Effects of imidacloprid on the physiology, growth and yield of cotton

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ABSTRACT

Imidacloprid (TRIMAX™) is a new insecticide from Bayer CropScience specifically for use on cotton for control of major sucking/piercing insects. Significant yield enhancement benefits have been observed from imidacloprid application even in situations without economic insect thresholds, but information is lacking on how imidacloprid affects plant growth and enhances yield. Field studies were conducted in 2002 in northeast Arkansas (Clarkedale) and in northwest Arkansas (Fayetteville) using the cotton (Gossypium hirsutum *L.) cultivars Stoneville 474 and Suregrow 215 BR, respectively, to understand plant growth responses to foliar application of imidacloprid and how these may effect the development of yield. Imidacloprid was foliar applied at 1.5 oz/acre as a single application at pinhead square (Fayetteville) and three weekly applications starting at pinhead square (Clarkedale). Imidacloprid increased lint yields at both locations when foliar-applied as either single or multiple applications. These yield increases support earlier reports of increased yields with foliar applications of imidacloprid. Applications of imidacloprid during square development had no significant effect on plant growth, although there was a consistent numerical trend for a stimulatory effect compared with the untreated control plants, i.e. in dry matter of plant components. These differences were visually obvious at first flower. Imidacloprid decreased specific leaf weight and increased chlorophyll content, but had no effect on leaf photosynthesis or canopy temperature. The decrease in specific leaf weight may be related to improved metabolism and translocation of carbohydrates out of the leaf. Imidacloprid did not significantly affect carbohydrate concentrations, whereas there was a significant decrease in the level of the antioxidant enzyme glutathione reductase. In-season measurements of growth suggest that the increase in lint yield following foliar imidacloprid application was due in part to more efficient maintenance of physiological processes by the cotton plant. This research will be continued to further elucidate the mode of action of imidacloprid* [in] *yield enhancement.*

Introduction

TRIMAX™ is an imidacloprid product discovered by Bayer in 1985 and was the first commercially introduced insecticide in the class of chloronicotinyl insecticides. TRIMAX™ provides control of the major sucking/piercing insects in cotton (aphids, cotton fleahopper, banded winged whitefly, plant bugs excluding *Lygus hesperus*, green stinkbug and southern stinkbug). It also has ovicidal effects on bollworms and budworms. The active ingredient in TRIMAX™ is imidacloprid, the only insecticide in the nitroguanidine subclass of chloronicotinyl insecticides with a chloropyridine side chain. This distinguishing side chain is structurally related to compounds like nicotinamide and chloronicotinic acid known as systemic plant resistance inducers. These substances help plants to better tolerate environmental stress during drought, disease, and insect attacks. Field use of TRIMAX™, especially when used in multiple application spray programs beginning early to mid-season, has resulted in enhanced yields including in situations where economic insect thresholds have not been reached (Anonymous, 2002).

Exogenously applied agrochemicals can induce biochemical and physiological changes in the host plants. Insects have also been shown to induce changes in the oxidative status of a variety of crops. It is hypothesized that the apparent growth advantage imposed by imidacloprid may be due, in part, to activation of antioxidant enzymes. These enzymes detoxify the plant of free radicals that are always present due to the numerous environmental stresses that crops face daily (Gould, 2003). The overall objective of these studies was to study the effect of the insecticide imidacloprid on the growth and physiology of cotton with emphasis on antioxidant enzyme activity. The objectives of the current research were (1) to determine the effect of foliar application of imidacloprid on yield and crop maturity, and (2) investigate the mode of action of imidacloprid for yield enhancement.

Experimental procedure

Field studies were conducted at the University of Arkansas Delta Branch Experiment Station in Clarkedale, northeast Arkansas, and also at the Main Experiment Station in Fayetteville, northwest Arkansas to investigate the effect of imidacloprid on the growth and yield of cotton. A randomized, split-plot design with six replications was used in Clarkedale, and a randomized complete block design with six replications was used in Fayetteville. At Clarkedale, the imidacloprid treatments were evaluated under both well-watered and water-deficit conditions accounting for the split-plot design. Water deficit was imposed using an irrigation system specially designed to impose well-watered and water-deficit conditions differentially to a randomized field plot system. In Fayetteville, foliar imidacloprid applications were evaluated only under well-watered conditions. Treatments consisted of (1) an untreated control, and (2) imidacloprid @ 1.5 oz/acre. The cotton cultivar Stoneville 474 was planted on May 16, 2002 in Clarkedale, and cultivar Suregrow 215 BtRR on May

22, 2002 in Fayetteville, in a Captina (Typic fragiudult) silt loam. Imidacloprid was applied with a CO_2 back-pack sprayer at 10 gal./acre at three weekly intervals after pinhead square at Clarkedale and once during peak squaring at Fayetteville.

