# Integrated fodder and grain crops production on upland black clay soils (*Vertisols*)

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## Abstract

In Ethiopia, livestock productivity is highly constrained mainly by feed shortage. The objectives of this experiment were to assess the possibility of sequential cropping of annual fodder legumes with chickpea under rain fed conditions on black clay soil (*Vertisol*) and explore the effect of these crops on grain yield of a succeeding cereal crop. The experiment was conducted on a heavy soil (cracking type clay, *Vertisol*) at two locations: Debre Zeit 1800 m altitude (9° N and 39° E, 45 km SE of Addis Ababa) and Akaki, 2200 m. (8° 45' N and 39° E, 15 km SE of Addis Ababa). The experiment consisted of a rotation involving three phases: fodder (*Phase I*) (four annual legumes), pulse (*Phase II*) (chickpea) and cereal (*Phase III*) (durum wheat). The fodder and chickpea were grown sequentially over the main rainy season while wheat was grown in the following year. A split-plot in RCBD was used; the fodder and chickpea crops as the sub-plot treatments and four application rates of fertilizer N on wheat in the second year as the main-plot treatments. The result of the experiment over the three cycles showed most fodder species to have produced high quality fodder with dry matter yield of 2-5 t $ha^{-1}$. Chickpea, grown as double crop gave an average grain yield of 8-20 $qha^{-1}$. The precursor legume crops increased wheat grain yield over that obtained from plots that had been fallow in the preceding phase. This positive effect on wheat grain yield was not consistent over years and locations; nonetheless, the general trend indicated that wheat yield had been enhanced due to incorporation of fodder and grain legumes in the rotation. Overall, the study indicated that sequential cropping of annual fodder species and chickpea under rain-fed conditions on *Vertisols* as being technically feasible system with considerable promise to alleviate feed shortage at the smallholder farmer level. Moreover, the technology is deemed to offer an additional advantage of more efficient utilization of black clay soils in the medium and high-altitude highlands of Ethiopia.

**Keywords:** *annual fodder legumes; chickpea; sequential crop;Vertisols; wheat*

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## Introduction

In Ethiopia, livestock, especially cattle play a pivotal role in the predominantly crop-livestock mixed farming system of the highlands, by providing food, cash income, and most importantly, farm power. However, the productivity of livestock has remained very low due to various factors, the most important one being feed shortage both in quantity and quality. Most of the available feed comes from crop residues and the natural pasture from marginal areas. Improved pasture production is almost inexistent at subsistent farm level mainly because farmers have very limited capacity to allocate labor, finance and, above all, arable land, a scarce resource, for pasture production. Livestock productivity can be improved if animal population is kept commensurate with the available feed resource. This balance can be realized only if the existing backward traditional livestock production system is transformed into a market-oriented and specialized form of production based on improved genetic makeup of animals.

In the short term, an alternative strategy to avert the feed crisis is deemed to be through introducing improved pasture technologies that integrate fodder crops with food crops in various techniques. A possible entry point has been identified by observing the traditional cropping cycle on black clay soils where it was deemed technically possible to introduce fodder crops in the traditional crop sequences in a way that does not detrimentally affect the yield of food crops. This technique, known as sequential cropping, is a shorter version of crop rotations based on three different crop categories- fodder, pulse and cereal.

The traditional cropping cycle in most Ethiopian highlands generally involves two seasons under cereal followed by a pulse phase (e.g., tef-wheat-chickpea). This can be modified to accommodate short-duration annual fodder crops that could be grown as a double crop with a drought tolerant pulse (chickpea or grass pea) in between any two cereal phases particularly on black clay soils (*Vertisols*) that retain residual moisture for sometime.

*Vertisols* are reported to occupy about 12.6 million hectares of arable and grazing lands accounting for 10.26 per cent of the country (Berhanu Debele, 1987). Water logging is a serious problem during the main rainy season (July-August), in most of the highland *Vertisols*. Seedbed preparation involves a laborious job of deep furrow tillage (*dirdaro*) using oxen plough to facilitate drainage. In flat landscapes where water logging is more severe, farmers are obliged to delay sowing of the more sensitive crops by several weeks until drainage improves. For drought tolerant pulse crops (chickpea and grass pea) sowing is delayed towards the end of the rainy season and the land meant for these crops stays idle for about three-fourth of the growing season. This practice was observed to offer an opportunity of introducing a short duration fodder legume as a double crop with drought tolerant pulse crops (chickpea and grass pea) that are adapted to utilize the residual moisture of *Vertisols*. Selected ecotypes among the annual fodder legumes such as vetches, medics and clovers are well suited for this purpose. Some native clovers such as *Trifolium quartinianum* and *T. steudneri* are well adapted to *Vertisols* and even favored by water logging, with reported yield potential of 4 to 7 t $ha^{-1}$ dry herbage (Kahurananga, J. and Asres Tsehay, 1984). These species with their fast growth rate and tolerance of water logging, offer opportunities for integrating them with drought tolerant pulse crops in a technique of sequential cropping.

The present long-term study was therefore aimed to assess the technical feasibility of sequential cropping of fodder and grain legumes, and determine the fodder yield of a number of annual fodder species during a growing period that is governed by earliness of rain and the latest possible planting time of chickpea. The study also aimed to explore the combined effects of chickpea and elite annual fodder species on grain yield of a subsequent cereal crop so as to finally develop an integrated package of food and forage crop production technology that would also contribute to an efficient utilization of highland *Vertisols*.

## Materials and Methods

### Experiment Location

The experiment was conducted at two locations: Debre Zeit (9° N and 39° E, 45 km SE of Addis Ababa), and Akaki (8° 45’ N and 39° E, 15 km SE of Addis Ababa). Debre Zeit (1850 m altitude) represented the medium highland and Akaki (2200 m), the highland sub-zones of the central Ethiopian highlands. The long term total annual rainfall at Debre Zeit is 850 mm, and at Akaki, 1025 mm; in both sites, about three-fourth of the total falling during the big rainy season, June-September. The mean annual temperature is 18.5 and 11.5 $^{o}$C at D Zeit and Akaki, respectively. The soil at both locations is black cracking type clay under the order *Vertisol*. The soil sampled (plough layer) from Debre Zeit was slightly acidic in reaction (pH 6.5); total N, 0.112%; C, 1.24%; organic matter, 2.0%; available P, 2.86 ppm; K, 1.63 and CEC, 48 meq./100g soil. The sample from Akaki had a pH of 7.66; total N, 0.101%; C, 1.18%; organic matter, 2.3%; available P, 2.22 ppm, K, 1.69 and CEC 62 meq./100g soil.

