Chapter I

Introduction

There are many environmental and physiological causes of fruit abscission in cotton (*Gossypium hirsutum* L.). These include insect feeding, heavy boll loads, temperature stress, water stress, nutrient stress, low light, diseases, and failure of pollination (Guinn, 1998). Insects can cause as much as ninety percent of early-season square loss if infestations are severe (Jones, 1999). Although fruit abscission is a natural occurrence in cotton, fruit retention has always been thought to be very important, as boll number and boll weight are the two major components of yield. However, cotton is able to compensate for some early-season square loss by reallocation of photosynthate to second position bolls and by setting new bolls farther up the plant (Kerby and Buxton, 1981).

Studies have shown that first sympodial fruiting position bolls produce 66 to 75% of the total yield of the plant; second position bolls produce 18 to 21%; and all other positions combined contribute 2 to 4% of total yield (Jenkins et al., 1990). While the value of the first position fruit to yield is clear, it has been noted that the value of retaining first position squares is difficult to measure, due to the cotton plant's ability to compensate for square losses (Phelps et al., 1998). When first position fruit is damaged by insects in early season, the plant compensates for this damage by diverting assimilates to the growth of second and even third position fruit, and by retaining a higher percentage of their later flowers. Furthermore, cotton plants generate many excess fruiting sites that do not result in mature bolls (Kerby and Buxton, 1981). In the case of first fruiting sites the plant may use diverted assimilates for development of bolls.

The compensatory capacity of cotton seems to be reduced as the season progresses. The abscission of first position squares results in enhanced retention and growth of second position bolls, but if the first position fruit is not abscised until the boll stage, boll retention in the second position is actually repressed (Kerby and Buxton, 1981). Thus, if an insect infestation occurs in the early season, before flowering, yield losses can be offset by compensation from second position fruit. However, later in the season, boll abscission may not be compensated for by the second position.

The University of Arkansas has developed a crop monitoring program, COTMAN, to follow the physiological progress of the cotton plant throughout the season (University of Arkansas, 1998). The program is designed to monitor the fruiting pattern during the squaring and flowering periods and assist with end-of-season management decisions (Bourland et al., 1992). Comparing actual recorded fruiting data with a standard Target Development Curve (TDC) is one facet of this crop monitoring technique (Oosterhuis, 1999). The TDC represents an optimum combination of early maturity and high yield to which actual growth patterns measured in fields can be compared (University of Arkansas, 1998). The TDC is useful for monitoring the effect of stress occurrences (such as square loss) on the subsequent growth and development of the cotton crop.

To gain a better understanding of the compensatory capacity of the cotton crop in Virginia, a study was conducted at the Virginia Tech Tidewater (Suffolk, VA) and the Southern Piedmont Agricultural Research and Extension Centers (Blackstone, VA). The overall objective was to evaluate the compensation capacity of cotton at various levels of square removal using two cotton cultivars at two planting dates at two Virginia locations. It was hypothesized that there would be no significant differences in yield or growth curves as shown by COTMAN among square removal treatments. The specific objectives were:

- To evaluate the effect of mechanical square removal on cotton yield components and lint quality.
- To evaluate the use and effectiveness of COTMAN in tracking major phenological stages (PHS, FF, cutout) of cotton at various levels of square removal.

Chapter II

Literature Review

The Cotton Plant

Originally a tropical plant, cotton (*Gossypium hirsutum* L.) is a woody perennial reaching up to six meters in height in the wild (Smart and Simmonds, 1995). It is indeterminate in its growth pattern, meaning that both vegetative and reproductive growth occur at the same time (Meredith and Bridge, 1973). In its wild state, this evolutionary tactic would be a benefit to the plant. However, in commercial cotton production, excessive vegetative growth is a hindrance to the producer during harvest and requires costly applications of growth retardant chemicals prior to harvest. Energy is wasted on vegetative growth that could be used for further fruit set. Plants continue to set their fruit over a period of time until one or more factors needed for growth become limiting. Plants then redirect the flow of assimilates from initiating new fruit to furthering the development of roots and fruit already set, and to supporting regrowth.

Commercial upland cotton was brought to North America from its native Mexico and Central America in the 1600's. Since its introduction, many studies have been conducted in an attempt to increase yields, including development of new cultivars with high yield potential, development of pest management techniques, and evaluation of new row spacing and tillage practices (Brown, 1938). In the last few decades, the development of new cultivars has been progressing in the direction of earlier and more rapidly maturing types (Jenkins, 1990). These new short-season cultivars develop more fruit early compared with older cultivars (Wells and Meredith, 1984a, 1984b). Major shifts towards these early cultivars began in the early 1970's and continued until roughly 1987 (Jenkins, 1990). Some of the new cultivars have reduced the time it takes to grow a cotton crop by 2-3 weeks, while improving yields (Jenkins, 1990; Bridge and McDonald, 1987).

Since the early 1900's, cotton breeders have been selecting cultivars best suited for specific environments (Meredith and Bridge, 1973). Virginia, the northernmost area in the United States where cotton is grown, has a considerably shorter growing season than other major U.S. cotton producing states. Therefore, those cultivars resulting in the earliest crop maturity are the ones most desired by Virginia producers. The short growing season makes fruit development and retention particularly important since the crop has less time to compensate for fruit abscission than in more southern areas. A longer growing season in those southern areas allows the plant more time to set new fruit to replace those that have abscised. It also allows more time for growth and development of existing fruit, resulting in larger and heavier fruit.

There has been much experimentation with planting dates. Cultivars have been developed to better tolerate cooler early-season temperatures, to permit earlier planting. Planting too early often leads to poor stands, and in the case of severe stand loss, to replanting (Livingston, 1998). Planting too late can significantly reduce yields (Livingston, 1998). Research shows that environmental factors such as soil temperature and moisture availability can have a great impact on the yield of the cotton crop (Bauer, 1998). Ewing (1918) did intensive studies on the varying responses of ten cultivars within different environments, and observed considerable differences among cultivars in date of first flower, rate of flowering, rate of boll abscission, and amount of lint per boll. Similar results have been found by other researchers (Hintz and Green, 1954; McNamara et al., 1940).

Causes of Fruit Abscission

Fruit (squares, flowers, bolls) abscission is a natural occurrence in cotton and can stem from many environmental and physiological factors. Cotton crops produce many more fruiting sites than the number of bolls that mature, and a certain amount of fruit abscission takes place under natural conditions (Kerby and Buxton, 1976; Kerby and Buxton, 1981). Any environmental or physiological condition which decreases the supply of photosynthate causes stress which increases square and boll abscission (Guinn, 1998). Stress conditions may include heavy boll loads, leaf-feeding by insects, insects feeding or ovipositing directly onto the squares or bolls, low light, water deficit, high temperatures, inorganic nutrient deficiencies, diseases, or failure of pollination (Guinn, 1998). Regardless of efforts made to increase cotton yield, yield reduction through excessive loss of squares is apparently common. Even under normal conditions, as many as fifty percent of early fruit and ninety percent of late developing fruit may abscise (Jones, 1999).

Physiological abscission can occur due to competition with vegetative growth or due to a heavy boll load necessitating excessive resources. Nutritional stress often occurs early in the season because the vascular system of young fruit has not had enough time to develop fully (Glover, 1993). Any of the previously mentioned environmental stresses can causes a reduction in photosynthesis that may potentially cause the abscission of young fruit.

A heavy fruit load is one of the most common factors affecting fruit retention. High abscission rate is associated with a large boll load (Kerby and Buxton, 1981; Ehlig, 1973; Patterson, 1978.). A large boll load causes a reduction in the amount of carbohydrates in the central portions of the main stem compared to upper or lower portions; thus, abscission is presumably due to the lack of assimilates (Kerby and Buxton, 1981; Saleem, 1976). If a fruiting form aborts, its subtending leaf is capable of supplying more assimilates to adjacent fruiting positions which should favor retention of remaining fruit (Kerby and Buxton, 1981).

Insect feeding on small fruit often results in their abscission. During extreme infestations, insects can contribute to up to ninety percent of square loss that occurs prior to early flowering (Jones, 1999). Pre-flowering square retention is one of the most important factors contributing to yield, as the squaring stage accounts for the majority of the developmental phase of the cotton boll (Glover, 1993). After initiation of squaring, it takes about three weeks for pinhead squares to become visible, and then another three weeks of square development before flowering. In this span of time, a wide variety of conditions can develop to affect the rate of square retention. Squares have a complex growth pattern and are more sensitive to injury than bolls (Glover, 1993). The size of the squares which have been abscised by the crop is a good indicator of the cause of abscission. Large squares are usually damaged by insects, but a mass abscission of small squares often indicates that environmental causes are to blame (Hake, 1989).

Theories of Fruit Abscission

Two theories have been proposed to explain the phenomenon of fruit abscission, termed the “nutritional” and the “hormonal” theories. The simpler of the two, the nutritional theory, states that the carbohydrate load of the plant will sustain only a certain number of fruiting forms (Jones, 1999). As carbohydrate reserves are used by the plant for growth and development, new or damaged fruiting forms are abscised. This theory is most applicable in the case of a heavy boll load.

One fact that is often not made clear to producers and others not associated with plant physiology is that insect induced abscission of fruiting forms in cotton is not necessarily caused by actual insect incision. Instead of the insect actually physically removing the fruit, more often the abscission occurs by an insect damage induced physiological separation of the fruit from the peduncle. Simply stated, any one of many types of events, be it any of the previously stated factors, such as insect feeding or excessively high temperatures, can cause the plant to undergo stress. When this happens, the plant increases production of certain chemicals and hormones that cause a weakening of the cell walls in the cells of the abscission zone of the fruiting forms. Two hormones, ethylene and abscissic acid (ABA) are associated with increased levels of pectinase and cellulase, which dissolve the middle lamella, weakening the cell wall (Jones, 1999). The cells in the abscission layer of the peduncle can then no longer support the growth of the fruiting form, and when enough cells are weakened, the fruiting form will abscise, and fall from the plant.

The hormonal theory of fruit abscission states that the initiation of the fruit abscission is controlled by the plant hormones ethylene, indole acetic acid (IAA) and ABA. When ABA and ethylene become relatively more abundant than IAA, squares begin the abscission process. It has been postulated that an increasing boll load increases the production of ABA and ethylene, weakening the middle lamella and thereby causing an increase in square and small boll abscission by the plant (Moore and Clark, 1995).

The two theories are not mutually exclusive, however, as nutritional stress causes an increase in ethylene production, resulting in the onset of abscission by hormonal means. The hormonal theory is the one most applicable in the case of insect feeding which is the major cause of pre-flowering square loss (Glover, 1993).

The Economics of Fruit Abscission

Two basic concepts in the economics of pest control are the "economic injury level" and the "economic threshold." The economic injury level has been defined as the lowest pest population that will cause economic damage, and the economic threshold is defined as the pest population density at which the best control techniques, such as insecticide treatments, should be initiated to prevent an increasing pest population from exceeding the economic injury level (Mi, 1998). Due to compensation by the plants, some level of insect damage is acceptable and not economically damaging (Holman, 1996). Producers find it difficult to accept even low levels of insect damage, but by observing economic thresholds, they may be able to save money on insecticide applications if the "break-even abscission rate" is known.

Several studies have been done to try and establish this break-even abscission rate, the point at which plant compensation will equal square loss. A break-even abscission rate at first flower is calculated as a model for an economic injury level. This is the point at which plant damage results in economic loss (Mi, 1998). The break-even abscission rate is then converted to an abscission rate limit for the number of squaring nodes left in the field on the latest plant monitoring date (Mi, 1998). Glover (1993) stated that the abscission rate of the first sympodial fruiting position of nodes 9 through 15 should be 20% or less. Research conducted in Arkansas in 1993-1996 found a break even abscission rate to be 19% (Holman, 1996). For every 1% increase in abscission rate above 19%, Holman (1996) found a lint yield decease of 7.56 kg/ha. Gutierrez et al. (1981) in Nicaragua found economically damaging yield losses occurred only if more than 30% of fruit was damaged. Prior to the work of Holman (1996), the generally accepted rate for Arkansas was 25% square abscission (Johnson and Jones, 1996). Thus, Mi (1998) reported that a realistic level for acceptable plant compensation to square loss was from 19 to 30%.

Some researchers argue that insects are simply a means of fruit abscission, i.e, that a heavy boll load would cause the bolls to be aborted anyway due to lack of carbohydrate assimilates. The abscission of insect damaged fruit may have evolved as a small-scale example of natural selection. It may simply be a method of preserving assimilates for the bolls with the best chance of survival and the best yield potential. If the insect damaged square is not abscised, it will usually result in the production of a mature boll with reduced lint quality (Jones, 1999).

Compensation to Fruit Abscission

It has long been accepted by cotton growers and researchers that the first sympodial fruiting position bolls of the cotton plant are the main contributors to yield, or in other words the "money bolls." Studies have shown that first position bolls produce 66 to 75% of the total yield of the plant; those in the second position produce 18 to 21%; all other positions combined produce from 2 to 4% of total yield (Jenkins et al., 1990). In their study, yields were averaged from the first three positions, and yield for first position bolls were found to be almost four times that of the second position bolls, and twenty-one times higher than those from third position bolls.

Although the importance of first position bolls to yield is clear, it has been noted that measuring the value of retaining the first position squares is very difficult due to the plants' ability to compensate for square losses (Phelps et al., 1998). When first position bolls are damaged by insects in early season, the plant compensates for this damage by diverting energy to the growth of second and even third position bolls. According to Kerby and Buxton (1981), a large boll load is associated with a high rate of abortion. The large boll load diverted energy from the middle to the lower and upper portions of the stem, resulting in abortions of those bolls due to lack of assimilates. Kerby and Buxton (1981) also found that the percentage of bolls retained in the second position was higher when the first position boll was aborted than when it was retained and vice versa. This study showed a strong compensatory effect between these two fruit positions. The compensation for loss of the economically important first position bolls seems to be due to those in the second position. These two fruiting sites also compete, and the degree of competition affects the rate of abortion (Kerby and Buxton, 1981).

It is noteworthy to add that while abortion of the first position as a square results in enhanced retention of second position bolls, boll retention in the second position is repressed when the first position is not aborted until it reaches the boll stage (Kerby and Buxton, 1981). Thus if an insect infestation happens in the early season, during the square stage, yield losses can be offset with compensation by second position. However, later in the season, boll losses may not be compensated for by the second position (Kerby and Buxton, 1981).

Monitoring the Cotton Fruiting Pattern with COTMAN

For many years, plant mapping has been utilized by researchers and producers as a tool to monitor fruiting patterns and plant growth and maturity. Mapping provides details on the location and number of fruit on a schematic of an individual cotton plant. The unique growth pattern of cotton allows for a good documentation of growth and development as well as determination of yield estimates simply from knowing where on the plant the fruit lies. Glover (1995) stated that the greatest return for the time invested in cotton mapping is to map the early season, as the information gained at that stage can be used to make management decisions affecting the entire rest of the growing season.

The University of Arkansas has developed an advanced crop monitoring program COTMAN to track the physiological progress of the cotton plant throughout the season. The program is designed to monitor the fruiting pattern during the squaring and flowering period and assist with end-of-season management decisions (Bourland et al., 1992). The COTMAN system uses plant monitoring techniques, current and historical weather data, and farm and field parameters to make management decisions (Bourland et al., 1994; Zhang et al., 1994). Comparing actual recorded fruiting data with a standard "target development curve" is a major facet of the crop monitoring technique (Oosterhuis, 1999). This aspect of the program is useful for monitoring the effect of stress occurrences on the growth and development of the cotton crop. As square loss can be related to the occurrence of stress in the growing season of the crop, COTMAN was a very useful tool in our research. Graphs generated by COTMAN have been used to evaluate the intensity of the stress to the plant when squares were removed, as well as the effect square removal had on further growth and development.

The COTMAN program is comprised of two components: SQUAREMAN and BOLLMAN. SQUAREMAN uses SQUAREMAP, a mapping procedure that documents retention of first position squares and the number of main stem sympodia having a first position square, to determine if early-season growth is acceptable and development of the squares is proceeding as would be desired (Oosterhuis et al, 1996). BOLLMAN uses Nodes Above White Flower (NAWF) data to assist with end-of-season management and is based on the development of the boll load relative to vegetative growth (Oosterhuis et al., 1996). NAWF is the count of the number of main-stem nodes above the highest first sympodial fruiting position white flower on the plant. NAWF data are useful for determining the last flower population which will be safe from insect injury and sufficiently advanced to withstand application of defoliant chemicals (Oosterhuis et al., 1996). Work by Bourland et al (1992) reinforced the importance of early season crop management. The authors (1992) found that cotton growth patterns were usually established by the first flower and were then difficult to change. Thus the importance of SQUAREMAN is to detect abnormal or deficient fruiting patterns during the growing season, allowing producers to correct input measures to reach maximum yield potential.

In the last five years, cotton production in Virginia has more than tripled, exceeding 107,000 acres in 1995 (Virginia Cooperative Extension, 1995). Virginia is the northernmost state where cotton is grown, thus it seems imperative to protect square development on the cotton plant early in the growing season. Little research has been done to determine the actual impact of early-season pests on cotton yield. Although several studies have been done to examine the impact of early-season square loss in more southern states, no such research had been conducted in Virginia. Our study was designed to determine the potential impact for Virginia's shorter growing season and later planting date. This information can be used to reassure the concerns of producers regarding fruit loss due to early-season insects or to any other stress situation.

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Chapter III

Plant Development and Fruit Growth in Virginia Monitored with the COTMAN Crop Monitoring System

Abstract

A crop monitoring program named COTMAN was used to track the physiological progress of the cotton plant during the season. The overall objective of the experiment was to investigate the effect of hand removal of squares on the nature of the fruiting curve. The specific objectives were 1) to evaluate the use and effectiveness of COTMAN in tracking major phenological stages (pinhead square, first flower, crop maturity) of cotton at various levels of square removal, and 2) to examine the compensation capacity of cotton to square removal. Experiments were conducted at two Virginia location using two cotton cultivars, one early and one late-maturing, planted two weeks apart. At two weeks after, and three weeks after pinhead square, squares were manually removed from cotton plants at 0, 12-15%, 20-25%, and 30-40% rates. The cotton plant was monitored using the COTMAN mapping program twice a week from pinhead square to first flower, and weekly from first flower to cutout. 1999, additional treatment of 20% small bolls removal was added. In both 1998 and 1999, the influence of square removal in excess of 30-40% resulted in lower apogee of the fruiting curve and premature cutout. In many cases, a lower level of square removal (varying between the 12-15% and the 20-25% rates) seemed to stimulate the growth and development of the crop, and it may also have contributed to a higher level of square retention. Generally, the graphs generated by COTMAN showed a delayed initial ascending slope and a lower apogee than the Target Development Curve, which is characteristic of cotton grown in the cooler climate of Virginia.

Introduction

For many years, plant mapping has been utilized by researchers and producers as a tool to monitor fruiting patterns of cotton. Mapping provides details on the location and number of fruit at a particular time on a schematic for an individual cotton plant. The unique growth pattern of cotton allows for a good determination of growth and development as well as yield estimates simply from knowing where on the plant the fruit is located. Glover (1995) stated that the greatest return for the time invested in cotton mapping is to map the early-season, as the information gained at that stage can be used to make management decisions affecting the remainder of the growing season.

The University of Arkansas has developed an advanced computer cotton monitoring program Cotton Management (COTMAN) to track the physiological progress of the cotton plant throughout the season (Danforth and O'Leary, 1998). The program is designed to monitor the fruiting pattern during the squaring and flowering periods and assist with end-of-season management decisions (Bourland et al., 1992). The COTMAN system uses simplified plant monitoring techniques, current and historical weather data, and farm and field parameters to make management decisions (Bourland et al., 1994; Zhang et al., 1994). Comparing actual recorded fruiting data with a standard Target Development Curve (TDC) is one facet of these crop monitoring techniques. The TDC is useful for monitoring the effect of stress occurrences on the growth and development of the cotton crop and for comparing treatments, other farm fields, and cotton in other production areas.

The COTMAN program is comprised of two components: SQUAREMAN and BOLLMAN. SQUAREMAN uses SQUAREMAP (a mapping procedure that determines retention of first position squares and the number of main stem sympodia having a first position square) to determine if early-season growth is acceptable and development of the squares is proceeding as desired (Oosterhuis, 1996). Work by Bourland et al. (1992) reinforced the importance of early-season crop management. These authors found that cotton growth patterns were usually established by the first flower and were then fairly permanent. Thus, the task of SQUAREMAN is to detect abnormal or deficient fruiting patterns while there is still time to rectify the problem and correct input measures to achieve maximum yield potential.

BOLLMAN uses the number of nodes above the uppermost white flower data to assist with end-of-season management and is based on the development of the boll load relative to vegetative growth (Oosterhuis et al., 1996). Node Above White Flower (NAWF) data is useful for determining the last flower population which will be safe from insect injury and sufficiently advanced to withstand application of defoliant chemicals (Oosterhuis et al., 1996). NAWF monitors the decline in the number of squares set as the boll load increases and white flowers appear closer and closer to the terminal of the plant, until the plant approaches NAWF 5, and cut-out (Oosterhuis et al., 1999) ensues.

Graphic Interpretation

COTMAN plots the number of squaring nodes by days from planting to provide a continuous graph of the growth and development of the crop during its effective fruiting period (Oosterhuis, 1996). The graphs generated by COTMAN to track the physiological progress of the cotton crop are matched to a standard pattern, the Target Development Curve (TDC). The TDC (Fig. 1) is based upon basic parameters of cotton plant growth and was designed to show a beneficial growth pattern for optimal yield and early maturation (Oosterhuis, 1996). Management suggestions are subsequently provided to help producers attain that optimal yield and maturation date.

This experiment was conducted to investigate the effect of mechanical square removal on the nature of the fruiting curve. It was hypothesized that square removal would have a negative physiological effect on the plant, impacting its fruiting curve. The specific objective of our experiment was to evaluate the use and effectiveness of COTMAN in tracking major phenological stages (PHS, FF, cutout) of cotton at various levels of square removal.

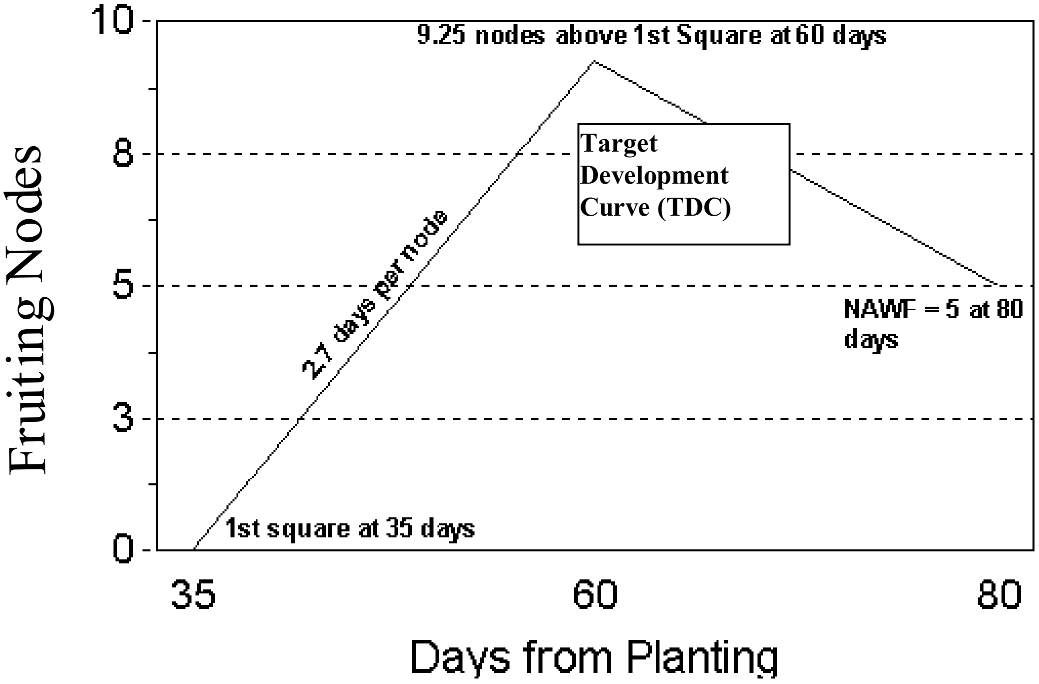

Fig. 1. Target Development Curve Used in the COTMAN Crop Monitoring Program (From Oosterhuis et al., 1996)

Materials and Methods

Field plots were established at the Tidewater Agricultural Research and Extension Center in Suffolk, in the Coastal Plain physiographic region of Virginia, and in the Piedmont physiographic region at the Southern Piedmont Agricultural Research and Extension Center in Blackstone, Virginia, during the 1998 and 1999 growing seasons. In 1998 only DPL 51 at a single planting date (May 1st) was planted at the Tidewater station. In 1999, the experiment was expanded to two locations, two planting dates, and two cultivars. During the 1998 growing season the early-maturing cultivar DPL 51 was planted at the earliest possible date (i.e., when the soil temperature at 2 inches reached 18.3^{o} C at 10 am) on May first only at the Tidewater (Suffolk) location. Because no effect of square removal treatments on yield components was observed under these favorable conditions (location, cultivar, planting date) the late-maturing cultivar (DPL 5111) was added in 1999. Also added was an additional planting date, two weeks after the first, and an additional location with a shorter growing season (Southern Piedmont, Blackstone) to observe compensation under these extreme conditions.

At both locations, plots were arranged in randomized complete block design with three replications. Two cultivars, DPL 51 (early-maturing), and DPL 5111 (late-maturing), were planted at a rate of 16.4 seeds per meter of row on two planting dates approximately two weeks apart, May 5th and May 18th (Suffolk) and May 13th and May 28th (Blackstone). The plots were 12.2 m long and 3.66 m wide (Suffolk) and 4.27 m wide and 7.63 m long with four rows and 1.1 m between the rows (Blackstone). Fertilizer (N, P, K, and B) was applied according to soil test recommendations (Donohue and Heckendorn, 1994).

