GERMINATION, YIELD, AND YIELD COMPONENTS OF TEF (Eragrostis tef (Zucc.) Trotter) AS AFFECTED BY ENVIRONMENT, TILLAGE AND WEED CONTROL PRACTICES

By

ABERRA DEBELO

Bachelor of Science
Addis Ababa University
Alemaya, Ethiopia
1977

Master of Science
Addis Ababa University
Alemaya, Ethiopia
1982

Submitted to the faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 1992

GERMINATION, YIELD, AND YIELD COMPONENTS OF

TEF (Eragrostis tef (Zucc.) Trotter)

AS AFFECTED BY ENVIRONMENT,

TILLAGE AND WEED CONTROL

PRACTICES

Thesis Approved:

Lavoy I. Croy
Thesis Adviser

Glenn W. Todd

Robert L. Westerman

Eugene G. Krenzer Jr.

Thomas C. Collins
Dean of the Graduate College

ACKNOWLEDGMENT

I would like to thank all those who directly or indirectly made the completion of this study possible.

My sincere appreciation goes to my former adviser, Dr. Richard C. Johnson, for assisting in initiating the thesis project. I am deeply indebted to Dr. Lavoy I. Croy not only for his willingness to serve as my major adviser when my former adviser was transferred to USDA/Washington State University, but also for his sincere support, guidance, encouragement, and for travelling to supervise part of the thesis research conducted in Ethiopia.

Sincere appreciation is also extended to members of my advisery committee, Drs. Robert L. Westerman, Eugene Krenzer, and Glenn W. Todd for their advice and constructive criticism in the preparation of this manuscript. Special thanks goes to Dr. David L. Weeks for being so kind and tireless in assisting in statistical analysis of the data. Thanks are also extended to Mr. Dave Ferris for his assistance in conducting controlled environment experiment at Oklahoma State University, and to Mr. Conrad Evans and his family and fellow graduate students who made life easier for me at Oklahoma State University.

I would like to thank the Institute of Agricultural Research, Ethiopia, for financial support, Food and Agricultural Organization of the United Nations for facilitating my study program in the United States, and Office of the International Program and Agronomy Department at Oklahoma State University for providing financial support when my scholarship discontinued.

I am also indebted to Dr. Tesfaye Tessema who served as my co-adviser in Ethiopia, Dr. Seifu Ketema and the staff of tef research section at Debre Zeit Research Center for their cooperation.

Cooperation and support provided to me from the managements of the Institute of Agricultural Research, Awasa and Debre Zeit Research Centers and the staff is highly appreciated.

I would also like to thank Ato Tesfaye Adane who tirelessly assisted me in collecting the field research data.

I give special gratitude to my father Ato Debelo Napo, brothers and sisters for their constant support and encouragement during my graduate program.

Finally, and above all, My wife Yeshi Chiche deserves a lot of thanks and appreciation not only for her understanding, love, and care, but also for taking the burden and responsibility of raising our children in my absence.

This work is dedicated to my father, Ato Debelo Napo, without whose initial support and motivation the dream would not have come true.

TABLE OF CONTENTS

PART III

PART IV

LIST OF TABLES

Table | Page

APPENDIX TABLES

Table Page

APPENDIX TABLES

PART III

APPENDIX TABLES

PART IV

Table | Page

LIST OF FIGURES

INTRODUCTION

This thesis contains separate chapters, each of which is based on data collected from separate experiments repeated over time/space. Each chapter is an article to be submitted to Agronomy Journal, an American Society of Agronomy Publication.

PART I

TEF (*Eragrostis tef* (Zucc.) Trotter) YIELD AND YIELD COMPONENTS AS AFFECTED BY TILLAGE AND WEED CONTROL PRACTICES

ABSTRACT

Current seedbed preparation for production of tef (Eragrostis tef (Zucc.) Trotter), a major cereal crop in Ethiopia, is based on frequent plowing which is time consuming and may not be appropriate from a soil management point of view. There is a need to reduce such excessive tillage without sacrificing yield. A two year (1988 and 1989) experiment was conducted on three sites: i) Arsinegelle loam soil (sand = 38 %, silt = 39 %, and clay = 23 %), ii) Sirba-Godetti light clay soil (sand = 29 %, silt = 31 %, and clay = 40 %), and iii) Sirba-Godetti black clay soil (sand = 21 %, silt = 26 %, and clay = 52 %). The objectives of the study were to investigate effect of reduced tillage and weed control practices on yield and yield components of tef, seasonal soil moisture, and compatibility of current weed control system to reduced tillage.

There were significant differences between seasons and treatments. Except for change in magnitude because of seasonal differences, trends of treatment effects were similar in both seasons at the three sites. No-tillage produced significantly the lowest yield. There were no significant differences between the remaining tillage treatments. Tillage more than once did not increase yield significantly provided weeds were controlled by nonselective herbicides before plowing. Of all yield components studied, number of panicle per unit area was the most affected by both tillage and weeding. Tillage affected grass and broadleaf weed distribution. Grass weeds were higher in notillage than

tilled plots and the reverse was true for broad-leaf weeds. Significant differences were observed between weeding treatments. Noweeding affected grain yield and yield components; however there were no significant differences between weeding as necessary which is farmer's weeding practice, recommended hand weeding or chemical herbicide once at early tillering stage of the crop.

Effects of tillage and weed control practices on soil moisture were not consistent. Therefore, the study merits further investigation under different environments.

INTRODUCTION

Tef is a major cereal crop grown in Ethiopia. The current production practice includes seedbed preparation by plowing from 2 to 5 times (Seifu, 1986) with oxen-drawn plows. Seeds are hand broadcast for planting and weed control is mostly practiced by hand. In most cases farmers prefer to plow from 3 to 5 times regardless of soil type and topography of the farm land.

Excessive tillage is time-consuming and since the first plowing has to start very early in the season, it can interfere with planting times of other crops. Moreover, excessive tillage exposes soils to wind and water erosion and destroys soil structure. Tef production under a reduced tillage system may help to overcome the afore mentioned problems. In addition, under a reduced tillage system a farmer may be able to produce more than one crop in a season or more lands can be plowed thereby increasing farmer's productivity.

Understandably, three major reasons for tillage are to control weeds, prepare a weed-free seedbed, and to incorporate organic residue into the soil (Brady, 1984). However, because of the long term negative effect of conventional tillage on soil structure and crop yield (Baeumer and Bakermans, 1973; Pereirra 1975; Richey et al., 1977; Cannel, 1985; Kayombo and Lal, 1986) and with the advent of nonselective herbicides the importance of frequent tillage is questionable. Under certain conditions, a conservation tillage system varying from reduced to no-tillage is generally recommended (Brady, 1984) as an alternative approach to overcome negative effects of conventional tillage. Research findings indicate that tillage practices vary according to soil type and availability of moisture. With adequate water conventional tillage results in a greater yield as compared to reduced tillage (Campbell et al., 1984). Moreover, poorly drained fine-textured soils require tillage to produce a satisfactory yield (Van Doren and Reicosky, 1987). A similar finding reported earlier by Lindsay et al. (1983) indicated that maize yield under conventional tillage on tropical clay soils of Trinidad was 40 percent more than the yield under reduced tillage. On the other hand, Deibert and Utter (1989) reported that on a Fargo clay soil of North Dakota sunflower production with adequate weed control is similar under reduced tillage to the conventional plow system.

Elliot et al. (1977) also reported that in a comparison of different cultivation methods there were no significant differences on aerial growth and grain yield of spring barley over a five year period. Bharati et al., (1986) and Elmore (1987) also reported that soybean yields are not affected by tillage systems. These findings suggest that tillage may not be necessary on all soil types. On the other hand, reduced tillage is also inferior to conventional tillage with fine textured soils (van Doren and Reicosky, 1987; Lindsay et al., 1983). Therefore, the tillage system selected for a particular situation should take into account such variables as soil type, climatic zones, social factors and crop types (Unger, 1984).

Currently, tef is produced through frequent plowing to prepare seedbed and by using recommended hand weeding (Berhanu, 1985) or herbicides (Berhanu ,1985; Wondimagegnehu and Parker, 1983) to control weeds. Negative effects of excessive tillage have been indicated earlier for different crops where tillage implements involved are tractor power and the necessary farm implements. However, there is no study conducted on different tillage effects on tef using either animal or tractor power. Frequent plowing of land may not be necessary with proper weed control.

The objectives of this study are : 1) to evaluate the effect of reduced tillage practice on yield and yield components of tef, 2) to determine effects of reduced tillage on soil moisture at selected growth stages of tef, and 3) to investigate if there is interaction between different tillage treatments and weed control practices.

MATERIALS AND METHODS

A two-year experiment was conducted during the 1988 and 1989 crop growing seasons to evaluate the effect of tillage and weed control practices on tef at two locations. The first experiment was conducted on two soil types , black and light colored clay soils with variable clay content (Appendix A), on Sirba-Godetti farmer's field located at an altitude of 1870 m above sea level (asl) 15 kilometers (km) east of Debre Zeit on the way to Mojo. Soil analytical data for the two research sites and weather data for the two seasons and 30 year mean rainfall data recorded at Debre Zeit Research Center are reported in Appendix A and B. The second experiment was conducted on a loamy soil on a farmer's field at Arsinegelle, 230 km south of Addis Abeba on the way to Awasa. Soil analytical data for the research site is given in Appendix A. Weather data were not available for this site. However, the research site was located at an altitude of 1930 m asl and the growing season extends from mid-April to late September or mid-October. Rainfall distribution is erratic with low rainfall expected in June with the highest amounts received in July-August and a decline in September until the end of the rainy season. The experiments were conducted on sites where wheat was grown the previous year. After wheat was harvested, as it is usually done by local farmers, crop residues were grazed by cattle during the December to May dry season, a time when animal feed is scarce. All plots were sprayed with paraquat (1,1'-

dimethyl-4,4′-bipyridinium ion) in 1988 and with glyphosate (N-(phosphonomethyl) glycine) in 1989 at the rate of 0.75 and 1.5 kg ha^{-1}, respectively, 10 days before plowing to kill germinating weeds after early shower. Soil samples were collected from two depth zones, 0-15 and 15-30 cm before spraying the field and analyzed for pH, texture, and organic matter content. The experiment was arranged in a split-plot design with four replications. The six plowing treatments (notillage, 1, 2, 3, 4, and 5 tillage times) for the two experiments at Sirba-Godetti and five tillage treatments (notillage, 2, 3, 4, and 5 tillage times) at Arsinegelle were randomly assigned to the sub-plots. The four weeding practices (1, no weeding, 2, farmers practice: weeding as required by weed infestation, 3, recommended hand weeding: hand weeding at early tillering stage of tef, and 4, recommended chemical: U-46 (2,4- dichlorophenoxy acetic acid) once at early tillering) were randomly assigned to main plots. Plot size was 3 m wide by 6 m long with an alley of 2 and 4 m within and between the main plots, respectively. The first plowing for the plots which received 5 plowing treatments started on 5 June 1988 at Sirba-Godetti and 7 June at Arsinegelle. Plowing was done at 10 day intervals so that all plots are planted on the recommended planting dates, July 15-17 of the respective locations. In both locations, the plots which received no tillage treatment were resprayed with recommended rate of paraquat 10 days before planting in 1988 and glyphosate in 1989. Seeds of tef cultivar, DZ-01-354, were hand broadcast for planting at the recommended rate of 30 kg ha^{-1}.

No fertilizer recommendations were available for specific sites, so general recommendations for light and heavy soils were used. Therefore, for Sirba-Godetti and Arsinegelle light soils, urea as a source of nitrogen (N) was applied at the rate of 40 kg N per hectare and diammonium phosphate (DAP) was applied as a source of phosphorous (P) at the rate of 26 kg P per hectare. Both P and N were each applied at the rate of 26 and 60 kg/ha on black clay soils, respectively. The herbicide U-46 was applied at the rate of 1 liter per hectare at tillering stage of tef to control broadleaf weeds.

Soil moisture was determined gravimetrically from 2 depth zones (0-15, and 15-30 cm) of one randomly selected core before plowing, at tillering, heading, and maturity stages of tef. Soil samples were collected by using an auger from the indicated depth zones and were immediately placed into separate plastic bags. The bags were sealed tightly to prevent moisture loss. A 10 g fresh weight was measured on a sensitive Mettler balance. To determine sample dry weight, fresh weighed samples were placed in an oven set at 105 °C for 24 hours and then removed and weighed immediately. Percent soil moisture was determined; where percent soil moisture is fresh weight minus dry weight divided by dry weight.

Four random weed samples from an area of 100 cm^2 of each plot were taken at early tillering stage of tef. The samples were separated into broad-leaf and grass types and reported in number of weeds per m^{-2}. Weed rating was made at maturity on a scale of 0 to 5 where 0-1, 1-2, 2-3, 3-4, and 4-5 represent about 20, 40, 60, 80, and 100 % weed infestation based on visual assessment, respectively, and then the ratings were separated into grasses and broadleaf weeds. The weed rating system at maturity was preferred to actual counts because using quadrant at this stage causes crop damage. Number of panicles m^{-2} at harvest were determined by counting panicles sampled from 4 randomly selected quadrants of 100 cm^2 each. Finally, plants were harvested from an area of 13.75 m^2 to determine grain yield and other plant characters. Panicle branches were counted from 10 panicles randomly selected from the harvested plants. Seed weight per panicle was determined from average seed weight of 10 sample panicles randomly selected from the harvested plants and reported in grams/panicle. In 1988, total drymatter (grain and straw) was determined by weighing plants harvested from an area of 13.75 m^{-2} on Sirba-Godetti light clay soil. Plants were threshed and harvest index was determined from weight of the grain as a fraction of total dry-matter. For threshing, harvested plants were spread on a large canvas and then a car (a pick-up or station wagon) was driven back and forth until most of the seeds were threshed and finally supplemented by beating with a stick. Seeds were cleaned manually, weighed and reported in kg ha^{-1}. The collected data were statistically analyzed using SAS software (SAS, 1985). After the analysis, error mean squares used to test the main plots and the sub-plots were tested for significance (F $p < 0.05$) for each variable. When the error mean squares were found significant, the data were analyzed as split plot design; whereas RCB design analysis was used by combining the two error mean squares, error(a) and error(b), whenever the two error mean squares were not significant (F $p < 0.05$). This was believed to increase efficiency of testing the treatment effects by pooling together the two error degrees of freedom. Treatment effects were tested for significance (F, $p < 0.05$). After significant F was observed at $p < 0.05$, Least Significant Differences (LSD, $p < 0.05$) was used to compare treatment means.

RESULTS AND DISCUSSION

Data were obtained from research conducted on three locations (Arsinegelle, Sirba-Godetti light and black soils). Statistical analysis was carried out on the combined data from the three locations over two seasons (1988 and 1989). Combined analyses indicated that there were highly significant differences ($p < 0.05$) between seasons (Appendixes C, D, E). The reason for such differences seems to be July to September rainfall distribution rather than the total amount (Appendix B). Hence, it was found necessary to report results for each location and season separately.

Arsinegelle - 1988.

There were highly significant weeding and tillage effects on grain yield, plant height, and panicle per unit area, but there were no tillage or weeding effects on other plant characters considered (Appendix H). In 1988, weeding practice averaged over tillage significantly affected grain yield (Table 1). As expected, no weeding treatment produced the lowest yield. There were no significant differences between the remaining weeding treatments. Yield loss due to weeds during this season was about 26 % of the highest yield obtained. There were no significant differences ($p < 0.05$) observed among the three weeding treatments. Weeding practice did not influence some of the yield components like 1000 seed weight, panicle length, and panicle weight (Table 1). However, there was a significant ($p < 0.05$) weed treatment effect on number of panicle meter^{-2} at harvest and plant height. The significant weed effect observed on the yield seems to be due to the effect of weeds on number of panicle per unit area.

There was a significant tillage effect ($p < 0.05$) on grain yield, panicle length, plant height, and number of panicles meter^{-2} at maturity (Table 2). However, no significant effect was observed on panicle weight, panicle branch, and 1000 seed weight (Table 2). There was no significant yield difference between plots plowed two to four times. Plowing 2 times has increased yield by 164 % over notillage. Lower yield in notillage could be attributed to lower plant population observed in no tillage plots due to displacement of seeds by erosion. In addition, since tef is planted by broadcasting, it may be possible that seeds on the soil surface may lack proper contact with soil moisture or a rain shower followed by a dry spell may cause some seed to germinate and subsequently die. Thus, early germinating seeds may die due to lack of enough moisture which eventually affects plant population and is reflected in yield. A similar result was reported by Young et al. (1970). Brady (1984) also reported that on loam and silty clay loam soils conventional tillage was better than notillage.

Arsinegelle - 1989.

Statistical analysis for the 1989 season at Arsinegelle indicated that there was significant ($p < 0.05$) tillage and weeding interaction effect on grain yield, significant tillage effect on all plant characters studied except seed weight and soil moisture at heading (Appendix I). For grain yield, comparison between weeding treatments were made for a given tillage practice and vice versa. For other agronomic characters for which an interaction effect was not observed, main plot and sub-plot means were averaged over sub-plots and main plots and reported in Tables 5 and 6. Weeding practice significantly ($p < 0.05$) affected grain yield at all levels of plowing treatments (Table 3). Under all plowing treatments no weeding reduced yield significantly. There was no significant difference between the other three weeding treatments. When fields were not plowed, weeding alone increased yield by 191% over plots which were not weeded and there was no significant difference ($p < 0.05$) between the other three weeding practices (Table 3). However, when plowed twice there was no significant difference between weeding once at early tillering stage of tef and noweeding. Moreover, hand weeding as necessary, which is farmers' practice, significantly out yielded all weeding treatments except applied herbicide. When field were plowed four or five times, no tillage alone produced significantly the lowest yield. This may be due to complete removal of both broad-leaf and grass weeds, from plots by hand as compared to the chemicals which controls only broadleaf weeds. In general, this study indicated that supplemental weeding is necessary even though nonselective herbicide was sprayed before plowing.

Notillage yield was by far inferior to any tillage practices regardless of weeding system (Table 3). The increase in yield because of tillage was about 414 % over notillage. However, there was no improvement by plowing more than twice. Therefore, the study indicated that extra tillage beyond two plowings may not be necessary if weeds were controlled by nonselective herbicide before plowing.

Table 4 shows that weeding practice did not influence the agronomic characters of tef and soil moisture in the study. Possible explanation for this could be that since nonselective herbicide was applied before plowing, those weeds which germinated after planting might have not influenced agronomic characters of tef during the growing season. However, when tillage effect is considered a different situation can be observed (Table 5). Except for seed weight and soil moisture at 15 to 30 cm depth, there was a significant ($p < 0.05$) tillage effect on all of the plant characters studied. Panicle number in plowed plots was 714 % greater than the number in notillage (Table 5). The small number of panicles in notillage could be attributed to removal of seeds by surface water movement because of poor seed contact with the soil surface. It was also observed that birds and insects pick seeds more easily from unplowed smooth surfaces (notillage) than rough plowed soil surfaces. Hence, these conditions might have contributed to reduced plant stands which eventually resulted in reduced grain yield. Lack of weeding effect on agronomic characters of tef and soil moisture may be due to effective control of weeds by application of nonselective herbicides before plowing.

Sirba-Godetti Light Clay Soil - 1988

There was no significant interaction between main plot (weeding) and sub-plot (tillage) treatments for grain yield and plant characters considered (Appendix J). Hence, tillage and weeding effects averaged over weeding and tillage, respectively, are reported in Tables 6 and 7.

