academicJournals

Vol.8(1), pp. 1-9, January, 2018
DOI: 10.5897/ISABB-JFAS2016.0058
Article Number: 4FBCB8755799
ISSN 1937-3244

http://www.academicjournals.org/ISAB-JFAS

ISABB Journal Of Food And Agriculture Science

Full Length Research Paper

Striga infestation and its interaction to density of sorghum, basic chemical and physical properties of the soil across Tigray Region, Northern Ethiopia

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Received 26 December, 2016; Accepted 16 February, 2017

In Ethiopia, sorghum is the major crop next to teff grown all over the country. Though the productivity of sorghum has increased in the last few years, the overall national productivity of sorghum is low (2.106 t/ha) compared to the average production of 2.3 t/ha of developed countries. The low productivity of sorghum is attributed mainly to infestation by *Striga.* The annual yield loss and geographic distribution of *Striga* infestation in Sub-Saharan Africa is steadily increasing. The region is mainly characterized by poor soil fertility and structure, lower distribution and intensity of rain fall. The average yield loss of sorghum due to *striga* exceeds 50% and in severe cases complete cop failure can occur forcing farmers to abandon cereal production. A survey was conducted in 2014 to determine the interaction of *Striga hermonthica* infestation with basic chemical and physical properties of the soil and to assess the association of *Striga* infestation and population density of sorghum in relation to Tigray region. There was a strong association between the average *Striga* count and population density of sorghum per unit area of land. Similarly, strong association was observed between *Striga* infestation and soil pH, available phosphorous, percent organic matter, total nitrogen and soil texture. The influence of soil organic matter on level of *Striga* infestation was observed superior to other soil chemical and physical properties. The highest level of *Striga* infestation was recorded at kebeles which had got the highest population density of sorghum, low soil organic matter and available phosphorous and sandy textured soils. Therefore maintaining optimum population of sorghum and improving the fertility status of the soil have been suggested for controlling of *S. hermonthica* in the region.

Key words: Correlation, *Striga* infestation, sorghum planting density, soil properties, Tigray region.

INTRODUCTION

Sorghum is dominant crop in Tigray (Northern Ethiopia). The average annual coverage of sorghum in the region is 255,000 ha (Shapiro and Wortmann, 2006). However the overall productivity is low (2.106 t ha^{-1}) compared to average production of developed countries (2.3 t ha^{-1}) (CSA, 2013). The low productivity of sorghum is partly attributed to infestation of parasitic weed mainly *Striga hermonthica* (Del.) Benth (Gebreyesus Brhane et al., 2011).

The genus *Striga* comprises about 50 to 60 species (Taye, 2013). Among these purple witch weed (*S. hermonthica* (Del.) Benth.) and Asiatic witch weed (*Striga asiatica* (L) Kuntze) are the most economically important to production of sorghum in the world. Likewise *S. hermonthica* is the most damaging parasitic weed in the study area. *Striga* infestation is related with population density of sorghum, low soil fertility and moisture status of the soil. Any action directed to management of density of sorghum and soil leads to a reduction of the weed. The emergence of *striga* is positively associated with the extensive root system of sorghum (Esilaba et al., 2000).

The level of *striga* infestation is strongly correlated with decline of soil fertility (Samaké et al., 2005; Parker**,** 2008). According to Ayongwa (2011) *Striga* control or management does not have impact on cereal yield if soil fertility management is neglected. The author also observed that a good supply of nitrogen to the soils leads to a reduction of *Striga* germination. Different types of nitrogen fertilization suppress *Striga* either by inhibition or stimulation of *striga* germination. Direct application of phosphorous decreases the exudation of strigolactone and therefore reduces *Striga* germination and also infestation of the weed (Cardoso et al., 2010).

The increasing application of important source of soil organic matter such as farm yard manures (FYM) reduces germination and survival rates of *striga* (Ayongwa, 2011). As the amount of soil organic matter increases *striga* infestation declines significantly. The local availability of organic manures promotes the use of both fertilizers so as to improve, not only soil properties, but also to increase crop yields and reduce the occurrence of *striga*. It has been reported that higher benefits are obtained by overall improvement of the soil physical, chemical and biological properties through recycling of organic materials, and increase in the availability of plant nutrients (Sanginga and Woomer, 2009).