Squares were manually removed from cotton plants at various rates. The crop was plant monitored using the COTMAN system to follow growth and development before and after the treatments were administered. In Suffolk, the square and boll removal treatments were: 1) control with no squares removed; 2) 12-15% square removal rate; 3) 20-25% square removal rate; 4) 30-40% square removal rate, and 5) 20% small boll (ranging in size from 0.81-3.54 cm in diameter) removal rate. Treatments were similar at the Blackstone site with the exception of Treatment 5, which was not included at this site.

Prior to square removal, 1.52 m long areas from the two inside rows were flagged for crop monitoring and intensive sampling. Approximately ten consecutive plants were located within each of those 1.52 m lengths. Two weeks after pinhead square, all first position squares were counted and treatments initiated to simulate the stage of cotton growth most susceptible to early-season insect damage. According to the assigned treatment number, a certain percentage of those first position squares were then carefully nipped off with fingernails. Squares ranged in size from pinhead (2.7-3.4 mm in diameter), to matchhead (4.4-5.4 mm in diameter), to the largest size of 8.8-11.8 mm in diameter. A few days prior to flowering, all first position squares were again counted and a percentage removed according to the desired treatment. Details of the square removal treatments are given in Fig. 2.

COTMAN crop monitoring data were recorded including plant height, number of main-stem nodes, first fruiting branch, squaring nodes, and percent square retention were recorded. Records were made when major phenological stages (such as pinhead square, first flower, and cutout) were reached.

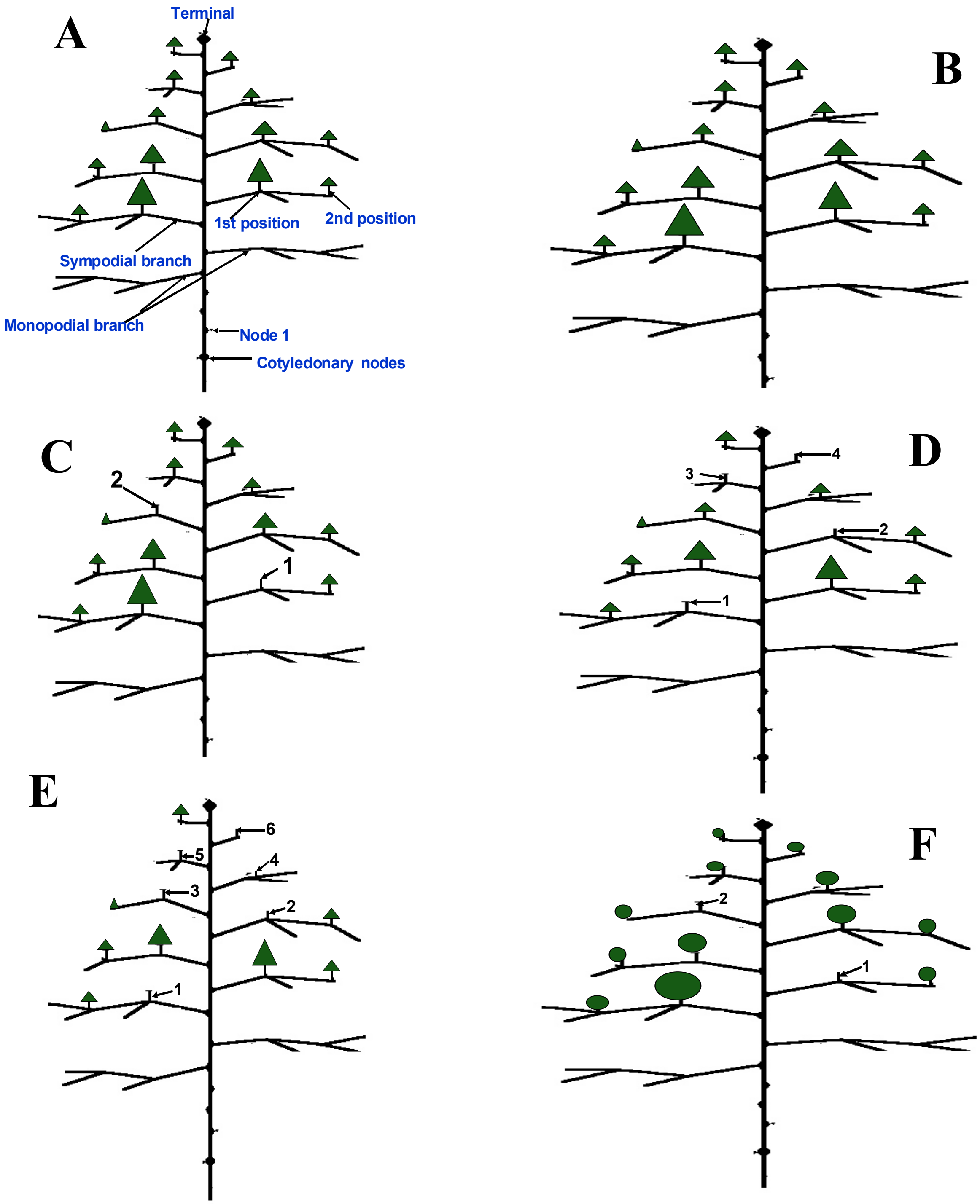

Fig. 2 (A) Schematic Diagram of a Cotton Plant; (B)Treatment 1 = 0 squares removed, total 1st position squares = 9; (C) Treatment 2 = 12-15% squares removed, total 1st position squares = 9, 2 squares removed; (D)Treatment 3 = 20-25% squares removed total 1st position squares = 9, 4 squares removed; (E) Treatment 4 = 30-40% squares removed, total 1st position squares = 9, 6 squares removed and, (F) Treatment 5 = 20% bol removed that is total 1st position bolls = 9, 2 bolls removed.

In addition, the daily maximum and minimum temperatures were obtained from the Tidewater Agricultural Research and Extension Center for heat unit accumulation [HU= (Max + Min / 2) – 18.3^0 C]. Rainfall was also monitored at each site.

SQUAREMAP data was collected starting at first square and then recorded twice weekly until first flower. The first branch on which fruit appears is recorded as the first fruiting node, and usually appears at roughly node 4-6. This is an indicator of the earliness of the crop and of the cultivar. Full -season cultivars usually begin fruiting one node higher. Nodes were counted upward from the cotyledonary node to determine the first fruiting branch. Five consecutive plants were chosen in the 1.52 m row length. From each row in a plot, plant height was measured with a meter rule from the cotyledons to the terminal. The same five plants were then mapped for the presence or absence of squares. Starting with the first fruiting node and working upward, each successive node was noted as having a square or an abort. An “abort” was identified as having the round scar of an abscised square. Later in the season, the position of flowers and bolls were also noted. Only first position fruit was mapped. Percent square retention was then calculated by the COTMAN program (O’Leary and Danforth, 1999).

NAWF data was collected weekly, starting at first flower. At each replication, NAWF data was collected from five plants from each row in a plot. The number of nodes above the highest first position white flower were counted. NAWF data was collected until NAWF equaled five, signaling physiological cutout of the crop (Oosterhuis et. al., 1999).

Results

Suffolk Location (Coastal Plain)

Weather

The total heat unit accumulation for the 1999 growing season was lower (2031) than the 1998 growing season by 225 heat units (Fig. 3). However, the 1999 heat unit total was only 68 heat units below the six year average. The total amount of rainfall for the 1999 cotton growing season exceeded both the 1998 and the long term average by 48.3 and 30.5 cm, respectively (Fig. 4). However the average of the July and August rainfall for the 1999 growing season versus the long term 67 yr average was almost identical (14.8 vs. 14.7 cm).

Plant Mapping Data

In 1998, the growth and development of the late-maturing cultivar DPL51, was significantly affected by the square removal treatments (Fig. 5-A). Fifty-five days after planting (DAP), the untreated control treatment tracked the TDC much more closely than those treatments where squares were removed at the 20-25% and 30-40% rates. The higher square removal rate showed slow nodal development, lower apogee and premature cutout.

In 1999, DPL 51 at the first planting date, showed a significant difference in growth and development of the cotton plant among the five treatments (Fig.5-B). At 55 DAP the higher square removal rate (30-40%) showed a faster nodal development unlike the 1998 growth pattern where a similar result was obtained for the untreated control treatment.

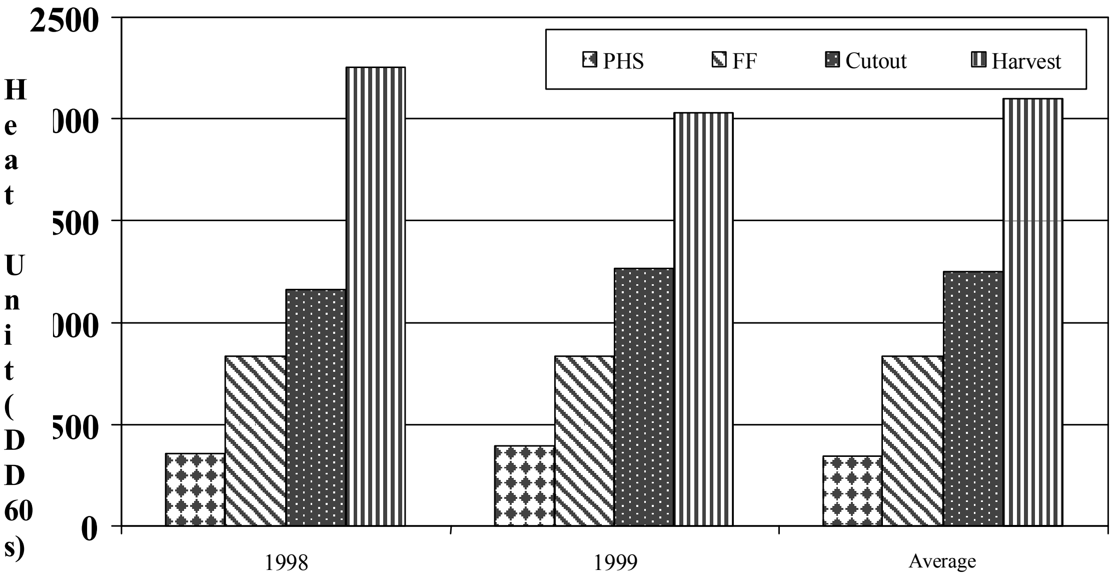

Fig. 3. Cumulative heat units (DD 60's) for : 1998, 1999 and 6 year average for the common cotton growth stages.

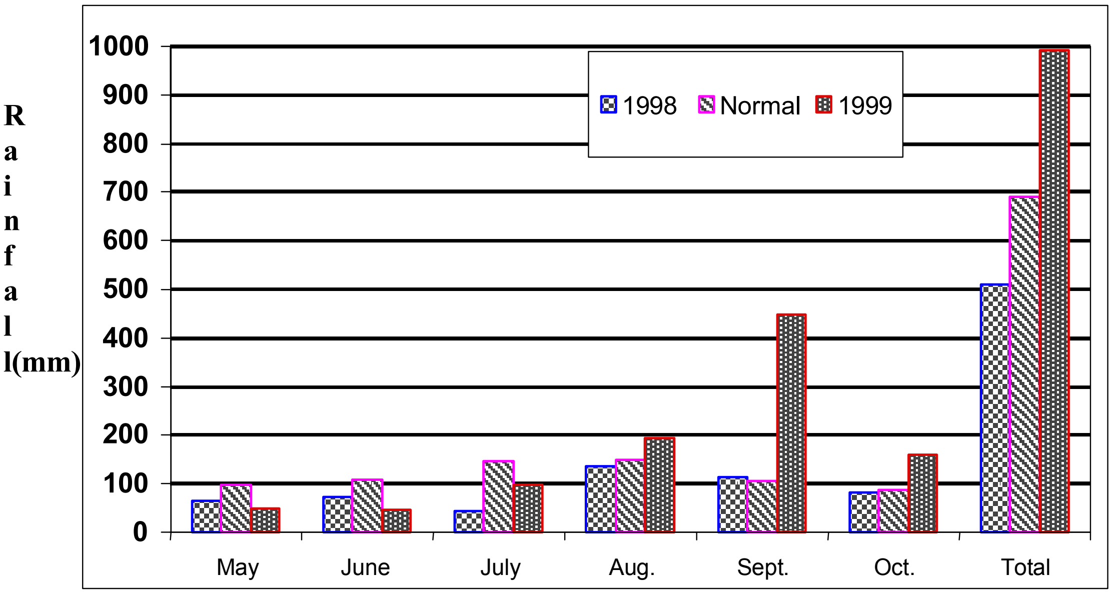

Fig. 4. Monthly and seasonal rainfall at the Tidewater AREC, Suffolk . Normal represents the 67 year average, total represents the total rainfall for normal and the year, 1998 and 1999.

Similar to the 1998 data, square removal in excess of 30-40% resulted in lower ($P < 0.05$) apogee and cutout prematurely as compared to the other treatments. However, in 1999, the low apogee observed for the 30-40% square removal rate was flattened after attaining the apogee.

Although the square removal rate at which the growth and development of the plant was affected differed for DPL 51 vs. DPL 5111 at the first planting date, a similar response to square removal was observed. In the case of DPL 5111, a square removal rate as low as 12-15% appeared to slow down nodal development. In contrast, square removal of 20-25% most closely ($P < 0.001$) tracked the TDC. Additionally, a higher apogee and delayed cutout was observed (Fig. 5-C).

The effect of both square removal and boll removal of the growth and development of DPL 51 at the second planting date was evident (Fig. 5-D). The removal of small bolls at 20%, as well as square removal at 30-40%, significantly affected the slope of the growth curve prior to and after the apogee. This effect was indicated by a flatter slope in response to stress caused by these treatments. However, the extended flattened curves prior to cutout indicated some level of compensation to boll and square loss. A similar growth pattern was observed for DPL 51 at the first planting date (Fig 5-B).

Initially, the growth and development of DPL 5111 for the second planting date appeared to be stimulated by the lower rate of square removal (12-15%). However, the plant structure was not maintained as later indicated by a lower apogee and earlier cutout. The higher square removal rate (30-40%) affected plant structure and nodal development significantly compared with other treatments. The delay in cutout associated with this treatment may have helped the plant to reward compensation (Fig. 5-E).

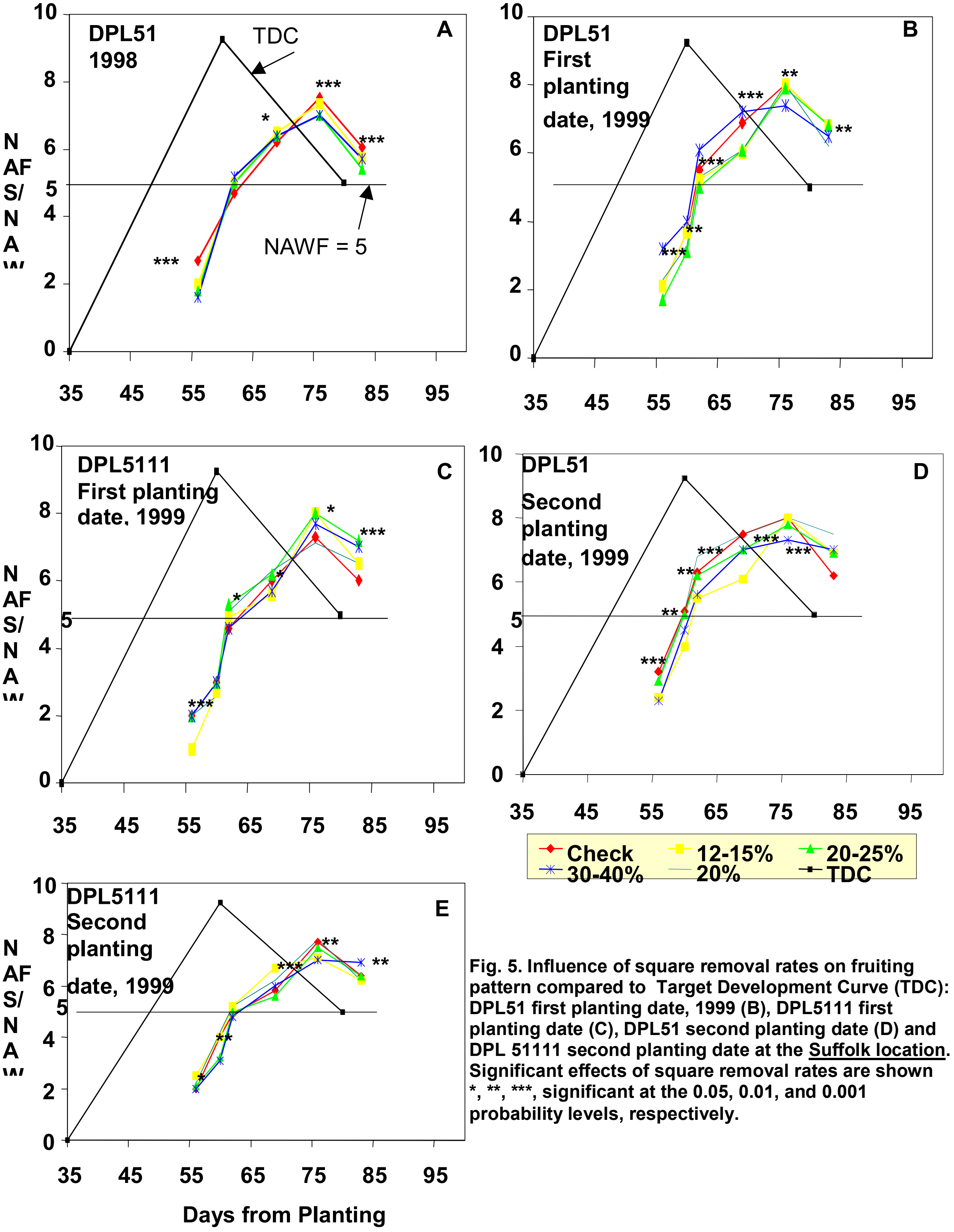

Fig. 5. Influence of square removal rates on fruiting pattern compared to Target Development Curve (TDC): DPL51 first planting date, 1999 (B), DPL5111 first planting date (C), DPL51 second planting date (D) and DPL 51111 second planting date at the <u>Suffolk location</u>. Significant effects of square removal rates are shown *, **, *, significant at the 0.05, 0.01, and 0.001 probability levels, respectively.**

Blackstone (Piedmont)

For the Blackstone location, the growth patterns of the early-maturing cultivar DPL 51 and the late-maturing DPL 5111 were very similar (Fig. 6 A and B). However, both cultivars were significantly affected by the square removal treatments. Starting from 57 days after planting (DAP) to first flower, the 30-40% square removal rate most closely tracked the TDC compared to the untreated control or the 12-15% square removal rate (Fig. 6 A and B). The higher square removal rate showed faster nodal development, a less steep negative slope, and a lower apogee. The flattened slope is a good indication of possible compensation for the excessive fruit loss associated with the square removal treatments. The plant growth and development of the untreated control and the low square removal (12-15%) treatments showed a significant reduction possibly associated with high square retention. Both of these sets of graphs (Fig. 6 A and B) were very similar to those of the first planting date of the Suffolk location, although with a notably lower apogee, stemming from a later planting date (eight days) and a location outside the traditional cotton growing area.

For the second planting date of DPL 51, the higher square removal rate of 30-40% significantly affected the plant structure (nodal development and apogee) compared with the untreated control and the low square removal treatment (Fig. 6 C). The crop emergence was very late, and seedlings developed proceeded slowly once it began. The apogee was somewhat higher for DPL 51 than DPL 5111, but still too low to allow for optimum growth and yield potential.

The second planting date of DPL 5111 had an extremely low apogee, barely surpassing NAWF = 5 at any time in the growing season (Fig. 6 D). The emergence of the cotton was very delayed, and the growth curve progressed at a less than optimum rate. The apogee of the curves was only slightly over half of that of the TDC. Square removal rates in excess of 30% appear to affect the development of the second planting date of DPL 5111 more so than DPL 51 planted on the same date.

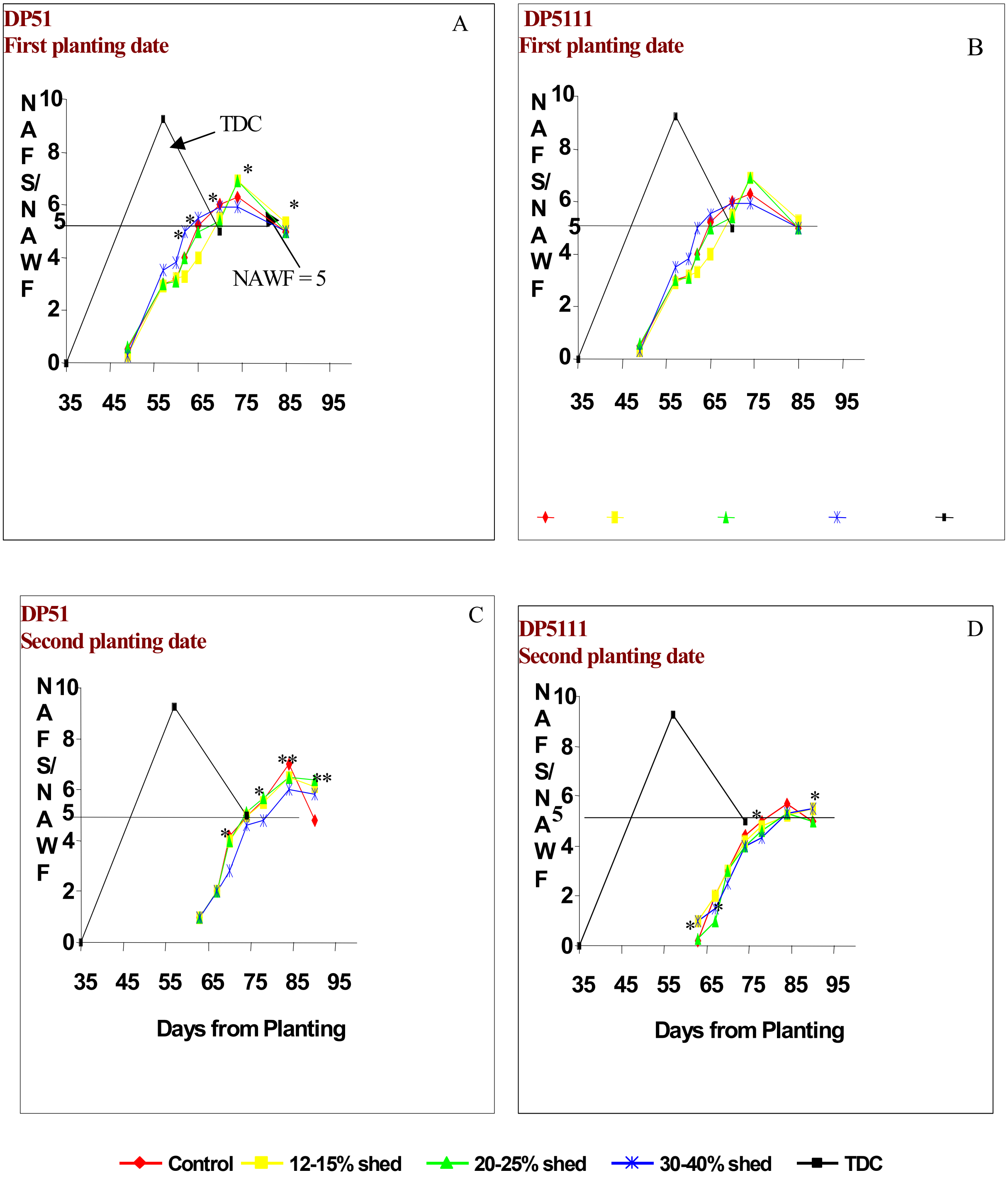

Fig.6. Influence of square removal rates on fruiting patterns compared to the Target Development Curve (TDC): 1999, for DPL51 first planting date (A), DPL5111 first planting date (B), DPL51 second planting date (C) and DPL 51111 second planting date at the Blackstone location. Significant effects of square removal rates are shown *, **, ***, significant at the 0.05, 0.01, and 0.001 probability levels, Respectively.

Discussion

Graphs generated by COTMAN were used to evaluate the intensity of the plant stress when squares were removed twice prior to first flower (i.e., two and three weeks after pinhead square, respectively) as well as the effect that manual square removal had on further growth and development. During the 1998 growing season the early-maturing cultivar DPL 51 was planted on May first only at the Tidewater (Suffolk) location. Because no effect of square removal treatments on yield components was observed under these favorable conditions (location, cultivar, planting date), in 1999 the late-maturing cultivar (DPL 5111) was added. Also added was an additional planting date two weeks after the first and an additional location with a shorter growing season (Southern Piedmont, Blackstone) to observe compensation under these more extreme conditions.

The manual removal of squares or small bolls is assumed to cause the plant some level of stress, and according to the COTMAN Target Development Curve, this was observed. In 1998, the square removal treatments significantly affected the fruiting development curves of DPL51. This data can be directly compared to 1999's DPL51 first planting date. In both years, square removal at the highest (30-40%) rate resulted in a lower apogee and premature cutout. In 1999, the apogee observed for the 30-40% rate was flattened after attaining the apogee, indicating additional vegetative terminal growth by the crop. The cotton showed slow early-season development of squaring nodes and a low apogee of curve at first flower across treatments for DPL 51 during the 1998 and 1999 growing seasons. The apogee was 7.5 and 8.3 for 1998 and 1999, respectively, compared with the apogee for the TDC of 9.25.

For the cultivar DPL5111, the square removal rate at which an effect on growth and development was noticed differed from the DPL51 cultivar. A square removal rate as low as 12-15% appeared to slow down nodal development. Interestingly, the 20-25% rate most closely tracked the TDC, and showed a higher apogee and delayed cutout. The moderate square removal rate might have helped this early-maturing plant cope with the stress associated with an early heavy fruit load compared with the untreated control where no squares were removed.

