1260 A nitrogen/insect model for conservation cotton/crop management

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A new high clearance Research Vehicle (RV) with precision IR (GreenSeeker™) plant stress sensors precision granular/liquid fertilizer applicators and a high vacuum insect collector was designed and assembled for the project in early 2006.

Data analysis showed a high correlation between NDVI readings, yield and nitrogen levels (R^2=0.93 and 0.83 in years 2004-2005) in cotton. Five irrigations and 80-lbs of nitrogen/acre were optimal for profit on Harkey clay loam soils in New Mexico.

Overall densities of *Lygus* spp. adults were reduced in insecticide free years

(2005 and 6) ~ 30% when nitrogen use rates were reduced from 135 to 80 -lbs N/acre while profits were increased. Although yields can be increased with higher nitrogen use rates, the highest crop yields do not necessarily give the highest profits and future insect control practices should be based on profit analysis rather than yield. Three applications of chlorpyrifos in 2003 did not control *Lygus* spp. adults or suppress the beneficial complex [predator/*Lygus* spp. ratio (P/L) was 4.2 - 4.8] but five chlorpyrifos applications in 2004 suppressed *Lygus* spp. adults and the beneficial complex (P/L was 5.4 - 7.2). In 2005, there were no insecticide applications and the P/L adult ratios were between 12.1 and 30.5. Precision/conservation farming methods [using NDVI (stress) readings, and improved insect sampling,] results in lower nitrogen fertilizer, water, insecticide, plant hormone and defoliant use, sustains natural predator/prey ratios, requires fewer expenditures of time and money and improves profit margins.

Key Words: Precision cotton production, Cotton insects, Nitrogen, Stress

Introduction

Nitrogen ultimately limits nearly all plant and animal growth on earth, being required for the development of RNA, DNA, amino acids and proteins (White 1993). The use of high-yield technology, based on the increased use of nitrogen and pesticides, introduced during the green revolution, has helped farmers produce, on average, three times higher yields on their land (Stovig 2004).

World nitrogen use between 1997/8-1999/00 was 120-137 million tons (International Fertilizer Industry Association 2000). The nitrogen use rate in the United States during this period was between 11.5 and 12.5 million tons. Between 472 and 567 thousand tons were applied to cotton (USDA Economic Research Service 2006).

World expenditures for pesticides in 2000-2001 were $32 billion of which $11 billion was spent in the US. Insecticides were $3.6 billion of the total US pesticide expenditures (US

Environmental Protection Agency 2006). If we could reduce nitrogen and pesticide use by even 10% it would save some 1.2 million tons of nitrogen and $3.2 billion in pesticide expenditures.

About half of this applied nitrogen is not taken up by plants but is lost to the atmosphere and to above and below ground water supplies (Smil 1997). Herrera (2001) found 77% of nitrogen applied to pecans in New Mexico is lost to ground water and the atmosphere. Growers often use more nitrogen and water than is necessary to insure optimum crop production. Warden et al. (1992) found a 50% reduction in the use of both nitrogen and water did not compromise yields in California lettuce production in the Salinas Valley. A 50% reduction of nitrogen and irrigation water was the point of maximum profit.

Because nitrogen for fertilization has been inexpensive and precision measuring and application methods have not been sufficiently developed, growers throughout the world tend to apply far more nitrogen than generally needed for crop production, leading to a plethora of subsequent problems.

The massive introduction of nitrogen to the soil, water and atmosphere results in profoundly detrimental consequences. Pollution factors include contamination of under and above ground water supplies causing algal blooms and contamination of the atmosphere (Simone 2005). High nitrogen and insecticide use has been linked to many cancers and multiple other health issues, including Parkinson's disease, allergies etc. (Simone 2005). Of special significance, excessive nitrogen drives up population densities of plant and animal pests cf 100 citations in White 1993, particularly in monocultures (Conway and Pretty 1991).

