ORIGINAL ARTICLE

Weed Interference in Cotton *(Gossypium hirsutum* L.) **in the Middle Awash, Ethiopia**

Esayas Tena[1], Abraham G/Hiwot[2] and Mashila Dejene[3]

[1]Sugar Corporation, Research and Training, P.O Box 15, Wonji, Ethiopia
[2]Werer Agricultural Research Center, P.O Box 2003 Addis Ababa, Ethiopia
[3]Haramaya University, P.O Box 138, Dire Dawa, Ethiopia
[1]Corresponding author: E-mail: esutena11@gmail.com Mobile: +251911678943

ABSTRACT

An investigation was made for two consecutive seasons (2000 and 2001) to determine the critical period of weed competition and yield and quality loss of cotton *(Gossypium hirsutum* L.) in the Middle Awash, Ethiopia. The experiment was conducted at two sites *viz.* research field of Werer Agricultural Research Center and Werer Cotton State Farm. Quantitative series of both increasing duration of weedy and weed free periods were compared with complete weed free and weedy check. Treatments were arranged in RCBD with three replications. Data was collected on yield and yield components and lint quality parameters. At both locations, the mean yields of weed-infested treatments showed a decline as the weed infestation period increased and vice versa as the weed free period increased. Yield loss of 62-96% occurred when weeding was completely denied. The study indicated that the critical period of weed competition in cotton in the Middle Awash was early to medium growth stage of the cotton plant, i.e. 20-60 days after crop emergence. This indicates that the weed management practice should focus on this stage to suppress weed competition and achieve optimum yield. Weeds which emerge after the critical period still need to be controlled to avoid harvesting difficulties and lint contamination and should not be allowed to set seed, as this will lead to increased weed problems in later seasons. With regard to quality parameters of cotton lint, a one-year data (2000) showed a significant difference ($p \leq 0.05$) for micronaire value and fiber maturity percent.

Keywords: Cotton, Critical period of weed competition, Ethiopia, Middle Awash.

INTRODUCTION

There are four domesticated species of the genus Gossipium among which *Gossipium hirsutum* L. is by far the predominant form of cotton grown in the world. It is grown primarily because of its relatively high productivity and wide adaptability.

Approximately 91% or more of the world's production is derived from cultivars of American upland cotton *Gossipium hirsutum* (Smith and Cotheren, 1999). The crop needs more than 160 days above 15^{o}C and it can grow on any type of soils if temperature and moisture are favorable. Cotton is a multipurpose crop providing more than one single utility. It is source of raw materials for textile industry, cooking oil for human consumption and seed cakes for animal feed. It is also used for manufacturing of various valuable items such as fuel, fertilizers, organic filters, particleboard's, high-grade writing papers and others.

The major cotton growing areas in Ethiopia include the Awash River basin, Arbaminch, Sile, Abaya, Woito and Omorate in the South; Gambella in the West; Beles in the North; and Metema and Humera in the Northwest. Large potential areas also exist in the western, southern and eastern parts of the country. The total area under cotton production is not exactly known, but the area under the former state farms was 42,584 hectares (WARC, 2000). The share of small-scale cotton producers was undetermined and thus no survey works were done to determine the share both in production and area coverage. According to information obtained from USAID Ethiopia (1994), the total area covered by small-scale cotton producers in 1993/94 cropping season was 56000 hectares.

Cotton yield potential is largely dependent upon its management from seedling to harvest. Therefore, there is great variation between research-managed and farm-managed fields. In Ethiopia, under research, cotton yields from 35-40-q ha-1, but yields in commercial farms and farmers' holdings are 20-30 and 5-10 q ha-1, respectively (WARC, 2000). Rains fed commercial farms obtain yields of 15-20 q ha-1 in years with good rainfall distribution.

The major problems of cotton production in Ethiopia include lack of high yielding and widely adaptable varieties, insect pest and disease management techniques, and crop and weed management practices (WARC, 2000). Cotton (*Gossypium hirsutum* L.) losses due to the presence of weeds may be severe although the damage caused is not always as obvious as losses caused by other pests (Lee, 1984). Weeds compete with cotton for water, nutrient, light, space, gases and other growth factors. The yield and lint quality losses occur at various stages in the cotton production cycle.

