academicresearchJournals

Vol. 4(1), pp. 18-30, January 2016
DOI: 10.14662/ARJASR2015.064

ISSN: 2360-7874
http://www.academicresearchjournals.org/ARJASR/Index.htm

Academic Research Journal of Agricultural Science and Research

Full Length Research

A review of Soil Fertility Improvement and Monitoring Studies on Cotton at Middle Awash and Arbaminch Areas, Ethiopia

Getinet Adugna*, Habte Nida, Abere Mnalku, Sosena Amsalu , Melese Mnaleshewa

Ethiopian Institute of Agricultural Research; Werer Research Center P.O Box 2003, Addis Ababa, Ethiopia

Accepted 6 December 2015

Studies were conducted at Middle Awash and Arbaminch areas including long-term exhaustion trial, fertilizer and cover crop studies, soil types and their fertility status and potassium forms, release dynamics and its availability. The results of the studies revealed that there were no remarkable depletion/changes in soil nutrient levels due to mono cropping of cotton at Middle Awash areas in the past two to three decades. Cotton was non-responsive and consistent to fertilizer application in most of the previous studies. However, according to some recent studies nitrogen was found to be the first and most limiting nutrient being very low both at Middle Awash and Arbaminch soils and its application resulted in significantly higher yield and economic benefit particularly on older cotton farms. Incorporation of cover crop also showed potential benefit in improving cotton yield. Studies on K also revealed that readily available as well as reserve forms of potassium were found to be well above the critical limits in all sites throughout the soil layers. Moreover, the main soil types, which include Salic Fluvisols, Eutric Fluvisols and Eutric Vertisols, were investigated, of which Eutric Fluvisols occupies the largest portion of the cultivated land of Awash river basin.

Keywords: Cover crop, fertilizer application, exhaustion trial, potassium, soil types, cotton

INTRODUCTION

Cotton is the most important fiber crop of the world and it has long history of production and weaving in Ethiopia. However, the country's overall production and productivity is still very low and it is declining from time to time. Lack of high yielding varieties with high quality fiber, poor crop management practices, increasing input price as well as price instabilities in international market are the major factors that are contributing to the low productivity of cotton.

A reconnaissance soil survey covering about 2 million ha and semi-detailed soil survey on selected areas totaling 500,000 ha indicated that the gross potentially irrigable land was approximately 206,000 ha, of which around 83,000 ha are located in the Middle Awash Valley (Halcrow, 1989). At present, more than 9,500 ha of land are under irrigation farming in the middle Awash. Regarding the soil classification in the Middle Awash basin, until now, only a few attempts have been done. Middle Awash cotton growing soils are predominantly Vertisols and Fluvisols having alluvial origin deposited from Awash River. Before the introduction and expansion of cotton production, the area was known to be under natural forest and grassland ecology. It used to be a high potential area for cotton production and yield was considerably high.

The availability of NPK fertilizers and water are the major constraints in most cotton producing environments (Morrow and Krieg, 1990; Raja Rajan et al., 2005). Nitrogen is the nutrient to which cotton most consistently responds and plays a major role in determining the expression of a wide range of plant parameters such as plant size, fruit intensity, boll retention rate, boll size and total number of bolls per plant (Silvertooth et al., 1999; Main et al. 2013). Nitrogen is generally considered a yield-limiting nutrient in cotton production systems that demand for optimum yield. Time of N application is also critical factor with respect to its availability at different crop growth stage. The N requirement of cotton reaches maximum during the period from peak squaring to blooming and continues through major boll-filling stage (Silvertooth et al., 1999).

Mono-cropping has remained the dominant production system in most of major cotton production areas in Ethiopia with no or little addition of external input which often reputed to result in depletion of essential plant nutrients as well as deterioration of soil physical, chemical and biological properties. Cotton is considered a low residue crop that may not provide sufficient residue to the soil (Daniel et al., 1999). Thus, it can be expected that mono-cropping with cotton could result in low total soil N and organic matter and poor soil protection.

State farms used to apply N fertilizer in the form of Urea at the rate of 100 kg ha^{-1} split-applied half at planting and half at peak flowering on farms where positive response and economic return were expected. Lately however, based on research results, it was realized that there was poor response to fertilizer application to cotton in the area that would not warrant economic benefit. As a result, fertilizer application has been terminated (Tadele, 1982). However, total N of soils of Melka Werer Research Center and Melka Sedi State Farm was low (Kamara et al., 1990). Similar to Middle Awash cotton soils, soil fertility assessment study by Engdawork et al. (2002) revealed that total N of Arbaminch state farm was very low in all described profiles while level of available P was in medium to high range. Level of K was also high in the entire soil described.

Yield becomes low and was particularly prevalent in some of the farms which are often considered as older. Stunted growth, premature senescence and pale/bright green appearance of leaves have been noticed in some of the cotton farms. These observations led to further and continued investigations on fertilizer studies, exhaustion trials, evaluation of cover crop, foliar application trials, soil characterization and K assessment studies. This review paper was therefore meant to make an overview of soil fertility improvement, monitoring and assessment studies that were being carried out in recent years.

MAJOR RESEARCH FINDINGS

Long term soil fertility monitoring study

Long-term exhaustion trial was conducted on Vertisols and Fluvisols at Werer Agricultural Research Center (WARC) during the period from 1968 to 2002 and 1974 to 2002, respectively, to determine after how many years of continuous mono-cropping of cotton would respond to fertilizer application and to investigate nutrient depletion rate and changes in soil chemical properties. Status of soil total N, organic matter, available P and K levels on both soils were determined in each of the years 1977, 1999 and 2003.

Soil test result for fallow, control and fertilizer treated plots during the soil test years revealed that there was no remarkable indication of depletion/change in soil total N, organic matter and available P level due to continuous mono-cropping with cotton. The general trend in level of each of the nutrients on each soil is indicated in Figure 1. Level of organic matter tended to increase after the 1999 testing year irrespective of the different practices. A substantial build up of available P was recorded over years on both soils irrespective of the practices. No explanation was made for such build up of P, except that sufficient P might had been deposited from sediment rich flood incident due to the over flow of Awash River in 1999. Trends in level of available K due to the different practices in both soils were reported to be similar to that of the other nutrients and considered adequate for cotton production (data not shown).

Regarding yield response during the trial period, seed cotton yield significantly increased only in four out of each of the thirteen and ten fertilizer application years on Vertisols and Fluvisols, respectively. Results of the years with significant response under each soil condition are presented in Table 1. Seed cotton yield significantly increased due to N application but there was no further significant increase due to inclusion of either P, K or both nutrients even if the experiment was not designed to easily differentiate effect of each nutrient. In a similar long term experiment at Altus, Oklahoma involving the three nutrients most of the response was attributed to nitrogen (Girma et al., 2007).