Initial insecticide use, to control primary pests, kills both pest and beneficial insect populations and often leads to multiple applications over large land masses which select out resistant biotypes which eventually may not be controllable. In contrast, phytophagous insect problems can often be reduced with proper cultural practices, i.e. by avoiding such things as over consumption of nitrogen and water (Leigh 1996, Altieri and Nicholls 2003), and by providing refugia for beneficial insects (Garr 2000).

New Mexico has been an ideal place to carry out this work because the primary exotic harmful insects in New Mexico (boll weevil *Anthonomous grandis grandis* Boheman and pink bollworm *Pectinophora gossypiella* (Sanders) have been reduced or completely eradicated leaving the way open for the use of integrated biological control techniques. Numerous small alfalfa fields, dispersed among the cotton fields provide a perfect model for management of complex integrated systems (74,000 acres of cotton/115,000 acres of alfalfa) in cotton growing counties.

Cotton has been chosen as a model system because it is one of the most difficult crops to manage; it is one of the largest users of nitrogen and pesticides in the world and it is supported by Governmental subsides, which if lost, will force U.S. growers to optimize production practices substantially to compete in world markets.

Background

Agronomic Factors

In most crops, water and nitrogen are the most limiting factors for plant growth. Farmers need to know the relationship between profit, water and nitrogen use i.e. the cost/benefit ratio (CBR). Factors such as water quality, evapotranspiration and soil type all interact to influence water use. Similarly, efficient nitrogen application rates depend on timing, application methods, soil type, nitrogen sources and carryover.

Determining Water and Nitrogen Availability

Traditional water and nitrogen monitoring requirements in complex agricultural production systems are difficult and labor intensive; however, both water and nitrogen can be monitored quickly and effectively by measuring plant stress. Plant stress measurements determine health irrespective of the factors that modify water and nitrogen availability as plant growth occurs.

Optimizing Plant NDVI Sampling

Raun et al. (2002, 1998) showed that significant differences in total available nitrogen, NH_4-N and N03-N, exist in soils areas 3.2ft^2 in size or less. Therefore, precision applications of fertilizer and nitrogen could theoretically optimize profit while reducing nitrogen use. NTech Industries Inc. and Oklahoma State University jointly developed the GreenSeeker™ which measures plant stress as a function of biological differences which exist in the field. GreenSeeker™ active lighting optical sensors use high intensity light emitting diodes (LED's) that emit 600nm (red) and 780nm (near infrared) light sources. These LED's are pulsed at high frequencies. Magnetic filters remove all background illumination. Magnitude of the filtered signal is measured by a multiplexed A/D converter. The sensors are temperature stable. One hundred readings/12.9 ft^2 are taken, averaged and plotted using GPS from which a normalized difference vegetative index (NDVI) is calculated (NDVI = IR -R/IR + R, where IR = infrared, R = red light). NDVI technology can be used to target places where site-specific fertilizer applications should be made. Measuring stress from GreenSeeker™ readings has the advantage over traditional soil samples of being fast and reliable and over aerial stress measurements of providing fast data turnaround without interference from cloud cover. Significant increases in nitrogen use efficiency of, on average, 15% have been reported in multiple wheat fields using GreenSeeker™ technology (Raun et al. 2002).

Insect Factors

Host Seeking by Insects

Insects find host fields passively by being blown into them or actively by following a scent trail upwind to them. Insects within fields predominately rely on plant-produced, volatile, soluble, secondary compounds, to locate optimal host plants. In the head-space of intact plants, generally 10-100 volatile compounds occur (Schoonhoven et al. 1998). The major groups of components released are six-carbon alcohols, aldehydes and esters of acetates and other short chain aliphatic acids and a variety of variable range mono- and sesquiterpenoids (Van Loon and Dicke 2001). For any plant species the composition and quantity of volatiles emitted is prone to considerable variation (Dicke and Vet 1999). The most important sources of variation are genotype, developmental stage and biotic factors, such as competing plants, infections by pathogens and arthropod damage. Abiotic factors that affect production of volatiles are, e.g. shading and soil nutrient level. Nitrogen levels may have profound effects on phytophagous insect densities affecting not only amino acid and protein synthesis but also the synthesis of volatile compounds which cue insects as to the most viable hosts (i.e. those with the highest nitrogen levels).