The extreme delay and low apogee of the second planting date at Blackstone can be explained by the very late planting date of May 28th. The plots were originally planted before this, but due to a mechanical malfunction, had to be replanted several days later. Blackstone is also not located in the traditional cotton growing area, as opposed to Suffolk. The delay in planting date only exacerbated the situation. DPL 51 is an earlier maturing cultivar, and reached a considerably higher apogee than DPL 5111 at Blackstone. It seems that the combination of an excessively late planting date and a late-maturing cultivar provided too much stress for the second planting date of DPL 5111 at Blackstone to overcome. However, despite not tracking the TDC, the Blackstone site yielded relatively well.

The flattened slope of many of the Blackstone growth and development curves may be indicative of compensation for the fruit loss associated with the square removal treatments. The control and lowest square removal treatment (12-15%) showed a reduction in their growth and development curves, possibly indicating high retention of existing squares.

Generally, the 30-40% square removal rate appears to be the rate at which growth and development of the cotton crop is most affected. In many cases, a lower level of square removal (varying between the 12-15% and the 20-25% rates) seems to stimulate the growth and development of the crop. It may also contribute to a higher level of square retention. However, at a later planting date, the crop may lack time to compensate for square loss, resulting in a lower apogee and earlier cutout.

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Chapter IV

Influence of Cotton Square Removal at Various Rates on Yield and Yield Components

Abstract

Fruit abscission is a natural occurrence in cotton (*Gossypium hirsutum L.*), and can be caused by many environmental and physiological factors. Due to compensation by the plants, some level of fruit abscission is acceptable and not economically damaging to yields. Virginia is the northernmost state where cotton is grown, thus it seems imperative to protect square development on the cotton plant early in the growing season. An experiment was designed to evaluate the compensation capacity of cotton at various levels of square removal and to investigate the effect of physical square removal on cotton yield components and lint quality. In 1998, only DPL 51 at the Suffolk location (Coastal Plain) was planted. The experiment was expanded in 1999 to ascertain whether cotton would have the same compensation capacity in more extreme conditions (location, planting date). In 1999, two cultivars were planted, DPL 51 (late-maturing) and DPL 5111 (early-maturing), on two planting dates (two weeks apart), and in a location outside of the cotton growing area, Blackstone (Southern Piedmont). Five levels of manual square removal treatments (0%, 12-15%, 20-25%, and 30-40% of first position squares, and 20% of small bolls [Suffolk, 1999 only]) were used in both years. The physiological progress of the crop was monitored using the COTMAN crop monitoring system and compared to the Target Development Curve (TDC). Over both years, there were no significant differences in boll numbers or yield among any of the square removal treatments. Comparison with the TDC showed that in both 1998 and 1999, the influence of square removal in excess of 30-40% resulted in a lower apogee and premature cut-out. Also, though not statistically significant, yield was greatly reduced at the 30-40% square removal rate, often by as much as 448 kg/ha. In many cases, a lower level of square removal (varying between the 12-15% and the 20-25% rates) seemed to stimulate the growth and development of the crop, and may also contribute to a higher level of square retention. These factors lead to the recommendation that a first position square loss of less than 30% could be adequately compensated for by the plant.

Introduction

Originally a tropical plant, cotton (*Gossypium hirsutum L.*) is a woody perennial reaching up to six meters in height in the wild (Smart and Simmonds, 1995). It is indeterminate in its growth pattern, meaning that both vegetative and reproductive growth occur at the same time during a portion of the growing season (Jones, 1999). Plants set their fruit over a period of time until one or more factors needed for growth become limiting. Plants then transfer the flow of assimilates from initiating new fruit to furthering the development of roots and fruit already set, and to supporting regrowth (Meredith and Bridge, 1973).

In the last few decades, the development of new cultivars has been progressing in the direction of earlier and more rapidly maturing types (Jenkins, 1990). These new short-season cultivars develop more fruit early as compared with older cultivars (Wells and Meredith, 1984a, 1984b). There has also been much experimentation with various planting dates. Cultivars have been developed to better tolerate the cooler, early-season temperatures, to allow for earlier planting. Research has shown that environmental factors such as soil temperature and moisture availability can have a great impact on the yield of the cotton crop (Bauer, 1998). The shorter season cultivars and later planting dates have made tremendous yield increases possible in cooler cotton growing regions, such as Virginia.

Abscission of squares and bolls is a natural occurrence in cotton and can be caused by many environmental and physiological factors (Guinn 1998). Cotton plants produce many more fruiting sites than mature bolls and a certain amount of fruit abscission takes place under natural conditions (Kerby and Buxton, 1976; Kerby and Buxton, 1981). Any environmental or physiological condition which decreases the supply of photosynthate causes stress, which increases square and boll abscission (Guinn, 1998). Stress conditions may include heavy boll loads, leaf-feeding by insects, insects feeding or ovipositing directly onto the squares or bolls, dim light, water deficit, high temperatures, inorganic nutrient deficiencies, diseases, or failure of pollination (Guinn, 1998). Regardless of efforts made to increase cotton yield, even under favorable conditions, as many as fifty percent of early fruit and ninety percent of late developing fruit may abscission (Jones, 1999).

Due to compensation by the plants, some level of insect damage is acceptable and not economically damaging (Holman, 1996). However, producers find it difficult to accept even low levels of insect damage, but by observing economic thresholds, they may be able to save money on insecticide applications if that "break-even abscission rate" is known. Several studies have been done to try and establish this break-even abscission rate, the point at which plant compensation will equal square loss. Research has shown the realistic level for plant compensation to square loss to be from 19 to 30% (Holman, 1996).

Although the importance of first position bolls to yield has been documented (Kerby and Buxton, 1981), it has been noted that measuring the value of retaining the first position squares is very difficult due to the plants' ability to compensate for square losses (Phelps et al., 1998). It is noteworthy to add that while abortion of the first position squares results in enhanced retention of second position bolls, boll retention in the second position is repressed when the first position is not aborted until it reaches the boll stage (Kerby and Buxton, 1981). Thus if an insect infestation happens in the early-season, during the squaring stage, yield losses can be offset with compensation by the second position. However, later in the season, boll losses may not be compensated for by the second position (Kerby and Buxton, 1981).

In the last five years, cotton production in Virginia has more than tripled, exceeding 107,000 acres in 1995 (Virginia Cooperative Extension, 1995). Virginia is the northernmost state where cotton is grown, and has the shortest growing season. Thus, it is imperative to determine if Virginia-grown cotton can also compensate to early-season square loss. It was hypothesized that there would be no significant differences among square removal treatments.

The objective of this experiment was:

- To evaluate the compensation ability of cotton to mechanical square removal on cotton yield, components of yield, and lint quality.

Materials and Methods

Field plots were established at the Tidewater Agricultural Research and Extension Center in Suffolk, Virginia, and the Southern Piedmont Agricultural Research and Extension Center in Blackstone, Virginia, during the 1998 and 1999 growing seasons. During the 1998 growing season, the cultivar DPL 51 was planted at the earliest possible date (when the soil temperature reached 18.3C at 10 AM) on May 1st, only at the Tidewater (Suffolk) location. Under these favorable conditions (i.e., location, cultivar, planting date) no effect of square removal treatments (0%, 12-15%, 20-25%, 30-40%) on yield components was observed. In 1999, the early-maturing cultivar (DPL 5111) was added. Also added was a second planting date, two weeks after the first, and a location with a shorter growing season (Southern Piedmont, Blackstone) to see if compensation occurs under these more extreme conditions.

At both locations, plots were arranged in a randomized complete block design with three replications. The two cultivars, DPL 51, later maturing, and DPL 5111, early-maturing, were planted at the rate of 16.4 seeds per meter of row on two planting dates approximately two weeks apart, May 5th and May 18th (Suffolk) and May 13th and May 28th (Blackstone). The plots were 12.2 m long and 3.66 m wide (Suffolk) and 4.27 m wide and 7.63 m long with four rows and 1.1 m between the rows (Blackstone). Fertilizer (N, P, K, and B) was applied according to soil test recommendations (Donohue and Heckendorn, 1994).

Squares were manually removed at various rates from the cotton crop to evaluate the effect on compensation capacity. At the Suffolk location, the square removal treatments were: 1) control with no squares removed; 2) 12-15%; 3) 20-25%; 4) 30-40%; and 5) 20% small boll (ranging in size from 0.81 cm to 3.54 cm in diameter). Treatments were similar at the Blackstone site with the exception of Treatment 5, which was not included at this site.

Prior to square removal, 1.52 m long areas from the two inside rows at each plot were flagged for mapping and intensive sampling. Approximately ten plants were located within each of those 1.52 m lengths. Two weeks after pinhead square, the time when cotton squares are most susceptible to insect damage, all first position squares were counted. According to the assigned treatment number, a certain percentage of those first position squares were then removed by hand. One week later, immediately prior to flowering, all first position squares were again counted and a percentage removed according to treatment (Figs. 1A-F).

COTMAN crop monitoring records were taken as follows: basic measurements of SQUAREMAN such as plant height, main-stem nodes, first fruiting branch, squaring nodes, and percent square retention. Records were kept of major phenological stages, such as pinhead square, first flower, and cutout. In addition, the daily maximum and minimum temperatures were obtained for heat unit accumulation [HU= (Max + Min / 2) – 18.3C]. Rainfall was also monitored daily at each site.

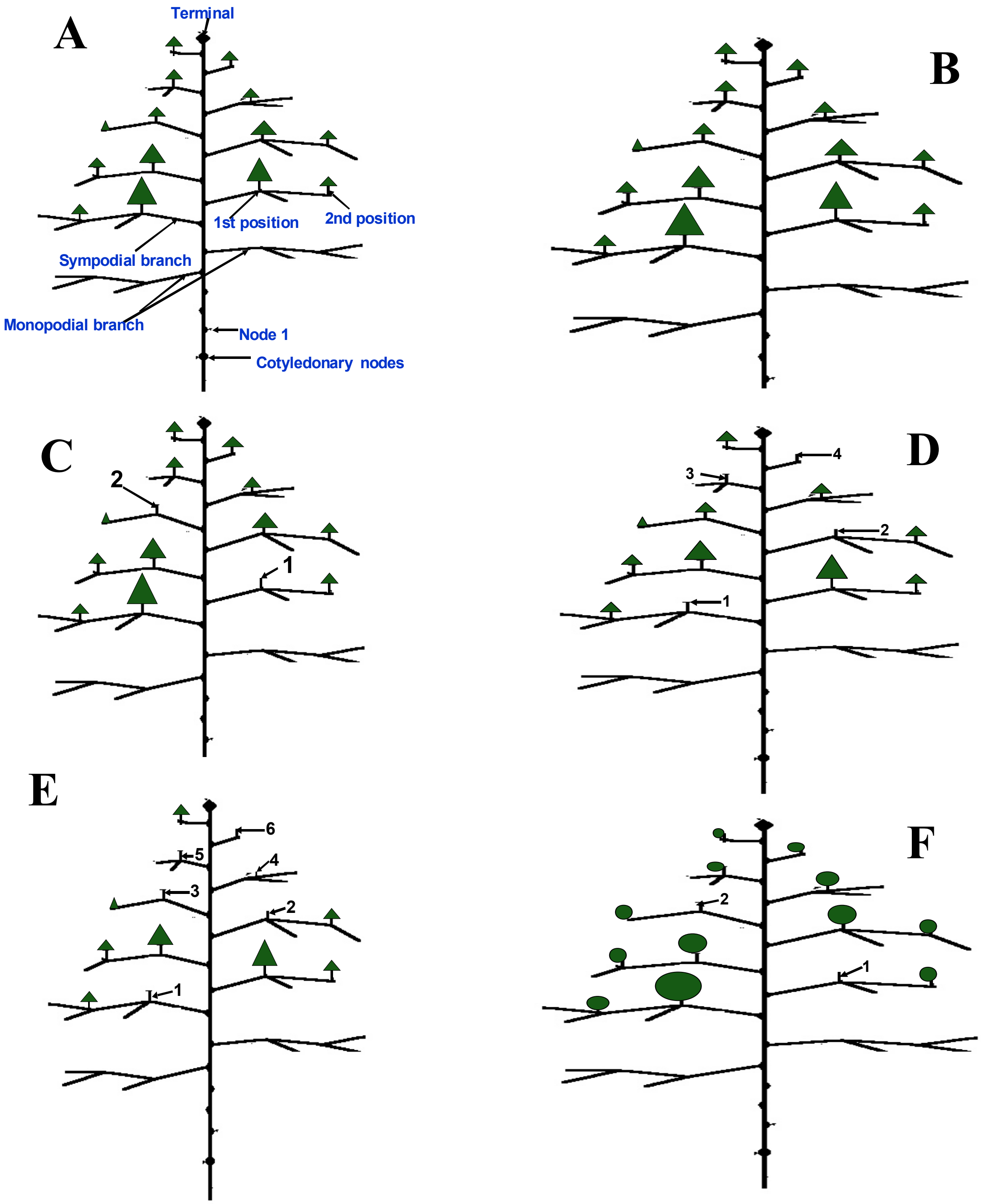

Fig. 1 (A) Schematic Diagram of a Cotton Plant; (B)Treatment 1 = 0 squares removed, total 1st position squares = 9; (C) Treatment 2 = 12-15% squares removed, total 1st position squares = 9, 2 squares removed; (D)Treatment 3 = 20-25% squares removed total 1st position squares = 9, 4 squares removed; (E) Treatment 4 = 30-40% squares removed, total 1st position squares = 9, 6 squares removed and, (F) Treatment 5 = 20% boll removed that is total 1st position bolls = 9, 2 bolls removed.

Results and Discussion

Weather data – Suffolk location

The heat unit accumulation for the 1999 growing season was lower than the 1998 growing season by 225 heat units (Fig. 2). However, it was only 68 heat units below the average for the growing seasons. The total amount of rainfall for the 1999 growing season exceeded both the 1998 season and the long term average by 48.3 and 30.5 cm, respectively (Fig. 3). However the average of the July and August rainfall for the 1999 growing season versus the long term average was almost identical (14.8 vs. 14.7 cm).

1998, Suffolk location

In 1998, total number of bolls at harvest was not significantly (P=0.05) affected by any of the square removal levels (Fig. 4). Numbers ranged from 87.7 bolls in the undamaged control to 98.8 bolls in the 20-25% removal level. Lint yields were also not different among square removal treatments (Fig. 5). In 1998, ideal growing conditions at a timely planting date might have helped cotton to compensate for early-season square removal. In 1998, the growth and development of the late-maturing cultivar DPL51, was significantly affected by the square removal treatments. Fifty-five days after planting (DAP), the untreated control treatment tracked the TDC much more closely than those treatments where squares were removed at the 20-25% and 30-40% rates. The higher square removal rate showed slow nodal development, a lower apogee and premature cutout.

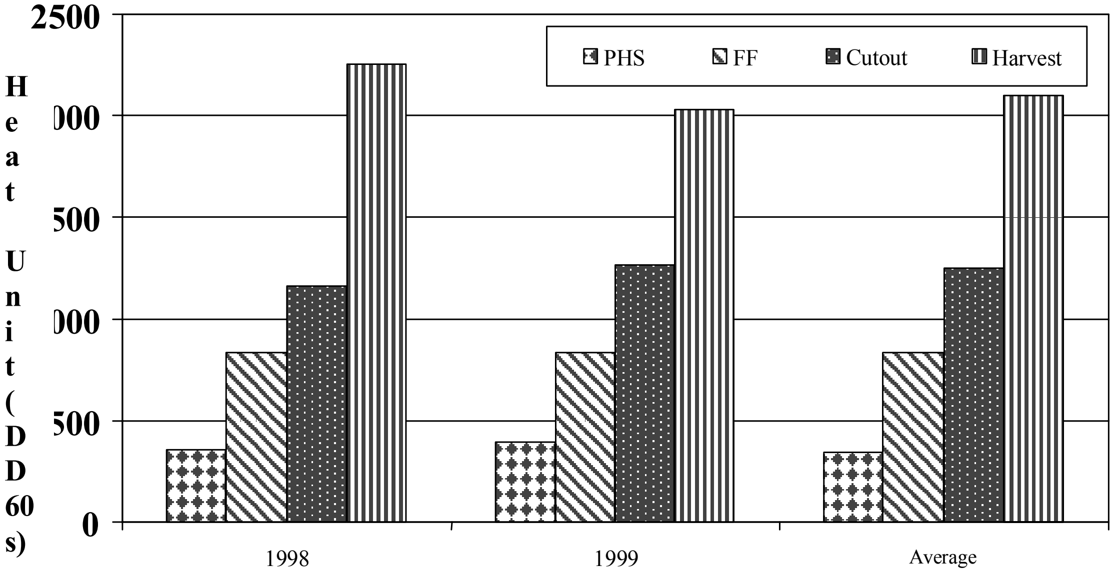

Fig. 2. Cumulative heat units (DD 60's) for : 1998, 1999 and 6 year average for the common cotton growth stages.

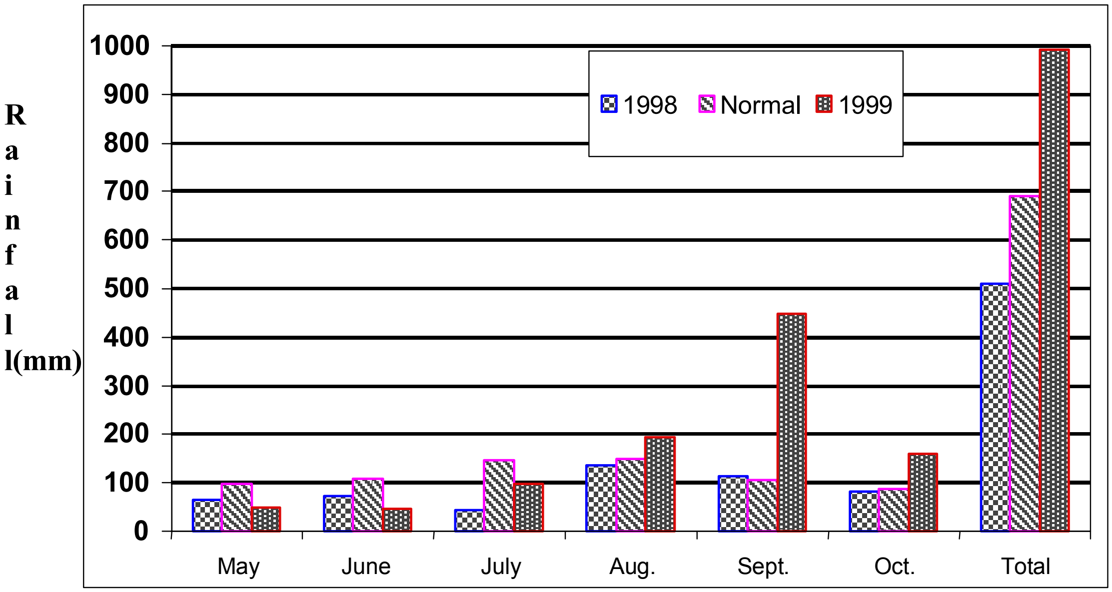

Fig. 3. Monthly and seasonal rainfall at the Tidewater AREC, Suffolk . Normal represents the 67 year average, total represents the total rainfall for normal and the year, 1998 and 1999.

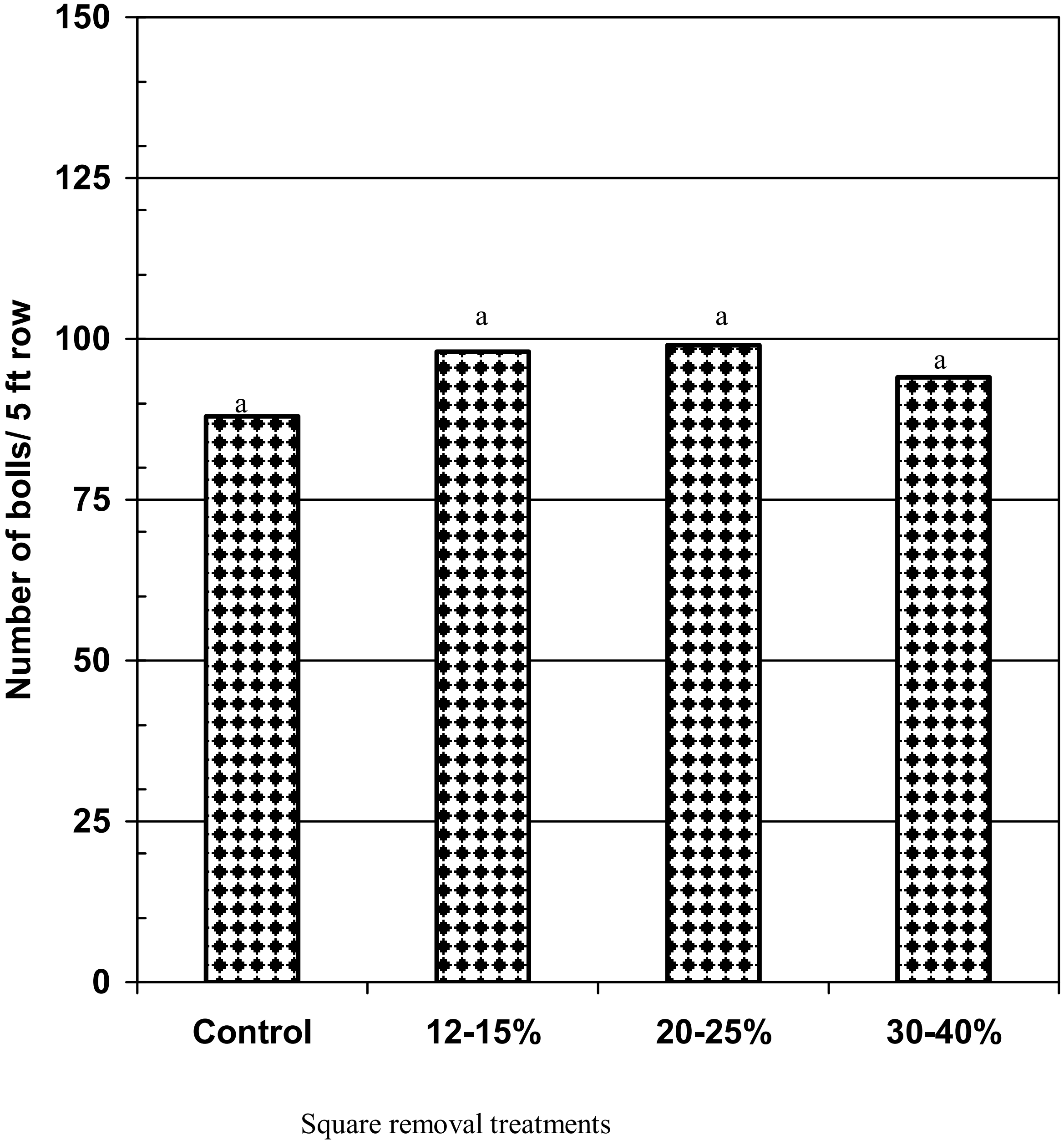

Fig. 4 The effect of square removal treatments on total boll numbers for DP51, for 1998 at the Suffolk location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

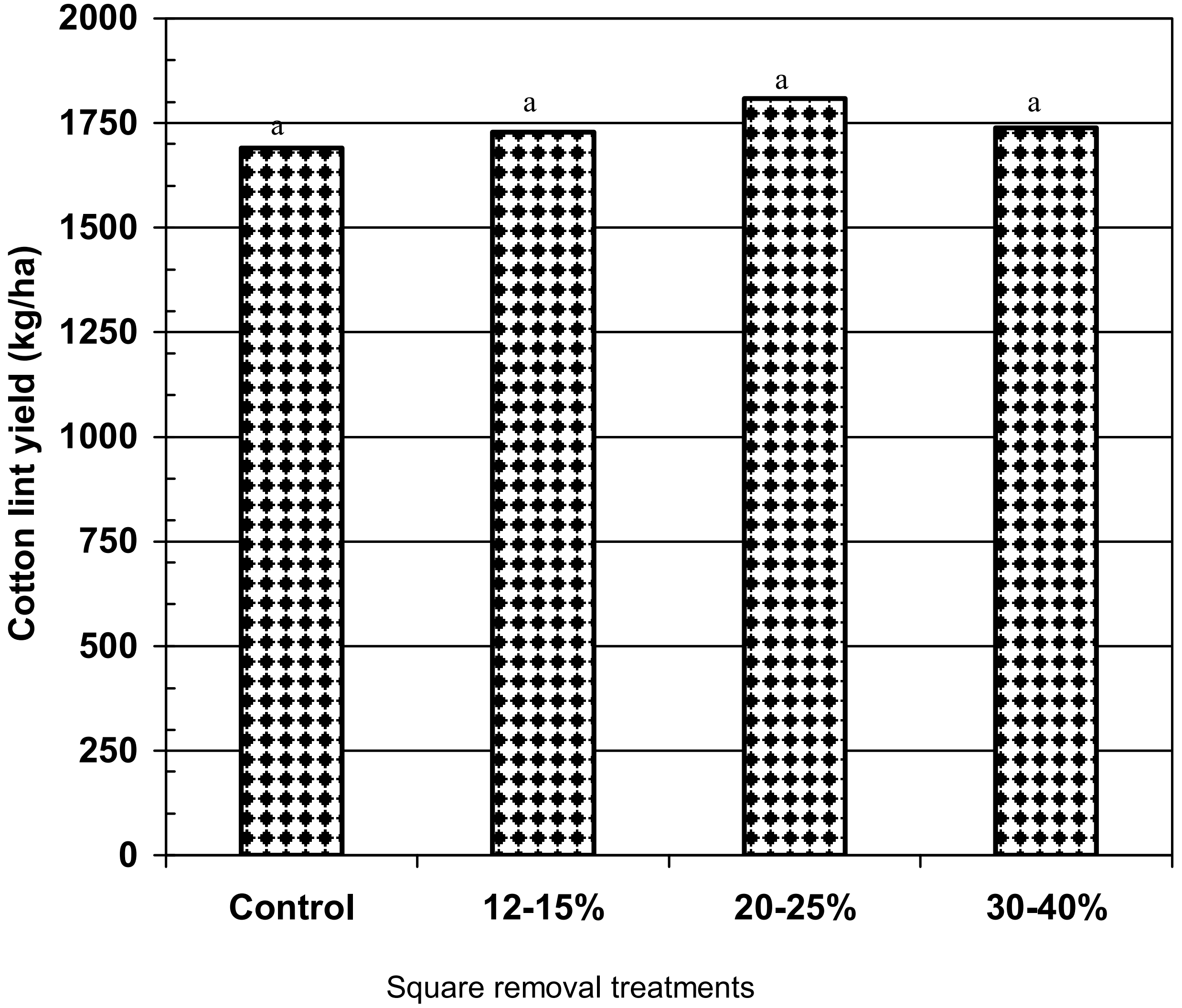

Fig. 5. The effect of square removal treatments on seed cotton yield for DP51, 1998 at Suffolk location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

1999, Suffolk location

Due to interactions between cultivar and planting date and extreme differences across years and location observed for yield and yield components, results are reported averaged over cultivars and planting dates as well as by year, cultivar and planting dates. Generally, the cultivar DPL 51 produced higher yields than DPL 5111 (cultivar effect $P < 0.001$) across square removal treatment (cultivar effect $P < 0.01$) and planting date (planting date effect $P < 0.001$) (Fig. 6). For DPL 51 at first planting date, cotton lint yield was stimulated by square removal treatments up to the 20-25% rate and a decline in yield was observed for the 30-40% square removal and the 20% small boll removal treatments (Fig. 6). To a lesser extent, the same trend was observed for DPL 51 at the second planting date. The square removal level at which compensation occurs differed for the different cultivars. Cultivar DPL 5111 showed compensation at the 12 –15% removal rate compared to the 20-25% rate for DPL 51.

