2011

NOZZLE TYPE AND ARRANGEMENT ALTERNATIVES FOR IMPROVED APPLICATION OF SUCKERCIDES IN BURLEY TOBACCO (*Nicotiana tabacum* L.)

Beau Robert Neal
University of Kentucky, beau.neal@uky.edu

ABSTRACT OF THESIS

NOZZLE TYPE AND ARRANGEMENT ALTERNATIVES FOR IMPROVED APPLICATION OF SUCKERCIDES IN BURLEY TOBACCO (*Nicotiana tabacum* L.)

Maleic hydrazide (MH) applications have been standard practice for sucker control in burley tobacco (*Nicotiana tabacum* L.) production for the last half-century because it is relatively inexpensive, effective and easy to apply. Non-MH suckercides such as fatty alcohols and local systemics can be utilized to reduce or replace MH and lower undesirable residues in the cured leaf. The objective of this study was to evaluate various nozzle types and arrangements for efficiency to determine if sucker control with fatty alcohol could be consistently improved over the currently used TG3-5-3 arrangement, as well as examine sprayer positioning (center vs. off-center) and leaf orientation variables using artificial plants. In the field study, the TG4-6-4 arrangement performed the best ($p<0.05$) when applying the same volume per hectare providing 80% sucker control with fatty alcohol only, not significantly different ($p>0.05$) than MH+Butralin treatment. For the artificial plant study, the TG4-6-4 provided more solution collected ($p<0.05$) at leaf axils as well as the highest percent of solution intercepted. Sprayer position and leaf orientation had less effect on solution intercepted with this arrangement than it did with the TG3-5-3. Results from this study support a recommendation of the TG4-6-4 over the TG3-5-3 for the application of contact chemicals for sucker control in burley tobacco.

KEYWORDS: Burley Tobacco, Sucker Control, Maleic Hydrazide, Fatty Alcohol, Nozzle Arrangement

Beau Robert Neal

17 June, 2011

NOZZLE TYPE AND ARRANGEMENT ALTERNATIVES FOR IMPROVED APPLICATION OF SUCKERCIDES IN BURLEY TOBACCO

By

Beau Robert Neal

Robert Pearce
Director of Thesis

Charles Dougherty
Director of Graduate Studies

17 June, 2011

RULES FOR THE USE OF THESES

Unpublished theses submitted for the Master's degree and deposited in the University of Kentucky Library are as a rule open for inspection, but are to be used only with due regard to the rights of the authors. Bibliographical references may be noted, but quotations or summaries of parts may be published only with the permission of the author, and with the usual scholarly acknowledgements.

Extensive copying or publication of the thesis in whole or in part also requires the consent of the Dean of the Graduate School of the University of Kentucky.

A library that borrows this thesis for use by its patrons is expected to secure the signature of each user.

<u>Name</u> <u>Date</u>

THESIS

Beau Robert Neal

The Graduate School

University of Kentucky

2011

NOZZLE TYPE AND ARRANGEMENT ALTERNATIVES FOR IMPROVED APPLICATION OF SUCKERCIDES IN BURLEY TOBACCO

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Agriculture at the University of Kentucky

By

Beau Robert Neal

Lexington, KY

Director: Dr. Bob Pearce, Associate Professor of Agronomy

Lexington, Kentucky

2011

Acknowledgements

I would like to begin by extending much gratitude and thanks to the chairman of my committee, Dr. Bob Pearce, for giving me the opportunity to work with him while pursuing my M.S. degree. Dr. Pearce graciously welcomed me to his staff and was more than helpful throughout my stay. He has taught me much in the area of tobacco research and I could not have finished this thesis without him. I also owe great appreciation to committee members Dr. Andy Bailey, Dr. William Witt, and Dr. John Wilhoit for serving on my committee.

A most helpful person in completing this project was staff member Jack Zeleznik. Jack offered thorough insight and knowledge for the duration of my time here. His experience was vital in conducting a thorough and accurate experiment. Keith Johnson must also be recognized for his valued support and willingness to help with any tasks involved with this study. Keith never hesitated to assist, no matter what the job entailed. I would also like to thank my fellow office-mates: Kenneth Cropper, Michael Deaton, Daniela Sarti, and Ana Balut. They provided academic assistance, moral support, and made my office hours very enjoyable. Special thanks go to Kenneth Cropper and Michael Deaton for assisting me with questions and problems along the way, as well as eating lunch with me on a regular basis.

In appreciation for funding this project, I would like to thank Philip Morris International Management LLC and the Burley Tobacco Growers Cooperative Association. Also, my sincerest thanks to the University of Kentucky Department of Plant and Soil Sciences as well as the Jeffrey family for their funding during my two year stay.

Last and certainly not least, I thank my family for supporting me throughout my ventures thus far. Most importantly, I thank the Good Lord for blessing me with all I have been given and all that he has allowed me to accomplish.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Literature Review

Introduction

Burley tobacco (*Nicotiana tabacum* L.) is a centuries old crop indigenous to North America and a member of the *Solanaceae* family. Burley (type 31) is an air cured type of tobacco used primarily for cigarette production. A crop widely grown in the southeastern United States due to its high value per acre and the region's favorable climate, burley has played a vital role in the economies of states such as Kentucky, Tennessee and North Carolina for many years. National Agricultural Statistics Service (NASS) reports show total (all types) tobacco production in the United States for 2007 was 353,177,905 kg with a harvested area of 144,068 hectares (USDA-NASS 2010). Kentucky production totaled 86,436,562 kg on 36,098 hectares, with burley accounting for 69,853,225 kg on 31,160 hectares. Kentucky is the leading producer of type 31 and the second leading producer for all tobacco in the United States.

In spite of much disparagement and criticism in recent years in regard to consumer health as it relates to smoking, burley tobacco continues to play an important role in both the economy and culture of Kentucky. Some might say burley production is a way of life, a family tradition, or just a reliable source of income for a farmer to help pay the bills in an ever-changing farm economy. Burley remains one of the largest cash crops for Kentucky, and for this reason is still a favorable crop for many producers. Its net return per hectare, averaging roughly $280 in 2008, is comparable to other high value crops such as alfalfa (Conrad 2009). Burley tobacco production has made its mark on Kentucky and still affects the lives of many people living in the Commonwealth state.

As long as there is domestic and/or international demand and potential profit for burley tobacco, interest will remain in producing the crop. If producers are going to continue growing burley crops, production practices must be environmentally and economically sustainable. Changes in production practices may be necessary to reduce the potential harm to consumers of tobacco products, and to comply with potential new regulations for tobacco products.

Sucker Formation and Topping

Like many crop plants, tobacco produces a flower and has a terminal meristem that suppresses growth of axillary shoots through hormonal activity (Taylor 2003). Producers remove the inflorescence (apical meristem) of tobacco plants, in a process commonly referred to as topping, to direct the plant's energy toward leaf production and increase yield and leaf quality in turn improving grower profits (Seltmann 1970; Garvin 1980; Steffens and Seltmann 1982; Clapp and Seltmann 1983; Meyer et al. 1987; Gorman et al. 1989). Topping is a necessary process for producing leaves with desired physical properties and chemical composition (Tso et al. 1965). Early topping and removal of suckers results in an increased leaf weight of those leaves which are retained, as well as improved quality (Steinberg 1950; Fisher and Priest 2007). Fisher and Priest (2007) state that in addition to improved yield and quality, topping has other advantages which include (1) reducing the possibility of plants blowing over in a windstorm, (2) stimulating root development which increases fertilizer efficiency, drought tolerance, and alkaloid production, and (3) helping to reduce buildup of certain insects because eggs and larvae are removed with the floral parts.

Upon topping, the source of apical dominance is removed and axillary buds (known as suckers) develop and can grow quite profusely (Decker and Seltmann 1971). This undesirable growth of suckers occurs in leaf axillary areas (leaf/stalk intercepts). Their vigorous growth, often rivaling that of tobacco leaves, can severely reduce yield and quality if not properly controlled (Bakht et al. 2007; Bailey et al. 2009). Not only do suckers redirect photosynthate away from the leaves, they also may harbor insect pests and disease organisms, further decreasing the yield of the crop (Bakht et al. 2007). Topping is a beneficial practice in tobacco production, but is of little benefit if suckers cannot be controlled and/or removed. Subsequent growth of meristems in leaf axils must be eliminated manually or chemically in order to achieve yield and quality goals (Atkinson and Sims. 1971; Link et al. 1982; Mosley 1959; Seltmann and Nichols 1984).

Preceding the introduction of chemical methods for sucker control, producers had no choice but to remove suckers by hand; this practice was very labor intensive and if not done often and adequately, yield and quality would suffer. This spurred research in the development of sucker control chemicals to allow an economical way in which tobacco could be raised with minimal sucker pressure. It is no surprise these chemical methods were rapidly and eagerly accepted by tobacco farmers upon their development. Optimum harvest of burley tobacco (all upper leaves showing distinct yellow color) usually comes between three and five weeks after topping of the crop depending on the variety and environmental conditions (Bailey et al. 2009). Sucker growth accumulates quickly after topping until harvest and therefore chemical control should begin at or near topping of the crop.

Chemical Sucker Control

Three types of sucker control chemicals are available to producers: contacts, local systemics and systemics. Contacts physically burn suckers, but must come into contact with them at the leaf axils to be effective because they are not absorbed by the plant nor are they translocated. Suckers longer than one inch should be removed prior to application. The active ingredient of contact sucker sprays is long chain fatty alcohols in emulsion form, which upon contact kills actively growing suckers. These chemicals can either be applied when the first apical bud appears or later after topping (Wheeler et al. 1991). In ideal situations, contacts run down the entire stalk, rapidly penetrating young sucker tissue at every leaf axil. This is followed by browning of the sucker tissue and then complete desiccation (control) of the sucker. The means by which sucker desiccation occurs from fatty alcohols can be attributed to the breakdown of the plasma membrane as well as the inhibition of meristematic tissue growth because of the selective penetration of fatty alcohol agents into the areas of actively dividing cells (Steffens et al. 1967; Wheeler et al. 1991). Previous research has shown some injury is possible on younger, less mature leaves if spray emulsions accumulate on those leaf surfaces or edges (Aycock and McKee 1975; Mylonas and Pangos 1978).

Similar to contacts sprays, local systemic chemicals must also come into contact with the leaf axils, but are absorbed at that location and inhibit cell division, hence retarding sucker growth. Local systemics belong to a class of chemicals called dinitroanilines and contain one of two active ingredients, butralin or flumetralin. Both contacts and local systemics have similar recommendations for use and application should be aimed towards stalk run-down and the leaf axil. Just as with fatty alcohols, suckers longer than one inch should be removed by hand prior to application. While local systemics do not burn suckers like fatty alcohol, growth at the axillary areas is stopped for several weeks after application.

Systemics are absorbed by the leaves and translocated to the leaf axils where they inhibit cell division; these do not have to physically contact the suckers. The only true systemic plant growth regulator used for sucker control in tobacco is maleic hydrazide (MH, 1,2-dihydro-3,6-pyridazinedione) (Bailey et al. 2009). MH has been the most effective and most extensively used plant growth regulator by growers of burley tobacco in the United States to arrest axillary bud growth following topping (Clapp and Seltmann 1983; Cui et al. 1995). Of all MH used in the U.S., most (86-88%) is used on tobacco followed by potatoes (11-12%) (EPA 1994). Although it was first synthesized in 1895, its ability to regulate plant growth was not discovered until 1949 and it was first registered in 1952 as a plant growth regulator (Peterson 1952). What makes MH a true systemic is that it is translocated throughout the plant to meristematic tissue (Fisher and Priest 2007). Upon application of MH on tobacco, cell division (mitosis) is inhibited/disrupted without affecting cell elongation; this prevents any subsequent growth of newly developing suckers without retarding the growth of more mature leaves (Hawks and Collins 1983; Darlington and McLeish 1951; Hoffman and Parups 1964; Nooden 1972). Much like contacts and local systemics, MH will not control large suckers which must be removed by hand. MH provides more reliable sucker control than other chemicals and MH applications are usually included (in some form) in the most effective sucker control programs (Fisher and Priest 2007; Bailey et al. 2009). The majority of tobacco grown in the United States today is treated with MH (Meyer et al. 1987). Some producers (mostly flue-cured) use what is called a sequential method which employs the use of fatty alcohol contacts just prior to or following topping, followed by MH application (Link et al. 1982). Research has shown using this method can allow producers to possibly achieve greater sucker control, yield, value, and net price than with MH alone (Collins et al. 1970).

A major issue dating back to the 1950s in the tobacco industry has been the amount of MH residues present in and on the cured leaf. Although studies have shown lower MH levels in burley tobacco than in flue-cured, residues are still of concern to tobacco product manufacturers and often exceed 50 ppm (Hunt et al. 1977; Sheets and Seltmann 1982; Sheets et al. 1994 a; Sheets and Nelson 1989). Shortly after MH came onto the market in the late 1950s, manufacturers became concerned about the effects of MH on tobacco quality (Coulson 1959; Mosely 1959). Interest since that time has only grown because of its almost ubiquitous presence in tobacco and tobacco products (Haeberer et al. 1978; Meyer et al. 1987). Referring to MH, Steingberg (1950) wrote "obviously, it would be of the greatest importance to make certain that no harmful effects would follow such use of a chemical in commercial practice before recommending it for the purpose of controlling suckers in tobacco." The Environmental Protection Agency (EPA) requires that all pesticides sold or distributed in the United States must be registered by the EPA, based on scientific studies showing that they can be used without posing unreasonable risks to people or the environment (EPA 1994). Despite the fact that there is no compelling evidence of harm caused by MH residues, several countries in the European Union such as Germany maintain an MH residue tolerance of less than 80 ppm on manufactured tobacco products at testing. Many other foreign cigarette manufacturers have proposed that a maximum level of MH residue in tobacco products be set forth (Link et al. 1982; Wittekindt 1978). The United States has no written tolerance levels on MH residues. However, a threshold level of 80 ppm has generally been the standard for tobacco produced here for either export or domestic use.

In a three year study (McKee 1995) with Maryland (type 32) air-cured tobacco, major emphasis was placed on the detection of MH residues and possible adverse effects to cured leaves. In order to simulate farmer application procedures, all treatments were applied using a high clearance sprayer and three nozzles per row. Treatments included 1) 2.5 kg MH ha^{-1} (labeled rate), 2) 5.0 kg MH ha^{-1}, 3) two applications of 2.5 kg MH ha^{-1} one week apart (total 5.0 kg/ha^{-1}), 4) 2.5% flumetralin solution, 5) tank mix of 1.7 kg MH ha^{-1} and 1.25% flumetralin, and 6) no chemical control. McKee found that for all chemical treatments, sucker control and yields were increased compared to no chemical treatment. Although sucker control was satisfactory with all chemical treatments, the labeled rate of MH produced tobacco with the highest quality index and greatest value. What is most noteworthy in this study is that MH residues were higher with increased rates of application. Residues were decreased with both the reduced rates of MH and the flumetralin tank mixes. The lowest yearly levels of MH residues in Maryland were recorded in 1992 when a total of 6.7 cm of rain fell starting nine days after application. Conversely, 1993 had the highest residue levels with only two days of rain occurring 15 days after chemical application. In conclusion, McKee found there was no benefit from using increased rates of MH on Maryland type tobacco and that residues were only increased by doing so.

Seltmann and Sheets (1987) examined residues of MH after simulated rainfall. Treatments were applied using a high clearance sprayer with three solid-cone nozzles arranged horizontally across the row and sprayed 30 cm above plants. The center nozzle was directed downward over the row with the outer two nozzles spaced 56 cm apart directed 45° toward the center. They found that MH was still being absorbed beyond 24 hours after its application but that rainfall had a significant effect on decreasing residues if it occurred within that 24 hour period. A 12 hour rain-free period was also found to be necessary after MH application in order for adequate sucker control without a reapplication. No significant main effects were found in relation to yield of the cured leaf, quality as measured by dollars per kilogram, quality index, or value per hectare.

Variation of MH residues on flue-cured tobacco was looked at by Sheets and Nelson (1989). Using the labeled rate (2.5 kg MH ha^{-1}) with conditions, cultural practices, and curing and handling procedures similar to commercial growers, they wanted to determine the residue expected after application. What they found was that for all years (1980-1984), locations, and harvests, the percentage of samples with residues in excess of 80 ppm was 36. A higher percentage (47%) of upper stalk tobacco than middle and bottom stalk tobacco contained MH in excess of 80 ppm at harvest. In a similar study Sheets et al. (1994 b) examined comparisons of residues at two locations (Clayton, NC and Reidsville, NC) when using MH, flumetralin, and butralin when these growth regulators were applied alone or when the dinitroanaline compounds were applied as a tank mix with MH. Although significantly different between the two locations, MH residues were relatively the same within each location for all the treatments. Residues on treatments at Clayton that received 1.26 kg MH ha^{-1} (half recommended rate) averaged

67 and 56 ppm; the same treatments at Reidsville exhibited 27 and 30 ppm. Plots receiving the full rate of MH (2.52 kg/ha^{-1}), including the tank mixes, averaged 126 ppm at Clayton and 62 ppm at Reidsville.

Palmer (1997) found tank mixes like those included in Sheets' and Nelson's (1989) study can provide excellent sucker control while reducing residues of MH. Combinations of MH (75% of standard rate) mixed with a local systemic (Butralin or Flumetralin) performed equal to or better than other treatments with a standard rate of MH alone. He concluded they not only offer better sucker control, but increase length of control and improve rain safety as well.

Cui et al. (1995) studied the changes in MH residues and major chemical components in leaves of burley tobacco after different MH application rates and methods were used. They found MH residues increased with the increased amount of application. When the recommended rate (170 mg MH plant^{-1}) was applied, MH residues of the top leaves decreased with time after application and best fit the model (R=0.99**)

$$\text{MH residue} = 502 \times \text{Day}^{-0.84}$$

where Day = days after MH application, and MH is in µg g^{-1}. For every day after application of MH, residues decreased by 502 µg g^{-1}. Treatments with a split application of MH and with reduced volume of water (increased MH concentration) had higher residue levels than the recommended single application. These high residue levels were explained by the second application being seven days closer to harvest time than the single application. Ultimately, they found from 12 treatments that MH application had no significant effect on dry matter accumulation of air-cured burley tobacco, nor was chemical composition significantly altered with a reduced rate compared to the recommended rate of MH. Although insignificant, they found that values for leaf dry weight and moisture content tended to be slightly higher, and stalk dry weight lower, for MH-treated tobacco compared to hand-suckered tobacco.

Although studies may not agree on MH residues and their effects on tobacco quality, what *can* be agreed upon is that tobacco companies are looking now more than ever for tobacco with reduced MH residue levels. In fact, some markets are now offering premiums for MH-free grown tobacco. In order to stay competitive in a global market, American tobacco producers are looking at alternative options for sucker control in hopes of reducing or eliminating their use of MH.

Many researchers (Bailey et al. 2010; Fisher and Priest 2007; Seltmann 1994; Rosa and Caughill 1991) suggest the most logical alternative would be the use of fatty alcohol contacts for sucker control. The environmental/health advantage to this type of chemical is that they leave minimal residues and are similar to naturally occurring plant constituents of tobacco (Rosa and Caughill 1991). The downfall, however, is that they have shown to be less reliable than systemics when applied with multi-row equipment, often missing suckers within the top three or four leaf axils.

Palmer et al. (2008) found all MH-free treatments to be unacceptable in a study conducted at the University of Kentucky Spindletop research farm. The experiment involved applying various sucker control chemicals mechanically to evaluate sucker control. Prime+, Butralin, Flupro, and fatty alcohol were applied with both a straight boom arrangement (alternating TG3 and TG5) and a three nozzle arrangement (TG5 center, TG3s directed towards row). In a related study to compare control with MH versus local systemics and contacts, similar results were found. Palmer et al. (2008)

found that MH provided significantly better sucker control than treatments without it, although no significant yield differences were found. Nozzle type and configuration had no significant effect on sucker control in these experiments. In a similar study, acceptable sucker control was achieved with treatments using fatty alcohol (4%) followed by a tank mix or sequential treatments using fatty alcohol plus Butralin or Flupro. The 4% solution of fatty alcohol used in this study performed better than a 3% solution (Palmer et al. 2008).

Seltmann (1994) conducted his study evaluating the effectiveness of contact suckercides because of a renewed interest in contacts due to MH residues. The author realized the 3/8 phyllotaxy of the tobacco plant may influence how suckercide would flow down the stalk. He also realized leaves would act as a natural funnel, catching the spray and directing it down the stalk and to the leaf axils to wet the suckers. Seltmann (1994) tested a roll-out diagram (model) of the 3/8 phyllotaxy on field grown plants using 1, 2, and 3 mL of a 4% fatty alcohol solution applied to the 1^{st}, 2^{nd}, and 3^{rd} leaf axils, in all possible combinations. It was found suckercides do in fact flow down the stalk according to the 3/8 phyllotaxy. If suckercide were only applied to the 1^{st} axil, then the 3^{rd} axil was missed; if applied only to the 2^{nd} axil, then the 1^{st} and 4^{th} axils were missed; if applied only to the 3^{rd} axil, then the 1^{st}, 2^{nd}, and 4^{th} axils were missed. The greatest control came when all three of the top leaf axils received suckercide. Control was increased with increased amounts applied as well. Results showed if contacts were to be used for controlling suckers effectively, 1-3 mL (preferably 3) of contact solution must be applied to each of the upper three leaf axils.

Rosa and Caughill (1991) evaluated the performance of fatty alcohol sucker control chemicals on flue-cured tobacco, including agronomic and chemical quality. Materials for all treatments were applied as a course spray in a tank mix with a total of 450 L ha^{-1} of solution, directed towards the top third of the plant. Treatments consisted of formulations of n-decanol in either single or dual applications. Parameters determined in relation to this study include leaf dimensions, sucker number and weights, and yield. Results of the main plot effect showed dual applications of the contacts provided significantly higher yields in two of the four years in which the study was conducted. For all years, the average yield increase was 3.6% (100 kg ha^{-1}) for the dual treatments. Dual application of the contact materials also resulted in significantly reduced number and fresh weight of suckers. Good sucker control was evident throughout the harvesting season when applications were made at both the bud elongation stage and approximately one week later. Leaf area of the top three leaves was not affected by the dual application treatments or the different n-decanol materials used.

Link et al. (1982) found similar results in determining sucker growth effects on yield. The treatments used in their study were 1) topped and not suckered, 2) hand suckered, 3) fatty alcohol 4% solution once after topping, 4) MH just after topping, 5) fatty alcohol applied twice at seven days apart, 6) fatty alcohol + MH, and two chemical free treatments. Results of three treatments (4, 5, and 6) showed 95% or higher sucker control and all three were significantly greater than other treatments. Only one of these three (5) did not include MH and was acceptable in terms of both yield and sucker control, that being the dual application of fatty alcohol. Although it requires added time and expense for dual application to achieve desirable results, the researchers feel it could substitute with little or no loss in yield or sucker control if MH were not available. They felt upon conclusion some form of chemical sucker control is vital in achieving acceptable yields without significantly increasing required labor time for sucker control.

Chemical Application Variables

In order to accomplish adequate sucker control with contact chemicals (fatty alcohol), application must be precise in regard to stalk run-down and axil bud contact. Producers/applicators must also keep in mind that fatty alcohols have no residual action within the plants which is why single applications are not very effective (considering a period of 3-4 weeks from topping to harvest). In comparison to MH, there almost always tends to be more escapes of suckers with the use of fatty alcohol simply because so many factors come into play during application. Stalks must be vertical and straight to accomplish a high degree of sucker control (Seltmann 1994). Leaf orientation and angle has much to do with chemical interception as well. Generally, during this stage of development, plant leaf angles tend to be more acute on the top three or four leaves. This “steep” angle allows the chemical to be captured and funneled down to the stalk rapidly, increasing run-down to lower leaf axils. Seltmann (1994) explained that with the top of the plant removed, the uppermost leaf/leaves can tend to fold over and block the stalk from spray, decreasing control. This can be an increased problem if windy conditions are at hand during application. Wind can also completely divert the spray pattern from the row, decreasing sucker control. Also, drought-stressed plants will usually show the top leaves essentially cupped together in more of an upright position, decreasing the ability of the chemical to contact the top of the stalk and top leaf axils. Often times, surface area of upper leaves is minimal, further decreasing interception. One circumstance which can be very devastating and uncontrollable is crooked plants. If a windstorm or mechanical damage causes plants to be crooked, sucker control can become quite difficult when dealing with not only contact suckercides, but MH in some cases. When you consider all of these factors, it is easy to understand why the shift towards MH-free tobacco production has been slow to catch on.

As mentioned, leaf area can have tremendous impact on interception of sucker control materials. It has also been questioned whether or not different sucker control chemicals can affect leaf area expansion. In the past, many farmers thought that making a second application of MH one to two weeks after the first would increase leaf area/weight and possibly speed up the ripening process. One can see why dual MH applications would especially be of concern today with much scrutiny regarding MH residues. Crafts-Brandner et al. (1994) found for burley tobacco, air-cured leaf yield was increased only slightly for MH treated plants compared to the hand suckered controls. Their application treatments consisted of MH amounts from 1.68 to 13.44 kg ha^{-1}, and treatments within this range had no influence on yield. In regard to the comparison of MH treated and hand suckered controls, a large portion (30-50%) of the cured yield increase was due to increased moisture content of the leaves which had been treated with MH. Just as in studies previously mentioned, they found the increased rates of MH only led to increased undesirable residue levels. Other researchers agree, and have found either MH or alternative chemical methods lead to at least some yield increase due to sucker suppression (Davis et al. 1974; Seltmann and Nichols 1984).

The means by which applications are made has a tremendous effect on sucker control performance. These methods can include using large power spraying equipment, drop lines, or hand spraying. The least laborious of these methods is the use of power equipment spraying over the top of the tobacco. In most large acreage burley operations, this is going to be the primary mode of application due to the fact that one person can cover many acres in a day (Bailey et al. 2010). When using high clearance spraying equipment to cover multiple rows in one pass, increased volumes of solution must be applied in order to achieve coverage for adequate sucker control. Extension specialists recommend a minimum of 468 L ha^{-1} with spraying pressure between 138-206 kpa (Bailey et al. 2010; Fisher and Priest 2007). Nozzle configurations can vary, but in recent years, many producers have been employing an arrangement in which the spray is directed more toward the tobacco row as opposed to a broadcast application. If contact suckercide use is to increase, this method must be utilized in order to concentrate more solution on the plant and attain coverage at every leaf axil. This directed arrangement is where problems can occur with crooked/leaning plants as mentioned earlier. If row spacing is inconsistent or the nozzle spacing is not in accordance with the rows, coverage can decrease greatly and control will be reduced.

Once the arrangement is decided upon, correct nozzles must be selected. Nozzles producing a coarse spray pattern with high outputs of solution are preferred, whether it be systemic or contact application. Palmer (1997) found a course spray (MH) outperformed a fine spray in terms of sucker control and yield. Most commonly used in recent years has been *TeeJet* (TeeJet Spraying Systems Co.) TG full cone spray tips. TG3, TG4, TG5, and TG6 are often arranged with one nozzle over the center of the row, and one adjacent on each side (Ex: TG5 center, TG3 on each side approximately 30 cm from center directed inwards toward row).

Objectives

There have been numerous studies examining sucker control and the variables involved including MH residue variations, chemical control, hand control, application methods, yield differences, and leaf area parameters. In order to minimize the use of MH and its undesirable residues in burley tobacco, contact suckercides and other non-MH suckercides must be utilized for sucker control. Application must be precise in order to achieve maximum sucker control. Also, with MH being relatively inexpensive, effective, and easy to apply, the transition to fatty alcohols may not be so smooth for producers. However, if premium prices are offered in the marketplace for MH-free tobacco, there will be a financial incentive to implement MH-free sucker control programs.

The objectives of this study were to: 1) Evaluate different combinations and arrangements of nozzles to determine if sucker control with contact suckercides could be consistently improved over the conventional TG3-TG5-TG3 arrangement. 2) Measure the leaf interception of spray solution with different nozzle combinations and calculate the percent interception to choose the most efficient nozzle arrangement(s) for achieving stalk rundown. 3) Measure the effect of leaf orientation and nozzle arrangement position with respect to the row on spray solution interception.

Chapter 2: Field Studies

Materials and Methods

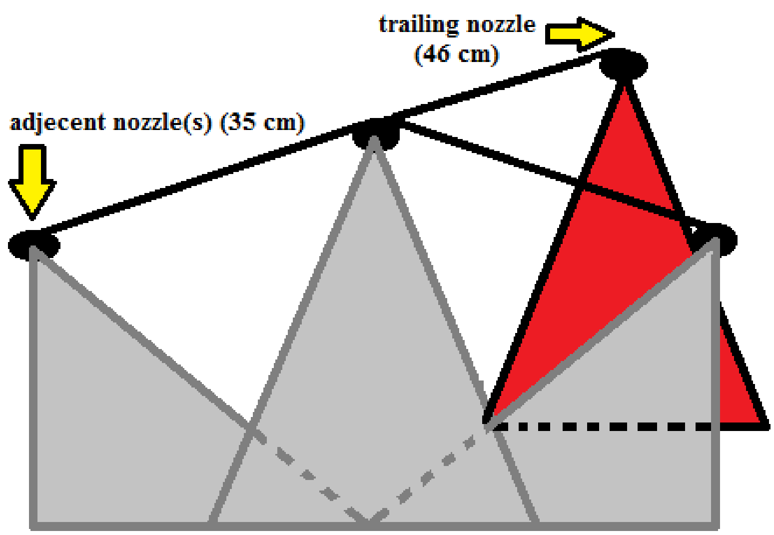
Research was conducted in 2009 and 2010 at the Kentucky Agricultural Experiment Station Spindletop Farm (38° 01' N, 84° 35' W) in order to determine if sucker control would be affected by using various nozzle types and arrangements different than the typical TG3-5-3 arrangement.

Soil type was a Maury silt loam (Fine, mixed, active, mesic Typic Paleudalfs) for both years. Experiments in both years received a herbicide application of sulfentrazone (Spartan4F, 0.7 L ha^{-1}) and clomazone (Command, 2.3 L ha^{-1}) prior to transplanting. Burley type 31 air-cured tobacco was planted for both years; cultivar KT206LC was transplanted on July 7^{th}, 2009 and KT209LC on June 8^{th}, 2010. Imidacloprid (AdmirePro, 0.6 L ha^{-1}) and acephate (Orthene97, 0.84 kg ha^{-1}) were added to the water at transplanting for both years as well. Each plot was two rows wide for both years with 107 centimeter row spacing and 51 centimeter plant spacing (planting approximately 18,525 plants per hectare). Production practices recommended by the University of Kentucky were followed except for sucker control treatments applied for both years (Bailey et al. 2010). Weather and rainfall data for both years from transplant to harvest are given (Table 2.1, Table 2.2, Table 2.3, and Table 2.4). Note that 2009 production season temperatures were slightly below average with above average (+12.4 cm) precipitation (Table 2.1). 2010 proved to be a dry season (-3.9 cm below average) with above average temperatures; this combination put the crop under stress and made sucker control slightly difficult, especially in the months of September and October (Table 2.2). When the crop was about knee high (July 19^{th}) in 2010, a severe storm containing high winds slightly damaged the tobacco and many plants were partially blown over. The entire field grew out of this setback with a crook in almost every plant, leaving the whole field essentially shifted from its original transplant position. Many plants, however, remained partially laid over and were not perfectly in-line with their respective rows.

Tobacco was topped on September 10th (2009) at 66 days after transplanting and August 9th (2010) at 62 days after transplanting. Eight treatments in 2009 (Table 2.5) and twelve treatments in 2010 (Table 2.6) were applied three times at six to seven day intervals with the exception of the third application in 2009, applied 13 days after the second due to unfavorable weather conditions (Table 2.3, 9/20-9/26) as well as the second application in 2010 applied 11 days after the first due to wet and windy conditions. The first applications were made on September 11th, 2009 (one day after topping) and August 12th, 2010 (three days after topping). Second and Third applications were made on September 17th and 30th (2009) and August 23rd and 30th (2010). Tobacco was harvested on October 8th, 2009 (29 days after topping) and September 10th, 2010 (31 days after topping).

Alternative nozzle types and arrangements in both years were compared with treatments 1, 2 and 3 (topped not suckered, TG3-5-3 MH+Butralin, and TG3-5-3 4% fatty alcohol). Treatment 2 using the TG3-5-3 arrangement included a single application of 14 L ha^{-1} MH + 4.7 L ha^{-1} Butralin per acre. Treatments 3-8 (2009) and 3-12 (2010) all used a 4% fatty alcohol (Fair85) solution (19 Liters 468 L ha^{-1} applied) to evaluate effectiveness of each treatment and make appropriate comparisons. Two *TeeJet* (TeeJet Spraying Systems Co.) adjustable row application kits (#23770) were secured to a spray boom to apply treatments over two rows. Modification to the row application kits included attaching an arm 46 cm behind the center nozzle to accommodate a trailing nozzle if desired in treatment (Figure 2.1). Using a high clearance sprayer, treatments were applied 30 cm above two rows at a time, at a speed of 4.8 kph. Nozzles used in this study are shown in Figure 2.2 with their descriptions in Table 2.7.

Figure 2.1: Row application kit spacing with attached trailing nozzle arm (3-dimensional).



Treatment classification was one-way, design structure in the field layout was randomized complete block, and experimental units were the plots in the field (sampling units were the plants). Four replications for each treatment were applied for both years making the total experimental units 32 (2009) and 48 (2010). Plots were two rows, 9.1 meters long in 2009 and 10.2 meters long in 2010. After the first application of fatty alcohol treatments in 2009, plots were split (a and b plots, still 9.1 m) for the purpose of examining a sequential method treatment (a MH/fatty alcohol tank mix was applied to B plots which received fatty alcohol only initially) at the second application seven days after topping. This treatment was compared with the continuing applications (3 total applications) of 4% fatty alcohol for sucker control, leaf area expansion, and yield.

Data on sucker control and leaf growth were collected four to five days after each of the three applications of treatments (Sept. 15th, 22nd, Oct. 1st (2009) and Aug. 20th, 27th, Sept. 2nd (2010)). Sucker number and weights for both years were recorded. Leaf area measurements (length * width * coefficient 0.664) were taken during the same time after all three applications from the uppermost leaf for both years to document leaf growth/expansion and make comparisons between treatments.

Suggs et al. (1960) explained leaf area is important in determining plant growth rate and that in regard to tobacco (vegetative portion is harvested) it is an exceptional indicator of yield. The purpose of his study was to find a more constant relationship of leaf dimensions and leaf area allowing it to be of more scientific and engineering use. With plant spacing of 47 cm (18.5 in) and row spacing of 106 cm (42 in), Suggs et al. (1960) found the most accurate proportionality constant to be used for determining leaf area was 0.664 for non-irrigated tobacco. The product of this coefficient and both the length and width of the leaf would give a reasonable estimate of leaf area. Raper et al. (1974) found essentially the same coefficient (0.6639) in their study on the geometry of tobacco leaves. Although their model incorporated other factors accounting for changes in intercept ratio and relative base width of the leaf, the predicted area was still essentially dominated by the length, width, and coefficient product. Maw and Mullinix (1992) agree according to their study comparing six models of various complexities for calculating leaf area. They found the most practical and reasonably precise model is the simplest model, using only length, width, and a coefficient. For two of the three years in which this study was conducted, the coefficient of correlation for this simple model was above 0.98.

Sucker escape counts were made on the top ten leaf axils of each plant after the first two applications only for both years. For each experimental unit (plot) to be represented, five successive (starting at the eighth plant in the row) plants were used from the left hand row (to establish a common border between each plot).

Fresh suckers were counted and their weights recorded for both years on ten plants per plot just prior to harvest approximately one week after the third and final application of treatments. For split plots in 2009, sucker number and weights were collected for both A and B plots. It was observed during collection of the suckers at harvest that some suckers had one or two relatively large leaves even though the bud was dead. The percent of total suckers per plot that exhibited a chemical burn (bud desiccation) were also documented at harvest in 2010 (only for three replications).

Table 2.1: Temperature and precipitation during the growing season for 2009.