Though cotton is a warm climate perennial, it is cultivated as an annual. Its early slow growth permits early and vigorous weed competition. As cotton-weed competition is concerned, the critical period of cotton plant is very important to determine the effective time of weed management in which weeding results in higher yield and economic advantage. In this connection, Zimdahl (1980) noted that the time of weed removal is as important as the weed removal itself.

Weeds and their competition are the major constraints in cotton production in Ethiopia and elsewhere. Weeds reduce the yield of cotton, impair the quality, increase cost of hand and mechanical tillage, fertilizer and herbicides, prevent efficient irrigation water management and harvesting, and serve as hosts and habitats for pests (Kohel and Lewis, 1984).

In the Middle Awash, Cotton State Farms have a practice of pre-planting irrigation followed by lilistone (trailed-rotarychopper) cultivation during planting in which emerging early flush of weeds are reduced (Middle Awash State Farms, personal communication). However, late-emerging weeds growing especially during blooming and near harvesting are responsible for yield loss and deterioration in lint quality as well (Heitholt, 1994).

In the Middle Awash Valley where cotton cultivation has been in progress for a long time, a steady increase in weed population as well as introduction has been reported (Tadesse, 1982; Esayas and Abraham, 2000). The result of weed survey conducted at Middle Awash cotton farms in 2000 confirmed that there are a total of 26 weed species that actually grow in association with cotton comprising of broad leaf, grass and sedges (Abrham and Esayas, 2000). The report indicated the infestation level is very high for most of the species. Higher weed density was recorded at flowering and near harvesting growth stage of cotton resulting in reduction of yield and harvest efficiency. An earlier crop loss assessment trial conducted at Werer Agricultural Research Center (WARC) indicated that the critical period of competition ranged between 30 and 60 days after crop emergence (DACE) (Tadesse and Ahmed, 1985). The results also indicated that late weeding has no influence on the yield of seed cotton. When no weeding was made the yield loss was reported to reach 73%. The results of that earlier work were concerned with weeds prevailing at that moment and did not include cotton quality losses, which is the focus of the current cotton production in the area. Research results in other countries indicated a loss of quality of lint especially in reduction of grade (Lewis and Kohel, 1984), and an adverse effect on micronaire, 2.5 and 50% span length and uniformity index when cotton was infested by weed (Doug *et al*., 1985).

Hence, the basis for any weed research program should be an objective appraisal of the problems and yield and quality losses caused by weed not only the direct losses on yield but also the indirect loss on quality, which is of paramount significance in the cotton lint production (Lewis and Kohel, 1984). There are many factors that govern the effectiveness of mechanical weed control, including soil type and conditions, weed species, weed growth stage and weather conditions after treatment (Böhrnsen, 1993). To identify the optimum timing for weeding operations, however, it seems appropriate to firstly identify the period when weeds are likely to exert their greatest competitive effects on the crop, viz. the critical period of competition (Akobundu, 1987). Once this period has been identified, it will be possible to target mechanical weeding operations appropriately.

The critical period represents the time interval between two separately measured components: the maximum weed-infested period or the length of time that weeds which have emerged with the crop can remain before they begin to interfere with crop growth; and the minimum weed-free period or the length of time a crop must be free of weeds after planting to prevent yield loss. These components are experimentally determined by measuring crop yield loss as a function of successive times of weed removal or weed emergence, respectively (Weaver *et al*., 1992).

In order to provide more precise information for growers, crop weed competition should be determined specifically for a particular region by considering the weed composition and climatic conditions (Knezevic *et al*., 2002). Therefore, the purpose of this experiment was to determine the critical weed competition period and yield and lint quality loss of cotton in Middle Awash, Ethiopia.

MATERIALS AND METHODS

Experimental sites

The experiment was conducted at two sites, Werer Agricultural Research Center (WARC) experimental field and the nearby Werer State Farm (WSF) cotton production field of the Middle Awash Agricultural Development Enterprise for two consecutive cropping seasons 2000 and 2001 (from months May to October of each year). The experimental sites were located 278 km east of Addis Ababa at an altitude of 740 masl and at latitudes of 90 60′N and $40^{0}9'$ E longitude. The dominant soil type of the study areas is chromic Vertisol (clay to silty clay) with particle size distribution: sand 3.83 %, silt 61.1 % and clay 35.07 % with a bulk density of 1.17. The pH of the soil is slightly alkaline and ranges from 7.5 to 8.5. The mean annual rainfall is 540 mm and the mean maximum and minimum temperatures are 34^{0}C and 19^{0}C, respectively.