Averaged over cultivars and planting dates, square removal at the 30-40% rate reduced the number of total bolls per 1.52 m row by 17 and 26 bolls compared to the untreated control and the 12-15% removal rate, respectively (Fig. 7). A similar response was observed for first and second position bolls (Fig. 8). Cotton lint yield was reduced by the highest square removal rate (30-40%). This yield reduction was 222, 291, and 323 kg/ha less than the check, the 12-15% rate, and the 20-25% rate, respectively (Fig. 9).

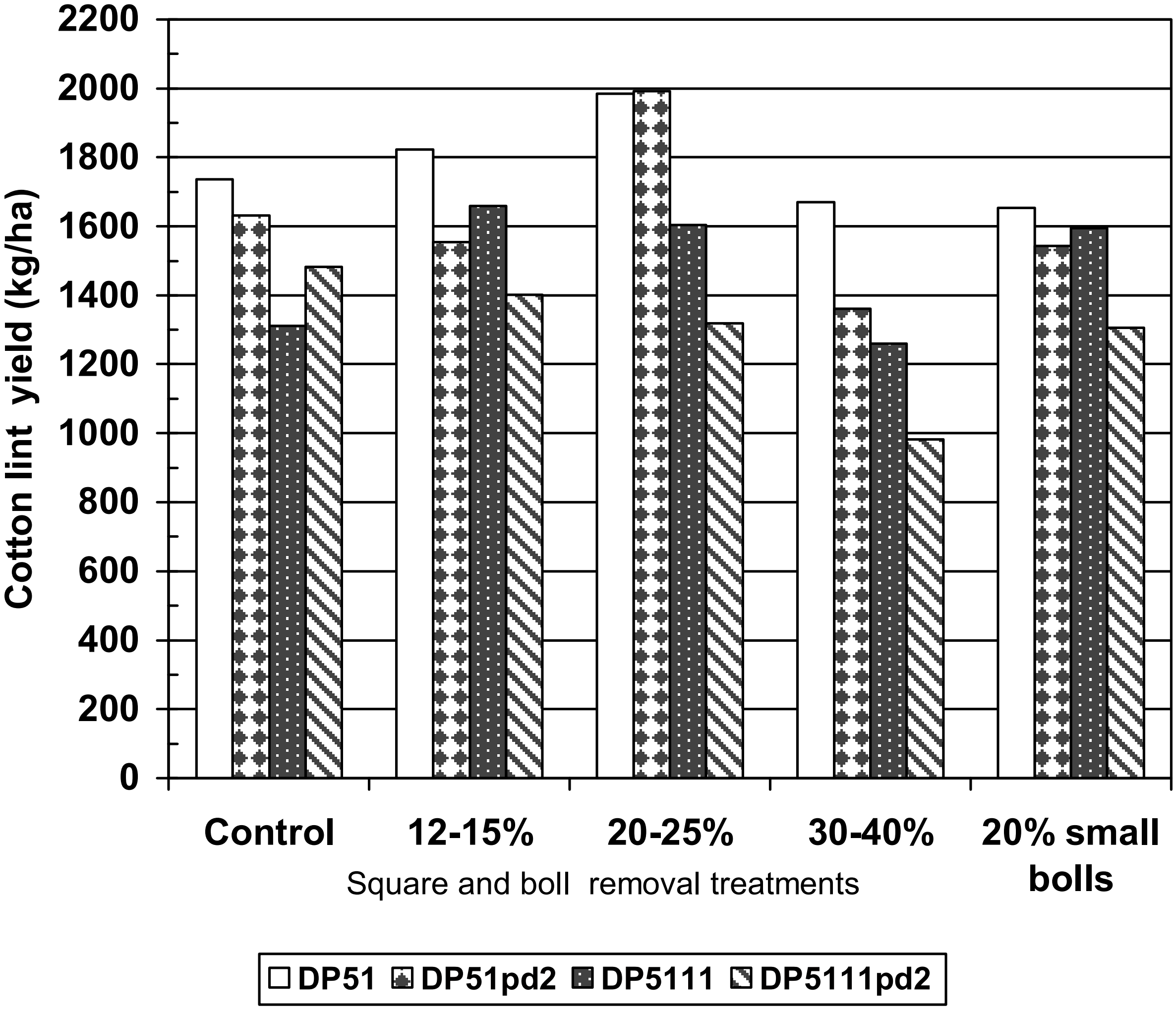

Fig. 6. Influence of square removal rates on lint yield by varieties and planting dates: 1999, Suffolk location

Variety effect P < 0.0001
Planting date effect P < 0 .001
Treatment effect P < 0.01

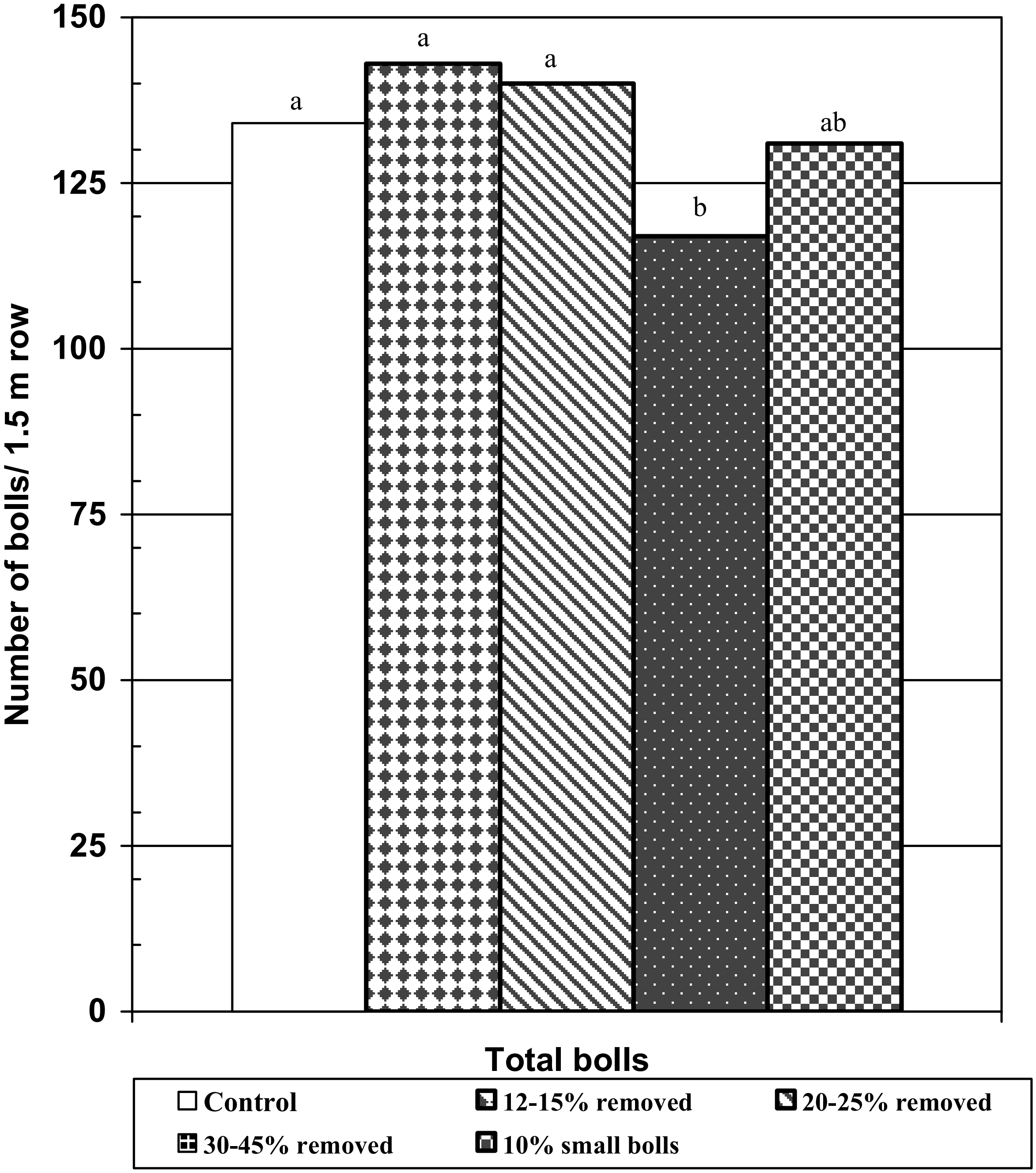

Fig. 7. Averaged over varieties and planting dates total boll numbers square removal treatments. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

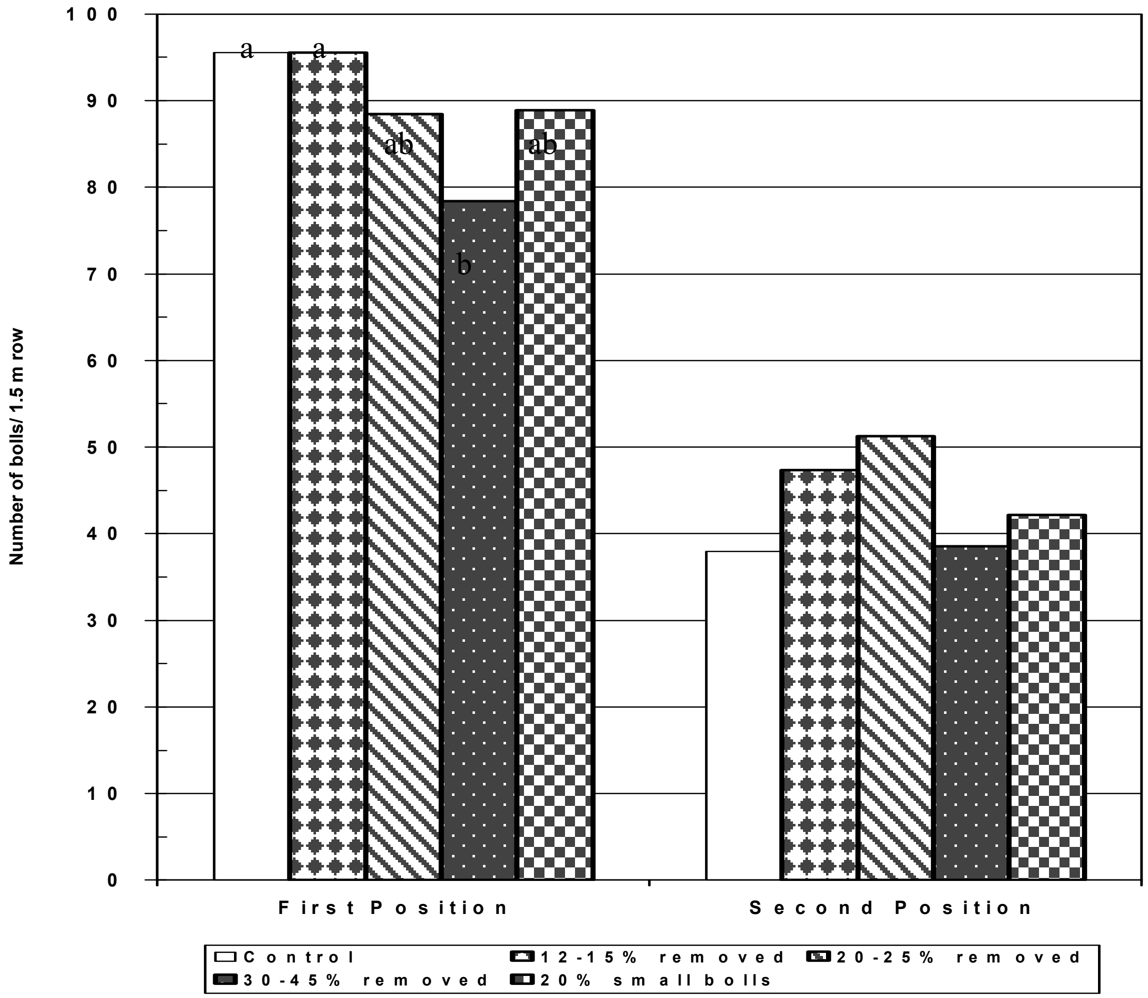

Fig. 8. Averaged over varieties and planting dates cotton boll numbers by position on the branch for each square removal treatments at Suffolk location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

No effect of Variety (Var)
Planting date (PD) effect P
< 0.05

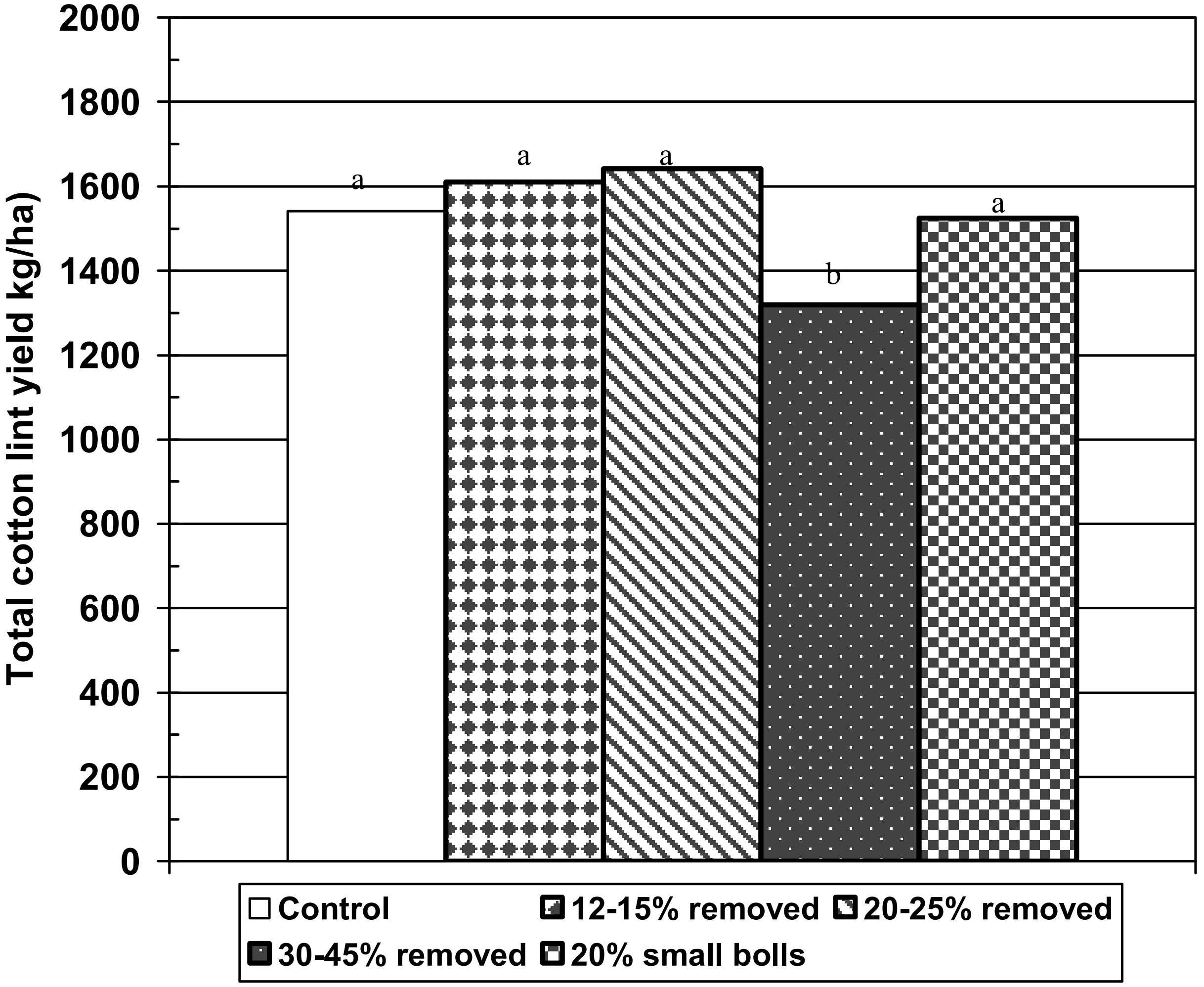

Fig. 9. Averaged over varieties, planting dates, and position cotton lint yield square removal treatments. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

No effect of Variety (Var)
Planting date (PD) effect P
< 0.05

There was no treatment effect on total boll numbers (Fig. 10) or bolls by position (Fig.11) for DPL 51, first planting date. Square removal ranging from 12 to 40% did not affect cotton lint yield for DPL 51 at the first planting date (Fig. 12). This result was similar to the result obtained for the same cultivar and location in 1998. However, the effect of square removal on total boll numbers and second position bolls was evident for DPL 51 at the second planting date (Figs. 13 & 14). Square removal at 30-40% reduced boll numbers compared with the 20-25% removal rate (Fig. 13). The number of second position bolls was increased by the 20-25% square removal rate compared with the other treatments (Fig. 14). Although not statistically significant, a numerical reduction in lint yield for the 30-40% square removal and the 20% small boll removal treatments was observed, as compared with the 20-25% square removal treatment. This yield reduction was 296 and 275 kg/ha lint for the 30-40% and 20% small boll removal, respectively (Fig. 15).

The early-maturing cultivar, DPL 5111, was affected by the square removal treatment differently as compared to the later maturing cultivar DPL 51 (cultivar effect $P < 0.01$). The lowest square removal rate (12-15%) increased boll numbers compared with the check (Fig. 16). The cultivar DPL 5111, under favorable conditions, sets a heavy boll load. This moderate square removal rate might have helped the plant to better reallocate its resources. Kerby and Buxton (1981) indicated association of square loss with a large boll load. Furthermore, they concluded that if a fruiting form aborts, its subtending leaf is capable of supplying more assimilates to adjacent fruiting positions which should favor retention of remaining fruit.

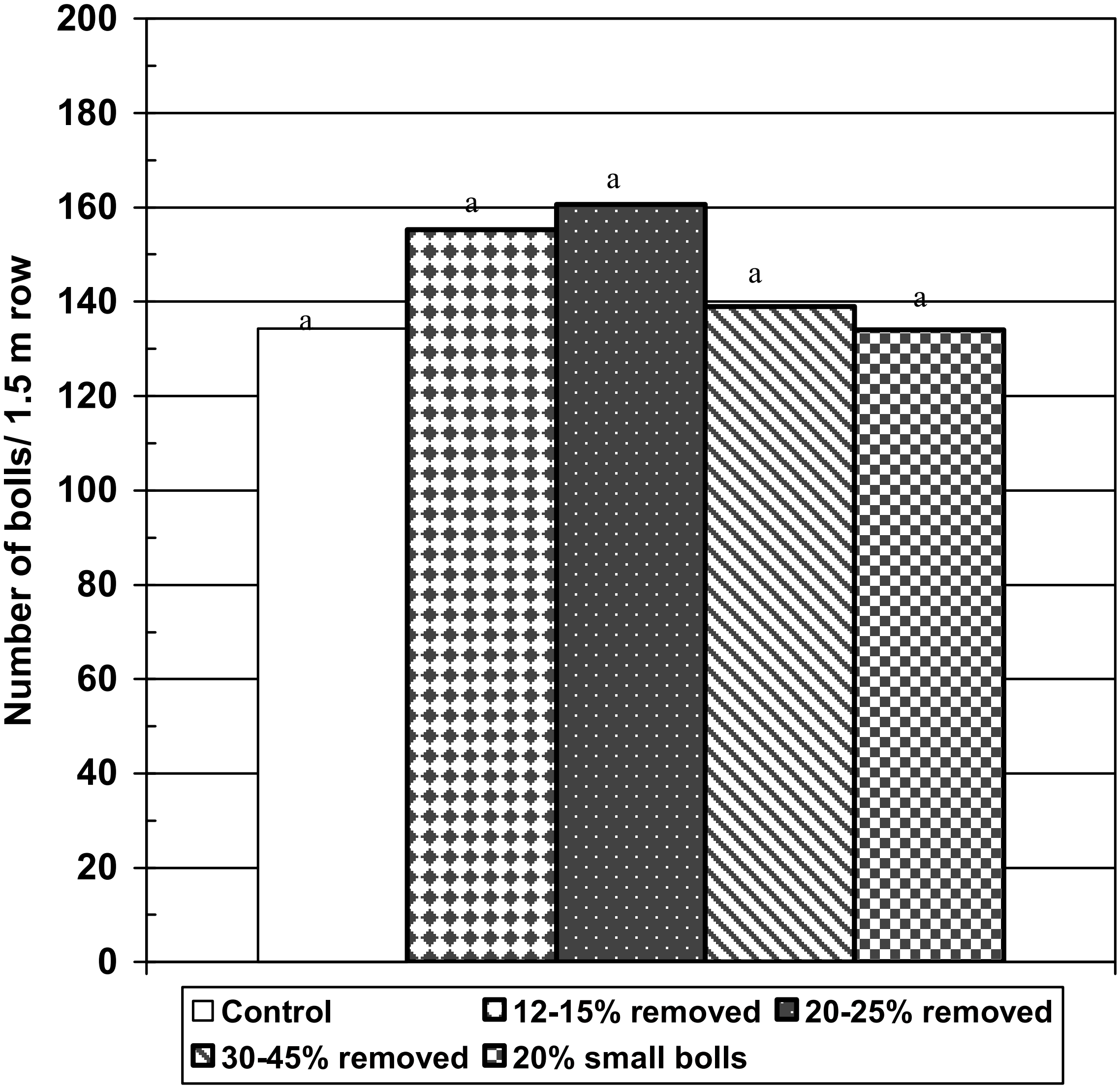

Fig.10. The effect of square removal treatments on total boll numbers for DP51 first planting date (May 5th). Means for bars s followed by the same letter are not significantly different P = 0.05 (DMRT).