Striga seed bank is significantly associated with soil pH. The optimal soil pH for good fertility of the soil is about 6.0 to 6.8 (Eriksson et al., 2005). No wonder that the highest amount of *Striga* seeds was also registered at pH range 6.2 to 6.3. This could imply that *Striga* prefers the same pH as considered to be optimal for having good soil fertility , that is, when most necessarily plant nutrients are available (Larsson, 2012).

The association of *Striga* infestation with soil texture is the function of moisture retention, nutrient holding capacity of the soil and rate of organic matter decomposition. The process of organic matter and nitrogen decomposition is significantly higher in sandy textured soils (Hassink et al., 1993). Soil texture indirectly affects *Striga* infestation through physical restrictions on activity of microorganisms that determine the process of mineralization of organic matter and total soil nitrogen (van and Kuikman, 1990).

The annual yield loss and geographic distribution of *S. hermonthica* is steadily increasing, particularly in Sub-Saharan Africa. Most of the available research findings show that the average yield loss of sorghum due to *Striga* exceeds 50% and in severe cases complete crop failure can occur (Abunyewa and Padi, 2003).

S. hermonthica is a major biotic constraint to production of sorghum in Tigray region. In addition the region is characterized by poor distribution and intensity of rain fall, poor fertility and structure of the soil (Tewodros et al., 2009). However, little or no research reports are available that indicate association of the weed with soil physical, chemical properties and population density of sorghum in the study areas. Therefore this study has been designed to assess the association of *S. hermonthica* infestation with density of sorghum, and basic chemical and physical properties of the soil.

MATERIALS AND METHODS

The research survey was conducted in 2014 in Tigray regional state located in the northern part of Ethiopia. Geographically, the region lies between 12º15'N and 14º57'N latitudes and 36º27'E and 39º59'E longitudes. It is bordered in the north by Eritrea, in the south by Amhara Region, in the East by Afar and in the west by Sudan (Ayenew Admasu et al., 2011) (Figure 1).

A total of six administrative zones and 12 main sorghum growing districts (administrative unit within zone) were selected across Tigray regional state in consultation with Tigray Bureau of Agriculture and Rural Development experts. Two woredas and Kebeles (smallest administrative unit within district) were selected purposively from each zone and woredas respectively. Thus, a total of five sorghum growing fields were selected from each kebele using systematic random sampling method. An initial visit or informal survey was made before the commencement of the actual /formal research survey (ILCA, 1990).

A total of 120 sampling fields were included in sampling of *S. hermonthica* throughout the study area. Accordingly field history like field management practices, preceding crops, and the type of variety that farmers grow was assessed by interviewing famers. Based on report of the field history the actual survey was conducted in fields sown by local cultivars of sorghum for at least three years and fields with no *striga* management practices for the last few years.

The actual survey was conducted when *S. hermonthica* was to an extent of full growth stage (flowering and maturity stage), that is, mid-September to the end of October 2014. Sampling was made following community made gravel or asphalt roads. Road transect survey method was employed for sampling of *striga* and sorghum between farms within Kebele (Wittenberg et al., 2004). Hence, two inverted 'M' patterned 50 m long transects, on average of one kilometer apart were established by systematic random sampling method. Finally, 10 evenly spaced sampling points per field (1