### Treatments

The trial consisted of three consecutive phases. The first (*Phase I*) was fodder phase that involved four annual fodder legumes including vetch (*Vicia dasycarpa*); clover (*Trifolium quartinianum* and *T. steudneri*) and medic (*Medicago scutellata*); the second (*Phase II*) was pulse (chickpea, var. DZ 1011), and the third (*Phase III*) was a cereal phase (durum wheat, var. Kilinto). The first two phase crops were raised as double crop one after the other during the main growing season of the first year of each cycle. Accordingly, in

*Phase I*, the fodder legumes were sown at the beginning of the rains around late-June and maintained till mid-September when they were harvested and replaced by chickpea (*Phase II*) which lasted up to December. In the following year the cereal phase (*Phase III*) continued when wheat was grown in the usual cropping season during the main rains. Thus each cycle (consisting of three phases) took two years to accomplish. The experiment was repeated for three cycles, lasting for six years in total.

The *Phase I* fodder crops were four annual legumes in three genera and they are valued for fast growth with fodder yield potential of 4-7 ton DM $ha^{-1}$ (Kahurananga J. and Asres Tsehay, 1984). These were planted at the beginning of the rainy season at the rate of 10, 20 and 25 kg $ha^{-1}$ recommended for clovers (Kahurananga J. and Asres Tsehay, 1984), medics and vetch (Bogdan A., 1977), respectively. Phosphorus (TSP) fertilizer was applied at a sub-optimal rate of 20 kg P $ha^{-1}$ at planting to enhance nodulation. This sub-optimum rate was fixed considering affordability of price at farmers' level and the rate reported as optimum (Haque and Jutzi, 1984), which is about double of the rate used in this experiment. A partial season fallow (F1) (fallow during June to mid-September and thereafter followed by chickpea); a full season fallow (F2) (fallow throughout the first year) treatments were included for comparison. Plot size was 2m by 3m ($6m^2$). These six treatments (sub-plots for *Phase III*) were arranged in four identical blocks with the purpose to explore how these treatments interact with incremental levels of N fertilizer application (main-plot treatments) on the subsequent wheat crop. Each block was replicated three times.

In *Phase II*, after harvesting the fodder crops, an early variety of chickpea (DZ-1011) was planted on each of the vacated plots at the rate of 75 kg $ha^{-1}$ in rows 30 cm apart (Tebikew Damte *et al*, 2009) towards the end of the rainy season, around September 12- 15 (Debre Zeit) and September 15-20 (Akaki). Prior to planting, the vacated plots were lightly tilled lengthwise without disturbing inter-plot path, using a traditional oxen plough. The variety used as well as the planting procedures were uniform for all plots. Moreover, the tilling and planting operations were accomplished in the same day so as to avoid excessive lose of residual soil moisture. Plot size and shape was maintained the same as the preceding fodder phase. Competitive coarse weeds were removed by hand.

In *Phase III* (year 2), the plots were carefully tilled lengthwise (as for chickpea in *Phase II*) using oxen plough and durum wheat (var. Kilinto) was planted at the rate of 150 kg $ha^{-1}$ during normal sowing time: mid-July and late-July at Debre Zeit and Akaki, respectively. Durum wheat was selected for this purpose because it is grown by the majority of the subsistence farmers in the area. Four incremental levels of nitrogen fertilizer were applied ranging from zero level to an optimum level recommended for the variety (Efrem *et al*, 1994). The four levels of application (main-plot treatments) were: without N (0 N), low level (18 kg N $ha^{-1}$), sub-optimum (32 kg N $ha^{-1}$), optimum level (64 kg N ha$^{-1}$). The N source was di-ammonium phosphate (DAP), at the higher rates the complement was adjusted from urea fertilizer.

## Measurements and Sampling

Herbage yield of each species in the fodder phase (*Phase I*) was determined by cutting the central rows of the stand at ground level using an open-ended sampling quadrat measuring 0.5 by 1.0 m. Three randomly placed quadrats were used, thus net sampling area was 1.5 m$^2$. The harvested herbage was measured using field balance and sub-samples were taken and dried in an oven at 65 $^o$C over 72 hours period for dry matter yield (DM) and fodder quality determination. Harvesting time was a compromise between high biomass yield from a stand as mature as possible, and the latest possible planting time of chickpea that insured successful germination and establishment, which more or less coincided with the time when most farmers in the area plant chickpea (about mid September). In the pulse phase (*Phase II*), chickpea was harvested at full maturity (around December of each cycle) and grain and straw yields were determined by sampling the central rows. In the cereal phase (*Phase III*), wheat was harvested at full maturity (about late October of each cycle), and both grain and straw yield was determined by sampling the central rows of each plot leaving the border rows on the either side.

### Data Analysis

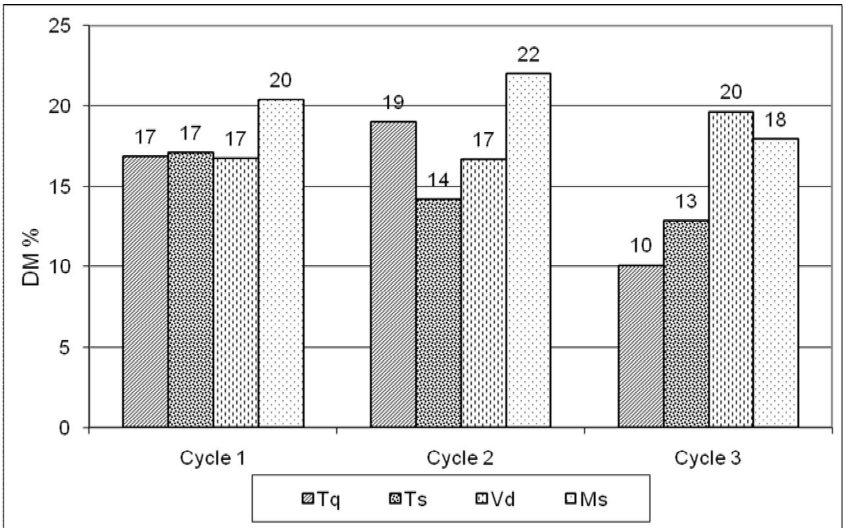
Data was analyzed separately for each phase. The data was subjected to analysis of variance according to Gomez and Gomez (1984) appropriate for the designs employed (RCBD for the first two phase treatments and split-plot for the third phase treatment. Data analysis was facilitated using SAS program (SAS Institute, 1999), and means were separated by using the LSD method.