In reviewing 50 years of research relating to crop nitrogen and insect attack, Scriber (1984) found 135 studies showed an increase in damage and or growth of leaf chewing insects or mites in nitrogen fertilized crops versus fewer than 50 studies in which herbivore damage was reduced by normal fertilizer regimens. In Letourneau's (1988) review of 100 studies on insects and mites, two-thirds showed an increase in growth, survival, reproduction rate, population densities or plant damage levels in response to increased nitrogen fertilizer use. The concentration of nitrogen in food plants generally plays a predominant role in the nutritional ecology of insect species (Soldaat and Vrieling 1992).

Several workers have noted the influence of varying levels of soil fertility on certain cotton insects such as the cotton aphid *Aphis gossypii* Glov. (McGarr 1942, Isley 1946), species of mirids, e.g. the cotton flea hopper *Psallus serialus* (Reut.) (Butt et al. 1946, Adkisson 1957), lygus *Lygus* spp. (Leigh and Goodell 1996) and the bollworm *Heliocoverpa zea* (Boddie) (Fletcher 1929, Thomas and Dunnam 1931). Gains (1932, 1933) reported that the rate of oviposition by bollworm moths and the rate of plant growth were closely correlated and they suggested rapidly growing cotton is a preferred site. Fletcher (1941) correlated the number of bollworm larva present in different fields with the moisture content of the growing tips of cotton plants. Swezey et al. (2004) found organic fields had significantly fewer western tarnished plant bug *Lygus hesperus* Knight nymphs and more generalist predators than conventional fields.

Sampling Insects

Because traditional hand-net samples catch only ~8% of the total insects present in cotton (Ellington et al. 1984a) and the beneficial complex is normally not counted, an attempt was made to improve speed, accuracy and inclusiveness of insect sampling.

Acquiring Samples - A small (hydraulically driven) self-propelled platform (Insectavac) with a 4,200-cfm high vacuum fan was designed and built to take representative cotton insect samples in 1983 (Ellington et al.)

984b). A later, but identically performing version (research vehicle, RV) constructed in 2006 (Fig 2), in addition to the vacuum system, uses three GreenSeeker™ sensors, mounted over cotton rows in front of the vehicle to control solenoid release valves for liquid or granular fertilizer applications mounted in back of the vehicle. These samplers can cross borders and are easily transported from field to field. **Calibration** - The Insectavac collector was calibrated for 24 genera of insects by comparing 83, 100-ft relative vacuum samples in three cotton fields to 830, 2.4-ft absolute clam shell samples in the same plots.

Efficiency ranged from 25-85% depending on insect species, densities, clumping patterns and plant height. Insectavac sample densities can be converted to absolute or sweep net densities when needed (Ellington et al. 1984a).

Sample Size - The optimum size and number of samples needed to estimate the mean density of 24 genera of insects in cotton was determined by vacuum sampling 100-ft quadrates end-to-end 12 times over a three year period in three cotton fields (590 samples). Data for each date and location were pooled and the data analyzed as a nested design (Fig 3). Variability in the data set increased with sample length because the samples went over clumped and nonclumped areas. In practical practice, the optimum sample size was found to be the smallest sample size possible while maintaining statistical integrity. In New Mexico, a good compromise is 100 row-ft replicated four times in a given field. Four 100-ft vacuum samples per cotton field generally catch on average 32% of the insects present, depending on plant height, density, and clumping patterns of species evaluated (Ellington and Southward 1996, Ellington et al.1988, Ellington et al.1984a, b and Amin et al. 1994).

Figure 2. 4WD research vehicle with IR, GPS, variable rate fertilizer application and insect vacuuming system.