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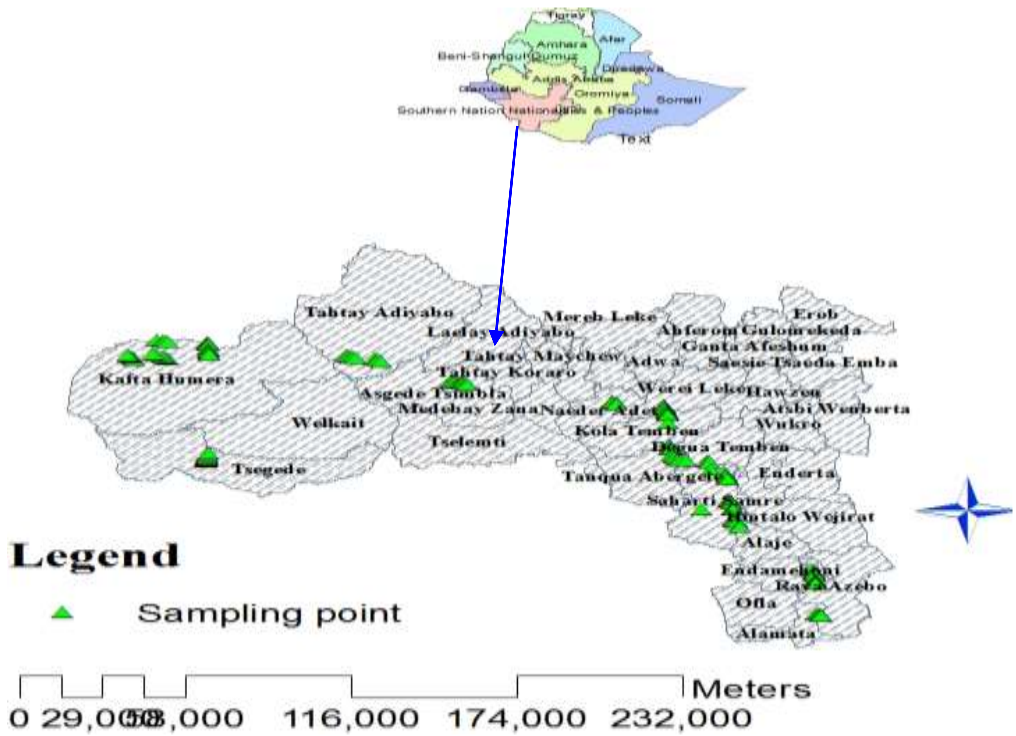

Figure 1. Map of the study area with survey.

square meter each) were established. Accordingly a total of 1200 sampling points from 120 sampling areas were delineated and finally *Striga* and sorghum count was made.

Soil sampling was done manually using an auger at a depth of 15 cm. Five sub samples were prepared from a total of 50 sampling points and 5 sorghum growing farms at each Kebelie. The sub samples were thoroughly mixed to have a representative composite sample of the fields of the study. Eventually 24 composite samples were prepared from a total of 24 Kebeles. Finally, the samples were air-dried, crushed and analyzed based on standard laboratory procedures for determination of soil reaction (pH), organic matter content, total nitrogen, available phosphorous and texture (Kettler et al., 2001)

The mean *Striga* and sorghum count per total sampling points (10 m^2) per sampled field was summarized, prevalence of *Striga* and sorghum per kebele was determined on average bases (Appendix 1 and 2). The interaction of *Striga* infestation with population density of sorghum, basic chemical and physical properties of the soil in the region was analyzed using SPSS version 20 software.

RESULTS AND DISCUSSION

Soil analysis

Soil samples were sent to Mekelle soil laboratory center and there subjected to analysis of basic chemical and physical constituents of the soil. Eventually, the laboratory results were summarized based on the laboratory guidelines of Mekelle soil laboratory center. The basic chemical and physical constituents of the soil in almost all locations were poor. Besides, considerable farms of the study site were found low and very low in their constituent of soil organic matter. Conversely, the organic matter content of Genetie and some other kebeles become in medium to high range (Table 1).

Association of *Striga* infestation and population density of sorghum

The correlation analysis result (Table 2) showed strong association between *Striga* infestation and the population density of sorghum. The level of *Striga* infestation was significantly and positively correlated ($r\ (118) = 0.537$, $P< 0.05$) with population density of sorghum. Esilaba et al. (2000) also found that, the emergence of *Striga* is positively associated with the extensive roots systems of sorghum and such a phenomenon is usually observed if an area of land accommodates higher population of sorghum. If density of sorghum per m^2 increases beyond the required level, the plants tend to compete for resources which fall below the combined demand of the population. Sorghum responds to deficiency of nutrient and other stress through the release of chemical signals or germination stimulant hormones (strigolactone) to the rhizosphere. Consequently the chemical signal provides germination stimulant for initiation of germination and subsequent growth of *Striga* and enhances arbisicular mycorrhizal symbiotic association of the roots of sorghum (Gomez et al., 2008).

Table 1. The laboratory analysis result on basic chemical and physical properties of the soils of the study areas.