Tillage has affected all plant characters considered except 1000 seed weight and harvest index (Table 6). There was a significant ($p < 0.05$) tillage effect on grain yield. Notillage produced the lowest yield. Plowing once increased yield by 202% over the notillage plot. It seems that this yield difference might have resulted from number of panicles per unit area and panicle weight which are important yield components. Even though there was no clear trend, it seems that plowing produced taller plants, longer panicle, and more panicle branches. Though a relationship between plant height, panicle length and panicle branches and yield is not clear at this point, these plant characters might contribute to panicle weight and hence final grain yield. There was no plowing effect on harvest index; however, there was a significant plowing effect on total drymatter produced per unit area. Lack of plowing effect on harvest index may indicate that all plants in any of plowing treatments allocated an equal proportion of energy to grain production, which means equal number of panicle per unit area could have produced equal grain yield. Since there was significant tillage effect on panicle number per unit area, the most probable contributing factor to grain yield could be panicle number per unit area.

Tillage did not affect soil moisture from 0-15 cm depth at heading stage of tef (Table 6). Even though it seems that there was a tillage effect on soil moisture at other depths and crop growth stages, there was no clear trend of tillage effect on soil moisture. One plausible explanation for some of the differences observed could be due to moisture accumulation arising from lack of well leveled plots which is commonly observed in oxen plowed field. The lack of plowing effect on soil moisture content could be due to ample rainfall throughout the growing season.

Noweeding produced significantly ($p < 0.05$) lower yields than weeded plots (Table 7). Hand weeding or chemical herbicide once at early tillering stage of tef produced significantly higher ($p < 0.05$) yield but there was no significant difference between chemical herbicide and farmers weeding practice. Even though nonselective herbicide was applied before plowing, data indicated that hand weeding is necessary to increase yield. Another conclusion from this data (Table 7) is that weeding practices recommended for conventional tillage after planting (Birhanu, 1985) can work for tef production under reduced tillage provided weeds are sprayed with a nonselective broad spectrum herbicide like paraquat or glyphosate before plowing.

Sirba-Godetti Light Clay Soil - 1989

Statistical analysis for 1989 experiment on Sirba-Godetti light clay soil indicated that there was significant interaction ($p < 0.05$) between main plots and sub-plots for grain yield but there was no interaction for other plant characters (Appendix K). Notillage produced the lowest yield of all plowed plots under all weeding practices considered in this study (Table 8). Trends of tillage effects were similar under all weeding practices except for hand weeding at early tillering stage of tef which might have caused the tillage by weeding interaction observed. Nevertheless, the reason for such discrepancy, which was not consistently observed, was not clear at this point. Generally, yield increase because of plowing once was about 282 % over no-tillage. But there was no significant yield increase because of additional plowing provided weedy vegetations are controlled by nonselective broad spectrum herbicides.

Noweeding was inferior to all weeding practices considered under each plowing treatment (Table 8). Yield increase because of weeding was 181 % on the average over no weeding plots which indicated that additional weeding is required even though nonselective herbicide was applied before plowing. There were no significant differences between herbicide and hand weeding. Hence, the choice between chemical herbicide and hand weeding depends upon availability of labor, economic situation of individual farmer and availability of herbicides on the market.

There was significant reduction in all agronomic characters considered when field was not plowed compared to plowing except for weed count and 1000 seed weight (Table 9). Plowing once improved stand establishment as evidenced by panicle per unit area by about 370 % over no-tillage. There was no significant stand increase because of additional tillage. It seems that plowing 5 times has significantly increased plant height and panicle weight as compared to plowing once. However, there was no difference between 1, 2, 3, or 4 times plowing. In general, plant characters such as panicle per unit area, plant height, panicle weight, panicle branch, and final grain yield were better in 1988 than in 1989 which could be attributed to better seasonal rainfall distribution in 1988 than 1989 and grasshopper outbreak at early germination stage of tef in 1989. Effect of tillage on weed density was assessed by counting number of broadleaf and grass weeds at early tillering stage of tef before weed control treatment was applied. Tillage did not influence broad leaf distribution but grass weeds (Appendix L). There were more grass weeds in notillage than tilled plots (Table 10). However, there was no difference between plowed plots for grass weed distribution. Lack of tillage effect on broadleaf weeds may be due to applied herbicides before plowing which controlled germinated weeds. Similar reasoning may apply for grass weeds but it seems that regeneration of grass weeds from underground stems might have contributed to difference observed. Hence, more grass were found on undisturbed plots. Except for panicle per unit area, there was no weeding effect observed (Table 10). Lack of weeding effect on most agronomic characters could be due to application of broad spectrum herbicide before plowing which eliminated competitive advantage of germinated weeds before planting tef. It also seems that tillage did not affect soil moisture at tillering, heading, and maturity stage of tef except at 15-30 cm depth at heading stage of tef (Table 11). Weeding practice did not affect soil moisture (Table 12), which could be because of one or more of the following factors. First, as indicated earlier, number of panicles (plants) per unit area in untilled plots was significantly lower than in tilled plots (Table 10), but the opposite was observed for number of grass weeds per unit area (Table 9). Hence, effect on soil moisture which could have been observed because of differences arising from tef plants per unit area might have been compensated by number of weeds per unit area observed in untilled plots. Second, little differences which could have been observed because of little variations in plant populations in different plots might have been compensated by sufficient moisture observed during the growing season.

Sirba-Godetti Black Clay Soil - 1988

Statistical analysis of data indicated that there was significant tillage effect on grain yield of tef (Appendix M). Plowing increased yield by 228 % over yield from plots that were not plowed with no differences between plowed plots (Table 13). Comparison of different weeding practices averaged over all tillage indicated that weeding more than once by hand was better than the three weeding treatments in the study. Hand weeding at tillering or application of selective herbicide once at early tillering stage of tef was not better than no weeding (Table 13). This could be due to regeneration of weeds in hand weeded plots or regeneration and/or high infestation of grass weeds in herbicide applied plots which was evidenced by high grass weed infestation on the site.

There were no significant ($p < 0.05$) tillage effects on plant height, panicle weight, broad leaf weed distribution, and soil moisture at heading (Table 14). But there were significant tillage effects on panicle braches and panicle length. The tillage effects mentioned above did not seem to follow trend of tillage effect on grain yield where significant differences between no-tillage and tilled plots were observed. Therefore, contribution of these factors to differences observed in grain yield was most unlikely. Since difference between tilled and untilled plots for number of panicles per unit area followed similar trend as in yield response to tillage (Table 14), it seems that tillage might have more influence on panicle formation to influence yield than on any other agronomic characters considered under current study.

More grass weeds were observed in plots which were not tilled than tilled plots (Table 14). As number of tillage increased there was a decreasing tendency of grass weeds but tillage effect was not observed on broadleaf weed distribution. It was possible that more plowing might have exposed underground stems from where grass weeds regenerate. Exposed underground stems lose moisture because of evaporation thereby leading to desiccation. Therefore, it is expected that regeneration of grass weeds in plowed plots would be reduced. Lack of significant tillage effect on broadleaf weeds might be attributed to equal regeneration of these weeds from weed seeds after plowing was completed since those which germinated were controlled by herbicide before plowing.

There were weeding effects on weed distribution and on number of tef panicle per unit area (Table 15). The significant difference observed could be because of the low number of plants observed in unplowed plots. However, there were no significant differences observed between the remaining weeding treatments. Since panicle number per unit area is expected to influence final yield, additional weeding is necessary to produce tef under reduced tillage system. The lack of significant tillage effect (Table 14) or weeding practice on soil moisture at heading stage of tef might be due to ample moisture during the growing season.

Sirba-Godetti Black Clay Soil- 1989.

There was no significant ($p < 0.05$) interaction between main plots and sub-plots (Appendix N) for grain yield and agronomic characters.

Notillage produced inferior yield to all of the tillage treatments but there was no significant difference between plowed plots (Table 16). Plowing one time increased yield by 265 % over notillage indicating that tillage is required for tef production. However, as shown in Table 16, additional plowing beyond the first one did not increase yield. When averaged over all weeding practices and compared to no weeding, weeding increased yield by about 143 %. Therefore, even though herbicide was applied before plowing to control weeds, additional weeding is required to increase yield.

Tillage affected all plant characters considered in the study except 1000 seed weight (Table 17). Panicle per unit area, plant height, and branch per panicle from notillage were less than from tilled plots, but there were no significant differences between 2, 3, 4, or 5 times tilling. Even though panicle weight significantly increased as a result of tillage, there was no consistent tillage effect trend between tillage treatments. It seems that yield difference observed (Table 16) might have come from panicle per unit area and panicle weight. Since there was no significant tillage effect on 1000 seed weight, it seems most unlikely that this plant character contributed to yield difference observed in the current study. It was found that there were more grass weeds in plots that were untilled than tilled plots. However, there were significant differences among tilled plots in grass weed distribution. No-till plots contained 260 % more grass weeds than plowed plots. Except for one time tillage, for reasons not clear now, it seems that there was no tillage effect on broadleaf weeds. Generally, there were more grass weeds than broadleaf weeds in all plots which could be due to regeneration of grass weeds from underground stems.

There were significant weeding effects on number of panicle per unit area, plant height, and panicle weight, but there was no significant weeding effect observed on panicle branch, panicle length, and 1000 seed weight (Table 18). The larger panicle weight and panicle number produced by hand weedings, which are either farmers practices or weeding once at tillering stage of tef, might have contributed to yield difference observed. Hand weeding, though laborious and time consuming, may be effective in removing grass weeds which could not be possible by selective herbicides applied after tef was planted.

Soil moisture determined before plowing indicated initial variation of soil moisture from plot to plot but not variation because of plowing (Table 19). Soil moisture was higher at tillering stage than before plowing and heading stage of tef because of total amount of precipitation in August, a time when tef tillers, as compared to mid-September, heading stage of tef (Appendix B). At tillering stage of tef, it seems that plowing more than once accumulated more moisture at 0-15 cm depth which may be due to accumulation of moisture in two to five times plowed plots. However, there was no consistent plowing effect trend on soil moisture at 15-30 cm depth. There was no significant tillage effect observed on soil moisture at heading stage of tef (Appendix O). Generally, effect of tillage on soil moisture was not consistent which could be due to enough precipitation during the growing season (Appendix B).

There were significant weeding effects on broadleaf weeds and soil moisture at heading (Appendix O). Noweeding had largest broadleaf weed infestation per unit area than the remaining weeding treatments; whereas, there was no significant difference between the weeded plots

(Table 20). Generally, it was observed that there were more grass than broadleaf weeds in black cay than light clay soils. Whether this was because of the differences in clay content of the two soils (Appendix A) was not clear. Plots with noweeding and farmers weeding practice had lower moisture than hand weeded or chemical applied plots (Table 20). Low moisture in plots that were not weeded could be because of larger broadleaf weeds observed in plots that were not weeded than in weeded plots (Table 20). Though weed density in farmers weeding practice was not larger than the remaining weeding treatments, the reason for difference observed in current moisture content of the soil was not clear.

SUMMARY AND CONCLUSION

Experiments were conducted for two seasons, 1988 and 1989, on three sites, Arsinegelle, Sirba-Godetti light clay soil, and Sirba-Godetti black clay soil. The purpose of the study was to evaluate the effect of tillage and weed control practices on yield and yield components of tef. Statistical analysis showed that there were significant differences between seasons which could be because of erratic rainfall distribution in the 1989 growing season.

Arsinegelle. In 1988, weeding significantly affected grain yield. No weeding produced the lowest yield of 549 kg ha^{-1}. There were no significant differences between the other weeding treatments. Yield loss due to weeds was about 26 % of the highest yield. Significant differences were observed between tillage treatments. Notillage produced the lowest yield, but there were no significant differences between 2, 3, 4, and 5 times tilling. Notillage also produced the lowest number of tef panicle per unit area.

In 1989, noweeding produced the lowest yield under no tillage. However, when plots were tilled twice there was no significant difference between no weeding and hand weeding once at early tillering stage of tef. Notillage produced significantly lower yield than all of the tillage treatments. Yield increased by about 414 % because of extra tillage. Weeding did not influence soil moisture and agronomic characters of tef. However, tillage significantly affected all the agronomic characters except seed weight and soil moisture. Notillage negatively affected all the agronomic characters of tef, except 1000 seed weight and panicle length.

Sirba-Godetti light soil. In 1988, tillage significantly affected all plant characters except seed weight and harvest index. Notillage produced significantly lowest yield than tilled plots. Yield increased by 202 % because of plowing once, but there were no significant differences between plowing 1, 2, 3, 4 or 5 times. Soil moisture was not affected by tillage. Hand weeding or herbicide once at early tillering produced significantly highest yield; whereas noweeding produced the lowest yield.

In 1989, notillage produced significantly lowest yield than all other tillage treatments. Yield increased by 282 % because of plowing once. There was no significant yield increase because of additional tillage beyond one time plowing. All plant characters studied, except weed count and seed weight, were negatively affected by notillage. Assessment of total weed infestation by type indicated that higher number of grass weeds were found in notilled plots than tilled plots; whereas the reverse was true for broadleaf weeds. Of all the plant characters studied weeding treatment affected number of panicle m^{-2}.

Sirba-Godetti black soil. In 1988, notillage produced significantly lower yield than all the tillage treatments. There were significant differences between tilled plots. Tillage did not affect all agronomic characters studied except panicle branch and panicle length. More grass weeds were observed in notillage plots. When plots were not plowed, weeding more than once gave better yield. When plots were plowed 1, 2, or 3 times, additional weeding did not increase yield.

Effect of weeding treatment averaged over tillage indicated that hand weeding more than once gave better yield than all weeding treatments in the study. Of all the plant characters studied number of panicle m^{-2} was affected by weeding treatment.

In 1989, as in the previous reports, no tillage produced the lowest yield of all tillage treatments. No significant differences were observed between tilled plots. All plant characters studied, except seed weight, were affected by tillage. Soil moisture at 0-15 cm depth at tillering stage was found to be lowest in plots that were not plowed. However, there was no tillage effect on soil moisture at 15-30 cm depths. Significant yield increase was observed because of weeding, but significant differences were not observed between the weeded plots regardless of weeding type. Weeding significantly affected number panicle m^{-2}, plant height, panicle weight, and soil moisture.

In general, tef yield performance in 1988 was found to be better than in 1989 which could be because of erratic rainfall distribution encountered and grasshopper infestation in 1989. This study indicated that plowing more than once may not be beneficial provided nonselective herbicides are applied to control weed flush before plowing, which means tef can be produced under reduced tillage. Even though nonselective herbicide was applied before plowing, the study indicated that additional weeding either by hand or chemical once at early tillering stage of tef increased yield. The use of chemical or hand weeding depends upon availability of labor, chemical in the market and financial status of individual farmer. Of the plant characters studied, number of tef panicles per unit area was the most sensitive to both tillage and weeding practices. Generally, consistent tillage or weeding effects were not observed on soil moisture under the current study. Since this study was conducted under relatively high rainfall areas different result may be expected in low rainfall areas. Therefore, this finding merits further investigation under different environmental conditions.

REFERENCES

Bharati, O. C., D.K. Whidham, and R. D. Voss. 1986. Soybean response to tillage and nitrogen, phosphorous and potassium fertilization. Agron. J. 78:947-950.

Baeumer, K,. and W. A. P. Bakermans. 1973. Zero tillage. Advances in Agronomy. 25:77-123.

Birhanu Kinfe. 1985. A review of weed control research activities of tef in Ethiopia. In Proceeding of crop protection Research in Ethiopia. Tsedeke Abate (ed.). Addis Abeba, Ethiopia.

Brady, N. C. 1984. The nature and properties of soil. McMillan Pub. Co. USA. pp. 50.

Campbell, R. B., D. L. Karlen, and R. E. Sojka. 1984. Conservation tillage for maize production in the U. S. Southeastern coastal plains. Soils & Till. 4:511-529.

Cannel, R. Q. 1985. Reduced tillage in north western Europe. A review. Soils & Till. 5:129-177.

Deibert, E. J., and R. A. Utter. 1989. Sunflower growth and nutrient uptake: Response to tillage, hybrid maturity, and weed control method. Soil Sci. Soc. Am. J. 53:113-138.

Elliot, J. G., F. B. Ellis, and F. Pillard. 1977. Comparison of direct drilling, reduced cultivation and ploughing on the growth of cereals. J. Agric. Sci. 89:621-629.

Elmore. R. W. 1987. Soybean cultivar response to tillage system. Agron. J. 79:114-119.

Elmore, R. W. 1987. Soybean cultivar response to tillage systems. Agron. J. 79:114-119.

Engstrom, E. 1974. Crop protection trials 1967-1972. Chilalo Agricultural Development Unit publication No. 97. P 50. Ministry Agric., Ethiopia.

Kayombo, B., and R. Lal. 1986. Effect of soil compaction by rolling on soil structure and development of maize in no till and disc plowing system on a tropical alfisol. Soils & Till. Res. (Neth.) 7:117-134.

Lindsay, J. I., O. Yaboah, and J. A. Gumbs. 1983. Effect of different tillage methods on maize growth on tropical inceptisol with impeded drainage. Soil & Tillage Res. (Neth.). 3:185-196.

Pereirra, H. C. 1975. Agricultural science and the tradition of tillage. Outlook on Agric. 8:211-212.

Richey, C. B., D. R. Griffith, and S. D. Parsons. 1977. Yield and cultural energy requirements for corn and soybean with various tillage planting systems. Adv. Agron. 29:141-182.

SAS Users Guide: Statistics Version 5 Edition. 1985. SAS Institute Inc. Cary, NC.

Seifu Ketema. 1986. Food self sufficiency and some roles of tef (Eragrostis tef) in the Ethiopian agriculture. (Paper presented at the National Workshop held at Alemaya Univ. of Agric., Ethiopia. Dec. 8-12, 1986).

Triplette, G. B., Jr., and G. D. Lytle. 1972. Control and ecology of weeds in continuous crop growth without tillage. Weed Sci. 20:453-457.

Unger, P. W. 1984. Tillage system for soil and water conservation.

Wondimagegnehu Mersie, and C. Parker. 1983. Response of tef (Eragrostis tef (Zucc) Trotter) to 2, 4-D and MCPA at various growth stages. Weed Res. 23:53-59.

Van Doren, D. M. Jr., and D. C. Reicoscky. 1987. Tillage and irrigation. In Soybeans: Improvement production, and uses. J. R. Wilcox (ed.) 2nd ed. Agron. Soc. of Amer. 16:319-428.

Young, J. A., R. A. Evans, and B. L. Kay. 1970. Germination Characteristics of range legumes. J. Range Mgmt. 23:90-103.

Table 1. Tef yield and yield components as affected by weeding practice averaged over tillage on Arsinegelle farmers field in 1988.

Weeding	Yield kg ha^{-1}	1000 seed weight mg	Panicle length cm	Panicle weight mg	Panicle branch no.	Panicle m^{-2} no.	Plant height cm
No weeding	594b*	279a	35a	234a	29a	1212b	97b
Farmers practice	801a	208a	36a	227a	25a	1885a	99ab
Weeding at tillering	770a	285a	35a	265a	25a	1763a	93c
Herbicide at tiller	742a	286a	36a	225a	26a	1830a	103a

* Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 2. Tef yield and yield components as affected by tillage practice averaged over weeding on Arsinegelle farmers field in 1988.

			Panicle				
Plant Tillage	Yield kg ha^{-1}	1000 seed mg	length cm	weight mg	branch no.	m^{-2} no.	Plant height cm
0	497c*	266a	31c	230a	25a	237b	88b
2x	816a	238a	37ab	220a	27a	2011a	101a
3x	812a	290a	36b	230a	26a	2190a	100a
4x	746ab	212a	36b	240a	26a	2090a	99a
5x	743b	207a	39a	220a	27a	2050a	103a

* Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 3. Grain yield (kg ha^{-1}) of tef as affected by weeding practices on Arsinegelle farmers' field in 1989.