Fertilizer Studies

Middle Awash

Field investigation at WARC and Amibera Agricultural Development Enterprise (Sheleko farm) involving five levels of N and three split N-application, response varied with year and testing site (Table 2). Seed cotton yield was not significantly affected by N at both locations in 2004, while rate and split N-application interaction had significant effect in 2005. The highest seed cotton yield was recorded from the interaction effect of 36 kg ha^{-1} N and split-applied half at planting and half at peak flowering at WARC in 2005. The next higher and lower levels of N (69 and 23 kg ha^{-1}) split-applied half at planting and half at peak flowering, resulted in the next higher seed cotton yields. Nitrogen at the rate of 36 kg ha^{-1} split-applied ¼ at early squaring + ½ at peak

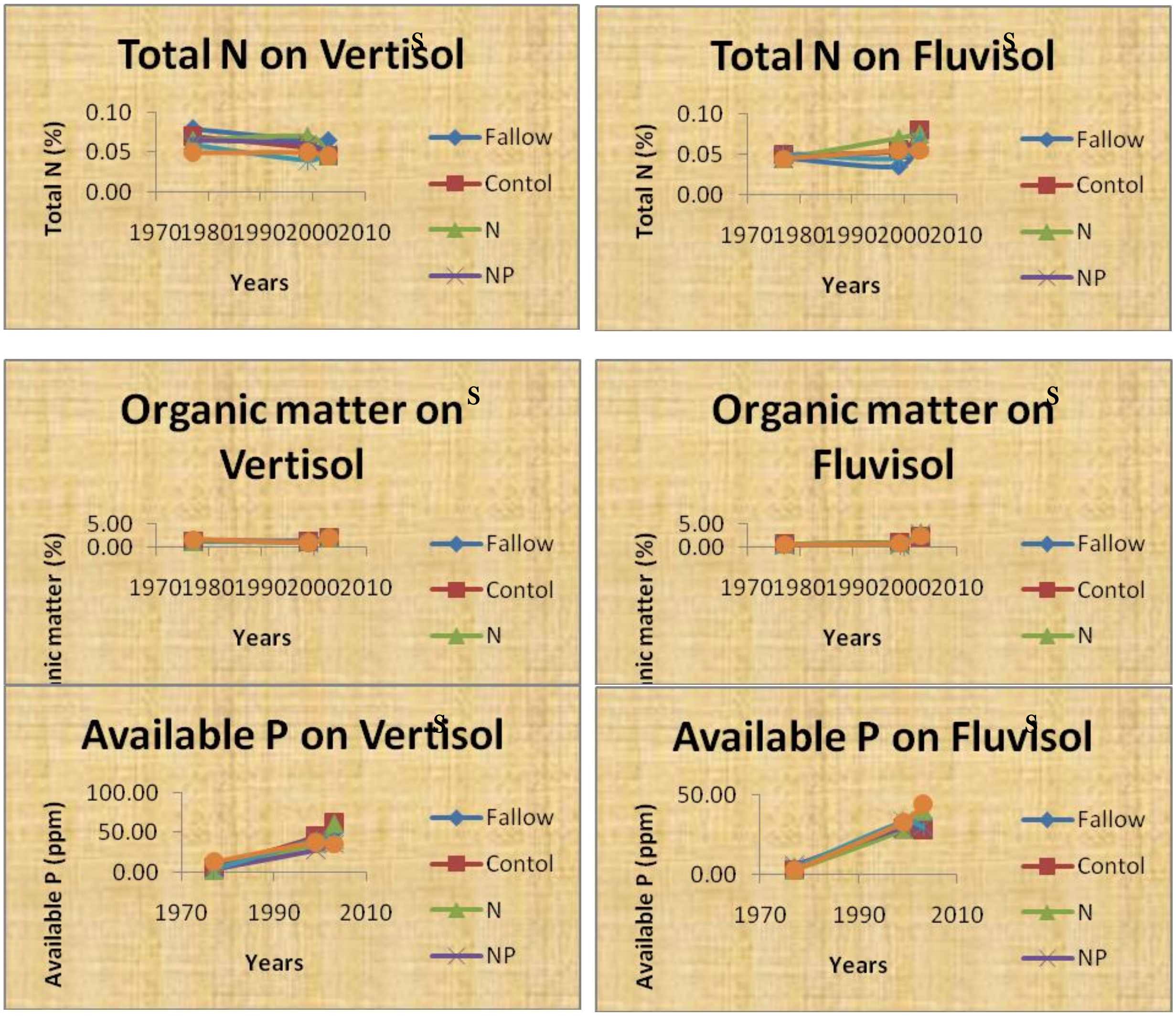

Figure 1: Effect of long-term mono-cropping (control), fallow and fertilization of cotton on soil total N, organic matter (OM) and available P levels on Vertisols and Fluvisols (Source: WARC, 2008a)

Table 1. Effect of N, P and K fertilization on seed cotton yield (t ha^{-1}) of cotton grown on Vertisols and Fluvisols at WARC

NPK levels	Vertisols				Fluvisols			
(kg ha^{-1})	1981	1984	1987	2001	1981	1984	1987	1990
Control	3.14^{b}	2.29^{b}	1.82^{b}	1.69^{b}	3.58^{cd}	3.05^{b}	1.53^{b}	2.46^{cd}
80 N	4.19^{a}	3.31^{a}	2.33^{a}	2.17^{a}	4.61^{a}	4.51^{a}	2.02^{a}	3.57^{a}
80-80 NP	4.14^{a}	3.02^{a}	2.42^{a}	2.49^{a}	4.10^{ac}	4.27^{a}	2.06^{a}	3.27^{ab}
80-80 NK	4.14^{a}	3.28^{a}	2.32^{a}	2.43^{a}	4.07^{ad}	4.68^{a}	2.12^{a}	2.92^{bc}
80-80-80 NPK	4.22^{a}	3.41^{a}	2.52^{a}	2.16^{a}	4.52^{ab}	4.53^{a}	2.14^{a}	2.68^{bcd}

Means followed by the same letter within each column are not significantly different at α=0.05; (Source: WARC, 2008a)

flowering + ¼ at 50% boll setting resulted in the lowest seed cotton yield. Such response would not be expected as lower and higher rates applied the same manner resulted better seed cotton yield than the control which indicated inconsistence in the result of the study. In contrast to WARC, at Sheleko, several of the N rate and split-application combinations resulted in lower seed cotton yield than the control (Table 2). The combinations

Table 2. Effect of rate and split N-application on seed cotton yield (t ha^{-1}) grown at WARC and Sheleko in 2004 and 2005

		2004			2005		
	Level of N	Time of application					
Test Location	(kg ha^{-1})	T1	T2	T3	T1	T2	T3
WARC	0	45.54			4.30^{g}		
	23	45.90	46.16	44.33	5.37^{b}	5.32^{bc}	4.73^{ef}
	36	47.01	48.38	44.40	5.66^{a}	4.60^{f}	4.28^{g}
	69	48.01	45.52	43.48	5.41^{b}	4.92^{de}	5.11^{cd}
	92	43.37	43.67	40.78	4.92^{de}	4.86^{de}	5.22^{bc}
Sheleko	0	25.09			2.60^{ef}		
	23	28.79	28.10	26.94	2.43^{fg}	2.15^{h}	2.43^{fg}
	36	32.22	30.90	28.77	2.81^{de}	2.17^{h}	2.86^{cd}
	69	28.44	30.76	31.77	3.07^{bc}	2.33^{gh}	2.56^{fg}
	92	34.11	30.36	31.02	2.48^{fg}	3.49^{a}	3.13^{b}

T_1 = ½ at planting + ½ at peak flowering, T_2 = ¼ at planting + ½ at early flowering + ¼ at 50% boll setting and
T_3 = ¼ at early squaring + ½ at peak flowering + ¼ at 50% boll setting; Means within each year and test location
followed by the same letter are not significantly different at α=0.05 (Source: WARC, 2007)

Table 3. Effect of nitrogen on plant height, seed cotton yield and foliar N content of cotton grown on Vertisols at WARC in 2007

Level of N (kg ha^{-1})	Plant height (cm)	Seed cotton yield (t ha^{-1})	Foliar N (%)
0	81.91^{d}	2.12^{b}	0.362^{c}
40	93.33^{c}	2.72^{a}	0.459^{b}
80	104.32^{b}	2.82^{a}	0.487^{b}
120	117.02^{a}	2.96^{a}	0.622^{a}

Means followed by the same letter within a column are not significantly different at α=0.05 (WARC, 2008a).

include both low and high N levels as well as the different split-application treatments without definite pattern questioning the methodologies followed. But, the highest seed cotton yield was recorded with N rate of 92 kg ha^{-1} split-applied ¼ at planting + ½ at early flowering + ¼ at 50% boll setting.