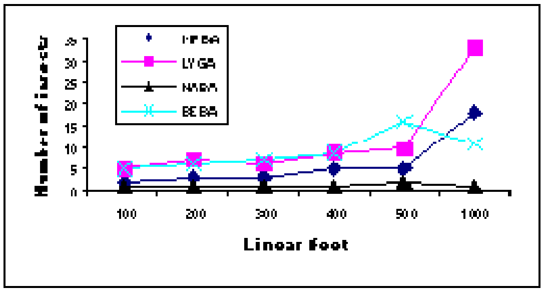

Figure 3. Number of replications needed to estimate the mean density of minute pirate bug adults (MPBA), lygus adults (LYGA), nabid adults (NABA), and big eyed bug adults (BEBA) to within 80± 5% if their true mean at various row lengths.

Predicting Primary Consumer Densities

The complex group of arthropods found in agricultural ecosystems may be composed of host-specific and host-nonspecific primary consumer, parasitoid, predator and hyperparasitoid species. These arthropods may interact in positive, negative, or neutral ways, depending on behavior and factors that influence natality, mortality, speed of development and migration (Ellington et al. 1988). Each system must be evaluated on its own merits.

Predator Switching

Some parasitoid species and most predaceous arthropods are relatively host-nonspecific (Ellington et al. 1997). A host switching parasitoid or predator can stabilize an otherwise unstable host-parasitoid interaction (Murdock 1969).

Migration

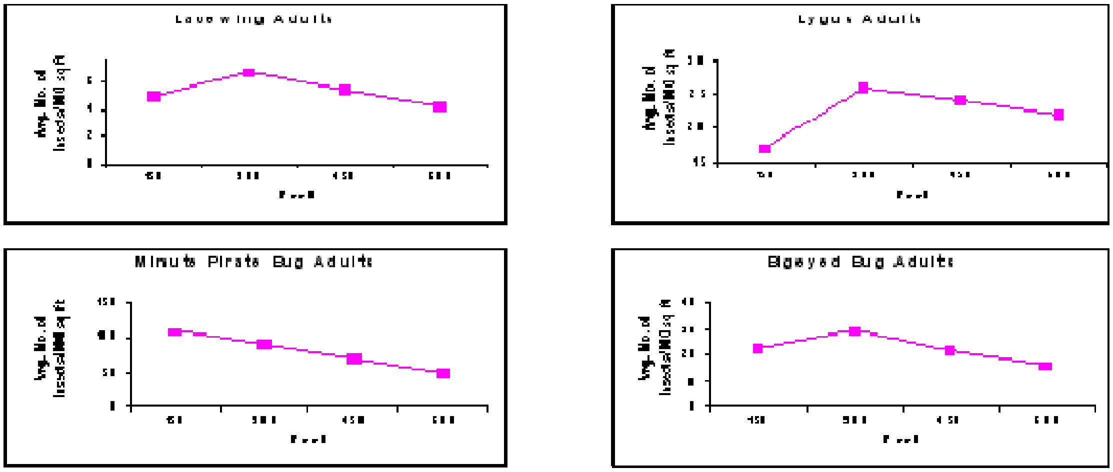

Figure 4. Average of four 100-ft Insectavac insect samples taken 150, 300, 450 and 600-ft from the edge of a 360-acre cotton field down-wind from a 360-acre drying safflower field, Boswell farms, Corcoran, CA.