	Weeding			
Tillage	No weeding	Farmers' practice	Hand weeding	Herbicide
0	143bB*	283aC	245aB	293aB
2x	803cA	1205aA	927bcA	959bA
3x	805cA	1156aAB	1006bA	1089abA
4x	700cA	1203aAB	1159abA	1016aA
5x	698cA	1133aB	1147aA	945baA

* Means followed by the same small letters with in a row are not significantly different (LSD, $p < 0.05$).

* Means followed by the same capital letters within a column are not significantly different (LSD, $p < 0.05$)

Table 4. Some agronomic characters of tef and soil moisture at selected growth stages of tef as affected by weeding on Arsinegelle farmers field in 1989.

	Plant characters+						% Soil moisture at			
							Heading		Maturity	
Weeding	1	2	3	4	5	6	7	8	9	10
No-weeding	1757*	290	28	252	95	21	23	20	10	12
Farmers practice	2056	283	30	288	95	22	20	24	12	13
Weeding once	1937	264	28	260	92	22	20	20	11	13
Herbicide once	2027	284	29	277	93	21	19	22	13	12

\+ 1) panicle m^{-2}, 2) 1000 seed weight (mg), 3) panicle length (cm), 4) panicle weight (mg), 5) plant height (cm), 6) panicle branch, 7) 0-15 cm depth, 8) 15-50 cm depth, 9) 0-15 depth, 10) 15-30 cm depth.

* Differences within a column were not significant for any characteristics (LSD, $p < 0.05$).

Table 5. Some agronomic characters of tef and soil moisture at selected growth stages of tef as affected by tillage on Arsinegelle farmers field in 1989.

	Plant characters+						Soil moisture at			
							Heading		Maturity	
Tillage	1	2	3	4	5	6	7	8	9	10
0	329c	298a	22b	193c	67c	13b	18b	19a	9c	11b
2x	2365ab	288a	30a	311a	95b	24a	21ab	20a	12abc	13ab
3x	2366ab	275a	30a	246bc	97b	23a	17b	22a	10bc	11b
4x	2221b	284a	31a	316a	103a	23a	21ab	23a	13a	14a
5x	2438a	253a	31a	278ab	108a	23a	25a	24a	12ab	14a

+ 1) panicle m^{-2}, 2) 1000 seed weight (mg), 3) panicle length (cm), 4) panicle weight(mg), 5) plant height (cm), 6) panicle branch, 7) 0-15 cm depth, 8) 15-50 cm depth, 9) 0-15 depth, 10) 15-30 cm depth.

* Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 6. Tef yield and yield components as affected by tillage averaged over weeding practices on Sirba-Godetti light clay soil in 1988.

	Tillage					
	None	1x	2x	3x	4x	5x
Yield (kg ha^{-1})	704c	1424ab	1312b	1494a	1427ab	1317ab
1000 seed weght (mg)	314a	341a	327a	344a	313a	319a
Panicle						
branch (no.)	28b	32a	30ab	29b	32a	30ab
length (cm)	39b	41ab	42a	43a	41ab	43a
wieght (mg)	175b	350a	295a	360a	318a	312a
no. m^{-2}	1692c	3825ab	4013ab	4039a	3491b	3938ab
Plant height (cm)	107b	112ab	113ab	114a	114a	115a
Harvest index	0.25a	0.23a	0.22a	0.23a	0.24a	0.23a
Total dry matter Kg ha^{-1}	2943b	6029a	5903a	6394a	6020a	5647a
% Soil moisture at tef						
heading (0-15 cm)	32a	33a	32a	32a	32a	32a
(15-30 cm)	32b	32b	36a	34ab	35a	31b
maturity (0-15 cm))	18ab	21a	19ab	15b	21a	18ab
(15-30 cm)	21ab	23a	21ab	18b	20ab	18b

Means followed by the same letters within a row are not significantly different (LSD, $p < 0.05$).

Table 7. Tef yield and yield components as affected by weeding averaged over tillage on Sirba-Godetti light clay soil in 1988.

	Weeding			
	No weeding	Farmers practice	Hand weeding	Chemical
Yield kg ha^{-1}	1138c	1229b	1411a	1340ab
1000 seed weight	289a	328a	305a	306a
Panicle				
branch (no.)	30a	30a	30a	31a
length (cm)	41a	41a	42a	42a
wieght (mg)	268a	273a	248a	232a
no. m^{-2}	3165b	3535ab	3682a	3618a
Plant height (cm)	115a	110a	111a	115a
Harvest index	0.23a	0.22a	0.25a	0.24a
Total drymatter Kg ha^{-1}	5169a	5870a	5418a	5500a
% Soil moisture at tef				
heading (0-15 cm)	31a	32a	32a	33a
(15-30 cm)	33a	34a	34a	34a
maturity (0-15 cm)	20a	18a	18a	19a
(15-30 cm)	19a	19a	19a	22a

Means followed by the same letters within a row are not significantly different (LSD, $p < 0.05$).

Table 8. Grain yield (Kg ha^{-1}) of tef as affected by tillage for specific weeding practices on Sirba-Godetti light clay soil in 1989.

Tillage	Weeding: No weeding	Farmers' practice	Hand weeding	Chemical	Mean
0	216bB*	501bA	606cA	537bA	465b
1x	951aB	1462aA	1280bA	1561aA	1314a
2x	765aB	1427aA	1696aA	1405aA	1324a
3x	773aB	1696aA	1721aA	1536aA	1432a
4x	820aB	1665aA	1628aA	1446aA	1390a
5x	1008aB	1636aA	1487aB	1396aA	1382a
Mean	756B	1398A	1403A	1314A	

* Means followed by the same small letters within a column are not significantly different (LSD, $p < 0.05$).

* Means followed by the same capital letters within a row are not significantly different (LSD, $p < 0.05$).

Table 9. Agronomic characters of tef and weed distribution as affected by tillage on Sirba-Godetti light clay soil in 1989.

						Weeds m^{-2}	
Tillage	panicle m^{-2} no.	Plant height cm	Panicle weight mg	Panicle branch no.	1000 seed wt. mg	Grass no.	Broad leaf no.
0	441b	59c	140c	17b	285a	564a	261a
1x	1486a	80b	271b	25a	301a	221b	289a
2x	1518a	84ab	339ab	25a	318a	224b	321a
3x	1526a	87ab	326ab	25a	290a	186b	227a
4x	1376a	87ab	289ab	26a	290a	249b	238a
5x	1595a	89a	349a	24a	295a	198b	223a

* Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 10 . Agronomic characters of tef as affected by weeding on Sirba-Godetti light soil in 1989.

Weeding	Panicle m^{-2} no.	Plant height cm	Panicle weight mg	Panicle branch no.	1000 seed wt. mg
No weeding	1224a*	85a	267a	24a	297a
Farmers practice	1468a	81a	302a	25a	293a
Hand weeding	1324a	77a	322a	24a	288a
Chemical	1276a	80a	253a	23a	310a

* Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 11. Soil moisture (per cent dry weight) at different growth stages of tef as affected by tillage on Sirba-Godetti light clay soil in 1989.

	Sampling stage							
	Pre-plowing		Tillering		Heading		Maturity	
	depth in cm							
Tillage	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
0	17a	15a	24a	25a	17a	16b	12a	13a
1x	17a	17a	27a	26a	18a	18ab	12a	14a
2x	14a	17a	27a	26a	19a	19a	13a	15a
3x	15a	15a	27a	26a	20a	19a	12a	12a
4x	16a	16a	29a	28a	19a	18ab	11a	12a
5x	15a	18a	28a	27a	19a	19a	12a	11a

Means followed by the same numbers within a column are not significantly different ($p < 0.05$).

Table 12. Soil moisture (per cent dry weight) at different growth stages of tef as affected by weeding on Sirba-Godetti light clay soil in 1989.

	Sampling stage							
	pre-plowing		Tillering		Heading		Maturity	
	depth in cm							
Weeding	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
No-weeding	16a	17a	28a	28a	20a	20a	12a	13a
Farmers practice	13a	16a	26a	27a	17a	16a	11a	11a
Hand weeding	15a	17a	27a	25a	18a	18a	12a	13a
Chemical	17a	17a	27a	26a	20a	19a	12a	13a

Means followed by the same numbers within a column are not significantly different ($p < 0.05$).

Table 13. Grain yield of tef as affected by tillage (averaged over weeding) and weeding (averaged over tillage) on Sirba-Godetti black clay soil in 1988.

Tillage	Mean yield kg ha^{-1}	Weeding	Mean yield kg ha^{-1}
0	651b		
		Noweeding	1177b
1x	1425a		
		Farmer practice	1475a
2x	1533a		
3x	1531a	Hand weeding	1366b
4x	1513a		
		Chemical	1368b
5x	1426a		

* Means followed by the same letters within a column are not significantly different.

Table 14. Agronomc characters of tef as affected by tillage averaged over weeding practices on Sirba-Godetti black clay soil in 1988.

	Tillage					
	None	1x	2x	3x	4x	5x
Plant height (cm)	107a	115a	111a	113a	114a	119a
Panicle						
branch (no.)	28b	32ab	33a	30ab	31ab	32ab
length (cm)	39b	44a	41b	41b	41b	44a
weight (mg)	251a	274a	240a	299a	245a	255a
no. m^{-2}	104b	2453a	2423a	2556a	2391a	2461a
Weed rating (0-5 scale)						
grasses	2.58a	1.1b	0.98b	0.73c	0.68c	0.85b
broad leaves	0.75a	0.70a	0.38a	0.33a	0.60a	0.48a
% Soil moisture at tef						
heading (0-15cm)	28a	29a	29a	29a	29a	29a
(15-30cm)	27a	28a	27a	28a	29a	29a
maturity (0-15 cm))	18b	21ab	18b	18b	18b	22a
(15-30 cm)	17b	20a	20ab	19ab	19ab	21a

Means followed by the same letters within a row are not significantly different (LSD, $p < 0.05$).

Table 15. Agronomc characters as affected by weeding averaged over tillage practices on Sirba-Godetti black clay soil in 1988.

	Weeding			
	No weeding	Farmers practice	Hand weeding	Chemical
Plant height (cm)	116a	111a	114a	111a
Panicle				
branch (no.)	32a	31a	31a	30a
length (cm)	39c	44a	41bc	41bc
wieght (mg)	269a	258a	269a	247a
no. m^{-2}	1322b	2216a	2404a	2184a
Weed rating (0-5 scale)				
grasses	1.30a	0.80b	1.03a	1.5a
broad leaves	1.50a	0.02b	0.40a	0.27b
% Soil moisture at tef				
heading (0-15 cm)	28.9a	28.0a	28.6a	28.7a
(15-30 cm)	28.6a	27.3a	28.6a	27.0a
maturity (0-15 cm)	19.5a	18.8a	20.1a	18.1a
(15-30 cm)	18.9a	19.2a	19.8a	19.6a

Means followed by the same letters within a row are not significantly different (LSD, $p < 0.05$).

Table 16. Grain yield of tef as affected by tillage (averaged over weeding) and weeding (averaged over tillage) on Sirba-Godetti black clay soil in 1989.

Tillage	Mean yield kg ha^{-1}	Weeding	Mean yield kg ha^{-1}
0	417b		
		Noweeding	713b
1x	1106a		
		Farmers practice	1238a
2x	1174a		
3x	1185a	Hand weeding	1039a
4x	1189a		
		Chemical	1163a
5x	1158a		

* Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 17. Agronomic characters of tef and weed distribution as affected by tillage on Sirba-Godetti black clay soil in 1989.

						Weeds m^{-2}	
Tillage	Panicle m^{-2} no.	Plant height cm	Panicle weight mg	Panicle branch no.	1000 seed wt. mg	Grass no.	Broad leaf no.
0	513b	68b	114d	18b	21a	800a	88a
1x	1115a	84a	300abc	28a	33a	351b	45c
2x	1026a	84a	351a	26a	31a	317b	70ab
3x	948a	85a	263c	27a	33a	298b	65b
4x	1068a	87a	269bc	27a	33a	301b	69b
5x	1057a	85a	316ab	28a	32a	283b	63bc

Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 18. Agronomic characters of tef as affected by weeding on Sirba-Godetti black clay soil in 1989.

Weeding	panicle m^{-2} no.	Plant height cm	Panicle weight mg	Panicle branch no.	Panicle length cm	1000 seed wt mg
Noweeding	905b	87a	241c	25a	31a	297a
Farmers practice	1123a	77a	321a	24a	30a	292a
Hand weeding	978ab	79ab	280b	26a	29a	288a
Chemical	810b	85ab	234c	27a	31a	310a

Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 19. Soil moisture (per cent dry weight) at different growth stages of tef as affected by tillage on Sirba-Godetti black clay soil in 1989.

	Sampling stage					
	Pre-plowing		Tillering		Heading	
	depth in cm					
Tillage	0-15	15-30	0-15	15-30	0-15	15-30
0	17a	21ab	30c	32ab	25a	24a
1x	14a	16c	32bc	31b	24a	23a
2x	14a	17bc	33ab	31ab	26a	24a
3x	15a	17c	33ab	32ab	26a	25a
4x	17a	16c	34a	32ab	27a	24a
5x	19a	22a	34ab	34a	28a	26a

Means followed by the same numbers within a column are not significantly different (LSD, p < 0.05).

Table 20. Soil moisture (per cent dry weight) at different growth stages of tef and weed density as affected by weeding on Sirba-Godetti black clay soil in 1989.

Weeding	Weeds m^{-2}		% Soil moisture			
			Tillering		Heading	
	Grass	Broad leaf	0-15	15-30	0-15	15-30
Noweeding	300a	105a	33a	33a	25b	23b
Farmers practice	409a	68b	33a	32a	25b	22b
Hand weeding	443a	51b	32a	32a	26ab	26a
Chemical	412a	40b	31a	32a	28a	26a

Means followed by the same letters within a column are not significantly different ($p < 0.05$).

APPENDICES

Appendix A: Soil analytical data for Sirba-Godetti (Adaa) and Arsinegelle research sites.

Research site	Soil type	Depth cm.	Texture % Sand	Silt	Clay	Class	pH	% OM
Sirba-Godetti	light	0-15	29.4	31.0	39.7	clay	6.5	1.3
		15-30	25.3	24.6	50.1	clay	6.7	1.4
	black	0-15	21.3	26.6	52.2	clay	6.5	1.9
		15-30	23.3	22.6	54.2	clay	6.7	2.0
Arsi-negelle	light	0-15	37.5	39.2	23.3	loam	6.5	2.5
		15-30	34.2	35.0	30.8	loam	6.6	1.3

Appendix B: Monthly rainfall (mm) by decade (10 days) at Debre Zeit Research Center during the year 1988 and 1989 and 30 year mean.

Year	Decade	J	F	M	A	M	J	J	A	S	O	N	D	year total
		month												
1988	1-10	8.8	6.4	0.4	1.5	10.9	49.4	70.6	82.7	82.1	0.0	0.0	0.0	
	11-21	0.0	31.1	0.0	13.4	10.6	26.5	26.7	100.5	65.4	16.7	0.0	0.0	
	21-31	0.0	0.1	1.7	38.0	1.3	45.9	58.6	61.8	42.9	0.0	0.0	0.0	
Monthly total		18.8	37.6	2.1	52.9	22.8	121.8	155.9	245.0	190.4	16.7	0.0	0.0	854.0
1989	1-10	0.0	24.8	0.0	55.2	0.9	20.4	38.7	54.0	54.5	0.0	0.0	0.0	
	11-21	0.0	0.0	38.2	6.6	4.2	17.0	144.2	43.3	20.2	27.4	0.0	0.0	
	21-31	0.0	0.0	42.0	18.6	0.3	24.5	39.6	105.2	23.6	0.0	0.0	12.4	
Monthly total		0.0	24.8	80.2	79.4	5.4	61.9	222.5	202.5	108.3	27.4	0.0	12.4	824.8
30 year mean		10.4	32.9	42.3	66.7	41.7	87.1	237.5	245.8	120.8	20.8	8.3	4.2	918.5

Appendix C. Mean squares for yield, yield component and soil moisture as affected by tillage and weed control practices on Arsinegelle Farmers field in 1988 and 1989.

source	df	Yield kg ha^{-1}	1000 seed mg	Panicle length cm	Panicle weight mg	Plant height cm	Panicle branch no
		mean square x 10^3					
Replication (R)	3	121.2	10.5	0.20	0.49	1.20	0.03
Weeding (W)	3	584.3**	23.9	0.02	2.60	0.10	0.02
R x W (Ea)	9						
Tillage (T)	4	1751.1**	42.4	0.30**	20.7**	3.90**	0.20**
T x W	12	15.2	20.0	0.02	3.20	0.06	0.01
R x T(W) (Eb)	48						
Year	1	569.5**	3254.7**	1.80**	2866.9**	0.60*	0.94**
Year x W	3	62.9*	8.1	0.02	2.60	0.30*	0.30*
Year x T	4	363.7	74.1*	0.03	20.70**	0.80**	0.14**
Pooled error	129+	15.4	0.1	0.01	3.29	0.08	0.01

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

+ Pooled degrees of freedom from three errors (R x W, R x T(W), Year x R(T x W) and high order interaction (Year x T x W).

Appendix C. (continued)

source	df	Parameters measured for one season (1989)				
		Panicle	% Soil moisture			
			Heading		Maturity	
		m^{-2}	0-15	15-50	0-15	15-30
		mean square x 10^3				
Replication (R)	3	560.2	0.30	0.02	0.08	0.09
Weeding (W)	3	363.7	0.04	0.06	0.03	0.01
R x W (Ea)	9	187.2	0.03	0.19	0.02	0.01
Tillage (T)	4	13136.6**	0.17	0.06	0.04*	0.04*
T x W	12	151.3	0.07	0.07	0.01	0.01
R x T(W) (Eb)	48	79.5	0.09	0.11	0.01	0.01

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

\+ Pooled degrees of freedom from three errors (R x W, R x T(W), Year x R(T x W) and high order interaction (Year x T x W).

Appendix D. Mean squares for yield and yield components of tef as affected by tillage and weed control practices on Sirba-Godetti light clay soil in 1988 and 1989.

Source	df	yield kg ha^{-1}	1000 seed wt	panicle length	panicle weight	plant height
		Mean square x 10^3				
Replication (R)		1650.4	123.7	0.03	10.7	0.1
Weeding (W)	3	2024.8	4.1	0.002	12.1	0.3
Tillage (T)	5	3467.9**	12.6	47.8	0.20**	1.6**
T x W	15	66.7	28.9	0.02	5.40	0.6
Year	1	183.4	3996.0**	4.30**	3848.4**	47.8**
Year x W	3	639.9**	2.5	0.01	12.0	0.1
Year x T	5	89.4	26.0	0.06**	48.1**	0.6**
Pooled error	156	87.7	20.9	0.02	5.9	0.1

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix D. (continued)

Source	df	panicle branch	panicle m^{-2}	% Soil moisture at Heading 0-15	Heading 15-30	Maturity 0-15	Maturity 15-30
		Mean square x 10^3					
Replication (R)	3	0.48	13607.9	0.30	0.34	0.33	0.11
Weeding (W)	3	0.01	1042.6	0.03	0.03	0.01	0.03
Tillage (T)	5	0.16**	14449.1**	0.01	0.04	0.03	0.08
T x W	15	0.01	217.5	0.02	0.01	0.04	0.04
Year	1	1.74**	2223.31**	8.60**	11.30**	2.18**	2.60**
Year x W	3	0.02	508.2	0.03	0.06**	0.01	0.02
Year x T	5	0.06**	18094.4**	0.01	0.03	0.04	0.01
Pooled error	156	0.02	569.6	0.02	0.02	0.04	0.04

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix E. Mean squares for tillage and weed control practices on yield and yield components of tef on Sirba-Godetti black clay soil in 1988 and 1989.