Woreda	kebele	Chemical properties				physical properties			
		pH	% Organic matter	% Total Nitrogen	Available P_2O_5 (ppm)	%Sand	%Silt	%Clay	Textural class
S/Samre	N/Hadinet	7.16	0.89	0.08	6.34	61	15	24	Sandy clay loam
	Hadas Lemlem	6.33	0.90	0.04	2.8	61	9	30	Sandy clay loam
T/Abergelle	Hadinet	6.42	0.58	0.04	2.12	73	1	26	Sandy clay loam
	Giera	7.33	0.90	0.11	2.8	61	15	24	Sandy clay loam
K/Tembien	Mitsa Werki	6.08	1.23	0.11	3.16	51	27	22	Sandy clay loam
	Dabano	7.53	0.79	0.05	3.02	57	21	22	Sandy clay loam
W/Tsegedie	Selam	6.41	0.99	0.05	1.88	47	27	26	Sandy clay loam
	Z/Dansha	6.36	1.01	0.05	2.04	41	37	22	Loam
K/Humera	Adabay	7.87	1.03	0.05	1.82	17	19	64	clay
	Rawyan	7.49	2.61	0.04	3.62	29	13	58	clay
T/Adyabo	Adiaser	6.01	1.90	0.05	2.94	47	31	22	Loam
	Mentebteb	7.09	2.40	0.06	2.42	11	13	76	clay
A/Tsimbilla	E-Hibret	6.02	1.02	0.05	1.88	59	17	24	Sandy clay loam
	May Shek	5.58	2.08	0.05	2.12	59	21	20	Sandy Loam
Hawzien	May Gobo	6.79	1.84	0.04	2.18	21	9	70	clay
	Koraro	6.73	2.04	0.06	1.74	51	17	32	Sandy clay loam
G/Afoshum	Simret	6.52	1.96	0.10	3.4	63	15	22	Sandy clay loam
	Wuhdet	6.53	2.05	0.04	4	67	15	18	Sandy Loam
Raya Azebo	Genetie	7.41	4.20	0.04	7.84	15	29	56	clay
	K/Adishabo	7.21	3.06	0.12	8.16	27	31	42	clay
G/Raya Alemata	Gergellie	7.47	3.32	0.14	8.52	27	31	42	clay
	K/Lemlem	7.31	1.45	0.07	7.62	61	11	28	Sandy clay loam
Hintallo Wajirat	Tsehafti	7.12	2.06	0.07	3.54	59	19	22	Sandy clay loam
	Adi Keyh	7.82	2.26	0.09	12.08	45	25	30	Sandy clay loam

Table 2. Association of *Striga* infestation with sorghum population per plot.

	Sorghum per m^2	Mean	Std. D
Striga per m^2	0.0537**	189.94	106.47
sorghum per m^2	-	15.87	6.67

*= Correlation is significant at the 0.05 level (2-tailed); **=Correlation is significant at the 0.01 level (2-tailed); List wise N = 24.

Table 3. Correlation of *Striga* infestation with major soil chemical properties.

Parameter	pH	% OM	% TN_2	Ava.P_2O_5	Mean	Std. deviation
Average *Striga* per m^2	-0.213*	-0.917**	-0.097	-0.408**	18.592	11.426
pH	-	0.247**	0.192*	0.522**	6.858	0.617
% OM	-	-	0.124	0.439**	1.774	0.894
% TN_2	-	-	-	0.385**	0.067	0.029
Ava.P_2O_5	-	-	-	-	4.125	2.770

*=Correlation is significant at the 0.05 level (2-tailed) **= Correlation is significant at the 0.01 level (2-tailed). c. List wise N = 24l; pH= a measure of soil reaction, %OM = percent of organic matter, %; TN_2 = Percent of total nitrogen; Ava.P_2O_5 = Available phosphorous in parts per million.

Association of *Striga* infestation with basic chemical properties of the soil

The correlation of soil reaction (pH) and mean number of *Striga* count revealed that soil pH was strongly and negatively correlated ($r(22)=-0.213$, $P<0.05$) to *Striga* infestation. Accordingly as soil pH increases the average level of *Striga* infestation significantly decreases. The soil laboratory analysis result (Table 1) revealed that the value of soil pH recorded at Hadinet was slightly acidic (6.42) whereas moderately alkaline (7.41) at Genetie. This suggests the highest level of *Striga* infestation prefers the same pH considered to be optimal for most crop growths. Larsson (2012) also stated that, the highest level of *Striga* seeds was observed at soil pH of 6.2 to 6.3 which is considered optimal condition for good soil fertility.