A study was conducted on N and P fertilizers on Vertisols and Fluvisols at WARC in 2007. Experimental soils were low in total N and organic matter but high in available P. Neither main effect of P nor its interaction with N was significant on yield and yield components of cotton grown on both soils. Main effect of N was significant on seed cotton yield, plant height and leaf N level of cotton grown on Vertisols (Table 3). Plant height significantly increased with each increase in the level of N. Regardless of rate of application seed cotton yield significantly increased with N as compared to the control. Foliar N level significantly increased with the increase in levels of soil applied N indicating low available N in the test soil.

Another field investigation was carried out at Amibera Agricultural Development Enterprise (Sheleko area) at two sites labeled D4-9 and C6-14 in 2007 to determine optimum rate of N fertilizer for cotton on older cotton farms. D4-9 has clayey textural group with vertic property, while C6-14 has silty to silty clay-loam texture. Some of the selected soil chemical and physical properties of the selected sites are presented in Table 4. Organic matter, total N as well as available forms of N were very low at both sites throughout the soil depth.

Combined analysis of variance on yield and yield components indicated that cotton grown in the two sites responded similarly to the different rates used in the study (analysis not shown). Plant height, boll number, seed cotton yield and lint yield significantly increased with application of N at the rates of 46, 69 and 92 kg ha^{-1} split-applied one third at 2nd irrigation and the remaining at flower initiation stage (Table 5). Yield improvements with N application were substantial and statistically similar with all rates used in the study.

Seed cotton and lint yields increased by as much as 1.6 to 2.0 and 0.7 to 0.8 t ha^{-1}, respectively under the

Table 4. Selected physical and chemical properties of soils at D4-9 and C6-14 tests sites

Test sites	Depth (cm)	Organic matter (%)	Total Nitrogen (%)	NH_4-N (ppm)	NO_3-N (ppm)
D4-9	0-30	1.60	0.112	17	10
	30-60	1.60	0.098	10	14
	60-90	1.30	0.098	14	14
C6-14	0-30	1.60	0.056	7	7
	30-60	1.30	0.042	14	7
	60-90	1.36	0.084	14	10

Source: WARC (2008a)

Table 5. Effect of N fertilizer rate on yield and yield components of cotton grown on older cotton farms at Sheleko combined over two sites (D4-9 and C6-14) in 2007

Level of N (kg ha^{-1})	Plant height (cm)	Boll number	Seed cotton yield (t ha^{-1})	Lint yield (t ha^{-1})
0	102.68^{c}	12.50^{c}	2.84^{b}	1.16^{b}
46	120.83^{b}	15.27^{b}	4.42^{a}	1.82^{a}
69	130.33^{ab}	17.50^{a}	4.58^{a}	1.88^{a}
92	138.20^{a}	17.30^{a}	4.82^{a}	1.97^{a}

Means followed by the same letter are not significantly different at α=0.05 (Source: WARC, 2008b)

Table 6. Partial budget for cotton production under different levels of nitrogen fertilization on older cotton farms of D4-9 and C6-14 sites at Middle Awash

	Level of Nitrogen (kg ha^{-1})			
Farm gate benefits	0	46	69	92
Seed cotton yield	2842	4424	4577	4820
Lint yield (kg/ha)	1163	1820	1875	1970
Value of lint	23,260.00	36,400.00	37,500.00	39,400.00
Value of seed	5708.60	8853.60	9186.80	9690.00
Gross farm gate benefits	28968.60	45253.60	46686.80	49090.00
Variable input costs				
Fertilizer - material	0.00	700.00	1050.00	1400.00
Fertilizer - labour	0.00	125.00	125.00	125.00
Peaking cost	1,136.80	1,769.60	1,830.80	1,928.00
Packing	28.42	44.24	45.77	48.20
Loading/unloading	34.10	53.09	54.92	57.84
Transport to gin factory	653.66	1,017.52	1,052.71	1,108.60
Ginning and bagging	2,131.5	3,318	3,432.75	3,615.00
Total variable input costs	3,984.48	7,027.45	7,591.95	8,282.64
Net benefit	24,984.12	38,226.15	39,094.85	40,807.36
Marginal rate of return (%)		435	154	248

enterprise's management. Fresh and dry matter per plant from a lath house experiment conducted on bulk soil sample collected from the sites and involving the same rate used under the field condition also indicated similar response (data not shown).

Partial budget analysis for cotton under different N fertilization on the older farms indicated that application of N at rate of 92 kg ha^{-1} resulted in the highest net benefit (40,807.36 Birr ha^{-1}) while N application at 46 kg ha^{-1} resulted in the highest marginal rate of return (435%) with a net benefit of 38,226.15 Birr ha^{-1}(Table 6).

Table 7. Effect of NP fertilization on seed cotton yield (t ha^{-1}) of cotton grown at Arbaminch state farm in 2005 and 2006

	2005			2006		
	Level of P (kg ha^{-1})					
Level of N (kg ha^{-1})	0	46	69	0	46	69
0	3.68^{g}	3.93^{e}	3.78^{f}	0.67^{i}	0.80^{gh}	0.80^{gh}
46	4.17^{c}	3.78^{f}	3.89^{e}	1.21^{cd}	0.79^{gh}	1.20^{d}
69	3.74^{fg}	4.41^{a}	4.12^{c}	0.72^{hi}	1.38^{ab}	1.30^{bc}
92	4.05^{d}	4.25^{b}	3.88^{e}	0.97^{f}	1.09^{e}	1.21^{cd}
115	4/04^{d}	4.43^{a}	4.17^{c}	0.86^{g}	1.44^{a}	0.99^{f}

Means followed by the same letter within each year are not significantly different (Source: WARC, 2007)

Table 8. Effect of Sunn hemp as a summer cover crop and plowing depth on seed cotton yield (t ha^{-1}) of cotton grown at WARC on black Vertisols, 2005 to 2007

	2005		2006		2007	
	Cover crop					
Plowing depth (cm)	Sunn hemp	None	Sunn hemp	None	Sunn hemp	None
25	2.62^{a}	2.37^{b}	3.06^{b}	2.21^{d}	2.26^{d}	2.05^{e}
35	2.61^{a}	2.33^{b}	3.09^{b}	2.62^{c}	2.48^{ab}	2.33^{cd}
45	2.62^{a}	1.94^{c}	3.29^{a}	2.61^{c}	2.59^{a}	2.44^{bc}
55	2.61^{a}	2.05^{c}	3.21^{a}	2.64^{c}	2.60^{a}	2.46^{b}

Means followed by the same letter within each year are not significantly different at α= 0.05 (Source: WARC, 2008b)

Soil fertility research in Arbaminch areas

Unlike Middle Awash areas where cotton was non-responsive to P fertilization, a study conducted in 2005 and 2006 at Arbaminch state farm revealed that cotton significantly responded to interactive effect of N and P (Table 7). The interaction effects of 69 and 115 kg ha^{-1} of N and 46 kg ha^{-1} of P resulted in significantly highest seed cotton yield in both years as compared to the rest of NP combinations. Responses due to the rest of NP treatments varied with year without a definite trend.