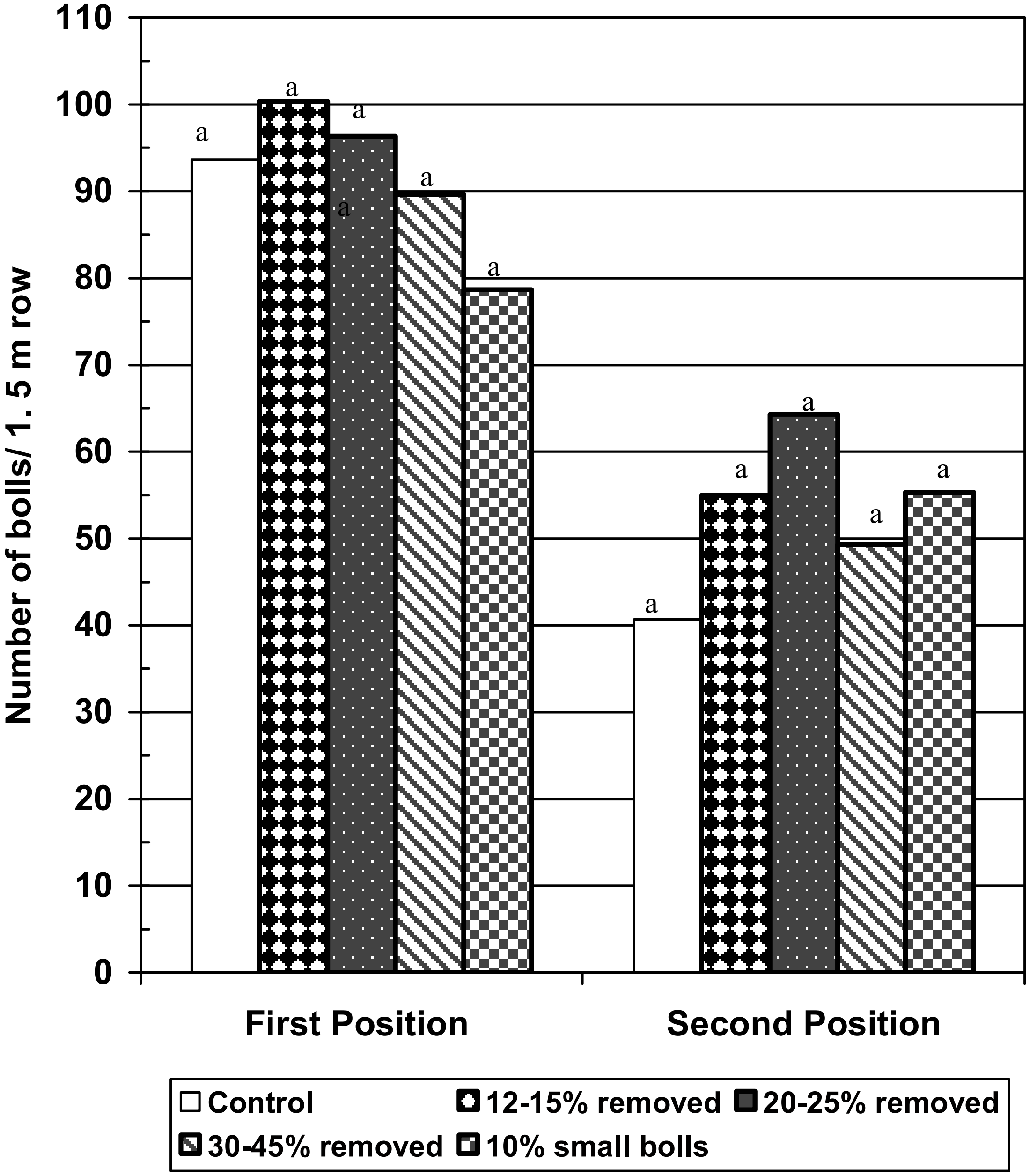

Fig. 11. The effect of square removal treatments on cotton boll numbers by position for DP51 first planting date (May 5th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

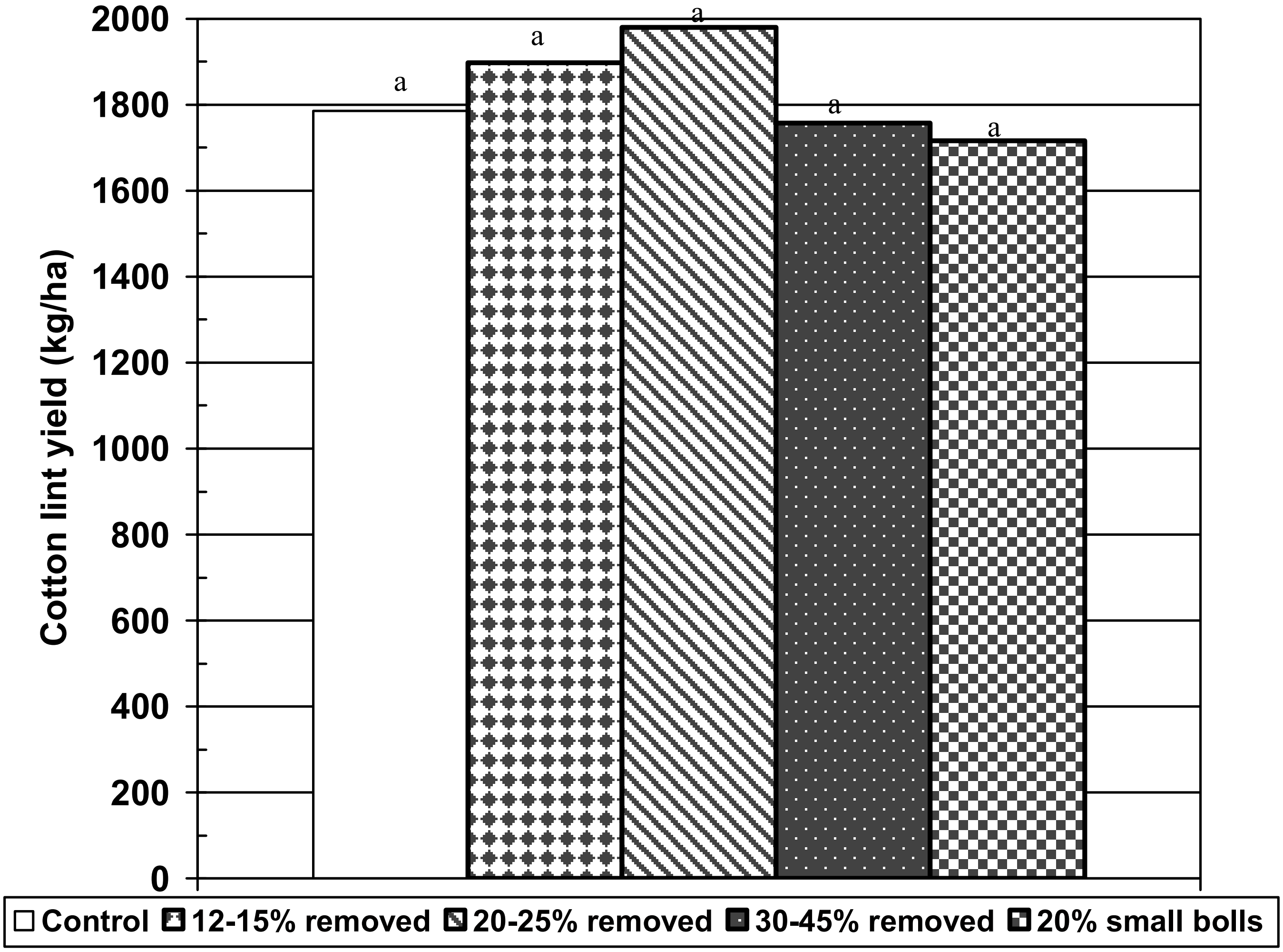

Fig. 12. The effect of square removal treatments on cotton lint yield for DP51 first planting date (May 5th). Means for bars within followed by the same letter are not significantly different P = 0.05 (DMRT).

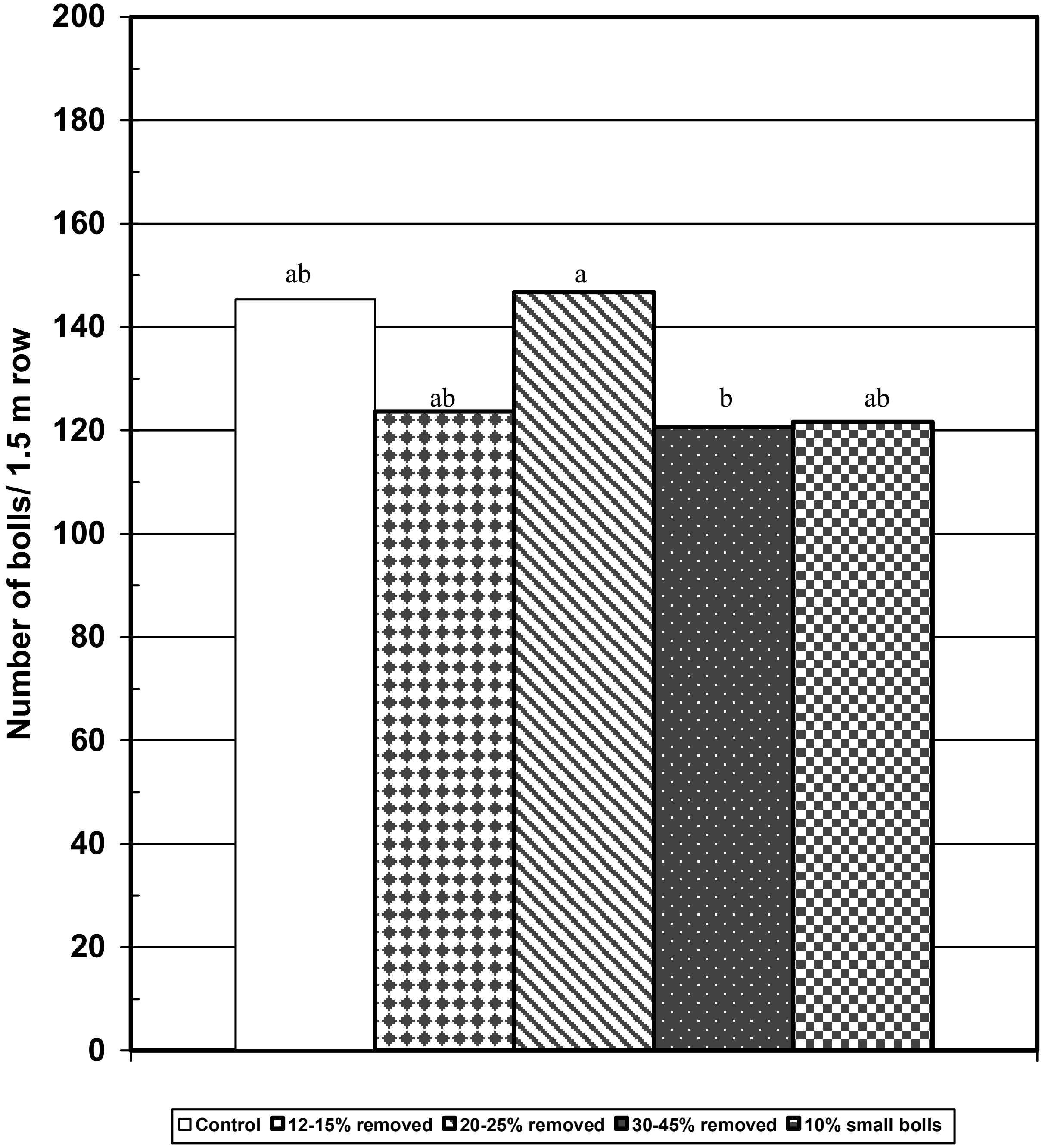

Fig. 13. The effect of square removal treatments on total boll numbers for DP51 second planting date (May 18th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

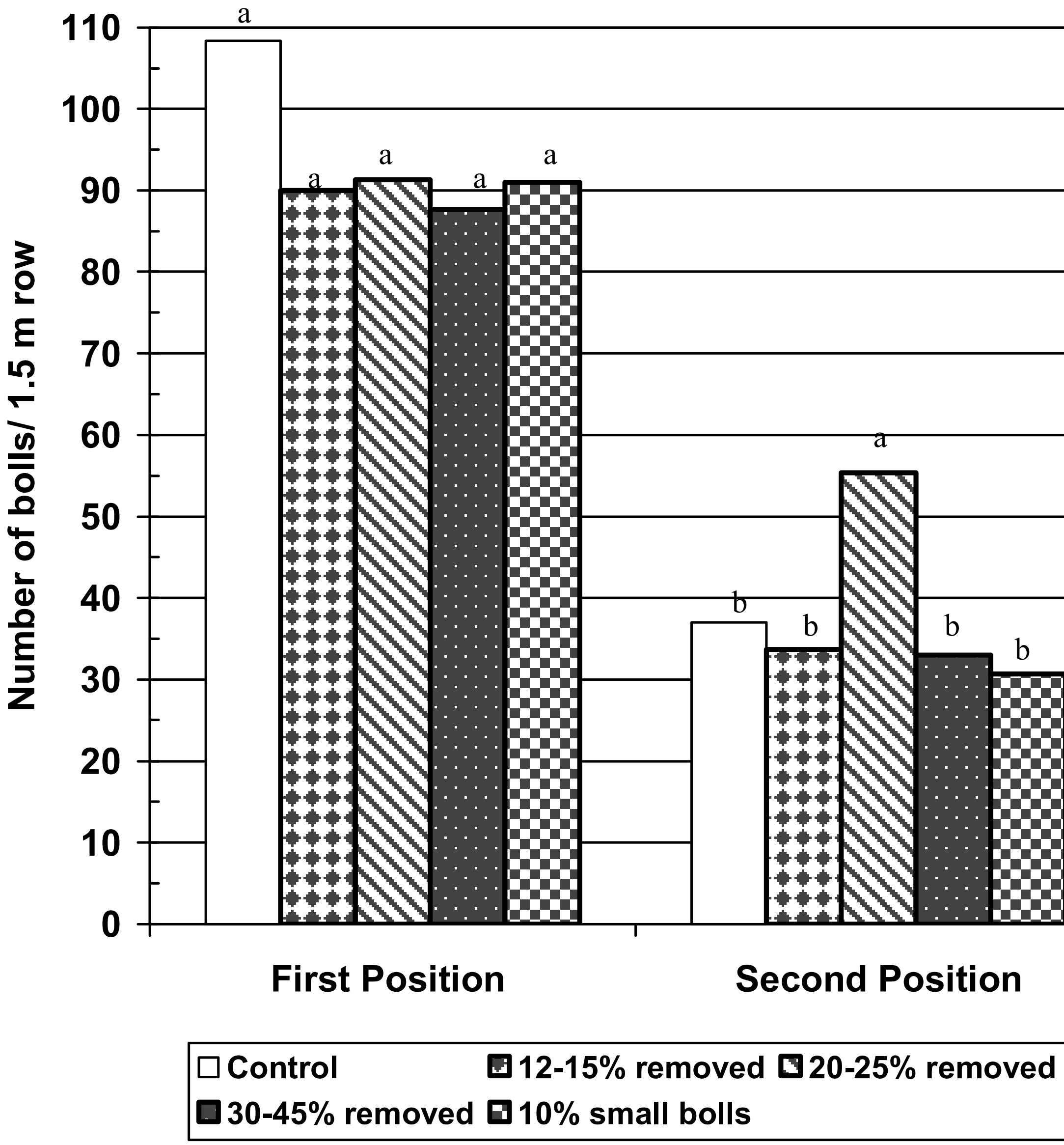

Fig. 14. The effect of square removal treatments on cotton boll numbers by position for DP51 second planting date (May 18th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

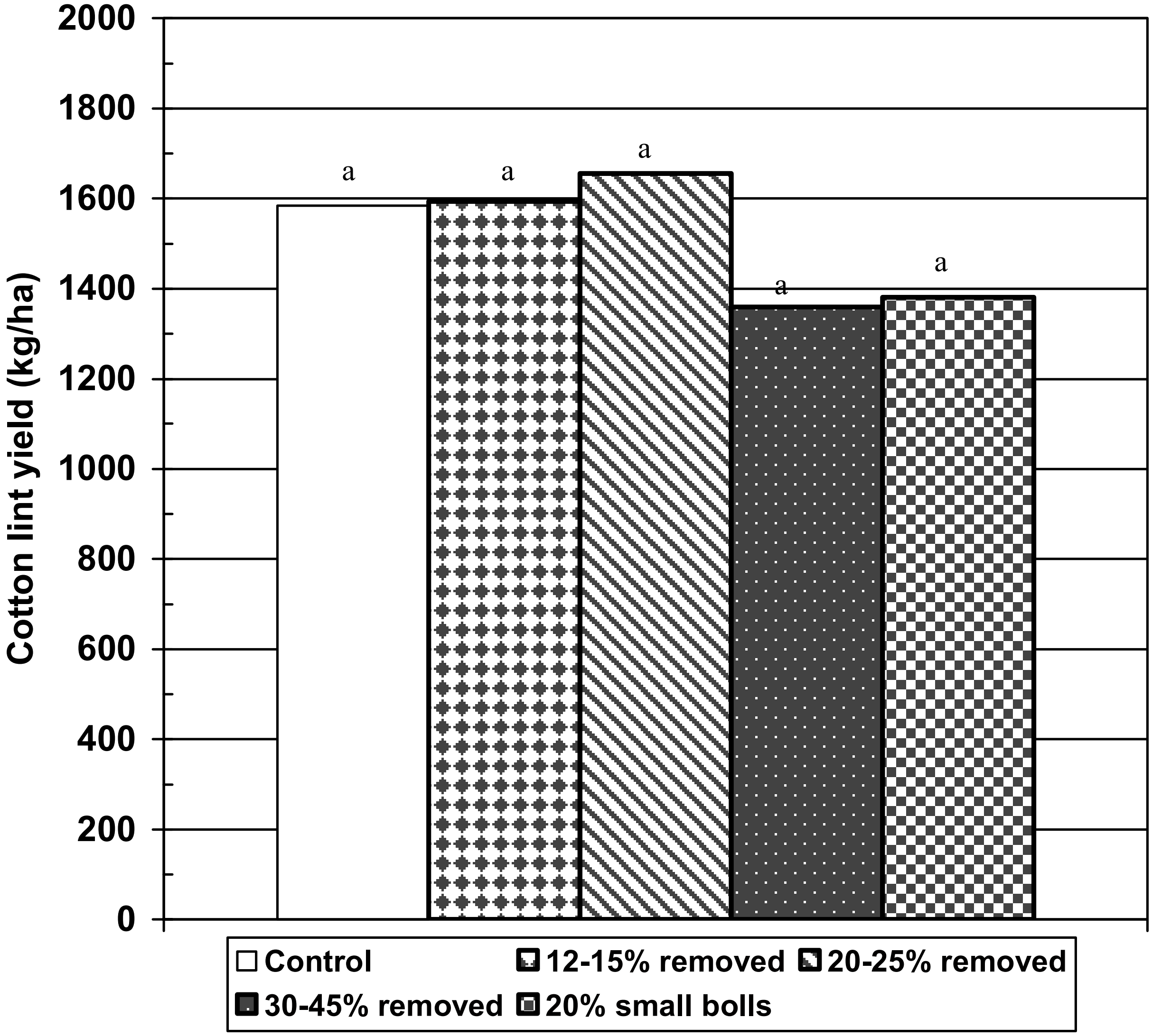

Fig. 15. The effect of square removal treatments on cotton lint yield for DP51 second planting date (May 18th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

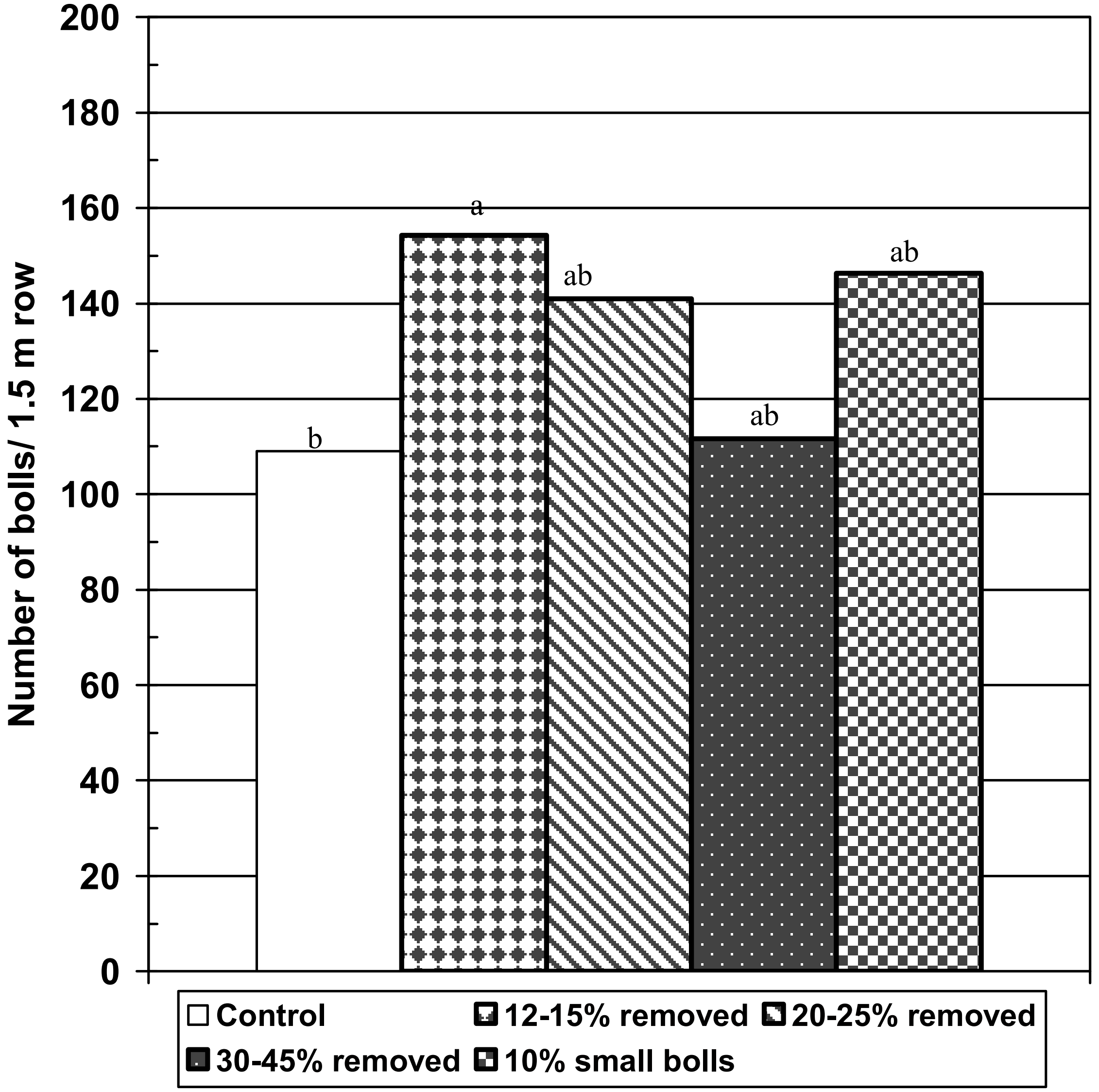

Fig. 16. The effect of square removal treatments on total boll numbers for DP5111 first planting date (May 5th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

Figure 17 shows the effect of square removal rates on the first and second position bolls for DPL5111, first planting date. Square removal in excess of 30-40% reduced number of first position bolls significantly compared with the 12-15%, 20-25% and 20% small boll removal rates. However, no effect of square removal treatments was observed for the second position bolls. Although not significant, square removal rate of the 30-40% reduced cotton lint yield by 486 kg/ha compared with the 20-25% square removal rate (Fig. 18).

Generally, the effect of square removal on yield and yield components was more pronounced for DPL 5111 at the second planting date. That is, total boll numbers, boll numbers by position, and lint yield were lower than DPL 5111 at the first planting date. Square removal at 30-40% reduced total boll numbers compared with the check and the 12-15% square removal rate (Fig. 19). Although a similar trend was observed, no significant difference in squares by position and lint yield was observed (Figs. 20 and 21).

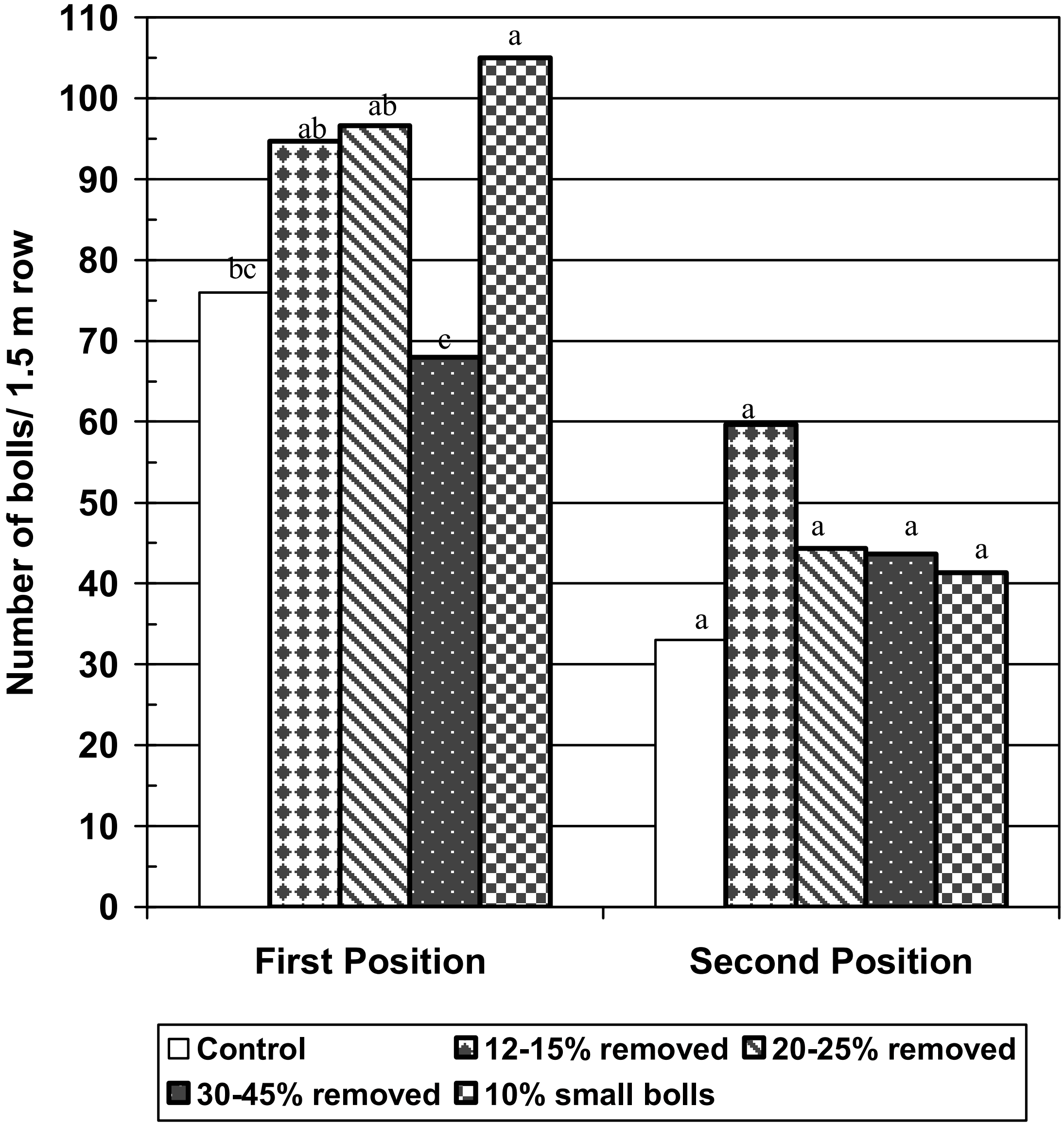

Fig. 17. The effect of square removal treatments on cotton boll numbers by position for DP5111 first planting date (May 5th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