Treatments and Experimental Design

Fourteen treatments were included in the experiment. Of the 14 treatments, seven dealt with weed-free treatments where the crop was kept weed-free for 0 (WF0), 15 (WF1), 30 (WF2), 45 (WF3), 60 (WF4), 75 (WF5) and 90 (WF6) DACE by repeated hand-weeding; the other seven treatments involved weed infested periods of 0 (WI0), 15 (WI1), 30 (WI2), 45 (WI3), 60 (WI4), 75 (WI5) and 90 (WI6) DACE. The popular cotton variety in the area, Deltapine-90, was used at spacing of 0.20 m x 0.9 m (a plot size of 27 m^2). The experiment was laid out in randomized complete block design (RCBD) with three replications.

Data Collection and Analysis

A quadrant with a dimension of 0.25 by 0.25 m was thrown randomly on four sampling points in each plot before weeding for each weed infestation treatments and at the end of the season for weed free treatments to determine or identify, by counting, the dominant weed species growing in association with cotton. Data on crop agronomic parameters, including plant height, number of open bolls per m^2, average boll weight, seed cotton weight per m^2, seed cotton yield, and leaf area index were collected at crop maturity. A one year data (2000) on cotton quality parameters, including fiber span length (2.5%), fiber span length (50%), fiber fineness (micronaire value), fiber maturity percent, fiber strength and fiber uniformity ratio were also collected. Data for the second year could not be recorded due to malfunction of quality measurement equipments.

Analysis of variance (ANOVA) and mean separation were computed using the MSTATC software of version 2.10. Data from the experiment at WARC was used to determine the critical period of weed competition since the weed infestation was high and uniform. Moreover, dominant weed species identified in the previous survey conducted before the present study (Abrham and Esayas, 2000) were occurred more at the experimental plots of WARC than on that of WSF. The onset and end of the critical period were determined using response curves. The onset of critical period was defined as the time at which weed interference reduces yields by 10% (Weaver *et al.*, 1992). Similarly, the end of the critical period was defined as the time during which the crop must be free of weeds to prevent yield loss exceeding 10% (Weaver *et al.*, 1992).

RESULTS AND DISCUSSION

Important Weeds Associated with Cotton in the Study Areas

The predominant naturally occurring weed species associated with cotton crop in the study areas were: *Bracharia eruciformis*, *Borhavia erecta*, *Corchorus* *olitorius, Corchorus trilocularis, Cyperus rotundus, Echinocloa colona, Eragrostis spp. Ericula fatumansis, Launaea cornut, Portulaca oleraceae, Sorghum arundillacium, and Xanthium strumarium*. The grassy weeds were mainly dominant (92 %) during near harvesting stage and were observed to spoil the lint quality by the addition of trash to the produce and reduce harvest efficiency.

Effect of Weed Competition on Seed Cotton Yield

Yield of cotton was greatly reduced due to the naturally-occurring mixed weed population in which a seed cotton yield loss of 62.43 - 96.21% occurred when weeding was completely denied throughout the crop growing season (Table 1 and Figure 1). A previous similar experiment conducted at the same place indicated a seed cotton yield loss of 73% when weeding was not practiced throughout the crop growth period (Tadesse and Ahmed, 1985). An increased higher yield loss on average in the present experiment than the former report could be due to increased weed population and introduction of other new weed species to the area. Survey conducted in Middle Awash in 2000 indicated that the infestation level was very high for most of the weed species (broad leaf, grass and sedges). Higher weed density was recorded at flowering and near harvesting growth stage of cotton resulting in reduction of yield and harvest efficiency. Weed species such as *Xanthium strumarium* that was not economical weed had become critical weeds in cotton fields (Esayas and Abraham, 2000). Similarly a seed cotton yield loss of 35.03-88.13% and 56.45-94.44% occurred when weeding was delayed for 60 and 75 DACE, respectively. So it could be shown that the major yield loss occurred up to 75 DACE during the cotton growth period.