2009	Air Temperature (°C)			Total Precipitation (cm)
	Max	Min	Average	
	26	16	21	42.5
Deviation from normal	1.666	0.555	-0.555	12.4

2009 monthly			
Month	Average temp. (C°)	departure	Precipitation (cm)
July	21.6	-2.7	15
August	22.7	-1.1	13.7
September	20	0	13.6
October	12.2	-1.6	2

Table 2.2: Temperature and precipitation during the growing season for 2010.

2010	Air Temperature (°C)			Total Precipitation (cm)
	Max	Min	Average	
	30.5	19.5	25	28.6
Deviation from normal	1.666	2.222	2.222	-3.9

2010 monthly			
Month	Average temp. (C°)	departure	Precipitation (cm)
June	24.4	2.22	11.7
July	25.5	1.1	13.9
August	25.5	1.6	3.9
September	21.6	1.6	0.9

Table 2.3: Precipitation during the growing season by day for 2009.

2009	
Precipitation by date and amount	
date	amount (cm)
7/7/2009	**Transplant**
7/10/2009	0.3
7/15/2009	0.2
7/17/2009	0.9
7/22/2009	2.1
7/25/2009	2.1
7/26/2009	0.7
7/28/2009	0.4
7/29/2009	0.5
7/30/2009	0.5
7/31/2009	5.3
8/1/2009	0.2
8/2/2009	1
8/4/2009	5.3
8/5/2009	0.1
8/11/2009	0.5
8/12/2009	0.3
8/17/2009	0.6
8/18/2009	1
8/20/2009	0.8
8/21/2009	2.5
8/27/2009	0.7
8/28/2009	0.4
8/29/2009	0.2
9/7/2009	1.2
9/8/2009	1.5
9/9/2009	0.03
9/10/2009	**Topping**
9/20/2009	2.3
9/21/2009	1.7
9/22/2009	0.5
9/23/2009	0.2
9/24/2009	2.8
9/25/2009	1
9/26/2009	2.5
10/2/2009	0.7
10/6/2009	0.1
10/8/2009	1.2
10/8/2009	**Harvest**

Table 2.4: Precipitation during the growing season by day for 2010.

2010	
Precipitation by date and amount	
date	amount
6/8/2010	**Transplant**
6/9/2010	1.8
6/12/2010	1.3
6/13/2010	0.8
6/14/2010	1.2
6/15/2010	1.3
6/19/2010	0.8
6/21/2010	1.1
6/24/2010	0.1
6/28/2010	1.5
7/9/2010	2.5
7/12/2010	0.5
7/13/2010	3.4
7/17/2010	0.9
7/19/2010	2.4
7/21/2010	3.0
7/27/2010	1.2
7/28/2010	0.1
7/31/2010	0.0
8/5/2010	0.1
8/9/2010	**Topping**
8/10/2010	0.2
8/14/2010	2.2
8/15/2010	1.3
8/19/2010	0.0
8/21/2010	0.3
9/3/2010	0.9
9/10/2010	**Harvest**

Table 2.5: 2009 field study treatments.

Treatment[1]	**Suckercide Applied**	**Nozzles used (per row)**	**Description[2]**
1	None	None	not topped, not suckered
2	**14 L MH30 + 4.7 L Butralin**	TG5, TG3 (2)	One TG5 center of row, TG3 on each side adjacent at 35 cm from center nozzle
3	4% Fatty Alcohol	TG5, TG3 (2)	One TG5 center of row, TG3 on each side adjacent at 35 cm from center nozzle
4	4% Fatty Alcohol	TT11005	One TT11005 dual polymer flat fan spray center of row
5	4% Fatty Alcohol	TT11005, TG3 (2)	One TT11005 center of row, TG3 on each side adjacent at 35 cm from center nozzle
6	4% Fatty Alcohol	TT11005 (2)	Two TT11005 over center of row. Trailing nozzle is 46 cm behind
7	4% Fatty Alcohol	TJ60SS (2)	Two TJ60SS over center of row. Trailing nozzle is 46 cm behind
8	4% Fatty Alcohol	DG8004 (2), TG3 (2)	Two DG8004 over center of row (trailing nozzle 46 cm behind), TG3 on each side adjacent at 35 cm from center nozzle

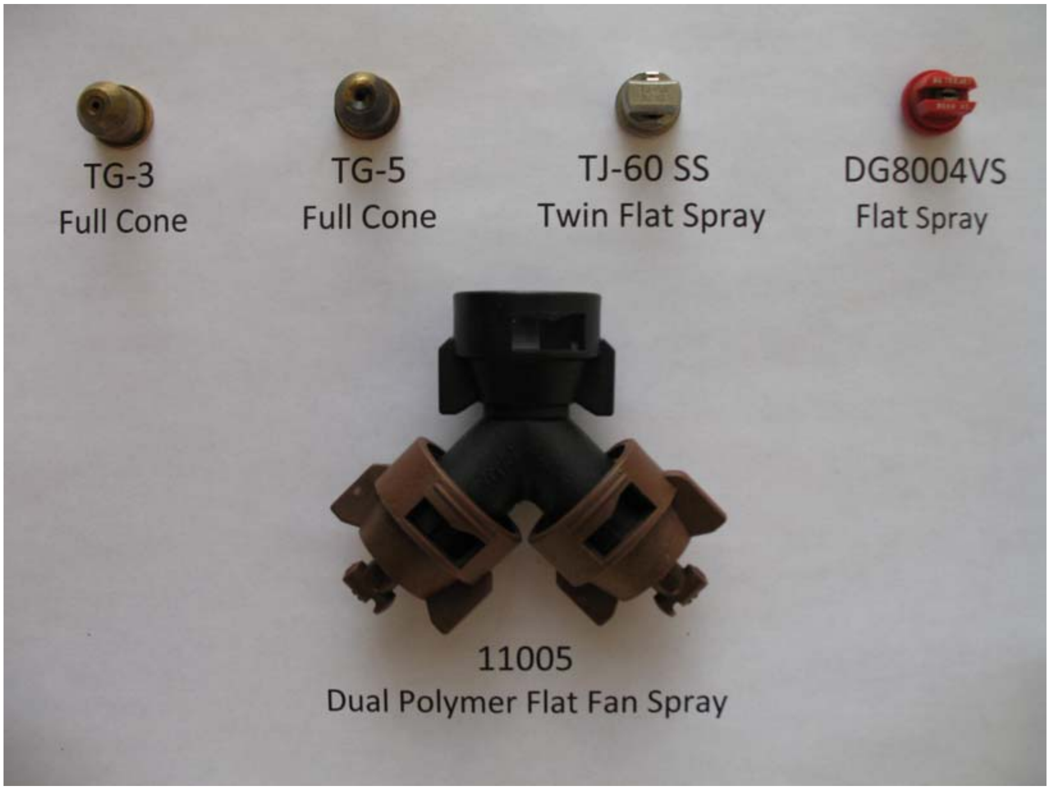
[1]All treatments applied approximately 468 liters per hectare at 4.8 kph except treatments 4 (374 L/h) and 8 (542 L/h).
[2]Pressure for all treatments was 138-206 kilopascals (kpa) with the exception of treatment 4 (344 kpa).
Note: Treatments 3-8 were split (a, b) after first application to include sequential method treatments (FA fb MH).

Table 2.6: 2010 field study treatments.

Treatment[1]	**Suckercide Applied**	**Nozzles used (per row)**	**Description**[2]
1	None	None	not topped, not suckered
2	**14 L MH30 + 4.7 L Butralin**	TG5, TG3 (2)	One TG5 center of row, TG3 on each side adjacent at 35 cm from center nozzle
3	4% Fatty Alcohol	TG5, TG3 (2)	One TG5 center of row, TG3 on each side adjacent at 35 cm from center nozzle
4	4% Fatty Alcohol	TT11005	One TT11005 dual polymer flat fan spray center of row
5	4% Fatty Alcohol	TT11005, TG3 (2)	One TT11005 center of row, TG3 on each side adjacent at 35 cm from center nozzle
6	4% Fatty Alcohol	TT11005 (2)	Two TT11005 over center of row. Trailing nozzle is 46 cm behind
7	4% Fatty Alcohol	TJ60SS (2)	Two TJ60SS over center of row. Trailing nozzle is 46 cm behind
8	4% Fatty Alcohol	DG8004 (2), TG3 (2)	Two DG8004 over center of row (trailing nozzle 46 cm), TG3 on each side adjacent at 35 cm from center nozzle
9	4% Fatty Alcohol	DG8005 (2), TG3 (2)	Two DG8005 over center of row (trailing nozzle 46 cm), TG3 on each side adjacent at 35 cm from center nozzle
10	4% Fatty Alcohol	TT11005 (2), TG3 (2)	Two TT11005 over center of row (trailing nozzle 46 cm), TG3 on each side adjacent at 35 cm from center nozzle
11	4% Fatty Alcohol	TG5, TG3 (3)	One TG5 center of row, one TG3 trailing 46 cm behind over row. TG3 on each side adjacent at 35 cm from center nozzle
12	4% Fatty Alcohol	TG6, TG4 (2)	One TG6 center of row, TG4 on each side adjacent at 35 cm from center nozzle

[1]All treatments applied approximately 468 liters per hectare at 4.8 kph except treatment 4 (355 L/h).
[2]Pressure for all treatments was 138-206 kilopascals (kpa) with the exception of treatment 4 (262 kpa).

Figure 2.2: Tee-Jet Nozzles used in configurations for 2009 and 2010.



*TG4 and TG6 not pictured.

Table 2.7: Tee-Jet nozzles used and their descriptions.

Nozzle	Description
TG3	full cone spray - provides coarse spray with full cone pattern
TG4	full cone spray - provides coarse spray with full cone pattern
TG5	full cone spray - provides coarse spray with full cone pattern
TG6	full cone spray - provides coarse spray with full cone pattern
TJ60 SS	twin flat spray - penetrates dense foliage, smaller droplets
DG8004 VS	drift guard spray - tapered edge spray pattern, large droplets
TT11005	wide angle flat spray - tapered edge wide angle spray, larger droplets

Results

Results are reported as the main effect means based on data analyzed using Statistical Analysis Software (SAS, Version 9.2), including the Mixed procedure type 3 tests of fixed effects, differences of least mean squares, and t tests (*least squares differences*) used to separate means. Sucker escapes per plant, sucker number, fresh sucker weight, top leaf area growth, and yield data are reported.

Sucker Escapes

Sucker escape counts on the top ten leaf axils after each of the first two applications were used to estimate the degree of spray coverage. The total number of sucker escapes per plant was recorded. The SAS Mixed Procedure was run for both data sets (applications 1 and 2) and type 3 tests of fixed effects were applied for both years. Least squares means were used to compare differences among treatments in both years.

Application in 2009 was significant ($p<0.05$) in regard to sucker escapes due to the addition of the sequential method (FA fb FA+MH) on half the plots for the second application. Treatment differences were found to be highly significant ($p<0.0001$); however, the interaction between application and treatment was not significant. In 2010, application, treatment, and the interaction between application and treatment were highly significant ($p<0.0001$).

2009

In 2009, all chemical treatments and nozzle arrangements (treatments 2-8) had significantly (<0.0001) fewer escapes than the untreated check (treatment 1) following each application for which escapes were recorded (Figure 2.3, Figure 2.4, and Figure 2.5). For the first two weeks after topping, the number of escapes with fatty alcohol only was comparable to the sequential method. No significant differences between chemical treatments were evident in sucker escape counts after the first application (Figure 2.3). Following the second application, plots which received initial MH treatments (2a, 2b) had significantly fewer escapes than treatments 7a and 8a only (fatty alcohol only, Figure 2.4). The sequential chemical method (FA followed by MH+FA) using the TG3-5-3 arrangement (treatment 3b) had significantly fewer escapes than treatments 2a (MH), 2b (MH), 4a, 6a, 7a, and 8a after the second application (Figure 2.4 and Figure 2.5). Comparing all treatments using the sequential method, treatment 3b only showed significance over 4b (Figure 2.5). Looking at the treatments which used only fatty alcohol (a) in comparison with the TG3-5-3 arrangement, treatment 3a had fewer escapes than treatments 4a, 6a, 7a, and 8a; it was even significantly better than treatment 4b (Figure 2.4). Treatment 5, with a dual flat nozzle over the row in place of the typical TG-5, proved to be comparable in number of escapes to treatment 3, showing no significant difference in either the fatty alcohol only or sequential method.

2010

For 2010, plots were not split and no sequential treatments were applied. MH treatment (2, TG3-5-3) was compared with fatty alcohol treatments (3-12), and treatment 3 (TG3-5-3) was compared with treatments 4 through 12 using fatty alcohol only (Figure 2.6 and Figure 2.7). Escapes were not controlled very well after the first application of treatments due to windy conditions during application combined with the non-uniform plants from the storm earlier in the growing season (Figure 2.6). The second application however, had good impact on burning the suckers. All chemical treatments and nozzle arrangements had fewer ($p<0.0001$) escapes than the untreated check (1) (Figure 2.7).

MH treatment (2) exhibited significantly ($p<0.0001$) fewer escapes than all arrangements with fatty alcohol after the first application, except fatty alcohol treatments 4, 11, and 12 which were not significantly different (Figure 2.6). Examining all fatty alcohol only treatments to compare arrangements, the standard TG3-5-3 arrangement had significantly fewer escapes than treatment 6 after the second application (Figure 2.6). Sucker escapes for treatments 4, 5, 7, 8, 9, 11, and 12 proved to be less ($p<0.05$) than those for treatment 3 after the first application (Figure 2.6). Treatments 11 (TG3-5-3-3) and 12 (TG4-6-4) really stood out and resulted in minimal escapes for both applications (Figure 2.6 and Figure 2.7). Treatment 12 proved significant over all other fatty alcohol treatments (except 11 and 4) showing the least amount of sucker escapes. Treatment 11 also had significantly fewer suckers than all other treatments with the exception of treatment 4 and 5. It should be noted that treatments 11 and 12 showed slight leaf burn damage.

Fresh suckers

Treatment effects were highly significant ($p<0.0001$) for both years in regard to both sucker number and fresh sucker weight at harvest.

2009

For 2009, sucker pressure was high in terms of weight due to high moisture conditions. All chemical treatments demonstrated significantly ($p<0.0001$) less sucker weight than the untreated check (>350 gm/plant, Figure 2.8 and Figure 2.9). Further, all sequential method treatments (3b-8b) averaged significantly less sucker weight than the fatty alcohol only treatments. Among the sequential method treatments, none of the arrangements were significantly different than any of the others, including the MH treatment (2) (Figure 2.9). It should be mentioned that although not significant, treatment

3b (sequential) exhibited less fresh sucker weight than treatment 2 (MH only). Considering only the fatty alcohol treatments, 3, 5, 6, and 7 had significantly less sucker weight than treatment 8 (Figure 2.8).

In reference to sucker number per ten plants, results similar to sucker weight were found (Figure 2.10 and Figure 2.11). All chemical treatments once again prevailed over the untreated check significantly ($p<0.0001$). Sequential method treatments 3b, 7b, and 8b had significantly fewer suckers than fatty alcohol only. There were also no significant differences when comparing all sequential method treatments with treatment 2a and 2b (MH) (Figure 2.11). Within the sequential method treatments, all were fairly equal with no significant differences. Fatty alcohol only (a) treatments were all similar, with the exception of treatment 8a which exhibited increased sucker number (Figure 2.10).

2010

2010 results differed and sucker pressure in regard to weight was not near as high as in 2009 (90gm/plant vs. >350gm/plant in 2009, Figure 2.12). All chemical treatments had significantly less sucker weight over the untreated check, with the exception of treatment 6. MH treatment (2) provided 100% sucker control for 2010 and performed significantly better than all fatty alcohol treatments, with the exception of treatment 12 (TG4-6-4) (Figure 2.12). Treatment 12 displayed the lowest sucker weight of all arrangements using fatty alcohol only, and was statistically equaled only by treatment 11 (TG3-5-3-3) (Figure 2.12).

Similar results were found for sucker number per ten plants. Although weight differed significantly across years (larger suckers in 2009), sucker number for 2009 and 2010 were very similar (Figure 2.13). All chemical treatments had significantly fewer suckers than the untreated check, with the exception of treatment 6 (Figure 2.13). MH treatment (2) performed significantly better than all fatty alcohol arrangements except treatments 11 and 12 (Figure 2.13). Comparing those treatments of fatty alcohol only, treatment 12 provided minimal sucker number with treatments 11 and 9 not being significantly different (Figure 2.13).

Sucker Control

Percentage of sucker control relative to the untreated check was calculated in terms of both sucker weight and number for both years. These are shown in Figure 2.14, Figure 2.15, and Figure 2.16. These results agree with those from sucker escape data. The TG3-5-3 arrangement provided 75% control relative to the check in 2009, and while that is not sufficient, it was the best when compared with all other fatty alcohol treatments (Figure 2.14). Also in 2009, the sequential methods provided equal sucker control to that of MH only treatment (Figure 2.15). For 2010, treatments 11 and 12 were the only treatments which provided comparable (to MH) control using fatty alcohol only (Figure 2.16). In 2010, observations of dead suckers were recorded (for three replications) as suckers were counted for each treatment. These are shown in Figure 2.17 in comparison with the sucker number. Looking at the treatments that performed the best (11 and 12) with minimal suckers, approximately half of those which were found had been burned.

Leaf Area

Type 3 fixed effect means from the SAS Mixed procedure were used to compare leaf area expansion rates. Treatments were compared as was application time (rate of expansion of top leaves between applications 1 and 2 and between 2 and 3). For each year, both application time and treatment were highly significant ($p<0.0001$). However, the interaction of time and treatment was not significant for either year. Time being highly significant shows the leaves were in fact expanding, but the lack of an application time and treatment interaction indicated there was no significant difference in the rate of expansion due to treatment. This is shown for both years in Figure 2.18 and Figure 2.19. Only treatments 1, 2, 3, and the best performing arrangements for each year were used in displaying these relationships in the figures.

2009

For 2009, treatment 5a had significantly (<0.0001) greater leaf area when compared with all other treatments. The only other treatments which showed significant differences were 5b, 6a, and 6b. These differences were thought to be due to higher initial leaf area for the measured plants after the first application. The actual rate of expansion of these leaves was no different than those of any other treatment and this growth rate is shown in Figure 2.20. With the exception of treatment 5, all fatty alcohol only (a) treatments resulted in increased growth rates after the 2nd application. Also, treatments 3b, 6b, 7b, and 8b (sequential method) showed a decrease in growth rate after their application during the same time period. These trends are evident in Figure 2.20.

.

2010

In 2010, significant differences between treatments were found, but they were only due to initial leaf area (observation after first application) being different. On many plants throughout both years of this study, the original top leaf was damaged or broken off due to varying circumstances (weather, topping), so sometimes it was in fact the second leaf from the point of topping used for measurement. This most likely was the cause of discrepancies between initial leaf area measurements. In 2009, leaf growth continued to increase after the second application of treatments. However, 2010 shows a plateau in leaf growth after this application. Severe dry weather and heat in 2010 is believed to be the cause of reduced expansion when compared to sufficient crop moisture at this stage in 2009. Growth rates for the top leaf in 2010 are shown in Figure 2.21. Some treatments in fact showed a negative growth rate after the second applications were made. Combining the droughty hot conditions with possible chemical damage to leaves may have contributed to this sudden halt in growth in 2010.

Yield

No significant differences in yield (total or by grade) were evident in either year of this study when treatments were compared. The SAS GLM Procedure was used to compare yields between treatments; $p>0.8954$ in 2009 and $p>0.6852$ in 2010. The mean total yield across all treatments for 2009 and 2010 were 2,747 kg/ha and 2,511 kg/ha respectively, and are shown in Figure 2.22 and Figure 2.23.

Figure 2.3: Sucker escapes four days after first application of sucker control treatments in 2009 (3-8 FA only).

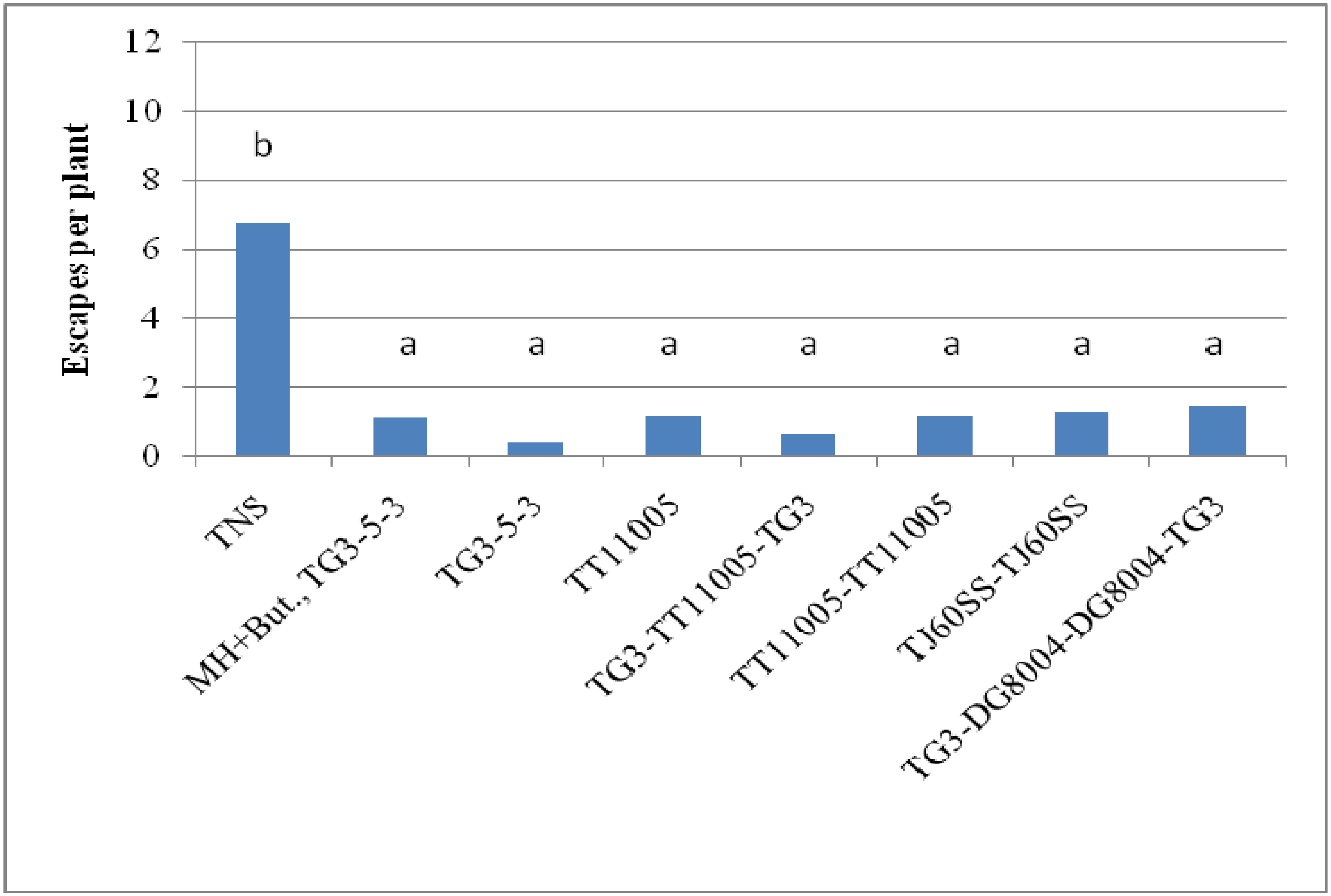


Figure 2.4: Sucker escapes five days after second application of fatty alcohol (a, 3-8) treatments in 2009.

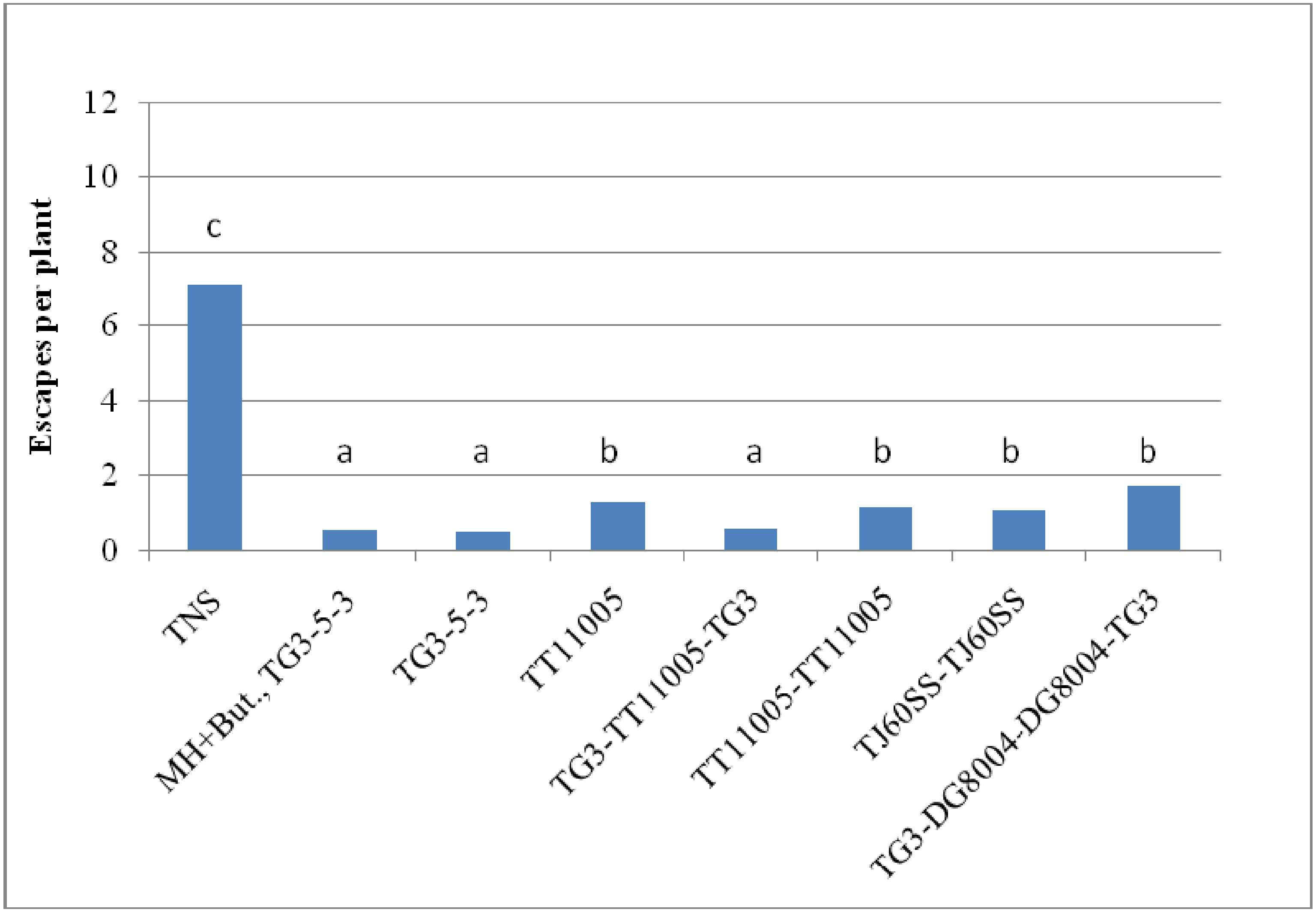


Figure 2.5: Sucker escapes five days after second application of sequential (b, 3-8) treatments in 2009.

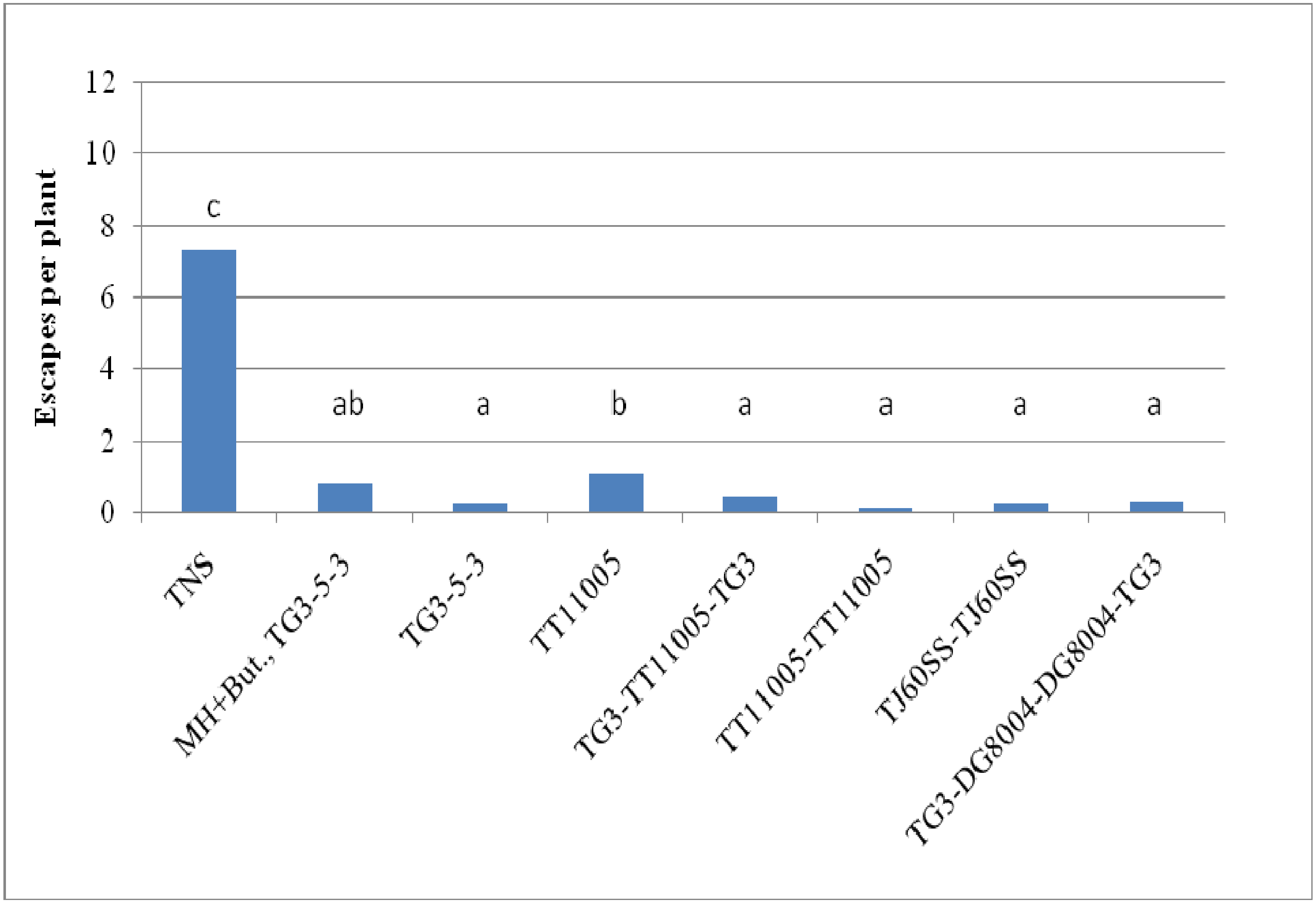


Figure 2.6: Sucker escapes eight days after first application of treatments (3-12 FA only) in 2010.

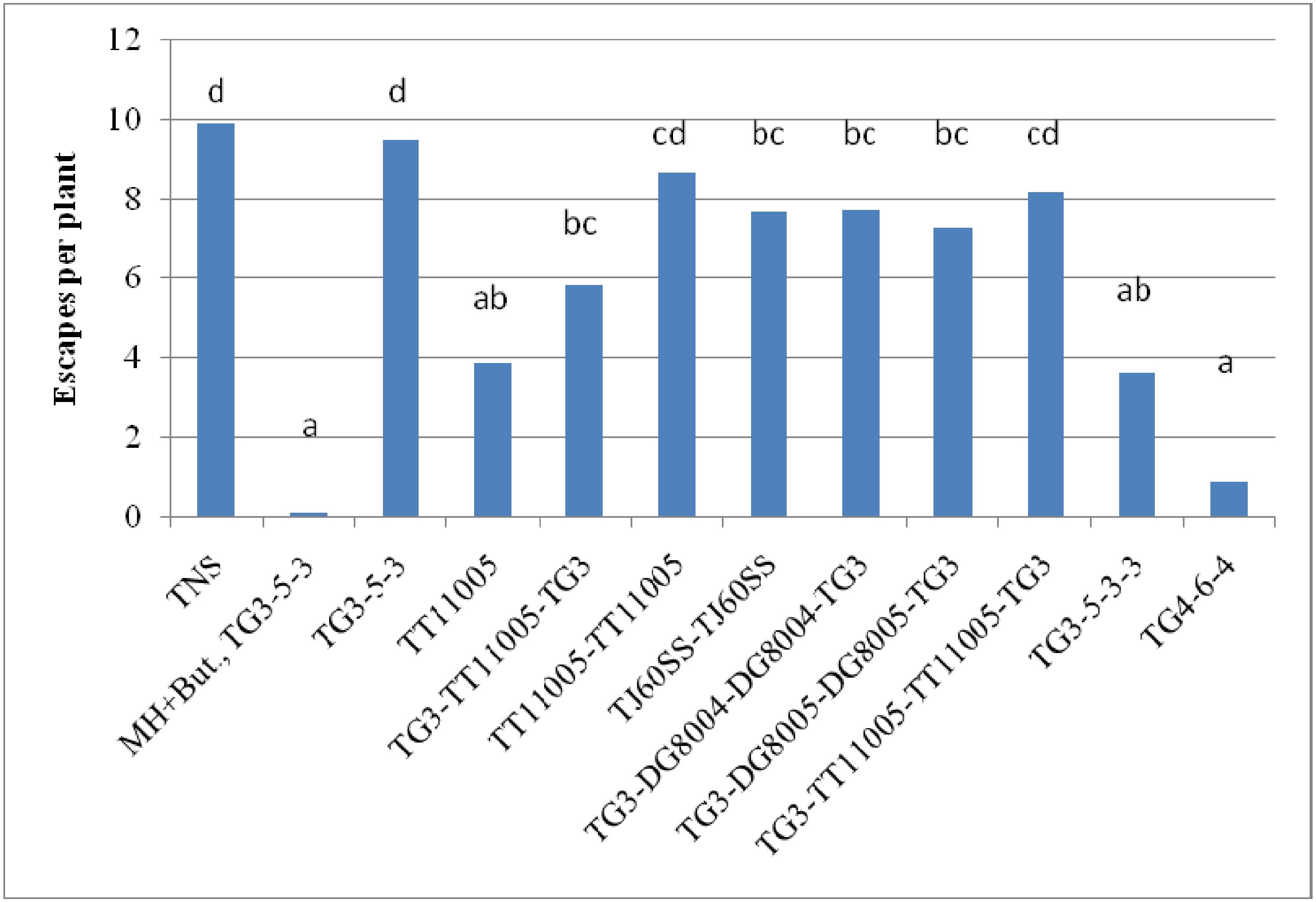


Figure 2.7: Sucker escapes four days after second application of treatments (3-12 FA only) in 2010.