Source	df	yield kg ha^{-1}	1000 seed wt	panicle length	panicle weight	plant height	Panicle branch	Panicle m^{-2}	% soil moisture Heading 0-15	% soil moisture Heading 15-30
		Mean square x 10^3								
Rep (R)	3	246.6	156.3	0.06	2.7	0.09	0.02	497.6	0.002	0.05
Weeding (W)	3	1494.8**	16.9	0.01	19.3*	0.48	0.02	363.0	0.04*	0.05*
Tillage (T)	5	3374.4**	11.7	0.27**	54.1**	0.91**	0.22**	3354.4**	0.01	0.02
T x W	15	43.5	29.6	0.02	9.0	0.10	0.03	103.2	0.01	0.02
Year	1	4580.9**	8205.3**	5.79**	3402.6**	45.90**	1.44**	84575.0**	0.03**	0.60
Year x W	3	160.7*	13.9	0.05*	19.2*	0.22	0.02	299.6	0.03*	0.04*
Year x T	5	18.7	12.0	0.10**	54.2**	0.17	0.07*	475.0*	0.01	0.01
Pooled error	156	58.4	18.2	0.02	5.4	0.21	0.03	169.6	0.01	0.01

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix F. Mean squares for tillage and weed control effects on parameters measured for one season on Sirba-Godetti light soil.

		1988		1989			
				% soil moisture at tillering		Weed count at tillering (m^{-2})	
source	df	Harvest index	Total dry-matter	0-15	15-30	Grass	broad leaf
		Mean square x 10^3					
Replication (R)	3	0.002	35637.1	0.34	0.30	274.8	718.6
Weeding (W)	3	0.008	2023.3	0.01	0.06	120.2	104.5
R x W (Ea)	9	0.007	1937.4	0.01	0.04	48.5	54.7
Tillage (T)	5	0.010	25827.9**	0.04	0.02	322.2	24.3
T x W	15	0.001	1347.1	0.01	0.03	29.8	14.8
R x T x W (Eb)	60	0.001	1513.1	0.02	0.03	28.6	15.9

** significant effect at F, $p < 0.01$.

Appendix G. Mean squares for tillage and weed control effect on parameters measured for one season on Sirba-Godetti black clay soil.

		1988		1989			
		Weed rating		Soil moisture at tillering		Weed count at tillering (m^{-2})	
Source	df	Grass	Broad leaf	0-15	15-30	Grass	Broad leaf
						mean square x 10^4	
Replication (R)	3	1.39	0.79	14.4	5.5	17.3	0.13
Weeding (W)	3	2.12**	10.6**	11.1	6.2	9.3	1.90
R x W (Ea)	9	0.63	0.34	7.2	2.3	13.1	0.21
Tillage (T)	5	8.19**	0.47	45.7**	11.0	65.0**	0.30
T x W	15	1.42	0.47	9.8	8.9	6.7	0.20
R x T(W) (Eb)	60	0.50	0.44	11.4	9.6	7.4	0.25

** Significant effect at F, $p < 0.01$.

Appendix H. Mean squares for tillage and weeding effect on yield and yield components of tef on Arsinegelle farmers field in 1988.

Source	df	Grain yield kg ha^{-1}	1000 seed wt	Panicle m^{-2}	Panicle weight	Panicle branch	Panicle length	Plant height
			Mean square. x 10^4					
Rep (R)	3	19.2	3.5	48.4	0.04	0.0020	0.018	0.10
Weeding (W)	3	16.8**	2.9	31.3*	0.01	0.0050	0.001	0.04**
R x W (Ea)	9	1.6	5.0	21.6	0.02	0.0070	0.005	0.02
Tillage (T)	4	27.9**	11.2	975.1*	0.03	0.0009	0.012**	0.06**
W x T	12	0.8	4.0	13.0	0.04	0.0008	0.001	0.01
R x T(W) (Eb)	48	1.1	5.0	11.0	0.02	0.0005	0.001	0.005

* ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix I. Mean squares for tillage and weed control effect on tef yield and yield components on Arsinegelle farmers field in 1989.

Source	df	Grain yield kg ha^{-1}	1000 seed wt	Plants m^{-2}	Panicle weight	Plant height
		Mean square x 10^4				
Replication (R)	3	1.2	0.63	56.0	0.10	0.031
Weeding (W)	3	47.9**	0.24	36.4	0.52	0.006
R x W (Ea)	9	2.4	0.22	18.7	0.45	0.011
Tillage (T)	4	183.4**	0.46	1313.6**	4.15**	0.415**
W x T	12	3.2**	0.32	15.1	0.63	0.002
R x T(W) (Ea)	48	1.1	0.61	7.9	0.69	0.006

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix I. (continued)

Source	df	Panicle branch	Panicle length	% Soil moisture Heading 0-15	Heading 15-30	Harvest 0-15	Harvest 15-30
Replication (R)	3	23.8	86.4	300.0	17.5	82.3	90.2
Weeding (W)	3	3.3	20.4	35.3	64.0	28.5	8.2
R x W (Ea)	9	7.6	10.3	26.5	190.3	17.0	9.7
Tillage (T)	4	353.0**	239.5**	165.8	57.3	35.5**	36.1*
W x T	12	8.6	15.5	73.4	74.1	13.7	12.4
R x T(W) (Ea)	48	8.5	11.3	90.9	113.7	12.9	12.0

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix J. Mean squares of yield and yield components of tef as affected by tillage and weeding on Sirbe-Godetti light clay soil in 1988.

Source	df	Grain yield	1000 seed wt	Panicle length	Panicle weight	Plant height	Panicle branch	Harvest index	Total dry wt
		Mean sq. x 10^4							x 10^4
Rep (R)	3	242.6	23.6	13.2	31.5	32.6	154.8	0.002	3563.7
Weeding (W)	3	34.9*	1.4	5.8	77.4	163.8*	11.7	0.008	202.3
R x W (Ea)	9	17.5	1.7	9.4	56.5	33.7	19.6	0.007	192.2
Tillage (T)	5	135.1**	3.3	30.6	118.9	122.3*	36.0	0.001	2582.8**
T x W	15	9.1	5.9	11.9	36.7	43.7	12.8	0.001	141.2
R x T(W) (Eb)	60	6.5	3.6	15.1	71.6	64.4	16.8	0.001	138.3

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix K. Mean squares of tillage and weed control effect on yield and yield components of tef on Sirba-Godetti light clay soil in 1989.

Source	df	Grain yield	1000 seed wt	Panicle weight	Panicle branch	Panicle length	Plant height	Tef plants m^{-2}
		Mean squares x 10^4						
Rep (R)	3	34.6	0.59	2.19	0.014	0.34	0.05	85.0
Weeding (W)	3	231.6**	0.53	1.80	0.020	0.31	0.06	26.5
Tillage (T)	5	220.6**	0.39	2.52	0.007	0.51	0.06	307.1**
T x W	15	8.2*	0.35	1.41	0.006	0.26	0.10	19.4
Pooled error	69	3.6	0.50	1.22	0.008	0.27	0.11	16.2

*, ** significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix L. Mean squares of tillage and weed control effect on soil moisture and weed counts on Sirba-Godetti light clay soil in 1989.

Source	df	Grass	Broad leaf	Soil moisture before plowing 0-15	before plowing 15-30	at tillering 0-15	at tillering 15-30	Heading 0-15	Heading 15-30	Maturity 0-15	Maturity 15-30
Rep (R)	3	27.4	71.9	28.4	109.4	340.0	302.4	182.4	179.6	112.6	62.7
Weeding (W)	3	12.0	10.4	66.9	6.6	12.0	58.6	41.9	79.6	3.6	21.6
R x W (Ea)	9	4.8	5.5	22.4	17.3	13.6	44.3	11.2	9.6	21.6	23.4
Tillage (T)	5	33.2**	2.4	20.9	29.1	36.4	15.6	16.4	23.9	2.2	32.8
W x T	15	3.0	1.5	25.4	23.0	14.5	29.6	18.2	11.3	29.4	24.1
R x T(W) (Eb)	60	2.8	1.6	26.5	24.1	18.8	32.6	15.2	18.2	27.0	32.9

** Significant effect at F, p < 0.01.

Appendix M. Mean squares of tillage and weeding effect on weeds, yield and yield components of tef on Sirba-Godetti black clay soil in 1988.

Source	df	Grain yield	1000 seed wt	Panicle length	Panicle weight	Plant height	Panicle branch	Weeds	
								Grass	Broad-leaf
		Mean square. x 10^4							
Rep (R)	3	20.2	25.7	17.4	82.7	576.6	48.8	1.38	0.79
Weeding (W)	3	36.8*	2.8	41.3	25.8	144.2	16.8	2.12	10.60**
R x W (Ea)	9	6.4	2.4	34.4	61.4	132.8	26.4	0.63	0.34
Tillage (T)	5	190.0**	2.2	48.1**	79.2	247.3*	37.9	8.19**	0.47
T x W	15	11.7	5.6*	14.9	64.5	85.5	24.9	1.43**	0.43
R x T(W) Eb	60	5.1	2.7	9.6	73.4	64.2	0.5	0.44	

*, ** Significant effect at F, P < 0.05 and 0.01, respectively.

Appendix N. Mean squares of tillage and weed control effect on yield and yield components of tef on Sirba-Godetti black clay soil in 1989.

Source	df	Grain yield	1000 seed wt	Plant height	Panicle m^{-2}	Panicle weight	Panicle branch	Panicle length
		Mean square x 10^4						
Rep (R)	3	43.3	0.40	0.59	42.5	10.7	10.7	87.0
Weeding (W)	3	128.8**	0.42	0.55	41.5**	29.8	29.8	22.8
Tillage (T)	5	149.3**	0.22	0.84	79.8**	248.8**	248.8**	326.8**
T x W	15	1.7	0.41	0.34	6.6	42.5	42.5	17.0
Pooled error	69	23.5	0.30	0.27	9.6	54.9	30.0	16.2

*, ** significant effect at F, $p < 0.05$ and 0.01, respectively.

Appendix O. Mean squares of tillage and weeding effect on soil moisture and weeds on Sirba-Godetti black clay soil in 1989.

		Weeds m^{-2}		% Soil moisture					
				Before plowing		At tillering		At heading	
Source	df	Grass	Broad leaf	0-15	15-30	0-15	15-30	0-15	15-30
		Mean sq. x 10^4							(x 10^4)
Rep (R)	3	17.3	0.13	31.9	22.6	14.4	5.5	10.3	60.6
Weeding (W)	3	9.3	1.89**	16.2	33.4	11.1	6.2	71.8*	74.7**
Tillage (T)	5	64.9**	0.30	62.8	110.3**	45.7**	11.0	15.0	12.3
T x W	15	6.7	0.20	64.0	23.4	9.8	8.9	13.0	15.6
Pooled error	69	8.1	0.24	46.5	25.7	10.9	8.6	18.6	16.2

*, ** Significant effect at F, $p < 0.05$ and 0.01, respectively.

PART II

TEMPERATURE, LIGHT, PLANTING DEPTH AND SOIL TEXTURE EFFECT ON GERMINATION OF TEF (*Eragrostis tef* (Zucc.) Trotter)

ABSTRACT

Tef (Eragrostis tef (Zucc.) Trotter), a major cereal crop in Ethiopia, is planted by broadcasting which exposes seeds to water and wind erosion and bird damage. Covering seeds with soil may reduce these problems and at the same time improves seed contact with soil moisture. Currently, tef planting depth is not known. Moreover, temperature and light requirement of tef seed at germination is not clearly known.

Experiments were conducted to evaluate germination and emergence of tef cultivars (DZ-01-99, DZ-01-354, and Dabbi) at different temperatures, under different light treatments, and in two soil types (clay loam and sandy loam) with variable planting depths. There were significant differences between temperature treatments. At lower temperatures (15 constant and 15/25 °C night/day temperature) germination of both cultivars, DZ-01-354 and DZ-01-99, was significantly lower. At intermediate temperatures, 25 constant and 15/35 °C, both cultivars attained peak germination within 48 hours. At higher temperature, 25/35 day/night and 35 °C, there was a declining tendency in germination of both cultivars. Comparison of both cultivars showed that DZ-01-99 germinated faster than DZ-01-354.

An experiment conducted to evaluate the light requirement of tef seed at germination indicated that tef seed can germinate either under continuous light, dark or alternating dark/light conditions. Planting

depth and soil type effect on germination and emergence of tef cultivars, DZ-01-354 and Dabbi, showed that emergence from surface planting and greater than 20 mm depths was significantly lower than either 5, 10, 15, or 20 mm depths. There were no significant differences between emergence from 5 and 20 mm depths. Dabbi, a relatively earlier maturing cultivar emerged faster than DZ-01-354. Plant height was not affected by planting depths between 5 and 15 mm. However, seedlings emerged from surface and planting depths of greater than 15 mm had significantly reduced height and seedlings that emerged from clay loam were taller than those from sandy loam.

INTRODUCTION

Tef is one of the major cereal crops produced in Ethiopia occupying about 25-30 % of the land area under cereal production. The grain is used for human consumption. The straw is used for animal consumption and as a component of reinforcing mud for plastering walls of houses. With a maturity range of 60 -120 days, tef is produced under variable ecological zones ranging from low (300 mm) to high (1000 mm) rainfall and altitudes ranging from sea level to 2800 m above sea level. It is also produced under variable temperature and soil type. Despite the wide adaptation of the crop, it is not uncommon for adverse environmental conditions to cause crop failure. Evaluation of the germination environment of tef with regards to temperature, light, planting depth and soil texture can be helpful in improving stand establishment under adverse environmental conditions.

Apart from moisture and viable seed, successful seed germination under field condition requires optimum environment such as temperature, light, soil and planting depth. Germination responses to different temperature regimes vary according to crop species (Ross, 1976) reflecting their ecological adaptation (Lodge and Whalley, 1981). Some crop species respond negatively to higher or lower temperature during germination. For example, high temperature in lettuce induced dormancy (Berrie, 1966); whereas both higher and lower temperatures induced dormancy in wild oats (Sawhney, et al., 1984). Cassava will not germinate if temperature is less than 30 °C (Ellis et al., 1982). For some species like sorghum, higher temperature induced loss of viability (Agrawal et al., 1981). According to Katayama and Nakagama (1972) freshly harvested tef seeds show some form of dormancy requiring 6 to 10 weeks for full germination, whereas older seeds require 3 to 7 days at constant temperature of 30 °C. On the other hand, some reports indicate that non-dormant tef seeds require 10 days to attain full germination at alternating temperatures of 20/30 °C for 16h/8h or for 18h/6h night/day temperatures, respectively (Ellis et al., 1985). Nevertheless, no report was encountered indicating alternating temperatures of equal day and night duration, which is similar to tef production environment in Ethiopia.

Planting depth and soil types are also among many factors affecting seedling emergence and stand establishment. The negative effect of deep planting on emergence was reported by Biveridge and Wilsie (1959). But under hot and dry environments and where rainfall is erratic, deep planting is recommended to ensure seedling establishment (Tadmore and Cohen, 1968). How deep a seed can be planted depends upon the crop species and soil type (Tishler and Voigt, 1983; Cox and Martin, 1984; Alba-Avila and Cox, 1988). According to Cox and Martin (1984), Lehmann lovegrass (Eragrostis lehmannia Nees) seeds planted below the surface failed to emerge in any of the soils they considered. Earlier, Tool (1973) reported that bluegrass seeds did not germinate well in darkness.

Currently tef is planted by hand broadcasting which leaves the seeds uncovered. Uncovered seeds are prone to erosion, birds and untimely germination known as ''false starts'' when a light shower is followed by a dry spell (Young et al., 1970). An understanding of germination responses of tef cultivars to temperature, light, planting depth, and soil types may lead to management for better crop stands and production of tef.

The purpose of this study is to identify and describe results obtained in the laboratory and growth chamber designed to determine the effect of: 1) alternating and constant day and night temperatures, 2) the light requirement for germination , and 3) planting depth and soil texture on germination of tef cultivars.

MATERIALS AND METHODS

Temperature Effect

Two tef cultivars, DZ-01-354 and Dz-01-99, white and reddish brown seeds, respectively, were planted in a greenhouse. Seeds harvested and stored from these plants were used in this study in spring of 1988. Fifty seeds of each cultivar were placed on blue blotter germination pads fitted into a plastic box of size 70 x 70 x 30 mm and watered with about 6 ml of de-ionized distilled water (DD H_2O). The experimental design was a 2 x 2 latin square (LSQ) for the two cultivars. The 2 x 2 LSQ was placed on the left and right side of the germination chamber to control any variation within the chamber that may influence the treatments. Hence, a total of 8 boxes were placed on each rack of the germination chamber. The 8 boxes were repeated 3 times which makes a set of 24 boxes for each of the temperature treatments. There were 6 night/day temperature combinations: 15/15, 25/25, 35/35, 15/25, 15/35, 25/35 °C, respectively. Germination test for each set of the 24 boxes was carried out one at a time for each temperature treatment. Each temperature treatment was repeated twice over time.

From a preliminary observation, tef seed was found to fully germinate within 48 hrs at about 25 °C. Based on this observation, trays for each temperature treatment were removed every 24 hr for the 72 hr test period to count germinated seeds. Seeds were considered germinated when shoots extended to a length of about 2 mm. Statistical analysis was carried out and LSD ($p < 0.05$) was used to separate means (SAS, 1985).

Light Effect

Two tef cultivars, DZ-01-354 and Dabbi were used to study the light requirement for germination of tef seed. DZ-01-354 is a late maturing (90-120 days) white seeded cultivar with wide adaptation whereas Dabbi is early maturing (80-95 days) type reddish brown seeded cultivar which is mostly grown as a mono crop in areas with low precipitation or grown as a double crop in high rainfall areas. Fifty seeds of each cultivar were placed in a petri dish containing two layers of Whatman #41 filter paper and watered with 5 ml of DDH_2O. The three light treatments were light, dark, and alternating (12/12 hr) light/dark and were applied to seeds of two tef cultivars for 24, 48, and 72 hr. The treatments were randomly assigned to a tray and placed on three shelves in a germination chamber to make three replications. The germination chamber was set at 25 °C, 55 % RH, and continuous light. The dark treatment was attained by wrapping petri dishes with aluminum foil. The alternate light/dark treatment was attained by wrapping and unwrapping petri dishes with aluminum foil every 12 hr. After the end of each time treatment, 24, 48, and 72 hr, petri dishes were removed from the chamber and seeds were checked for germination. Seeds were considered germinated when shoots were about 2 mm long. Percent germination was calculated on the basis of non-damaged healthy seeds observed visually. Data on percent germination were statistically analyzed using SAS software (SAS, 1985).

Data were tested for significant F values at $p < 0.05$. After treatment effects were found significant at the specified level of probability, differences between treatment means were determined using LSD ($p < 0.0$ 5).

Soil Texture and Planting Depth Effect

Two contrasting tef cultivars, Dabbi early maturing type and Dz-01-354, late maturing type, were studied in Spring 1988 to determine the effect of planting depth and soil type on germination and emergence of seeds. Two soil types, clay loam and sandy loam, were screened to 5 mm, thoroughly mixed and added to 150 x 150 mm plastic pots to 127, 122, 117, 112, 107, 102, and 97 mm depth above the pot base. Twenty five seeds were sown on each soil surface in the pot. Then soil was added to a depth of 127 mm in all pots to attain planting depths of 0, 5, 10, 15, 20, 25, and 30 mm below the soil surface. Pots were subirrigated to avoid soil disturbances and at the same time to keep the soil moist. Emergence was considered complete when the first leaf was 15 mm above the ground surface for the seeds planted at 5 to 30 mm depth or when the first leaf is 15 mm above the soil surface and the seed radicle had penetrated the soil in surface sown pots. Any subsequent emerging seedlings were counted and recorded every day for the 8 day test period and data were converted to percent germination. The experiment was conducted in a growth chamber set at 20/30 °C night/day alternating temperatures, respectively.