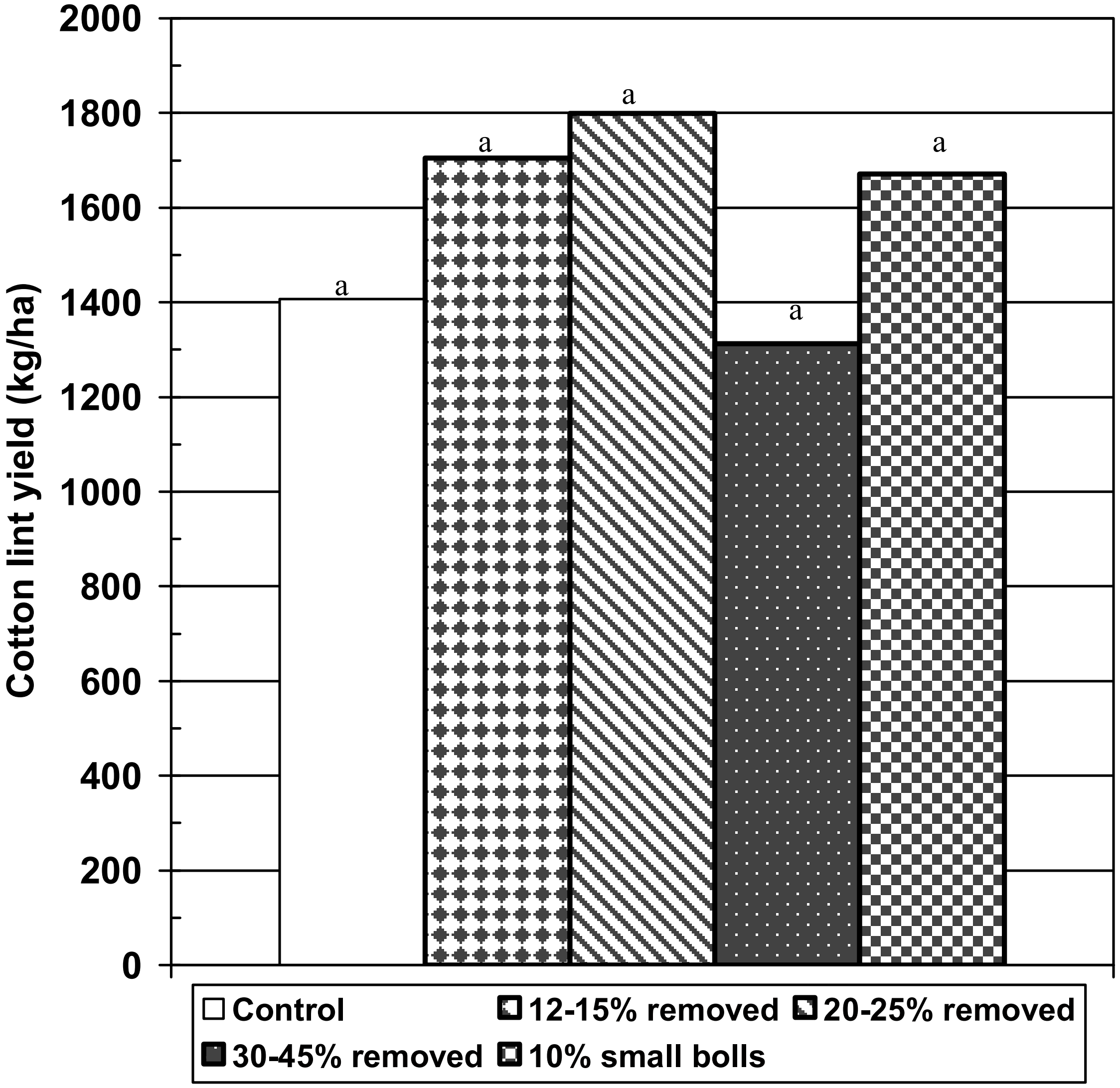

Fig. 18. The effect of square removal treatments on cotton lint yield for DP5111 first planting date (May 5th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

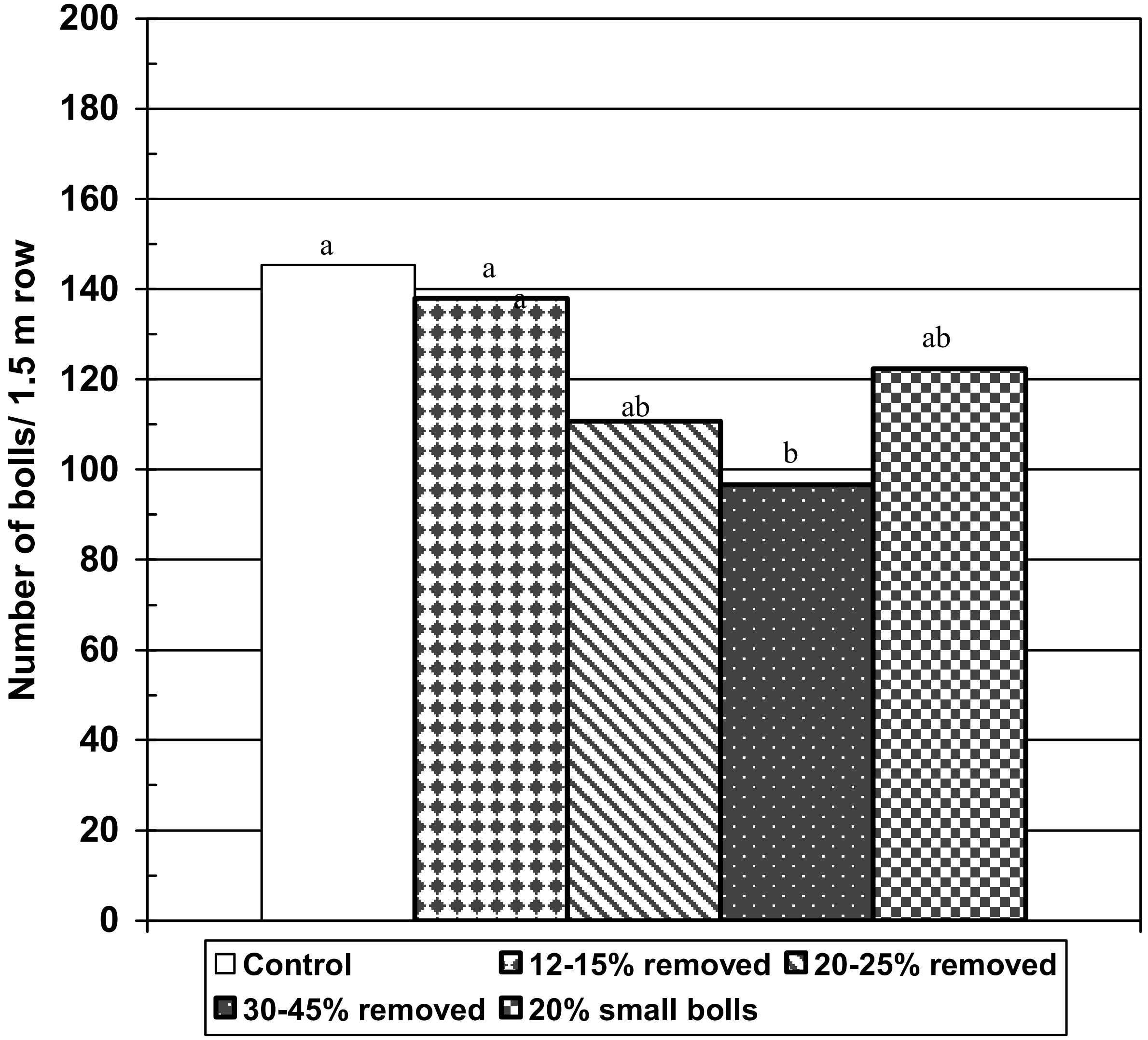

Fig. 19. The effect of square removal treatments on total boll numbers for DP5111 second planting date (May 18th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

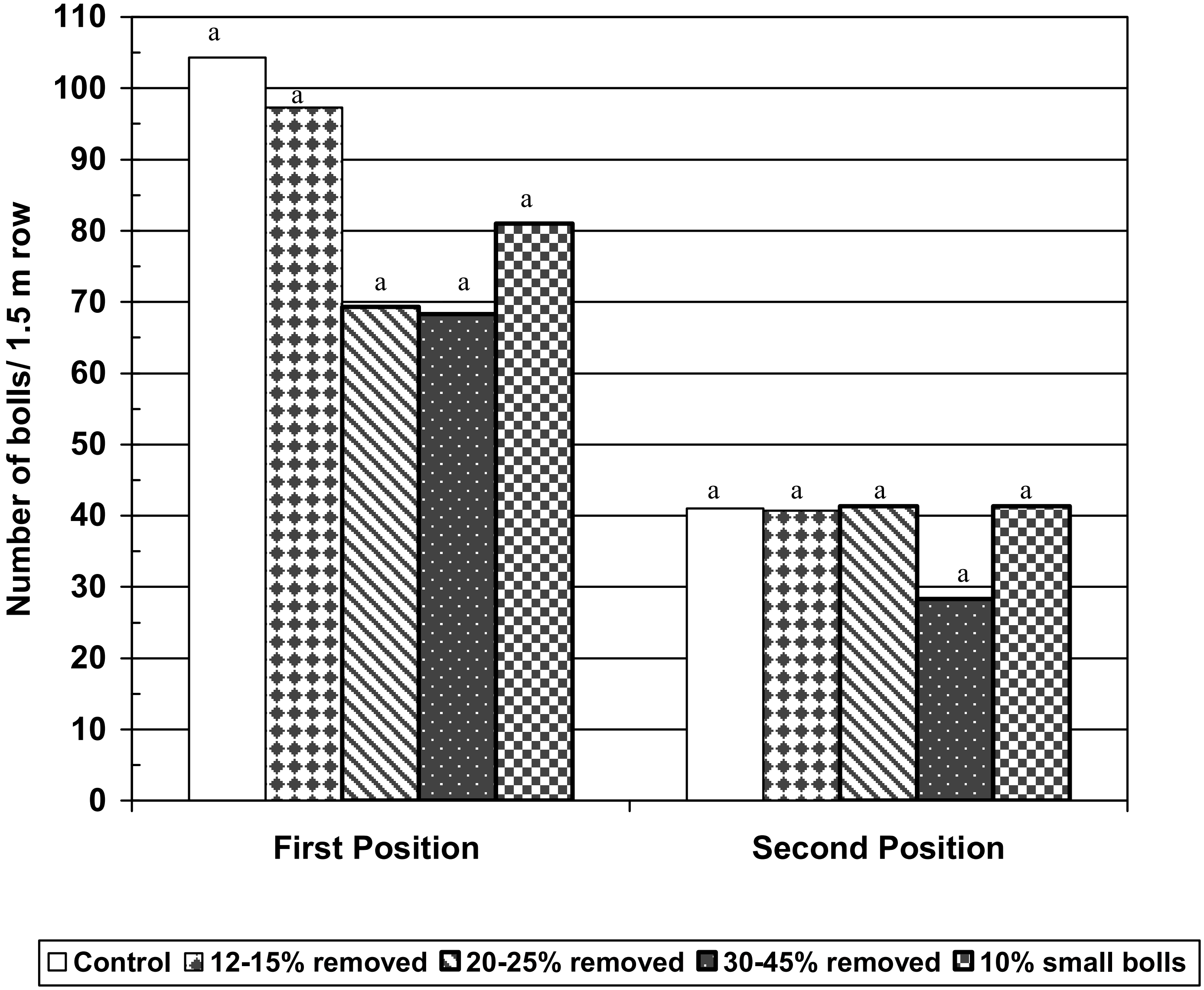

Fig. 20. The effect of square removal treatments on cotton boll numbers by position for DP5111 second planting date (May 18th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

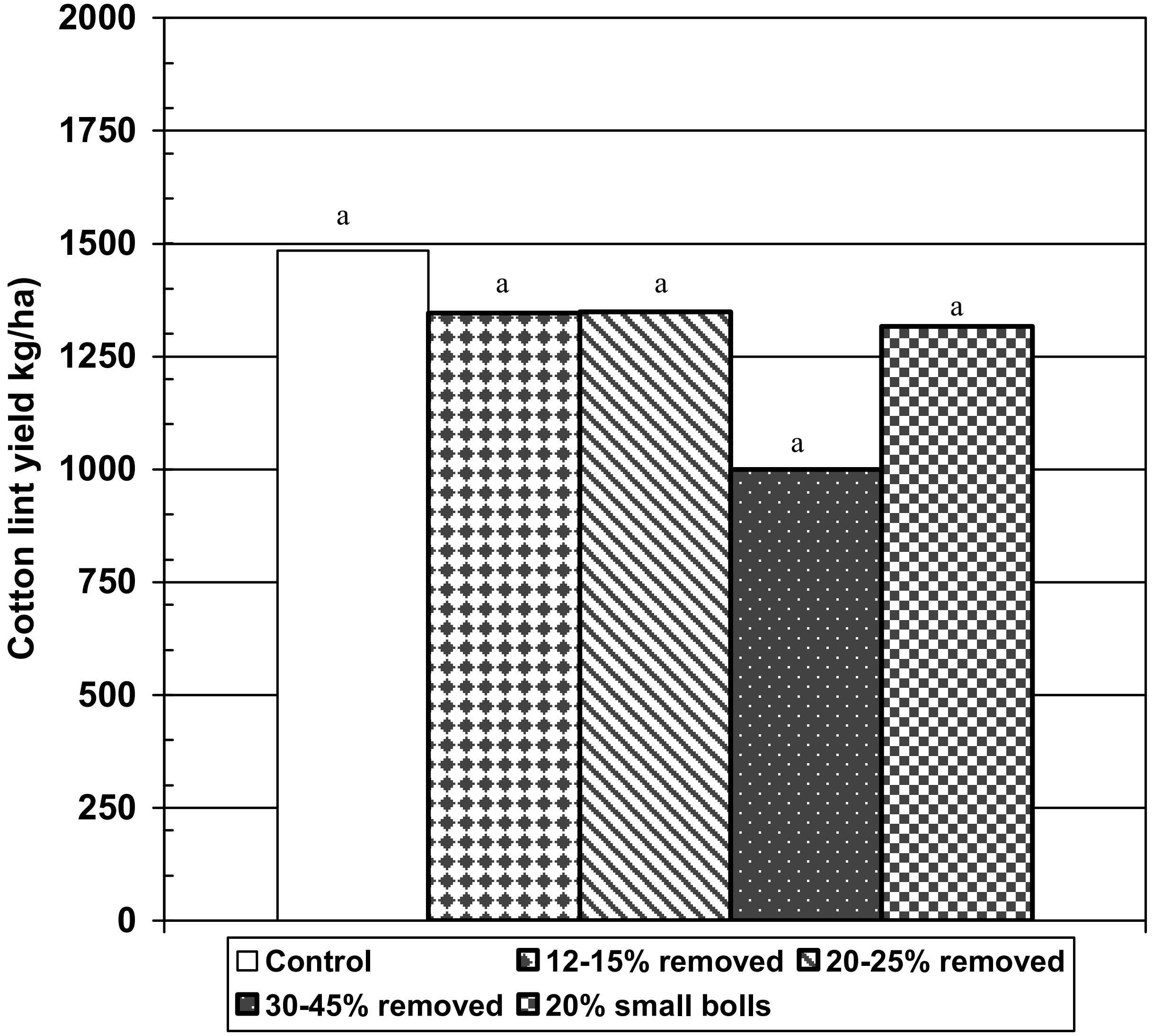

Fig. 21. The effect of square removal treatments on cotton lint yield for DP5111 second planting date (May 18th). Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

1999, Blackstone location

As mentioned earlier, Blackstone has a shorter cotton growing season thus limiting cotton yield compensation time as compared to the Suffolk location. Averaged over cultivars and planting dates, square removal at the 30-40% rate reduced the number of total bolls per 1.52 m row (Fig. 22). Unlike the Suffolk location where yield reduction was observed only for the 30-40% square removal level, at the Blackstone location cotton lint yield was affected by the 20-25% and 30-40% square removal rates compared to the check. This yield reduction was 198 and 235 kg/ha over the check for 20-25% and 30-40%, respectively (Fig. 23).

There was no treatment effect on total boll numbers, bolls by position, or lint yield for DPL 51, first planting date (Figs. 24, 25, and 26). However, a trend for a reduction in boll numbers and lint yield was observed where squares were removed at the 30-40% rates. Although not significant (P=0.05), the effect of square removal on total boll numbers, second position bolls, and lint yield was evident for DPL 51 at the second planting date (Figs. 27, 28 and 29). Total boll numbers per 1.52 m row was lower by 59 bolls for the 30-40% square removal rate compared with the check. Similarly, a yield reduction of 283 and 357 kg/ha was observed for the 20-25% and 30-40% square removal rates, respectively, compared with the check.

No treatment effect on total boll numbers was observed for DPL 5111 at the first planting date (Fig. 30). However, a reduction in the number of first position bolls was evident where squares were removed at the 30-40% rate compared with the 20-25%

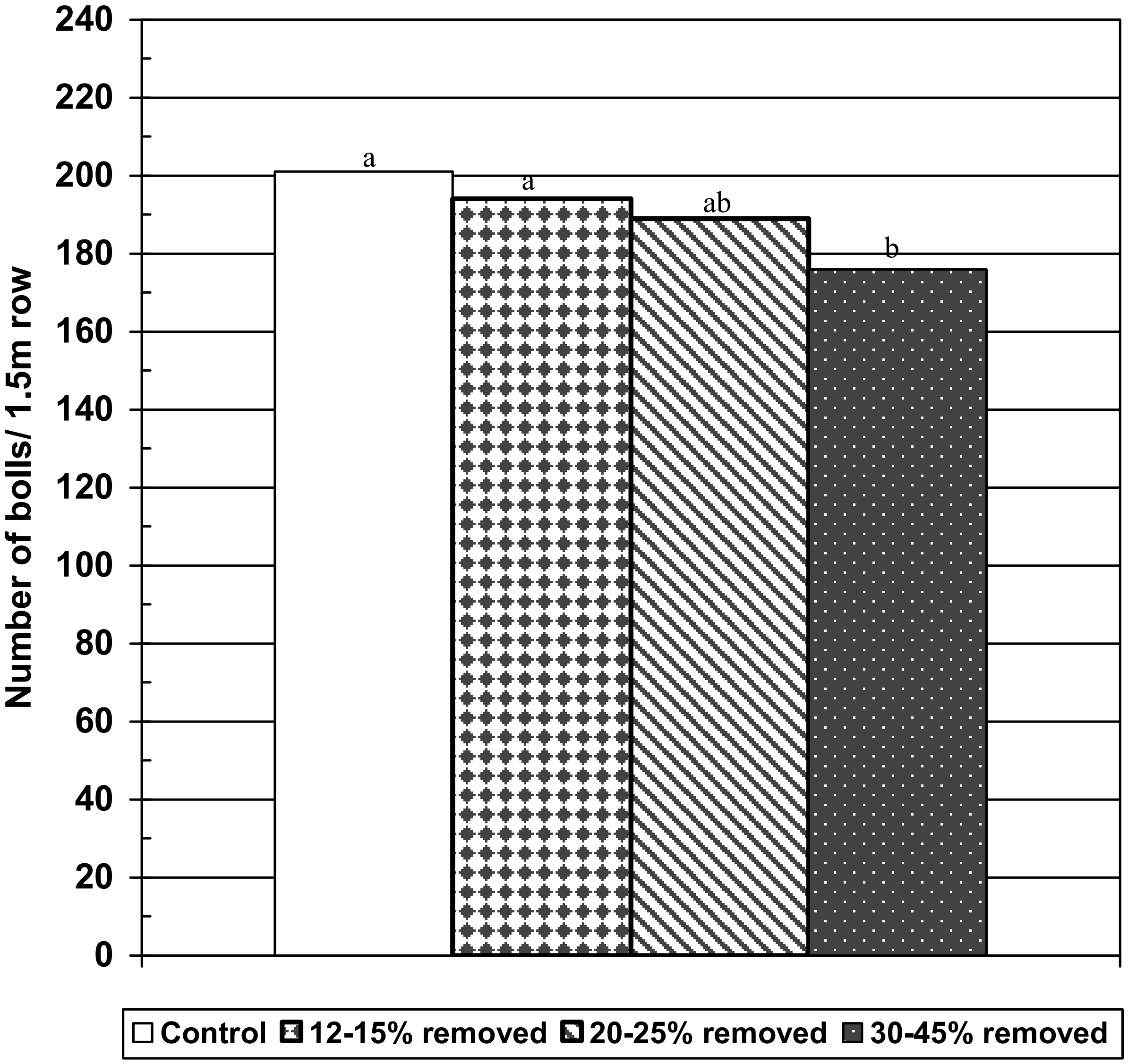

Fig. 22. Averaged over PD and Var. the effect of square removal treatments on total boll numbers at **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

Var effect ($P < 0.01$)
PD effect ($P < 0.01$)
PD x Var. effect ($P < 0.07$)
Treatment effect ($P < 0.05$)

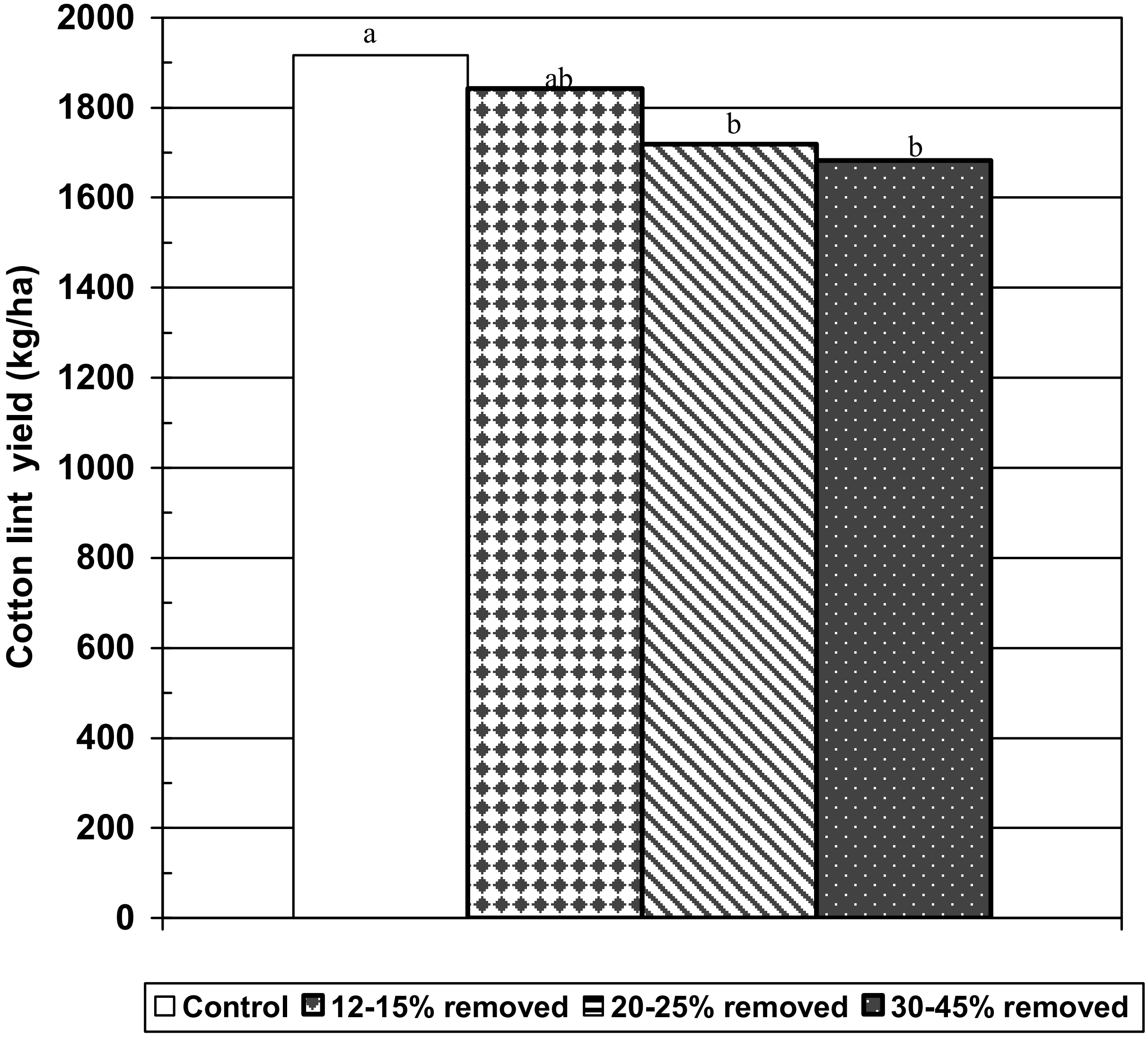

Fig. 23. Averaged over PD and Var. the effect of square removal treatments on seed cotton yield at **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