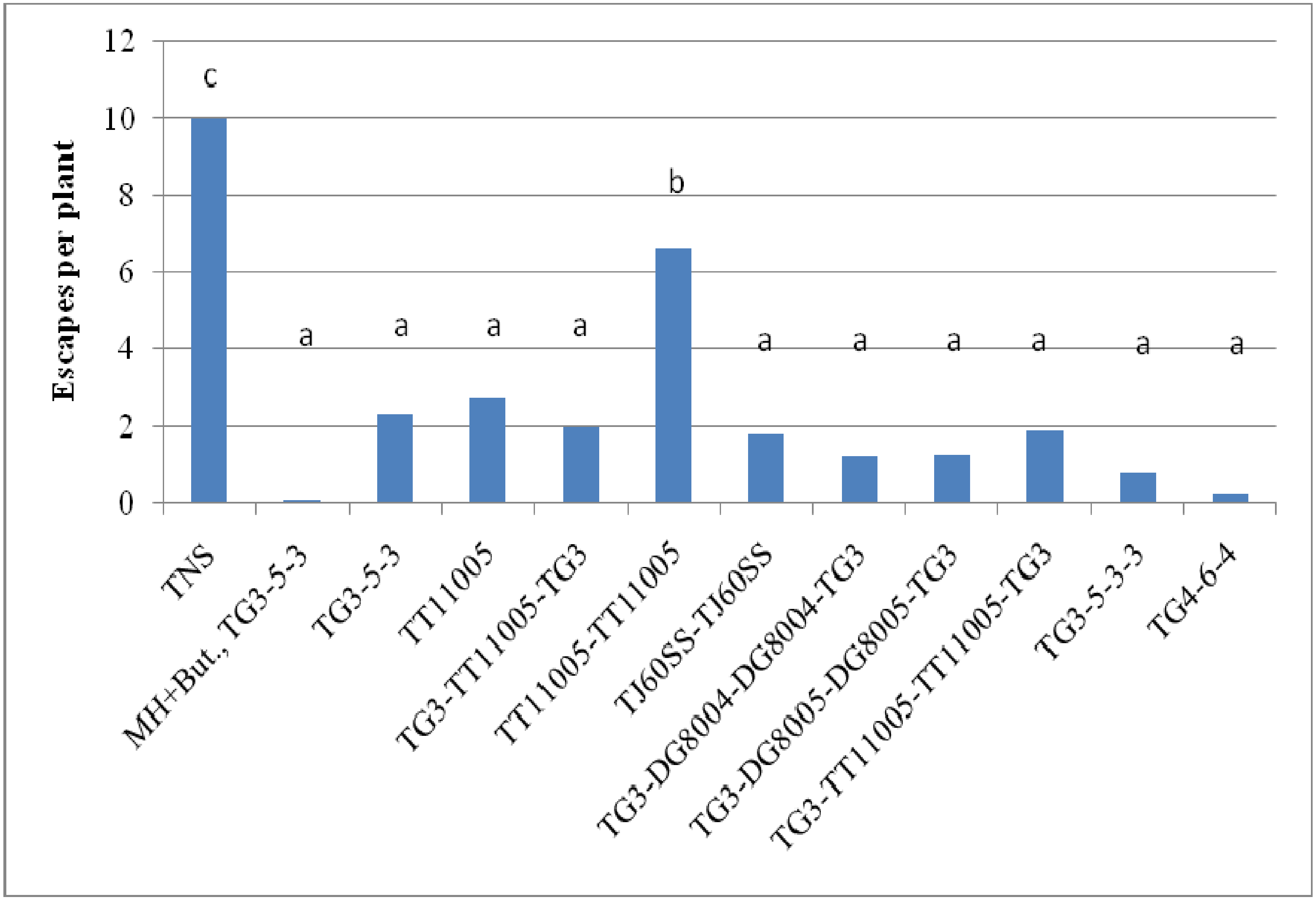


Figure 2.8: Fresh weight of suckers per ten plants two days after third application of fatty alcohol (a, 3-8) treatments in 2009.

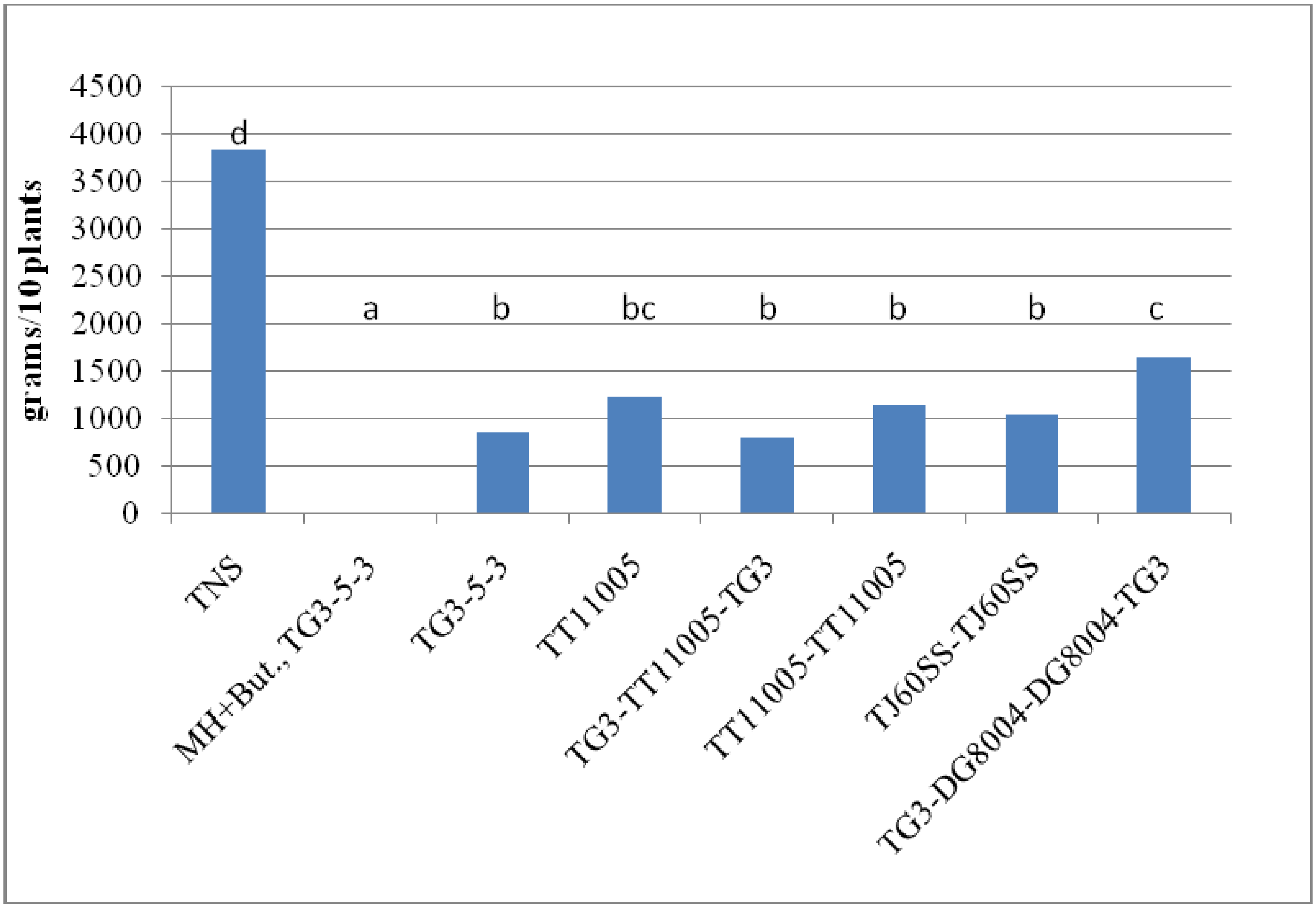


Figure 2.9: Fresh weight of suckers per ten plants two days after third application of sequential (b, 3-8) treatments in 2009.

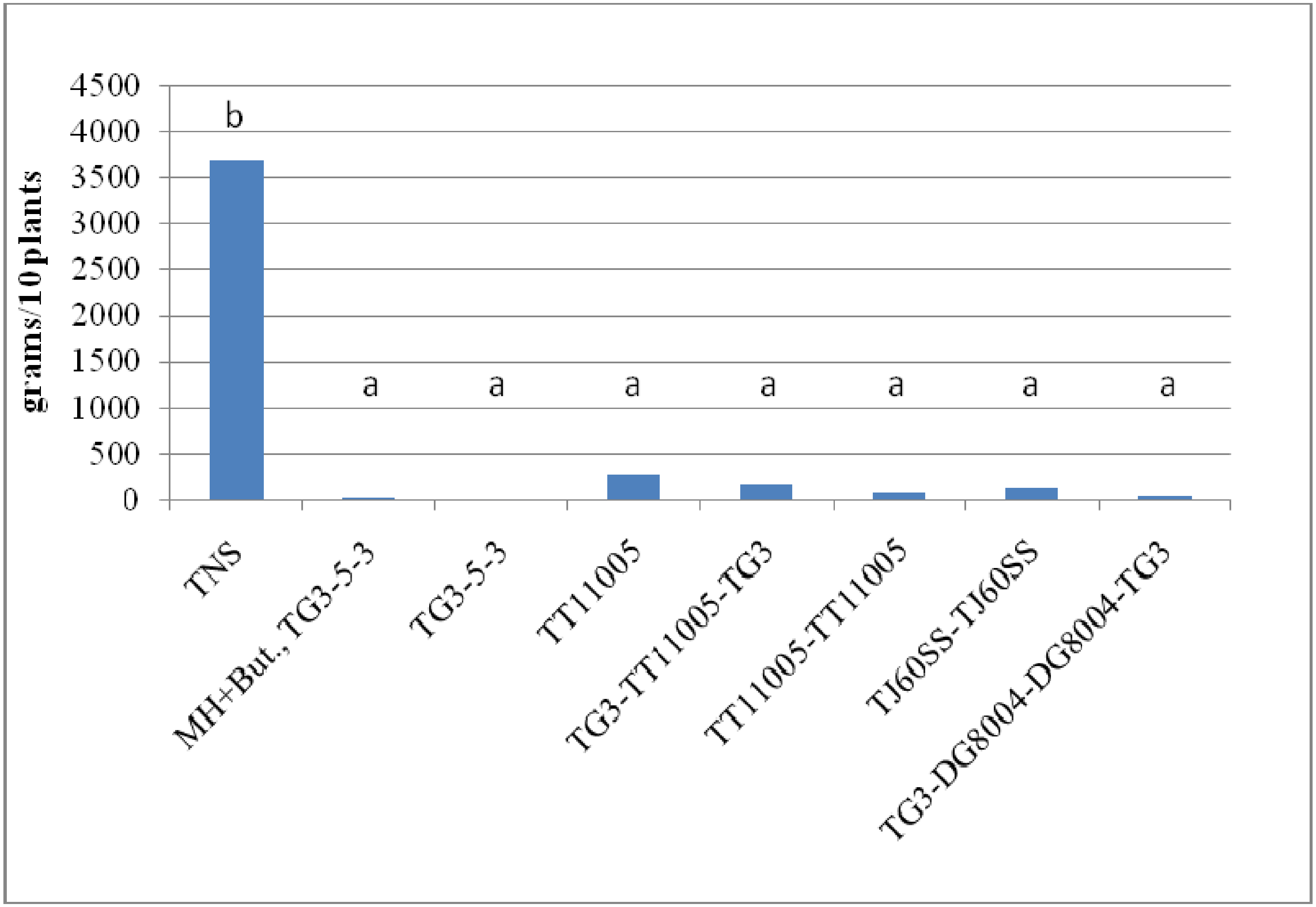


Figure 2.10: Number of suckers per ten plants two days after third application of fatty alcohol (a, 3-8) treatments in 2009.

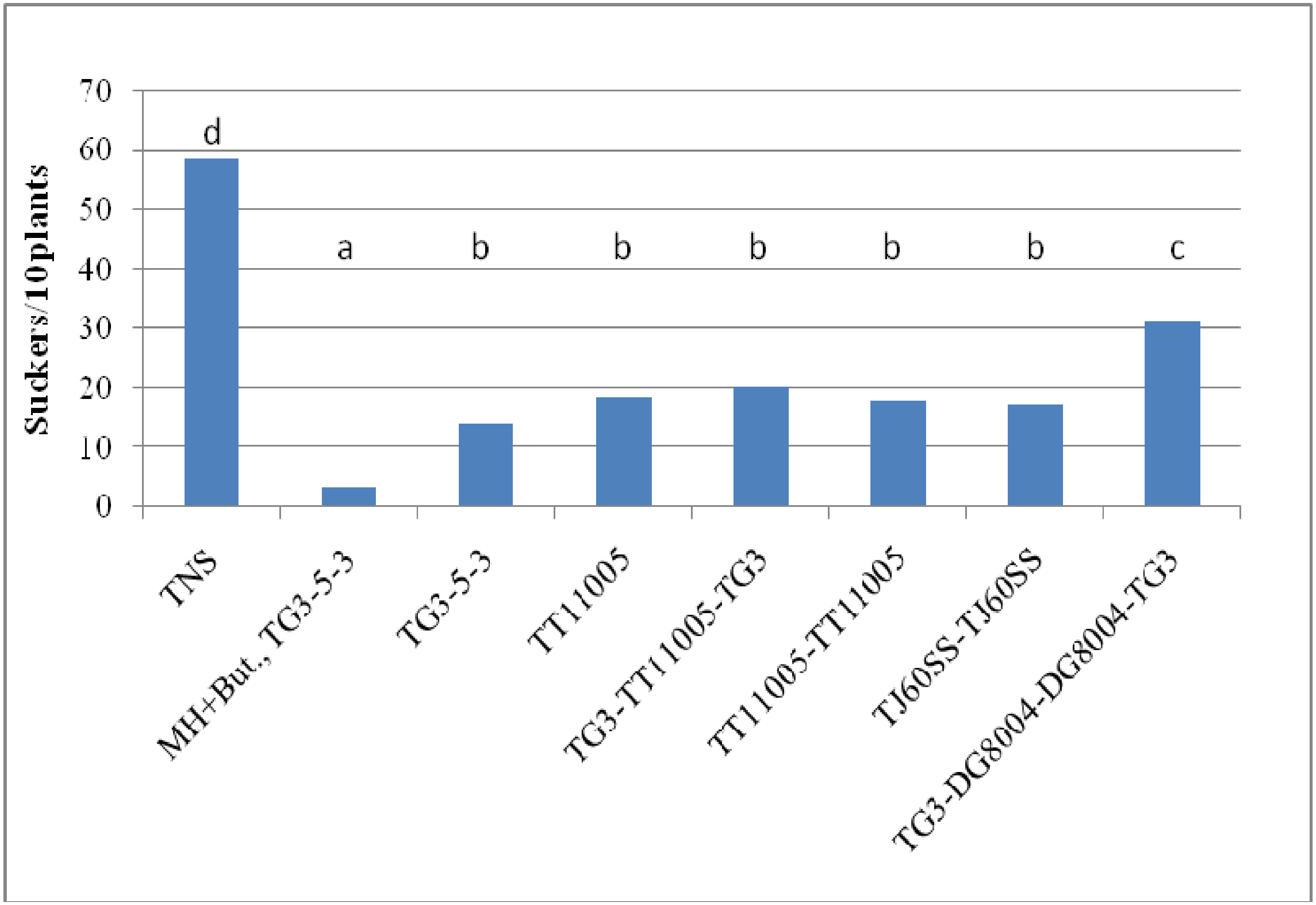


Figure 2.11: Number of suckers for per ten plants two days after third application sequential (b, 3-8) treatments in 2009.

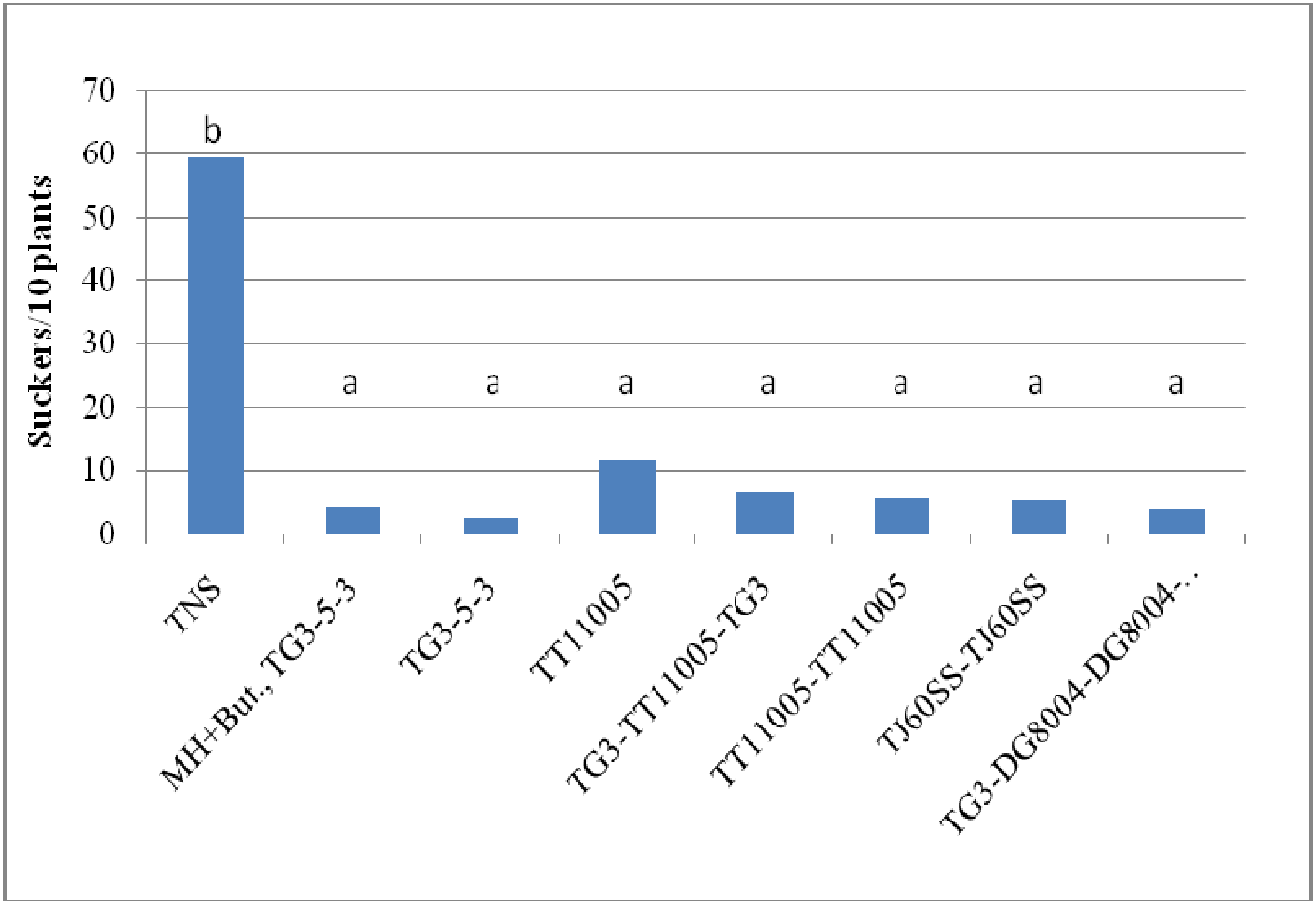


Figure 2.12: Fresh sucker weight per ten plants nine days after third application of treatments (3-12 FA only) in 2010.

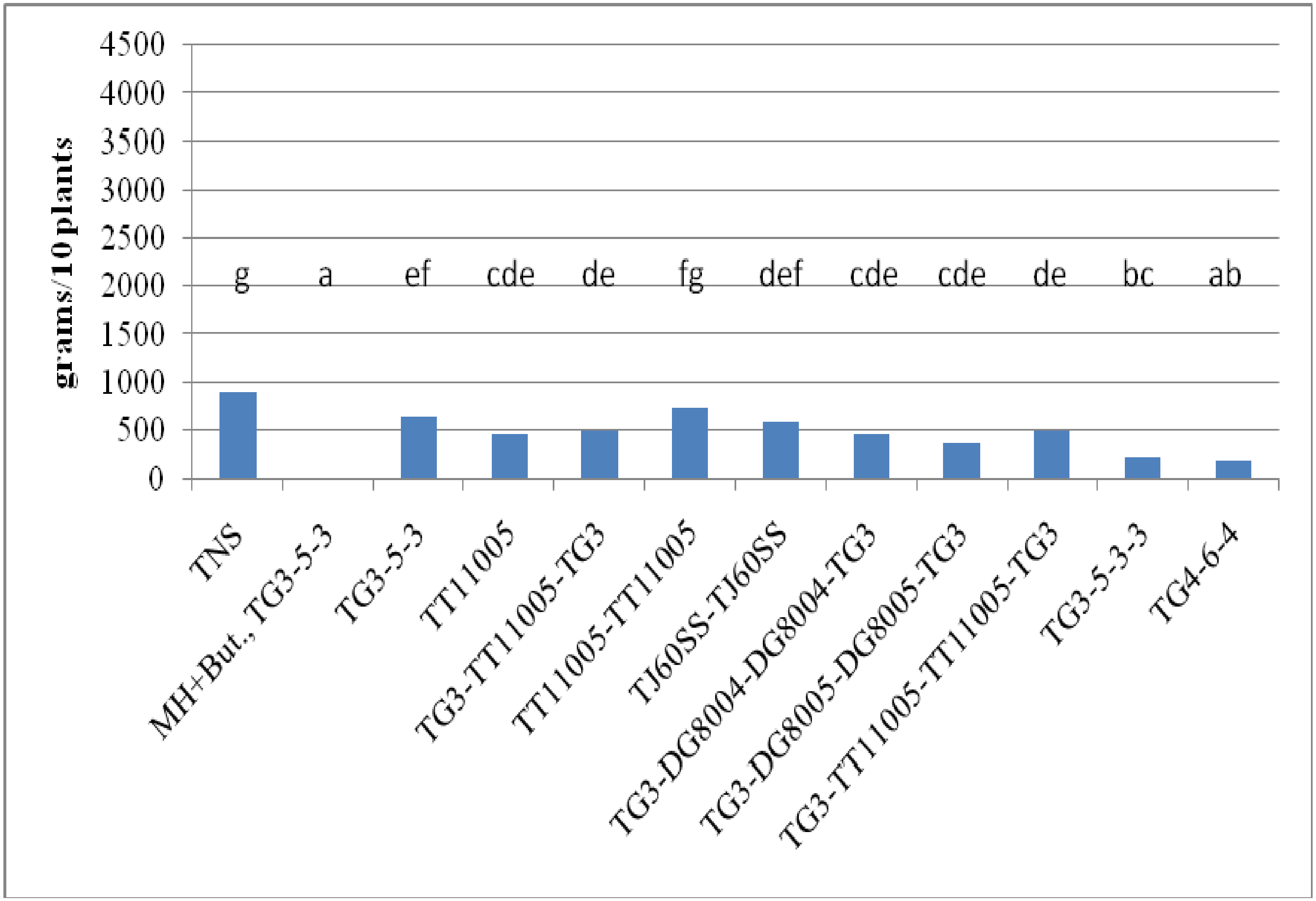


Figure 2.13: Number of suckers per ten plants nine days after third application of treatments (3-12 FA only) in 2010.

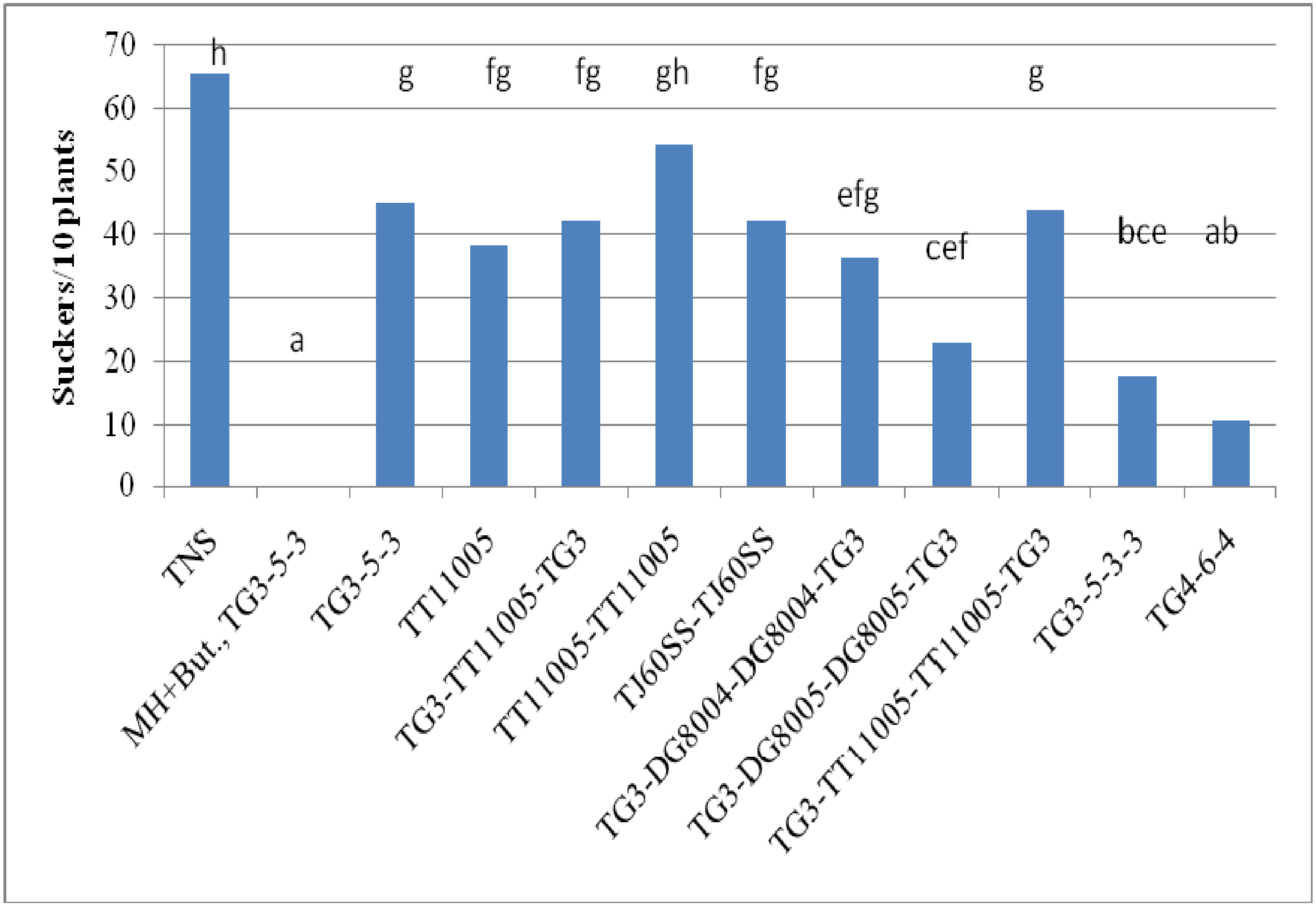


Figure 2.14: Percent sucker control relative to the untreated check for fatty alcohol (a, 3-8) treatments in 2009.

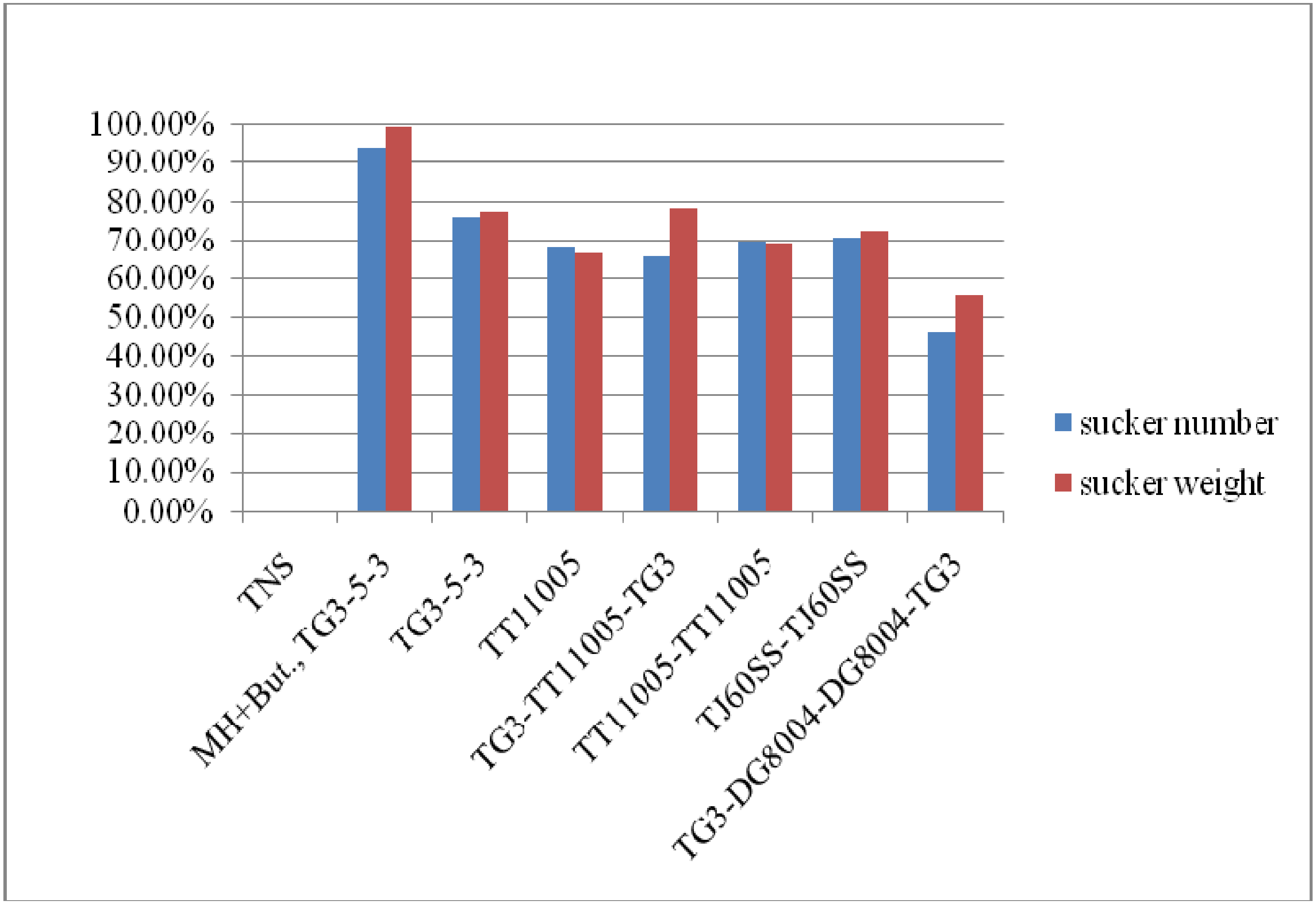


Figure 2.15: Percent sucker control relative to the untreated check for sequential (b, 3-8) treatments in 2009.

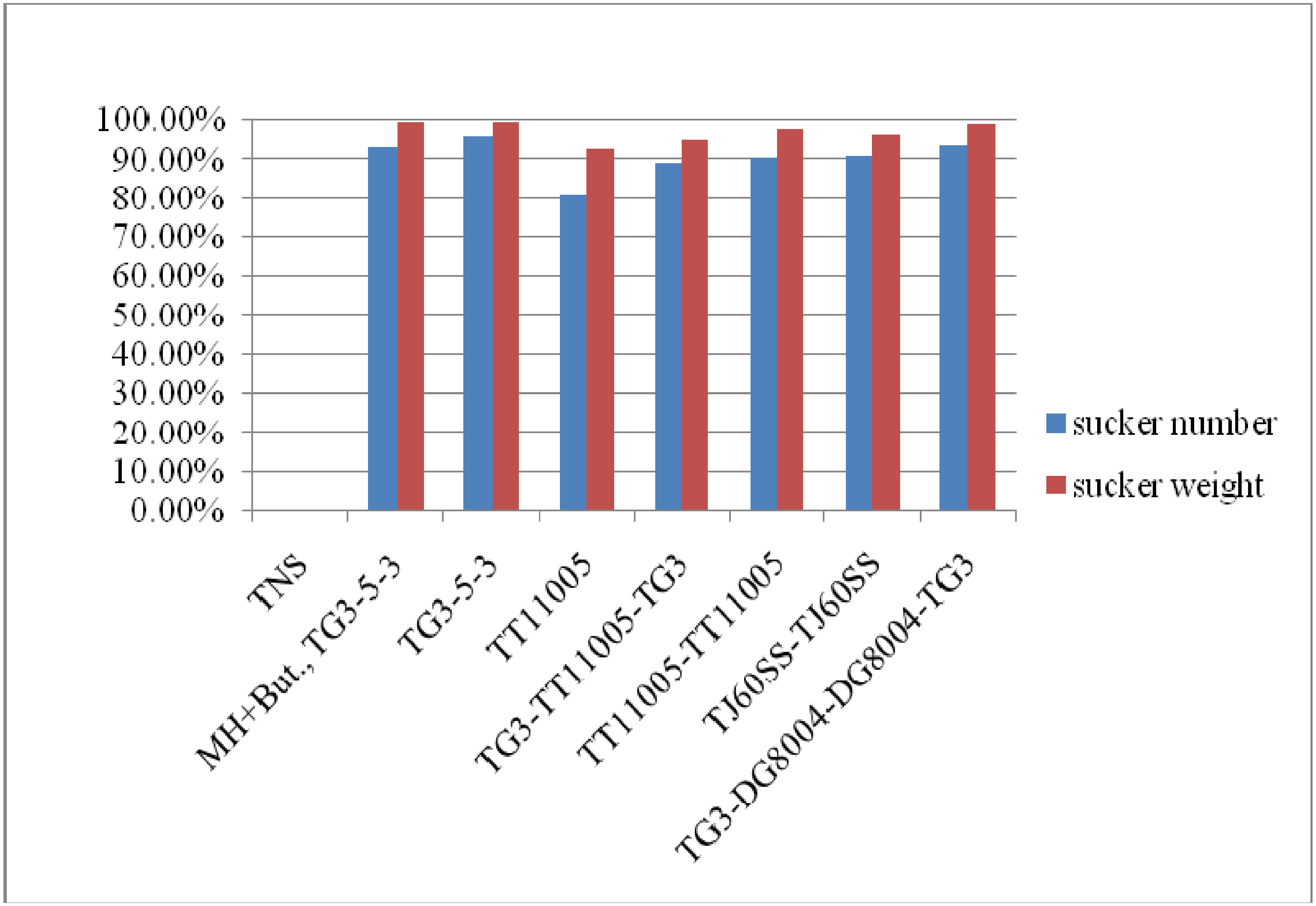


Figure 2.16: Percent sucker control relative to the untreated check for treatments (3-12 FA only) in 2010.

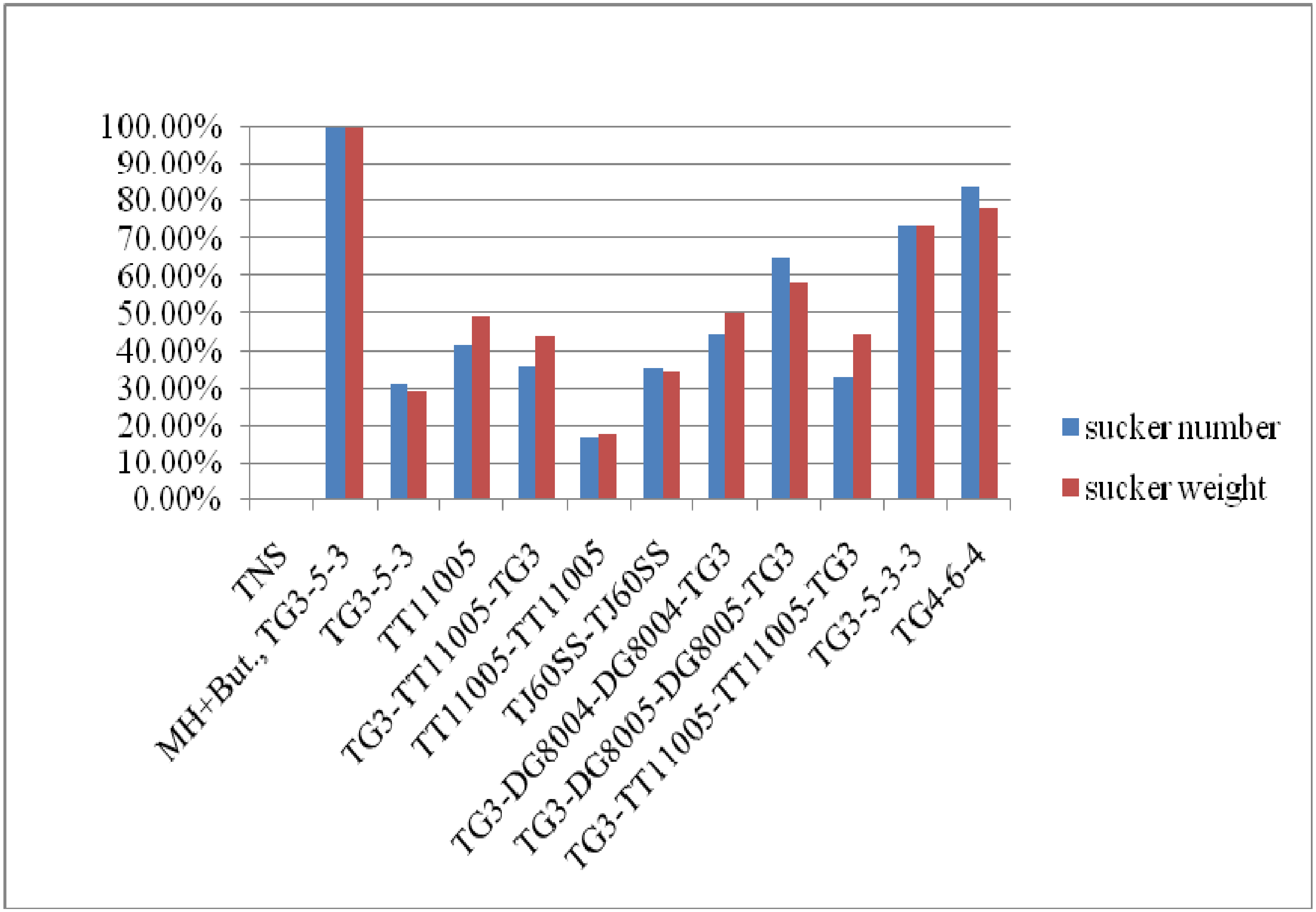


Figure 2.17: Number of suckers vs. number of suckers burned/desiccated for treatments (3-12 FA only) in 2010.

