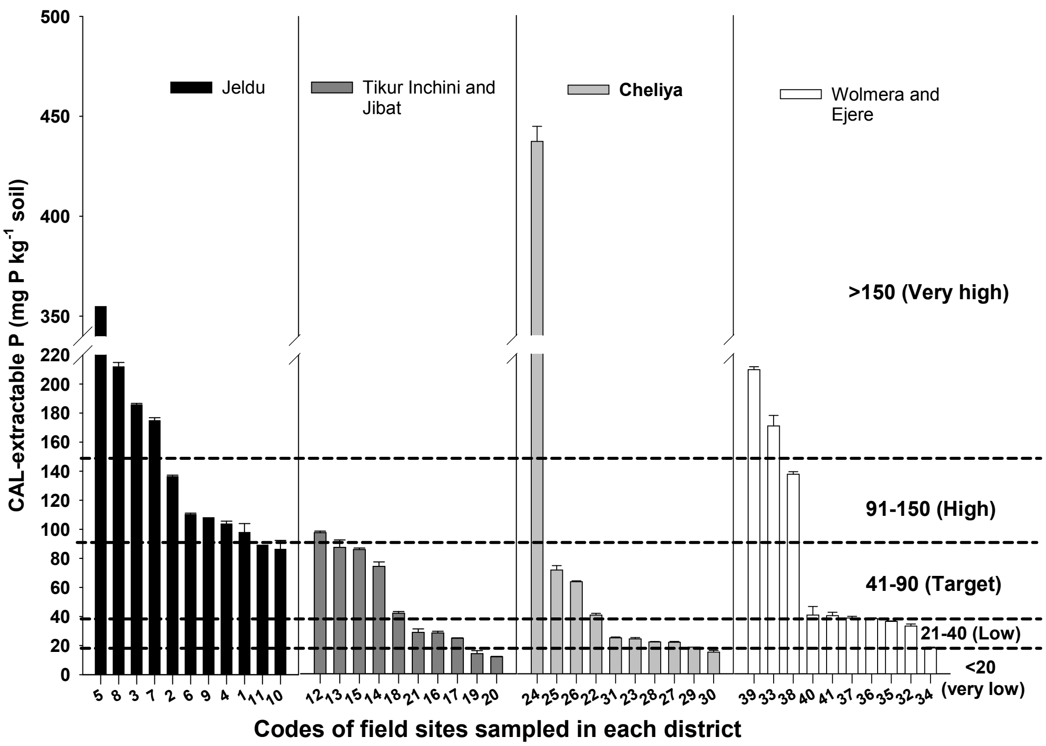

Fig. 5. CAL-extractable phosphorus content of soils of different districts in West Shoa Zone