Incorporation of a summer cover crop in cotton

A study on incorporation of a legume cover crop, Sunn hemp (*Crotalaria juncea* L.) on black Vertisols of WARC from 2005 to 2007 with varying plowing depth for cotton resulted in a positive impact on cotton yield. It was intended to identify potential benefit in improving deteriorating soil structure and organic matter content and improve cotton yield. Sunn hemp has been considered an excellent choice as a summer cover crop in terms of N addition to soil, improving soil tilth and water holding capacity and suppression of weeds (Danielle and Mike, 2008). Plots were established in autumn, planted with Sunn hemp following cotton harvest, grown for 2-3 months, and incorporated in to the soil. The plots were plowed with varying depth (25, 35, 45 and 55 cm), during main cropping season and grown with cotton. The result indicated that seed cotton yield of cotton varied with year and there was significant interaction effect between cover crop and plowing depth (Table 8).

During first testing year, incorporation of Sunn hemp significantly increased seed cotton yield irrespective of cotton plowing depth, but deeper plowing (45 and 55 cm) without Sunn hemp resulted in significant yield reduction. It was therefore an indication that there may be yield reduction during first years of deeper plowing unless supplemented with external input. During subsequent years however, plots plowed deeper resulted significantly in higher yields even without incorporation of the cover crop. Interactive effects of Sunn hemp and deeper plowing resulted in significantly higher seed cotton yields during the next testing years.

Vertical distribution of potassium forms, release dynamics and availability

This study was undertaken in 2006 to investigate the vertical distribution of potassium forms, release dynamics, and availability status for cotton plant in Fluvisols and Vertisols of the Amibara irrigated cotton

Table 9. Potassium status of cotton plant (% K)

Sampling site	% K concentration in cotton leaf	
	Vertisols	Fluvisols
Melka Sadi state farm	1.50	2.08
Werer research farm	1.50	1.43
Werer state farm	2.02	2.11
Sheleko private farm	1.24	1.58
Sublele private farm	1.41	1.68
Mean	1.53	1.78

Source: WARC (2006)

Table 10. Mean values of soil potassium forms (Cmol kg^{-1})

Soil type	depth (Cm)	H_2O-K	Exch.-K	N-exch.K	Lattice-K	Total K
Fluvisols	0-30	0.14	2.41	3.65	16.42	22.61
	30-60	0.10	1.80	2.68	13.11	17.65
	60-90	0.09	1.40	2.16	14.21	17.85
Vertisols	0-30	0.12	2.42	3.51	17.82	23.85
	30-60	0.10	2.05	3.20	18.36	23.02
	60-90	0.08	1.82	2.91	17.77	22.57

Source: WARC (2006)

farms. Fourty composite soil and ten cotton leaf samples from 150 representative sampling spots were used for this study. Results showed that readily available as well as the reserve forms of K in all sites throughout the soil layers were found to be well above the critical limits (WARC, 2006). Foliar K status of cotton, which appeared to be within the range of sufficiency level, further, reflects adequate supplying capacity of this nutrient in these soils (Table 9).

Vertisols have better capacity to buffer change in K concentration in soil solution relative to that in Fluvisols; while the intensity of K appeared to be more in Fluvisols than in Vertisols (Table 10). Generally, the AR_e^k values in both soil types were found to be above the critical limits indicating adequate level of release of exchangeable K into the soil solution for plant uptake. Presumably, these soils can be characterized as having adequate supplying capacity to support shallow as well as deep-rooted crops. Therefore, decline in cotton fiber yield and lint quality claimed by cotton growers of Amibara area should not be ascribed to K nutrition. As these soils showed adequate level of readily available K, in one hand, and K fixing property, on the other hand, plant response from normal potash application at present condition could be most unlikely. Though present study indicates high K supplying capacity in these soils, it must be noted, however, that K bearing minerals do not provide an inexhaustible K source, and with time, the rate of release of non-exchangeable K may decline. Thus, periodic checking of K supplying status of these soils is required.

Soil characterization study

Physical and chemical characteristics of soil samples from 12 representative soil profiles, irrigation water, subsurface drained water, and ground water were studied in 2001 in the Middle Awash basin to determine the soil types and their fertility status of the soils of Middle Awash irrigated farms. Results showed that the main soil types are Salic Fluvisols, Eutric Fluvisols and Eutric Vertisols (Annex 1 and 2). Among these soil types, Eutric Fluvisols occupies the largest portion of the cultivated land of the basin. Salic and Eutric Fluvisols show stratification with weak horizon differentiation with alternating silt and clay particle size dominance within profile depth, while the Eutric Vertisols have homogenous solum overlaying stratified subsoil. Eutric and Salic Fluvisols have 1.2-1.3 g cm^{-3} bulk density, pH values ranging from 7.0 - 8.7 and low to high EC_e (0.4-26 dSm^{-1}). The bulk density, pH and EC_e of the Eutric Vertisol range from 1.3–1.6 g cm^{-3}, 7.6-8.5 and 0.4-14.1 dSm^{-1}, respectively. Accordingly, profiles 2 and 3 from WARC and 9 from MSSF have EC_e value >4 dSm^{-1} and are severely affected by salt. These profiles represent about 60 ha of WARC and 350 ha of MSSF.

Total N in all soil types is low to medium, while available P and CEC is high. The organic matter content in all soil types are very low and ranges between 0.7% and 1.8%. The value is similar to most of cultivated soils of Ethiopia, which have low organic matter content due to complete removal of biomass from the field. As observed from ground and irrigation water analysis, the ground water contains higher concentration of electrolytes, while the irrigation water contains very low amount and it is safe to be used for irrigation. The major limitation for crop production in relation to the physical and chemical properties of these soils is the undesirable neutral salt accumulation, which commonly aggravates salinity and sodicity.

The Way Forward

Although the soils of both Middle Awash and Arbaminch are known to be very low in the level of N, response of cotton to N application was not consistent over years. Suggests detailed and further investigation over the factors associated with N availability and responsiveness of the crop such as choice of appropriate N fertilizer, timing and method of application, climatic features, soil characteristics and crop management practices. There may be substantial loss of applied N through leaching, denitrification, volatilization, immobilization, or a combination of these pathways, which need studies in relation to method, and time of N application and other crop management practices followed in the areas.

Further research in improving soil N and organic matter through addition of different fertilizers and/or incorporation of cover crops and evaluation of their economic benefit is required. Apart from the yield advantage obtained from incorporation of cover crop, improvement in soil properties were not quantified. Therefore, further investigation on positive impact of incorporating cover crop on soil properties should be identified. Studies on N recommendations for various yield levels of cotton at Middle Awash and Arbaminch as well as other cotton growing areas are vital. Estimates of mineralizable N, soil test for residual NO_3, NO_3 addition due to irrigation water and potential yield under each of the growing locations could be valuable basis for accurate and profitable N recommendations. There have been indications that level of soil P and K were considerably high both at Middle Awash and Arbaminch areas and this could be attributed to the inherent high level of the nutrients and substantial yearly addition through sediment rich irrigation water. However, this could not be everlasting and periodic check on status of P and K levels as well as further research on annual input/output balance of soluble nutrients is required. In addition, further research is required regarding the annual input output balance of this nutrient to formulate sound K management strategies in long term basis.

The fertility status of the irrigated soils of the middle Awash as observed from this work is medium to high except the deficiency of Zn. The major limitation in relation to soil physical and chemical properties is the undesirable salt accumulation, which commonly aggravates salinity and sodicity. The salt problem of the studied area is associated with poor drainage, rise of ground water table and moisture drawn to the surface by capillary movement bringing with it dissolved salts thereby leaving behind the salt as the moisture evaporates.