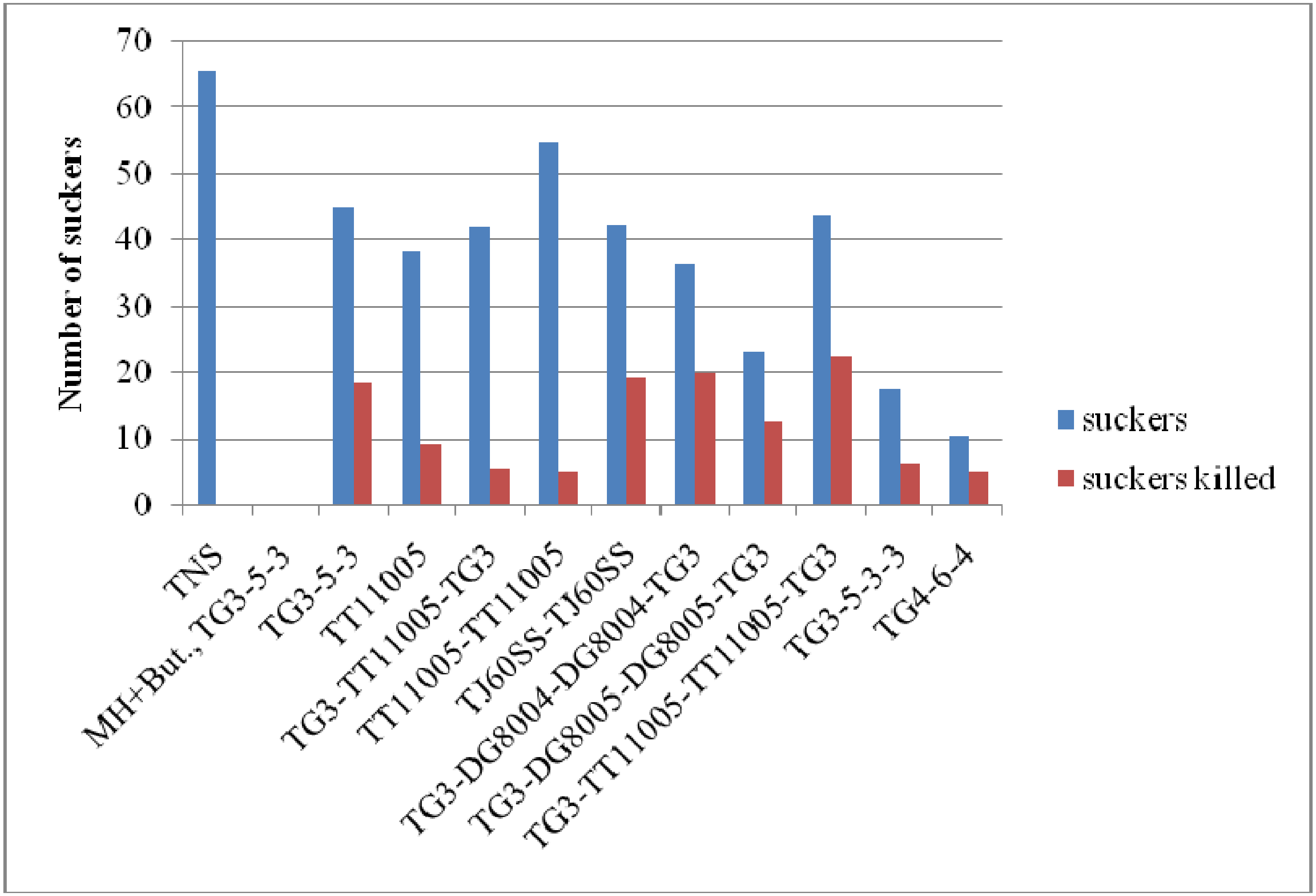
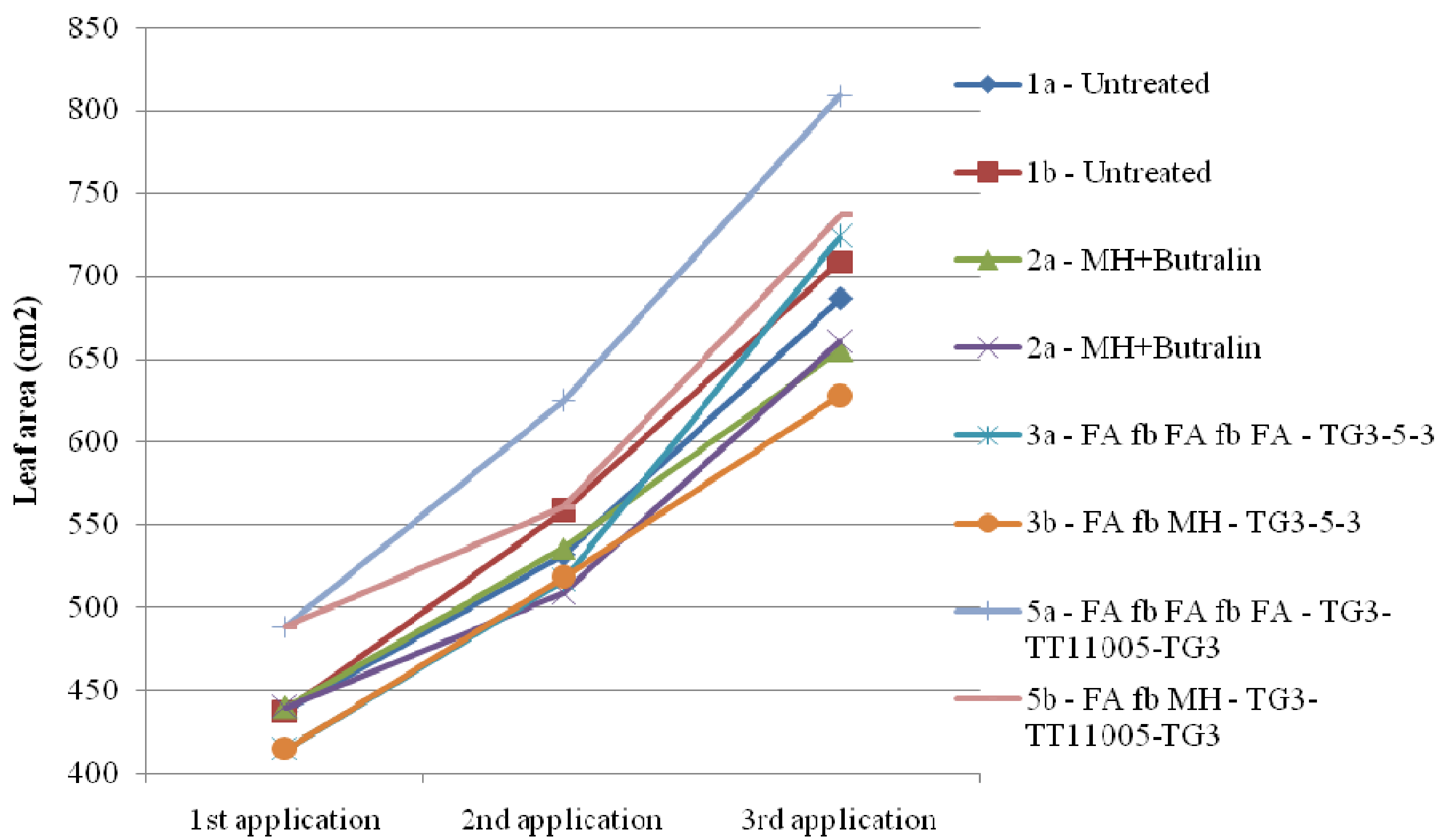


Figure 2.18: Leaf area growth trend between applications in 2009.



* data collected 4 days after first application, 5 days after second, and 3 days after third.

Figure 2.19: Leaf area growth trend between applications in 2010.

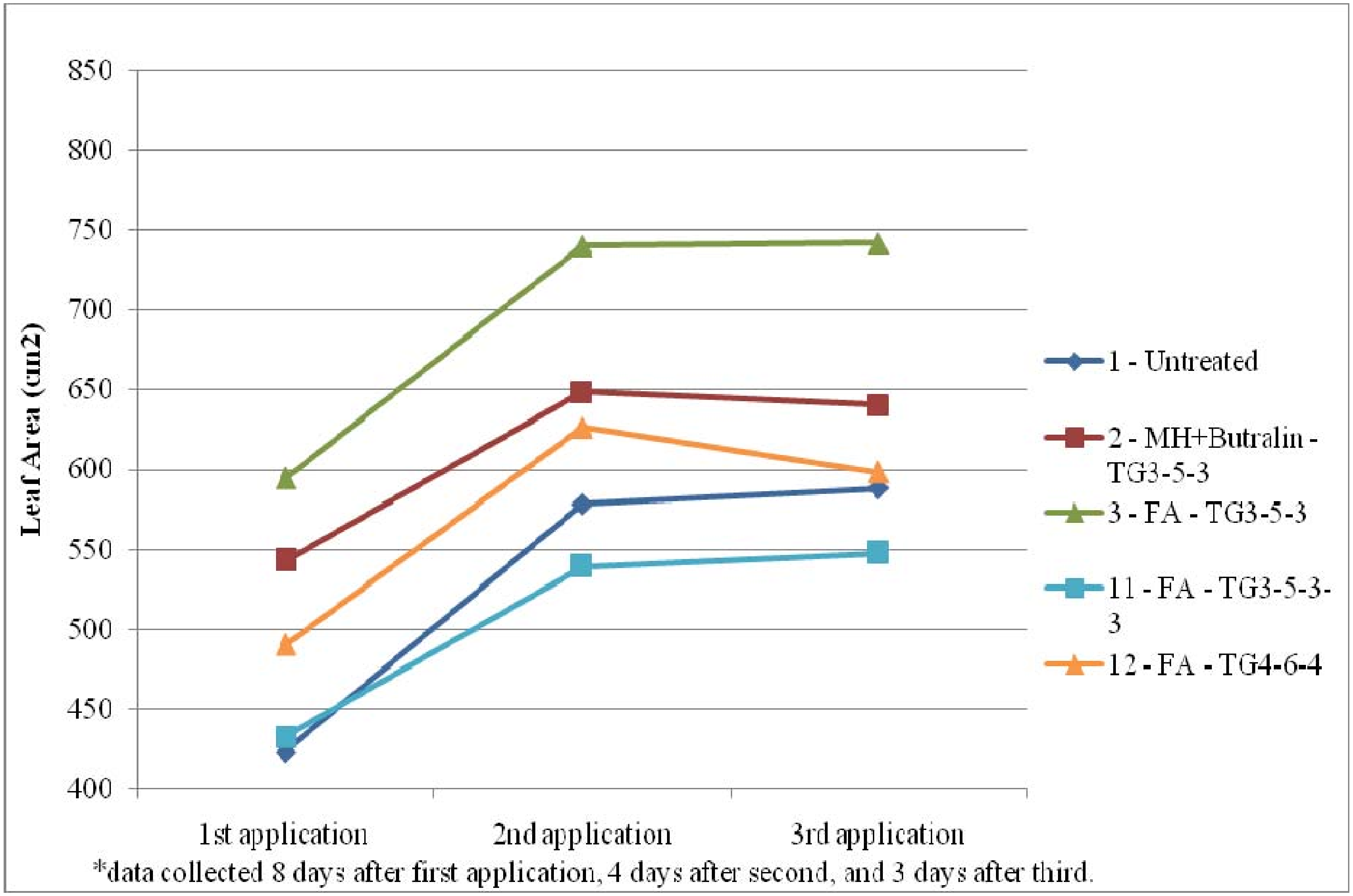


Figure 2.20: Top leaf growth rate between 1st, 2nd, and 3rd applications for treatments in 2009.

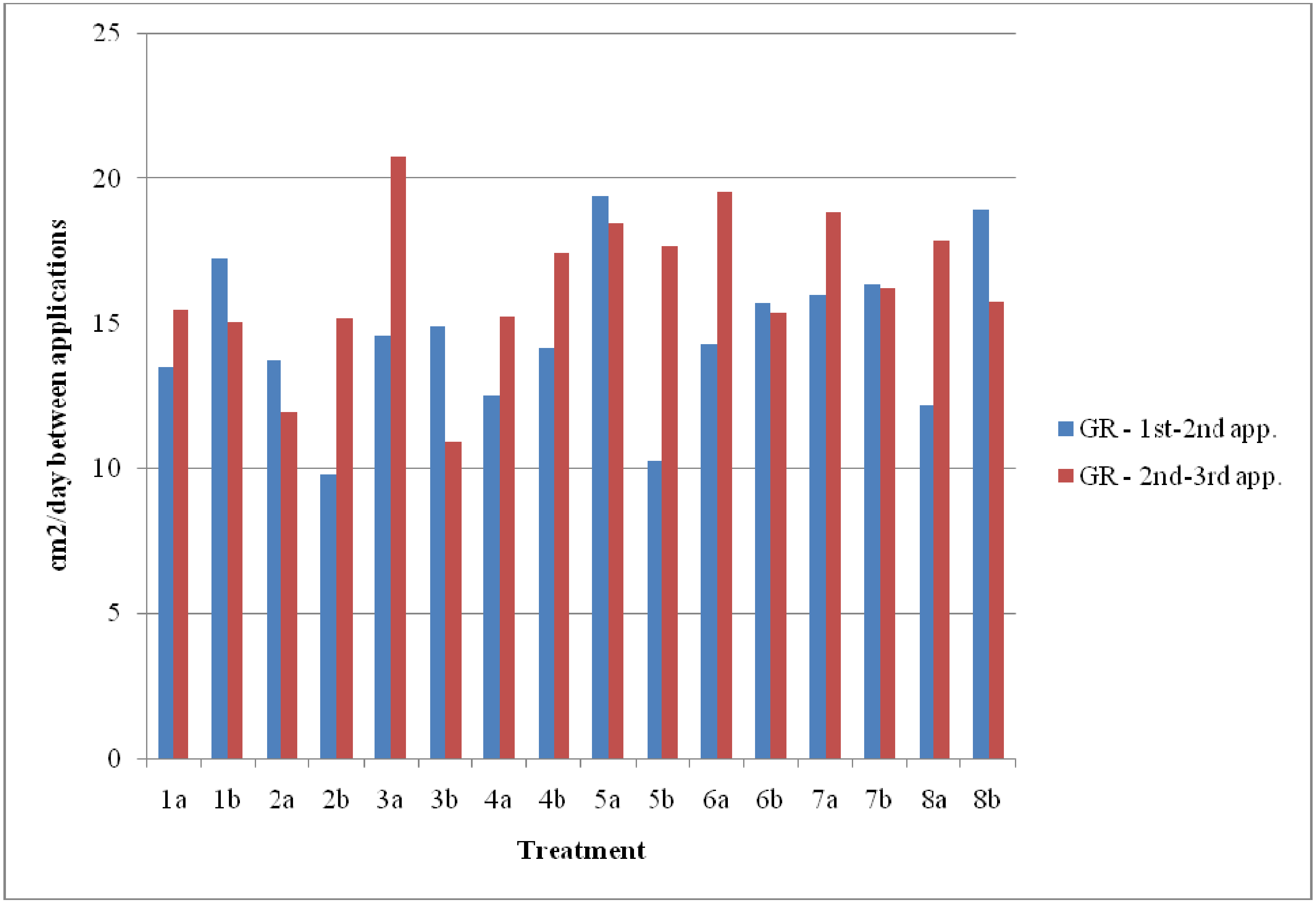


Figure 2.21: Top leaf growth rate between 1st, 2nd, and 3rd applications for treatments in 2010.

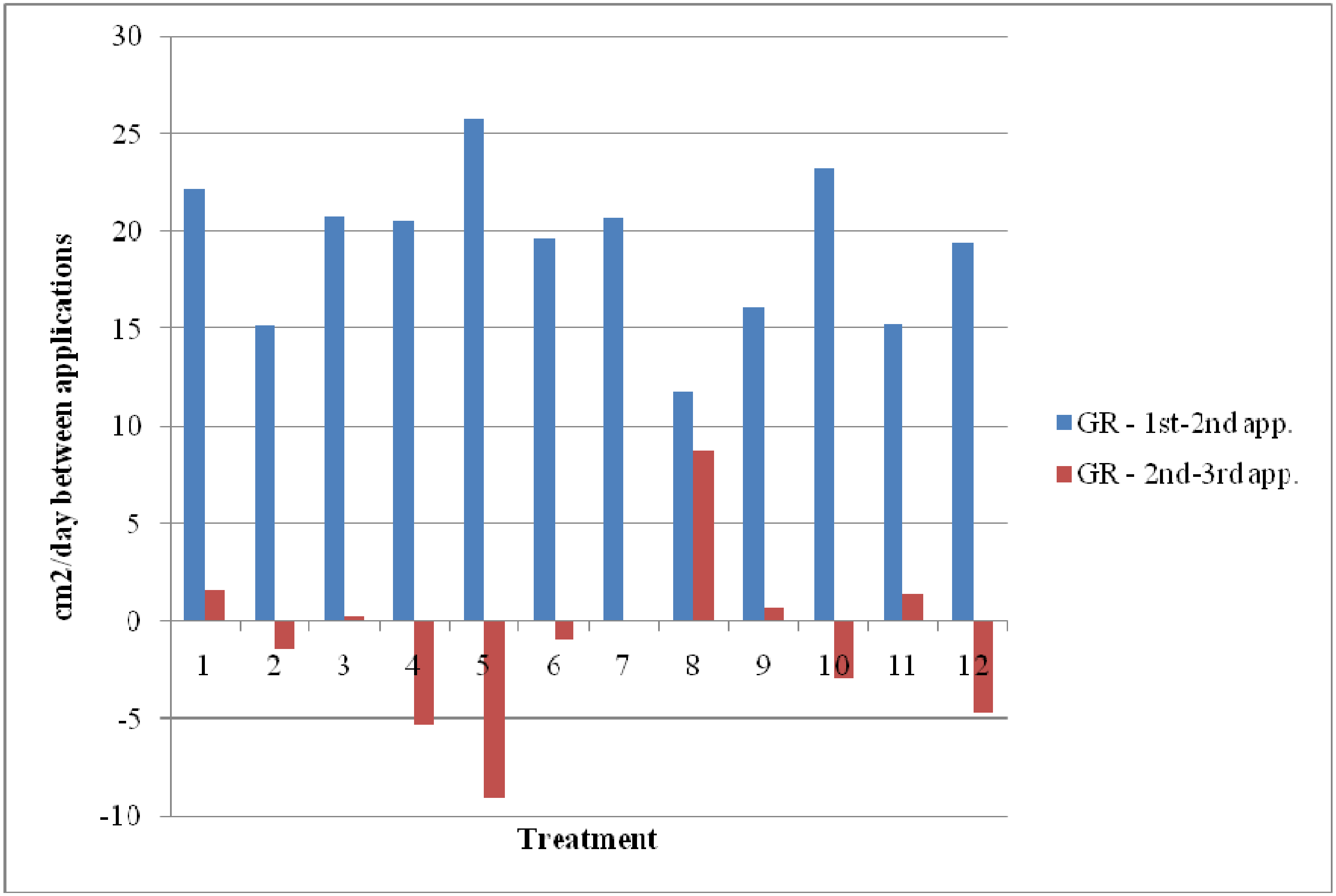


Figure 2.22: Cured yields for treatments in 2009.

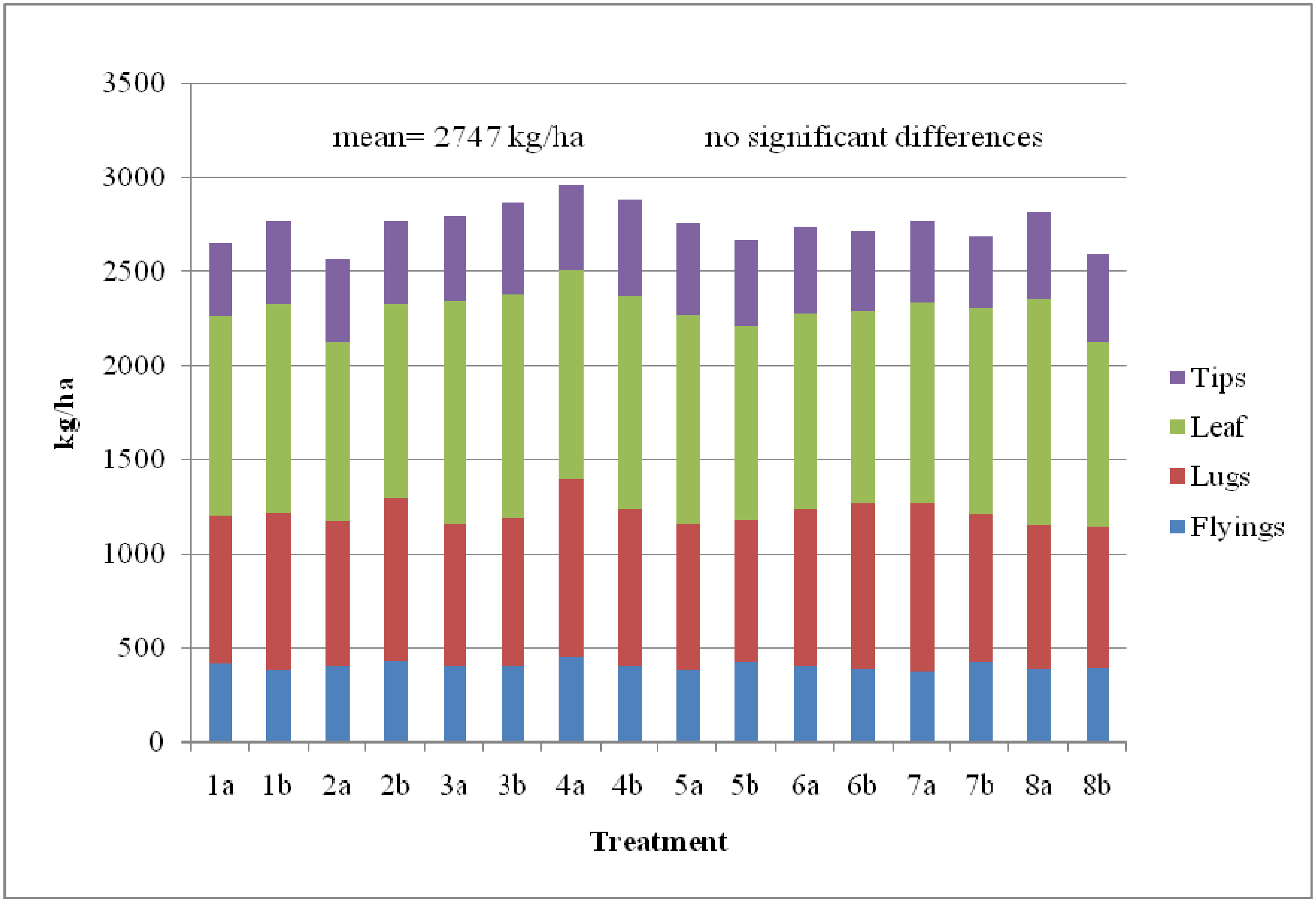
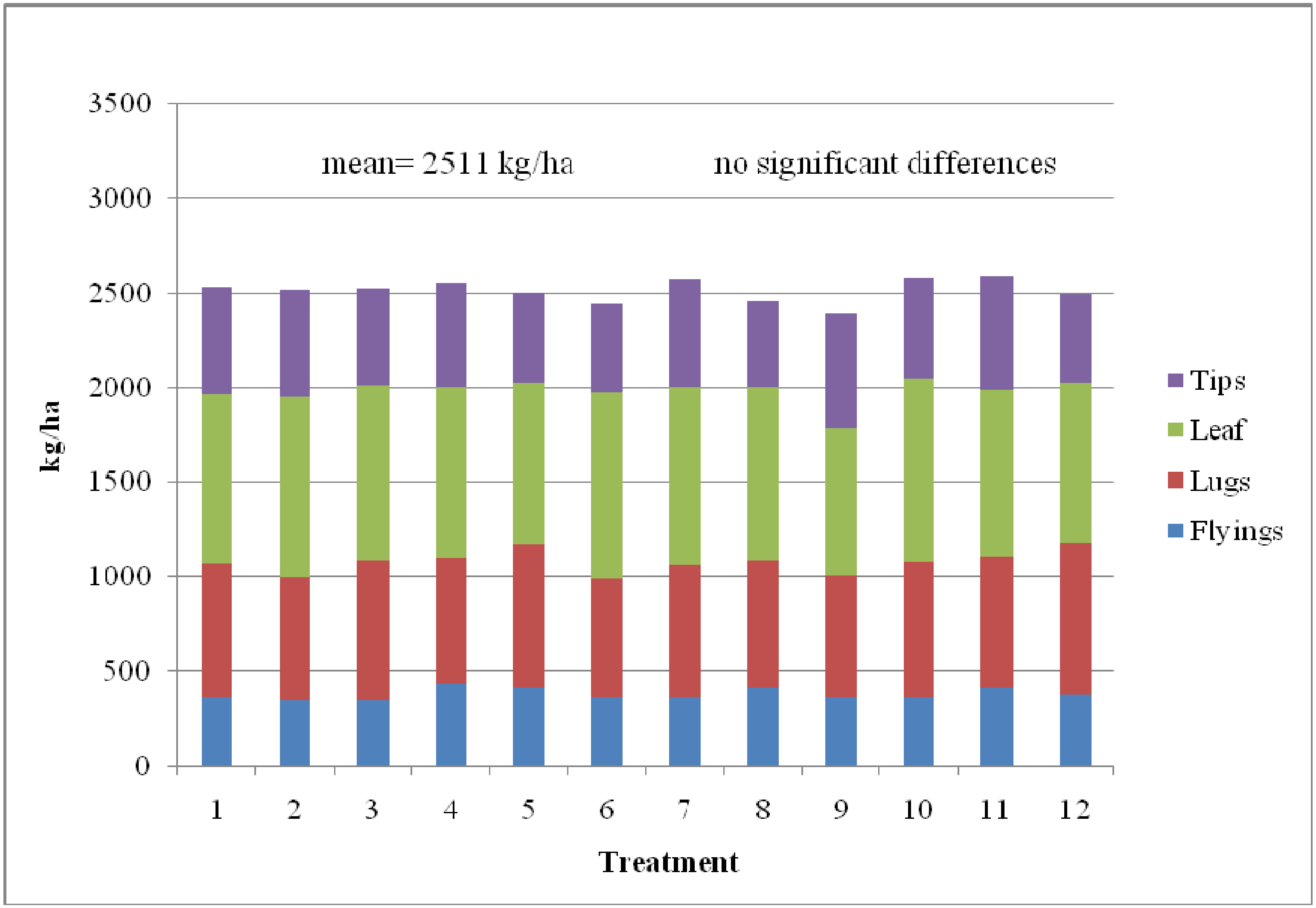


Figure 2.23: Cured yields for treatments in 2010.



Chapter 3: Artificial Plant Studies

Materials and Methods

Research for this experiment was conducted in 2010 at the Kentucky Agricultural Experiment Station Spindletop Farm (38° 01’ N, 84° 35’ W) as well. Using artificial tobacco plants (Figure 3.1), studies were done to evaluate collection of spray solution on individual leaves (at leaf axillary areas) as well as the total solution collected (top four leaves) for each plant as a percentage of total solution sprayed over that plant. These observations would allow comparisons to be made between the best performing nozzle types and arrangements from field studies, perhaps suggesting a significantly better arrangement than the typical TG3-5-3.

Upon beginning construction of the artificial plants, it was determined that actual stalks from burley tobacco plants would be used as support for the artificial leaves. Stalks were selected from cured tobacco still hanging from the previous year. The cured stalks would ensure strength and stability in the structure of the plant. The greatest benefit of utilizing real stalks is that it allowed the artificial leaves to be placed in their proper locations (dried leaf axils still present after breaking leaves off), making certain of the proper leaf phyllotaxy. Holes were drilled into the lids of five gallon buckets in order to place the stalks in a standing position. Sand was added to approximately one-third of the bucket in order to both stabilize the stalk in its position and increase weight of the entire artificial plant.

In order to simulate realistic shape and size, 18 gauge sheet metal was used to construct the leaves. To create an accurate plant contour, average size (length and width) of the top leaves recorded from the previous year of field studies was used. Size was increased with each descending leaf by approximately 10% down to the fourth leaf. Only the top four leaves were used in this study because it was felt this would provide an accurate representation of sucker collection as it relates to in-field applications. Also, for good sucker control Seltmann (1994) found it is critical that the top 3-4 leaves catch the solution in order to naturally funnel the chemical down the stalk. Anchor arms were included (cut) with the shape of the leaves in order to fasten them to the stalks. Holes were then drilled in those anchor sections so that zip tie fastener straps could be placed through the leaves and around the stalk, holding the leaves in place.

Once the leaves were in place, ½ inch holes were drilled at the axillary areas so as to insert ½ inch all tube compression inserts (#27638). Clear vinyl collection tubes (7/16” outside diameter x 5/16” inside diameter, #22272) were attached to the insert and routed to a specimen cup for solution collection. Each of the four measurement cups were placed in a hole-sawed seat in a fabricated float tray which was cut to fit securely around the stalk on top of the bucket lid (Figure 3.1). This would allow for solution running down the leaf to be funneled down the tube to the cup for measurement.

Figure 3.1: Artificial plants 1 and 2

A total of 16 treatments (Table 3.1) were applied twice (two plants) with four replications of each treatment. The same high clearance sprayer, boom, and row application kits used in the field studies were used for the artificial plants. Treatments were applied at a speed of 1.6 kph (1 mph) in order to make certain there was a measureable amount of solution collected. Treatments were applied at the same clearance as the field studies (30 cm). All 16 treatments were applied twice, first over leaves positioned relatively horizontal or similar to normal position when drought stress is not present. The second application of treatments was made with leaves in more of an upright position, essentially "cupped" together at the top of the plant simulating drought stress or windy conditions. The two artificial plants used in this study were labeled plant 1 and plant 2; both were used for all treatments applied throughout this portion of the study. While each of the four leaves were the same size for both plant 1 and plant 2, leaf position and plant height varied slightly as they would in field conditions. A total of four nozzle arrangements made up the 16 treatments. With each arrangement, treatments consisted of two possible top leaf positions (parallel or perpendicular to the row) and two nozzle arrangement positions (center of row or 15 cm off-center).

After each replication of each treatment was applied, solution collected from the cups was measured for each leaf. Leaves were wiped off with paper towels after each and every application to ensure consistent measurements between replications.

Table 3.1: Artificial plant treatments applied.

Treatment	Nozzle(s) used/arrangement	Description of top leaf and sprayer orientation
1	TG3-5-3	parallel, centered
2	TG3-5-3	perpendicular, centered
3	TG3-TT11005-TG3	parallel, centered
4	TG3-TT11005-TG3	perpendicular, centered
5	TG3-5-3	parallel, 15 cm off-center
6	TG3-5-3	perpendicular, 15 cm off-center
7	TG3-TT11005-TG3	parallel, 15 cm off-center
8	TG3-TT11005-TG3	perpendicular, 15 cm off-center
9	TG3-DG8004-DG8004-TG3*	parallel, centered
10	TG3-DG8004-DG8004-TG3	perpendicular, centered
11	TG3-DG8004-DG8004-TG3	parallel, 15 cm off-center
12	TG3-DG8004-DG8004-TG3	perpendicular, 15 cm off-center
13	TG4-6-4	parallel, centered
14	TG4-6-4	perpendicular, centered
15	TG4-6-4	parallel, 15 cm off-center
16	TG4-6-4	perpendicular, 15 cm off-center

*these treatments consisted of both DG8004 nozzles over top of the row (one trailing the other) approximately 46 cm apart.

Results

Data are reported as the main effect means based on tests analyzed in Statistical Analysis Software (SAS, Version 9.2), including the GLM procedure and t tests (*least squares differences*) for volume collected. Collected solution as a percentage of total sprayed solution was also computed to estimate the efficiency of interception for each treatment. Data from plant 1 and plant 2 were analyzed separately and were not compared as they differed slightly in form and leaf arrangement.

For both plants 1 and 2 with normal and upright leaves, SAS results showed treatment and leaf were both highly significant ($p<0.0001$); Treatment and leaf interaction was significant as well (highly significant for the normal leaves) because one or more leaves (1, 2, 3, or 4) captured more solution than others for various treatments. For both plants 1 and 2, results were fairly similar in comparison of treatments and solution collected within the normal leaf angles and the vertical leaf angles.

In comparing treatments applied to the normal more horizontally positioned leaves (Figure 3.2-3.9), the TG4-6-4 treatments generally had a greater volume of total solution collected (Figure 3.8 and Figure 3.9). For plant 1, treatments 14, 16, 15, and 2 (TG4-6-4, TG3-5-3) produced significantly higher collected volumes over all the other treatments (Figure 3.2 and Figure 3.8). For plant 2, the highest collected volumes came from TG4-6-4 and TG3-5-3 treatments (Figure 3.3, Figure 3.7, and Figure 3.9). Treatment 2 (TG3-5-3 centered) was significantly greater than all treatments except 14 (TG4-6-4 centered). Treatment 14 also proved greater than all except 2, 12, 1, and 16.

Results for treatments applied to plants with upright leaves (Figures 3.10 thru Figures 3.17) simulating drought stress or windy conditions proved to be significantly different than those of the horizontally positioned leaves. The volume of solution collected (leaves 1-4 and total) when leaves were essentially “cupped” together averaged less than one half the volume of solution collected on “normal” leaves. While only minimal differences occurred in regard to solution collected across treatments on these plants, treatment 2 (TG3-5-3 centered) resulted in the largest volume of solution collected. Treatment 2 collection was significantly more than all other treatments for plant 1, and significantly more than all treatments for plant 2 except treatments 6 and 14. Treatment 14 (TG4-6-4 centered) also performed well over plant 1. Once again, there were only minimal differences observable due to the low volume of solution overall.

The total volume of solution collected by both plants 1 and 2 decreased significantly ($p<0.0001$) when the TG3-5-3 arrangement was run 15 cm off-center of the plant (Figure 3.18). Seeing as how this is the most commonly used arrangement currently in use, this factor could be very critical in sucker control for producers. Treatments 6, 8, 5, 11 and 7 (off-center treatments) sprayed over plant 1 with normal leaves showed significantly less solution collected. The other three nozzle arrangements were less affected when the sprayer was run 15 cm off-center. Treatments 16 and 15 using the TG4-6-4 arrangement being applied off-center exhibited the most amount of solution collected when averaged over plants 1 and 2 and was not affected at all by the sprayer being off-center. Over plant 2 with normal leaves, results were variable and center vs. off-center had no observable differences. When run off-center, it is evident that the distribution of solution captured is altered (Figures 3.2 thru 3.7). While the same total amount of solution may have been intercepted by the plant, it may have been from just one, two, or three leaves. In field situations this would equate to leaves being missed and sucker escapes in those leaf axils.