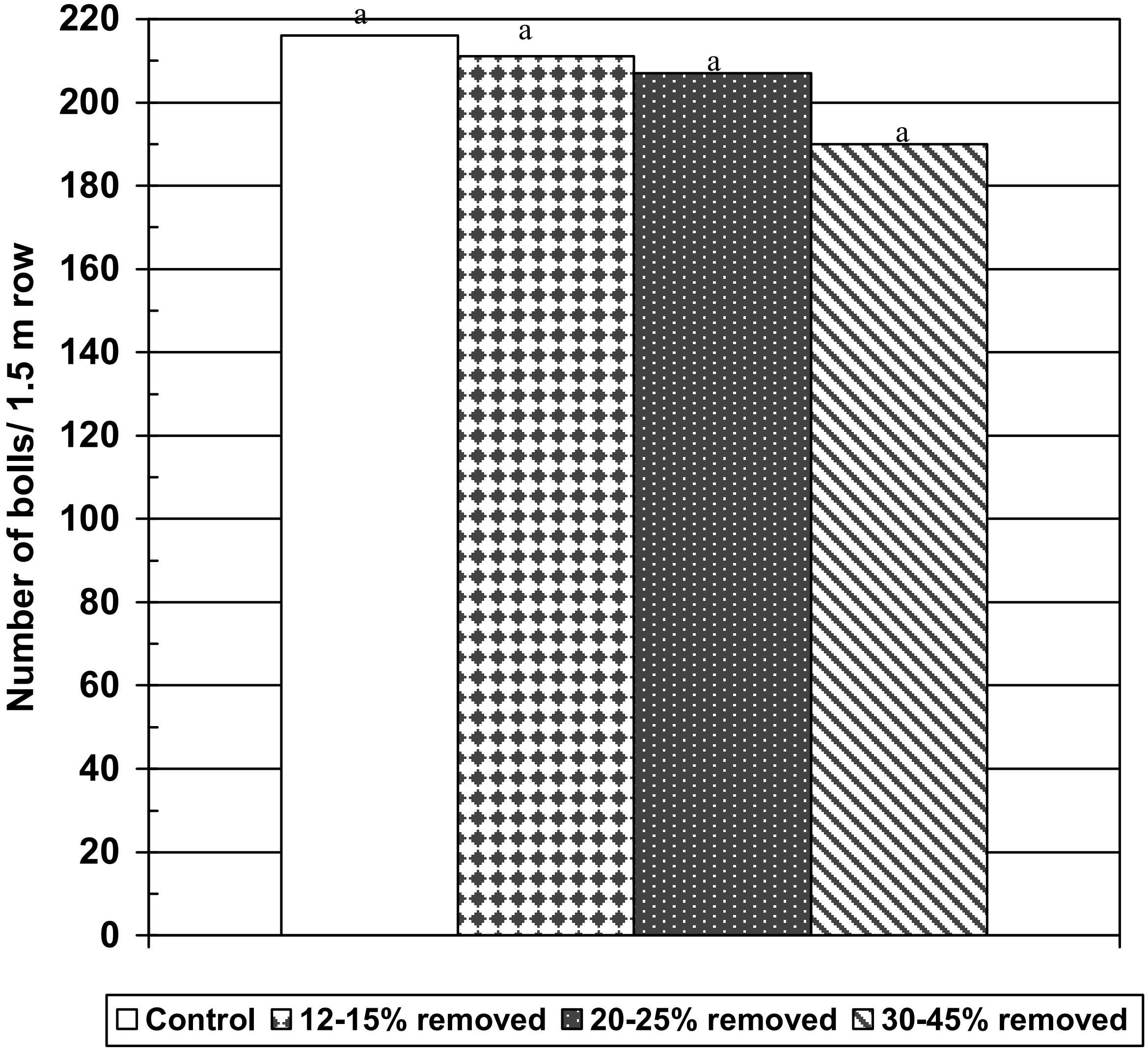

Fig. 24. The effect of square removal treatments on total boll numbers for DP51 first planting date at the **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

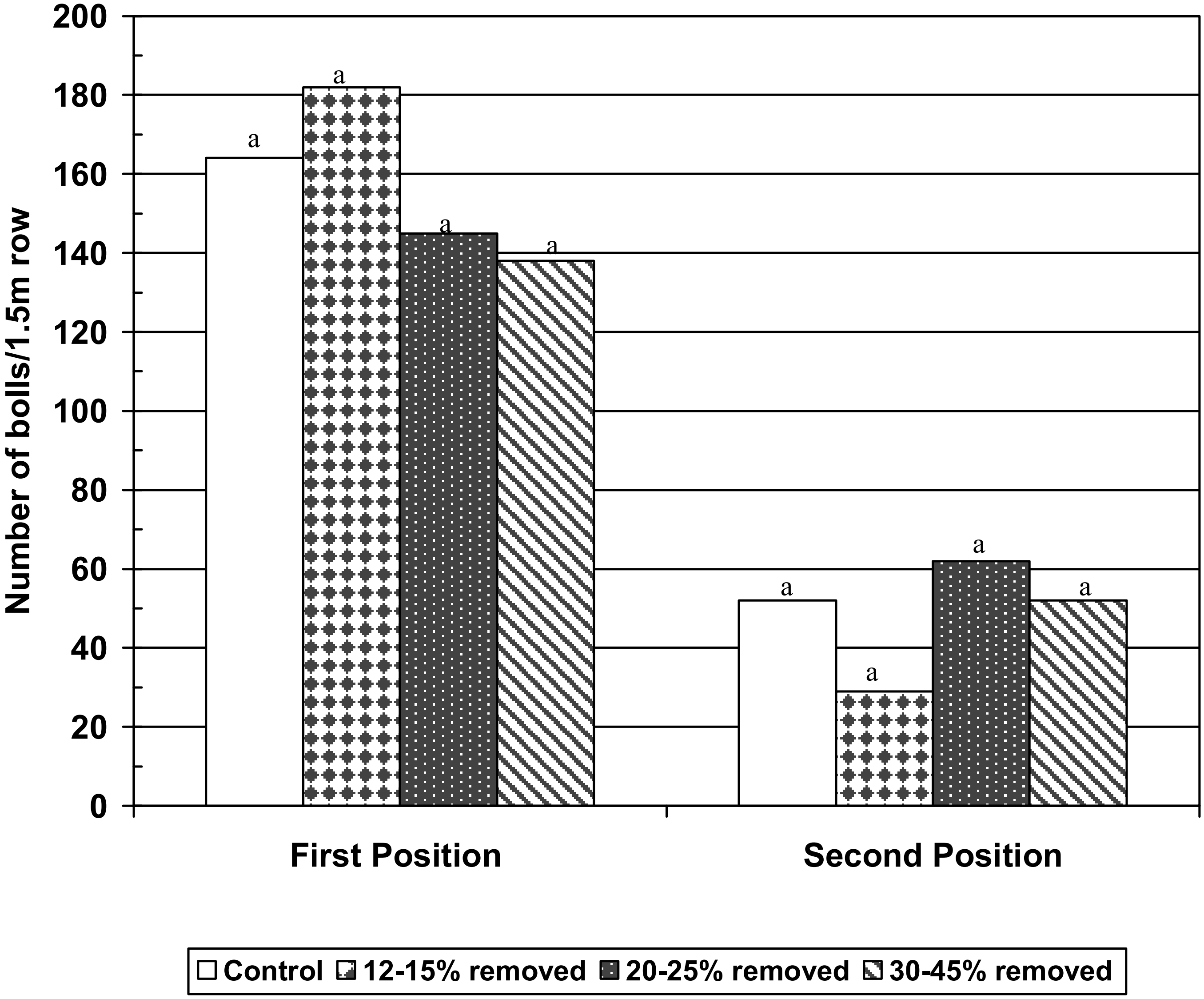

Fig. 25. The effect of square removal treatments on cotton boll numbers by position for DP51 first planting date at the **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

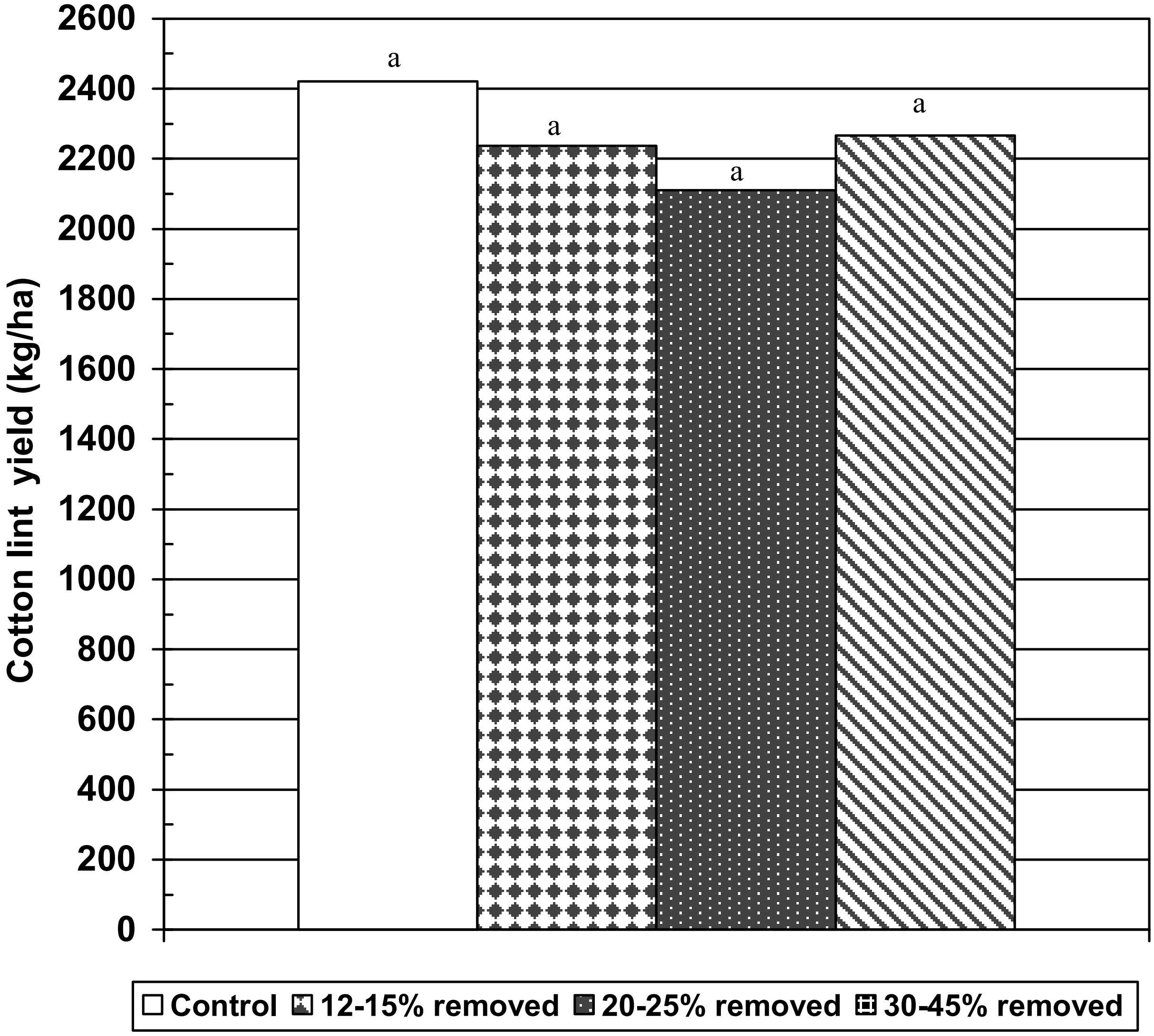

Fig. 26. The effect of square removal treatments on cotton lint yield for DP51 first planting date at the **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

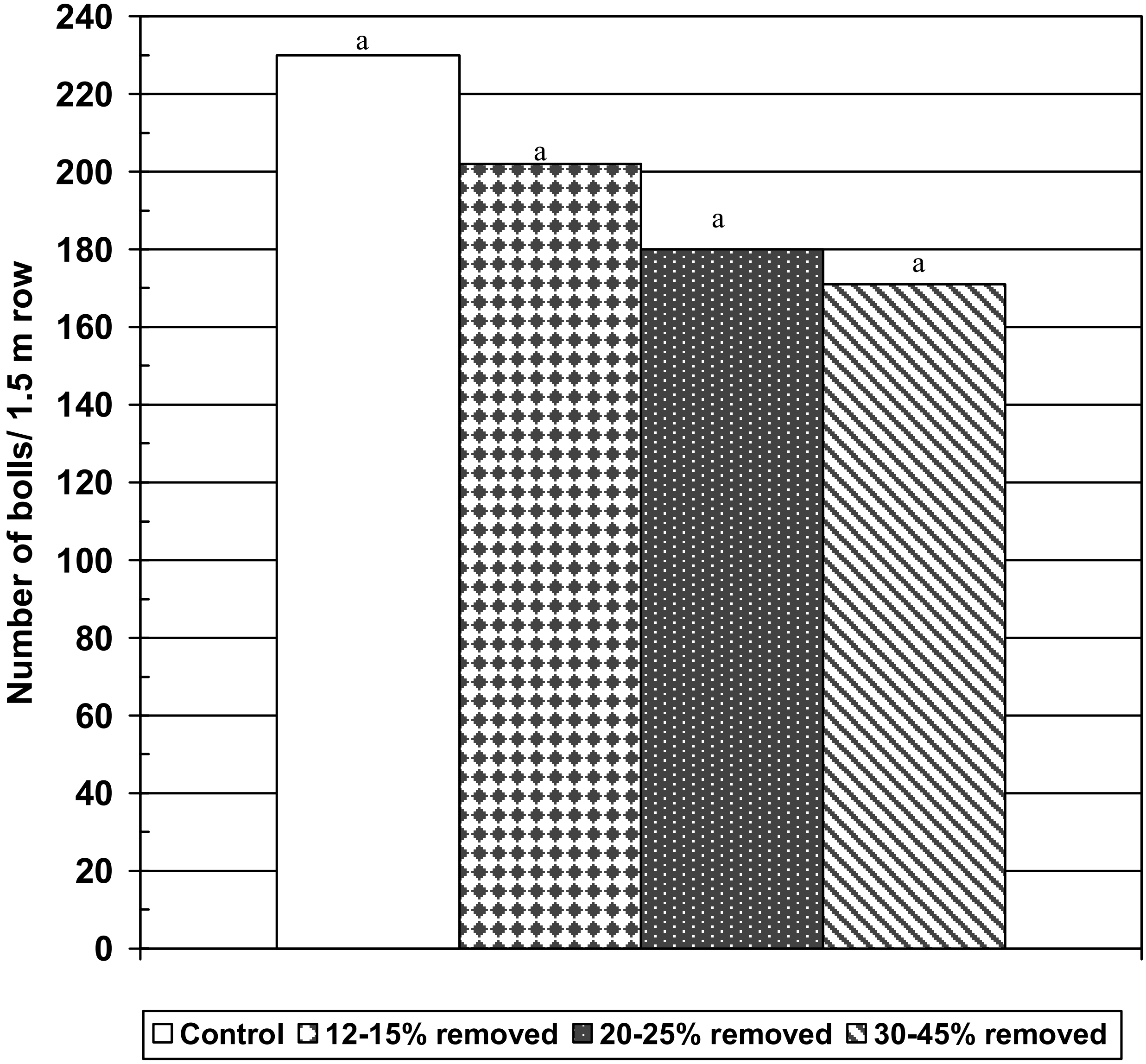

Fig. 27. The effect of square removal treatments on total boll numbers for DP51 second planting date at **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

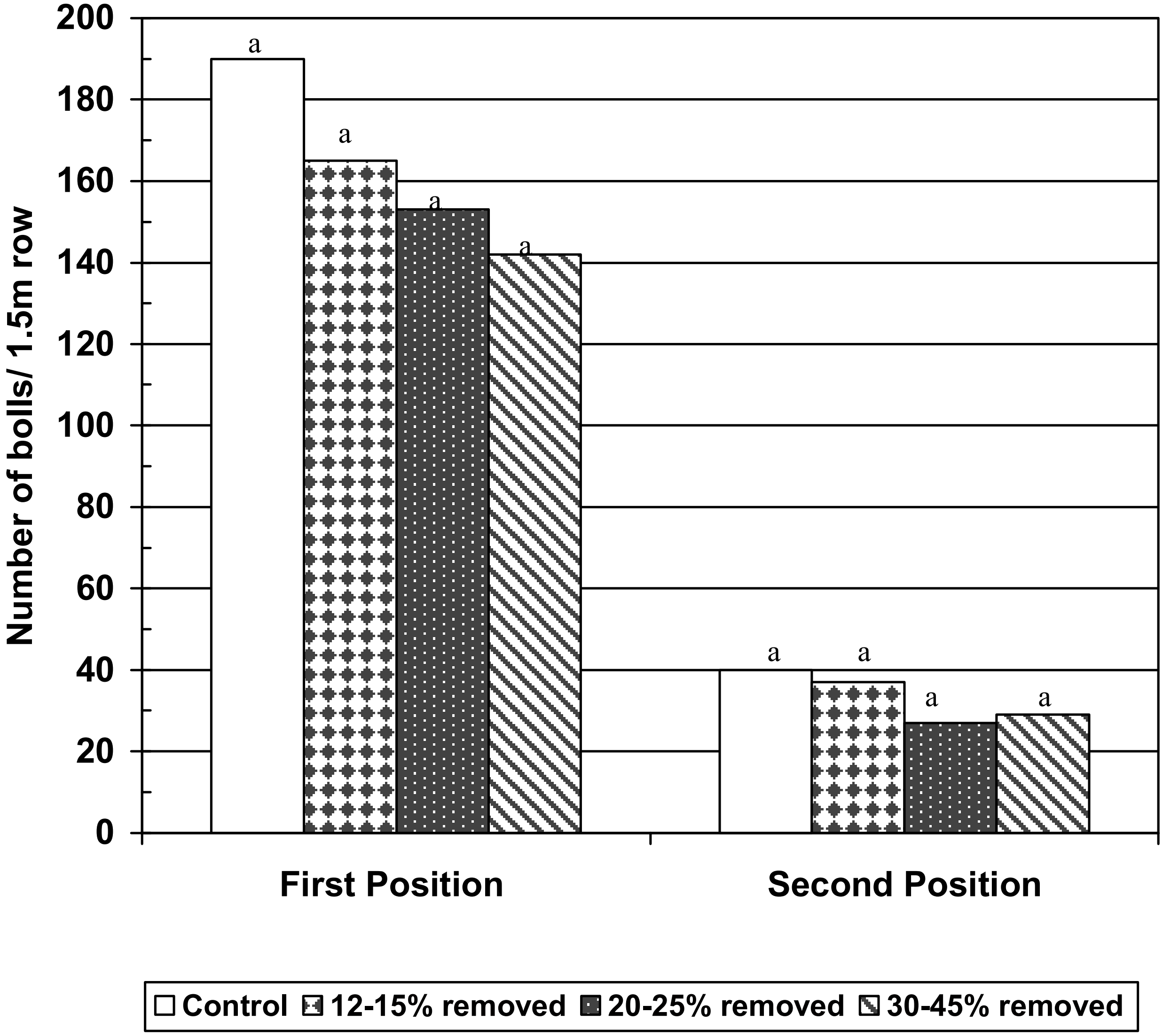

Fig. 28. The effect of square removal treatments on cotton boll numbers by position for DP51 second planting date at **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

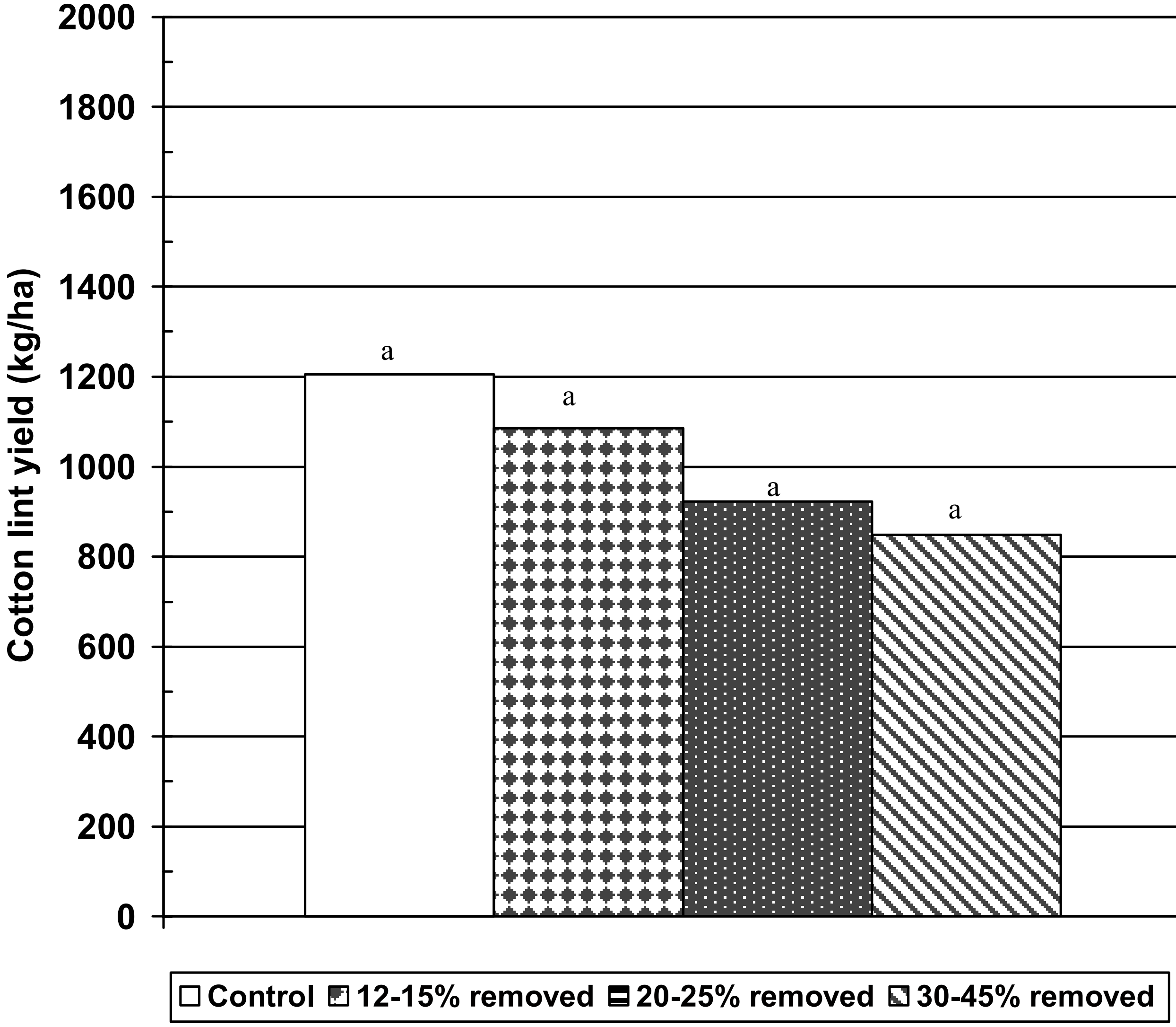

Fig. 29. The effect of square removal treatments on cotton lint yield for DP51 second planting date at **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

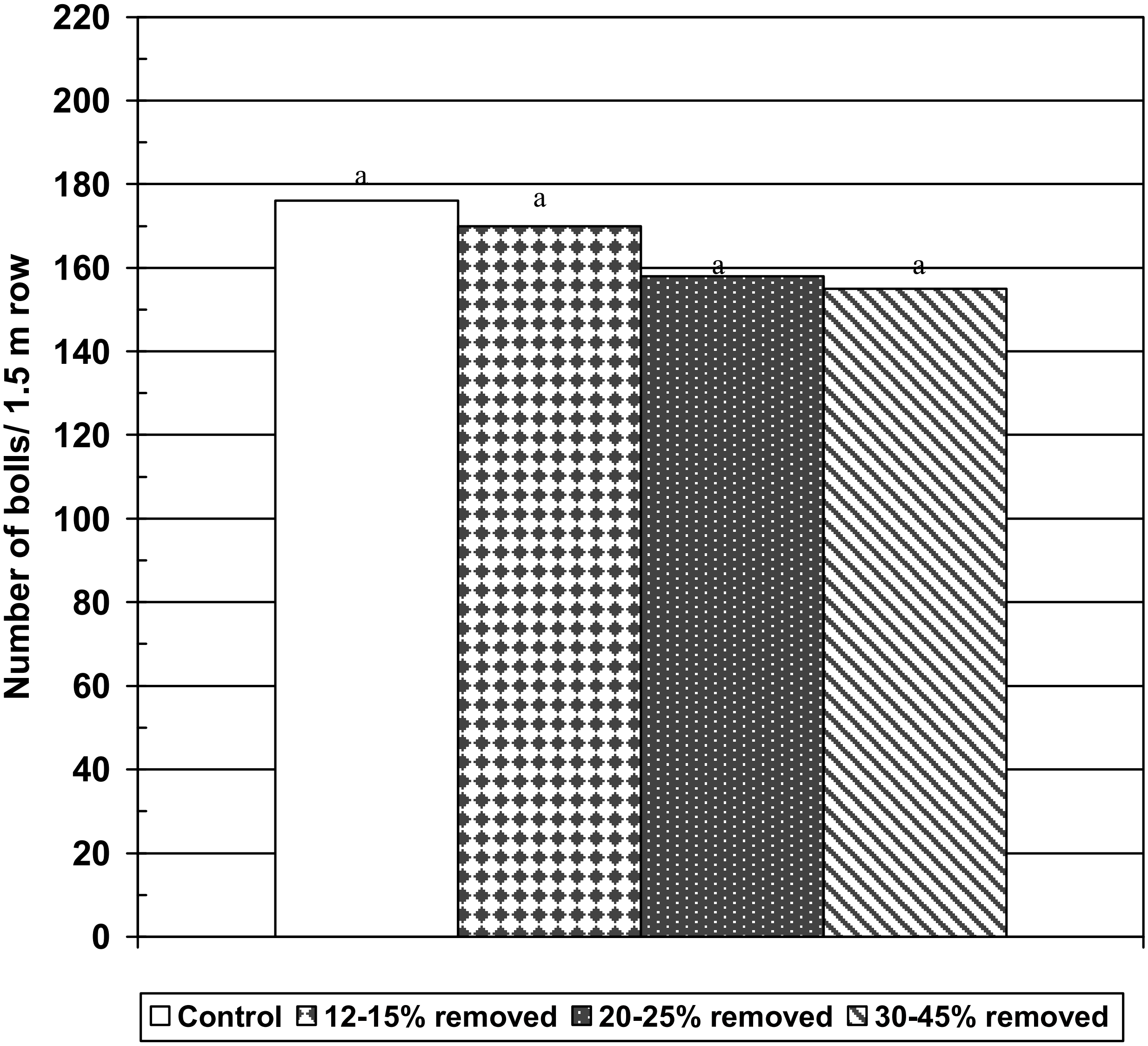

Fig.30. The effect of square removal treatments on total boll numbers for DP5111 second planting date at the **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

square removal rate (Fig. 31). Although a similar trend was observed, varied square removal rates did not significantly reduced lint yield (Fig. 32). Similar trends were observed for DPL 5111 at the second planting date (Figs. 33, 34, and 35).