## Results and Discussions

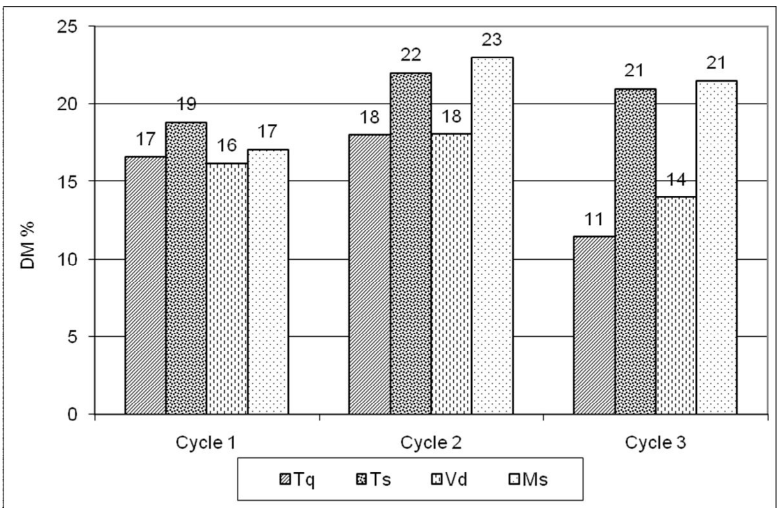
The result of the experiment over three cycles (six years in total) from two locations is presented phase by phase (*Phase I*, fodder; *Phase II*, chickpea; *Phase III*, wheat) as follows.

### *Phase I*- Fodder Crops

The dry matter yield of the fodder species was a function of the length of the growing period that was governed by the prevailing rainfall distributionand the latest possible planting time of the subsequent pulse crop (chickpea). Therefore, taking precaution against any delay in the planting time of chickpea, fodder species were harvested by mid-September at 70-75 and 75-80 days after sowing at Debre Zeit and Akaki, respectively. At this growth period, the species were at different stages of maturity as manifested by their flower initiation. *Medicago scutellata* and *Trifolium steudneri* were relatively fast-maturing and reached 50% flowering at harvest. *Vicia dasycarpa* reached initial flowering while *T quartinianum* was in vegetative stage until it was harvested. Accordingly, the dry matter content of the harvested herbage varied widely with the species and ranged from 10 to 23% (Figure 1).




*1.a) Debre Zeit*

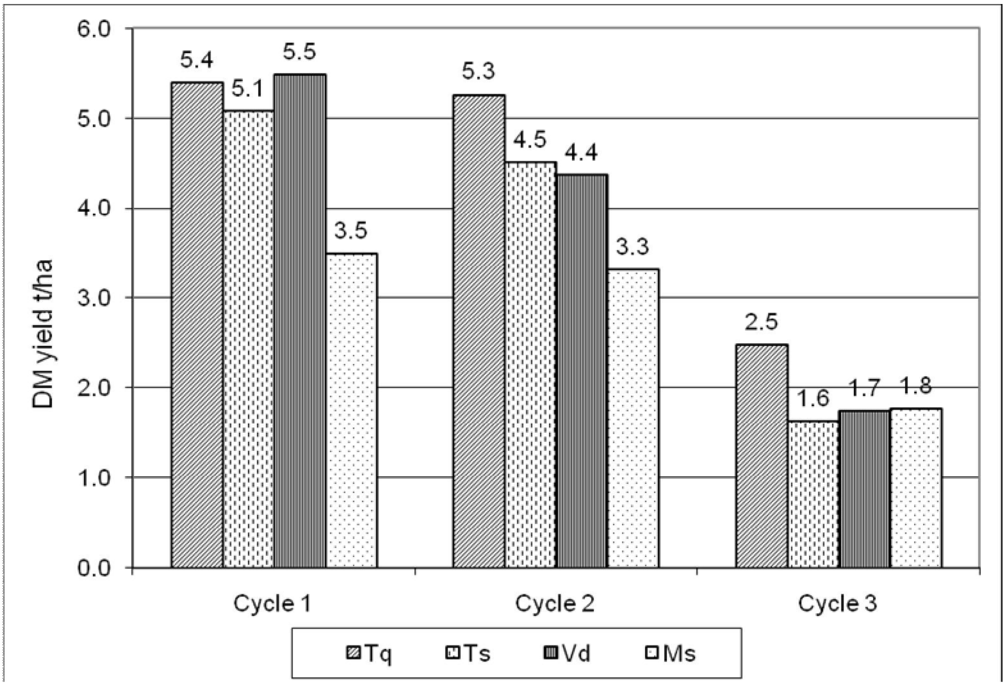



*1.b) Akaki*

Designations: Tq= *Trifolium quartini anum*; Ts= *T. steudneri*; Vd= *Vicia dasycarpa*; Ms= *Medicago scutellata*

*Figure 1. Dry matter percent by weight of herbage samples from four fodder species grown as double crops with chickpea at Debre Zeit (1.a) and Akaki (1.b) sites*

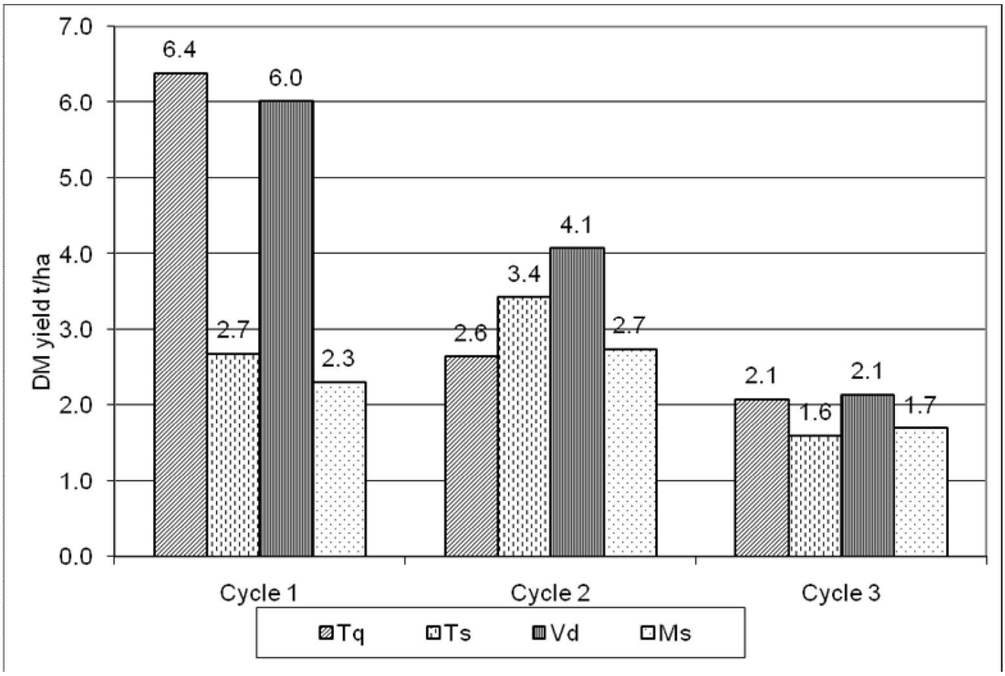
The average dry matter (DM) yield of these crops varied widely according to species, location and the harvesting time which depended upon the prevailing rainfall distribution. At Debre Zeit, the warm weather favored better accumulation of DM and the average dry herbage yield ranged 3.5-5.5, 3.3-5.3, and 1.6-2.5 t ha$^{-1}$ in the first, second and third cycles respectively (Figure 2). Interspecies difference in average DM yield was statistically significant ($P<0.05$) for the last two cycles. Consistently over the three cycles, *Trifolium quartinianum* and *Vicia dasycarpa* had the highest DM yield.