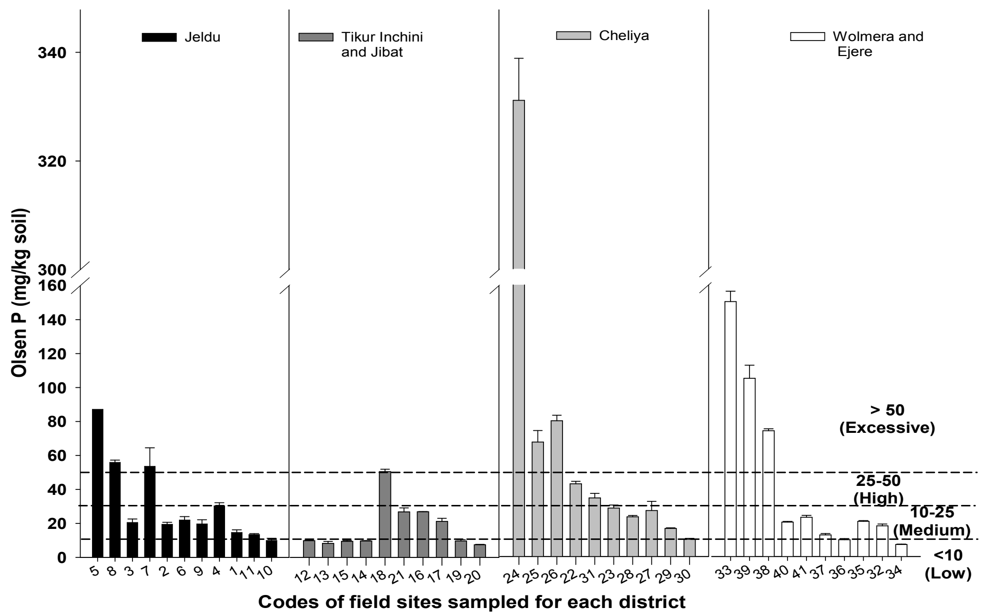

Fig. 6. $NaHCO_3$-extractable phosphorus (Olsen-P) content of soils of different districts in West Shoa Zone

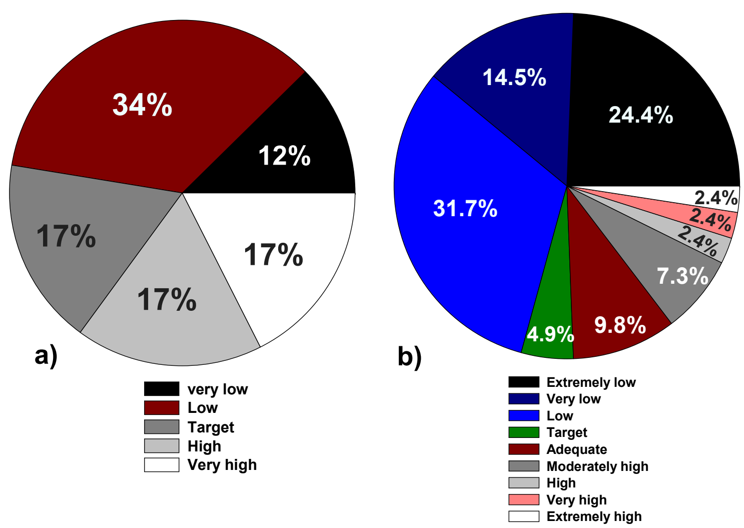

Fig. 7. Classification of soils of surveyed area in terms of CAL-P index (a) and Olsen P index (b)

Table 3. CAL and Olsen extractable phosphorus contents of soils collected from different districts in West Shoa Zone

Sl. No	Name of Districts	No. of field sites per district	CAL-extractable P (mg P kg^{-1} soil)		Olsen P (mg P kg^{-1} soil)	
			Range	Average	Range	Average
1	Jeldu	11	86-355	150.7	10-87	31.0
2	Tikur Inchini and Jibat	10	12-97	49.1	7-50	19.1
3	Cheliya	10	15-437	73.7	10-331	61.9
4	Welmera and Ejere	10	18-209	76.0	7-150	44.6