Factorial arrangement of treatments were randomly assigned to each block and the experiment was conducted in RCB design with 4 replications. Data were statistically analyzed (SAS, 1985) and LSD ($p < 0.05$) was used to separate the treatment means after treatment effects were found significant (F, $p < 0.05$)

RESULTS AND DISCUSSION

TEMPERATURE EFFECT

Analysis of variance for germination response of tef cultivars to varying day and night temperature indicated that there was significant interaction between the three factors, time after planting, temperature, and cultivars (Appendix A). Therefore, the effect of any one factor was evaluated at fixed level of the remaining two factors and reported in Tables 1, 2, and 3. As indicated in Table 1, there were significant ($P < 0.05$) temperature effects on germination of both tef cultivars throughout the test period. At lower temperatures of 15/15 and 15/25 °C night/day temperatures, respectively, both cultivars did not germinate 24 hours after planting. However, germination increased to 98.4 and 88.8 % for DZ-01-99 and DZ-01-354, respectively as day temperature increased from 25 to 35 °C (Table 1). When day temperature was kept at 35 °C, germination was between 89 and 93 % for DZ-01-354 (Table 1). Even though, 15/35 and 25/25 °C night/day temperatures, have the same average temperature of 25 °C, there were significant differences between germination at 25/25 and 15/35 °C. This may indicate that these tef cultivars establish faster within 24 hours once temperature is above 25 °C and lowering night temperature to 15 °C did not affect germination once day temperature was greater than 25 °C (Table 1).

At 48 hours after planting, neither cultivar had germinated at 15/15 °C night/day temperature. Germination of DZ-01-99 increased to about 97 % whereas DZ-01-354 had 70.8 % germination as day temperature increased from 15 to 25 °C. There were no significant temperature effects on both cultivars once day temperature was above 25 °C. As time progressed to 72 hours after planting, there was no significant difference between the effect of 15/25 and 35/35 °C night/day temperature for DZ-01-99. However, there was significant difference for DZ-01-354 at 72 hours after planting indicating slower response of this cultivar to increasing temperature. As indicated in Table 1 germination of both cultivars increased as temperature increased. Although there was no significant difference between 25/35 and 35/35 °C, there was a decreasing tendency in germination of both cultivars as night temperature increased from 25 to 35 °C at 48 and 72 hours after planting (Table 1).

Data summarized in Table 2 was meant to identify time at which peak germination was attained at a given temperature for a given variety. At 15/15 °C germination of DZ-01-99 was 20.8 % at 72 hours after planting; whereas, there was no germination at 24 and 48 hours. DZ-01-99 attained peak germination at 15/35, 25/35, and 35/35 °C (night/day temperature) 24 hours after planting. When temperature was at 25 °C, this cultivar attained highest germination a day later. Generally, a similar trend was observed for DZ-01-354 except that germination was lower for this cultivar.

Response of the two tef cultivars to temperature was found to be similar except that DZ-01-99 had better germination than DZ-01-354 (Table 3). Generally, the study indicated that when day temperature was about 35 °C and night temperature varied between 15 and 35 °C, germination of more than 98 % was attained by DZ-01-99 24 hours after planting (Table 2). Since there was no significant difference ($p < 0.01$) between 24 and 72 hour germination (Table 2), it can be concluded that DZ-01-99 attained maximum germination within 24 hours. Whereas DZ-01-354 required 48 hours for full germination at the afore mentioned temperatures. When day/night temperature was 25/35 °C, respectively, DZ-01-354 attained full germination 48 hours after planting (Table 2). Since there was no or very little germination at lower temperature (Table 1), this finding where tef attained full germination within short period confirms that tef is a warm season crop. Therefore, germination response of species to temperature regime reflect their ecological adaptation (Lodge and Whalley, 1981).

Hence, it can be generalized in such a way that highest germination of tef cultivars under laboratory conditions can be attained at alternating night/day temperature of 25/35 °C or at mean temperature of 30 °C for 48 hours. In this study tef attained full germination by one day less than the lower range of time reported by Ellis et al., (1985). Since the cultivar used in their study was not indicated, the slight difference observed could be attributed to varietal differences . However, the finding that tef required 10 days to attain full germination (International Seed testing Association (ISTA) cited by Ellis et al., 1985) was far longer than the two days reported in this study.

LIGHT EFFECT

Seed of two tef cultivars, DZ-01-354 and Dabbi, were treated with three light treatments, continuous light, dark, and alternate light (12/12 hours (h) day/night) for 24, 48, and 72 h. Treatment combinations of cultivar, light treatment, and time were randomly assigned to the three replications. Statistical analysis indicated that cultivar, light, treatment, and duration of light treatment significantly (0.05) interact to affect germination of tef (Appendix B). Therefore, each treatment effect was compared at fixed levels of the other two factors and reported (Tables 4, 5, 6).

Seeds of both tef cultivars did not germinate within the first 24 hr (Table 4). There was no significant difference between germination of seeds under continuous light, dark, and alternate treatments for 48, and 72 h. The three light treatments did not affect cultivar DZ-01-354 at 48 and 72 h of the test period. After 48 h of light treatment germination of cultivar Dabbi under continuous dark treatment with 85% germination was significantly better than the continuous or alternate light germination. However, this difference disappeared after 72 h.

Germination responses of the two tef cultivars to the light treatments were compared in Table 5. Except at alternating and continuous light treatment at 48 h when cultivar DZ-01-354 was better then Dabbi, it appeared that there was no significant difference ($p < 0.05$) between the two cultivars. Duration of light treatment comparison indicated that there was no significant difference between the 48 and 72 h for cultivar DZ-01-354 but the 48 h continuous and 12 h alternate light germination of Dabbi was significantly lower than the 72 h (Table 6).

The three factor interaction observed in Table 5 could be because of the low germination of cultivar Dabbi at 48 h for the 2 light treatments indicated earlier.

Generally, it appeared that tef can germinate under alternate or continuous light or dark conditions. According to Tool (1973) a great many changes take place under natural conditions where temperature fluctuations occur. Some non-light requiring seeds buried in the soil sometimes become light requiring (Wesson and Wareing, 1969b). On the other hand dormant seed not sensitive to light at the time of burial in the soil become light requiring during burial (Taylorson, 1970). This acquired light dormancy is attributed to the changing levels of phytochrome (Tool, 1973). Because of such reports in other crops, the current finding that tef can germinate under dark condition has to be confirmed by planting tef seeds in soil media. If this finding is confirmed, tef which is currently planted by broadcasting can be covered by soil at planting to improve seed contact with soil moisture, protect seeds from water and wind erosion, and bird damage thereby increasing seedling establishment.

Soil Type and Planting Depth Effect

Analysis of variance (SAS Institute, 1985) of soil type and planting depth effect on germination of tef cultivars indicated that there was significant interaction between the three factors mentioned earlier at early stage of seedling emergence, 2 days after planting.

However, as days after planting increased, there was neither soil, nor two or three factor interaction effect on emergence of tef. There were significant cultivar and planting depth effects on seedling emergence up to the end of the test period (Appendix C). Analysis of data collected on plant height at the end of the test period indicated that there were significant soil and planting depth effects on plant height, but no significant cultivar effect was observed.

Planting depth had significant effect on emergence of any given cultivar for a given soil type (Table 7). Lower emergence from surface planting could be due to reduced seed moisture contact resulting from evaporation of moisture from surface of sub-irrigated soil as compared to other planting depths. Both tef cultivars, DZ-01-354 and Dabbi had better germination in clay loam than sandy loam soils when surface planted which could be due to better water holding capacity of clay loam soil than sandy loam. DZ-01-354 had significantly higher germination in sandy loam soils than clay loam at 5 mm depth. At this depth emergence was about 33 % from sandy soils where as it was about 17 % from clay loam soil. Contrary to DZ-01-354, Dabbi had better emergence from clay soils than from sandy loam at 5 mm depth. However, at depths greater than 5 mm there was no significant difference at early stage of germination. Comparison of the 2 cultivars at a given depth and a given soil type indicated that Dabbi established faster than DZ-01-354.

As days after planting progressed, from day three on, there were no soil but there were cultivar and planting depth effect on emergence of tef (Appendix C). Therefore, cultivar effect averaged over soil type and planting depth was reported in Table 8. Emergence ranged from 7 to about 70 % for DZ-01-354 whereas for Dabbi it ranged from 14 to 75 % for 2 and 14 days after planting, respectively, and it seems that emergence was complete by about 7 days after planting for both cultivars. Dabbi which is relatively early maturing type showed better seedling establishment than DZ-01-354. At 2 days after planting emergence of Dabbi was about 100 % more than DZ-01-354. However, the wide emergence gap between the two cultivars narrowed down to about 8 % at the end of the test period, 14 days after planting. Nevertheless, there were significant differences between the two cultivars throughout the test period in seedling emergence and establishment.

Effect of planting depths averaged over cultivar and soil type were shown in Table 9. There were significant differences between planting depths at any given day after planting. Surface planting was inferior to all the planting depths studied throughout the test period. At 3 days after planting there was no significant difference between 5 and 15 mm depths. As days after planting progressed beyond 3 days, there was no significant difference between 5 and 20 mm planting depth. Generally, emergence increased as seeds were covered by soil and as planting depth increased. Regression analysis on percent emergence and planting depth for 4 and 14 days after planting showed that quadratic function was significant ($p < 0.01$) with r^2=0.71 and 0.67, and 0.70 and 0.66 for cultivars DZ-01-354 and Dabbi, respectively, and was used to predict emergence of tef cultivars from the soil better than the linear and cubic functions (Fig. 1). As indicated in Table 9, surface planting was inferior to all planting depths studied. The most probable reason could be increasing moisture gradient from soil surface to atmosphere. As planting depth increased, since the soil was sub-irrigated, the moisture stress gradient from soil to atmosphere decreases thereby encouraging seeds to germinate. As also reported by Biveridge and Wilsie (1959) and Parker and Taylor (1965), deeper planting was not favorable for tef emergence. In this study tef seed emergence was not affected when planting depth was between 5 and 20 mm. However, emergence was affected when seeds where planted deeper than 20 mm which could be due to lack of enough stored energy in the tiny tef seeds, about 0.88 mg in weight and 0.50 mm in size (Lester and Bekele, 1981). A similar finding was reported by Tishler and Voigt (1983) that Wilman lovegrass emergence was affected when planting was deeper than 20 mm.

This study revealed that surface planted seeds were inferior to covered seeds in seedling establishment. Cox and Martin (1984) also suggested planting seeds below the soil surface is advisable because of faster surface drying under hot environment, even though their study indicated surface planted seeds germinated better than covered seeds. This situation is even more serious in coarse than in fine textured soils which could be attributed to low water holding capacity of the former soil. The two tef cultivars, early and late maturing types, were found to respond differently to planting depth regardless of soil type and planting depth (Table 8). Dabbi, an early maturing cultivar, was found to establish faster than DZ-01-354, a late maturing type, in both soil types.

As indicated in the mean square table (Appendix C), there were significant soil type and planting depth effects on plant height measured 14 days after planting. Plant height data averaged over cultivars were reported in Table 10. Plant height as affected by planting depth when averaged over cultivar and soil type ranged from 6.0 to 9.6 cm for surface planted and seeds planted at 10 mm depth, respectively. As indicated in Appendix C, there were no significant differences between plant height of seeds planted at 5 and 15 mm. However, there were significant decreases in plant height as planting depth increased to more than 15 mm. The fact that surface planting produced shortest plants could be due to increased moisture gradient from soil surface to atmosphere which may encourage evaporation of moisture from surface soil. Deeper planted seeds also produced shorter plants because of longer time required for seeds to emerge as compared to shallower planted seeds. Soil type significantly affected plant height (Appendix C), where seeds planted in clay loam soils produced relatively taller plants than those planted in sandy loam soils. The difference observed could be attributed to inherent difference in water holding capacity of the two soils. Contrary to other Eragrostis species (Lovegrass) reported by Cox and Martin (1984) who stated that emergence was poor from soils with expanding clay fractions (silty clay loam) as compared to coarse textured soils, the two tef cultivars studied emerged and grew better in clay loam soils than in sandy loam soils.

SUMMARY AND CONCLUSION

Two tef cultivars, Dabbi and DZ-01-354, were used to evaluate light and planting depth effects on germination whereas DZ-01-99 and DZ-01-354 were used in the experiment designed to investigate temperature effects on germination of tef seeds. There was significant interaction between cultivar, time, and temperature.

Germination of both tef cultivars was significantly lower at 15/15 and 15/25 °C night/day temperature than higher temperature treatments. DZ-01-99 attained peak germination within 24 hours when day temperature was kept at 35 and night temperature varied from 15 to 35 °C. Whereas, DZ-01-354 required 48 hours to attain peak germination. When day temperature was kept at 35 °C and night temperature was greater than 25 °C, there was a declining tendency in germination of both cultivars. Comparison of both tef cultivars indicated that DZ-01-99 had better germination potential than DZ-01-354.

In general, this study indicated that tef seeds germinated better in warm than cool temperature reflecting their ecological adaptation. Second, full germination of tef under laboratory condition can be attained within 48 hours at alternating temperature of 25/35 or at 30 °C constant temperature. Third, germination potential and response time difference to temperature observed between the two cultivars warrants further investigation in germination response of tef germplasm to temperature. Such investigation may also help to group cultivars according to their temperature requirements for better tef production.

In the study to determine light requirements of tef seeds for germination, two tef cultivars, DZ-01-354 and Dabbi, were treated with continuous light, dark, and alternating light and dark for 24, 48, and 72 hours. It was found that there were significant interactions between cultivar, light, and duration of light treatments. The interaction observed was because of lower germination of Dabbi in continuous light and alternating light and dark treatments at 24 and 48 hours. However, at 72 hours there were no significant differences between the treatment effects on germination of both cultivars. Therefore, tef seed can germinate under light or dark conditions. Practical implication of this finding is that tef seed which is currently planted by broadcasting and left uncovered can be covered by soil at planting to improve seed contact with soil moisture, minimize displacement of seeds by water and wind erosion and birds damage for better seedling establishments to increase yield.

Dabbi and DZ-01-354, early and late maturing tef cultivars were used to evaluate effect of planting depth and soil type on germination of tef seeds. It was found that soil type did not affect emergence but plant height measured at the end of test period was affected. Cultivar did not affect plant height but did affect emergence. Planting depth affected both emergence and plant height. Comparison of planting depth effect on emergence indicated that there was no significant difference between 5 and 20 mm depths. Surface planting and planting depths greater than 20 mm significantly affected emergence. Regression analysis indicated that quadratic function was significant and predicts emergence better than the linear and cubic functions. Comparison of the two cultivars indicated that emergence of Dabbi was faster than DZ-01-354. Peak emergence was attained by both cultivars at 7 days after planting. Plant height was not affected when planting depth was between 5 and 15 mm. Seeds planted in clay loam soils produced taller seedlings than sandy loam soils. Therefore, it can be concluded that tef seed can be planted at planting depths between 5 and 20 mm for better seedling establishment.

REFERENCES

Agrawal, P. K., R. Patil, M. Debani, and D. Singh. 1981. Effect of relative humidity and temperature on germination of seeds of two Fl sorghum hybrids and their parents. J. Seed Tech. 6:32- 37.

Alba-Avila, A. D., and J. R. Cox. 1988. Planting depth and soil texture effect on emergence and production of three alkali sacations. J. Range mgmt. 41:216-220.

Berrie, A. M. 1966. The effect of temperature and light on the germination of lettuce seeds. Physiol. Plant. 190:429-436.

Biveridge, J. C., and C. P. Wilsie. 1959. Influence of depth of planting, seed size and variety on emergence and seedling vigor in alfalfa. Agron. J. 51:731-734.

Cox, F. R., and M. H. Martin. 1984. Effects of planting depth and soil texture on the emergence of four lovegrass specie. J. Range Manage. 37:204-205.

Ellis, R. H., T. H. Hong, and E. H. Roberts. 1982. An investigation of constant and alternating temperature on the germination of casava seeds using a two dimensional temperature gradient plate. Ann. Bot. 49:241-246.

Ellis, R. H., T. H. Hong, and E. H. Roberts. 1985. Handbook of Seed Technology for Gene banks vol. II. Compendium of specific germination information and test recommendations. Intnl. Board for Pl. Genetic Resource, Rome. pp. 390-392.

Katayama, T. C., and Nakagama, A. 1972. Studies on the germination behavior of teff seeds (Eragrostis abyssinica Schard.) with the emphasis on storage conditions. Japanese J. Trop. Agric. 16:97-105.

Lester, R. N. and E. Bekele. 1981. Amino acid composition of the cereal tef and related species of Eragrostis (Graminae). Cereal Chem. 58: 113-115.

Lodge, G. M. and R. O. B. Whalley. 1981. Establishment of warm season native perennial grass on the north west slopes of New South Wales. I. Dormancy and Germination. Aust. J. Bot. 29:111-119.

Parker, J. J. Jr., and H. M. Taylor. 1965. Soil strength and seedling emergence relations I. Soil type, moisture tension, temperature, and planting depth effects. Agron. J. 57:289-291.

Matthew, S., and Ross, M. A. 1976. The effect of temperature on germination and early growth of tree plant species indigenous to Central Australia. Aust. J. Ecol. 1:259-263.

Ross, M. A. 1976. The effect of temperature on germination and early growth of tree plant species indigenous to Central Australia. Aust. J. Ecol. 1:259-263.

SAS Users Guide: Statistics Version 5 Edition. 1985. SAS Institute Inc. Cary, NC.

Sawhney, R. A., A. I. Hsiao, and W. A. Quick. 1984. Temperature control of germination and its possible role in the survival of a non dormant population of Avena futua. Physiol. Plant. 61:331-336.

Tadmore, N. H., and Y. Cohen. 1968. Root elongation in the preemergence stage of Mediterranean grasses and legumes. Crop Sci. 8:416-419.

Taylorson, R. B. 1970. Changes in viability of weed seeds in soils. Weed Sci. 265-269.

Tishler, C. R., and P. W. Voigt. 1983. Effect of planting depth on vegetative characteristics of three forage grasses at 14 days post emergence. Crop Sci. 23:481-484.

Tool, V. K. 1973. Effect of light, temperature, and their interactions on germination of seeds. Seed Sci. and Tech. 1:339-396.

Young, J. A., R. A. Evans, and B. L. Kay. 1970. Germination characteristics of range legumes. J. Range Mgmt. 23:98-103.

Voigt, W. 1983. Effect of planting depth on vegetative characteristics of three forage grasses at 14 days post emergence. Crop Sci. 23:481-484.

Wesson, G. and P. F. Wareing. 1969. The induction of light sensitivity in weed seeds by burial. J. Expt. Botany. 20:414-425.

Table 1 : Effect of different temperatures on per cent germination of tef cultivars at a given time.

Temperature Night/Day °C	DZ-01-99			DZ-01-354		
	24 h	48 h	72 h	24 h	48 h	72 h
15/15	0.0d*	0.0c	20.8b	0.0d	0.0c	7.9d
15/25	0.0d	96.9b	99.3a	0.0d	70.8b	90.3c
15/35	98.4b	99.6a	99.8a	88.8b	96.5a	97.8ab
25/25	93.2c	99.7a	99.8a	55.2c	95.3a	95.4b
25/35	99.1a	99.6a	99.8a	92.1a	98.3a	98.5a
35/35	98.5ab	99.6a	99.5a	93.4a	97.3a	97.7ab

* : Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 2 : Comparison of mean per cent germination of tef cultivars at different times after planting at a given temperature.

Temperature Night/Day °C	DZ-01-99			DZ-01-354		
	24 h	48 h	72 h	24 h	48 h	72 h
15/15	0.0b*	0.0b	20.8a	0.0b	0.0b	7.9a
15/25	0.0c	96.9b	99.3a	0.0c	70.8b	90.3a
15/35	98.4a	99.6a	99.8a	88.8b	96.5a	97.8a
25/25	93.2b	99.7a	99.8a	55.2b	95.3a	95.4a
25/35	99.1a	99.6a	99.8a	92.1b	98.3a	98.5a
35/35	98.5a	99.6a	99.5a	93.4b	97.3a	97.7a

* : Means followed by the same letters within a row for a given cultivar are not significantly different (LSD, $p < 0.05$).