Note: LSD (alpha 0.05) for Cycle II= 0.667; Cycle III= 0.437. Designations: Tq= Trifolium quartinianum; Ts= T. steudneri; Vd= Vicia dasycarpa; Ms= Medicago scutellata

*Figure 2. Herbage yield of four annual fodder legume species each grown as double crop with chickpea for three cycles on a Vertisol at Debre Zeit.*

At Akaki, most of the fodder species delayed to mature due mainly to the cool temperature (11.5 $^{o}$C). Fortunately, the rainfall distribution being fairly longer (June to late September) than that at Debre Zeit (June to mid September), the crops were allowed to grow for longer growth period which somewhat compensated for the slower growth rate. The average DM yield ranged 2.3-6.4, 2.6-4.1, and 1.6-2.1 t ha$^{-1}$ in *Cycle I*, *Cycle II*, and *Cycle III*, respectively. Interspecies difference in mean DM yield at Akaki was statistically significant in all cycles ($P<0.05$), and the highest yield was from *Vicia dasycarpa* which appeared to be favoured by the cool temperature (Figure 3).




Note: LSD (alpha 0.05) for *Cycle I*= 0.992 ; *Cycle II*= 0.425; *Cycle III*= 0.401. Designations:: Tq= *Trifolium quartini-anum*; Ts= *T. steudneri*; Vd= *Vicia dasycarpa*; Ms= *Medicago scutellata*

*Figure 3. Herbage yield of four annual fodder legume species grown as double crop with chickpea for three cycles on a Vertisol at Akaki*

Generally, the DM yield of the fodder species from a growth period not exceeding eighty days can be taken as satisfactory in view of the complementary value of the second crop, chickpea. The DM yield of *Trifolium quartinianum* and *T. steudneri* nearly equaled the yields reported under full season growth (4-7 t DM ha$^{-1}$) (Kahurananga J. and Asres Tsehay, 1984). Similarly, *Medicago scutellata* yielded about three-fourth of its reported yield (5-6 t DM ha$^{-1}$) when grown as full season crop (Johnson and Lloyd, 2005).

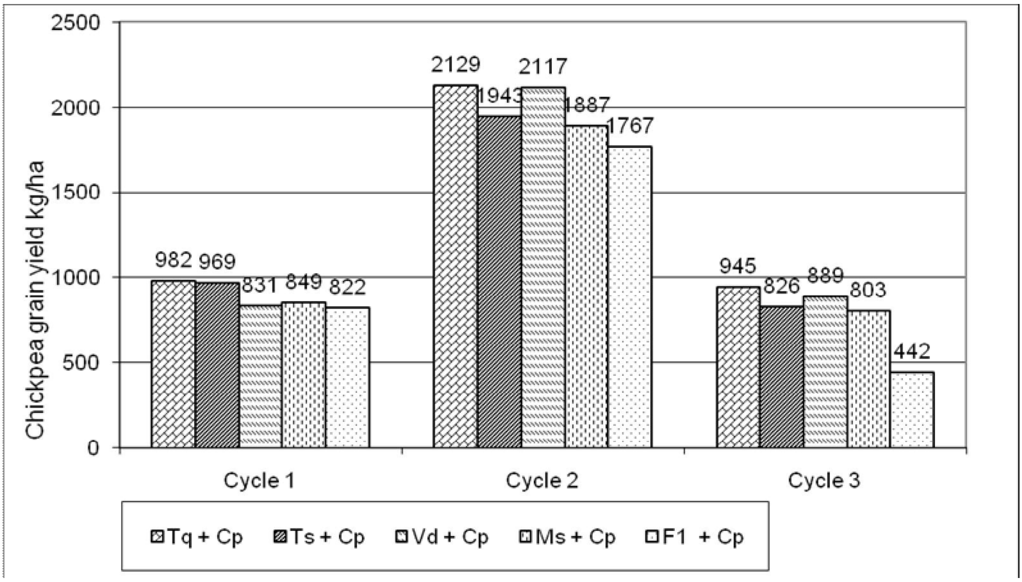
The nutritional quality of the fodder species as determined by laboratory analysis for the more critical attributes did not vary greatly among species and between locations (Table 1). The in-vitro digestibility (>40%) and crude protein (>22%) recorded for all the species was reasonably high and generally falls within the standard nutritional levels reported for tropical ruminant livestock (Kearl, 1982). The observed high nutritional quality is actually expectable from such early harvested fodder crops, most of which were from initial to 50% flowering at the time of harvest.

Table 1. Crude protein (CP) and in-vitro dry matter digestibility (IVOMD) of annual forage legume species grown as double crop with chickpea on a *Vertisol*, at Debre Zeit and Akaki sites.

| Fodder species | Debre Zeit | | Akaki | |
|---|---|---|---|---|
| | CP% | IVOMD% | CP% | IVOMD% |
| Trifolium quartinianum | 24.10 | 39.63 | 21.49 | 49.64 |
| Trifolium steudneri | 26.67 | 41.55 | 26.12 | 72.92 |
| Vicia dasycarpa | 26.44 | 46.32 | 18.33 | 73.81 |
| Mdicago scutellata | 23.48 | 48.00 | 22.94 | 47.94 |