When sprayed over upright leaves, the results in comparing center vs. off-center were similar (Figure 3.19). Over both plants, although off-center treatments 6, 16, and 5 performed well, there were still no significant differences in volume of solution collected compared to other treatments. Making comparisons within each treatment, no significant differences were found in comparing center vs. off-center.

In regard to top leaf orientation being parallel or perpendicular, no significant differences (except TG4-6-4 over normal) were present when comparing treatments for either the normal or upright leaf orientations. Although not significant, the top leaf being perpendicular to the row increased the total (4 leaves) solution collected for all treatments over both plants 1 and 2 for normal and upright leaves (significant for TG4-6-4 over normal). This is displayed in Figure 3.20 and Figure 3.21.

When the top leaf was analyzed separately for solution collection, significant differences were shown as well as a significant interaction of treatment and leaf. Leaf 1 had significantly less solution collected when compared to leaves 2, 3, and 4. When treatments were applied over normal leaf plants, leaf 1 solution was significantly less than the other three leaves on plant 1, and significantly less than leaves 2 and 3 for plant 2. For the upright positioned leaves, leaf 1 solution was significantly less than leaves 2 and 4 for plant 1. Over plant 2, however, it had the highest amount of solution collected and was significant over leaves 2, 3, and 4.

When comparing the top leaf (1) orientation (parallel vs. perpendicular) between treatments, the top leaf consistently captured more solution when it was parallel to the row and leaves were at the normal angle (Figure 3.22); this difference was significant for arrangements TG3-5-3, TG3-TT11005-TG3, and TG3-DG8004-DG8004-TG3. The amount of solution collected by the top leaf with the TG4-6-4 arrangement was not affected at all when the top leaf was perpendicular to the row. This result was not evident when applications were made over plants with upright leaves. Even though there were no significant differences, the perpendicular top leaf tended to intercept more solution (Figure 3.23).

Interception as percentage of solution sprayed over the artificial plants was calculated for this study. When analyzed for treatments sprayed over plants with upright leaves, no differences existed and percent collected averaged 8.61%. However, there were differences when the treatments were applied over plants with normal leaves. Percent collected across all treatments averaged 29.59%, significantly greater than with the upright leaf plants. No significant differences existed for the TG3-TT11005-TG3 (Figure 3.26 and Figure 3.27) and TG3-DG8004-DG8004-TG3 (Figure 3.28 and Figure 3.29) arrangements in regard to sprayer or top leaf orientation. When looking at the common TG3-5-3 (Figure 3.24 and Figure 3.25) arrangement and the best performing TG4-6-4 (Figure 3.30 and Figure 3.31) arrangement, there were some observable differences. The TG3-5-3 performed significantly greater when the sprayer was center of the plant and top leaf orientation did not have much effect. The TG4-6-4 arrangement provided a greater percent of collected solution than the other treatments and was un-affected by the sprayer being off-center or top leaf being perpendicular. Nozzle arrangement orientation did not have as much of an effect as did top leaf orientation where perpendicular provided more solution collected. This arrangement provided average to above average percent interception across all variables making it the most efficient arrangement.

Figure 3.2: TG3-5-3, Normal leaves, Plant 1, solution collected.

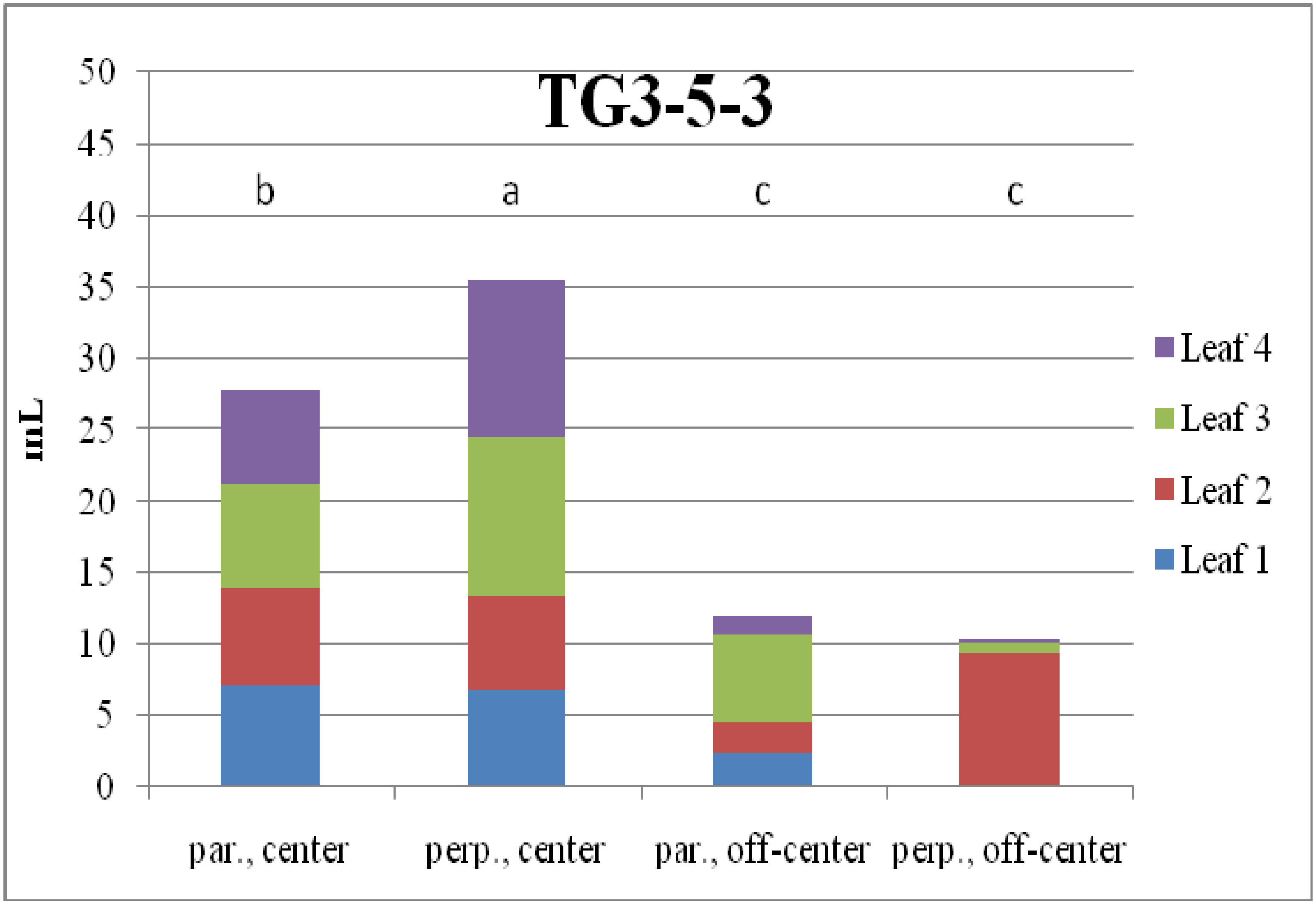


Figure 3.3: TG3-5-3, Normal leaves, Plant 2, solution collected.

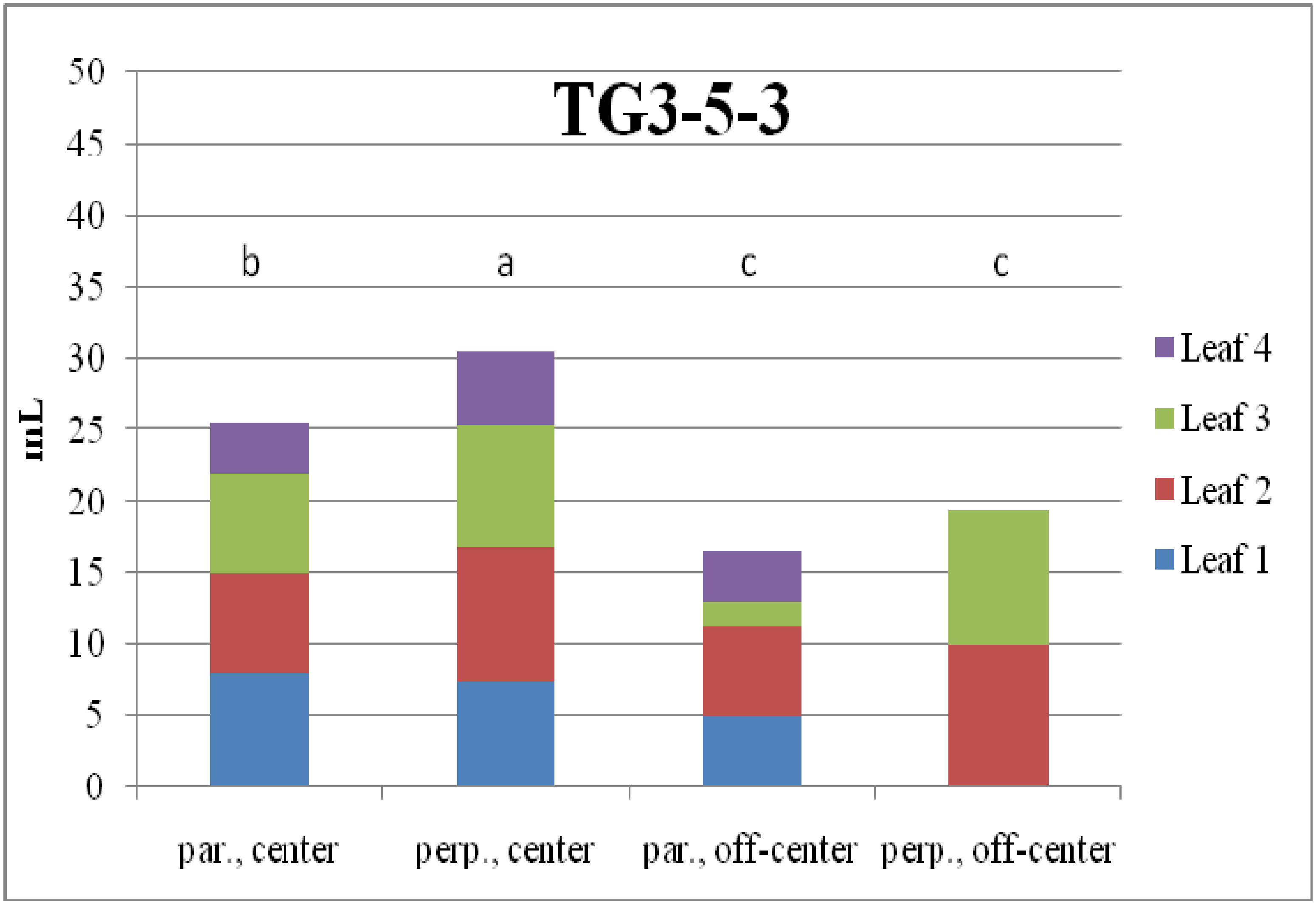


Figure 3.4: TG3-TT11005-TG3, Normal leaves, Plant 1, solution collected.

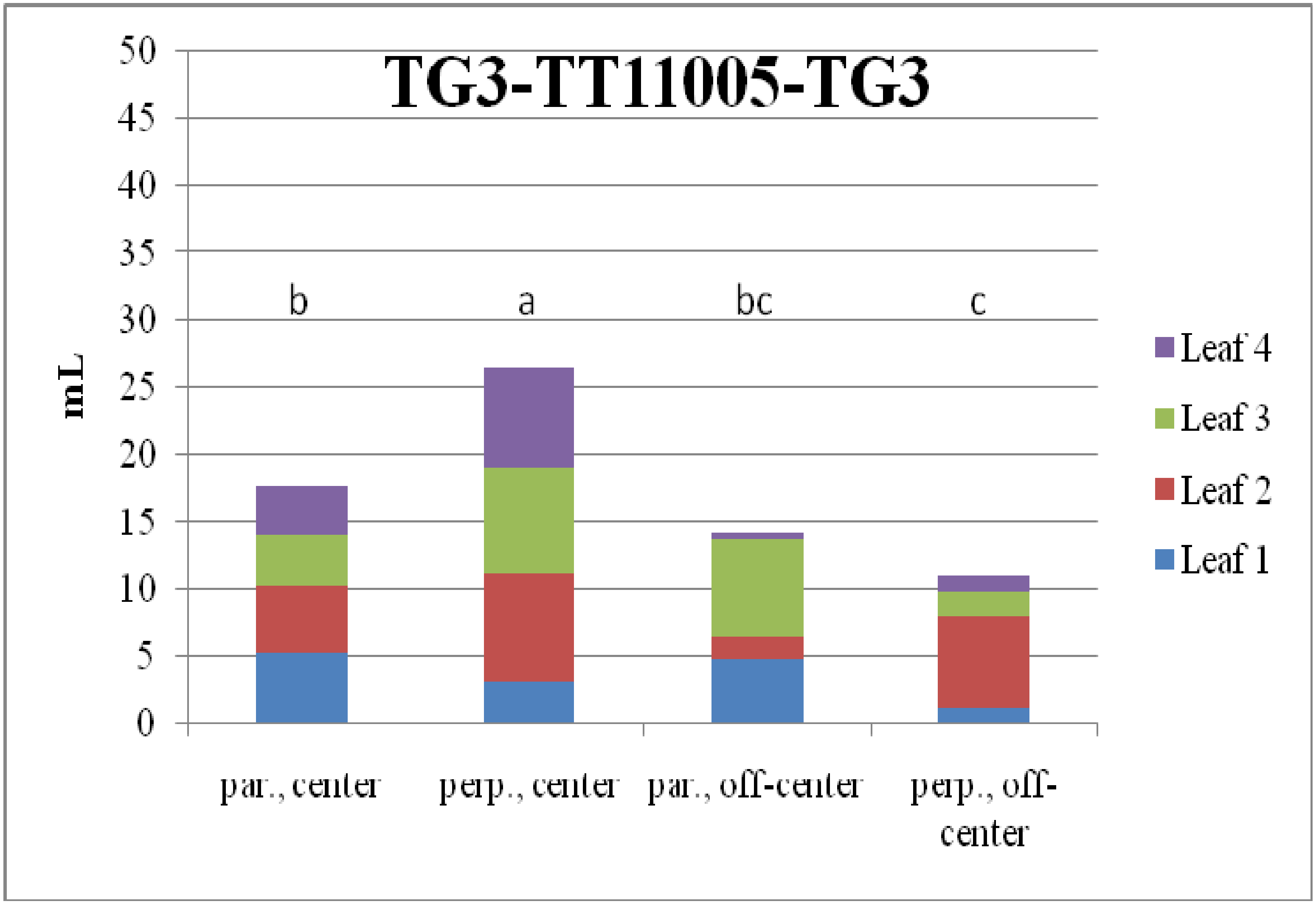


Figure 3.5: TG3-TT11005-TG3, Normal leaves, Plant 2, solution collected.

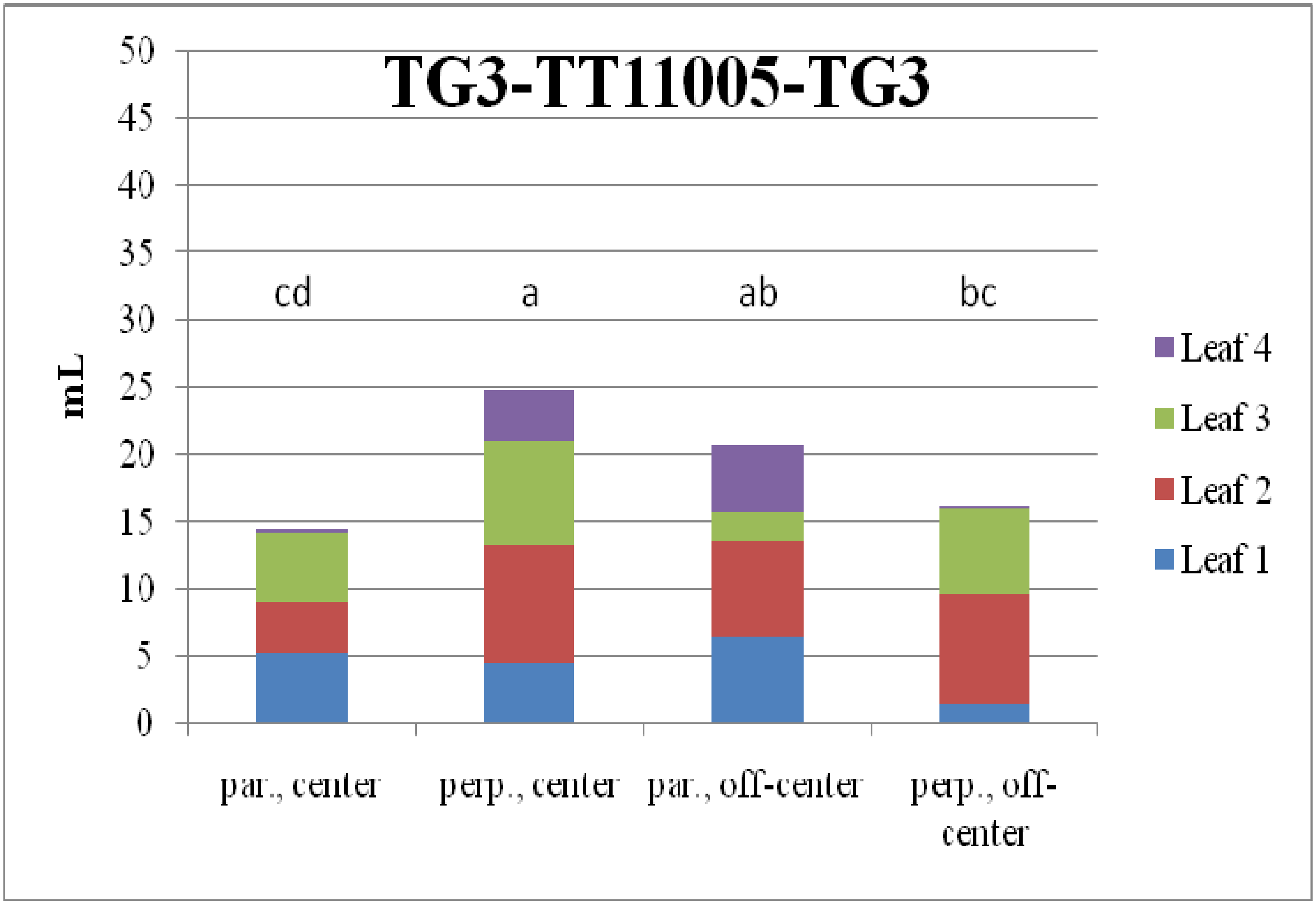


Figure 3.6: TG3-DG8004-DG8004-TG3, Normal leaves, Plant 1, solution collected.

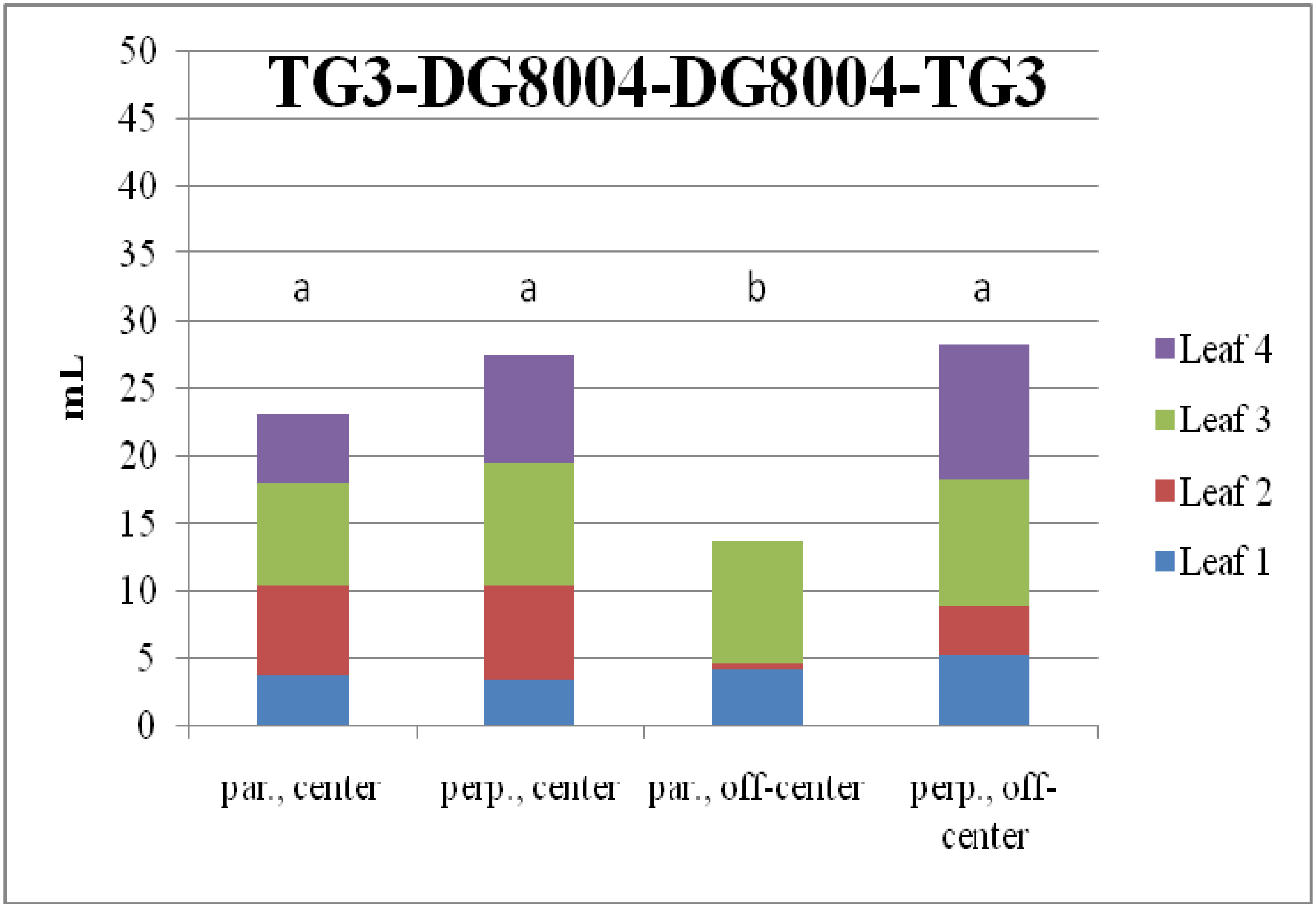


Figure 3.7: TG3-DG8004-DG8004-TG3, Normal leaves, Plant 2, solution collected.

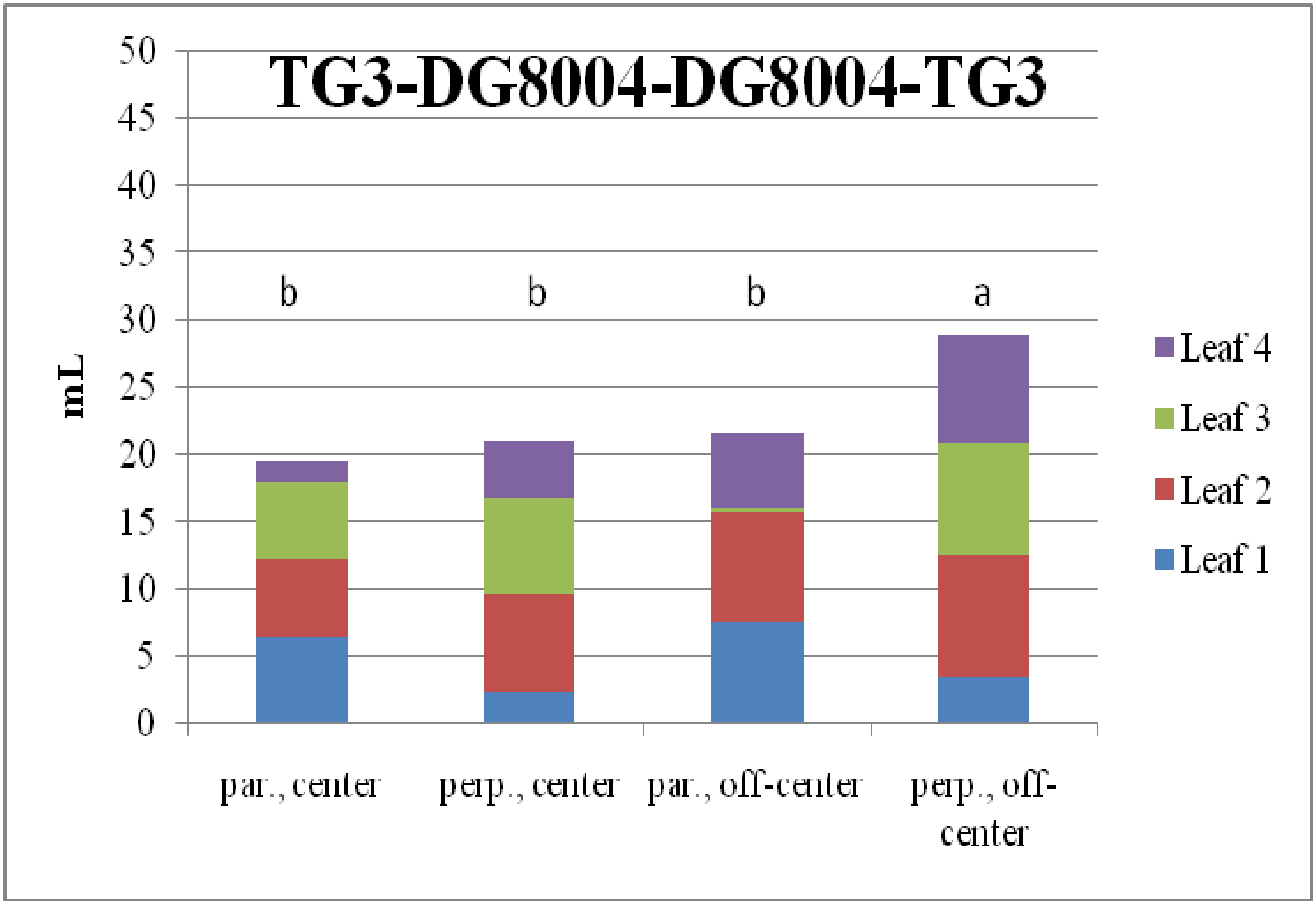


Figure 3.8: TG4-6-4, Normal leaves, Plant 1, solution collected.

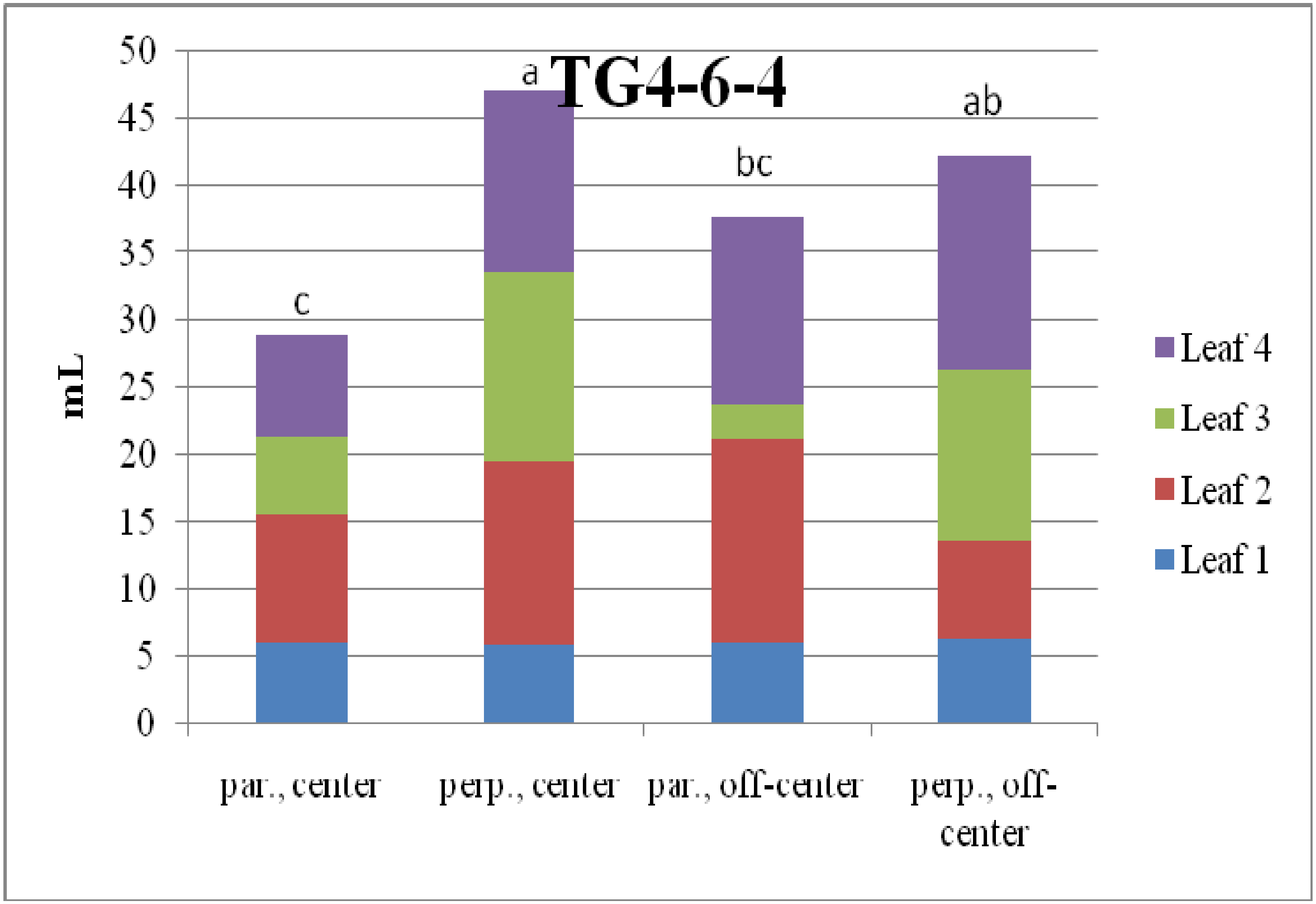


Figure 3.9: TG4-6-4, Normal leaves, Plant 2, solution collected.

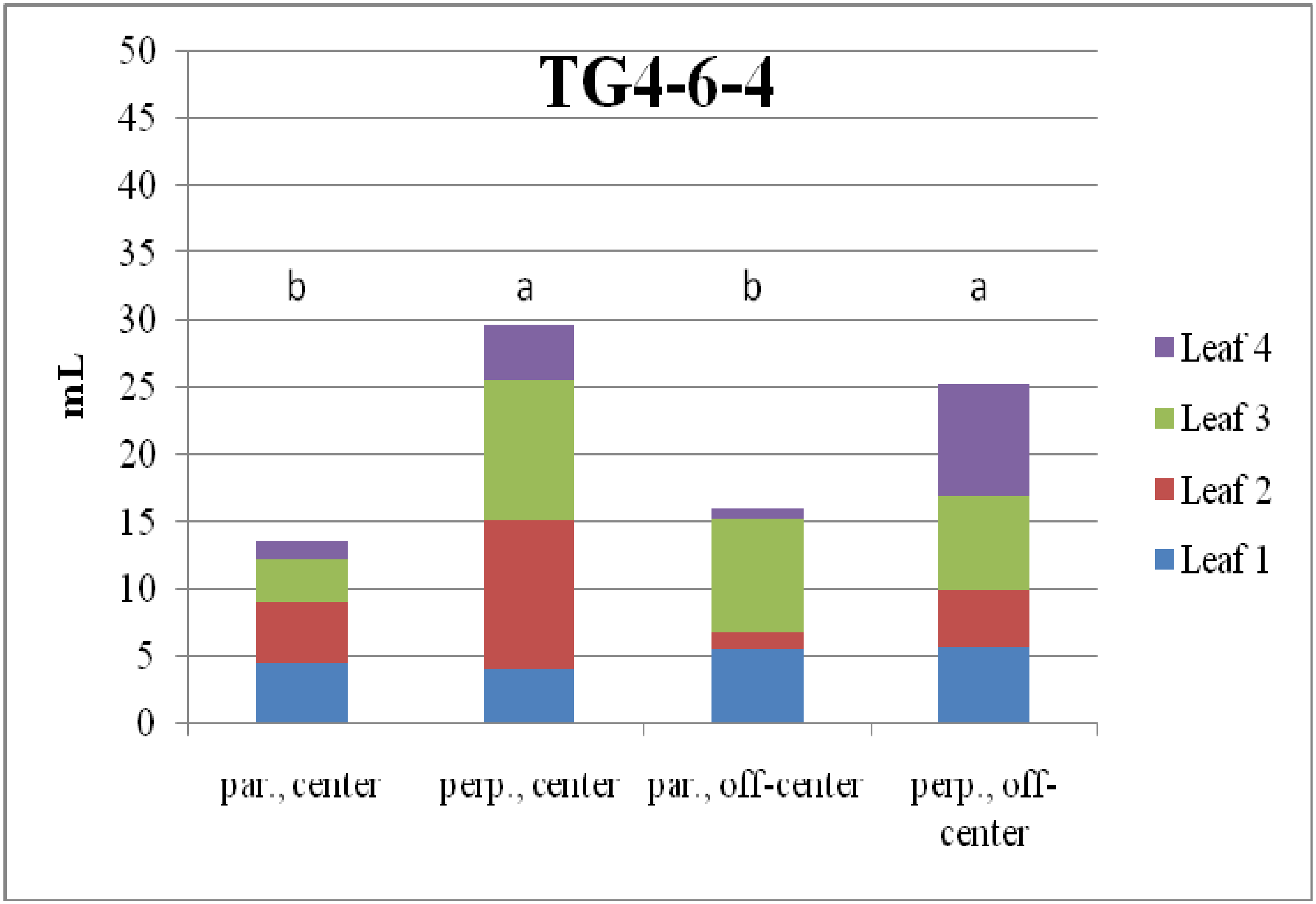


Figure 3.10: TG3-5-3, Upright leaves, Plant 1, solution collected.

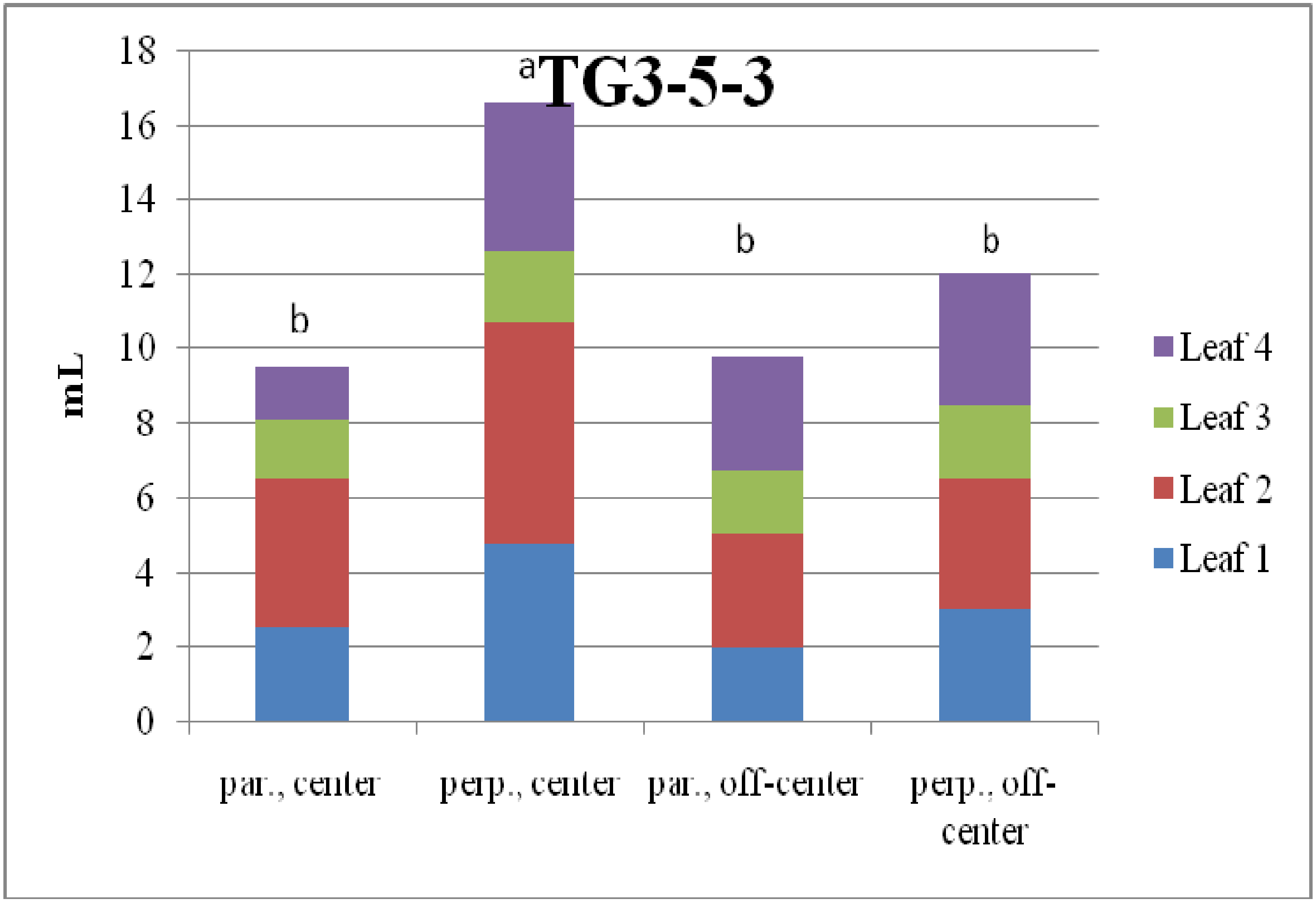


Figure 3.11: TG3-5-3, Upright leaves, Plant 2, solution collected.