In both experimental sites, the increase in seed cotton yield was observed to be consistent with advancement of weed-free period (Table 1). On the other hand, the longer the weeds were allowed to grow and compete with the crop, the higher the seed cotton yield reduction would be. In agreement with the present study, loss of yield with increase in the weed infestation period was reported in different crops including cotton (Chiarrapa, 1971; Young *et al*., 1984).

Effect of Weed Removal on Yield and Yield Components

Different yield attributes, such as plant height, leaf area index, number of open bolls m^2 and average boll weight were shown to be affected due to weed removal (Table 1). The yield components showed increasing as the weed-free period increased and decreasing as the weed infestation period increased from 15 to 90 DACE (Table 1). Weed removal treatments resulted in significantly higher plant height, more number of open bolls, higher boll weight, and leaf area index and seed cotton yield than weedy control. The presence of weeds throughout the season reduced the yield components and consequently seed cotton yield in weedy check. On the other hand weed removal resulted in optimum utilization of environmental resources by the crop which enhanced the yield components and finally seed cotton yield. These results are supported by other findings elsewhere (Douti, 1997; Sadras, 1997; Lamm *et al*., 2002).

The correlation analysis (data not presented) revealed that there were positive and highly significant ($p \leq 0.01$) correlation between seed cotton yield and yield components and among yield components as well. A positive significant ($p \leq 0.05$) correlation ($r=0.84$) was recorded between seed cotton yield and 2.5% span length. This result indicated that the effect of weed competition on seed cotton yield also seriously affect the cotton lint fiber length which is an important quality parameter in textiles (Doug *et al*., 1985).

The correlation with the yield components was positive though not significant. There was a significant negative correlation between other quality parameters and seed cotton yield as well as yield components.

Effect of Weed Competition on Cotton Lint Quality

With regard to fiber quality, no significant ($p>0.05$) difference was observed for all quality parameters at WSF (Table 2). At WARC, treatment effects showed a significant ($p \leq 0.05$) difference for micronaire value (fiber fineness). The value was shown to have a decreasing trend as the weed infestation period increased. The difference at the two sites may be due to difference in weed population and type of weed species occurred. This result is consistent with the work of Craft (1975) and Doug *et al*., (1985) where it was reported that micronaire value was adversely affected due to weed infestation and that there is a positive significant ($p \leq 0.05$) correlation ($r = 0.82$) between fiber fineness and fiber maturity. Other quality parameters did not show significant difference due to treatment effects (Doug *et al*., 1985). Scoring of the trash content of the lint showed (data not shown), late coming weeds particularly grassy weeds have added more trash to the lint due to dried leaves and seeds, especially in treatments infested with weed for more than 60 DACE.

Critical Period of Weed Control in Cotton

The two threshold points of the critical period were set according to the definition presented by Weaver *et al*. (1992). There is likely to be a point when the effort, cost and difficulty of weeding outweigh the benefit to yield. Therefore, a decision needs to be made on the level of acceptable yield loss before the critical weed-free period identified. A 10% acceptable yield loss was considered on the two, increasing and decreasing response curves. The two threshold levels, onset and end, were determined when yields in both the increasing and decreasing response curves attained a 10% yield loss of the season-long weed-free yield.

Accordingly, weed infestation up to 20 DACE (Figure 1), considered as the beginning of the critical period, was unable to reduce seed cotton yield by more than 10% compared to the season-long weed-free period. This is the length of time that weeds which have emerged with the crop can remain before they begin to interfere with the crop growth causing significant yield loss. On the other hand, keeping the crop free of weeds up to 60 DACE prevented yield loss from exceeding 10% (Figure 1). This is the end of the critical period. Weed control after this time does not have a significant yield loss, but can help in reducing weeds that can interfere with the cultural practices. Furthermore, it reduces the trash added to the lint due to dried leaves and seeds of the weeds during harvest which spoil the quality of the lint. Therefore, based on the two threshold points set, it is needed the crop should be free of weeds starting 20 up to 60 DACE to prevent seed cotton yield loss from exceeding 10%. Thus regarding weed control in cotton in the Middle Awash Valley the crop need a minimum of 40 weed-free days to prevent yield loss go beyond 10%. This result is in conformity with the result found by Tadesse and Ahmed (1985) at the same place where the critical period was reported to be between 30 and 60 DACE. At the present experiment the critical period begins earlier than the previous report which could be due to high infestation of weed population and introduction of new weed species to the valley.