Alfalfa remains a primary source of beneficial insects in many western agricultural regions. We have documented 120 species of parasitoids and two dozen predators which occur in cotton and alfalfa fields in New Mexico. These beneficial insects may migrate from ¼ - ½ mile to adjacent cropping systems each time an alfalfa field is cut (Ellington et al. 2001, Ellington et al. 2003 and Loya 2002). A similar system was documented at the Boswell farms, Corcoran, CA (Fig. 4), when beneficial insects (lacewings *Chrysoperla* spp., minute pirate bugs *Orius* spp. and bigeyed bugs *Geocoris* spp.) were tracked down-wind from a drying safflower field to cotton with an Insectavac sampler (Ellington et al. 2003). Because the safflower was no longer attractive these insects remained in the cotton. In New Mexico, the density of the beneficial complex in cotton returns to previous levels shortly after the residue from insecticide applications dissipate (Ozkock 1997 and Loya 2002), suggesting constant migration of the beneficial complex from recently cut alfalfa to standing alfalfa or to other cropping ecosystems such as cotton; however, alfalfa appears to outcompete cotton for a variety of insects common to both crops. Much more work is needed to clarify the dynamics of insect migration between cropping ecosystems.

Predator Feeding Preferences

Ellington et al. (1997) in an extensive six-year study based on over 1200 (100-ft) samples, taken with the Insectavac vacuum sampler in 31 different cotton fields, found predators were associated with various primary consumers 163 times and various other predators 191 times, suggesting switching by predators may occur readily. If this is true, an invading primary consumer might be primarily controlled by nonhost-specific, switching predators. Predator rich systems may have an element of stability not found in predator poor systems.

Control of Primary Consumers by Predators

To determine the power of predators in controlling phytophagous insect species in fields, five bollworm eggs per plant were glued to 40 cotton plants (200 eggs) five times in three cotton fields in 1998 (10,000 eggs per field). Egg morality was evaluated daily for two days after initiation of the test. Fifty and 85% bollworm egg mortality occurred one and two days after initiation of the test. Final R_2 values from regressions of total predator densities on bollworm egg mortality in these cotton fields were above 90%. Additional mortality might be expected from third day exposure of eggs and young larvae to predators, parasitoids and possibly weather factors (Ellington and El-Sokkari 1986).

Lygus spp. Damage and Compensation

The impact of *L. hesperus* on cotton square and yield loss is controversial because of conflicting experimental results and different interpretations of cotton's ability to compensate (Rosenheim et al. 2006). Rosenheim et al. (2006) found mobile transit populations of *L. hesperus* sweeping through fields in the San Joaquin Valley did not seem to explain higher or lower than expected levels of square abscission.

Chapman (2002), and Kerby et al. (1987) reported Acala cottons, even under ideal conditions, drop 60% of young squares and defoliation up to 70% had no economic effect. Pierce et al. (2006 and 2007) found that one time mechanically applied injury, by removing all 1/3 and younger squares to simulate insect damage one time, mid-and late August, did not compromise yield; however, repeating this procedure two times did significantly reduce yield. Wilson et al. (2003) suggested early season pest damage to cotton is largely cosmetic. Crop yield and crop maturity was not affected by 100% defoliation before first flower buds appeared and 100% fruit removal from the first four fruiting branches did not affect yield but delayed maturity seven days. Cotton can compensate for large square losses. Compensation may be modified by stress i.e. season length, cloudiness, water availability, nutrient availability, variety etc. Applying insecticides early season is expensive, may destroy the beneficial complex and often does not improve yield or profit. "One can succeed by simply doing nothing" (Wilson et al. 2003). Additional work is needed to clarify economic thresholds of migrating adult *Lygus* spp. populations sweeping, for short periods of time, through cotton fields at different times during the growing season.

Materials and Methods

Plot Design

Cotton was grown with high and low applications of nitrogen and water in split-plot randomized complete block designs. Treatments consisted of four, five and six irrigations in 2003 and five irrigations in 2004, 5, and 6. Nitrogen fertilizer treatments consisted of one preplant broadcast application of 45-lbs N/acre and one side-dress application at layby to bring up total nitrogen levels to 45 and 135-lbs N/acre in 2003 and 2004; 50, 80,115, 142, 234-lb N/acre in 2005 and 45, 80 and 135-lbs N/acre in 2006. One 80-lb N/acre application in 2006 was applied as a precision side-dress application and compared to conventional 45, 80 and 135-lbs N/acre side-dress applications. Stress was measured and recorded with a GreenSeeker™ and insects collected with an RV collector. NDVI readings for the precision nitrogen applications were set between 0.6 and 0.8. ANOVA's were conducted to compare plant responses from nitrogen and soil moisture to yield, development, lint quality and insect densities.