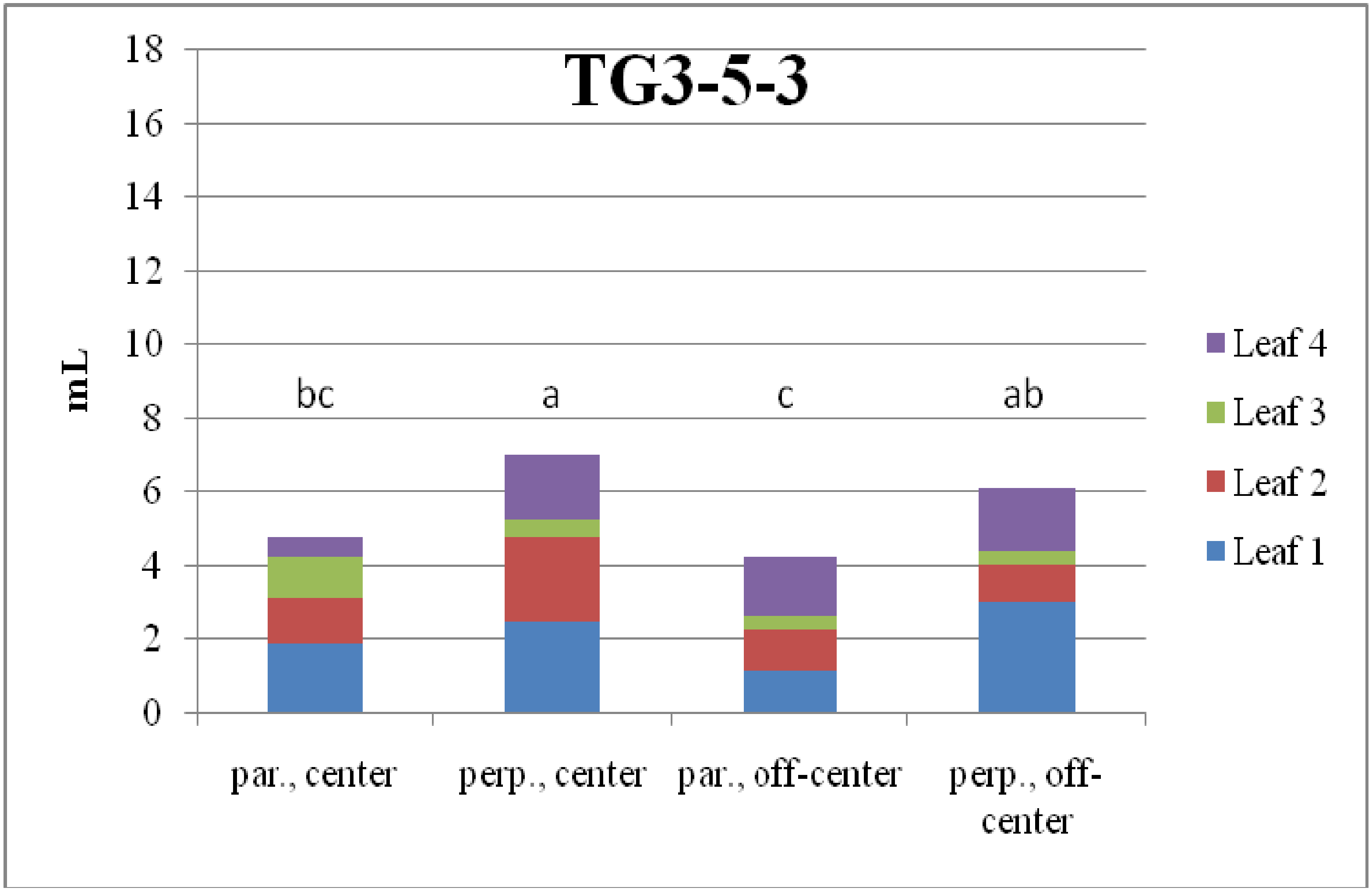


Figure 3.12: TG3-TT11005-TG3, Upright leaves, Plant 1, solution collected.

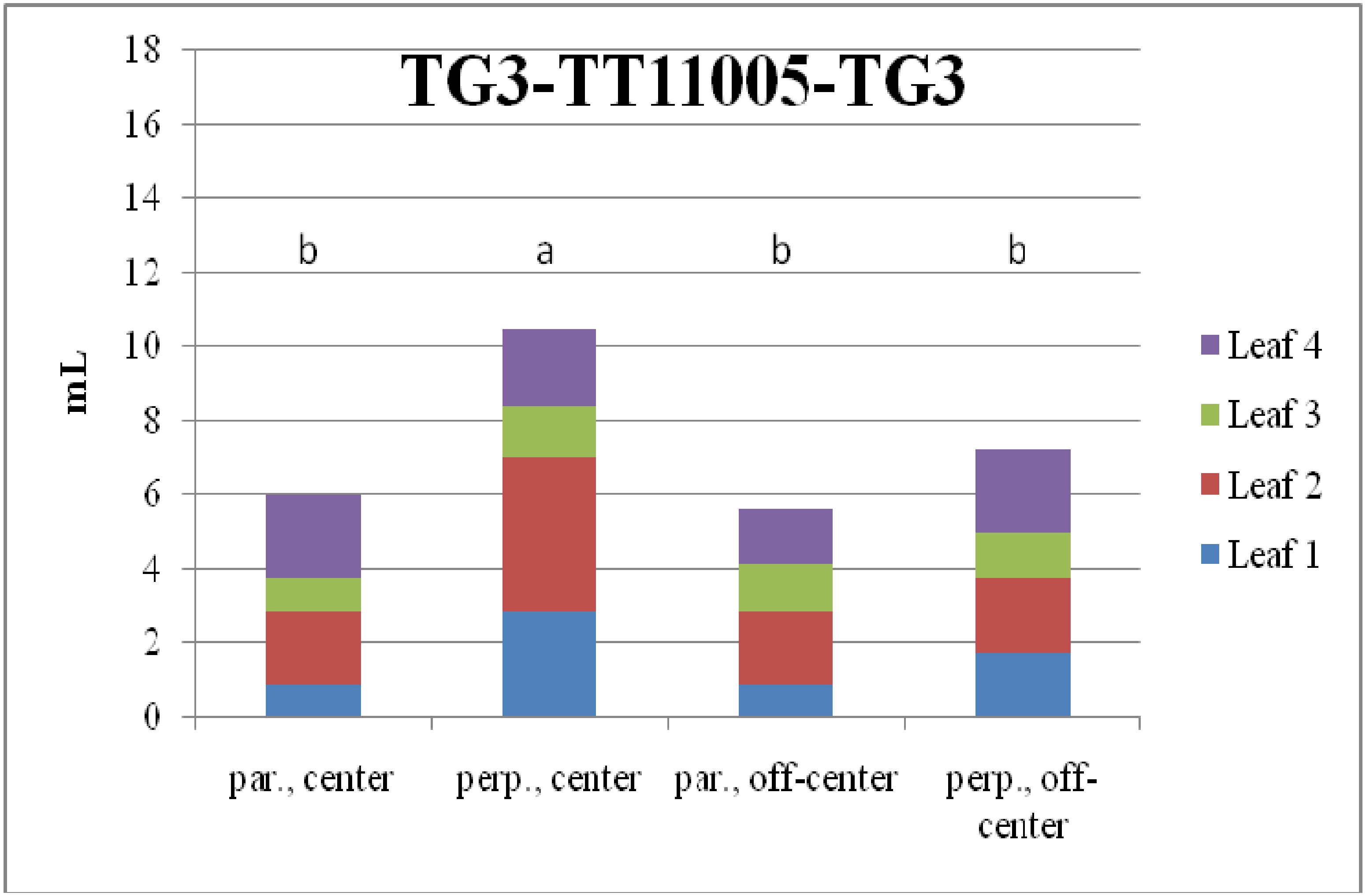


Figure 3.13: TG3-TT11005-TG3, Upright leaves, Plant 2, solution collected.

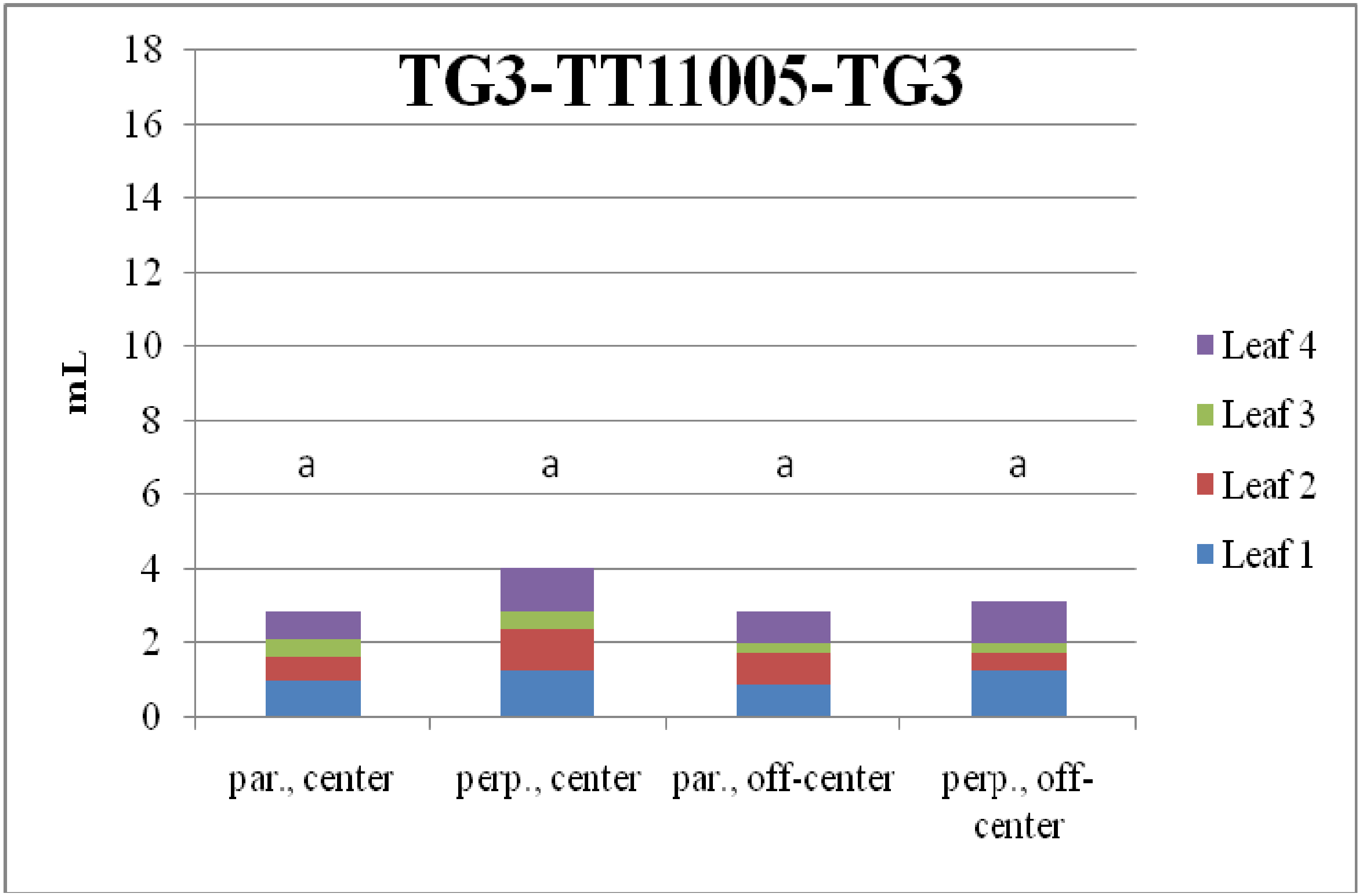


Figure 3.14: TG3-DG8004-DG8004-TG3, Upright leaves, Plant 1, solution collected.

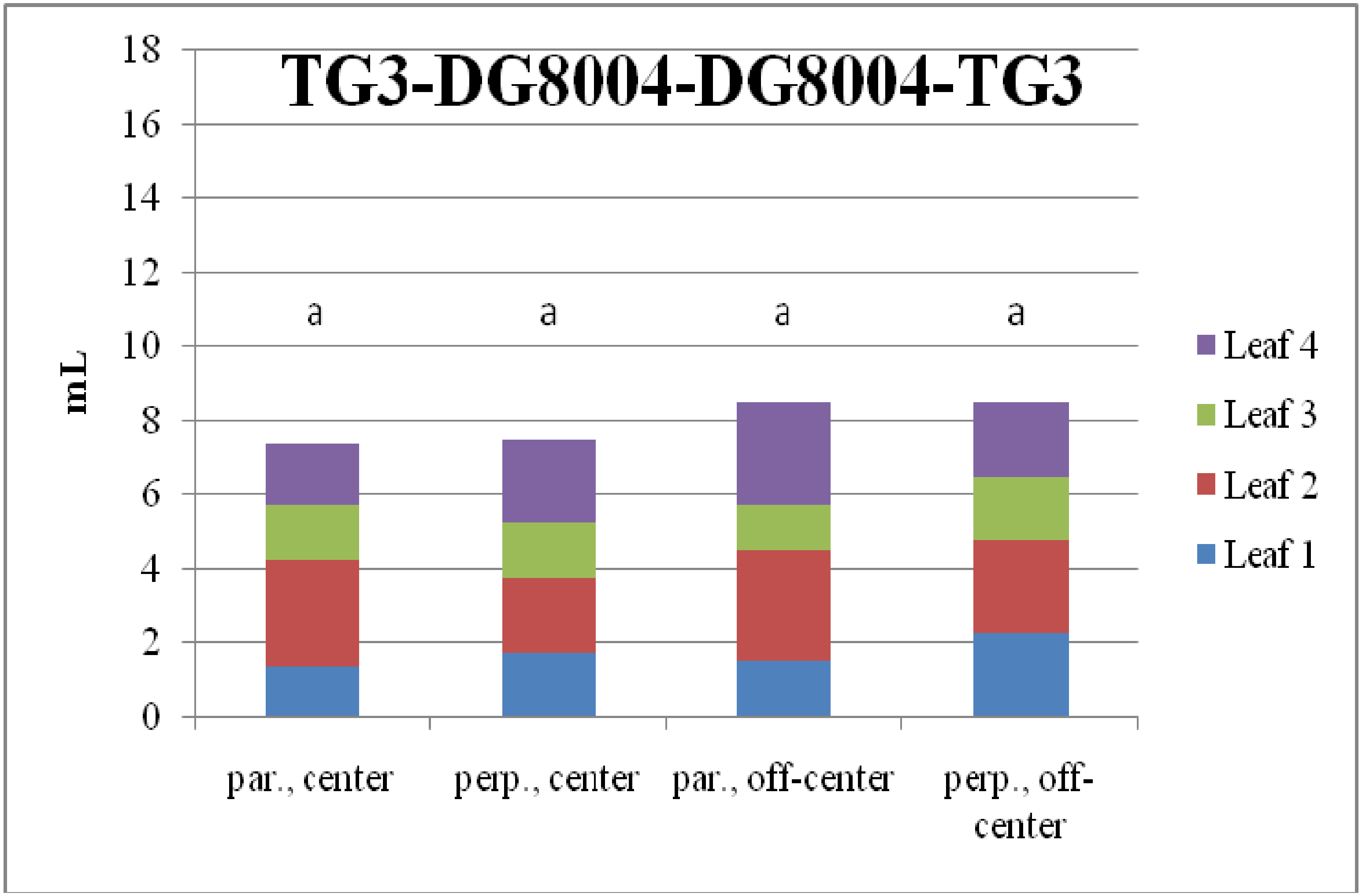


Figure 3.15: TG3-DG8004-DG8004-TG3, Upright leaves, Plant 2, solution collected.

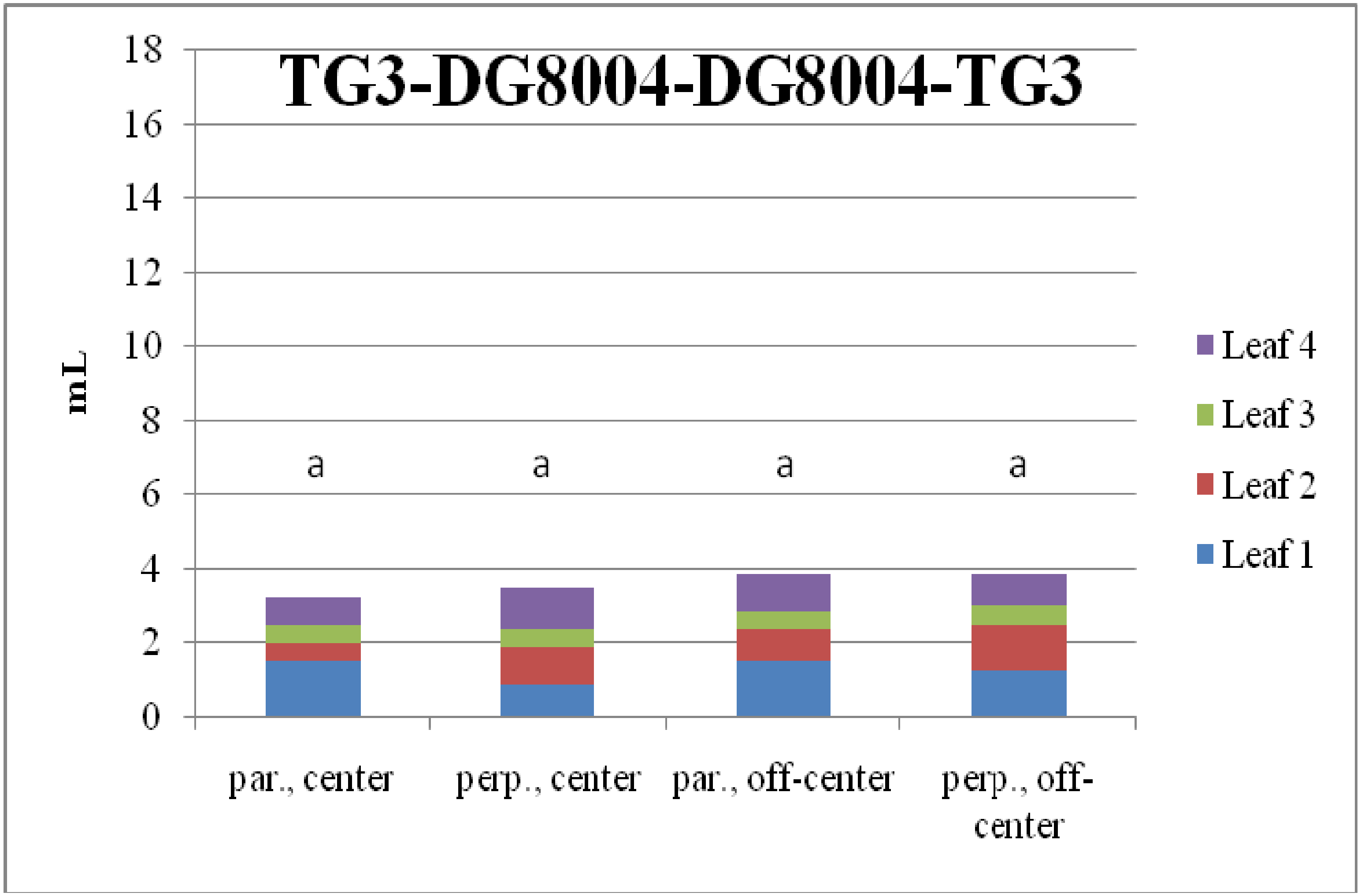


Figure 3.16: TG4-6-4, Upright leaves, Plant 1, solution collected.

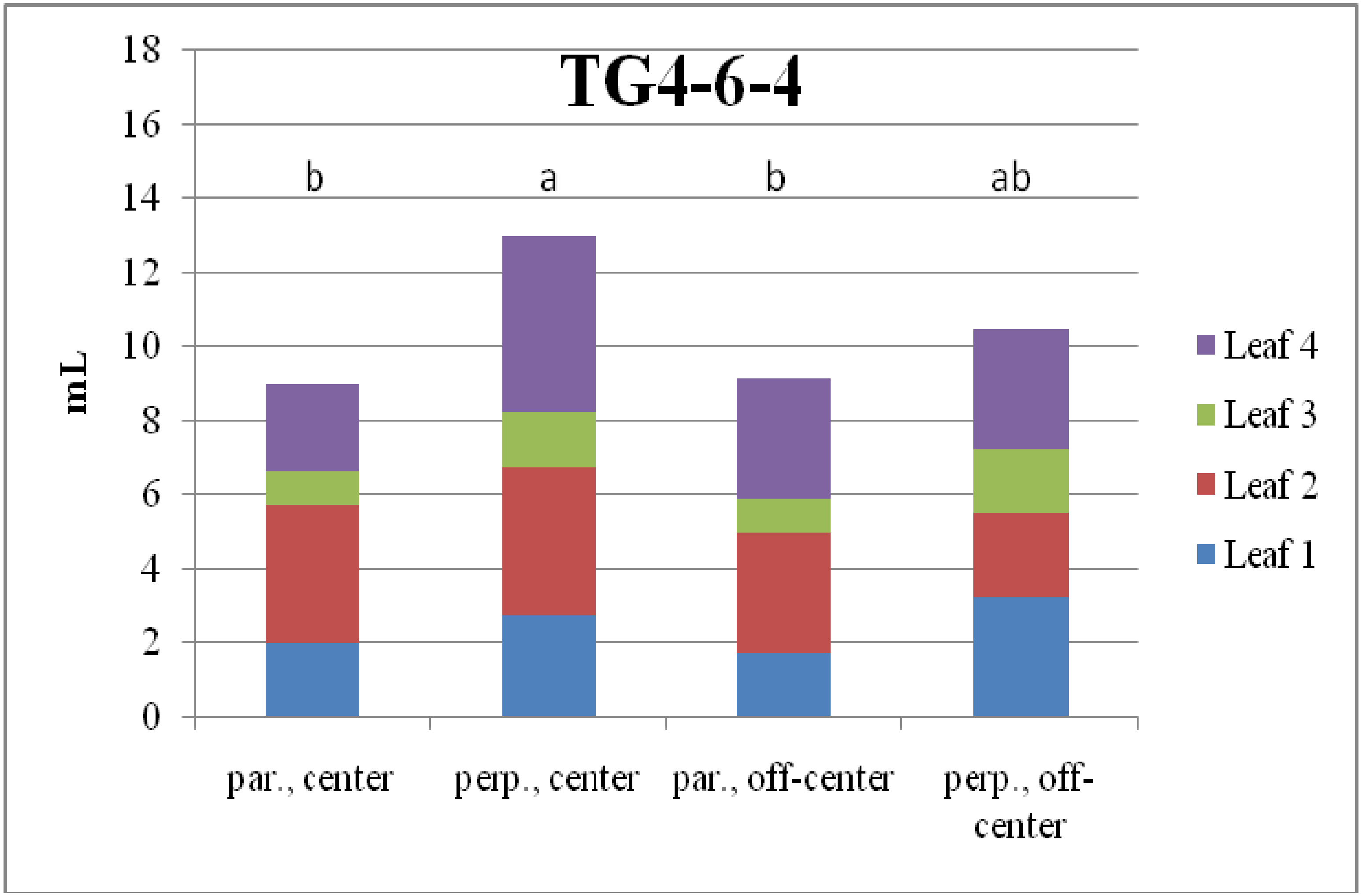


Figure 3.17: TG4-6-4, Upright leaves, Plant 2, solution collected.

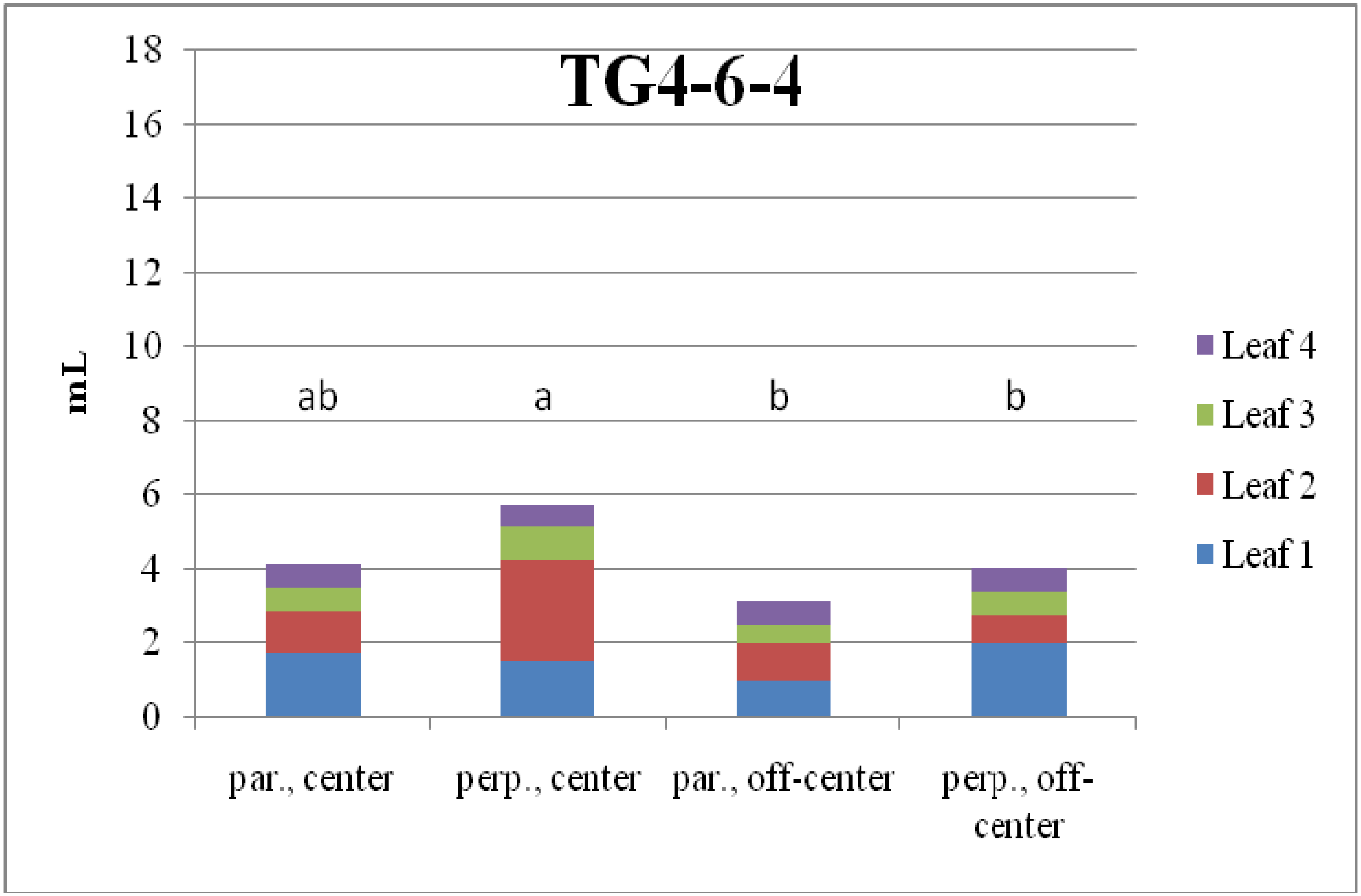


Figure 3.18: Sprayer centered vs. 15 cm off-center over normal leaves, solution collected.

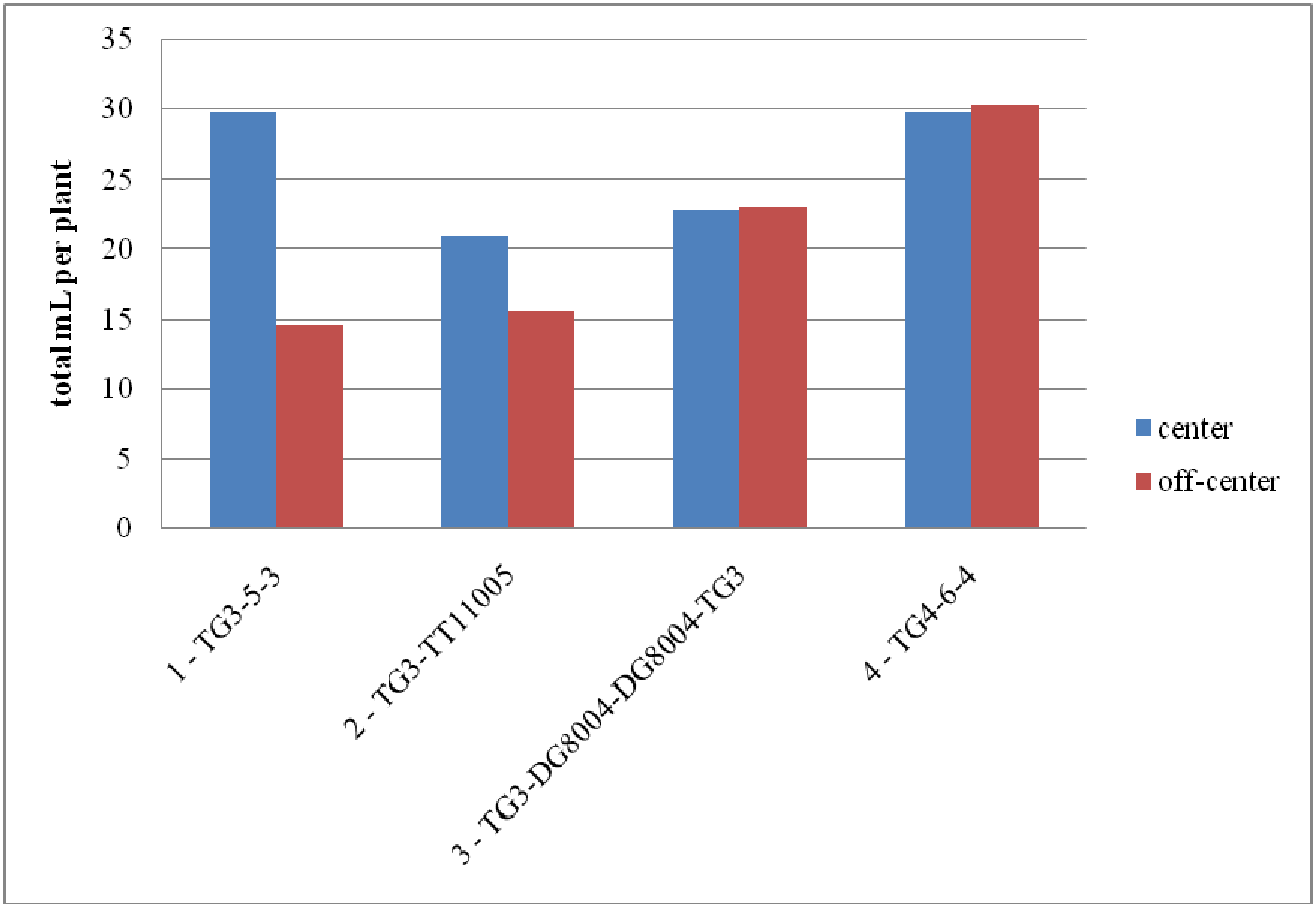


Figure 3.19: Sprayer centered vs. 15 cm off-center over upright leaves, solution collected.

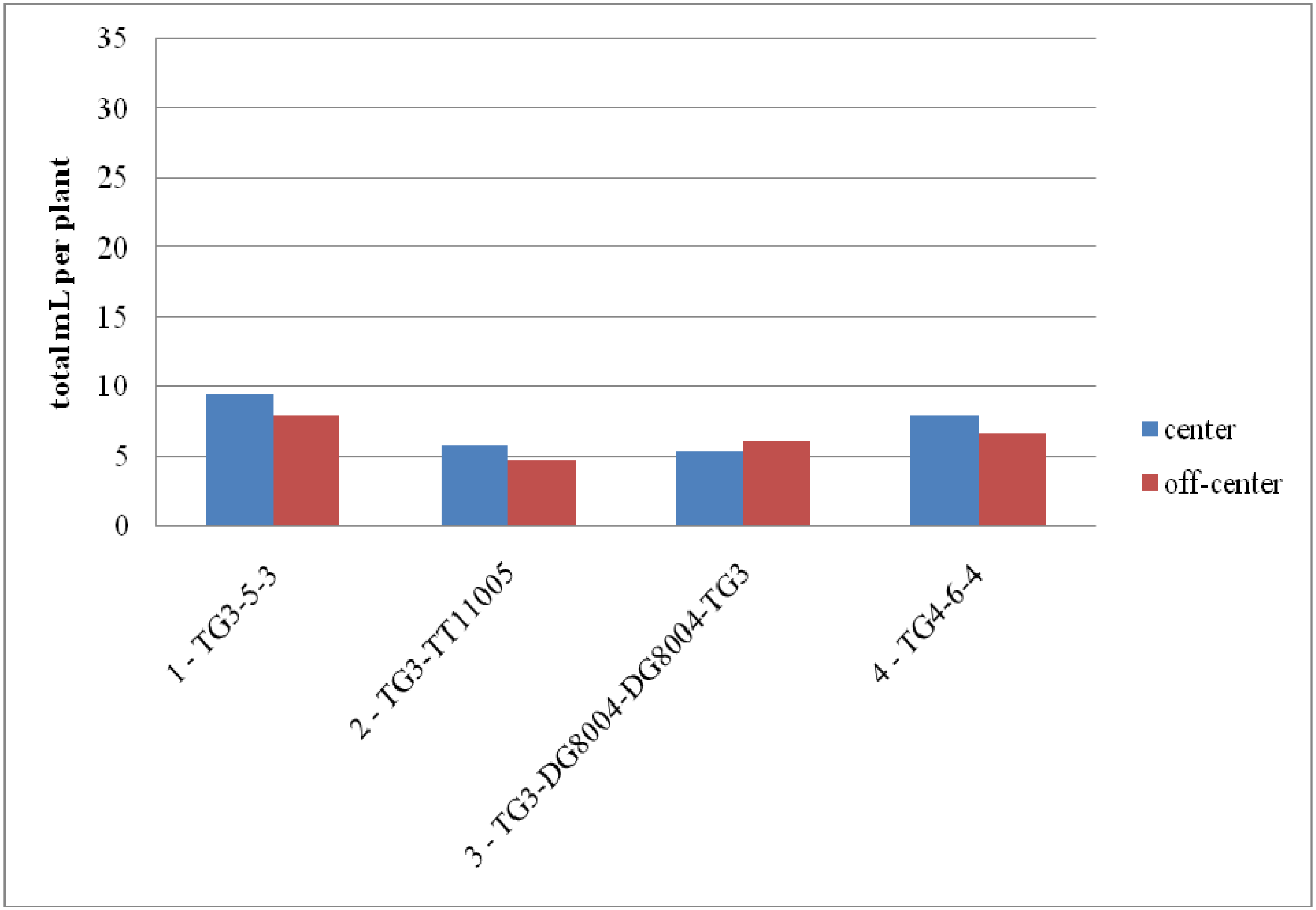


Figure 3.20: Top leaf parallel vs. perpendicular over normal leaves, solution collected for all leaves.