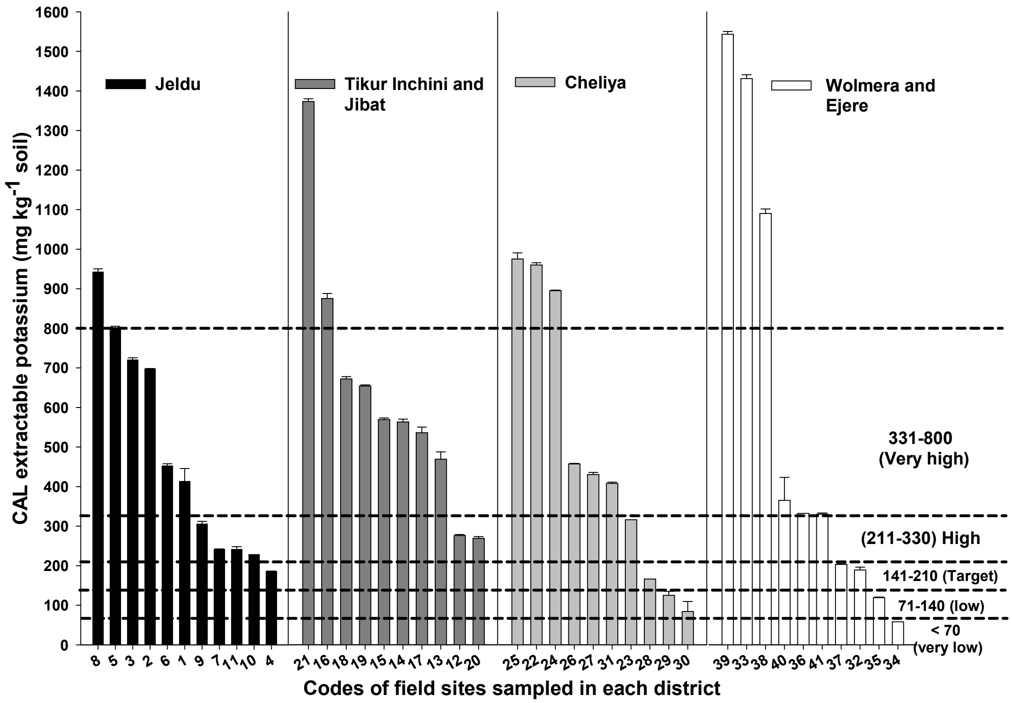

Fig. 8. CAL-extractable K content of soils of different districts in West Shoa Zone

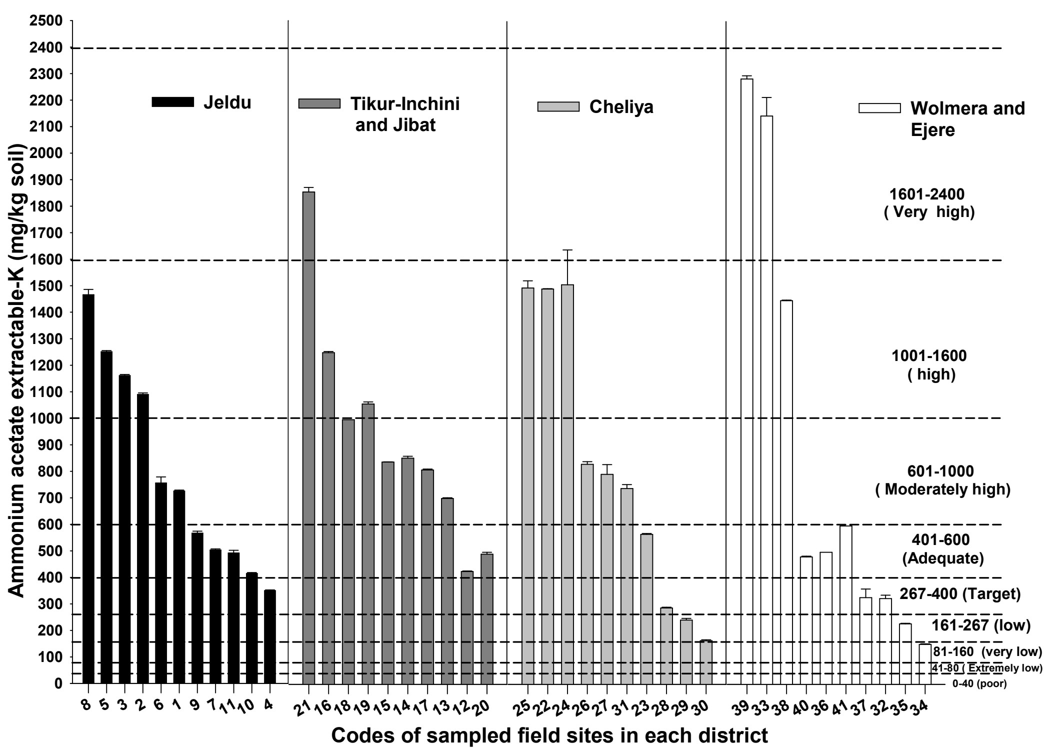

Fig. 9. Ammonium acetate-extractable K content of soils of different districts in West Shoa Zone

Table 4. CAL and ammonium acetate extractable potassium contents of soil of different districts in West Shoa Zone