Table 1. Effects of weed removal on yield and yield components of cotton (Werer Agricultural Research Center and Werer State Farm, 2000-2001)

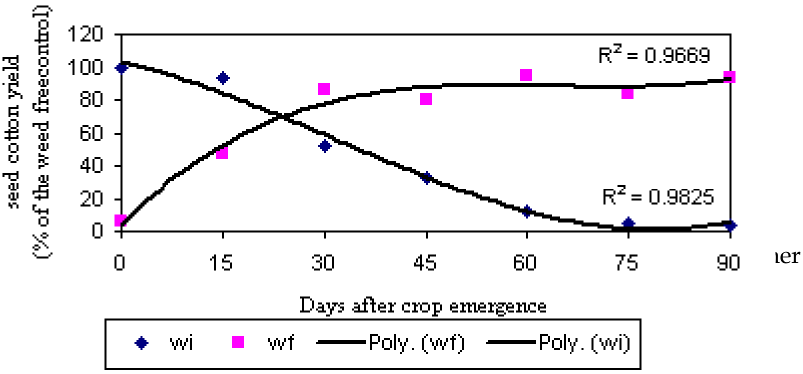
Weed removal Treatments (DACE)[a]	Plant height(cm)		Number of open bolls m^{-2}		Boll weight(g)		Seed cotton yield(q ha^{-1})		Leaf area index	
	WRC[b]	WSF[c]	WRC	WSF	WRC	WSF	WRC	WSF	WRC	WSF
	A. Weed infested									
WI0	69.52ab	80.30	87.96abc	80.72abc	4.23ab	4.43a	48.76b	36.28a	1.62de	2.09abc
WI1	69.30ab	73.77	91.85ab	61.67cdef	4.28ab	4.03ab	45.67a	29.13abc	1.45bcd	1.49bc
WI2	50.67de	79.80	48.71ef	82.77a	4.73a	3.78abc	25.30a	32.18ab	0.92e	1.97abcd
WI3	53.80c	68.83	38.88f	69.95abcdef	3.65g	4.00ab	15.68a	28.40abcd	1.22abc	1.63abcd
WI4	51.40de	69.87	15.73g	58.13def	3.03c	3.75abc	5.79a	23.57cd	0.71abcd	1.47bcd
WI5	42.00ef	67.53	14.43g	52.03f	1.63d	4.35ab	2.62a	20.63de	0.44abc	1.38cd
WI6	34.67f	75.60	10.56g	55.72ef	1.38d	3.68abc	1.85a	15.8e	0.34cde	1.29cd
	B. Weed free									
WF0	33.27f	73.67	13.32g	34.42g	1.60d	3.17c	2.71a	13.63e	0.29abc	1.32cd
WF1	63.03abc	79.53	58.88def	62.40bcdef	3.72bc	3.60bc	22.97b	24.43bcd	0.76ab	1.25d
WF2	69.03ab	70.00	92.39ab	58.87def	4.67ab	3.92abc	41.92bc	24.88bcd	1.65a	1.88abcd
WF3	64.50abc	82.10	88.48ab	70.17abcdef	4.23ab	3.80abc	38.89c	34.32a	1.63cde	2.33a
WF4	68.53ab	73.67	93.70ab	74.08abcde	4.32ab	4.13ab	46.18d	34.83a	1.57a	2.22ab
WF5	70.67a	75.60	100.91a	74.05abcde	4.30ab	4.33ab	40.92d	34.2a	1.38a	1.75abcd
WF6	73.63a	78.07	89.07ab	81.58abd	3.83bc	4.22ab	45.67d	31.22abc	1.65ab	1.82abcd
CV(%)	11.97	15.79	23.17	30.63	15.92	15.45	21.05	20.68	38.30	34.88
S.E ±	2.86	4.86	2.82	8.30	0.23	0.25	2.43	2.35	0.18	0.24
LSD (0.05)	8.1	ns	16.47	23.48	0.66	0.71	6.89	129.6	0.5	0.69

[a] DACE= Days after crop emergence, [b] WARC= Werer Agricultural Research Center, [c]WSF = Werer State Farm, ns= non-significant. Means followed by the same letter within the column are not significantly different at 5% probability level.