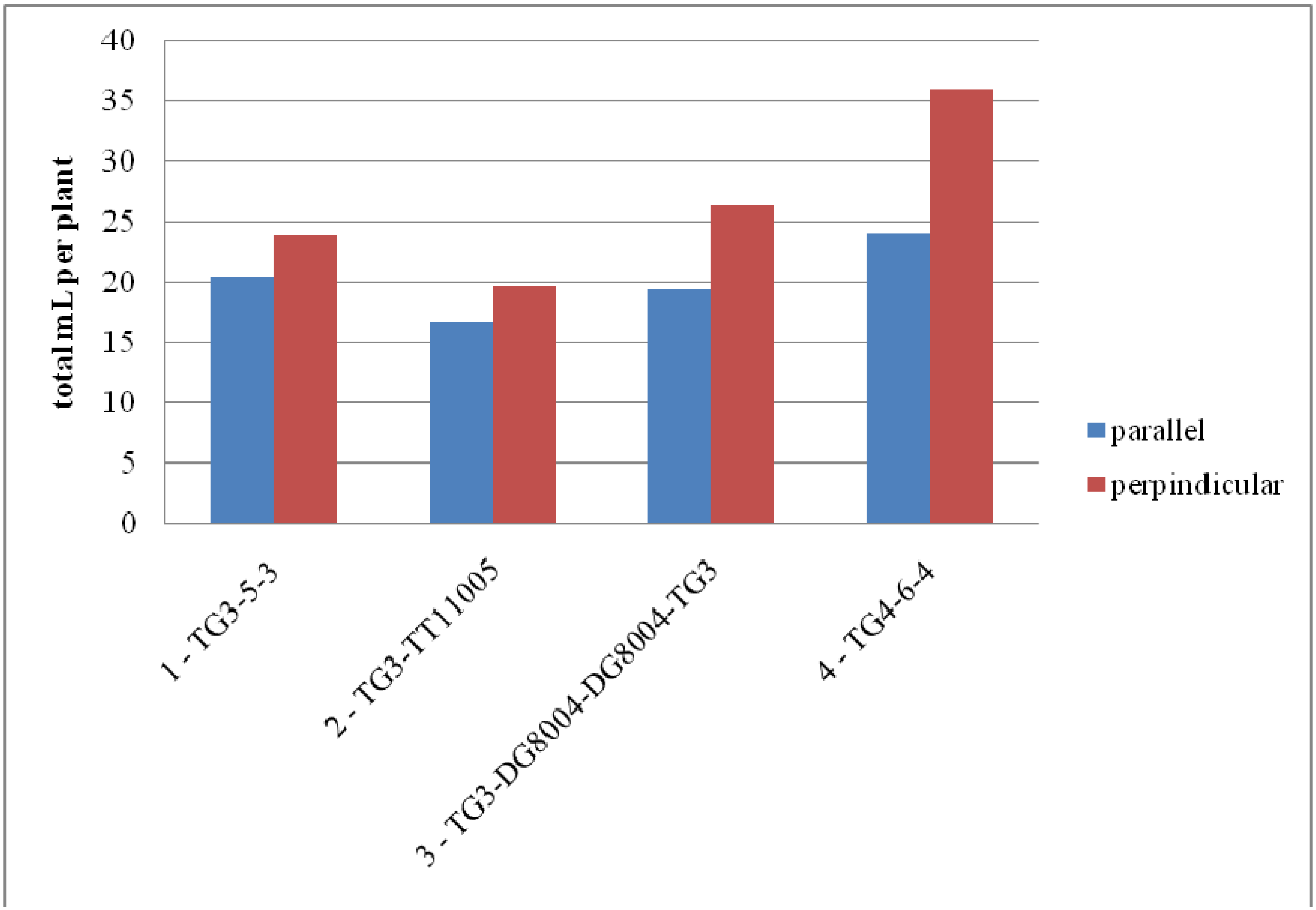


Figure 3.21: Top leaf parallel vs. perpendicular over upright leaves, solution collected for all leaves.

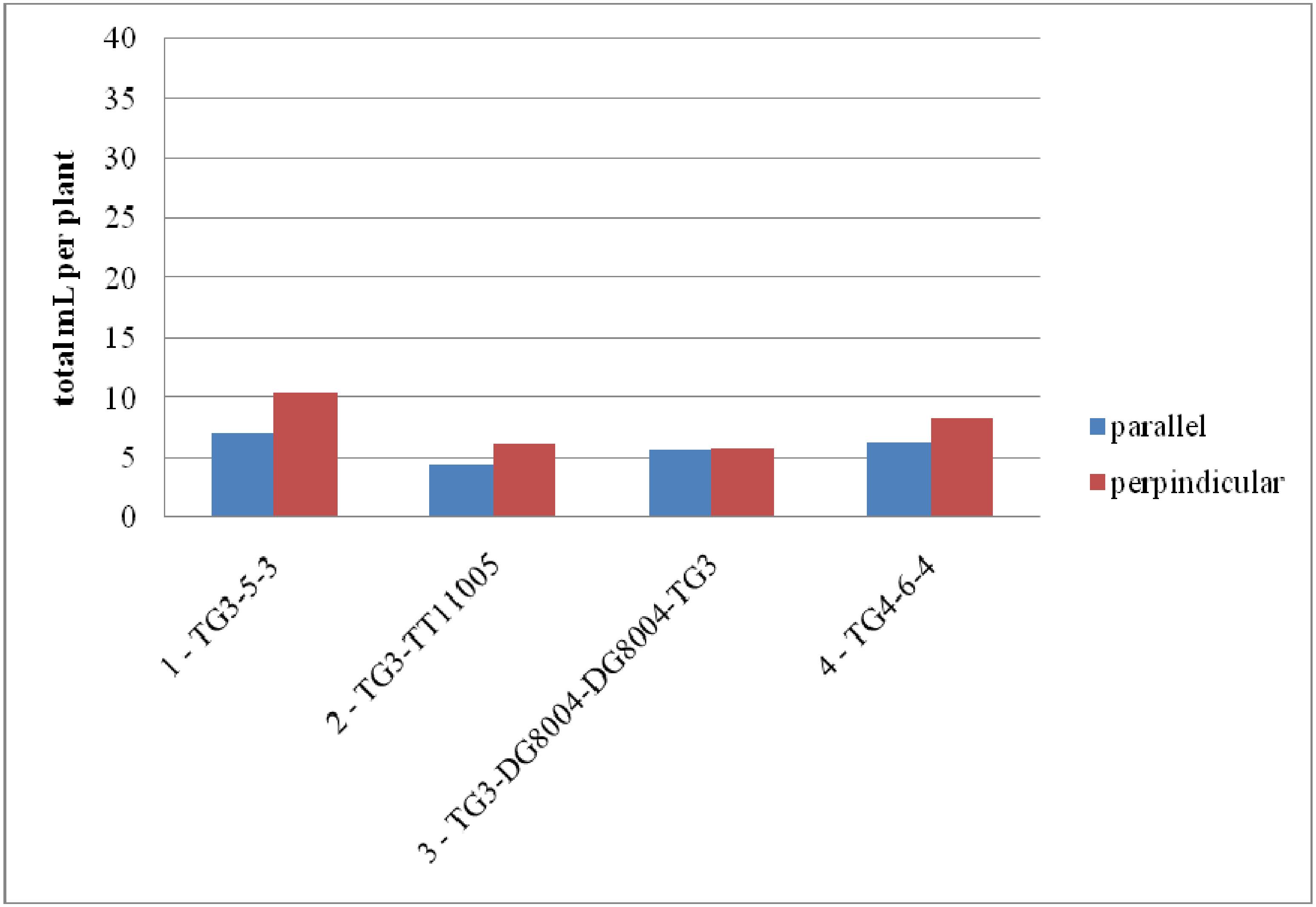


Figure 3.22: Top leaf parallel vs. perpendicular over normal leaves, only top leaf solution collected.

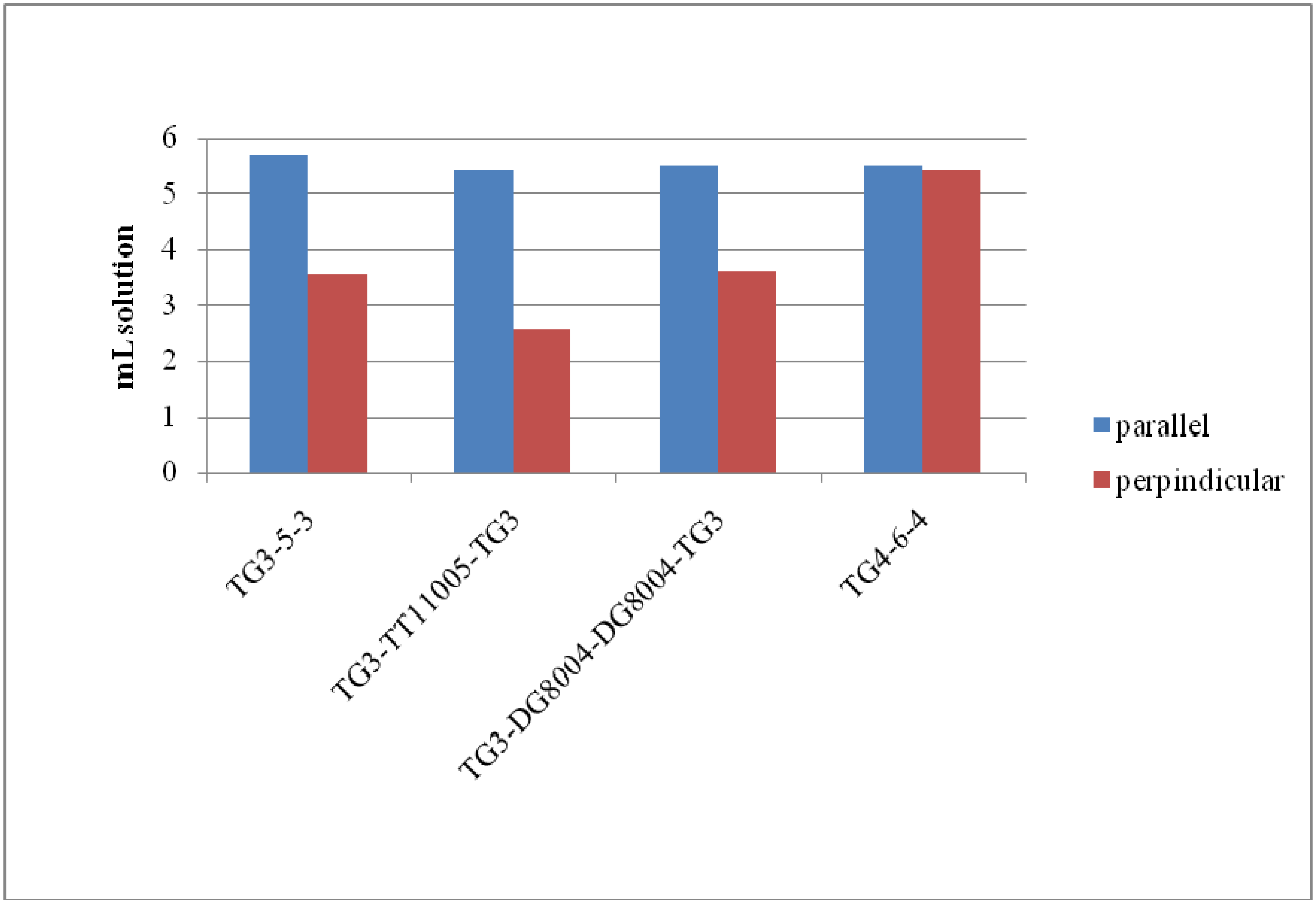


Figure 3.23: Top leaf parallel vs. perpendicular over upright leaves, only top leaf solution collected.

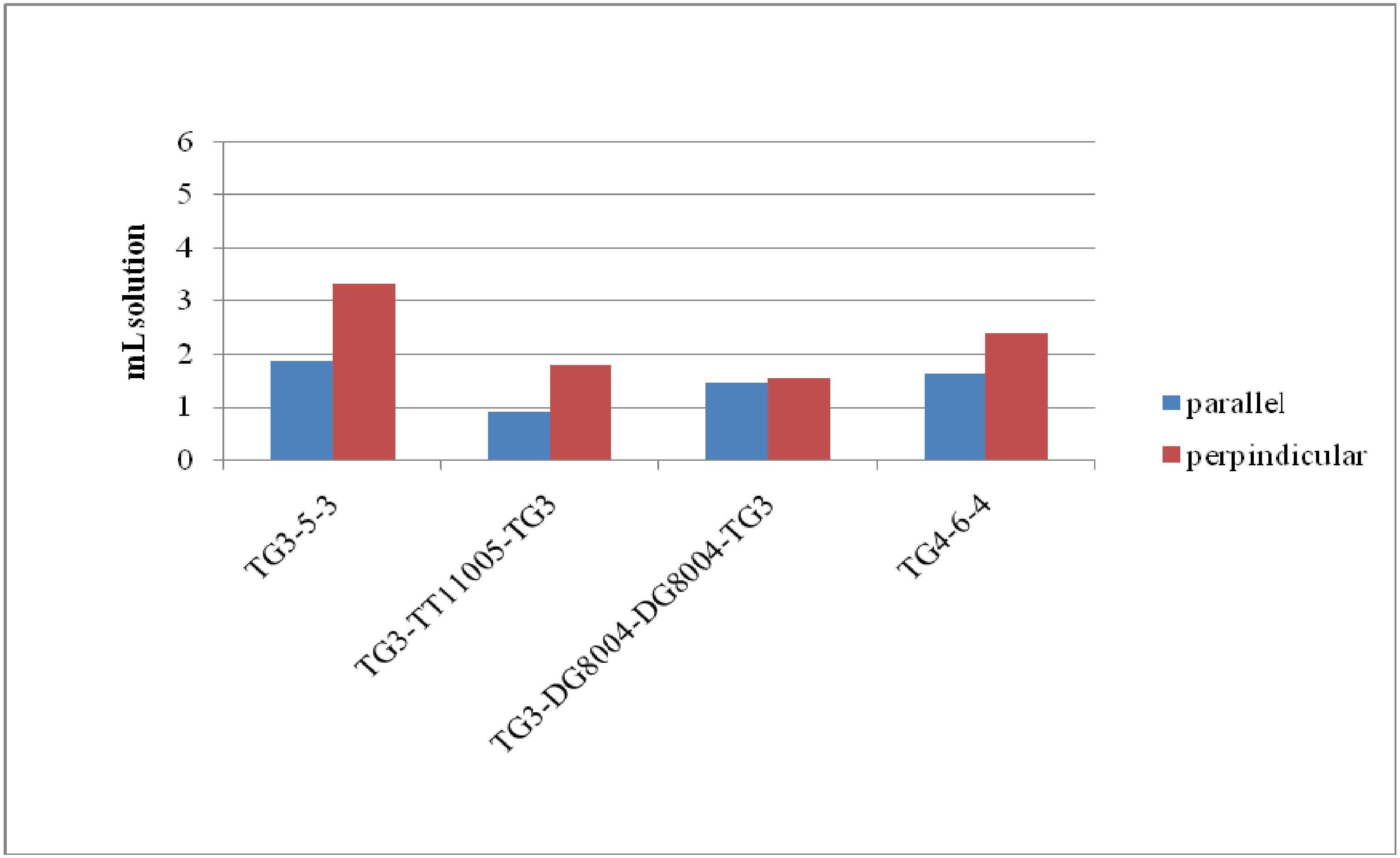


Figure 3.24: Percent solution collected from total sprayed over plant, normal leaves, TG3-5-3.

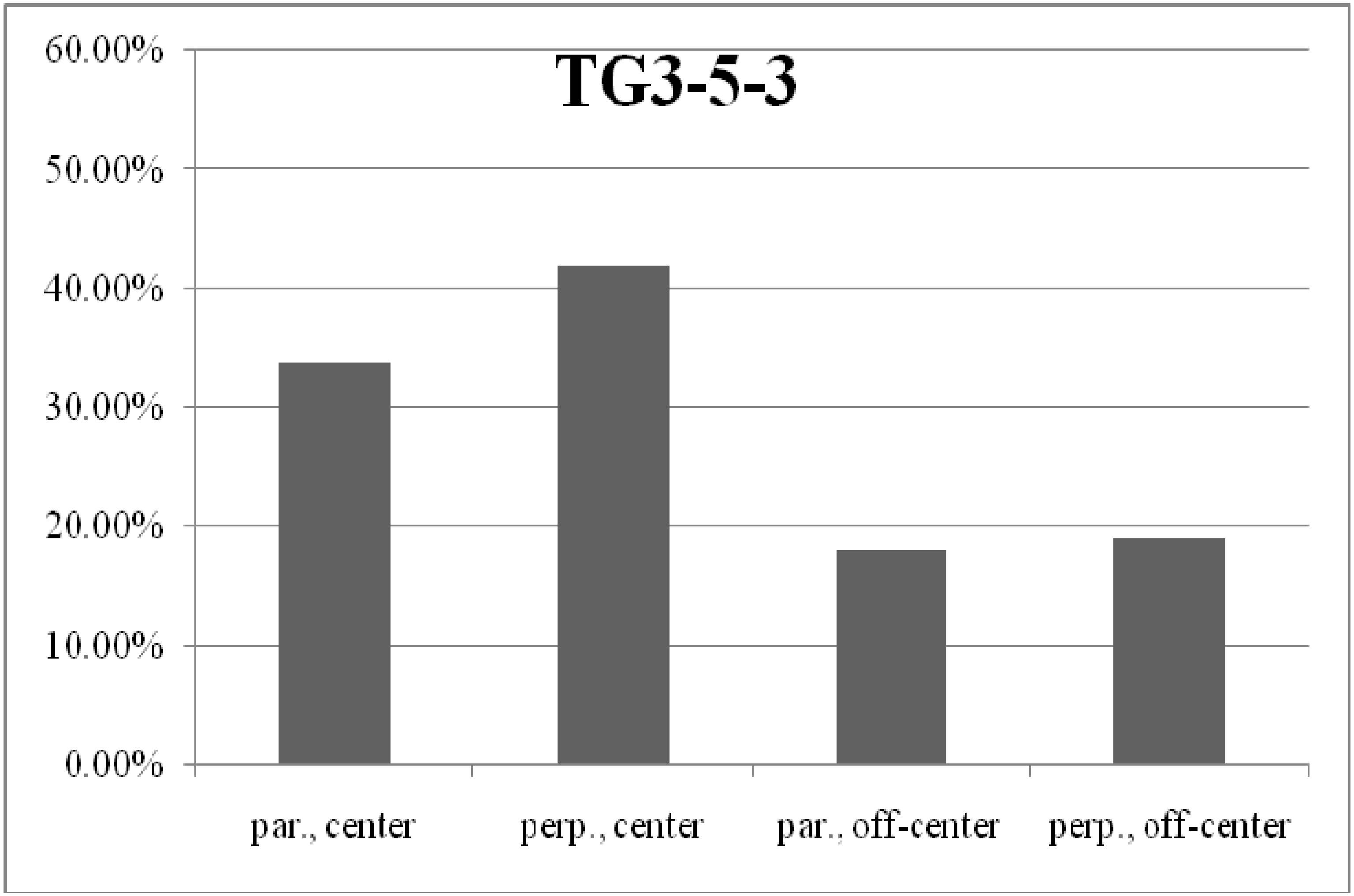


Figure 3.25: Percent solution collected from total sprayed over plant, upright leaves, TG3-5-3.

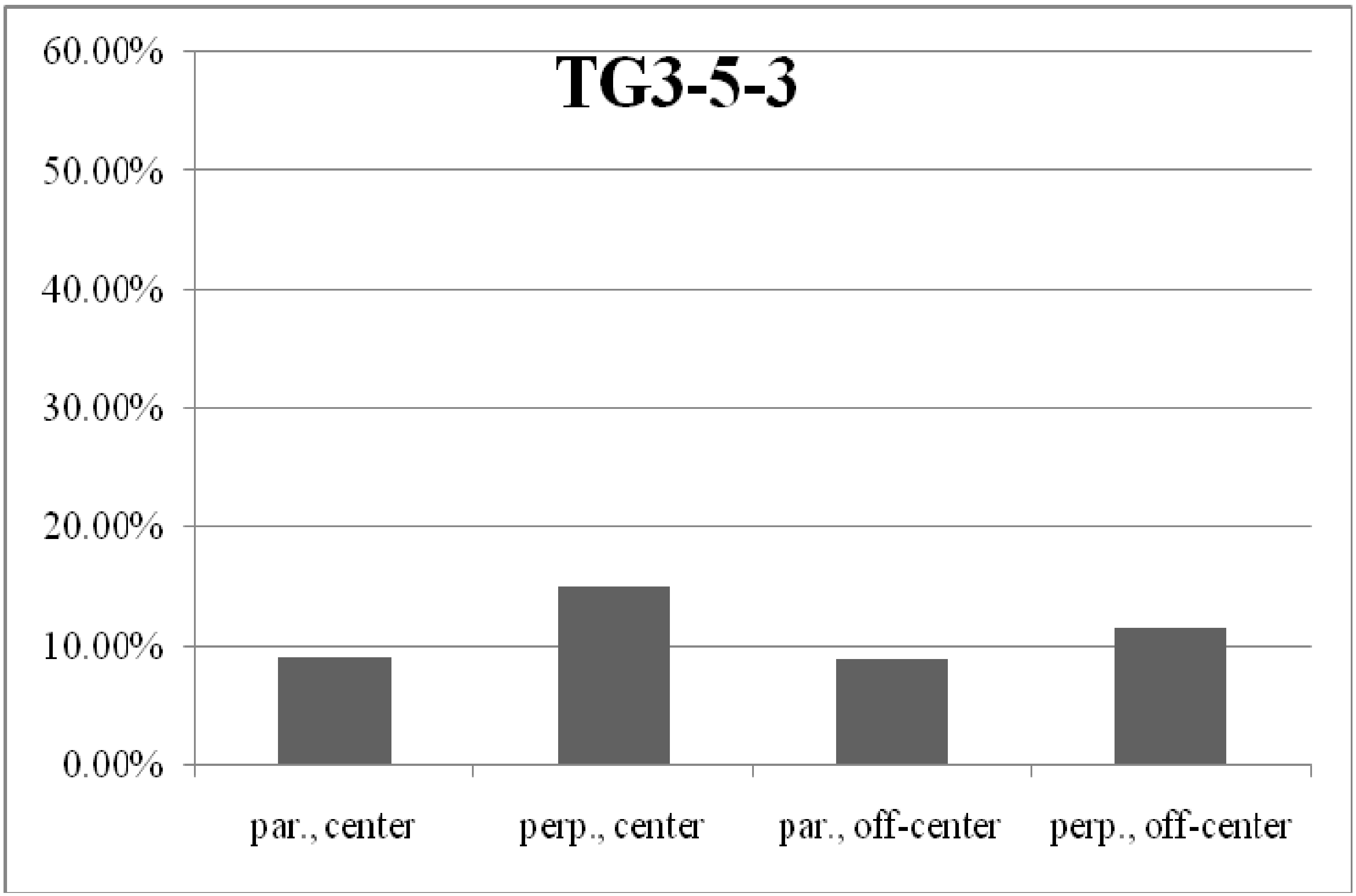


Figure 3.26: Percent solution collected from total sprayed over plant, normal leaves, TG3-TT11005-TG3.

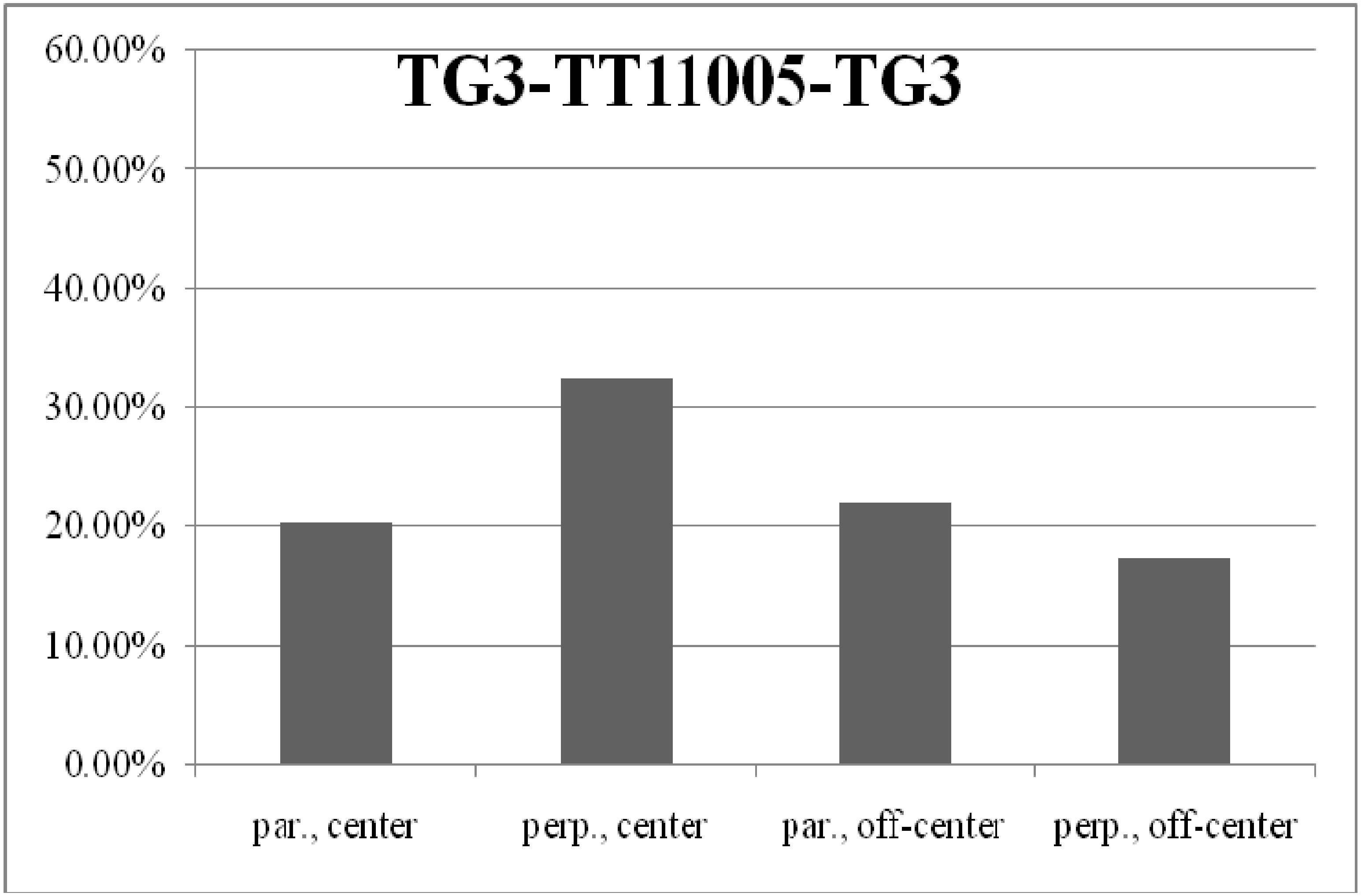


Figure 3.27: Percent solution collected from total sprayed over plant, upright leaves, TG3-TT11005-TG3.

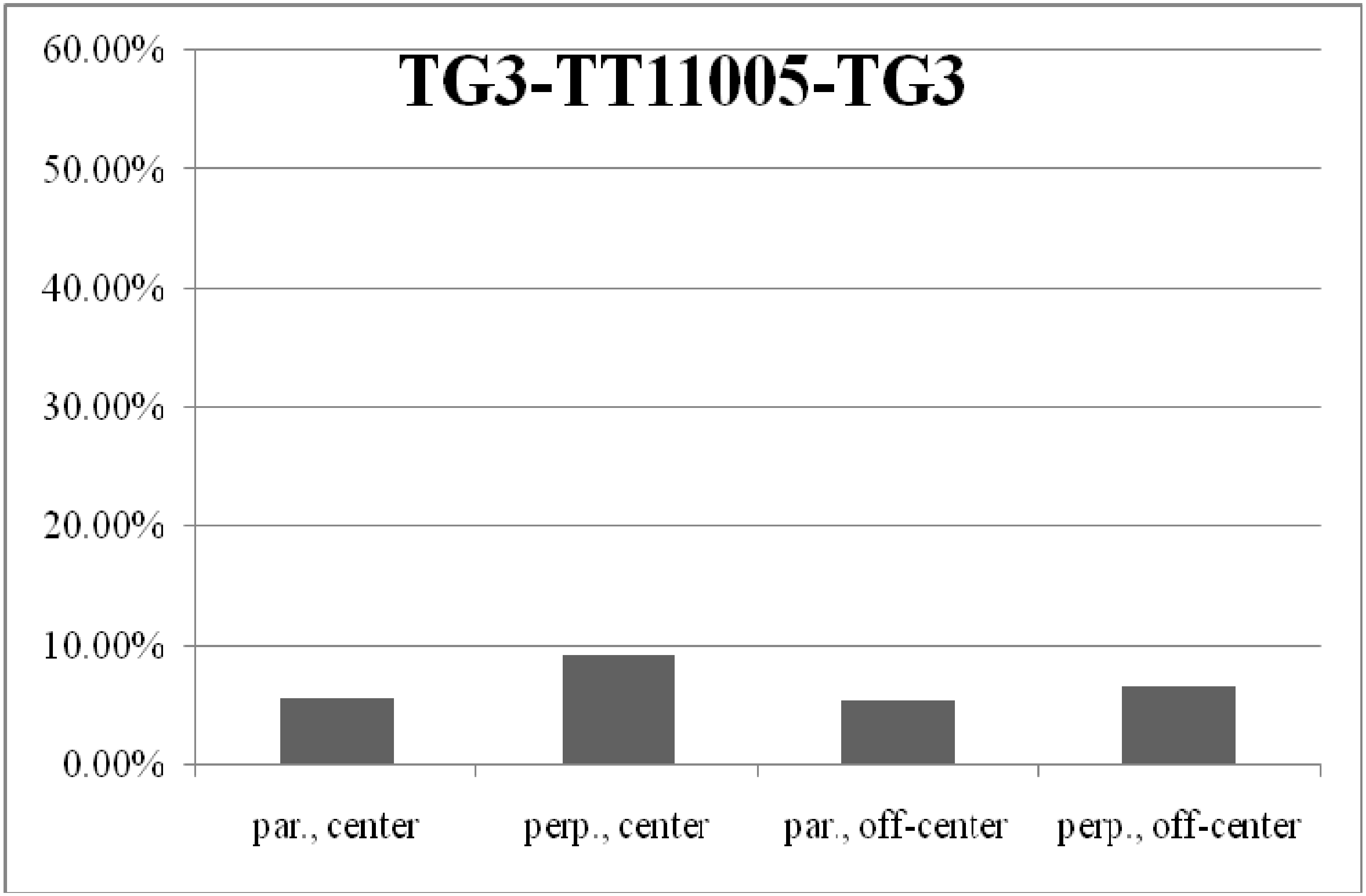


Figure 3.28: Percent solution collected from total sprayed over plant, normal leaves, TG3-DG8004-DG8004-TG3.

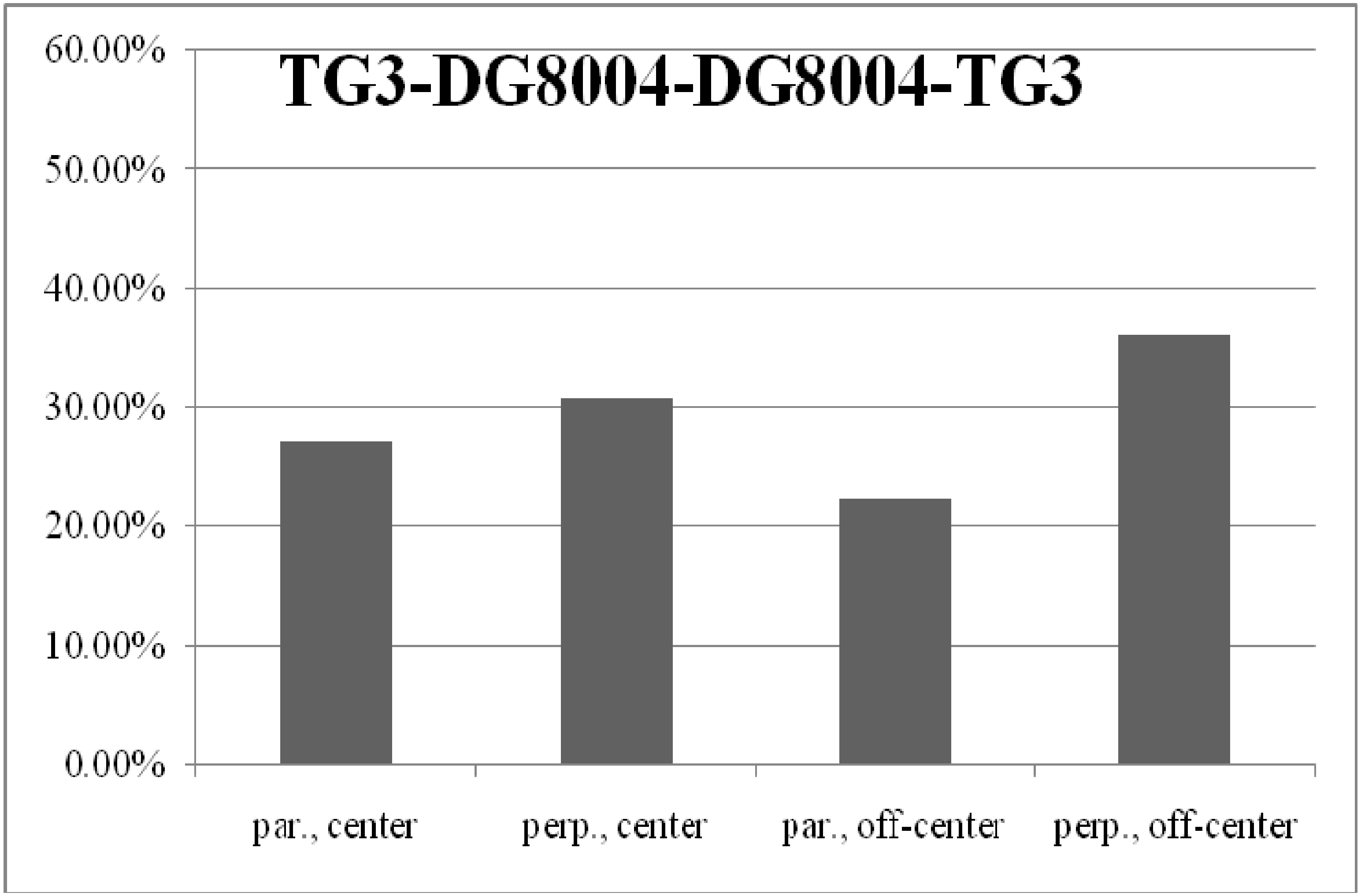


Figure 3.29: Percent solution collected from total sprayed over plant, upright leaves, TG3-DG8004-DG8004-TG3.