***Phase II* - Chickpea**

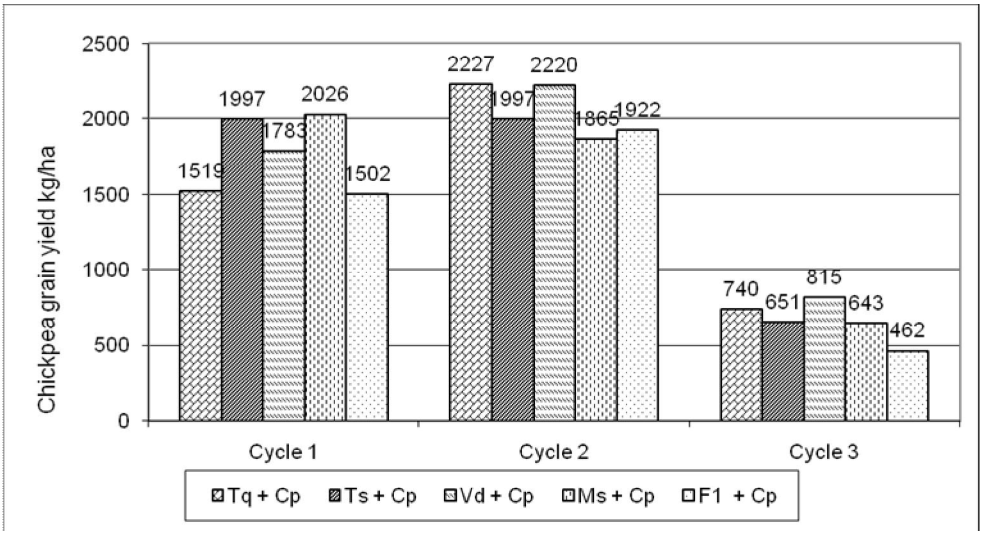
Almost uniformly over the three cycles of the experiment, within a few days after harvesting fodder crops, chickpea was planted on the vacated plots around September 10-12 (Debre Zeit) and September 15-20 (Akaki), when intermittent rain was available to initiate germination. Thereafter, the crop utilized the residual soil moisture retained by the heavy clay soil colloids of the *Vertisols*. At Debre Zeit, mean grain yield was in the range 822-982 kg ha$^{-1}$ in *Cycle I* and there was no significant (P>0.05) difference due to the effect of the preceding fodder crops (Figure 4). In C*ycle II*, the yield was more than twofold of that in cycle I probably due to the more favourable climate in the growing season of the year. The mean grain yield difference due to species effect from the preceding phase was significant (P<0.05). While in *Cycle III*, the magnitude of average grain yield was closely related to that in *Cycle I* and the effect of the fodder species from the preceding phase was manifested by a significant (P<0.05) mean grain yield difference.




Note: LSD (alpha 0.05) for Cycle II= 111.3; Cycle III= 253.4. Designations: "T. q.+Cp" = Trifolium quartinianum before chickpea; "T.s+Cp" = T. steudneri before chickpea; "V.d+Cp" = Vicia dasycarpa before chickpea; "M.s+Cp" = Medicago scutellata before chickpea; "F1+Cp" = Fallow (partial) before chickpea.

*Figure 4. Grain yield of chickpea var. DZ-1011 grown as double crop with fodder species for three cycles on a Vertisol at Debre Zeit*

At Akaki, the mean grain yield was generally higher than that at Debre Zeit especially during the first two cycles, which ranged 15000-20000 kg ha$^{-1}$ and 18000-22000, in *Cycles I* and *II* respectively, while the average yield in *Cycle III* was low across treatments (462-815 kg ha$^{-1}$) (Figure 5), which may be due to seasonal fluctuation in rainfall distribution. Treatment effects of the preceding fodder crop types on grain yield of chickpea was not significant (P>0.05) in the first cycle. However in *Cycles II* and *III*, there was significant (P<0.05) difference in chickpea grain yield due to the effects of the different fodder species in the preceding phase. Accordingly, grain yield was the highest due to the effects of *Vicia dasycarpa* and *Trifolium quartinianum* and the least due to partial fallow (*F1*). *T. steudneri* and *Medicago scutellata* had moderate effects on chickpea grain yield (Figure 5).




Note: LSD (alpha 0.05) for Cycle II= 176.4; Cycle III= 130.2. Designations: "T. q.+Cp" = Trifolium quartinianum before chickpea; "T.s+Cp" = T. steudneri before chickpea; "V.d+Cp" = Vicia dasycarpa before chickpea; "M.s+Cp" = Medicago scutellata before chickpea; "F1+Cp" = Fallow (partial) before chickpea.

*Figure 5. Grain yield of chickpea var. DZ-1011 grown as double crop with fodder species for three cycles on a Vertisol at Akaki*

In general, the grain yield produced from chickpea grown in a double crop system by utilizing residual moisture during the later part of the growing season is comparable to that produced as full season crop at farmers' level around Debre Zeit (Tebikew Damte *et al*, 2009). In addition, earlier research reports on the yield potential of chickpea varieties developed from native lines, including DZ-1011, ranged between 800 and 2000 kg $ha^{-1}$ on *Vertisols* around Debre Zeit (Geletu Bejiga, *et al*, 1994). Therefore, the grain yield obtained in the present experiment can be considered satisfactory especially in view of the additional benefit obtained from the high quality fodder produced that can be made available to stock at the time when livestock face critical feed shortage (Jutzi S. *et al*, 1987).

***Phase III*- Wheat**

The third phase of the experiment involved a cereal crop which was durum wheat, var. Kilinto. The data on the effect of the precursor food and fodder legume crops on wheat performance, particularly in terms of grain yield, was not consistent over locations and cycles. Therefore, the outcome of the data analyzed separately for each cycle and location is presented as follows.

***Cycle I-*** In the first cycle, the mean grain yield of Kilinto showed significant (P<0.05) difference in response to the treatments in the preceding phases as well as to the nitrogen fertilizer application rates at both Debre Zeit and Akaki sites (Table 4). The interaction effect of the precursor crops and fertilizer levels was also significant (P<0.05) at Debre Zeit but not at Akaki. Two of the precursor fodder species, *Trifolium quartinianum* and *Vicia dasycarpa* significantly contributed to higher grain yield of wheat at both locations while the other two, *T. steudneri* and *Medicago scutellata* had intermediate effect uniformly at both locations and the least was that of partial fallow (*F1*) and full season fallow (*F2*). Generally, across most treatments, grain yield at Akaki was inferior to that from Debre Zeit. This is attributed to the cool temperature (11 $^{o}$C) and possibly to the waterlogged condition and associated effects of poor aeration on plant physiology.