Results From 2003-6

Results of NDVI/Nitrogen Experiments

Two year's data show there was a high correlation between average NDVI readings, yield and nitrogen levels (R^2 =0.93 and 0.83 in years 2004-2005) in cotton (Carrillo et al. 2006a, b and c). Nitrogen needs may be modified by previous crops, nitrogen source, application methods, rainfall, soil type, organic matter, crop variety etc. There were no significant micronair (fiber quality) differences between fertilizer and irrigation treatments. All treatments expressed similar height/node ratios, but higher water and nitrogen plots needed Pentia™ applications to hold growth back. Defoliants were used only on the higher nitrogen/water treatments (142 and 234-lbs N/acre). There were no yield differences between conventional and precision applications of nitrogen at 80-lbs N/acre in 2006.

Results of Insect Experiments

The eradication of primary insect pests (boll weevil and pink bollworm) makes sustainable biological control of secondary insect pests (aphids, whiteflies, bollworm and *Lygus* spp.) practical in New Mexico. Our research focused on *Lygus* spp. control in 2003, 4, 5 and 6. Figure 5 shows *Lygus* spp. densities in year 2003 when three applications of chlorpyrifos were not enough to completely control *Lygus* spp. and did not decrease the density of the beneficial complex. Five applications of chlorpyrifos in 2004 controlled *Lygus* spp. and decreased the density of the beneficial complex. In 2005, there were no insecticide applications. Predaceous insect densities were high and *Lygus* spp. densities low, giving high PPR (predator/prey ratios). Predator/prey ratios were calculated by adding the densities of the major adult and nymph predator groups (*Nabidae, Geocoris, Collops, Chrysoperla, Hippodamia* and *Orius*) divided by the major economic prey (*Lygus* spp. adults). In 2006, very high migratory adult populations of *Lygus* spp. occurred (Fig 6). Densities spiked at nearly six times the normal rate. The predator/prey ratio was low and the *Lygus* spp. densities high in 2006. Even so, *Lygus* spp. densities were halved in the lower nitrogen fertilizer plots (135-80-lb N/acre) in both 2005 and in 2006 when insecticides were not used.

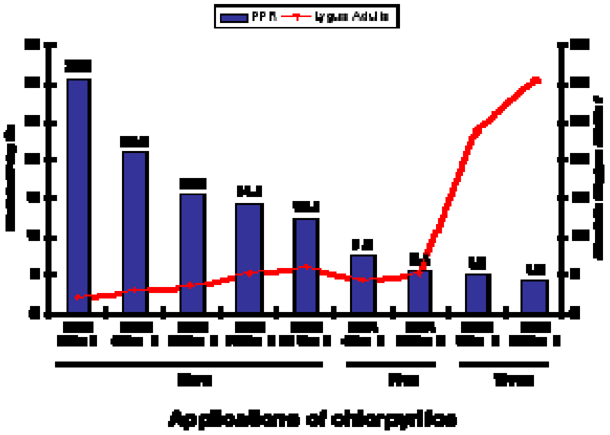

Figure 5. Predator/adult *Lygus* spp. densities derived from 100-ft absolute vacuum samples from Acala 1517-99 cotton in 2003, 4 and 5 and DP-555. Three, five, and zero chlorpyrifos insecticide applications were made in 2003, 4 and 5 respectively. *Lygus* spp. adult densities increased as nitrogen use rates increased. Predator densities remained about the same in zero insecticide use years.