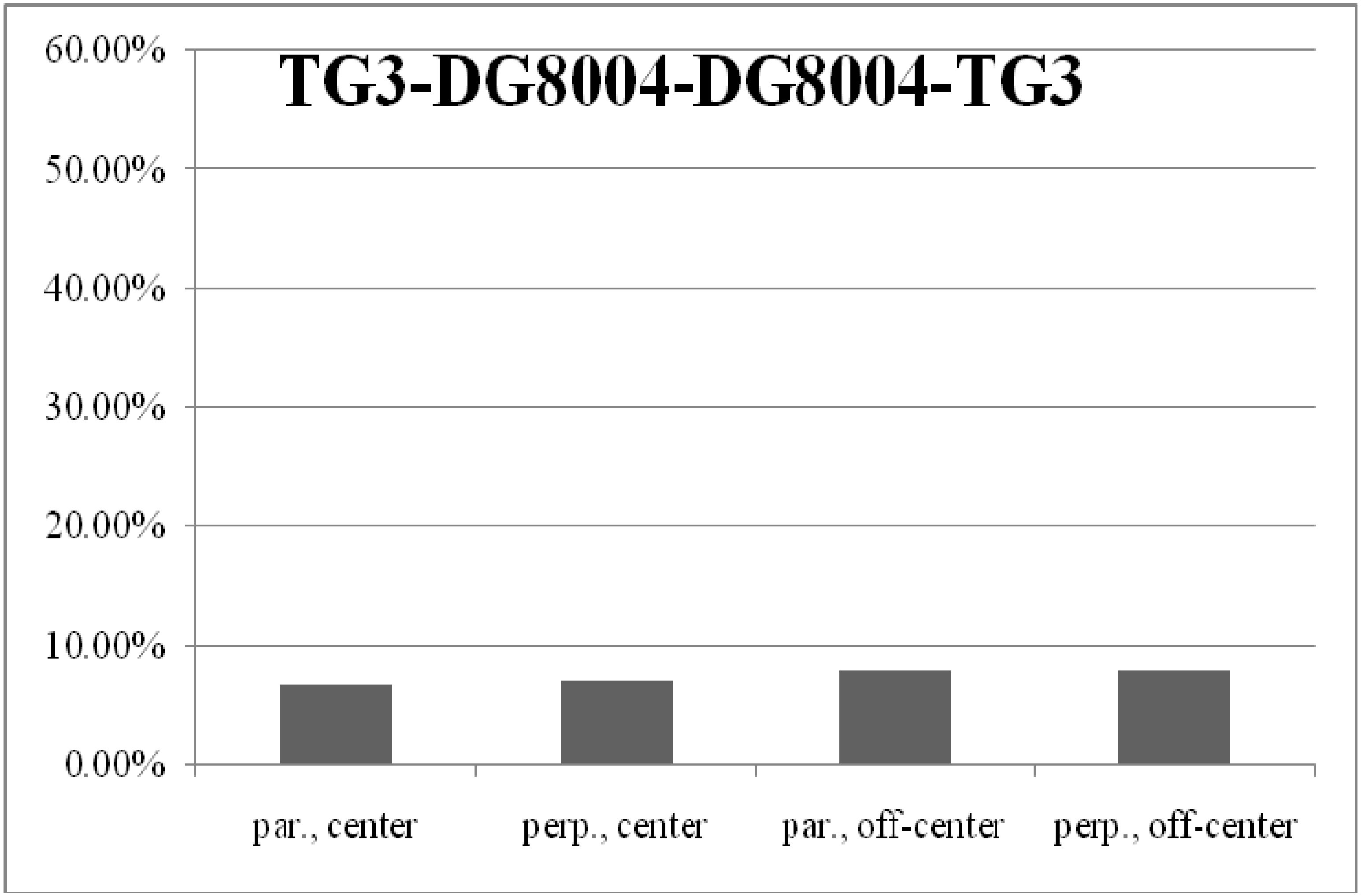


Figure 3.30: Percent solution collected from total sprayed over plant, normal leaves, TG4-6-4.

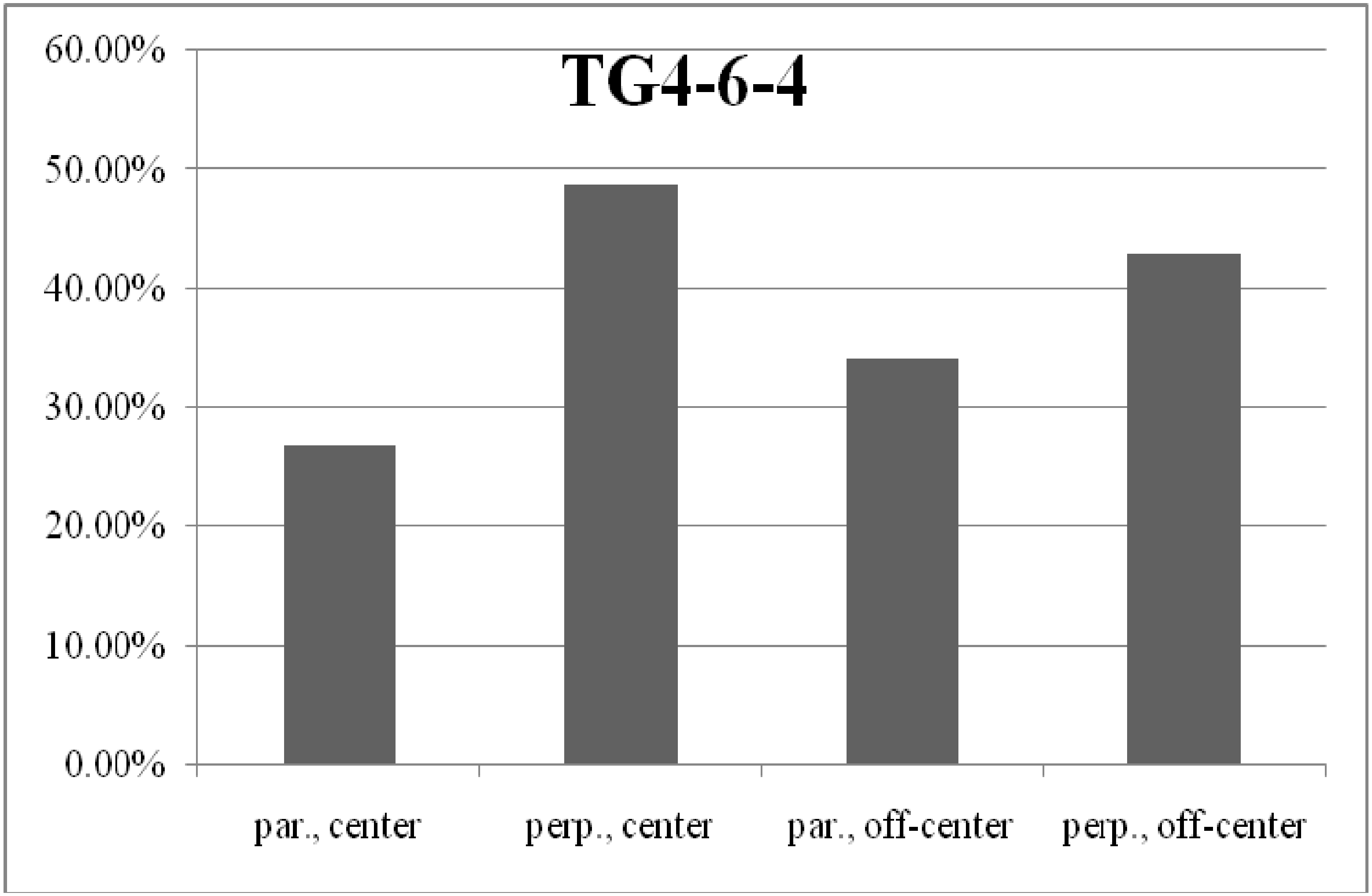
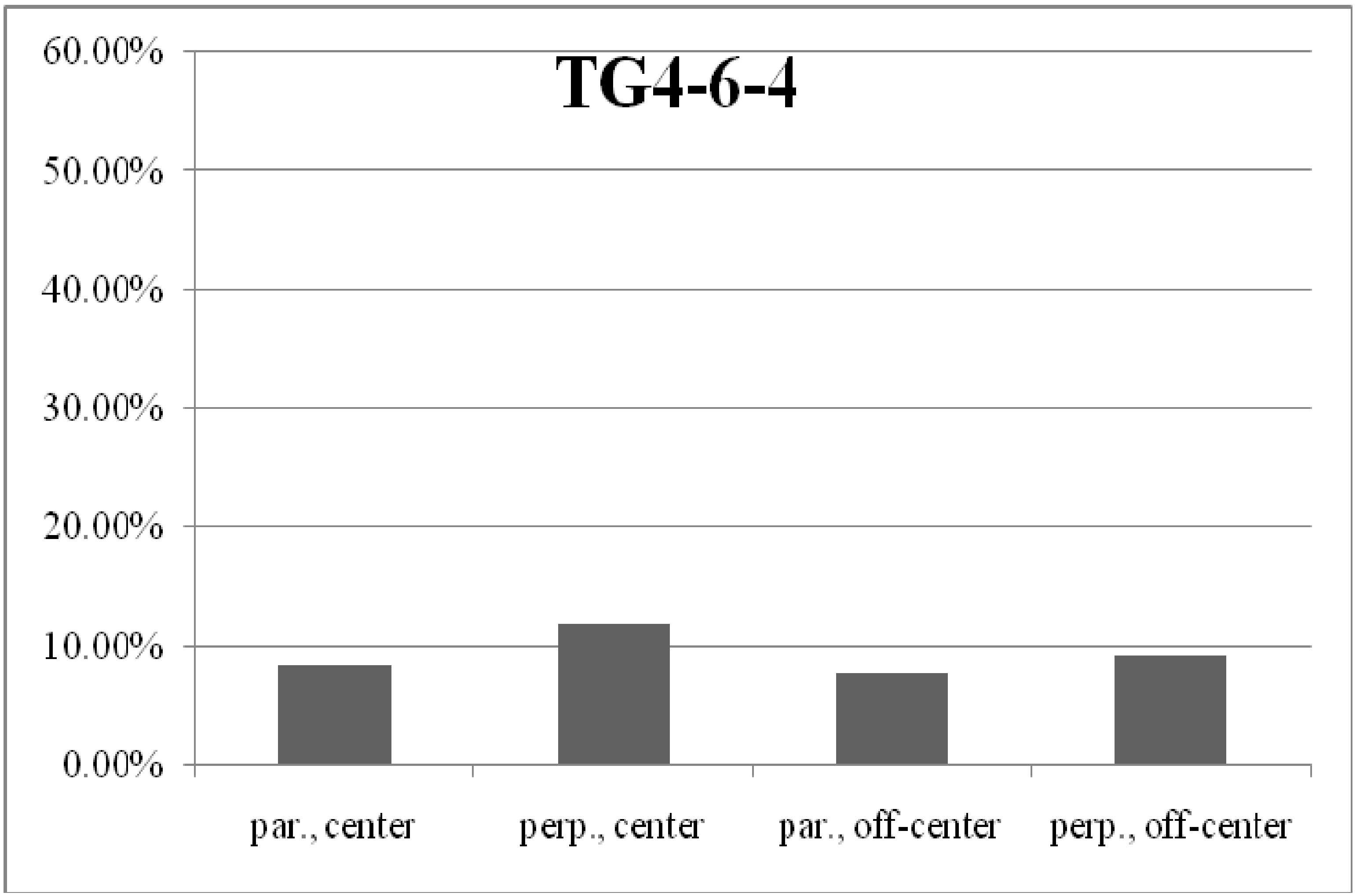


Figure 3.31: Percent solution collected from total sprayed over plant, upright leaves, TG4-6-4.



Chapter 4: Discussion and Conclusions

Field Studies

In comparing years for the field studies, conditions could not have been any more dissimilar. 2009 was a moderately wet year with about average temperatures throughout the growing season. These conditions kept plant stress to a minimum and provided good production conditions with relatively high sucker pressure. The study for 2009 was planted somewhat later (July 7th) than recommended by the University of Kentucky (2010). 2010 proved to be a dry season with above average temperatures, increasing the likelihood of plant-stress situations. A severe thunderstorm with high winds also occurred on July 19th, 2010 causing plants in this study to be partially blown over. This occurred when plants were approximately 60 cm in height. The plants were able to grow out of the setback, but most were left with a crook near the base of the stalk. It should be noted this occurrence caused the alignment of the rows to be skewed. Uniformity and alignment (lodging and crooked stalks) were altered as a result of this storm.

2009 and 2010 showed mixed results for the commonly used arrangement TG3-5-3. In 2009, the TG3-5-3 provided acceptable sucker control in regard to escapes when using fatty alcohol only. However, suckers and sucker weight were still not controlled at an acceptable level (75%) for this arrangement relative to the non-treated. Performance was poor in 2010 for the TG3-5-3 arrangement, possibly due in part to extreme weather conditions and non-uniformity of plants. These results agreed with the artificial plants study that when the TG3-5-3 was run off-center, solution intercepted by the plant significantly decreased. For tobacco produced with no MH in 2009, this arrangement provided better sucker control (escapes, fresh sucker number and weight) than any of the other nozzle combinations when using fatty alcohol at a 4% solution applying 468 liters per hectare with the exception of the TG3-TT11005-TG3 arrangement (provided equal control). It also performed the best when applying the sequential sucker control treatments of fatty alcohol followed by MH+FA in 2009. In 2010, the TG3-5-3 arrangement only provided 30% sucker control but equal yields using 4% fatty alcohol solution. The lack of uniformity of the plants due to the storm combined with dry weather conditions likely had some influence on the results for that year.

Arrangements which were added in 2010 that outperformed the TG3-5-3 treatment (as well as all other treatments) included the TG3-5-3-3 arrangement, which employed an additional TG3 nozzle trailing behind the TG5 center nozzle, and a TG4-6-4 arrangement. In both of these cases, no more volume of solution was being applied over the plants than with the TG3-5-3. With increasing the coarseness of spray (4-6-4) or including an additional coarse nozzle (3-5-3-3), leaf contact/interception may have increased. These results were backed up by results from the artificial plants that were sprayed with the TG4-6-4 arrangement. This arrangement performed significantly better than the TG3-5-3 over both normal and upright leaves, for each of the top four leaves over both plants 1 and 2. When comparing percent of solution intercepted over normal leaves for the TG4-6-4 and TG3-5-3, results were similar when the sprayer was run center of the plant. But when run 15cm off-center, percent interception was un-affected and essentially doubled (when compared to TG3-5-3) for the TG4-6-4 (Figure 3.24 and Figure 3.30). Although these two arrangements provided the same volume applied per plant, the TG4-6-4 showed more volume reaching the plant and this would equate to increased sucker contact at the leaf axils. It was noted earlier that the two best performing treatments in 2010 (TG3-5-3-3, TG4-6-4) showed slight leaf burn damage, perhaps due to a higher percentage of the spray making contact with the leaves coupled with the dry weather and high temperatures. Leaf damage is not un-common and has been observed in instances of accumulation of contact chemicals on the leaf (Aycock and McKee 1975; Mylonas and Pangos 1978). Although sucker control with fatty alcohol using the TG4-6-4 and TG3-5-3-3 arrangements was not 100% as with the recommended rate of MH in 2010, they were not significantly different. As long as application occurred when high temperatures were not present and drought stress was at a minimum in order to decrease leaf damage, both of these arrangements would be very desirable alternative options (to the TG3-5-3) for sucker control using only fatty alcohol. Taking into account that the same amount of solution (FA + water= 468L/ha) per acre is being applied, no economic loss would occur in using these arrangements in comparison with the TG3-5-3.

In comparing the rate of expansion of the top leaves for both years, no differences were found. Neither MH nor fatty alcohol had a significant effect on leaf growth when compared in this study. Although treatment 5 showed significance in 2009, it was only because the initial leaf areas were higher at the first application. Many inconsistencies existed with both fatty alcohol and sequential method treatments. When looking at growth rates after the second application though, FA treatments tended to be higher than the sequential treatments with the exception of treatment 5. Although growth rates differed slightly, no conclusions were drawn from results for 2010. Dry weather conditions may have severely stressed leaf growth near the end of the growing season after the second application of treatments.

Yield between treatments within each year showed no significant differences, including the topped-not suckered check. Previous researchers agree when comparing chemical sucker control treatments; generally no significant differences are observed (Cui et al. 1995; McKee 1995; Crafts-Brandner et al. 1994; Rosa and Caughill 1991; Link et al. 1982). However, in most cases the uncontrolled (even hand-controlled) treatments have shown a significant decrease in yield compared to chemical treatments for the same research. In 2009, although temperatures were moderate and rainfall adequate, the late planting most likely limited yield potential across the entire crop and masked any differences in yield. The droughty hot conditions in 2010 stressed the entire crop as well and with favorable production conditions lacking, this likely kept yields similar across all treatments including the unsuckered check. Average yields across years were slightly different (higher in 2009), primarily due to very dissimilar weather conditions.

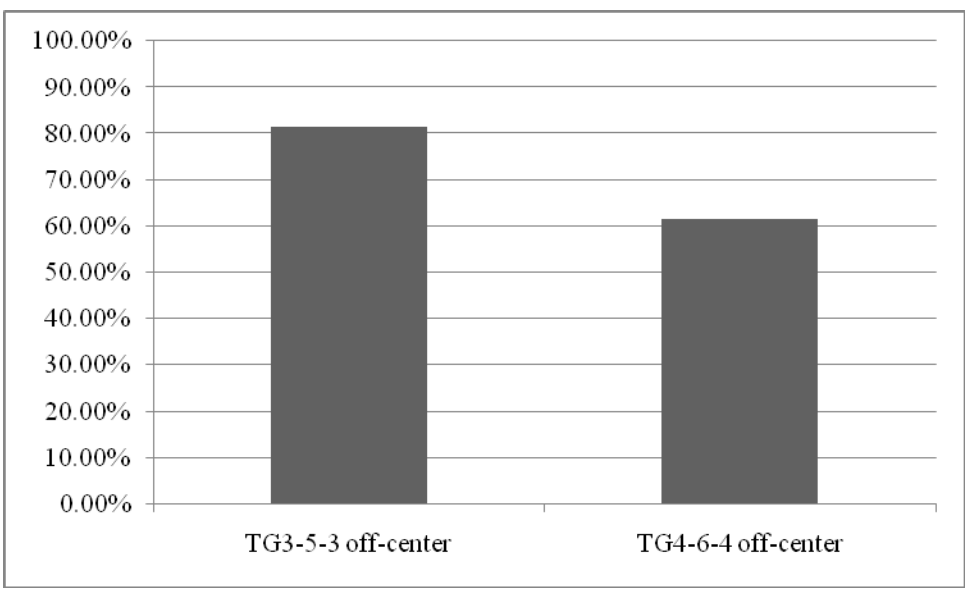
While it may be tempting to disregard sucker control due to no yield differences, the economics do not agree. There are two routes a producer could take when it comes to disregarding chemical sucker control. Producers can leave the suckers on the plants saving the money involved in chemicals, labor, and time; or hire labor to hand control suckers. The former will affect quality significantly in the barn as suckers do not tend to cure as do mature leaves. This can hinder those mature leaves from curing properly and cause a producer to have high moisture or green tobacco. The latter of the two methods can cost a producer significantly when hiring labor to accomplish hand sucker control and has also shown less sucker control and yield. Many of the benefits that come from topping (root growth, quality and smoking characteristics, insect control) would be eliminated if sucker control was not practiced. All of these scenarios lead back to quality, which is the ultimate goal for producers who plan on remaining in a competitive market.

Artificial Plant Studies

From initially constructing the artificial plants to applying the treatments to them, several questions were raised. Would the metal flashing provide a surface repellent enough to accumulate a measureable collection of solution? Would the solution be able to flow entirely to the collection cups through the tubes? Would different treatments show a difference in solution collected? Results indicated the answer to these questions was yes. Now, could this be compared to actual field situations? Upon beginning collection of solution on the artificial plants, it was noticed immediately that total solution (all four leaves) collected was going to be significantly less with the upright positioned leaves as opposed to the horizontally positioned leaves. With much less surface area of the leaf being exposed to the spray, the amount of solution being intercepted would likely decrease. Also, much of the chemical in this case would most likely either be wasted (bypassing plant) or miss those top 3-4 leaves which have been shown to be critical for sucker control (Seltmann 1994). Another hypothesis was that solution collected would be dramatically decreased with the sprayer set-up being run 15 cm off center. The third variable of the experiment included the top leaf of the plant being either parallel or perpendicular to the row; in this case it was presumed the parallel top leaf (having the entire leaf center of the row) may collect more solution because of the outside nozzles being directed inward towards the center of the row.

Results from the artificial plants proved to corroborate the results of the field studies nicely. First of all, of the four different nozzle arrangements used in treatments over the plants, the best performing was the TG4-6-4 just as in the field study in 2010. On average, this arrangement provided more solution collected over all leaves on both plants 1 and 2, for both normal and upright leaves, as well as the greatest percentage of interception. This provides the explanation of why the TG4-6-4 arrangement provided the best control over all other treatments using fatty alcohol only, and was not significantly different than the MH treatment in the field study. Most importantly, the volume applied per acre with the TG4-6-4 was not different than that of the traditional TG3-5-3 arrangement, increasing the efficiency of chemical interception with this arrangement. In this case it would mean less suckercide is wasted. Percent solution wasted for the TG3-5-3 versus TG4-6-4 when the sprayer was run 15 cm off-center, averaged over plants 1 and 2, as well as top leaf orientation, is shown in Figure 4.1 below.

Figure 4.1: Percent solution wasted for TG3-5-3 vs. TG4-6-4 when sprayer was run 15cm off-center.



There was a consistent and significant decrease in the amount of solution intercepted by the top leaves when they were upright or cupped together (drought stress, windy conditions) when compared to plants with more horizontally positioned leaves. Less surface area of those leaves is exposed, so it only makes sense that less solution would make contact with them. Decreasing the amount of solution hitting the leaves will undoubtedly decrease sucker control due to minimal amounts of chemical being able to run down the stalk. These results verify recommendations to avoid spraying sucker control in the heat of the day especially when plants are under drought stress.

The sprayer being run 15 cm off-center significantly decreased (by 50%) the volume of solution intercepted compared to centered application with the commonly used TG3-5-3 arrangement (Figure 3.24). This is particularly of concern because the TG3-5-3 is currently the most common used arrangement in burley tobacco sucker control operations. These results agreed with the poor sucker control provided in the field study with the TG3-5-3 arrangement (sprayer was likely off-center). However, with the TG4-6-4 arrangement, there were no differences in solution collected when run off-center (Figure 3.30). This is a very encouraging find and could assure producers have a reliable nozzle arrangement which could ensure sucker control even if machinery and plant/row spacing were not exactly in congruence. Differences were not observed with either the TG3-TT11005-TG3 or the TG3-DG8004-DG8004-TG3 but it is likely escapes in these cases would exist due to the arrangements not covering the plant uniformly. In order to minimize escapes and assure adequate coverage, the TG4-6-4 would be desirable.

Parallel and perpendicular top leaves are one of those things producers have no control over. Although amount collected tended to be higher for plants with a top leaf perpendicular to direction of travel, none of the differences were significant. Producers often question why control may not be sufficient, when applications were made in what they thought were ideal spraying conditions. This variable could be a portion of the explanation in this situation. If more top leaves (the leaf to which plant was topped) are perpendicular to the row, sucker control may decrease. Results from this study indicate this would be most likely due to a higher concentration of spray solution being directed towards the center of the row. The random escapes and misses after a sucker control program has been employed may be due in part to this anatomical characteristic of the plant.

Conclusion

If producers are going to continue to raise tobacco, the means by which they do so must be economically profitable, environmentally sound, and adhere to quality standards set by tobacco companies and consumers. Eliminating the use of MH would most definitely satisfy the latter two of the three objectives. However, is a sucker control program that does not include MH an effective program?

Results from this experiment indicate that an effective sucker control program with powered spraying equipment *can* be utilized without using MH. Management practices must be finely tuned in order to make the program effective. It begins at transplanting when rows and plants must be uniform and spaced evenly across the field. If this is accomplished, sprayer/nozzle booms can be adjusted accordingly and the producer will know they are lining up with the plant rows. Results from this study clearly showed keeping the nozzle arrangement directly over the row is critical to achieving consistent results with MH-free spray solutions. Growers may need to consider spraying fewer rows at a time in multiples matched to their transplanting equipment (ex: two row sprayer for two row transplanters). Once these parameters are in order, it is vital that application of chemicals such as fatty alcohol be done at the proper time. Spraying should not be done during peak sun periods or high temperatures. As shown in 2010, this could increase the likelihood of leaf burn. Wind conditions must also be minimal in order to make sure the maximum amount of chemical possible is making contact (being intercepted) with the top of the plant. Producers must also remember these chemicals will not control suckers greater than one inch and those must be removed by hand. Multiple applications made at the right intervals during optimum spraying conditions will provide sufficient sucker control.

Most importantly, the proper nozzle type(s) and arrangement must be selected and fabricated for over the row application. Results from this study support a recommendation of using a TG4-6-4 arrangement when applying contact suckercides. This arrangement provided significantly better sucker control when compared to the TG3-5-3 as well as all other arrangements. It also provided equal control when compared to applications of MH+Butralin at the recommended rate. Total solution collected as well as percent interception was the greatest with this arrangement when sprayed over the artificial plants, making it the most efficient arrangement for the same amount of solution applied. Also, solution applied and solution intercepted was not compromised when the TG4-6-4 was run off-center of the plants making it a reliable choice even when conditions are not the best. When results from the field study are coupled with the artificial plant results, the TG4-6-4 is a significant improvement and excellent choice as an alternative to the commonly used TG3-5-3 arrangement. Although it was not tested over the artificial plants, preliminary results from the field study in 2010 show the TG3-5-3-3 with the additional trailing nozzle would be an effective alternative as well.

If willing to improve their management practices, producers can implement MH-free sucker control using fatty alcohols with high powered spraying equipment. This will allow them to stay competitive economically and environmentally on a global scale, as well as meet the satisfaction of both the consumer and the tobacco industry.

References

Aycock, M.K., and C.G. McKee. 1975. Effects of Contact and Systemic Sucker Control Chemicals on Maryland Tobacco Cultivars. Tobacco Science 19: 104-107.

Atkinson, W.O., and J.L. Sims. 1971. Nitrogen Composition of Burley Tobacco II. Influence of Nitrogen Fertilization, Suckering Practice and Harvest Date on Yield, Value and Distribution of Dry Matter Among Plant Parts. Tobacco Science 15: 63-66.

Bailey, A., R. Pearce, and P. Denton. 2010. 2011-2012 Kentucky & Tennessee Tobacco Production Guide: Topping, Sucker Control, and Harvest Management for Burley and Dark Tobacco. University of Kentucky College of Agriculture, Cooperative Extension Service. Lexington, KY. ID-160.

Bailey, A., R. Pearce, P. Denton, and G. Palmer. 2009. 2009-2010 Kentucky & Tennessee Tobacco Production Guide: Topping, Sucker Control, and Harvest Management for Burley and Dark Tobacco. University of Kentucky College of Agriculture, Cooperative Extension Service. Lexington, KY. ID-160.

Bakht, J., S.K. Khalil, M. Shafi, A. Rehman, S. Akhter, and M.I. Jan. 2007. Comparative Effect of Suckercides and Manual Desuckering on the Yield and Quality of FCV Tobacco. Sarhad J. Agric. 23(1): 11-15.

Clapp, M.K. and H. Seltmann. 1983. Anatomy of Axillary Meristems from Tobacco Plants Treated with Maleic Hydrazide. Bot. Gaz. 144(1): 86-91.

Collins, W.K., S.N. Hawks Jr., and B.U. Kittrell. 1970. Effects of Systemics Alone and Contacts Followed by a Systemic Sucker Control Agent on Some Agronomic-Economic Characteristics of Flue-Cured Tobacco. Tobacco Science 13: 86-88.

Conrad, Evan M. 2009. 2008 Tobacco Enterprise Analysis. Kentucky Farm Business Management Program. University of Kentucky Agriculture Economics-Extension No. 2009-33.

Coulson, D.A. 1959. Some Effects of Maleic Hydrazide on Flue-Cured Tobacco Quality. Tobacco Science 3: 69-72.

Cui, M., H.R. Burton, L.P. Bush, T.G. Sutton, and S.J. Crafts-Brandner. 1995. Effects of Application Methods and Rates of Maleic Hydrazide on the Composition of Burley Tobacco. Tobacco Science 39(1): 9-16.

Crafts-Brandner, S.J., M. Collins, T.G.Sutton, and H.R. Burton. 1994. Effect of Leaf Maleic Hydrazide Concentration on Yield and Dry Matter Partitioning in Burley Tobacco (*Nicotiana Tabacum* L.) Field Crops Research 37: 121-128.

Darlington, C.D., and J. McLeish. 1951. Action of Maleic Hydrazide on the Cell. Nature 167: 407-408.

Davis, D.L., W.O. Atkinson, and J.Smiley. 1974. Maleic hydrazide residue from air cured burley tobacco. Crop Science 14:109-112.

Decker. R.D., and H. Seltmann. 1971. Axillary Bud Development in *Nicotiana tabacum* L. after topping. Tobacco Science 14: 144-148.

Environmental Protection Agency. 1994. R.E.D. Facts, Maleic Hydrazide. EPA-738-F-94-009.

Fisher, L.R., and J.A. Priest. 2007. 2007 Flue-Cured Tobacco Information. NC State University, Raleigh, NC. Section 7: Topping and Sucker Management and Use of Ethephon. AG-187 pp 122-151.

Garvin, R. 1980. Topping and Suckering for Maximum Yield and Quality. Zimbabwe Tobacco Today 3(11): 11-13.

Gorman, D.P., M.T. Nielsen, and J.H. Smiley. 1989. Effect of Maleic Hydrazide on Sucker Growth in Different Burley Tobacco Cultivars and Hybrids. Tobacco Science 33: 61-63.

Haeberer, A.F., B.C. Nichols, and O.T. Chortyk. 1978. Effects of Application Rates on Maleic Hydrazide Residues in Burley Tobacco. J. Agric. Food Chem., Vol. 26, No. 2: 385-388.

Hawks, S.N. Jr., and W.K. Collins. 1983. Principles of Flue-Cured Tobacco Production. NC State University, Raleigh, NC. Pp 233-262.

Hoffman, I., and E.V. Parups. 1964. Mode of Action of Maleic Hydrazide in Relation to Residues in Crops and Soils. Residue Rev. 7: 96-113.

Hunt, T.W., T.J. Sheets, W.K. Collins. 1977. MH Residues on Flue-cured Tobacco. Tobacco Science 21: 128-130.

Link, L.A., W.O. Atkinson, B.C. Nichols, and H. Seltmann. 1982. Effects of Sucker Control Practices on Amount of Suckering Time and Yield of Burley Tobacco. Tobacco Science 26: 35-36.

Maw, B.W., and B. Mullinix. 1992. Comparing Six Models of Various Complexity for Calculating Leaf Area from Measurements of Leaf Width and Length. Tobacco Science 36: 40-42.

McKee, C.G. 1995. Effects of Maleic Hydrazide and Flumetralin on Residues, Yield, Quality, and Chemical Content of Maryland Tobacco. Tobacco Science 39: 5-8.

Meyer, S.A., T.J. Sheets, and H. Seltmann. 1987. Maleic hydrazide residues in tobacco and their toxicological implications. Reviews of Environmental Contamination and Toxicology, Vol. 98: 43-60.

Moseley, J.M. 1959. The Effects of Maleic Hydrazide when used as a Sucker Control Agent upon Quality of Flue-Cured Tobacco. Tobacco Science 3: 73-74.

Mylonas, V.A., and F.A. Pangos. 1978. Effects of Chemical Agents on Sucker Control and on Certain Agronomic and Chemical Characteristics in Burley Tobacco. Tobacco Science 22: 85-88.

National Agricultural Statistics Service. 2010. United States Department of Agriculture. *Commodity Productions and Rankings.* 2007. Web. 7 Jan, 2010.

Nooden, L.D. 1972. Inhibition of Nucleic Acid Synthesis by Maleic Hydrazide. Plant Cell Physiology 13: 609-621.

Palmer, G.K., R.C. Pearce, and W.A. Bailey. 2008. Evaluation of MH-free Chemicals for Sucker Control. Paper presented at 43rd Tobacco Worker's Conference. University of Kentucky.

Palmer, G.K. 1997. Changing Sucker Control Methods. CORESTA Meetings. Agro-Phyto Groups, Montreux, AP22. University of Kentucky.

Pearce, R. Personal communication. University of Kentucky Extension Tobacco Specialist.

Peterson, E.L. 1952. Controlling Tobacco Sucker Growth with Maleic Hydrazide. Agronomy Journal 44: 332-334.

Raper, C.D., W.T. Smith, and E.K. York. 1974. Geometry of Tobacco Leaves: Effect on Estimation of Leaf Area. Tobacco Science XVIII: 11-14.

Rosa, N., and C.W.H. Caugill. 1991. Performance of Sucker Control Material on Agronomic and Chemical Quality of Flue-Cured Tobacco. Tobacco Science 35: 54-56.

SAS Proprietary software 9.2. Copyright 2002-2008. SAS Institute Inc., Cary, NC.

Seltmann, H. 1994. Contact Suckercide Effectiveness: A Comparison of Theoretical and Actual Results. Tobacco Science 38: 58-61.

Seltmann, H. and T.J. Sheets. 1987. Sucker Control and Maleic Hydrazide Residues after Simulated Rain and MH Reapplication. Tobacco Science 31: 79-84.

Seltmann, H., and B.C. Nichols. 1984. Agronomic, Chemical, Physical and Visual Characteristics of Hand-Suckered vs. Maleic Hydrazide-Treated Flue-Cured and Burley Tobaccos. Agronomy Journal 76: 375-378.

Seltmann, H. 1970. Modern Methods of Tobacco Sucker Control. Proc. Intl. Tob. Sci. Congress (CORESTA) 5: 77-80.

Sheets (a), T.J., R.B. Leidy, W.L Jones, P.L. Messick, J.M. Boyd, K.G. Reinbold, and J.W. Laws. 1994. Fate of Pesticide Residues on Tobacco. Twenty-third Annual Rep., Pesticide Residue Research Lab, N.C. State University; pp 48.

Sheets (b), T.J., H. Seltmann, and F.H. Yelverton. 1994. Residues of MH, Flumetralin, and Butralin on Flue-Cured Tobacco. Tobacco Science 38: 25-29.

Sheets, T.J. and L.A. Nelson. 1989. Variation of MH Residues on Flue-Cured Tobacco. Tobacco Science 33: 5-8.

Steffens, G.L. T.C. Tso, and D.W. Spaulding. 1967. Fatty Alcohol Inhibition of Tobacco Axillary and Terminal Bud Growth. J. Agr. Food Chem. 15(6): 972-975.

Steffens, G.L. and H. Seltmann. 1982. Plant Regulators for Tobacco Growth Modification and Improved Safety. Chemical Manipulation of Crop Growth and Development. Butterworth Scientific, London. pp 193-209.

Steinberg, R.A. 1950. Greenhouse Tests with Chemicals for Suppression of Lateral Branching of Decapitated Tobacco Plants. American Society of Plant Biologists. 25(1): 103-113.

Suggs, C.W., J.F. Beeman, and W.E. Splinter. 1960. Physical Properties of Green Virginia-Type Tobacco Leaves. Tobacco Science 4: 194-197.

Taylor, Z. G. 2003. Management of Axillary Shoot Growth and Maleic Hydrazide Residues with Diflufenzopyr in Flue-Cured Tobacco (*Nicotiana tabacum*). M.S. Thesis, North Carolina State University.

TeeJet Spraying Systems Company. 2010. P.O. Box 7900, Wheaton, Illinois 60189.

Tso, T.C., G.L. Steffens, and M.E. Engelhaupt. 1965. Inhibition of Tobacco Axillary Bud Growth with Fatty Acid Methyl Esters. J. Agr. Food Chem. 13(1):78-81.

Wheeler, J.J., H. Seltmann, and A.G. Motten. 1991. The Mode of Action of Fatty Alcohols on Leaf Tissue. Journal of Plant Growth Regulation. 10: 129-137.

Wittekindt, W. 1978. Current West German Regulations on Maximum Pesticide Residues in Tobacco Products. Tob. J. Inst. 10: 223-228.

Vita

The author, Beau Robert Neal, was born 8 October, 1985 in Wilmore, Kentucky. An Associate of Science degree was obtained from Walter's State Community College in Agriculture Science in May 2007. A Bachelor of Science degree in Agriculture Extension and Education was obtained from the University of Tennessee in May 2009. Upon graduation, the author received a research assistantship at the University of Kentucky in the department of Plant and Soil Sciences. Memberships include Farmhouse Fraternity, Phi Kappa Phi Honor Society, and Gamma Sigma Delta.

Beau Robert Neal