Table 4. Grain yield response of durum wheat var. Kilinto to sequentially grown precursor crops of annual fodder species and chickpea in *Cycle I*, at Debre Zeit and Akaki sites

4a. Debre Zeit

| Phases I & II crops (Fodder + chickpea) | Phase III. Wheat yield (Kg/ha) at four levels of $N_2$ application | | | | |
|---|---|---|---|---|---|
| | 64 N* | 32 N | 18 N | 0 N | Mean |
| T. quartinianum + CP | 2885AB | 2790BC | 2385EFG | 1575IJ | 2409B |
| T. steudneri + CP | 2790BC | 2446DEF | 2227FG | 1414JK | 2219C |
| V. dasycarpa + CP | 3052A | 2891AB | 2559CDE | 1876H | 2594A |
| M. scutellata + CP | 2672BCD | 2318FG | 2162G | 1569IJ | 2181C |
| ρF1 + CP | 2448DEF | 1698HI | 1689HI | 1286KL | 1780D |
| @F2 | 2171G | 1496IJK | 1322KL | 1156L | 1536E |
| LSD (α0.05) | 235.5 | | | | |
| $N_2$ means | 2670A*2 | 2273B | 2057C | 1479D | |
| LSD (α0.05) | 127.6 | | | | 117.8 |
| C.V. % | 6.73 | | | | |

* N fertilizer levels: optimum level (64 kg N/ha), sub-optimum (32 kg N/ha), low level (18 kg N/ha), & zero (without N). DMΘ = dry matter herbage; *1NS = Not significant; ©CP = chickpea; ρF1= partial season fallow during phase I; @F2= fallow for full season during phases I and II. *2Means followed by similar letters are not significantly different at α 0.05.

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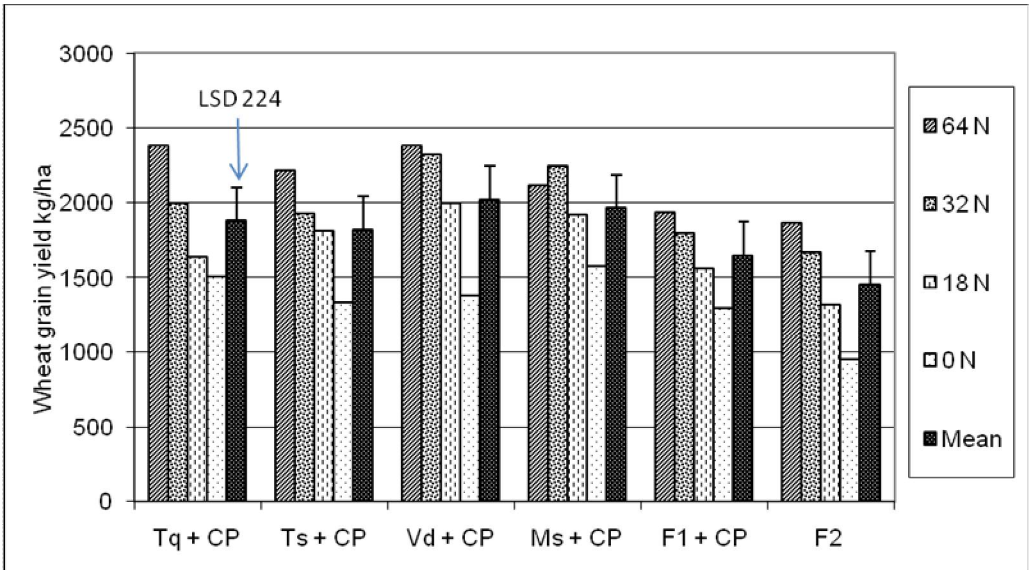
4b. Akaki

| Phases I & II crops (Fodder + chickpea) | Phase III. Wheat yield (Kg/ha) at four levels of $N_2$ application | | | | |
|---|---|---|---|---|---|
| | 64 N* | 32 N | 18 N | 0 N | Mean |
| T. quartinianum + CP | 1591 | 1308 | 1107 | 853 | 1215AB |
| T. steudneri + CP | 1420 | 1430 | 979 | 803 | 1158BC |
| V. dasycarpa + CP | 1556 | 1431 | 1175 | 877 | 1259A |
| M. scutellata + CP | 1481 | 1182 | 962 | 796 | 1105C |
| [p]F1 + CP | 1415 | 1030 | 782 | 702 | 982D |
| [@]F2 | 1427 | 999 | 715 | 708 | 962D |
| LSD (α0.05) | *[1]NS | | | | |
| $N_2$ means | 1481A | 1230B | 953C | 790D | |
| LSD (α0.05) | 73.51 | | | | 101.2 |
| C.V. % | 11.01 | | | | |

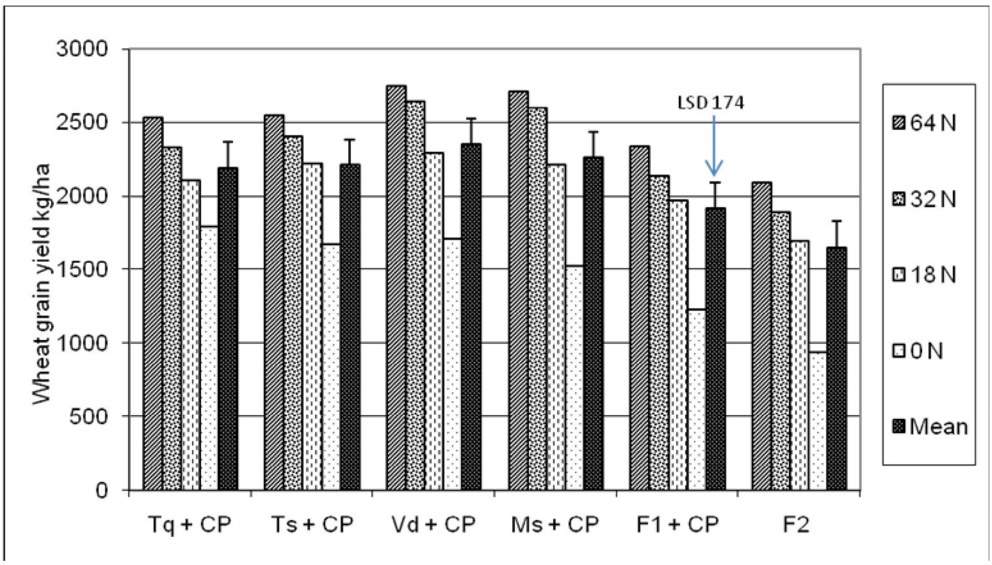
***Cycle II-*** In the second cycle, main effects of precursor double crops (fodder and pulse) and N fertilizer levels were significant ($P<0.05$) while interaction of these were not significant ($P>0.05$) in their effect on mean grain yield of durum wheat at both locations (Figure 6). While nitrogen fertilizer application rate contributed to significant variation in mean grain yield with an increasing trend proportional to the rate of N application. At both locations, wheat grain yield was higher when the preceding crops were the fodder crops as compared with that when the preceding phase of the rotation was either partial (*F1*) or full season fallow (*F2*). Effect of partial fallow was better than full season fallow in enhancing grain yield of wheat especially at Akaki which can be attributed to the more favourable conditions that might have led to higher vigour and growth rate that apparently enhanced the $N_2$ fixation efficiency of chickpea at the site during that cycle (observe chart *Cycle II* in Figure 5). In this cycle inter species difference amongst the four fodder species in the yield of wheat was not significant which may imply that all the species had fairly equal positive effects on the yield of wheat.