At Clarkedale, measurements were made of (a) plant growth by classical growth analysis, plant mapping, and NAWF (Nodes Above White Flower), (b) plant physiological response by measuring nonstructural carbohydrate concentrations, leaf photosynthesis, canopy temperature, specific leaf weight (SLW) and chlorophyll content, (c) the plant's ability to tolerate stress by measuring antioxidant enzymes, and (d) final lint yield, yield components, and sequential harvest as a measure of yield earliness. Photosynthesis and canopy temperature were recorded using a LICOR 6200 portable photosynthesis system and a handheld infrared thermometer, respectively.

At Fayetteville, measurements were made of (a) final yield and yield components, and (b) enzyme activity from leaf material collected at 3-hour intervals for the first 24 hours and daily for one week beginning immediately following the foliar application of imidacloprid (data not shown).

Results and Discussion

Effects of imidacloprid on lint yields

Multiple foliar applications of imidacloprid numerically increased lint yield of field-grown cotton at Clarkedale in northeast Arkansas (Figure 1A) and significantly increased ($P<0.05$) lint yield at Fayetteville in northwest Arkansas (Figure 1B) where a single application of imidacloprid at 1.5 oz/acre was sprayed. This increase in yield further supports earlier reports of increased yields with multiple applications of imidacloprid.

Effects of imidacloprid on earliness

Imidacloprid-treated plants showed significantly earlier crop maturity as exhibited by a more rapid decline in Nodes-Above-White-Flower (NAWF) at both locations (Figure 2A). NAWF is a standard measure of earliness in the COTMAN crop monitoring program (Danforth and O'Leary, 1999), with a rapid decline to physiological maturity at NAWF=5 (Oosterhuis *et al.*, 2002) indicating earliness. In addition, a larger percentage of the total yield was harvested at the first pick (Figure 2B). This indicated that a greater proportion of the total number of harvestable bolls matured earlier and were ready for picking before those of the untreated control plants. Early crop maturity is a very important attribute in cotton production for economic and pest control reasons. Also, early maturity is particularly important in the US Mid-South where the season length is already limited.

Effects of imidacloprid on plant growth

Applications of imidacloprid during square development appeared to have a stimulatory effect on plant growth, although most of the parameters measured (i.e., leaf area, leaf and fruit dry weight, and number of squares) were not significantly different ($P<0.05$) from the untreated control (Table 1). Table 1 shows that imidacloprid stimulated plant growth as demonstrated by a numerical increase in dry matter of plant components. These differences were visually obvious at first flower but not apparent during boll development and at harvest.

Effects of imidacloprid on plant physiology

Imidacloprid decreased specific leaf weight and increased chlorophyll content, but had no effect on leaf photosynthesis or canopy temperature (Table 2). The lack of effect on canopy temperature is to be expected as the crop was not under any appreciable water deficit stress and imidacloprid was not expected to effect plant water relations. The increase in chlorophyll was difficult to explain. The decrease in specific leaf weight may be related to improved metabolism and translocation of carbohydrates out of the leaf.

Effects of imidacloprid on carbohydrates and antioxidant enzymes

In order to understand the biochemical changes induced by imidacloprid on cotton, the activity of antioxidant enzymes after foliar application on cotton leaves was determined. Imidacloprid did not significantly affect carbohydrate concentrations (Table 3). However, there was a significant ($P<0.05$) decrease in the level of the antioxidant enzyme glutathione reductase (Table 3).

All living organisms produce reactive oxygen species (such as superoxide, hydrogen peroxide and hydroxyl radicals) as part of normal metabolism particularly under stressful environments. To prevent excessive cellular oxidation from the production of these reactive oxygen metabolites, plants have evolved strategies such as an antioxidant defense system to detoxify the plant and remove these harmful oxygen radicals. It was hypothesized that the apparent growth advantage imposed by imidacloprid is in part due to the plants experiencing less stress, i.e. as evidenced by less activation of antioxidant enzymes to detoxify the plant of free radicals which are always present due to the numerous environmental stresses that crops face daily. Glutathione is involved in a wide range of metabolic processes (Meister and Anderson, 1983) and its content increases considerable under stressful conditions (Smith *et al.*, 1990). A major function of glutathione is thought to be that of protection against oxidative biotic and abiotic stress, i.e. SO_2, O_3, UV irradiation, drought, extreme temperatures, and attack by other organisms. Our results show a significant decrease in glutathione reductase in imidacloprid untreated plants that would support the hypothesis that the untreated plants are exhibiting stress whereas stress was alleviated in imidacloprid-treated plants.