Table 2. Effects of weed removal on fiber quality parameters (Werer Agricultural Research Center and Werer State Farm, 2000-2001).

Weed removal treatments (DACE[a]	Fiber span length (2.5%)		Fiber span length (50%)		Micronaire value (*Mg*/")		Maturity(%)		Presley strength (g/tex)		Uniformity Ratio (%)	
	WRC[b]	WSF[c]	WRC	WSF	WRC	WSF	WRC	WSF	WRC	WSF	WRC	WSF
	A. Weed infested											
WI0	30.83	34.58	22.17abcde	24.17	4.23abc	4.39	89.67	86.67	30.87	25.51	71.82	69.73
WI1	32.75	31.67	21.25bcde	22.92	4.17abc	4.46	87.67	86.67	32.30	27.09	65.45	72.33
WI2	35.50	34.17	23.67ab	24.17	4.36ab	4.20	90.33	81.00	30.76	26.51	66.68	70.99
WI3	35.33	32.50	23.33abcd	23.33	4.17abc	4.31	88.33	85.67	31.81	27.40	66.33	71.79
WI4	32.17	32.50	18.42e	22.50	4.57a	4.39	87.00	88.67	31.08	26.11	58.16	69.15
WI5	33.33	33.33	20.58bcde	23.33	4.13abc	4.50	91.00	87.33	32.35	25.52	61.98	69.99
WI6	29.75	32.08	19.58cde	21.25	3.60e	4.31	83.33	84.00	29.80	24.73	65.77	66.29
	B. Weed free											
WF0	30.17	33.33	19.50de	22.08	3.67de	4.35	84.00	83.67	30.54	24.07	64.94	6.61
WF1	30.00	34.58	21.83abcde	22.08	3.98bcde	3.91	84.67	84.33	31.24	25.03	73.61	63.73
WF2	33.92	32.50	23.60abc	23.33	4.07bcd	4.22	89.33	87.00	29.66	27.45	69.73	71.51
WF3	32.58	33.33	21.92abcde	22.92	4.08bcd	4.22	90.67	87.67	30.08	25.51	67.37	68.73
WF4	34.17	32.50	25.41a	23.92	4.35ab	4.27	88.00	86.00	30.52	27.33	74.45	70.50
WF5	32.58	31.67	22.67abcd	22.50	4.10bcd	4.28	90.67	85.33	30.39	28.90	69.49	70.96
WF6	34.92	32.92	21.33bcde	22.92	4.21abc	4.43	90.67	85.33	28.58	25.95	61.28	69.57
CV (%)	8.84	7.23	9.24	10.42	5.8	5.01	5.84	5.00	6.98	10.81	10.91	6.01
S.E±	1.68	1.38	1.20	1.38	0.14	0.12	2.97	2.47	1.24	1.63	4.22	2.40
LSD (0.05)	ns	ns	3.45	ns	0.40	ns	ns	ns	ns	ns	ns	ns

[a] DACE = Days after crop emergence, [b] WARC= Werer Agricultural Research Center, [c]WSF= Werer State Farm, ns= non-significant; Means followed by the same letter within the column are not significantly different at 5% probability



Using this critical period as a reference a study was conducted at Werer Agricultural Research Center to evaluate cultural practices that can effectively and economically control cotton weeds. The study found that the best and most economical cultural practice to control cotton weeds in Middle Awash is to use: pre-planting irrigation + pre-planting machine cultivation + manual cultivation at 15, 35 and 75 DACE (Esayas *et al*., 2007). The report also indicated that providing a basket of options for agricultural producers with different economic status is believed to be a good approach. Accordingly, for small scale cotton farmers that practice dry planting and can not afford machine cultivation they can use: manual cultivation at 20, 40 and 75 DACE and at 15, 35 and 75 DACE, respectively. Economically these two cultural practices were the second and third best economical cultural practices, respectively, that the study showed.