Sl. No	Name of Districts	No. of field sites per district	CAL extractable K (mg kg^{-1} soil)		Ammonium acetate extractable K (mg kg^{-1} soil)	
			Range	Average	Range	Average
1	Jeldu	11	185-942	475.0	350-1466	797.8
2	Tikur Inchini and Jibat	10	269-1373	625.6	426-1857	928.1
3	Cheliya	10	84-975	481.6	165-1507	811.4
4	Welmera and Ejere	10	58-1543	566.0	151-2283	847.9

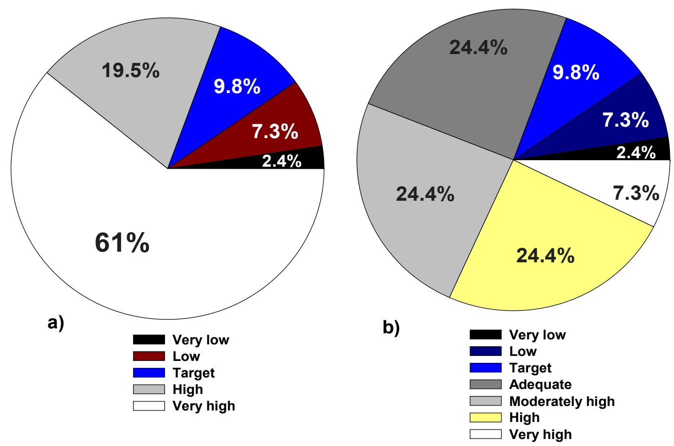

Fig. 10. Classification of soils of surveyed area in terms of CAL-K index (a) and ammonium acetate extractable-K index (b)