Table 3: Comparison of mean per cent germination of tef cultivars at a given temperature and time.

Temperature Night/Day °C	24 hr		48 hr		72 hr	
	CV1	CV2	CV1	CV2	CV1	CV2
15/15	0.0a*	0.0a	0.0a	0.0a	20.8a	7.9b
15/25	0.0a	0.0a	96.9a	70.8b	99.3a	90.3b
15/35	98.4a	88.8b	99.6a	96.5b	99.8a	97.8b
25/25	93.2a	55.2b	99.7a	95.3b	99.8a	95.4b
25/35	99.1a	92.1b	99.6a	98.3a	99.8a	98.5b
35/35	98.5a	93.4b	99.6a	97.3b	99.5a	97.7b

* : Means followed by the same letters within a row at a given time and temperature are not significantly different(LSD, $p < 0.05$).

CV1 and CV2 are cultivars DZ-01-99 and DZ-01-354, respectively.

Table 4: Germination response of tef cultivars to Different periods of light treatments.

Cultivar	light treatment	Duration of Treatment (h)		
		24	48	72
DZ-01-354	light (continuous)	0	87.7a*	73.7a
	dark (")	0	78.0a	86.7a
	alternate (12/12 h day/night)	0	86.0a	76.3a
Dabbi	light (continuous)	0	68.0b	86.0a
	dark (")	0	84.7a	86.7a
	alternate (12/12 h day/night)	0	63.8b	90.0a

* : Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 5: Comparison of tef germination at fixed time and light treatments.

Light Treatment	Cultivar	Duration of Treatment (h)		
		24	48	72
Light (continuous)	DZ-01-354	0	87.7a	73.7a
	Dabbi	0	68.0b	86.0a
Dark (")	DZ-01-354	0	78.0a	86.7a
	Dabbi	0	84.7a	86.7a
Alternate 12/12 h Day/Night	DZ-01-354	0	86.0a	76.3a
	Dabbi	0	63.8b	90.0a

* : Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 6: Comparison of duration of light treatment for a given cultivar light treatment.

Clultivar	Duration of Light Treatment	Continuous Light	Continuous No Light	Alternate (12/12 hr Day/Night)
DZ-01-354	24	0.0	0.0	0.0
	48	87.7a*	78.0a	86.0a
	72	73.7a	86.7a	76.3a
Dabbi	24	0.0	0.0	0.0
	48	68.0b	84.7a	63.8a
	72	86.0a	86.7a	90.0a

* : Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 7: Mean per cent germination of tef cultivars as affected by soil type and planting depth at early germination stage (2 days after planting).

Planting Depth in (mm)	Soil Type: Sandy loam		Soil Type: Clay Loam	
	DZ-01-354	Dabbi	DZ-01-354	Dabbi
	% emergence			
0	1.5bA*	2.0bA	4.5abA	10.5cA
5	32.5aB	34.0aB	17.0aC	54.0aA
10	6.0bB	33.0aA	13.0abB	31.0bA
15	7.5bA	4.5bA	8.0abA	7.0cA
20	4.0bA	6.5bA	2.0bA	3.5cA
25	0.0bA	6.0bA	0.0bA	2.5cA
30	0.0bA	4.0bA	0.0bA	3.0cA

* Means followed by the same small letters within a column are not significantly different (LSD, $p < 0.05$).

* Means followed by the same capital letters within a row are not significantly different (LSD, $p < 0.05$).

Table 8: Mean per cent germination of tef cultivars averaged over planting depth and soil types at successive days after planting.

Cultivar	Days after Planting							
	2	3	4	5	6	7	8	14
DZ-01-354	7.0b*	43.8b	61.4b	66.3b	68.3b	69.3b	69.3b	69.5b
Dabbi	14.4a	55.2a	69.6a	72.9a	73.9a	74.7a	75.0a	75.0a

* Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 9 : Mean per cent germination of two tef cultivars as affected by planting depth averaged over cultivar and soil type.

Planting Depth (mm)	Days after Planting							
	2	3	4	5	6	7	8	14
0	4.6c*	12.3e	20.5d	24.5d	24.8d	25.5d	26.8d	26.8d
5	34.4a	65.4a	82.8a	86.4a	88.3a	88.3a	88.4a	88.4a
10	20.8b	69.1a	82.1a	85.8a	86.9a	86.9a	87.1a	87.3a
15	6.6a	65.6a	81.3a	84.8a	85.8a	86.3a	86.5a	86.5a
20	4.0c	86.1b	76.8a	80.8a	82.3a	83.1a	83.8a	83.8a
25	2.1c	47.3c	62.8b	68.3b	70.6b	71.3b	71.4b	71.9b
30	2.3c	30.9d	52.4c	56.9c	58.8c	60.6c	61.1c	61.1c

* Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

Table 10 : Effect of planting depth and soil type on plant height averaged over cultivar 14 days after planting.

Planting depth in (mm)	Soil type		
	Sandy-loam	Clay-loam	Depth* mean
	height in cm		
0	4.9	7.1	6.0d
5	8.8	9.3	9.5a
10	9.2	9.9	9.6a
15	8.8	9.6	9.2ab
20	8.1	8.9	8.5bc
25	7.3	8.1	7.7c
30	6.1	7.1	6.6d
Soil mean⁺	7.6b	8.7b	

* and + Means followed by the same letters within a column and row are not significantly different (LSD, $p < 0.05$), respectively.

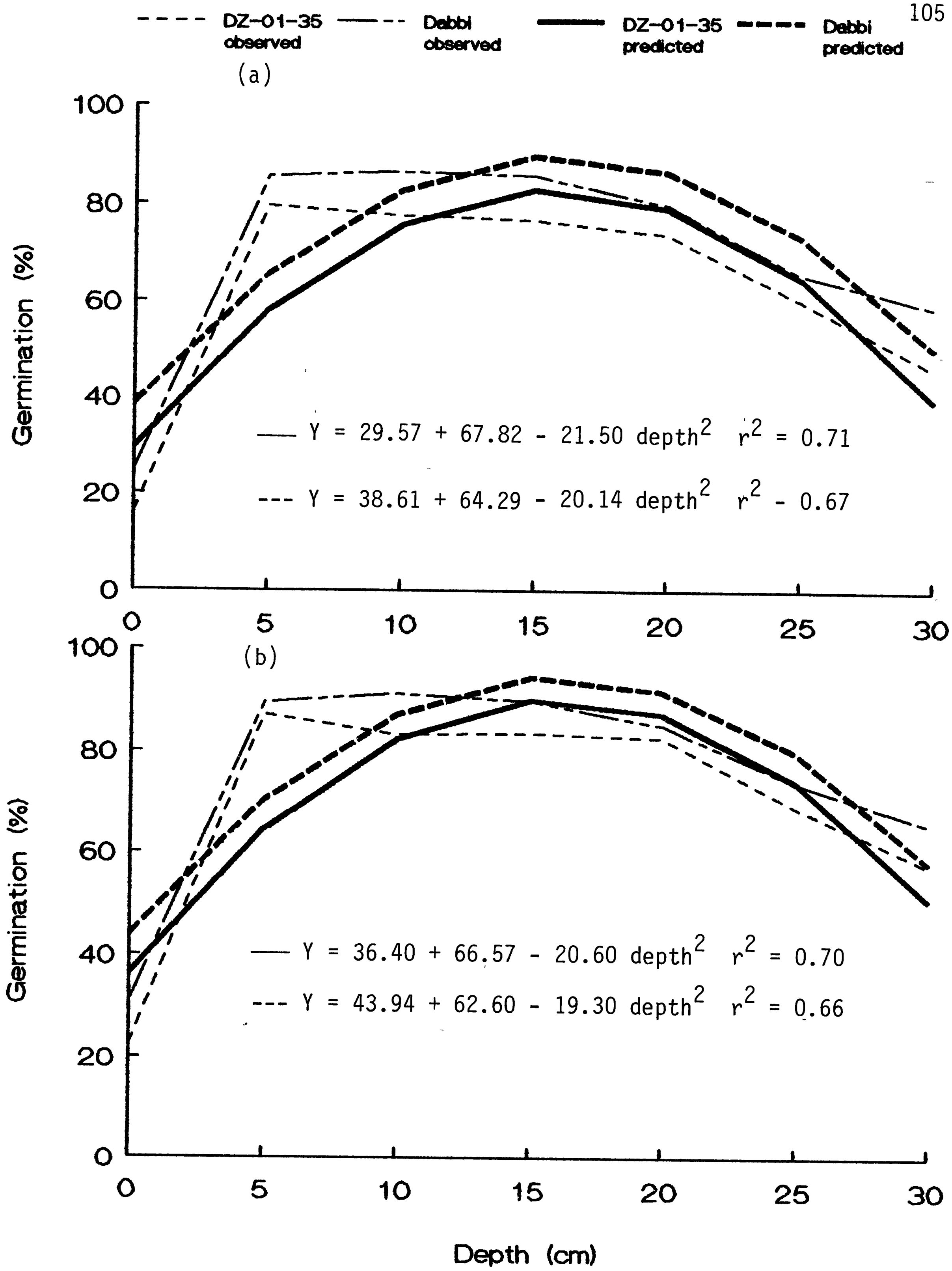

Fig. 1. Emergence of Dabbi (---) and DZ-01-354 (——) from seeds planted at 7 depths and (a) 4 days abd (b) 14 days after planting.

APPENDICES

Appendix A : Mean squares for temperature effect on germination of tef cultivars.

Source	df	mean squares
Super Rep (SR)	1	79.61*
Temperature (T)	5	1655.35*
Cultivar (C)	1	911.11*
T x C	5	82.76*
Time	23	908.58*
Time x T	10	1583.08*
Time x C	2	36.70
Time x T x C	10	120.28*
Error	35	9.37

* : significant (F, $p < 0.05$)

Appendix B: Mean squares for light effect on germination of tef cultivars.

Source	df	mean square
Super rep (SR)	1	39.01
Reps (SR)	4	910.28
Cultivars (C)	1	51.68
Time (T)	1	455.01
C x T	12	1932.35**
Light Treatment (LT)	2	390.08
C x LT	2	227.53
T x LT	2	137.53
C x T x LT	2	1693.86*
Error	55	364.83

* and ** : significant (F, $p < 0.05$ and 0.01, respectively).

Appendix C: Mean squares of germination and plant height of tef cultivars as affected by planting depth and soil types.

		Days after Planting				
Source	df	2	4	8	14	height
Super Rep (SR)	1	42.88	62.16	41.14	38.61	47.36
Rep (R)	6	8.71	12.10	5.62	6.29	6.20
Treatment Combination (TC)						
Cultivar (C)	1	189.45**	232.07**	114.29*	107.25*	0.75
Soil (S)	1	5.16*	1.14	11.16	13.50	67.54**
C x S	1	13.02	7.14	3.02	4.29	3.25
Depth (D)	6	301.61**	1051.13**	1003.76**	1004.83**	64.60**
C x D	6	45.15	3.27	3.33	3.47	3.99
D x S	6	3.89	13.36	26.91	26.51	2.03
C x D x S	6	27.00*	2.19	2.21	2.70	2.05
R x TC(SR)	162	9.52	8.54	4.00	4.08	2.41
SR x TC	27	10.76	17.19	17.77	17.71	3.50

*, **, Significant (F, $p < 0.05$ and 0.01, respectively)

PART III

GERMINATION RESPONSE OF TEF (*Eragrostis tef* (Zucc.) Trotter) CULTIVARS TO POLYETHYLENE GLYCOL (PEG 8000) AND SODIUM CHLORIDE (NaCl) INDUCED DROUGHT AND SALT STRESS

ABSTRACT

Tef (Eragrostis tef (Zucc.) Trotter) crop failure due to drought stress is not uncommon in Ethiopia and often arises from erratic rainfall at any crop developmental stage. Effect of drought stress on germination of tef and response of tef cultivars to drought stress is not known. Experiments were conducted in fall 1987 and spring 1988 to evaluate PEG 8000 and NaCl induced drought and salt stress on germination of tef cultivar, DZ-01-354 and to evaluate resistance or tolerance level of 16 tef cultivars at the water potential level which significantly affected germination of DZ-01-354. Germination significantly decreased as water potential decreased. PEG solution of -0.6 MPa and NaCl solution of -0.9 MPa significantly affected germination of DZ-01- 354. However, -0.3 and -0.6 MPa PEG and NaCl solutions, respectively, did not affect germination. Germination of 16 tef cultivars were evaluated in DD H_2O, -0.6 MPa PEG, and -0.9 NaCl solution. Five late maturing cultivars had a germination range of 95 to 100 % in DD H_2O and were significantly higher than all other cultivars in the study. Early maturing cultivars had the lowest germination percentage. As evidenced by germination index, at the end of test period Dabbi and Gealami, early maturing cultivars, were found to have significantly highest drought or salt tolerance level. Of the late maturing cultivars, Karadebi has high, Magna and Tulunasi were found to have intermediate drought tolerance and poor salt tolerance. The study

indicated that germination under normal (DD H_2O) conditions did not reflect germination of that cultivar under stress conditions. Moreover, the two tef cultivars, Dabbi and Gealami can be used in relatively low moisture and high salt stress areas. However, further field evaluation is recommended

INTRODUCTION

Tef is a major cereal crop produced in Ethiopia. It has variable maturity ranging from 60-120 days, which makes it adaptable to different ecological zones with varying levels of precipitation (Tadessa, 1975). Traditionally tef is referred to as stress tolerant. Sometimes when crops like maize, which are planted early in the rainy season, fail due to drought stress, the land is replowed and planted to early maturing tef cultivars which can produce a crop with limited moisture. Despite this, tef crop failure due to drought stress is not uncommon and often arises from erratic rainfall at any crop developmental stage. But drought stress occurring at planting affects seedling establishment thereby reducing final grain yield. Ensuring proper germination of planted seeds and subsequent seedling establishment is of general importance in agriculture. The germination, emergence, and establishment phase is critical in the growth cycle of plants, as it determines the density of the stand obtained, influences the degree of weed infestation, and limits eventual yield (Hillel, 1972). Unless the success of this early phase is ensured, an entire planting may fail from the very beginning. Therefore, tef cultivars which germinate well under drought stress should be helpful in reducing risk of overall crop failure.

Effect of drought stress at different growth stages of crops was reviewed and reported by Begg and Turner, 1976; Boyer and McPherson, 1975; Kozlowski, 1962. Occurrence of drought stress at planting results in reduced plant stand per unit area which finally affects total yield. For this reason many attempts to screen cultivars which can germinate under reduced moisture level have been completed (Gul and Allan, 1976a; Helmeric and Pfeiffer, 1954). However, the problem faced in conducting such experiments under field conditions is the interaction arising from a complex soil-water system. Because of this, in assessing drought stress effects on seed germination, soil is often intentionally by-passed (Heydecker, 1976) and experiments are conducted under controlled matric or osmotic potential by using different solutions to develop dehydration stress. Of the different solutions used, a solution of polyethylene glycol (PEG) of molecular weight greater than 4000 was recommended for germination test (Parmar and Moore, 1968; Kaufman and Ross, 1969; Kaufman and Ekard, 1970; Sharma, 1973; McGinnis 1960). Later, Michel (1983) recommended PEG of molecular weight 8000 (PEG 8000) because of its stability.

These investigators reported that decreasing water potential decreased germination in different crops. Saint-Clair (1976) reported that a fast growing drought avoiding sorghum cultivar had better germination than the slower growing and late maturing cultivar. In a recent study Smith et al. (1989) reported that sorghum germination was significantly affected when osmotic potential fell below 0 MPa. A pearl millet, however, was not affected until osmotic potential was -0.8 MPa. They also pointed out that the ability to germinate under stressful conditions could give an advantage in stand establishment under less than ideal conditions frequently occurring in the field. The existence of variability among cultivars within a crop specie in response to drought stress at germination (Helmerick, and Pfiefer 1954; Delaney et al., 1986) encouraged many researchers to extend the study into different crops (Kaufman and Ross, 1969; Parmar and Moore, 1968; Sharma, 1973). However, the effect of drought stress on germination of tef and response of tef cultivars to drought stress during germination is not known. Therefore, the objectives of this study are: 1) to determine at which water potential tef germination is reduced and, 2) to compare and identify tef cultivars with improved germination under dehydration stress.

MATERIALS AND METHODS

The experiment was conducted in fall, 1987 and the spring, 1988 to study the effect of drought stress on tef germination and to screen tef cultivars resistant or tolerant to drought stress at germination. Two different solutions of the same water potential ranging from 0.0 to -1.5 MPa at -0.3 interval were prepared from polyethylene glycol (PEG 8000) and sodium chloride (NaCl) to simulate dehydration stress. NaCl solution was included in the test for two purposes: 1) to determine if the same water potential level of PEG 8000 and NaCl have the same effect on germination of tef and, 2) to determine salt concentration level that reduces tef germination. Solutions of PEG 8000 and NaCl were prepared according to Michel (1983) and Lang (1967), respectively. Water potential of both solutions were counter checked by thermocouple psychrometry (Johnson et al., 1986; Ferris and Johnson, 1987). Fifty seeds of DZ-01-99 were placed on a blue blotter germination pads in a germination box of size 7 cm x 7 cm x 3 cm. The seeds were moistened with 6 ml of 5 water potentials (0.0 to -1.5 at -0.3 interval) of the two solutions (PEG 8000 and NaCl) and a check distilled deionized water (DD H_2O). Factorial arrangement of these treatments were randomly assigned to each of the 4 racks in the germination chamber set at 30/20 °C day/night temperature and the experiment was conducted in an RCB design with 4 replications. Seeds were considered germinated when shoots were two mm long and daily germination was recorded for 8 days.

Statistical analysis was made on arcsin transformed relative percent germination (RPG), where RPG is germination in solution expressed as percentage of germination in pure water and treatments were compared using LSD ($p < 0.05$) after treatment effects were found significant at the specified level of probability (SAS, 1985). From this analysis the first water potential level which significantly affected germination as compared to the check was identified for the PEG 8000 and NaCl solutions for testing germination dehydration resistance or tolerance of the 16 tef cultivars indicated in Table 2, 3, and 4. Factorial arrangement of the 16 cultivars and 3 water potential levels, one for each of PEG 8000, NaCl, and a check (DD H_2O), were randomly assigned to a set of racks in the chamber considered as replications and the experiment was conducted in RCB design with 4 replications. Seeds were considered germinated when shoots were 2 mm long and germination was recorded every 24 hours for 8 days. SAS (1985) software was used to run statistical analysis and means were separated using LSD ($p < 0.01$) after treatment effects were found significant.

RESULTS AND DISCUSSION

As indicated in Appendix A and Table 1, germination of tef cultivar, DZ-01-354 was significantly affected as drought and salt stress increased as simulated by polyethylene glycol (PEG 8000) and sodium chloride (NaCl), respectively. This findings was consistent with studies conducted on different crops and reported by several investigators (Parmar and Moore, 1968; Kaufman and Ross,1969; Kaufman and Ekard, 1970; and Sharma, 1973). Germination ranged from 22.5 to 99 % at 2 days after planting to 84.5 to 100 % at 8 days after planting for -0.6 and 0.0 MPa PEG solution, respectively. Germination was not affected throughout the test period at -0.3 MPa stress level. Although germination increased from 22.5 % 2 days after planting to 84.5 % 8 days after planting at -0.6 MPa PEG solution, germination was slower and significantly affected as compared to germination either in DD H_2O (control) with water potential of 0.0 MPa or in -0.3 MPa PEG solution. There was no germination as stress level increased beyond -0.6 MPa in PEG solutions. Comparison of germination of the same tef cultivar in both PEG and NaCl solution at a given water potential level indicated that there was no significant difference between germination at -0.3 MPa PEG and -0.6 MPa NaCl solutions (Table 1). In fact, seeds germinated in -0.9 MPa NaCl solution whereas germination did not take place in PEG solution of -0.9 MPa. However, germination sharply decreased from 99 to 8.5 % 2 days after planting as water potential decreased from 0.0 to

-0.9 MPa NaCl solution, respectively. In this solution germination ranged from 8.5 to 61 % 2 to 8 days after planting, respectively. Nevertheless, germination was affected significantly throughout the test period.