Such conditions could have been removed through leaching. This approach is only satisfactory whenever there is appropriate subsurface drainage at the face of high water table. Since subsurface drainage outlay is very costly, caution should be exercised on the amount, method and frequency of irrigation water use. Selection of salt tolerant varieties of the major crops in the area should get due attention too. Studies should also be undertaken on the relation of sodium and major plant nutrients uptake by crops and on improving soil physical condition measures as well as on plant response to Zn fertilizer.

REFERENCES

Daniel JB, Abaye AO, Alley MM, Adcock CW, Maitland JC (1999). Winter annual cover crops in a Virginia no-till cotton production system: I. Biomass production, ground cover, and nitrogen assimilation. J. Cotton Sci. *3:74-83*.

Danielle DT, Mike A (2008). Sunn hemp (*Crotalaria juncea* L.): A summer cover crop for Florida vegetable producers. (http://plants.usda.gov/plantguide/doc/pg_crju.doc). (Accessed on June 10, 2010).

Engdawork A, Kinfe K, Daniel T (2002). Analysis of chemical properties of soils and irrigation water quality of Sille, Arbaminch and Abaya state farms. Arbaminch Water Technology Institute.

Girma K, Teal RK, Freeman KW, Boman RK, Raun WR (2007). Cotton lint yield and quality as affected by applications of N, P and K Fertilizers. J. Cotton Sci. 11:12–19.

Halcrow Sir, Sons (1989). Rift valley lakes integrated natural resources development master plan. Ethiopian Valleys Development Studies Authorities. Unpublished Technical Report, Addis Ababa, Ethiopia.

Kamara CS, Haque I (1990). Characterstics of lowland soils of Melka Sedi state farm and Melka Werer Research Center in the Harerge Region of Ethiopia. International Livestock Centre for Africa (ILCA), Plant science Division Working Document No. B11., Addis Ababa, Ethiopia. p. 77.

Main CL, Barber LT, Boman RK, Chapma K, Dodds DM, Duncan S, Edmisten KL,

Horn P, Jones MA, Morgan GD, Norton ER, Osborne S, Whitaker JR, Nichols RL, and Bronson KF (2013). Effects of nitrogen and planting seed size on cotton growth, development, and yield. Agron. J. 105:1853-1859.

Morrow MR, Krieg DR (1990). Cotton management strategies for a short growing season environment: water-nitrogen considerations. *Agron. J. 82:52-56*.

Raja Rajan A, Janaki P, Appavu K, Vadivel A (2005). Effect of Fertilizer NPK and
FYM on Yield of Cotton and Nutrient Status in Black Soil. Madras Agric. J. 92
(4-6) 266-270.

Silvertooth JC, Edmisten KL, McCarty WH (1999). Nitrogen management experiments for Upland and Pima cotton. *In*: Silvertooth, J. C.and Norton, E. R. (eds.). Cotton: Origin, History, Technology, and Production. John Willy and Sons. pp. 451-488.

Tadele Gebreselassie (1982). Fertilizer requirement. *In*: Proceedings of the Symposium: Cotton Production under Irrigation in Ethiopia. Institute of Agricultural Research, Addis Ababa, Ethiopia. pp. 91-108.

WARC (Werer Agricultural Research Center) (2006). Progress report, Soils Research Division. Melka Werer, Ethiopia.

WARC (Werer Agricultural Research Center) (2007). Progress report, Agronomy and Physiology Research Division. Melka Werer, Ethiopia.

WARC (Werer Agricultural Research Center) (2008a). Progress report, Soils Research Division. Melka Werer, Ethiopia.

WARC (Werer Agricultural Research Center) (2008b). Progress report, Agronomy and Physiology Research Division. Melka Werer, Ethiopia.

Annexes

Annex 1. Soil Soluble cations and anions of Werer Agricultural Research Center (WARC) and Melka Sedi State Farm (MSSF)

Annex

Location	Soil type	Depth (cm)	SAR	Soluble Cations (meq/l) Na	K	Ca	Mg	sum	Soluble Anions (meq/l) Cl	HCO_3	SO_4	sum
		Profile 1 0-19	4.6	6.5	0.5	2.0	2.0	11.0	7.6	1.8	1.9	11.3
		19-37	4.3	4.8	0.6	6.0	2.0	18.2	15.2	0.9	0.4	16.5
		37-55	5.3	13.9	0.4	12.0	2.0	28.3	19.0	1.8	0.4	21.2
WARC 105/106	Eutric Fluvisol	55-70	6.0	13.4	0.2	8.0	2.0	23.6	15.2	3.6	0.8	19.6
		70-80	5.6	14.8	0.3	8.0	6.0	29.1	17.1	3.6	1.1	21.8
		80-95	5.4	16.3	0.4	12.0	6.0	34.7	20.9	7.2	0.8	28.9
		95-115	5.3	19.0	0.2	22.0	4.0	45.2	22.8	10.8	4.0	37.6
		115-130	7.4	27.7	0.3	26.0	2.0	56.0	34.2	9.9	1.9	46.0
		130-168	6.1	27.4	0.4	26.0	14.0	67.8	36.1	16.2	1.1	53.4
		Profile 2 0-17	3.4	4.3	1.6	56.0	16.0	77.9	98.8	9.0	0.8	108.6
		17-33	2.9	3.8	1.5	58.0	22.0	85.3	100.7	8.1	0.4	109.2
		33-50	3.5	3.3	0.6	40.0	14.0	57.9	79.8	3.6	1.3	84.7
WARC 111/112	Eutric Fluvisol	50-65	3.8	3.2	0.4	28.0	12.0	43.6	41.8	6.3	0.7	48.8
		65-83	4.2	4.1	0.4	26.0	14.0	44.5	55.1	5.4	0.8	61.3
		83-135	4.9	3.7	0.6	28.0	16.0	48.3	49.4	9.0	4.4	62.8
		135-157	4.9	6.5	0.5	28.0	8.0	43.1	47.5	5.4	1.1	54.0
		Profile 3 0-26	1.2	6.5	2.7	57.0	3.0	69.2	4.5	7.2	0.8	112.5
WARC 129/130		26-44	1.0	5.6	1.5	58.0	3.5	68.6	148.2	7.2	1.3	156.7
	Salic Fluvisol	44-64	1.1	6.7	0.7	71.5	6.5	85.4	134.9	7.2	0.4	142.5
		64-88	1.4	7.8	0.9	61.0	5.5	75.2	119.7	8.1	0.4	128.2
		88-110	1.5	8.1	1.2	55.5	5.0	69.8	110.2	11.7	4.8	126.7
		110-135	1.5	8.5	1.3	56.5	9.5	75.8	83.6	8.1	1.3	93.0
		135-158	1.6	8.7	1.3	57.5	5.5	73.0	76.0	7.2	0.8	84.0
WARC 202/203	Eutric Vertisol	**Profile 4** 0-10	4.2	0.2	1.0	0.6	6.0	4.7	4.0	1.0	0.7	5.7
		10-25	3.5	0.2	1.0	0.8	5.5	3.7	2.0	1.0	2.0	5.0
		25-45	3.0	0.1	0.8	0.2	4.1	4.2	2.0	0.2	2.0	4.2
		45-70	3.4	0.1	0.6	0.2	4.3	5.3	2.0	0.2	2.4	4.6
		70-95	2.9	0.2	0.6	0.2	3.9	4.6	2.0	0.1	2.0	4.1
		95-123	3.4	0.1	0.8	0.2	4.5	4.8	4.0	0.5	0.3	4.8
		123-150	3.1	0.3	0.8	0.2	4.4	4.4	2.0	1.0	1.6	4.6
WARC 213	Eutric Fluvisol	**Profile 5** 0-20	2.7	0.3	2.0	0.8	5.8	2.8	2.0	0.6	3.3	5.9
		20-45	2.1	0.4	1.0	0.6	4.1	2.4	2.0	0.6	1.6	4.2
		45-60	2.1	0.2	0.8	0.2	3.3	3.0	2.0	1.0	0.7	3.7
		60-100	2.2	0.2	1.4	0.6	4.4	2.2	2.0	0.8	2.0	4.8
		100-120	2.2	0.2	0.8	0.2	3.4	3.2	2.2	0.2	3.3	5.7
		120-138	2.8	0.1	1.0	0.4	4.3	3.2	2.8	0.5	1.0	4.3
		138-155	2.8	0.1	1.0	0.6	4.5	3.2	3.0	0.6	1.0	4.6
WARC 229/230	Eutric Fluvisol	**Profile 6** 0-25	3.2	0.2	3.0	0.6	7.0	2.4	3.0	0.5	3.8	7.3
		25-46	2.5	0.2	2.0	0.2	4.9	2.4	1.8	0.2	2.9	4.9
		46-78	2.6	0.1	1.0	0.2	3.9	3.3	1.2	0.4	3.8	5.4
		78-95	3.6	0.1	1.0	0.2	4.9	4.6	1.6	0.3	2.9	4.8
		95-160	4.5	0.1	1.6	0.4	6.6	4.5	3.2	0.1	3.3	6.6
		Profile 7 0-20	0.2	0.4	0.1	4.0	1.6	6.1	3.8	1.0	0.8	5.6
		20-47	0.2	0.4	0.1	4.0	1.6	6.1	3.8	1.0	0.6	5.4
		47-65	0.2	0.3	0.1	3.2	0.8	4.4	1.9	1.0	0.2	3.1
		65-90	0.3	0.4	0.0	3.2	0.8	4.4	1.9	1.0	1.4	4.3
		90-123	0.2	0.3	0.1	3.2	0.8	4.4	1.9	1.0	0.6	3.5
		123-152	0.2	0.4	0.0	4.0	2.4	6.8	3.8	2.0	0.8	6.6
		152-180	0.3	0.5	0.0	4.0	1.6	6.1	3.8	1.0	0.2	5.0
		180-225	0.3	0.4	0.0	4.0	1.6	6.0	3.8	1.0	0.8	5.6