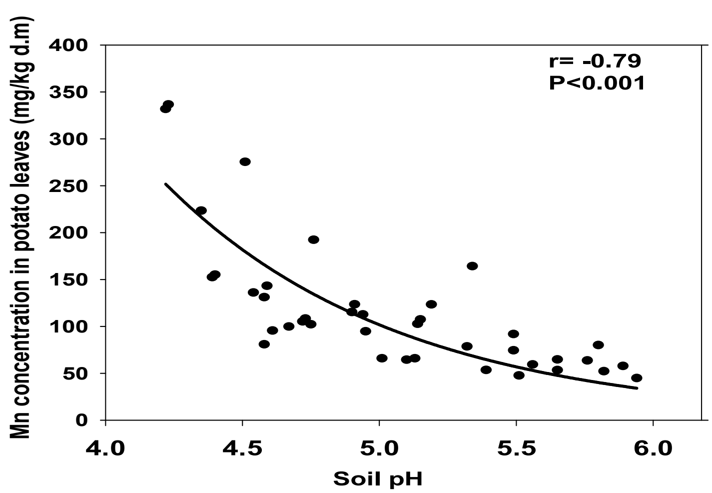

Fig. 11. Relationship between soil pH and Mn concentration in potato leaves

4.2 Soils Phosphorus and Potassium Status

The CAL-P values were generally higher compared to Olsen P values although the factor of difference varied with field sites and districts probably due to variation in soil characteristics specifically soil pH [12] and soil texture [13]. The analysis of soil textural class of the study area showed that there was a considerable variability in soil pH (Figs. 2 and 3) as well as in clay, silt and sand contents of the soils (data not shown). As average of all the sampled fields, the CAL-P value was higher than the Olsen P value by a factor of 4.8, 2.6, 1.2 and 1.7 for Jeldu, Tikur Inchini-Jibat, Cheliya and Welmera-Ejere districts. Surprisingly, in few field sites especially in Jeldu as well as Tikur Inchini and Jibat districts a considerable difference between CAL-P value and Olsen-P value was observed, presumably due to difference in soil pH (Figs. 2 and 3) and soil texture (data not presented). However, the CAL-P and Olsen P values determined for all the sampled fields in the present study significantly correlated (Fig. 12), despite the variation in the extend of P extraction capacity of the two methods. However, [13] observed that Olsen method was able to extract only half of the P that was extracted by Bray-1 and accounted the weak relationship (less correlation) between the two methods in different soils to difference in soil texture. The variation between calcium acetate lactate and sodium bicarbonate methods in the extent of the available P extraction ability from the soils of Jeldu and Cheliya districts might be attributed to difference in soil types, especially in soil texture [13]. The fact that most of the sampled fields, except those in Welmera and Ejere districts, showed a *very low* and *low* P class demonstrates that most of the soils in the major potato growing regions of West Shoa Zone were poor in available phosphorus, which might be related to the acidic nature of the soil (Table 2, Figs. 2 and 3), since in such soils phosphorus can be fixed in the form of Al and Fe-phosphates or strongly adsorbed to oxides or hydroxides of these elements [14]. The leaf P concentration (data not presented) from the same surveyed fields was below the optimum range for potato and this agrees with the *low* or *very low* soil P test value for most of the districts presented in Table 3 and Figs. 5 and 6. The fact that potassium extracted using 0.01 M ammonium acetate solution was higher than the ones extracted using CAL (calcium acetate and lactate) solution was on average higher by a factor of 1.7 agrees with the results of [15], who also observed two-fold higher extraction capacity of acidic ammonium acetate solution over the calcium acetate lactate solution, which was relatively a weak extractant. However, despite the difference in the amount of K extracted, the potassium content determined through both extraction methods showed highly significant positive correlation (Fig. 12), indicating that the extraction methods were not influenced by differences in soil pH and organic matter contents between the field sites, unlike the observation of [15], who reported that the amount of K extracted by the two methods was strongly influenced by organic matter content. Most of the surveyed fields had potassium content above the *target level* (Figs. 8 and 9) despite the absence of potassium fertilizer application in all the districts in particular and in Ethiopia in general. This confirms the long existing general view that the parent materials from which most Ethiopian soils are formed was rich in potassium. Some soils even had *very high* potassium content. However, few pocket areas (three field sites) have shown low potassium content (Figs. 8 and 9).

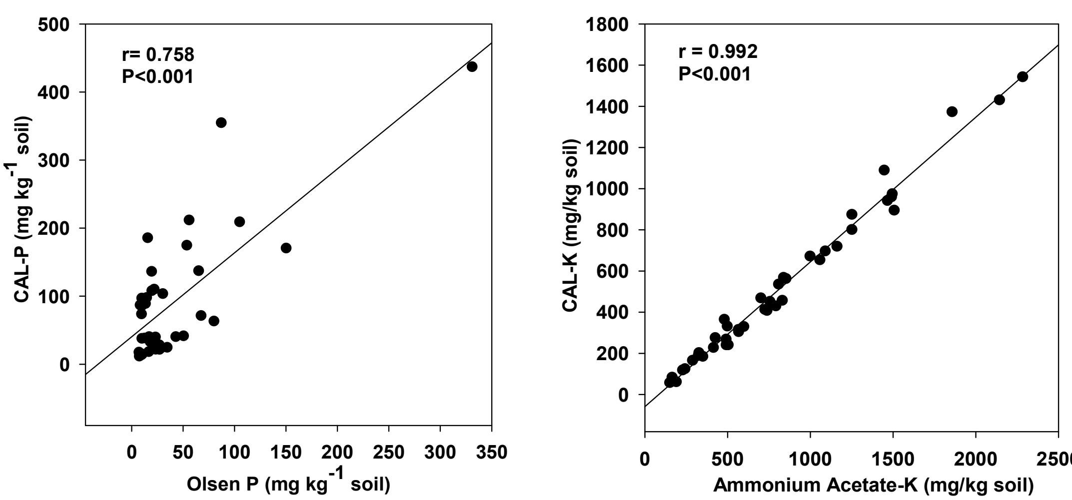

Fig. 12. Relationship between CAL-P and Olsen-P (left) and ammonium acetate extractable and CAL-extractable soil potassium content (right)

Table 5. Soil pH and Soil nutrient content in selected field sites of major potato growing districts of West Shoa Zone