CONCLUSIONS

A seed cotton yield loss of 62.43-96.21% occurred when weeding was completely denied. The two threshold points, onset and end of the critical period, were determined to be 20 and 60 DACE, respectively. Weed control practices should be given due attention during this period in order to get better seed cotton yield. Late-coming weeds after this period had no detrimental effect on yield but interfered with the cultural practices and harvesting. These weeds spoiled the quality of the lint by addition of non-lint materials, such as dried leaves and seeds. Therefore, cotton farmers should pay attention to control these late-coming weeds besides those imminent during the critical period.

Acknowledgments

The authors are grateful to the financial grant of Ethiopian Institute of Agricultural Research (EIAR).

REFERENCES

Akobundu, OI. 1987. Principles and practices: Weed Science in the Tropics. John Willy and Sons Ltd, London.

Böhrnsen, A. 1993. Several years results about mechanical weed control in cereals. Communication of the Fourth International conference IFOAM – Non chemical weed control. Dijon.

Chiarrapa, L. (ed.). 1971. Crop loss assessment methods. FAO manual on the evaluation and prevention of losses by pests, diseases and weeds. Alden 6 Mowbray Ltd., Alden press, Oxford.

Craft, S. A. 1975. Weed control in fiber crops. University of California presses, USA.

Doug, WR, Don, SM and Laval, MV. 1985. Weed interference with cotton, Buffalobur (*Solanum rostratum*). *Weed Sci.* 33: 810-814.

Douti, PY. 1997. Cotton crops versus weeds: when is the competition period? Agric. Dev. (May special issue): 11-16.

Esayas, T. and Abraham, GH. 2000. Quantitative and qualitative survey of weeds growing in association with cotton in the Middle and the Lower Awash. Progress report for the period 2000/2001. Werer Agricultural Research Center.

Esayas, T, Abraham, GH and Agajie, T. 2007. Evaluation of cultural practices for effective and economical control of cotton weeds in the Middle Awash Valley. *Eth. J. Weed Mgt.* 1(1): 15-28.

Heitholt, JJ. 1994. Canopy characteristics associated with deficient and excessive cotton plant densities. *Crop Sci.* 34:1291-1297.

Knezevic, SZ, Evans, SP, Blankenship, EE, Van Acker, RC and Lindquist, JL. 2002. Critical period for weed control: The concept and data analysis. *Weed Sci.* 50:773–786.

Lamm, RD, Slaughter, DC and Giles, DK. 2002. Precision weed control system for cotton. *Transact. ASAE* 45: 231-238.

Lee, JA. 1984. Cotton as a world crop. pp. 1-25. *In* Kohel RJ. and Lewis CF. (eds.) Cotton. American Society of Agronomy, Crop Science Society of America and Soil Science Society of America, Inc., Publishers, Madison, Wisconsin, USA.

Lewis, CF and Kohel, RJ. 1984. *Cotton*. ASA, CSSA & SSSA, inc. Madison, Wisconsin, 53711. USA.

Sadras, VO. 1997. Effects of simulated insect damage and weed interference on cotton growth and reproduction. *Anna. Appl. Biol.* 130: 271-281.

Smith,CW and Cotheren, JT. 1999. Cotton: origin, history, technology and production. John Wiley and Sons, Inc., New York.

Tadesse, E and Ahmed, S. 1985. A review of weed research in Ethiopia. pp. 233-244. *In* Proc. of the first crop protection symposium, 4-7 February 1985, Institute of Agricultural Research, Addis Ababa, Ethiopia.

Tadesse, E. 1982. Weed control in irrigated cotton cultivation. pp. 144-147. *In*: Proc. of the Symposium on Cotton Production under Irrigation in Ethiopia. IAR. Addis Ababa, Ethiopia.

USAID Ethiopia. 1994. Cotton sector Assessment III. Cotton Growing Report.

Weaver, SE, Kropff, SE and Groeneveld, RMW. 1992. Use of ecophysiological models for crop-weeds interference: The critical period of weed interference. Weed Sci. 40: 302-307.

Werer Agricultural Research Center (WARC). 2000. Strategies and priorities for cotton research. Werer.

Young, FL, Wyse, DL and Jones, RJ. 1984. Quackgrass (*Agropyron repens*) interference on maize (*Zea mays*). *Weed Sci.* 32: 26-234.

Zimdahl, RL. 1980. Weed-crop competition. Review. International Oregon Plant Protection Center, State University, Corvallis/ Oregon, USA.