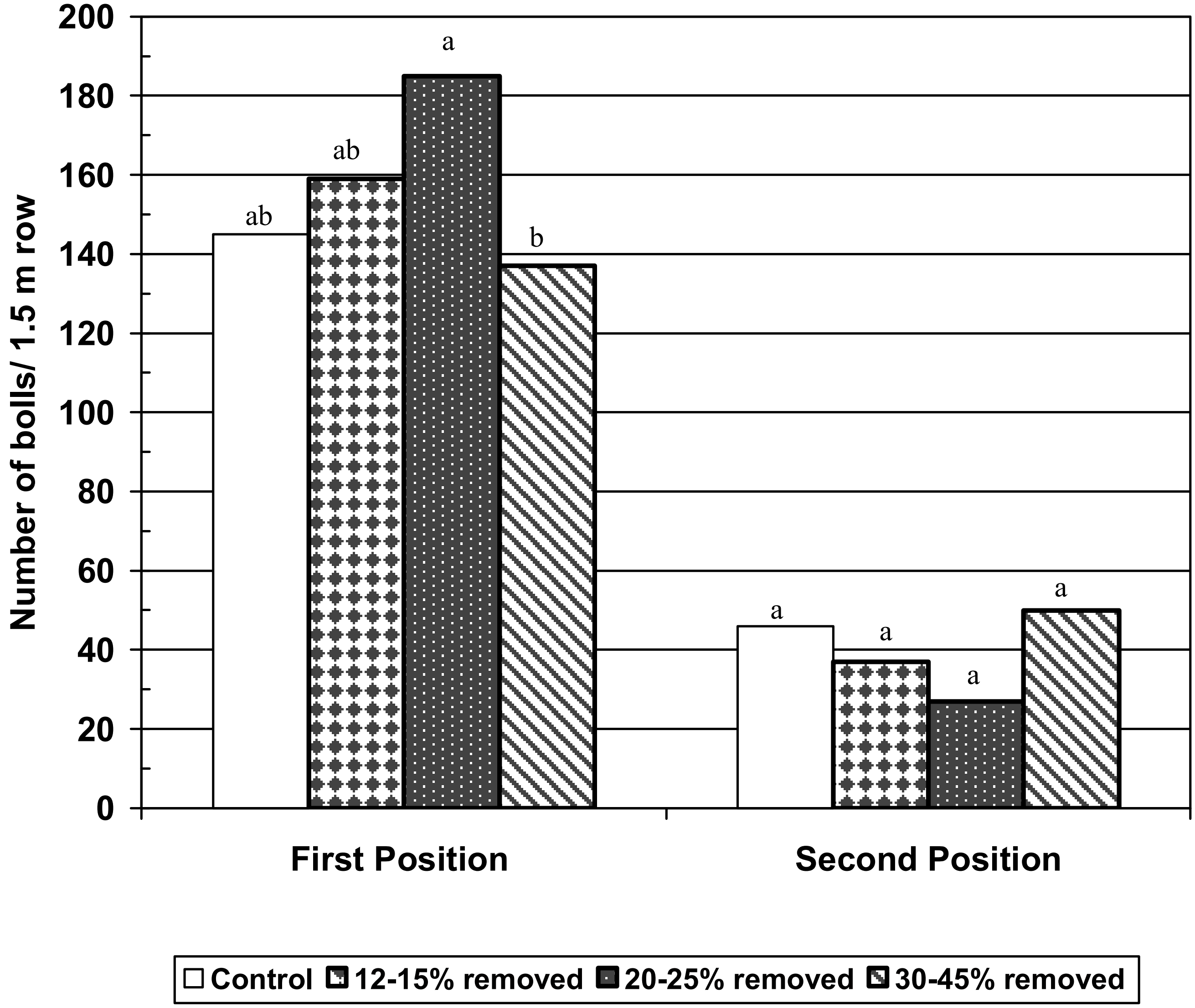

Fig. 31. The effect of square removal treatments on cotton boll numbers by position for DP5111 first planting date at the **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

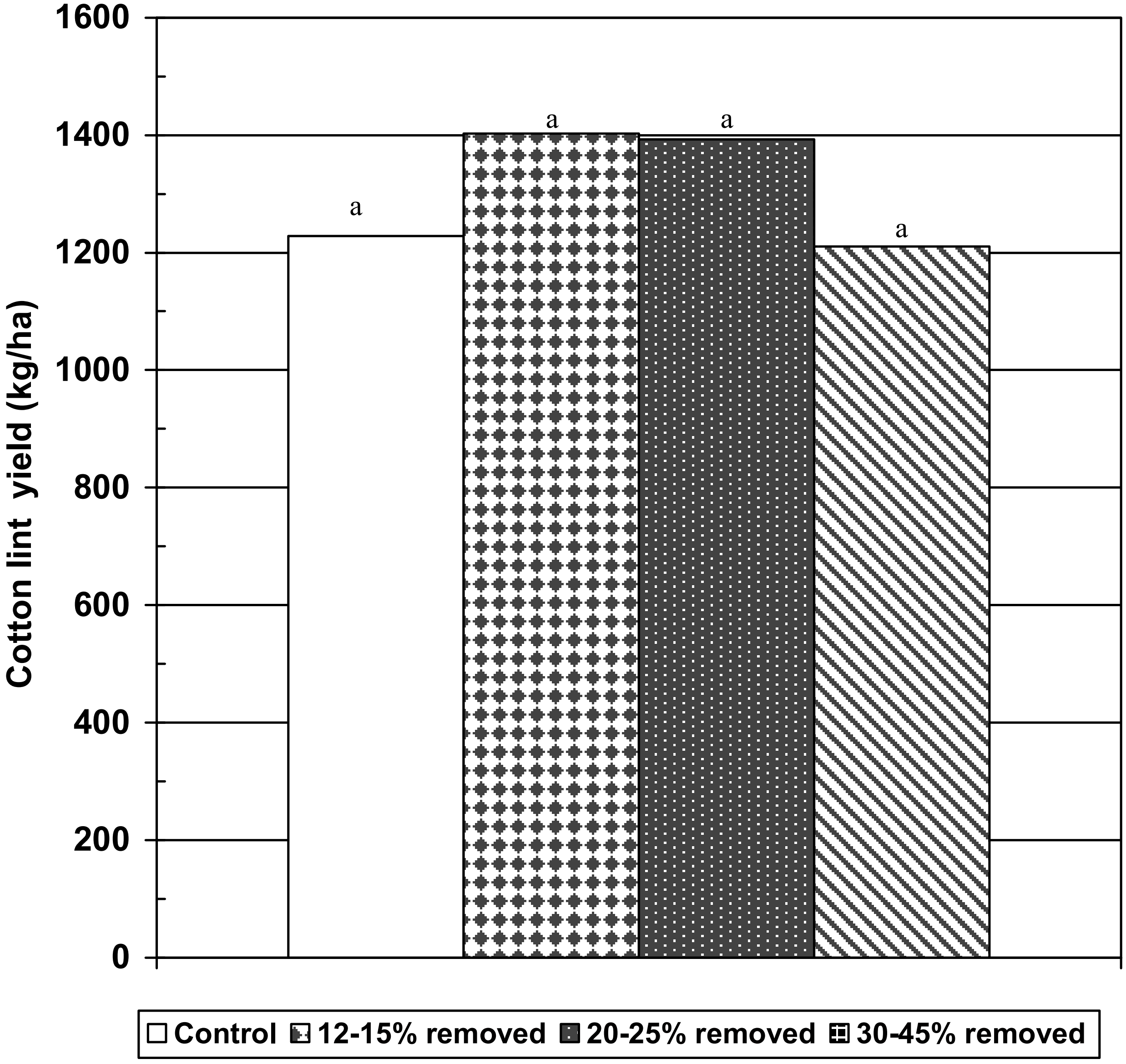

Fig. 32. The effect of square removal treatments on cotton lint yield for DP5111 first planting date at **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

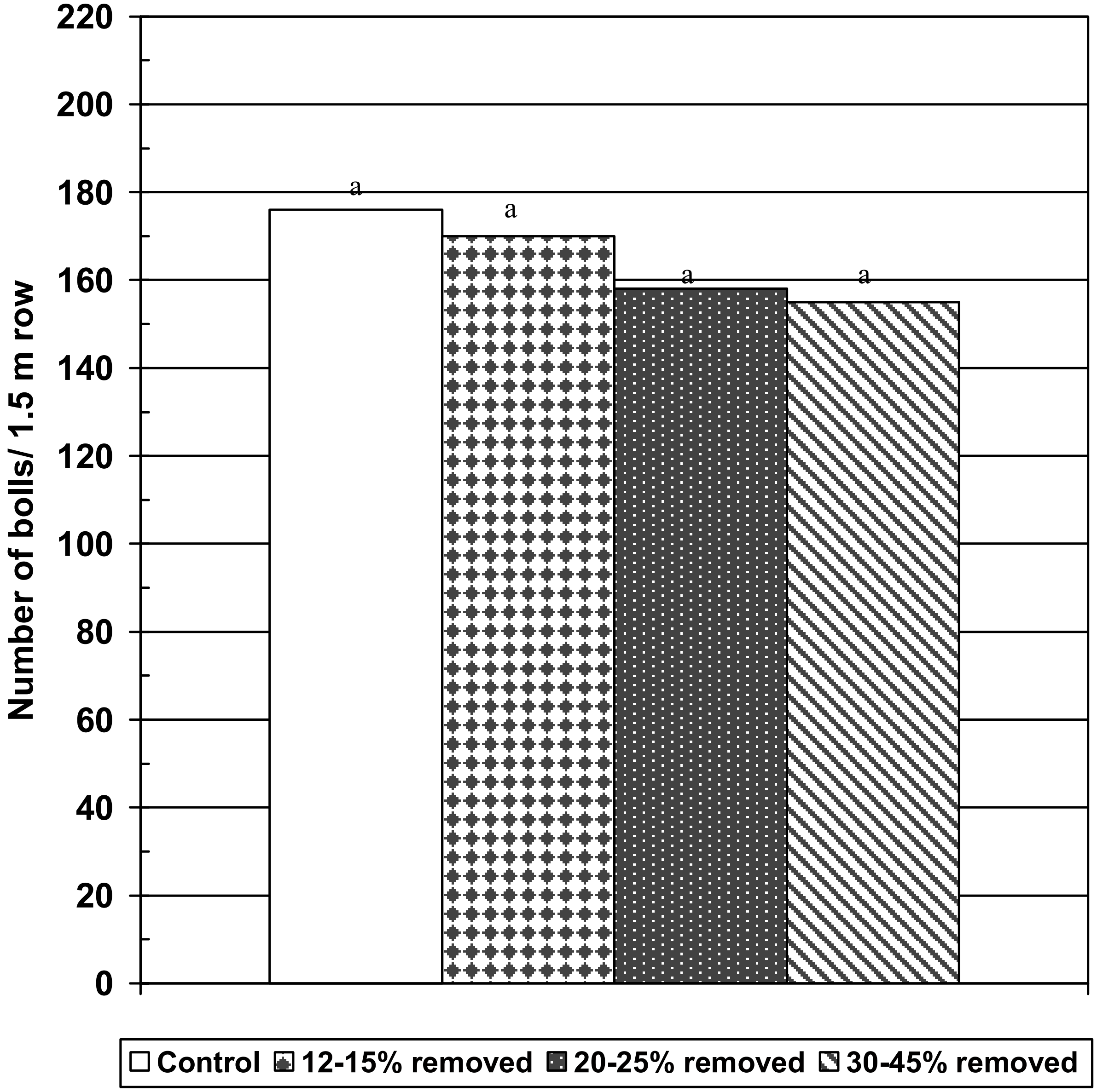

Fig.33. The effect of square removal treatments on total boll numbers for DP5111 second planting date at the **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

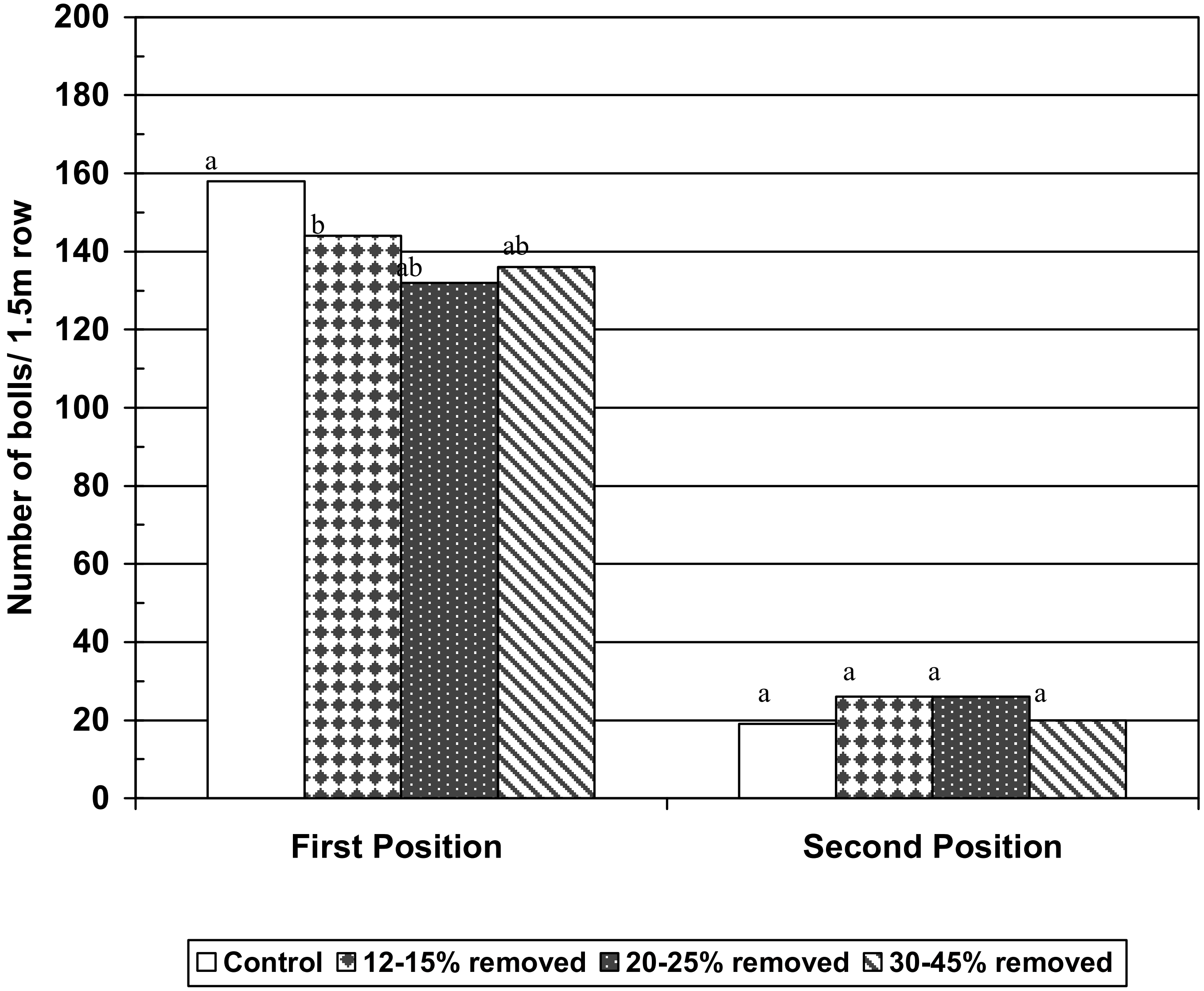

Fig.34. The effect of square removal treatments on cotton boll numbers by position for DP5111 second planting date at the **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

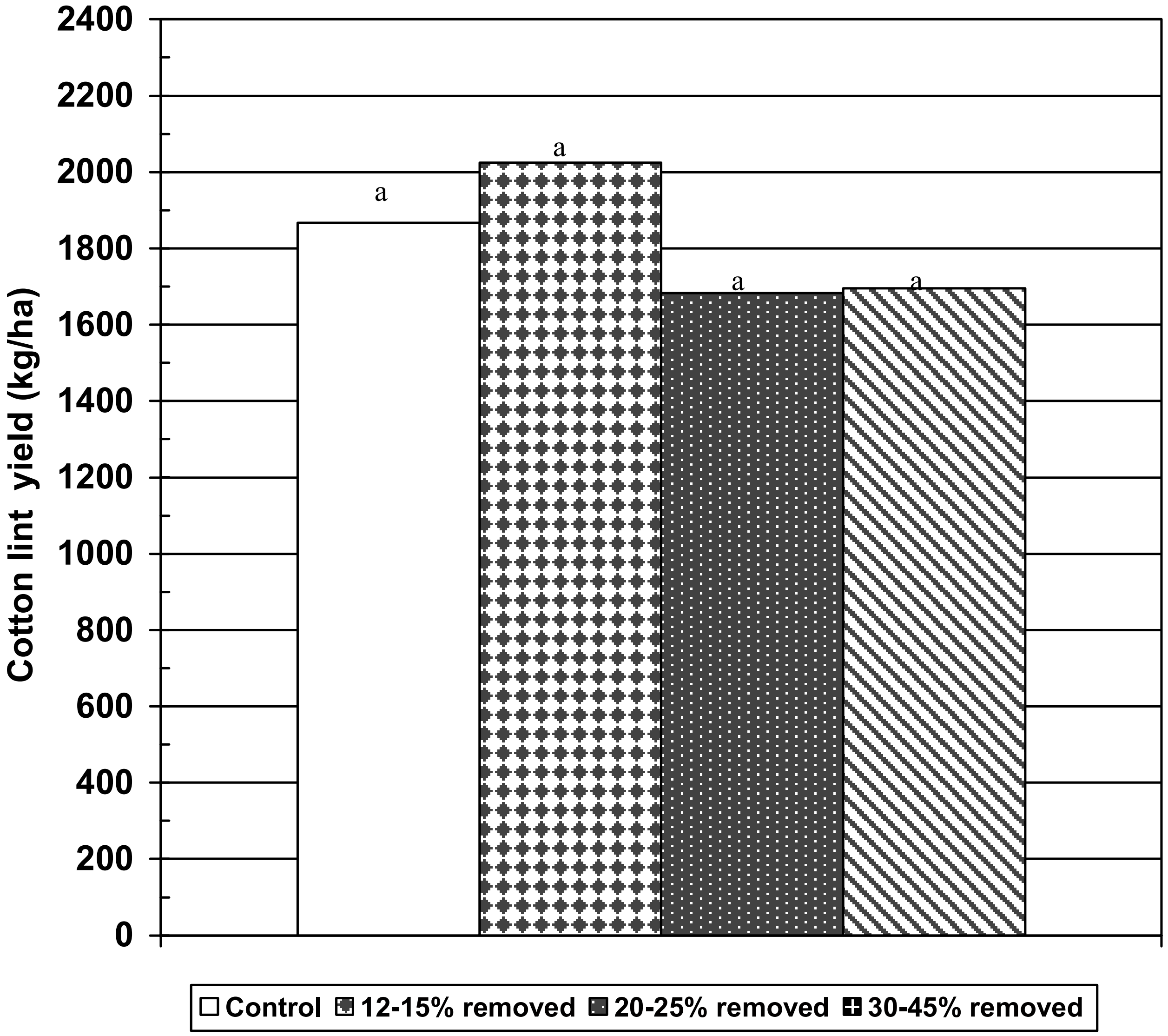

Fig. 35. The effect of square removal treatments on cotton lint yield for DP5111 second planting date at the **Blackstone** location. Means for bars followed by the same letter are not significantly different P = 0.05 (DMRT).

Discussion

DPL 51, a later maturing cultivar, yielded highest and seemed to tolerate the square removal stress most easily, although both cultivars performed well when planted early. The lowest yielding experiment was the DPL 5111 cultivar at the second planting date. The combination of a early-maturing cultivar and the late planting date appears to disadvantage the cotton so that compensation is not at an optimum level.

Only data from DPL 51, first planting date in Suffolk, can be compared to data from 1998. There were no significant differences in treatments in either year in either boll numbers or lint yield, averaged across positions. This strongly indicates that any level of early-season square removal under 40% caused little or no damage to the crop and resulted in no net losses in yield. However, for cotton producers, lint yield is the most important factor, and averaged over cultivars, planting dates, and fruiting positions in 1999, cotton lint yield was significantly lowered at the 30-40% square removal rate. Even when the difference was not statistically significant, the 30-40% square removal treatment was, in most cases, the lowest yielding in both years, often by as much as 448 kg/ha. These data are supported by crop monitoring data generated by the COTMAN program, which showed that the influence of square removal in excess of 30-40% resulted in lower apogee and premature cutout. According to both yield and COTMAN data, it also appeared that some level of square removal actually stimulated growth, and this overcompensation increases yields (Kerby and Buxton, 1981). This may suggest that the ideal level of square removal for optimal compensation is slightly less than 30%. This has meaningful implications for cotton producers. This research indicates that early-season square loss up to 30% may not be as important as was previously thought. Cotton is a very resilient plant and should recover from some early-season square removal with little or no yield loss, and in some cases, square removal many even contribute to higher yields (Kerby and Buxton, 1981; Phelps et al., 1998).

It was previously thought that the primary means for compensation by the cotton plant was either an increase in second position boll numbers or an increase in their weight. However, it is interesting to note that in 1999 neither was the case. Second position boll numbers did not increase with removal of first position squares, nor did their boll weight increase proportionally. Generally lint yields were not significantly lowered by the square removal treatments, indicating that compensation in some other form was occurring.

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Chapter V

Interpretive Summary

The major cause of pre-flowering square loss is by insect damage, and during extreme infestations insects can contribute up to ninety percent of square loss that occurs prior to early flower. Therefore, control of insects as early-season pests is important, and insecticides are the major control technique used in cotton. However, insecticide treatments are unfavorable to producers due to their high cost, toxicity to the applicator, potential for environmental contamination and phytotoxicity to the crop. The purpose of these experiments was to ascertain and quantify the level of plant compensation to early-season square loss in Virginia, and to establish a break-even square loss level, at which point plant compensation would equal square loss. The results of this study suggest that cotton plants will compensate for up to 30% of first position square loss, with no reduction in yields. In the case of square loss due to insect damage, it can be assumed that producers now know at which point to initiate insecticide treatments, knowing that square loss above 30% may negatively affect yields. Based on these results, it is likely that producers might be able to reduce the number of early-season insecticide applications, therefore saving time, money and labor.

Thirty percent was considerably higher that the 19% square loss rate that is widely accepted in the Cotton Belt (Holman, 1996). The higher number in Virginia may be due to differences in geographical regions and in experimental methods. Nineteen percent is based on an experiment that released live insects to feed on the cotton plants (Holman, 1996), as opposed to manually removing the squares.

There were no significant differences in square removal treatments in 1998 and 1999 for DPL 51 first planting date in Suffolk in either boll numbers or lint yield, averaged across positions. This strongly indicates that any level of early-season square removal under 40% causes little or no damage to the crop and results in no net losses in yield. However, from the crop monitoring data generated by the COTMAN program, it was found that square removal at the highest rate (30-40%) resulted in a lower apogee and premature cutout. Averaged over planting dates, cultivars, and fruiting positions in 1999, lint yield was significantly lower at the 30-40% square removal rate. Also, even when not statistically significant, the 30-40% square removal treatment, was, in most cases in 1998 and 1999, the lowest yielding, often by as much as 448 kg/ha. The two lower levels of square removal treatments, 12-15% and 20-25%, often showed an increase in yield over that of the control. These treatments actually seemed to stimulate growth. Taking both of these trends into consideration, it is suggested that the optimal level of early-season square removal lies with some number just under 30% loss of first position squares.

Cultivar and timing of planting did make a difference in plant compensation to square loss. DPL 51, a late-maturing cultivar, yielded higher than DPL 5111 and appeared to adjust to excessive square removal better, due probably to the fact that this cultivar allowed a longer compensation period compared with the earlier maturing cultivar. The lowest yield was from DPL 5111 at the second planting date. The combination of an early-maturing cultivar and the late planting date appears not to allow an optimum level of compensation. However, the performances of both cultivars were similar when planted at the earliest possible date.

It was initially hypothesized that the primary means for compensation by the cotton plant was either an increase in second position boll numbers or an increase in their weight. However, it is interesting to note that in 1999 that was not the case. Second position boll numbers did not increase with removal of first position squares, nor did their boll weight increase proportionally. Generally lint yields were not significantly lowered by the square removal treatments, indicating that compensation of another type was occurring.

Glossary

Cutout – final stage of cotton plant growth prior to boll opening. Characterized by predominance of mature fruit, absence of squares and blooms, and cessation of new terminal growth. Generally begins to occur at five nodes above white bloom.

Degree Day 60's (DD's) – best description of relationship between cotton development and temperature as defined by:

[(° F Max + ° F Min Temp)/2] - 60 = DD-60 calculation for each day

Monopodium (Vegetative branch) – lateral branch that does not have any fruit at each node; however, vegetative branches can develop fruiting branches under low plant populations.

Matchhead square – early stage of growth when the flower bud (square) is approximately the size of a large kitchen matchhead.

Node Above White Flower (NAWF) – number of mainstem nodes from the last developed first-position white flower to the plant terminal.

Node Above First Square (NAFS) - number of mainstem nodes from the first developed first-position square to the plant terminal

Pinhead square (PHS) – squares just visible to the naked eye

Square – the flower bud of a cotton plant. Surrounded by three to four bracts, the square contains the central corolla with the pollen anthers and sepals.

Sympodium – lateral branch with a fruit position at each node

Vita

Virginia Leigh Pitman

The author was born on January 29, 1976 in Richmond, Virginia. She is the daughter of Robert M. and Helen M. Pitman, has a brother Robert K. Pitman, and grew up in Lancaster County, Virginia. She attended Mary Baldwin College from August of 1992 until May of 1994, at which time she transferred to Virginia Polytechnic Institute and State University. Upon completion of a B.S. in Environmental Science (Aquatics Option) in December of 1997, she entered the masters program in Crop and Soil Environmental Science under the guidance of Dr. A. Ozzie Abaye. While attending graduate school, Ginny was also a member of Omicron Delta Kappa Honor Society, President of the Environmental Coalition of Virginia Tech, Vice President of the CSES Graduate Student Organization, Assistant Coach of the Virginia Tech Crops Judging Team, and a Teaching Assistant in the CSES department. During summers between college semesters, Ginny worked for Zeneca Ag Products as a Technical Sales Associate. Since April of 2000, she has been employed as the Agriculture and Natural Resources Extension Agent for Lancaster and Northumberland Counties, Virginia. In September of 2000, she married Brian Barnes and they reside in Northumberland County.