Location	Soil type	Depth (Cm)	SAR	Soluble cations (meq/l)					Soluble anions (meq/l)			
				Na	K	Ca	Mg	Sum	Cl	HCO_3	SO_4	Sum
MSSF	Eutric	**Profile 8**										
F3/4/50	Vertisol	0-20	0.2	0.5	0.1	8.0	3.2	11.8	5.7	3.0	0.2	8.9
		20-40	0.2	0.4	0.0	4.0	1.6	6.0	3.8	1.0	0.2	5.0
		40-74	0.3	0.6	0.1	4.0	1.6	6.3	3.8	1.0	0.2	5.0
		74-90	0.3	0.4	0.0	4.0	1.6	6.0	3.8	1.0	0.2	5.0
		90-110	0.6	1.9	0.1	11.2	9.6	22.8	19.0	4.0	0.2	23.2
		110-133	0.7	3.7	0.2	26.4.	28.0	31.9	62.0	5.0	0.2	67.2
		133-165	0.8	4.2	0.4	31.2	24.0	59.8	89.0	6.0	0.8	95.8
		165-200	0.8	3.9	0.3	24.0	25.6	53.8	79.8	5.0	0.9	85.7
MSSF	Salic	**Profile 9**										
F3/2/22	Fluvisol	0-20	0.6	2.7	0.6	24.0	24.0	51.3	115.9	7.0	1.1	124.0
		20-33	1.9	9.2	0.3	24.0	24.0	57.5	96.9	6.0	2.0	104.9
		33-49	1.7	8.1	0.2	24.0	24.0	56.3	87.4	5.0	1.4	93.8
		49-68	2.4	9.6	0.4	16.0	16.0	42.0	114.0	5.0	0.2	119.2
		68-113	1.7	5.9	0.2	14.4	11.2	31.7	95.0	3.0	0.2	98.2
		113-166	1.6	5.9	0.2	15.2	12.0	33.3	98.8	4.0	0.2	103.0
		166-200	0.9	2.5	0.1	8.0	7.2	17.8	26.6	4.0	0.2	30.8
MSSF	Eutric	**Profile 10**										
F1/28/49	Fluvisol	0-16	0.6	0.3	0.1	4.8	3.2	8.4	5.7	2.0	0.2	7.9
		16-44	0.5	0.3	0.2	4.8	1.6	6.9	3.8	2.0	0.2	6.0
		44-65	0.7	0.5	0.1	5.6	4.0	10.2	5.7	3.0	0.2	8.9
		65-87	1.1	1.2	0.1	12.8	7.2	21.3	9.5	4.0	0.4	13.9
MSSF	Eutric	**Profile 11**										
F1/28/49	Fluvisol	0-20	0.2	0.3	0.1	2.4	0.8	3.6	1.9	1.0	0.2	3.1
		20-45	0.2	0.3	0.1	2.4	1.6	4.4	1.9	1.0	0.2	3.1
		45-70	0.2	0.3	0.1	2.4	1.6	4.4	3.8	1.0	1.1	5.9
		70-105	0.2	0.3	0.0	3.2	1.6	5.1	3.8	1.0	0.6	5.4
		105-125	0.3	0.8	0.1	9.6	4.0	14.5	9.5	4.0	0.2	13.7
		125-151	0.5	1.3	0.1	11.2	1.6	14.2	32.3	6.0	0.2	38.5
		151-200	0.6	1.7	0.1	9.6	4.8	16.2	47.5	6.0	0.9	54.4
MSSF	Eutric	**Profile 12**										
2D/8	Fluvisol	0-19	0.2	0.3	0.1	4.0	2.4	6.8	3.8	2.0	0.2	6.0
		19-37	0.1	0.2	0.1	3.2	1.6	5.1	1.9	2.0	0.2	4.1
		37-60	0.1	0.2	0.1	2.4	0.8	3.5	1.9	1.0	0.2	3.1
		60-90	0.2	0.2	0.1	2.4	0.8	3.5	1.9	1.0	0.2	3.1
		90-130	0.1	0.2	0.1	2.4	0.8	3.5	1.9	1.0	0.2	3.1
		130-200	0.1	0.1	0.0	2.4	0.8	3.3	1.9	1.0	0.4	3.3

Annex 2. Soil Chemical Characteristics of Werer Agricultural Research Center (WARC) and Melka Sedi State Farm (MSSF)