Based on this finding, -0.6 and -0.9 MPa solutions of PEG and NaCl were selected, respectively, to determine stress tolerance level of 16 tef cultivars at germination. There were significant differences in germination stress tolerance/resistance level between the 16 tef cultivars in solutions of 0.0, -0.6 and -0.9 MPa PEG and NaCl (Appendices B and C), respectively. Germination response of the 16 tef cultivars in DD H_2O (Table 2) and germination indices as affected by drought and salt stress simulated by -0.6 and -0.9 MPa of PEG and NaCl are given in Tables 3 and 4, respectively. Germination in DDH_2O ranged from 72 to 99.4 % 2 days after planting to 77 to 100 % 8 days after planting for cultivars Gealami and DZ-01-99, respectively (Table 2). At the end of test period cultivars DZ-01-99 followed by Variegata, Tulunasi, DZ-01-354, Karadebi, and Enatit with germination percentage of 100, 97.6, 97.2, 96, 95.2, and 95, were significantly better than most of the cultivars. These cultivars are relatively late maturing which are widely grown under major tef producing environments. The early maturing cultivars like Gealami and Balami with germination of 76.6 and 77 %, respectively, were found to have the lowest germination percentage in DD H_2O.

Germination index which was germination in either drought or salt stress expressed as a fraction of germination in DD H_2O was indicated in Tables 3 and 4. There were significant differences between germination indices of the 16 tef cultivars under drought stress induced by PEG 8000

(Table 3) at any given day after planting. Germination index increased as days after planting increased for all cultivars up to the end of test period. At 2 days after planting, Dabbi, Balami, Karadebi, and Gealami had the highest germination indices of 0.48, 0.44, 0.36, and 0.29. These early maturing tef cultivars, except Karadebi and Dabbi, had the lowest germination percentage with DD H_2O as a media.(Table 2). At the end of test period cultivars Dabbi and Balami, with germination indices of 0.96 and 0.83, were found to be the most stress tolerant/resistant of the 14 cultivars in the study. The widely produced late maturing cultivars were found to have less than 0.5 germination index. Among the widely grown late maturing cultivars Magna and Tulunasi were found to have intermediate moisture stress tolerance at germination. Similar finding was reported by Saint-Clair (1976) where a fast growing drought escaping sorghum variety had better germination than late maturing variety under moisture stress.

Germination salt tolerance of tef cultivars expressed as germination index was indicated in Table 4. There were significant differences between germination salt tolerances of the 16 tef cultivars at any given time during the test period. Germination indices increased as days after planting increased. Two days after planting germination indices ranged from 0.004 to 0.87 for Rosea and Dabbi, respectively. At this time, Dabbi and Gealami had germination indices of 0.86 and 0.79, respectively, whereas Balami which was the third highest had germination index of 0.23. These two cultivars had consistently higher salt tolerance level than all of the tef cultivars in the study. Cultivars Adaa, Balami, and Tulunasi had intermediate salt tolerance at germination; whereas, the remaining cultivars can be grouped together as cultivars with low salt tolerance level.

Generally, this study revealed that cultivars with high germination percentage under normal condition (DD H_2O) did not show either high drought or salt stress tolerance at germination. Secondly, early maturing tef cultivars had better moisture or salt stress tolerance at germination. Finally, except the two cultivars, Dabbi and Gealami, which were consistently tolerant to both drought and salt stress, cultivars which were tolerant to drought stress did not show the same tolerance level for salt stress. The ability of these cultivars to germinate under stressful conditions could give an advantage in stand establishment under less than ideal conditions that frequently occur in the field (Smith et al., 1989). The current finding has far-reaching implication in tef production particularly under drought stress areas. Moreover, in lowland areas of Ethiopia where cotton is produced under irrigation, salt problems are often encountered because of high evaporative demand of the environment. The two early maturing tef cultivars may be produced between two cotton growing seasons when land is kept idle until the following cotton planting season. However, further field evaluation is recommended before implementing this idea.

SUMMARY AND CONCLUSION

An experiment was conducted in Fall 1987 and Spring 1988 to study the effect of drought or salt stress on germination of tef cultivar DZ-01-354 and then to evaluate level of resistance or tolerance to moisture or salt stress in 16 tef cultivars at germination.

Germination of tef cultivar, DZ-01-354, significantly decreased as drought or salt stress induced by PEG or NaCl increased. PEG solution of -0.3 MPa did not affect germination. However, germination was significantly affected at -0.6 MPa. Seeds did not germinate beyond -0.6 MPa PEG solution. Salt concentration of -0.6 Mpa did not affect germination. However, germination was significantly affected as salt concentration increased to -0.9 MPa.

Germination of 16 tef cultivars were evaluated for resistance or tolerance to drought or salt stress at -0.6 and -0.9 MPa PEG and NaCl solutions, respectively. Germination in DD H_2O ranged from 77 to 100 % at 8 days after planting. Five late maturing cultivars, DZ-01-99, Variegata, Tulunasi, DZ-01-354, Karadebi, and Enatit, had significantly better germination than most cultivars and ranged from 100 to 95 %. Early maturing cultivars had the least germination percentage ranging from 77 to 83.

Germination index which was germination either in PEG 8000 or NaCl solutions as a fraction of germination in DD H_2O was used as a measure of drought or salt tolerance at germination. At the end of test period, Dabbi and Gealami, were found to have better drought and salt tolerance than all the cultivars considered in the study. Magna and Tulunasi had intermediate drought tolerance but poor salt tolerance.

In conclusion, this study revealed that germination under normal condition does not necessarily reflect germination of that cultivar under stress situation. Second, two early maturing tef cultivars, Dabbi and Gealami had better germination drought and salt tolerance. These cultivars may be used in low rainfall areas. Moreover, to alleviate food shortage of irrigated cotton producing areas, these cultivars may be produced between two cotton growing seasons when land is kept idle. However, further field evaluation is recommended.

REFERENCES

Begg, J. E., and N. C. Turner. 1976. Crop water deficit. Adv. Agron. 28:161-212.

Boyer, J. S., and H. J. Mcpherson. 1975. Physiology of water deficits in cereal crops. Adv. Agron. 27:1-23.

Delaney, R. H., R. H. Abarnethy, and D. W. Johnson. 1986. Temperature and water stress effects on germination of Ruby valley point vetch (Oxytropis riparis Litu.). Crop Sci. 26:161-164.

Ferris, D. M., and R. C. Johnson. 1987. Thermocouple psychrometer management utilizing turbostat data files. Agric. Expt. Station. Oklahoma State University.

Gul, A., and R. E. Allan. 1976a. Stand establishment of wheat lines under different levels of water potential. Crop Sci. 16:611-615.

Helmeric, H., and R. P. Pfiefer. 1954. Differential varietal responses to winter wheat germination and early growth to controlled limited moisture conditions. Agron. J. 46:560- 562.

Heydecker, W. 1976. Drought hazards to seed germination. Ann. Arid Zone. 6:23-24.

Hillel, D. 1972. Soil moisture and seed germination. In Water Deficits and plant growth. T. T. Kozlowski (ed). 3:65-89.

Johnson, R. C., H. T. Nguen, R. W. McNew, and D. M. Ferris. 1986. Sampling error for leaf water potential measurements in wheat. Crop Sci. 26:380-383.

Kaufmann, M. R., and K. J. Ross. 1969. Water potential, temperature, and kinetin effects on seed germination in soil and solute system. Amer. J. Bot. 57:413-419.

Kaufmann, M. R., and Ekard. 1970. Evaluation of water stress control with polyethlene glycol by analysis of gutation. Plant Physiol. 47:453-456.

Kozlowski, T. T. 1962. Water deficits and plant growth. I. Academic Press, New York.

Lang, A. R. G. 1967. Osmotic coefficients and water potentials of sodium chloride solutions from 0 to 40 C. Aust J. Chem. 20:2017-2023.

McGinnis, W. J. 1960. Effect of moisture stress and temperature on germination of 6 range grasses. Agron. J. 52:159-162.

Michel, M. 1983. Evaluation of the water potential of solution of polyethelene glycol 8000 both in the abscence and presence of other solutions. Plant Physiol. 72:66-70.

Parmar, M. T,. and R. P. Moore. 1968. Effect of simulated drought by polyethlene glycol solutions on corn (Zea mays L.) germination and seedling development. Agron. J. 58:391-392.

Saint-Clair, P. M. 1976. Germination of Sorghum bicolor under polyethylene glycol induced stress. Can. J. Plant Sci. 56:21-24.

SAS Users Guide: Statistics Version 5 Edition. 1985. SAS Inistitute Inc. Cary, NC.

Seifu Ketema. 1986. Food self sufficiency and some roles of tef (Eragrostis tef) in the Ethiopian agriculture. Paper presented at the National Workshop held at Alemaya Univ. of Agric., Ethiopia. Dec. 8-12, 1986).

Sharma, M. L. 1973. Simulation of drought and its effect on germination of five pasture species. Agron. J. 65:982-987.

Smith, R. L., C. S. Hoveland, and W. W. Hanna. 1989. Water stress and temperature in relation to seed germination of pearl millet and sorghum. Agron. J. 81:303-305.

Tadessa Ebba. 1975. Tef (Eragrostis tef) cultivars, morphology and classification. Part II. Expt. Sta. Bull. No. 69. Addis Abeba Univ. College of Agric. Dire Dawa, Ethiopia.

Table 1. Germination of tef cultivar, DZ-01-354, as affected by polyethylene glycol (PEG 8000) and sodium chloride (NaCl) solutions.

Water Pote-Ntial (-MPa)	Days after Planting						
	2	3	4	5	6	7	8
0.0 (control)	99.0	99.5	99.5	100.0	100.0	100.0	100.0
0.3 PEG	97.5	98.5	99.0	99.0	99.0	99.0	99.5
0.6 "	22.5	72.5	81.0	83.5	84.0	84.5	84.5
0.9 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3 NaCl	99.0	99.5	99.5	99.5	99.5	99.5	99.5
0.6 "	94.5	97.0	97.0	97.0	97.0	97.0	97.0
0.9 "	8.5	48.5	58.0	60.0	61.0	61.0	61.0
1.2 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LSD, 0.05	6.5	9.2	7.7	7.8	7.4	7.4	7.4
0.01	8.7	12.4	10.4	10.5	10.0	10.0	10.0

Table 2 : Germination response of tef cultivars in distilled deionized water (DD H_2O).

Cultivars	Days after Planting					
	2	3	4	5	6	8
Addise	90.6	93.6	94.3	94.3	94.3	94.3
Enatit	92.3	94.6	95.0	95.0	95.0	95.0
Magna	88.6	91.6	92.0	92.0	92.0	92.0
Alba	91.0	92.0	92.0	92.0	92.0	92.0
Dabbi	92.0	93.0	93.6	94.0	94.0	94.0
Karadebi	94.3	95.0	95.2	95.3	95.3	95.3
DZ-01-354	92.6	94.6	95.6	96.0	96.0	96.0
Beten	82.3	86.3	86.6	87.3	87.3	87.3
DZ-01-99	99.4	99.6	100.0	100.0	100.0	100.0
Balami	72.0	76.0	77.0	77.0	77.0	77.0
Varigata	96.6	97.6	97.6	97.6	97.6	97.6
Gomayde	89.0	92.6	94.0	94.0	94.3	94.3
Adaa	90.3	93.0	97.0	97.3	97.3	97.3
Tulunasi	93.3	97.0	97.3	97.3	97.3	97.3
Rosea	91.0	93.0	93.3	93.3	93.3	93.3
Gealami	76.6	76.6	76.6	76.6	76.6	76.6
LSD, 0.05	5.4	3.9	4.6	4.5	4.5	4.5
CV. %	6.0	4.4	4.2	4.2	4.2	4.2

Table 3 : Germination index of tef cultivars as affected by Polyethylene glycol (PEG 8000) induced drought stress (-0.6 MPa).

	Days after Stress Application					
Cultivars	2	3	4	5	6	8
Addise	.073	.137	.164	.190	.190	.190
Enatit	.043	.110	.148	.180	.183	.183
Magna	.085	.210	.223	.242	.245	.245
Alba	.103	.157	.170	.180	.180	.180
Dabbi	.477	.924	.962	.962	.962	.962
Karadebi	.168	.212	.292	.323	.338	.338
DZ-01-354	.105	.217	.273	.315	.315	.315
Beten	.063	.120	.130	.135	.142	.142
DZ-01-99	.220	.290	.320	.340	.340	.340
Balami	.443	.600	.604	.692	.692	.692
Varigata	.670	.115	.137	.147	.155	.155
Gomayde	.076	.117	.125	.172	.172	.172
Adaa	.231	.355	.433	.508	.508	.508
Tulunasi	.163	.398	.457	.511	.511	.511
Rosea	.097	.152	.192	.203	.203	.203
Gealami	.286	.651	.743	.829	.829	.829
LSD, 0.05	.241	.227	.217	.210	.208	.208
CV, %	24.200	23.600	22.700	24.200	22.100	22.100

Table 4. Germination index of tef cultivars as affected by salt (NaCl) induced salt stress (-0.9 MPa).

	Days after Planting					
Cultivars	2	3	4	5	6	8
Addise	.007	.007	.011	.025	.025	.025
Enatit	.014	.025	.046	.049	.053	.053
Magna	.007	.010	.018	.033	.048	.048
Alba	.069	.101	.105	.123	.123	.123
Dabbi	.866	.925	.931	.935	.938	.938
Karadebi	.127	.200	.203	.224	.227	.227
DZ-01-354	.067	.124	.140	.150	.154	.154
Beten	.028	.055	.078	.100	.140	.140
DZ-01-99	.151	.194	.213	.223	.227	.227
Balami	.232	.405	.428	.453	.458	.458
Variegata	.088	.130	.147	.174	.184	.184
Gomayde	.023	.025	.036	.040	.040	.040
Adaa	.127	.030	.412	.452	.481	.481
Tulunasi	.078	.187	.243	.277	.318	.318
Rosea	.004	.010	.010	.021	.021	.021
Gealami	.791	.902	.905	.913	.921	.921
LSD, 0.05	0.128	0.150	0.184	0.190	0.184	0.184
C.V., %	24.100	22.200	23.400	22.300	23.100	23.100

APPENDICES

Appendix A: Mean squares for germination of tef cultivars in distilled deionized water (DD H_2O).

Source	d	Days after Planting 2	3	4	5	6	8
Super Rep(S)	1	2.34	9.38	16.67**	19.26**	20.17*	20.17**
Rep (S)	4	17.75**	4.56	6.04	5.29	5.38	5.38
Cultivar (C)	15	7.35*	55.71*	48.86*	48.72*	48.82*	48.82*
S x C	15	4.94	2.60	3.51	3.44	3.48	3.48
Error	60	7.16	4.10	3.84	3.84	3.82	3.82

* , ** : significantly different (F, $p < 0.05$, 0.01,respectively).

Appendix B: Mean squares for germination of tef cultivars under -0.6 MPa polyethylene glycol (PEG 8000) induced drought stress.

Source	df	Days after Planting				
		2	3	4	5	6
		mean square x 10^3				
Super rep (S)	1	4.11	2.84	3.52	2.82	2.43
Rep (S)	4	0.15	0.33	0.26	0.24	0.24
Cultivar (C)	15	0.17*	0.59*	0.64*	0.67*	0.67*
S x C	15	0.08*	0.08*	0.08*	0.08*	0.07*
Error	60	0.01	0.02	0.02	0.02	0.02

*: significantly different (F, $p < 0.05$).

Appendix C: Mean squares for germination of tef cultivars under -0.9 MPa salt (NaCl) induced salt stress.

Source	df	Days after Salt Application					
		2	3	4	5	6	8
Super rep(S)	1	1.71*	2.00*	2.10*	1.19*	0.67*	0.67*
Rep (S)	4	0.12*	0.15*	0.19*	0.17	0.22*	0.22*
Cultivar (C)	15	4.24*	5.09*	5.14*	5.12*	5.14*	5.14*
S x C	15	0.11*	0.15*	0.22*	0.24	0.22*	0.22*
Error	60	0.04	0.04	0.05	0.05	0.05	0.05

* : significantly different (F, $p < 0.05$).

PART IV

ACCELERATED AGING EFFECT ON GERMINATION OF TEF (*Eragrostis tef* (Zucc.) Trotter) SEED AND SOLUTE LEAKAGE IN SALT AND SALT-FREE SOLUTIONS

ABSTRACT

Poor storage conditions before and after harvesting of tef (Eragrostis tef (Zucc.) Trotter) may enhance seed aging. Accelerated aging (storing seeds at 40 °C and about 100 % relative humidity) experiment was conducted on seeds of two tef cultivars, Alba and Variegata, to evaluate how fast tef seeds age, to determine effect of aging on germination in salt and salt free solution, and evaluate leakage from aging seeds.

Germination of both cultivars significantly decreased quadratically (r^2 = 0.85) as accelerated aging increased. However, there was no significant germination decrease up to one and two weeks of accelerated aging in Variegata and Alba, respectively. Cultivar Variegata had better germination percentage before aging and deteriorated faster than Alba after aging. Solute leakage from imbibing aged seeds of both cultivars significantly increased quadratically (r^2 = 0.80) as accelerated aging increased.

Germination of aged seeds of both cultivars was evaluated in salt solutions of different concentrations (-0.6 and -0.9 MPa NaCl). Germination of aged seeds of Alba was significantly reduced in -0.6 MPa; whereas, Variegata did not germinate at all. Both cultivars did not germinate in -0.9 MPa solution of NaCl. The study showed that high temperature and relative humidity affect viability of tef seed and aged seeds of tef are sensitive to salt stress. Moreover, further

investigation on naturally aged seeds is required to determine how long tef seed can be stored before it loses viability.

INTRODUCTION

Tef is harvested and stored exposed to field weather conditions before threshing where it encounters untimely precipitation and fluctuating temperature. Even after threshing, tef seed is thought to be unsusceptible to insect attack (Seifu, 1986), and farmers usually store either in traditional silos or in sisal sacks for long period of time under fluctuating humidity and temperature conditions. At times when seed supplies are low, farmers purchase seeds from the market without consideration of seed quality or age.

Seed aging has practical significance because aging initially reduces seed vigor which can lead to germination loss and reduced stands. In view of the importance of seed vigor for seedling establishment and crop production, seed aging has drawn attention of several investigators. Delouche and Baskin (1973) reported that aged seeds generally result in reduced seedling growth or vigor, greater susceptibility to microorganisms, non-uniform stands, and ultimately reduction in crop yield. Susceptibility to seed deterioration is generally linked to genetic and environmental factor and marked differences exist between species and between cultivars in the level and rate of seed deterioration in a given environment (Delouche and Baskin, 1973). Of these parameters, the storage temperature and relative humidity as they affect seed moisture content appear to be the most crucial (McDonald and Nelson, 1986).