*Note. N fertilizer levels: 64N= optimum level (64 kg N/ha), 32N= sub-optimum (32 kg N/ha), 18N= low level (18 kg N/ha), & 0N= zero (without N).

Precursor crops: Chickpea (CP) followed by: Tq= *Trifolium quartinianum*; Ts= *T. steudneri*; Ms= *Medicago scutellata*; Vd= *Vicia dasycarpa*; F1= Partial fallow period before chickpea; F2= full season fallow.

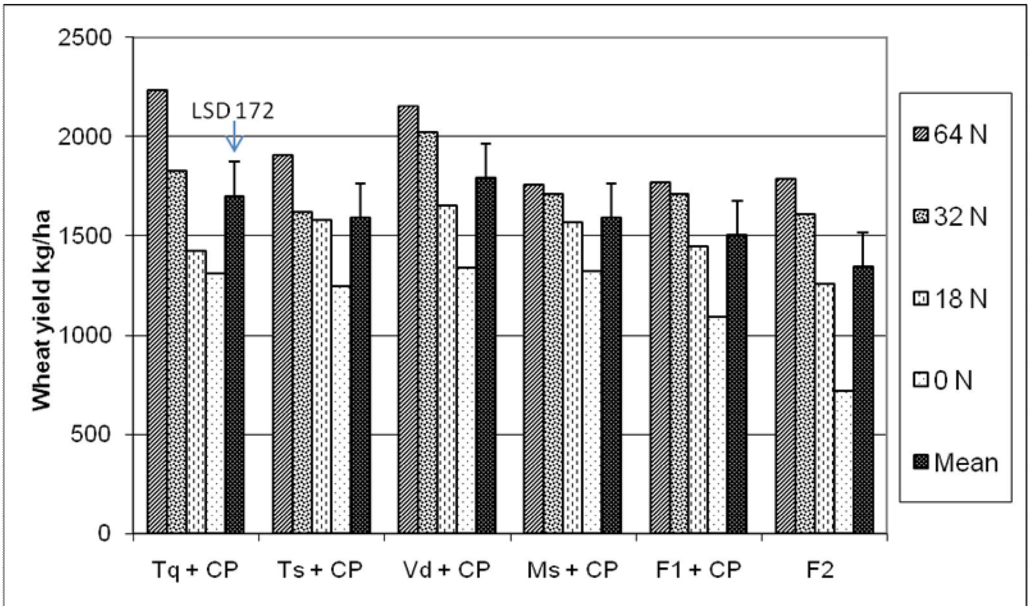
*6a) Debre Zeit*




*6b) Akaki*

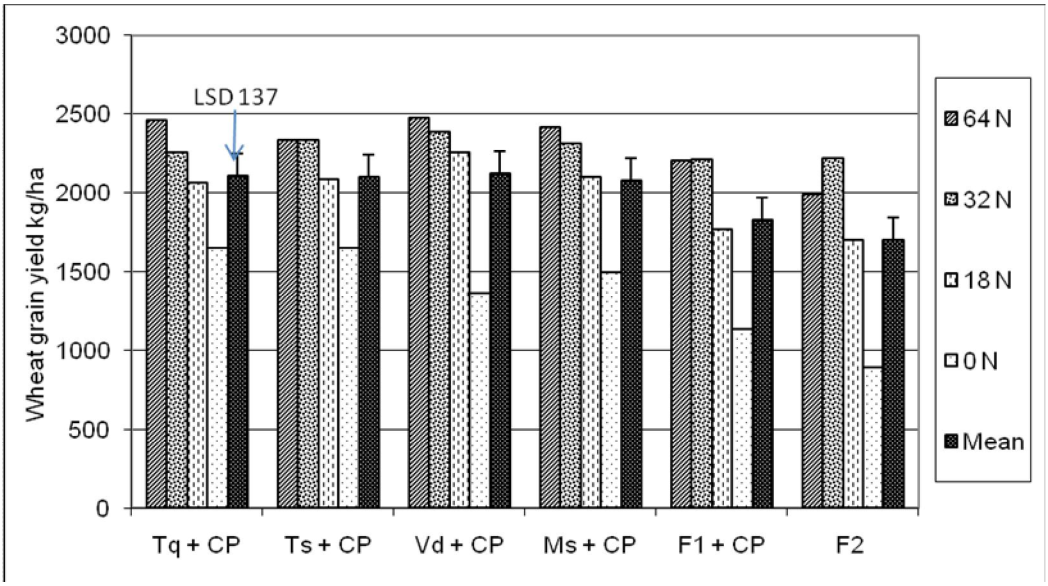
*Figure 6. Grain yield (kg/ha) of durum wheat var. Klinto grown subsequent to a double crop of annual fodder legume species and chickpea at four levels of nitrogen fertilizer on a Vertisol at Debre Zeit and Akaki sites (Cycle II of experiment).*

***Cycle III-*** As in *Cycle II*, in the third cycle of the experiment, main effects (fodder species and $N_2$ levels) but not the interactions of these had significant difference in mean grain yield of durum wheat. At Debre Zeit, significant (P<0.05) inter-species difference was exhibited among the four fodder precursor crop species in their effect on mean grain yield of wheat (Figure 7). At Debre Zeit, wheat grain yield was significantly higher when the precursor crops were *Trifolium quartinianum* and *Vicia dasycarpa*, as compared to the yield when the precursor crops were the other two species (Figure 7a). While at Akaki, all the fodder species had more or less similar effect on wheat grain yield as was in *Cycle II*. Generally, the mean grain yield (averaged over all levels of $N_2$) grouped the precursor treatments into two: the fodder species that significantly increased wheat grain yield and the fallow treatments (*F1* and *F2*) that resulted in relatively lower grain yield of wheat. The partial fallow and the full season fallow had no significant (P<0.05) difference, and this might be due to poor growth condition and so low efficiency of N fixation of chickpea in the partial fallow treatment.




*7a) Debre Zeit*

***Note.** N fertilizer levels: 64N= optimum level (64 kg N/ha), 32N= sub-optimum (32 kg N/ha), 18N= low level (18 kg N/ha), & 0N= zero (without N).
Precursor crops: Chickpea (CP) followed by: Tq= Trifolium quartinianum; Ts= T. steudneri; Ms= Medicago scutellata; Vd= Vicia dasycarpa; F1= Partial fallow period before chickpea; F2= full season fallow.