Code	Field site		Soil pH (in water suspension)	Soil pH (in $CaCl_2$ suspension)	P-CAL (mg/kg soil)	Olsen P (mg/kg soil)	K-CAL ($mgkg^{-1}$ soil)	Ammonium Acetate Extractable K (mg /kg soil)
01	Galesa Qota Gesher-1	Jeldu district	5.3	4.8	98	15	413	726
02	Galesa Qoftu		5.5	5.1	136	19	697	1090
03	Chilanko-1		5.6	5.2	186	16	720	1161
04	Chilanko-2		4.8	4.4	104	30	185	350
05	Edensa Gelan-1		5.9	5.5	355	87	801	1251
06	Edensa Gelan-2		5.5	5.1	110	22	452	756
07	Edensa Gelan -3		5.0	4.6	175	54	241	503
08	Kolu Gelan-1		5.7	5.3	212	56	942	1466
09	Kolu Gelan-2		4.9	4.6	108	20	305	567
10	Chilanko-4		5.0	4.5	86	10	228	415
11	Galesa Qota Gesher-2		5.0	4.4	89	13	241	492
12	Birbira fi Doguma	Tikur Inchini and Jibat districts	5.3	4.9	97	10	276	426
13	Ula Lankiso		5.1	4.6	87	8	469	701
14	Maganur		5.1	4.6	74	10	563	853
15	Walda Hidhe-1		5.0	4.5	85	9	569	839
16	Buyema Qochore		5.7	5.1	28	27	875	1251
17	Bilo Abaye		5.6	5.0	24	21	536	809
18	Togo Wixate		6.1	5.7	42	50	672	998
19	Mugno Abayi (Jibat)		5.5	4.9	14	10	654	1058
20	Tutu Jibat		5.2	4.7	12	7	269	491
21	Walda Hindhe-2		5.7	5.2	28	27	1373	1857
22	Rafiso Alenga-1	Cheliya disctrict	5.9	5.5	40	43	960	1491
23	Rafiso Alenga-2		5.5	5.0	24	29	316	566
24	Alle Ula Dhabi		6.3	5.9	437	331	895	1507
25	Jasro Dire Geda-1		5.8	5.4	71	67	975	1495
26	Jarso Dire Geda-2		5.9	5.3	63	80	457	830
27	Bilo fi Kaku		5.2	4.7	22	27	430	792
28	Tulu Kosoru-1		5.4	4.9	22	23	166	288
29	Tulu Kosoru-2		4.8	4.2	18	17	125	243
30	Tulu Kosoru-3		4.7	4.2	15	10	84	165
31	Jarso		5.2	4.7	25	35	408	739
32	Kurkusami Robgebya	Welmera/Ejere Districts	5.6	5.3	33	18	189	324
33	Kurkurfa Ilu Barga		5.2	5.8	170	150	1431	2144
34	Ilu Aga, Ejere		4.9	4.4	18	7	58	151
35	Ilu Aga, Ejere		5.2	4.8	36	21	119	228
36	Dufa (welmera)		6.2	5.8	38	10	332	498
37	Dufa (Welmera)		6.2	5.6	38	13	203	327
38	Dufa (Welmera)		6.2	5.8	137	65	1090	1447
39	Talacho Ganreli (Welmera)		5.9	5.7	209	105	1543	2283
40	Birbirsa Siba (Welmera)		6.3	5.9	40	17	365	481
41	Barfata Tokofa Roge (Welmera)		6.1	5.5	40	23	330	598

5. CONCLUSION AND RECOMMENDATIONS

The soil pH of all the surveyed area was in the acidic range with most of the soils (80.5%) either in the strongly acidic, very strongly acidic or extremely acidic range. The results of the soil analysis revealed that nearly 70% of the soil phosphorus status was rated as *low, very low* and *extremely low* according to Olsen P test whereas only 9.5% of the surveyed soil was rated as having *low* or *very low* potassium status and the rest 80.5% of the surveyed soils were rated as having potassium status of target value and above. Since most of the surveyed area had a low soil pH, which can result in deficiency of phosphorus and toxicity of manganese and aluminum, multi-location field experiment should be conducted in low pH spot areas to investigate effect of lime application in reclaiming the soil acidity, and in enhancing P availability, crop growth and yield. Phosphorus fertilizer trials also need to be executed on sites having low P-status to assess yield response to applied mineral P fertilizer and the extent of P fertilizer recovery. Since few pocket areas in the current investigation showed lower potassium content, crop response to potassium fertilizer application in those particular areas should be assessed through conducting multi-location field experiments.

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