Earlier, Harrington (1972) developed two general principles relating storage temperature and moisture to seed aging. First, for each one per cent increase in seed moisture the life span of the seed is halved for seed moisture between 5 and 14 %, and for each 5 °C increase in storage temperature, the life span of seed is halved for temperature between 0 and 50 °C. These principles were reported to work independently. Based on this finding, Delouche (1965) reported that an accelerated aging technique which exposed seeds to 40 °C and greater than 90 % relative humidity be used as a test for seed quality. Byrd and Delouche (1971) reported that germination percentage and rate of seedling growth of soybean seed in storage decreased significantly with time. In a detailed study conducted by Delouche and Baskin (1973) on different crops, it was found that those seeds that deteriorate rapidly under conditions of accelerated aging performed poorly in long term open storage. The authors also reported that accelerated aging responses are closely correlated with emergence potential of seeds, growth, and development, and productivity of plants.

Therefore, the accelerated aging technique has been subsequently recognized as a useful vigor test for some species (Assoc. Offic. Seed Anal., 1983). Aged seeds are sensitive to hydration stress which results in extensive surface cell damage (Powell and Matthews, 1978; Duke and Kakefuda, 1981; Berjak and Villiers, 1971). Damaged membranes malfunction and lose their integrity (Duke et al., 1983) resulting in increased solute leakage in a linear manner in the range over which vigor was depressed (Shoettle and Leopold, 1984). Nevertheless, solute leakage can also take place prior to loss of vigor (Ferguson et al., 1989) which is a sign of deterioration at early stage of storage.

A relationship between solute leakage and field emergence has been developed (Matthews and Bradnock, 1967) and confirmed by many researchers (Matthews and Powel, 1981). This relationship shows that when seed lots with acceptable germination (greater than 80 %) are soaked with water, those lots yielding large quantities of electrolyte into the water emerge poorly in the field. Hence, this procedure is routinely used as seed test in United Kingdom and New Zealand (Matthews and Powel, 1981). However, the relationship between solute leakage evidenced by conductivity test and field emergence has not been established in North America (Matthews and Powel, 1981).

The use of accelerated aging to test seed vigor, predict storability, and to study associated physiological changes that take place in different crop species during the aging process was reported by several investigators (Berjak and Villiers, 1971; Delouche and Baskin, 1973; Powel and Matthews, 1978; Parrish and Leopold, 1978; Duke and Kakefude, 1981; Baskin, 1981; Shoettle and Leopold, 1984; Smith and Dobrenz, 1987; Furguson et al., 1989). However, such study has not been conducted on tef a major cereal crop in Ethiopia and a potential new crop in North America.

Understanding the effect of aging on germination may lead to improved seed production and storage systems for tef. This research was initiated to 1) study accelerated aging effect on germination of tef seed, 2) study the relationship between germination and aging, and 3) study the relationship between solute leakage and germination in tef.

MATERIALS AND METHODS

Accelerated aging

An accelerated aging box was prepared through a modification of procedures of Byrd and Delouche (1971). A wire mesh was placed in a box (20 x 30 x 12 cm) to support petri dishes so that seeds placed in the petri dishes did not come in direct contact with water. Seeds were treated with fungicide (Captan : PCNB : Streptosulfate) in a ratio of 1 : 1 : 1 at the rate of 2.5 gm kg^{-1} seed to control infestation from fungi or bacteria which are encouraged by high temperature and high humidity. Four replications of five 2 gm seed lots of cv Enatit were placed in a 35 x 15 mm petri dish and placed on the wire in the aging box. The box was tightly covered so that external temperature and humidity did not affect environment in the aging box thereby building the internal moisture close to saturation. The box was kept in incubator at 41 °C. Seeds were removed from the box daily for five days to obtain seeds aged for different times. The aged and unaged seeds (control treatment) were kept in their respective petri dishes and stored at 4 °C until the germination test was begun.

In preliminary tests it was found that there was no significant germination difference between unaged and seeds aged for 5 days. Based on these observations, an experiment was designed to test the aging effect on imbibitional solute leakage and germination of two tef cultivars, Albar and Variegata, which are white and red seeded, respectively. Because of a lack of enough seed of cultivar Enatit, it was replaced by cv Alba which has similar seed color and maturity in days. A shortcoming which may be expected is that the preliminary observation which was conducted on cv Enatit may not be applicable for other cultivars since the aging process may vary between cultivars. In this case, seeds were removed from the aging chamber weekly for three weeks to obtain seed aged for different times.

The germination test was completed by placing 50 seeds aged for different times on two layers of Whatman # 42 filter paper in a 100 x 15 mm standard petri dish into which 6 ml of distilled deionized water (DD H_2O) was added. Treatments were randomly assigned to each of the four racks in germination chamber and the experiment was conducted in RCB design with 4 replications. The experiment was conducted for 14 days and seeds were considered germinated when shoots were about 2 mm long and data were converted to percent germination.

To test germination of aged seeds under salt stress, sodium chloride (NaCl) solutions of -0.6, and -0.9 MPa were prepared (Lang, 1967). Four and half ml of appropriate solution was added to each petri dish of size 100 x 15 mm containing a single layer of Whatman # 42 and then 25 seeds of the different aging treatments were placed in each petridish. Petri dishes were kept in a germination chamber at constant temperature of 25 °C for 8 days in RCB design with 4 replications. At the end of the test period, seeds were taken out of the chamber and considered germinated when shoots were 2 mm long. Data were converted to percent germination and statistical analysis was carried out on arcsin transformed data.

When treatment effects were found significant (F, $p < 0.05$), least significant difference was used to compare the treatment means at the specified level of probability (SAS, 1985).

Solute Leakage Test

Imbibitional solute leakage test was carried out on a 0.2 gm seed sample representing each of the different aging treatments. Seeds were placed on a nylon mesh sieve and washed for a three minutes period with (DD H_2O) to remove external contaminants. Seeds were blotted with paper towels and allowed to dry at room temperature for 24 hours. The seeds were then placed in a micro-centrifuge tube into which 0.75 ml of DD H_2O was added and let stand for 6 hrs (Smith and Dobrenz, 1987). The tubes were shaken briefly and 75 $_{u}$L of the solution was drawn from each of the tubes and added into a second micro centrifuge tube to determine the osmotic potential of the leachates. Three osmotic potential determinations were made using thermocouple psychrometer and the experiment was repeated twice. The data were analyzed using SAS (1985) software and LSD ($p < 0.05$) was used to compare the means for different aging treatments after treatment effects were found significant (F, $p < 0.05$).

RESULTS AND DISCUSSION

Results of preliminary observation of artificial aging effect on germination of tef and solute leakage are given in Table 1. Seeds of tef cultivar Enatit were aged from 0 to 5 days where seeds were taken out of the aging chamber at one day intervals. Even though there were no significant differences, germination declined from 100 to 88 % as aging increased from 0 to 5 days, respectively (Table 1). The aged seeds were also tested for solute leakage and data were analyzed and reported as leachate osmotic potential in MPa g^{-1} dry weight (Table 1). Contrary to the aging treatment, there was a significant ($p < 0.05$) aging effect on solute leakage. Solute leakage ranged from -0.12 to -0.44 MPa for unaged and seeds aged for 5 days, respectively. Significant differences were observed for solute leakage before a significant aging effect was observed on germination and indicated that considerable solute leakage takes place before seed vigor declines significantly. This finding is in agreement with the finding reported by Parish et al. (1982) in artificially aged soybean. The authors described the initial fast solute leakage before viability declined as a period when the membrane re-organizes upon rehydration.

Based on preliminary observation seeds of two tef cultivars, Alba and Variegata were artificially aged for 3 weeks and were taken out of the aging chamber at weekly intervals. Analysis of variance of germination in DD H_2O indicated that there was age by cultivar interaction effect on germination of tef seeds (Table 2). Germination decreased as aging increased in both cultivars (Table 3). Germination ranged from 98 to 60 % for unaged seeds and seeds aged for 3 weeks, respectively, in cultivar Alba. Germination in cultivar Variegata ranged from about 100 to 28 % for unaged and aged seeds, respectively. There was no significant aging effect on germination of cultivar Alba until seeds were aged for more than 2 weeks whereas germination in Variegata significantly declined from 97 to 58 % for 2 weeks of aging. This finding indicated that germination declines faster with aging in cultivar Variegata than Alba, even though there were no significant differences between germination of both cultivars before aging. Hence, germination percentage of a given cultivar before aging may not indicate how fast that cultivar may or may not deteriorate in germination after aging.

The solute leakage test on aged seed samples taken from both cultivars indicated that there was only an aging effect (Table 2). Results of the solute leakage test as affected by age when averaged over cultivars indicated that solute leakage increased with aging (Table 3). Leakage osmotic potential measured in MPa g^{-1} dry weight of seed ranged from -0.582 to -2.790 for unaged and aged seeds, respectively. When seeds were aged for 1 week, solute leakage in aged seeds was more than twice that from unaged seeds. As reported in the preliminary observation earlier, significant solute leakage was observed before germination declined. The amount of leachate produced during imbibition was negatively correlated with germination in DD H_2O at each aging treatment. The relationship between germination percentage and seed age appeared to be negative and quadratic ($r^2 = 0.85$, $p < 0.05$). Loss of leachates into the imbibing media increased quadratically ($r^2 = 0.80$, $p < 0.05$) with the duration of accelerated aging. As indicated in Table 3, solute leakage in aged seeds was more than double that of unaged seeds. Many investigators attribute this to malfunctioning of cell membranes (Powell and Matthews, 1978; Duke and Kakefude, 1981; Berjak and Villiers, 1971; Shoettle and Leopold; 1984). Supporting evidence was reported by Berjak and Velliers (1972) who, through ultrastructural and cytological investigations of artificially aged maize seeds, found that there is increased membrane aberration through ultrastructural and cytochemical investigations of artificially aged maize seeds. Buckvarove and Grantcheff (1984) observed loss of total phospholipids which increased with aging because of membrane peroxidation by oxygen radicals leading to loss of viability. The authors also measured increased level of free oxygen radicals in aged seeds. Therefore, the membrane loses integrity which makes it unable to respond osmotically which leads to loss of viability.

Germination performance of aged seeds of the same tef cultivars reported earlier were tested under two concentrations (-0.6 and -0.9 MPa) of NaCl solutions. There were no significant differences between the treatment combinations (Table 2). Aged seeds of both tef cultivars did not germinate in salt solution of - 0.9 MPa (Table 3). Therefore, only data from germinated treatments were included in the statistical analysis for mean comparison. Germination in -0.6 MPa NaCl solution dropped from 81 to 1 % in cultivar Alba for unaged and seeds aged for 3 weeks, respectively. In cultivar Variegata, germination dropped from about 85 % to 0 for unaged and aged seeds that received one week of aging treatment, respectively. As indicated in Table 3 , comparison of germination of unaged seeds of the 2 cultivars in the two salt solutions revealed that there was no significant difference between the cultivars tested under each solution. Contrary to germination in DD H_2O, germination had dropped from 81 to 11 % in Alba and 85 to 0 % in Variegata after one week of aging in salt solution of -0.6 MPa. Although germination was from very low to none after 1 week of aging treatment in Alba and Variegata, respectively, it was found that seed deterioration was faster in Varigata than in Alba. As indicated in Table 3, seeds which received 1 to 2 weeks of aging treatment showed similar germination response in both cultivars under DD H_2O. Whereas germination was tremendously reduced to about 11 and 0 % in Alba and Variegata after one week of aging treatment.

This finding revealed that aged tef seeds germination is very sensitive to salt stress.

SUMMARY AND CONCLUSION

Two tef cultivars, Alba and Variegata, white and reddish brown seeded, respectively, were artificially aged for three weeks at 40 °C and about 100 % relative humidity. Seeds were taken out of aging chamber at weekly interval to get seeds of three age groups. Unaged seeds were included in the test as a check. Germination of aged and unaged seeds was evaluated in DD H_2O and salt solution. Solute leakage from imbibing aged seeds was assessed.

Germination significantly decreased as aging increased in both cultivars. Germination of cultivar Variegata in DD H_2O ranged from 100 to 28 % for unaged and seeds aged for three weeks, respectively. Before aging, Variegata had better germination potential than Alba. However, Variegata deteriorated faster than Alba as evidenced by germination after aging. Hence, germination potential of a given cultivar before aging may not indicate how fast that cultivar may or may not deteriorate.

Solute leakage from imbibing aged seeds increased significantly as aging increased. Solute leakage from aged seed for one week was twice that from unaged seeds. It was also observed that significant solute leakage took place before germination declined significantly. The relationship between aging and percent germination appeared to be negative and quadratic (r^2 = 0.85); whereas positive quadratic (r^2 = 0.80) relationship was observed between solute leakage and aging. Many investigators attribute solute leakage from imbibing aged seeds to malfunctioning of cell membrane.

Germination of aged seeds of the same cultivars was tested under salt solution of two concentrations (-0.6 and -0.9 MPa NaCl). Aged seeds of both cultivars did not germinate in -0.9 MPa salt solution. Germination of Alba in -0.6 MPa dropped from 81 to 10 % after one week of aging; whereas Variegata did not germinate at all indicating that this cultivar deteriorates faster and is more sensitive to salt stress than Alba.

Generally, this study indicated that high moisture and relative humidity affected viability of tef seed; second, lack of significant decrease in germination up to two weeks of accelerated aging may suggest that tef seed may be stored longer before it loses viability. However, how long tef seed can be stored before it loses viability needs to be evaluated on naturally aged seeds.

REFERENCES

Association of Official Seed Analysts, Seed Vigor Test Committee. 1983. Seed Test Hand Book. N. P. In Seed Aging. D. A. Priestley (ed.). pp 57.

Baskin, C. C. 1981. Accelerated seed aging test. In Handbook of Vigor test methods. D. A. Perry (ed). The Int. Seed Test Assoc. Zurich. pp. 43-48.

Berjak, P., and T.A. Villiers. 1972. Aging in plant embryo. II. Age induced damage and its repair during early germination. New Phytol. 71:135-144.

Byrd, H. W., and J. C. Delouche. 1971. Deterioration of soybean seeds in storage. Proc. Assoc. Off. Seed anal. 61:41-75.

Delouche, J. C. 1965. Accelerated aging technique for predicting storability of crimson clover and tall fescue seed lots. Agron. Abst. Amer. Soc. Agron. Meetings. p. 40.

Delouche, J. C., and C. C. Baskin. 1973. Accelerated aging for predicting the relative storability of seed lots. Seed Sci. and Tech. 1:427-452.

Duke, S. H., and G. Kakafuda. 1981. Role of the testa in preventing cellular rapture during imbibition of legume seeds. Plant Physiol. 67:449-456.

Duke, S. H., G. Kakefuda, and T. M. Harvey. 1983. Differential leakage on intracellular substances from imbibing soybean seeds. Plant Physiol. 72:919-924.

Ferguson, J. M., D. M. Tekrony, and D. B. Egli. 1989. Accelerated aging and seed viability of pecan (Carya illonoensis (Wang.) K. Koch. Proc. Annu. Conv. Southeast pecan grow. Assoc. 82:143-147.

Harrington, J. F. 1972. Seed storage and longevity. T. T. Kozlowski (ed.). In Seed Biology. pp. 145-245.

Lang, A. R. G. 1967. Osmotic coefficients and water potentials of sodium chloride solutions from 0 to 40 °C. Aust. J. Chem. 20:2017-2023.

Matthews, S., and W. T. Bradnock. 1967. The detection seed samples of wrinkled-seeded peas (Pisum sativum L.) of potentially low planting value. Proc. of the Intnl. Seed Test. Assoc. 32:555-563.

Matthews, S., and A. A. Powel. 1981. Electrical conductivity test. In Handbook of vigor test methods. D. A. Perry (ed.). The Int. Seed Test Assoc. Zurich. pp. 37-42.

McDonald, M. B. Jr., and C. J. Nelson (ed.). 1986. Physiology of seed deterioration. CSSA Special. Pub. no. 11 Crop Sci. Soc. Am. Inc. Madison, Wisc.

Powell, A. A., and S. Matthews. 1978. The damaging effect of water and low temperature on germination of pea seeds. J. Exp. Bot. 21:504-512.

Parrish D. J., and A. C. Leopold. 1978. On the mechanism of aging in soybean seeds. Plant Physiol. 59:1111-1115.

Parrish, D. J., A. C. Leopold, and M. C. Hanna. 1982. Turgor changes with accelerated aging of soybean. Crop Sci. 22:666-669.

SAS Users Guide: Statistics Version 5 Edition. 1985. SAS Institute Inc. Cary, NC.

Schoettle, A. W., and A. C. Leopold. 1984. Solute leakage from artificially aged soybean seeds after imbibition. Crop Sci. 24:835-838.

Seifu Ketema. 1986. Food self sufficiency and some roles of tef (Eragrostis tef) in the Ethiopian agriculture. (Paper presented at the National Workshop held at Alemaya Univ. of Agric., Ethiopia. Dec. 8-12, 1986).

Smith, S. E., and A. K. Dobrenz. 1987. Seed age and salt tolerance at germination in alfalfa. Crop. Sci. 27:1053-1056.

Table 1: Preliminary observation of artificial aging effect on germination and solute leakage of tef (cv. Enatit) seed.

Aging treatment (days) wt.	Percent germination	Leachate osmotic potential MPa g^{-1} dry
0	100	-0.12
1	95	-0.24
2	92	-0.26
3	90	-0.31
4	89	-0.33
5	88	-0.44
LSD, 0.05	N.S.	0.25
C.V.	9.8 %	11.2

Table 2 : Mean squares for germination of tef cultivars and solute leakage as affected by seed age grown in DD H_2O and sodium chloride (NaCl) solution.

Source	df	Germination in DD H_2O	df	Solute leakage	df	Germination in NaCl
Super Rep (SR)	1	2139.06	1	0.148	1	62.16
Rep (SR)	6	154.64	4	0.433	6	57.35
Treatment combination (TC)					6	10563.87
Age	3	10363.56*	3	11.529**		
Cultivar (C)	1	3052.56**	1	0.031		
Age x C	3	1408.56**	3	0.102		
S x TC	7	307.92			6	210.54
Rep x TC(S)	42	92.74	35	0.175	36	63.17

* and ** : significantly different (F, $p < 0.05$ and 0.01, respectively)

Table 3 : Effect of accelerated aging on solute leakage and subsequent germination in DD H_2O and NaCl solutions.

	DD H_2O		Leachate osmotic potential	NaCl solution (-MPa)*			
				-0.6		-0.9	
Age (week)	Alba	Varie-gata	(-MPa g^{-1} dry wt.)	Alba	Varie-gata	Alba	Varie-gata
0	97.5a	99.5a	0.504d	81.0a	84.5a	16.1b	12.0b
1	93.8a	96.5a	1.041c	10.6b	0.0	0.0	0.0
2	85.5a	57.5b	1.631b	5.1b	0.0	0.0	0.0
3	59.5b	27.5c	2.790a	1.0b	0.0	0.0	0.0

Means followed by the same letters within a column are not significantly different (LSD, $p < 0.05$).

* Means followed by the same letters within columns and rows are not significantly different ($p < 0.05$).

2

VITA

ABERRA DEBELO

Candidate for the Degree of

Doctor of Philosophy

Thesis: GERMINATION, YIELD AND YIELD COMPONENTS OF TEF (*Eragrostis tef* (Zucc.) Trotter) AS AFFECTED BY ENVIRONMENT, TILLAGE AND WEED CONTROL PRACTICES

Major Field: Crop Science

Biographical Data:

Personal Data: Born in Haru, Wollega, Ethiopia on January 12, 1953, the son of Debelo Napo and Bizunesh Jimilu.

Education: High School certificate from Shimelis Habte Comprehensive High school, May 1970; Bachelor of Science degree in plant Sciences in July, 1977 and master of Science in Agronomy in July, 1982, from Alemaya College of Agriculture, Addis Ababa University; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in May 1992.

Professional Experience: Assistant Research officer and Agronomy Section Head, August, 1977; Research Officer, Agronomy Section Head and National Maize Research Coordinator, Institute of Agricultural Research, Ethiopia, August, 1982-1986.

Professional Membership: Ethiopian Journal of Agricultural Sciences.