Location	Soil type	Depth (cm)	OM %	Nt 0/00	C/N	P ppm	pH Sat.E	CEC	CEC/ Clay	Exchangeable cations meq/100g Na	K	Mg	Ca	sum	Surplus Ca	ESP	ECe (ds/m)
WARC	Eutric	**Profile 1**															
105/106	Fluvisol	0-19	1.4	0.7	11.0	73.0	8.1	37.0	122.0	3.4	2.2	3.0	30.5	39.1	1.9	9.2	1.2
		19-37	1.4	0.6	13.0	75.0	8.0	38.0	125.0	3.4	1.8	2.5	31.5	39.2	1.2	8.8	2.0
		37-55	1.4	0.6	13.0	80.0	7.8	35.0	171.0	3.0	0.8	2.0	31.5	37.3	2.9	8.8	2.9
		55-70	1.3	0.6	13.0	90.0	7.9	39.0	161.0	3.5	1.0	6.5	31.0	42.0	10.9	8.9	2.5
		70-80	1.2	0.6	12.0	50.0	7.8	44.0	145.0	3.3	0.6	5.5	31.5	40.9	9.5	7.5	2.8
		80-95	1.2	0.6	12.0	55.0	7.8	43.0	117.0	3.4	0.8	2.0	33.5	39.7	6.2	8.0	3.6
		95-115	1.2	0.5	13.0	35.0	7.5	41.0	143.0	3.8	0.9	5.0	30.0	39.7	9.7	9.5	4.8
		115-130	1.2	0.5	13.0	58.0	7.5	49.0	116.0	4.4	1.0	2.0	34.0	41.4	7.4	8.9	5.6
		130-168	1.0	0.5	11.0	65.0	7.5	55.0	87.0	4.6	1.2	2.0	29.5	37.3	7.7	8.3	6.9
		168-200	0.9	0.5	11.0	75.0	7.4	56.0	102.0	4.6	1.4	1.0	29.0	36.0	7.0	8.1	8.6
WARC	Eutric	**Profile 2**															
111/112	Fluvisol	0-17	1.4	0.6	13.0	20.0	7.0	40.0	130.0	4.3	1.8	1.5	32.5	40.1	0.1	10.7	13.0
		17-33	1.2	0.5	14.0	10.0	7.1	38.0	123.0	3.8	1.7	2.5	31.0	39.0	0.5	10.1	13.0
		33-50	1.0	0.5	15.0	42.0	7.0	44.0	143.0	3.3	1.0	3.5	32.5	40.3	3.7	7.5	9.6
		50-65	1.0	0.5	12.0	45.0	7.1	37.0	138.0	3.2	0.7	3.0	31.0	37.9	0.8	8.6	7.0
		65-83	1.0	0.5	12.0	52.0	7.3	51.0	133.0	4.1	1.3	4.0	29.5	38.9	12.7	7.9	6.8
		83-135	0.9	0.4	13.0	46.0	7.2	37.0	163.0	3.1	1.0	5.0	32.5	41.6	5.2	10.0	7.7
		135-157	0.8	0.4	13.0	61.0	7.3	53.0	96.0	6.5	1.5	5.0	60.0	73.0	20.0	12.3	7.3
		157-200	0.8	0.4	13.0	45.0	7.5	52.0	145.0	5.9	1.4	4.0	55.0	66.3	14.3	11.4	6.7
WARC	Salic	**Profile 3**															
129/130	Fluvisol	0-26	1.3	0.7	11.0	51.0	7.0	49.0	126.0	6.5	2.7	3.0	57.0	69.2	20.2	13.3	12.0
		26-44	1.2	0.6	12.0	40.0	7.1	51.0	131.0	5.6	1.5	3.5	58.0	68.6	0.1	11.1	17.5
		44-64	1.3	0.5	14.0	44.0	7.1	45.0	155.0	6.7	0.7	6.5	71.0	84.9	40.9	15.1	15.6
		64-88	1.0	0.5	11.0	43.0	7.2	51.0	124.0	7.8	0.9	5.5	61.0	75.2	24.6	15.4	14.3
		88-110	0.9	0.5	10.0	51.0	7.3	53.0	99.0	8.1	1.2	5.0	55.5	69.8	16.6	15.4	13.3
		110-135	0.8	0.5	9.0	50.0	7.2	53.0	96.0	8.5	1.3	9.5	56.5	75.8	19.4	16.2	10.9
		135-158	0.7	0.5	8.0	51.0	7.5	48.0	94.0	8.7	1.3	5.5	57.5	73.0	25.5	18.3	10.1
		158-200	0.7	0.4	11.0	61.0	7.5	51.0	96.0	9.0	1.4	5.0	62.5	77.9	26.9	17.6	10.7
WARC	Eutric	**Profile 4**															
202/203	Vertisol	0-10	1.3	0.7	11.0	59.0	8.4	41.0	80.0	4.6	2.2	3.3	52.5	62.6	10.0	11.3	0.6
		25-Oct	1.4	0.6	13.0	54.0	8.4	47.0	85.0	5.5	1.8	3.5	49.5	60.3	10.8	11.8	0.6
		25-45	1.1	0.5	13.0	59.0	8.5	49.0	87.0	5.3	1.7	2.5	53.0	62.5	9.6	10.9	0.5
		45-70	1.1	0.5	13.0	53.0	8.5	45.0	76.0	4.9	1.6	2.0	55.0	63.5	8.5	10.9	0.5
		70-95	1.1	0.5	13.0	64.0	8.3	53.0	90.0	5.3	1.8	5.0	51.0	63.1	12.1	10.1	0.4
		95-123	1.2	0.4	15.0	61.0	8.3	53.0	94.0	5.0	1.7	2.0	50.0	58.7	8.7	9.5	0.5
		123-150	1.0	0.3	18.0	58.0	8.3	43.0	152.0	4.4	1.6	2.5	43.5	52.0	8.6	10.3	0.5
		150-200	1.0	0.3	18.0	66.0	8.3	46.0	113.0	4.6	1.7	2.0	55.0	63.3	8.3	10.0	0.4
WARC	Eutric	**Profile 5**															
213	Fluviso	0-20	1.8	0.8	13.0	60.0	8.4	42.0	84.0	5.3	2.4	3.5	48.0	59.2	11.3	11.3	0.6
		20-45	1.7	0.8	12.0	65.0	8.5	47.0	86.0	5.1	2.4	3.5	48.0	59.0	12.0	10.7	0.4
		45-60	1.7	0.7	14.0	63.0	8.3	48.0	88.0	5.3	2.2	3.0	59.0	69.5	21.5	11.1	0.4
		60-100	1.4	0.6	13.0	60.0	8.2	40.0	132.0	4.4	2.2	8.5	66.0	81.1	41.1	11.0	0.5
		100-120	1.3	0.6	13.0	60.0	8.2	41.0	182.0	4.0	1.6	5.0	87.5	98.1	57.6	9.8	0.4
		120-138	1.2	0.5	13.0	63.0	8.3	43.0	193.0	4.4	1.4	3.0	80.0	88.8	45.9	10.3	0.4
		138-155	1.1	0.5	13.0	57.0	8.3	41.0	184.0	4.1	1.7	3.0	70.0	78.8	37.8	10.0	0.5
		155-180	1.0	0.5	12.0	63.0	8.3	53.0	114.0	4.6	1.7	4.0	56.5	66.8	13.8	8.6	0.5
WARC	Eutric	**Profile 6**															
229/230	Fluvisol	0-25	1.4	0.6	13.0	58.0	8.2	53.0	113.0	5.3	2.2	2.5	55.0	65.0	7.5	10.1	0.7
		25-46	1.4	0.7	12.0	60.0	8.3	51.0	120.0	5.5	2.2	3.0	55.0	65.7	6.1	10.7	0.5
		46-78	1.2	0.5	14.0	55.0	8.4	52.0	117.0	4.6	1.6	2.0	51.0	59.2	8.2	8.8	0.4
		78-95	1.1	0.4	15.0	64.0	8.5	50.0	108.0	5.3	1.4	3.0	45.0	54.7	9.8	10.6	0.5
		95-160	1.0	0.4	15.0	53.0	8.4	51.0	120.0	6.2	1.7	3.5	51.5	62.9	12.0	12.2	0.7
		160-195	1.0	0.4	14.0	63.0	8.1	51.0	125.0	7.2	1.7	4.5	62.0	75.4	24.9	14.2	1.4