*7b) Akaki*

*Figure 7. Grain yield (kg/ha) of durum wheat var. Klinto grown subsequent to a double crop of annual fodder legume species and chickpea at four levels of nitrogen fertilizer on a Vertisol at Debre Zeit and Akaki sites (Cycle III of experiment)*

Overall, the outcome of the third phase (cereal phase) of the experiment in particular was not consistent over locations and years (cycles) such that combined data analysis over locations or years would not be appropriate. Interaction effects were not significant except in the initial cycle. One of the reasons could be due to the exploratory nature of the experiment, especially in the third phase (cereal) that is subject to influence of numerous factors besides the too many treatments considered. This would suggest that where the emphasis is on the contribution of the precursor crops on cereal crops, each potential fodder species must be evaluated one at a time so as to reduce technical difficulties as well as the amount of complexity in data analysis. This may allow a more precise determination of yield increment of the subsequent cereal crops, including the amount of biologically fixed $N_2$ accretion to the soil.

## Conclusion

In the face of the highly increasing demand for arable land in the Ethiopian highlands, allocation of cultivable land for pasture crops seems unlikely now and in the near future. An alternative promising approach would be fitting fodder crops into the existing cropping system without displacing food and cash crops.

The present long-term study capitalized on a shorter version of crop rotation- “Sequential” or “Double cropping” so modified to accommodate short duration fodder crops. It is to be noted that the two antecedent crops (forage and pulse) are grown during a season, one after the other whereby the two crops do not overlap, the second being sown only after the harvest of the first. In the present study, short-duration native clovers and medics were successfully grown in one cropping season sequentially with chickpea on a black heavy clay soil (Vertisol). The advantages of the double crop technology were twofold: production of food grain and high quality fodder and improve productivity of a subsequent non-legume crop (wheat) through Rhizobial nitrogen fixation by both fodder and pulse crops. The fodder phase enabled to produce high quality fodder (CP 23-27%; IVDMD 40-48 %) fodder with an average DM yields ranging from 2.2 to 6.4 t ha-1 which is comparable to the yield obtained from these species when grown as full- season crop (Kahurananga J. and Asres Tsehay, 1984). Chickpea, which succeeded the fodder crop had normal establishment and growth and did not suffer terminal drought stress and the grain yield ranged 8 to 20 quintals ha-1, which was also comparable to the yield from the same variety produced in the traditional way as full-season crop by farmers around Debre Zeit (Tebikew Damte et al, 2009.). Wheat yield recorded at low and suboptimal level of N2 fertilizer application was in the range 15-25 q ha-1, indicating the complementary value of the fodder crops in maintaining the N content of the soil through biological fixation. This yield range was again close to that produced at farmers' level in areas where the variety had been distributed (Tesfaye Tesema et al, 1993; Efrem Bechere, 1994). Therefore, the present long-term experiment enabled to identify a number of short-duration forage legumes with attributes of: tolerance to water logging; fast growth and high DM accumulation potential that confer an opportunity of growing them as double crop with late-season pulse crops such as chickpea (also possible with grass pea, data not shown). Moreover, the phenology and growth form of these crops make them well suited for conserved fodder production in which they can be raised either as pure stand or in mixture with annual fodder grass species such as oats (Solomon Mengistu, 2006).

A notable feature of this food and fodder crop integration technology is that the traditional cropping cycle has not been altered. Therefore, the technology is expected to have high scope for adoption by the smallholder farmers as has been learned from an on-farm verification trials launched in three Woredas around Debre Zeit (Adaa, Lume and Ginbicho) (data not shown). Further on-farm verifications of the technology at a national level should ideally include areas from the medium and higher-highland zones (1500 m altitude and above) characterized by mixed crop/livestock farming systems; where black heavy clay soils (Vertisols) make up a good proportion of the arable land; mean annual rainfall of at least 800 mm, with a continuous distribution of about 90 days or longer.

## References

Berhanu Debele. 1985. *The Vertisols of Ethiopia Their properties, classification and management.* 5th Meeting of the Eastern African Soil Correlation and Land Evaluation Sub-Committee, 4-10 December 1983, Wad Medani Sudan. World Soil Resources Report 56. FAO, Rome. pp. 31-54.

Bogdan, A.V., 1977. Tropical pasture and fodder plants. Longman, New York.

Efrem Bechere, Tesfaye Tesema and Demisse Mitiku. 1994. Improved varieties of durum wheat in Ethiopia. Research Report Series No 2. Debre Zeit Agricultural Research Center, Debre Zeit, Ethiopia.

Geletu Bejiga and Abebe Tulu 1982. The influence of planting dates on the yield of three chickpea (*Cicer arietinum*) varieties. Eth. J. Agri. Sci. 4(2): 61-66

Gomez, K.A. and Gomez A.A. 1984. Statistical procedures for agricultural research. (Second ed.) John Willey and Sons New York. pp. 89-97.

Johnson, B. and Lloyd, D. 2005. The role of annual medics in Queensland agriculture. Queensland Government Department of Primary Industries and Fisheries. Plant Science, Toowoomba, Queensland. <http:www2.dpi.qld.gov.au/pastures/3625.html> Accessed May, 2010.

Jutzi, S. and Haque, I. 1984. Some effects of P and N/P fertilization on three African clovers (*Trifolium tembense, T. rueppellianum, and T. steudneri*) on a P deficient Vertisol. ILCA Newsletter 3:5-6.

Jutzi, S., Haque I. and Abate Tedla. 1987. The production of animal feed in the Ethiopian highlands. Paper presented at the First National Livestock Improvement Conference, 11-13 Feb. 1987. IAR, Addis Ababa, Ethiopia.

*Kahurananga, J. and Asres Tsehay. 1984. Preliminary assessment of some annual Ethiopian Trifolium species for hay production. Tropical Grasslands 18 (4): 215-217.*

Kearl, L.C.1982.Nutreint Requirement of Ruminants in Developing Countries. International Feedstuffs Institute, Utah Agricultural Experiment Station, Utah State University Longman 84322.USA. pp 381.

SAS (Statistical Analysis System) Institute, 1999. SAS/STAT user's guide, Version 8, SAS Inst, Cary, North Carolina.

Solomon Mengistu. 2006. Evaluation of oats and native annual clover species as mixed fodder crops and assessment of their suitability for rotational production with cereal crops. Proceedings of the 14th ESAP Conference, 5-7th Sept., 2006. A.A., Ethiopia. pp. 43-52.

Tebikew Damte, Asnake Fikre, Kibebew Asefa, and Lijalem Korbu, 2009. Improved chickpea (*Cicer arietnum* L.) technologies and seed production in Ethiopia. Ethiopian Institute of Agricultural Research (EIAR), Debre Zeit, Ethiopia.

Tesfaye Tesema, HC Becker, H.C. Getachew Belay, Demise Mitiku, Efrem Bechere and Seifu Tsegaye. 1993. Performance of Ethiopian tetraploid wheat landraces at their collection sites. Euphytica 71: 221-230.