Conclusions

Imidacloprid insecticide increased lint yields at both Arkansas test sites when foliar-applied at either single or multiple applications at a rate of 1.5 oz/acre. These increases in yield further support earlier reports of increased yields with multiple applications of imidacloprid. In-season measurements suggest that the increase in lint yield following foliar imidacloprid application was due in part to more efficient maintenance of physiological and biochemical processes by the cotton plant. However, more research needs to occur to fully validate the effectiveness of imidacloprid for increasing lint yields and crop maturity.

References

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Table 1. *Effect of imidacloprid on plant growth and development measured three weeks after first flower (Clarkedale Arkansas, 2002).*

		Dry weights			
Treatment	LAI (m^2/m^2)	Leaf (g/m^2)	Fruit (g/m^2)	Total (g/m^2)	Squares # ($\#/m^2$)
Control	2.9a[1]	115a	27.6a	303a	193a
Imidacloprid	3.3a	132a	36.6a	356a	187a

[1] Numbers followed by the same letter are not significantly different ($p \leq 0.05$).

Table 2. *Effect of imidacloprid on physiological parameters measured three weeks after first flower (Clarkedale Arkansas, 2002).*

Treatment	Specific leaf weight (g/m^2)	Chlorophyll (SPAD units)	Photosynthesis ($\mu mol/m^2/s$)	Canopy temperature (C^o)
Control	64.1 b[1]	45.7 b	23.3 a	26.7 a
Imidacloprid	56.8 a	51.7 a	24.5 a	26.6 a

[1] Numbers followed by the same letter are not significantly different ($p \leq 0.05$)

Table 3. *Effect of imidacloprid on carbohydrate concentrations and antioxidant enzyme activity measured three weeks after first flower (Clarkedale AR, 2002).*

Treatment	Glucose ($\mu g/cm^2$)	Sucrose ($\mu g/cm^2$)	Fructose ($\mu g/cm^2$)	Glutathione reductase (mmol/min)
Control	62.8a[1]	133.6a	86.4a	202.85a
Imidacloprid	39.3a	110.4a	47.1a	126.56b

[1] Numbers followed by the same letter are not significantly different ($p \leq 0.05$)

Figure 1. Effect of imidacloprid on lint yield in Arkansas in 2002. Columns superseded by a different letter are significantly different (P<0.05).

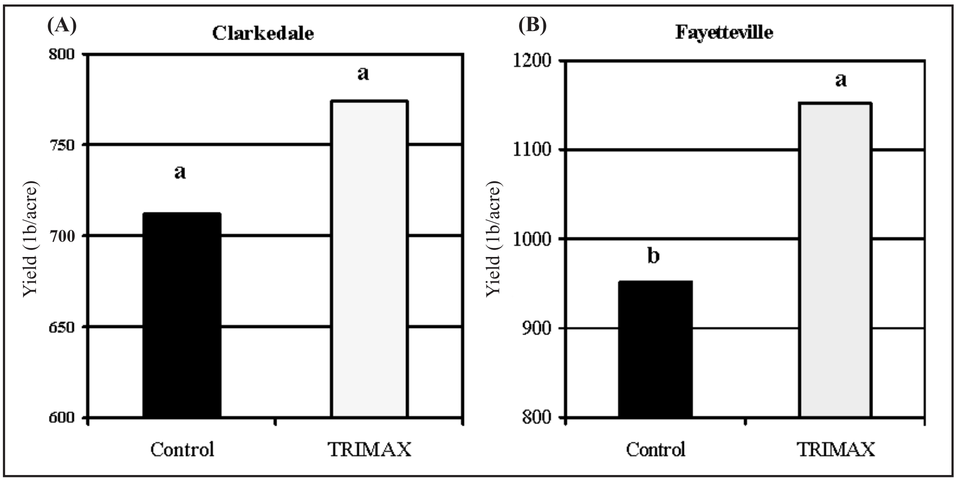

Figure 2. Effect of imidacloprid on earliness indicated by NAWF and percent first pick of total yield at Clarkedale, AR. Columns superseded by a different letter are significantly different (P<0.05).