Annex 2. Continued

										Exchangeable cations meq/100g					Surplus		
Location	**Soil type**	**Depth (cm)**	**OM %**	**Nt 0/00**	**C/N**	**P ppm**	**pH Sat.E**	**CEC**	**CEC/ Clay**	**Na**	**K**	**Mg**	**Ca**	**sum**	**Ca**	**ESP**	**Ece (ds/m)**
MSSF	Eutric	**Profile 7**															
F3/3/35	Fluvisol	0-20	1.1	0.8	8.0	25.0	8.4	48.0	89.0	5.9	3.7	3.2	53.1	65.9	18.3	12.4	0.6
		20-47	1.2	0.8	8.0	36.0	8.4	48.0	86.0	6.2	3.5	6.8	54.0	70.5	22.4	12.9	0.6
		47-65	0.9	0.5	10.0	22.0	8.3	45.0	104.0	4.7	2.8	2.5	85.5	95.5	50.5	10.5	0.5
		65-90	0.6	0.7	5.0	23.0	8.3	51.0	85.0	5.9	3.1	3.2	83.3	95.5	44.3	11.7	0.5
		90-123	0.5	0.3	9.0	22.0	8.3	44.0	106.0	7.4	2.5	4.1	86.4	100.4	55.4	16.9	0.5
		123-152	0.2	0.2	7.0	21.0	8.1	31.0	178.0	2.7	1.4	4.1	72.0	80.2	49.7	8.9	0.8
		152-180	0.3	0.3	5.0	21.0	8.4	44.0	110.0	5.3	1.0	4.1	97.2	107.6	64.1	12.2	0.7
		180-225	0.4	0.4	6.0	20.0	8.5	44.0	96.0	5.6	0.9	4.5	99.0	110.0	66.5	12.9	0.6
MSSF	Eutric	**Profile 8**															
F3/4/50	Vertisol	0-20	0.8	0.6	8.0	27.0	8.5	63.0	87.0	5.5	2.7	5.4	62.5	76.1	10.0	8.7	1.2
		20-40	0.6	0.8	5.0	22.0	8.4	63.0	80.0	5.8	2.6	3.6	62.5	74.5	7.6	9.2	0.7
		40-74	0.7	0.4	10.0	24.0	8.3	64.0	77.0	6.7	2.5	3.2	63.5	75.9	9.1	10.5	0.6
		74-90	0.3	0.5	3.0	22.0	8.4	56.0	68.0	6.7	2.2	3.2	56.0	68.1	12.3	11.9	0.7
		90-110	0.3	0.4	5.0	26.0	8.1	64.0	817.0	6.5	2.1	4.1	64.0	76.7	3.1	10.2	3.1
		110-133	0.4	0.5	5.0	25.0	7.6	59.0	81.0	8.1	2.0	3.6	58.5	72.2	14.7	13.9	13.2
		133-165	0.3	0.2	10.0	22.0	7.8	36.0	132.0	5.9	1.3	3.6	36.0	46.8	45.9	16.4	14.1
		165-200	0.4	0.2	12.0	20.0	7.7	38.0	251.0	5.0	1.0	3.5	38.0	47.5	39.0	13.2	12.5
MSSF	Salic	**Profile 9**															
F3/2/22	Fluvisol	0-20	1.0	0.6	10.0	23.0	8.1	34.0	62.0	13.0	3.2	3.5	73.5	93.2	59.2	38.3	26.0
		20-33	1.2	0.4	18.0	22.0	8.0	42.0	101.0	12.7	2.0	3.2	94.5	112.4	70.4	30.3	17.8
		33-49	0.7	0.3	15.0	17.0	7.9	36.0	143.0	10.6	1.2	3.1	80.1	95.0	58.9	29.6	14.4
		49-68	0.7	0.3	15.0	20.0	7.8	37.0	125.0	10.1	0.9	2.8	91.5	105.3	69.1	27.5	18.5
		68-113	0.5	0.2	15.0	17.0	7.9	28.0	146.0	7.1	1.0	3.2	38.5	49.8	21.5	25.3	13.8
		113-166	0.4	0.1	15.0	20.0	7.8	27.0	157.0	5.8	0.8	4.5	34.2	45.3	18.3	21.6	15.1
		166-200	0.4	0.1	17.0	18.0	7.9	18.0	162.0	4.0	0.6	1.4	29.3	35.3	17.2	22.0	3.8
MSSF	Salic	**Profile 10**															
F3/2/22 l	Fluvisol	0-16	3.8	2.1	10.0	38.0	8.7	53.0	106.0	5.2	4.2	2.7	54.9	67.0	14.5	9.9	1.0
		16-44	2.4	1.0	14.0	28.0	8.5	46.0	85.0	4.4	2.7	3.6	54.0	64.7	19.1	9.9	0.7
		44-65	3.1	1.7	11.0	24.0	8.4	50.0	105.0	4.8	2.1	1.8	54.0	62.7	12.7	9.6	1.1
		65-87	3.4	1.2	17.0	24.0	8.4	51.0	102.0	4.4	2.4	1.8	44.5	53.1	2.6	8.7	2.9
MSSF	Eutric	**Profile 11**															
F1/1/1	Fluvisol	0-20	0.8	0.7	7.0	20.0	8.6	57.0	88.0	5.0	2.6	1.4	49.1	58.1	1.0	8.8	0.5
		20-45	0.7	0.7	6.0	22.0	8.5	56.0	84.0	4.4	2.3	3.2	48.6	58.5	3.0	7.9	0.5
		45-70	0.5	0.6	5.0	20.0	8.4	53.0	85.0	4.3	2.0	7.2	51.8	65.3	12.8	8.2	0.5
		70-105	0.3	0.6	3.0	20.0	8.4	48.0	72.0	4.6	1.9	8.1	51.8	66.4	18.8	9.7	0.6
		105-125	0.3	0.7	5.0	19.0	8.2	53.0	83.0	5.2	1.7	7.2	54.0	68.1	15.2	9.8	1.6
		125-151	0.3	0.7	2.0	23.0	8.0	51.0	87.0	5.6	1.6	7.7	51.8	66.7	15.7	11.0	4.6
		151-200	0.2	0.6	2.0	27.0	7.9	51.0	97.0	5.8	1.6	4.5	52.2	64.1	13.1	11.5	6.6
MSSF	Eutric	**Profile 12**															
2D/8	Fluvisol	0-19	1.5	0.7	12.0	24.0	8.6	77.0	181.0	4.6	3.2	1.8	52.2	61.8	15.2	6.0	0.8
		19-37	1.2	0.6	11.0	22.0	8.6	57.0	135.0	4.2	2.7	2.7	50.9	60.5	4.4	7.3	0.6
		37-60	1.6	0.6	15.0	22.0	8.4	45.0	124.0	4.0	2.1	4.5	47.3	57.9	12.8	8.8	0.5
		60-90	1.4	0.5	16.0	21.0	8.3	49.0	186.0	3.3	1.3	2.3	17.7	24.6	5.6	6.8	0.5
		90-130	1.3	0.4	19.0	22.0	8.2	45.0	186.0	2.9	1.4	4.1	46.4	54.8	9.7	6.5	0.5
		130-200	1.1	0.3	20.0	21.0	8.2	41.0	107.0	3.5	1.3	2.3	45.0	52.1	11.1	8.6	0.4