The results of the survey showed that the level of *Striga* infestation was highly associated (r (22) $=-0.917$, $P<0.05$) with soil organic matter content (Table 3). Variation in *Striga* infestation can be attributed to the high (84%) percent of soil organic matter, soil pH (4.5%) and available soil phosphorous (16.65%) respectively. This illustrated the influence of organic matter on *Striga* infestation surpasses over the rest stated factors. Farms which had relatively higher soil organic matter content had lower level of *Striga* infestation. The soil laboratory analysis result (Table 1) indicated that the amount of organic matter content recorded at Genetie, Gergellie and Kara Adishabo was 4.2, 3.32 and 3.06%, respectively. The lowest level of *Striga* infestation was also observed in these kebeles. This is in agreement with the findings of Eriksson et al. (2005) and Ayongwa (2011) who stated that the incidence and survival rate of *Striga* reduces as the amount of soil organic matter increased.

According to the guide line of Cohen (1988), the association of total soil nitrogen and the level of *Striga* infestation was weak (r (22) $=-0.097$, $P>0.05$), may be because the correlation was made based on the association of *Striga* infestation and total soil nitrogen, which does not indicate its uptake. Cogger et al. (2002) also reported that, knowing the total amount of nitrogen does not indicate how much will become available for crop uptake during the growing season. Ayongwa (2011) argues that, a good supply of nitrogen to soil leads to a reduction of *Striga* germination. Camberato (2001) also, revealed that soil nitrogen (N) exists in two major forms, that is, organic and inorganic form. More than 90% of soil nitrogen is in the form of organic, which is not readily available to crop growth.

The correlation analysis results (Table 3) revealed that *Striga* infestation was negatively correlated ($r(22)=-0.408$, $P<0.05$) to available phosphorous. As illustrated in Table 1 available phosphorous were scarce in almost all studied areas compared to the required optimum amount (15 to 25 ppm). The highest level of *Striga* infestation was a possibility due to the presence of low available phosphorous in most kebeles. Cardoso et al. (2010) also noted that the direct application of phosphate decreases the exudation of strigolactone, thus germination and subsequent establishment of *S. hermonthica*.

Strong association were observed between soil pH and available soil phosphorous ($P<0.05$). However, when the pH exceed 7.5, calcium can tie up phosphorus, making phosphorous less available to plants. Besides, soil pH was strongly associated ($P<0.05$) with percent of soil

Table 4. Correlation of *Striga* infestation with soil texture in Tigray Region

	Percent of sand	Percent of silt	Percent of clay	Mean	Std. Deviation
Average *Striga* per m^2	0.532**	-0.302	-0.329	189.9367	106.469
Percent of sand	-	-0.437*	-0.667**	46.25	18.329
Percent of silt	-	-	-0.221	19.50	8.733
Percent of clay	-	-	-	34.25	17.399

*=Correlation is significant at the 0.05 level (2-tailed) **=Correlation is significant at the 0.01 level N = 24

organic matter. Similarly, soil pH was positively associated with percent of total soil nitrogen (P<0.05). However, the strength of the association was found weak compared to the association of pH with available soil phosphorous and percent of soil organic matter (Table 3).

Soil organic fertilizers enhance basic chemical and physical properties of soil compared to inorganic fertilizers. The result revealed that soil organic matter has small effect on total nitrogen may be because 95% of nitrogen found in the form of organic as organic matter. However, its effect was not significant (r(22) = 0.124 P>0.05) compared to the effect on available phosphorous and soil pH.

Soil organic matter associates with the relative proportion of soil particles (sand, silt and clay). The application of different types of organic manures enhance available soil phosphorous, total soil nitrogen, exchangeable potassium and cation exchange capacity (CEC) better than synthetic fertilizer in all type of soils (Whitbread, 1995; Bayu Wondimu et al., 2006; Adeniyan et al., 2011). Similarly soil organic matter improves soil structure and texture, thus improved moisture retention capacity of the soil. Overall organic matter is better at enhancing basic chemical and physical properties of the soil compared to inorganic fertilizers.

Association of *Striga* infestation with soil type

The level of *Striga* infestation was strongly associated with moisture holding capacity and nutrient retention capacity of the soil. As presented in Table 4 *Striga* infestation was significantly influenced by the relative proportion of sand in the soil (r (22)=0.532, P<0.05). In contrast, there was no significance association between the level of *Striga* infestation and the relative proportion of silt and clay particles in the soil.

Clay soil has higher moisture retention capacity and higher content of organic carbon. This was demonstrated by Vogt et al. (1991) that, severe *Striga* infestation was strongly correlated not only with low soil fertility but also with poor moisture content of the soil. The relative proportion of soil particles was also significantly associated among the textural class of soil separates (sand, silt and clay). The correlation result revealed that there was strong association between the relative proportion of silt, clay and sand.

Conclusion

Appropriate planting density of sorghum cultivars/or varieties is likely to reduce the level of *Striga* infestation in Tigray region (Northern Ethiopia). The level of *Striga* infestation is significantly affected by soil pH, organic matter content and available phosphorus. The highest level of *Striga* infestation most likely occurs at pH level suitable for availability of most plant nutrients (6.0-6.3). Similarly, the presence of optimum amount of phosphorous and organic matter content in the soil will result in reduction of *S. hermonthica* infestation. The influence of soil organic matter on *Striga* infestation was much more important compared to the influence of pH and available soil phosphorous.

However there is no indication that total nitrogen will result in reduction of *S. hermonthica* infestation. But other research findings suggest that *Striga* can be controlled using proper amount of source of nitrogen. The level of *Striga* infestation is significantly determined by the type of soil in which sorghum is growing. Therefore sandy type of soil significantly increases *S. hermonthica* infestation. However, there is no indication that *Striga* infestation is affected with clay and silt dominated soils.

The correlation analysis result of *Striga* infestation to population density of sorghum, chemical and physical properties of the soil suggested that any action directed towards appropriate use of organic matter source, available phosphorous and keeping the proper planting density of sorghum during planting result in reduction of *Striga* infestation. An interaction between *Striga* infestation and population density of sorghum, basic chemical and physical properties of the soil had been observed. However the degree of their relationship is not yet determined. With this, further studies should be required to determine the degree of the relationship among these variables. The present study was specific to sites close to road sides. Therefore, further studies should be needed to assess wider area of the region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Appendix 1. Mean striga count (No m^{-2}) at each study site (N=120).

Locations (Kebeles)	N	Mean striga count (Nº m^{-2})	Mean Rank
Nebar Hadinet	5	351	3
H/ Lemlem	5	278	5
Hadinet	5	400	1
Giera	5	299	4
M/Werki	5	219	10
Dabano	5	391	2
Selam	5	268	6
Z/Dansha	5	261	7
Adabay	5	221	9
Rawyan	5	81	21
Adiaser	5	155	13
Mentebteb	5	82	20
E-Hibret	5	252	8
May Shek	5	110	18
Mygobo	5	191	12
Koraro	5	145	15
Simret	5	152	14
Wuhdet	5	134	16
Genetie	5	33	24
K/Adishabo	5	59	22
Gergellie	5	54	23
K/ Lemlem	5	209	11
Tsehafti	5	129	17
Adi Keyh	5	85	19
Total	120	190	

Appendix 2. Mean density of sorghum (Nº m^{-2}) in different locations of Tigray Region (N=120).

Locations (Kebeles)	N	Mean sorghum stand count per m^{2}(Nº m^{-2})	Mean rank
Nebar Hadinet	5	14	14
Hadas Lemlem	5	24.6	3
Hadinet	5	26	2
Giera	5	19.2	6
M/Werki	5	35.6	1
Dabano	5	23.6	4
Selam	5	15.4	12
Z/Dansha	5	10.8	20
Adabay	5	18.2	7
Rawyan	5	16	10
Adiaser	5	15.6	11
Mentebteb	5	19.2	5
E-Hibret	5	17.2	9
May Shek	5	17.8	8
Mygobo	5	13.6	15
Koraro	5	13.6	17
Simret	5	14	13
Wuhdet	5	13.6	16
Genetie	5	8.8	21.5

Appendix 2. Contd.

K/Adishabo	5	8.8	21.5
Gergellie	5	7.2	23
K/Lemlem	5	6	24
Tsehafti	5	11.2	18
Adi Keyh	5	11	19
Total	120	15.875	14