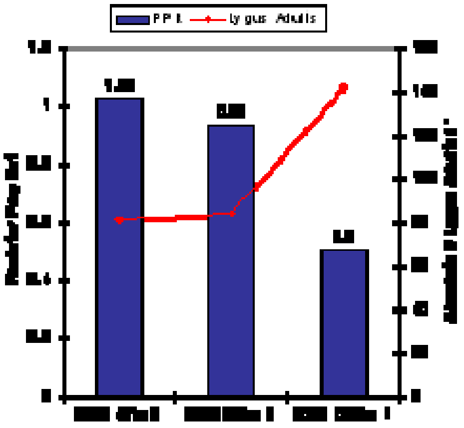

Figure 6. Predator/prey ratios derived from 100-ft absolute vacuum samples from DP555 cotton in 2006. The predator/prey ratio was doubled and the *Lygus* spp. adult densities nearly halved in the reduced nitrogen fertilizer applications (45, 80-lb N/acre).

Discussion

Nitrogen/Insect/and Conservation Interactions

Lygus spp. densities are often lower in New Mexico than neighboring states, perhaps due to numerous alfalfa fields which act as habitat for *Lygus* spp., a short growing season restricting biotic potential (Ellington et al. 1984b) and, on average, the application of half the amount of nitrogen used in California and Arizona. The Arizona and California use rates in lbs/acre from 1978-1993 was 113-178 and 106-140, twice as much as New Mexico from 1978-86, at 54-88-lbs N/acre (Economic Research Service 2006).

Average rainfall in July and August 2006 was 5.68-in. compared to a 10 year average of 2.40-in. from 1996-2005 (Mottt et al. 1992). Frequent rainfall may have encouraged the growth of alternate weed hosts for *Lygus* spp., but also alfalfa hay cutting was delayed until the rain subsided. Many growers cut alfalfa hay late and at the same time forcing high adult *Lygus* spp. populations into cotton rather than back into alfalfa. The control of migrating adult *Lygus* spp. populations from weeds and alternate cropping systems into cotton is a particularly difficult problem. Broad spectrum insecticide use further exacerbates this problem by decreasing the density of the beneficial complex, and flaring in-field *Lygus* spp. populations. Solutions to this problem include: strip cutting alfalfa hay, releasing *Peristenus stygicus* or *P. digoneutis* and leaving border strips of alfalfa in hayfields to keep *Lygus* spp. adults there. Predator densities remained relatively stable in 2005 and 2006 when insecticides were not used.

Lygus spp. nymph densities were very low in 2003-2006 [1.17 average (range 0.5-14.5)/100 row-ft absolute], suggesting *Lygus* spp. populations in the Mesilla Valley are made up of mostly migrating adult populations as in the San Joaquin Valley (Rosenheim et al. 2006). Predators are not likely to control migrating adult *Lygus* spp. but they probably do help control eggs and nymphs of the next *Lygus* spp. generations. Predator and *Lygus* spp. adult densities resurged quickly after insecticide residues dissipated from three insecticide applications in 2003 but remained low after five insecticide applications in 2004. The very large between year *Lygus* spp. density variations experienced between 2003-6 suggest cotton fields should be sampled, with precision equipment, multiple times, during the growing season, to determine *Lygus* spp. densities, predator/prey ratios; adult/nymph ratios and their effect on yield and profit.

The densities of *Lygus* spp. and other harmful insects in New Mexico and other production areas can be reduced with proper cultural practices, by avoiding such things as luxury consumption of nitrogen and water (Leigh 1996, Altieri and Nicholls 2003) and by providing habitat for beneficial insects (Garr 2000). Other factors that influence *Lygus* spp. densities in specific fields include: adjacent crops, timing of harvesting of adjacent crops, host weed populations, crop variety etc. In most years and in most fields, *Lygus* spp. are not an economic problem in New Mexico cotton production.

Profit

Maximum yields do not necessarily equate to maximum profits and future changes in technology at the farm level can be used to evaluate management decisions with this in mind. Many of the production costs for conservation cotton production are similar to that of conventionally grown crops. Production cost differences occur primarily in soil fertility, pest management, irrigation, plant growth regulator and defoliation expenses which vary with different soil types, varieties etc. An economic analysis (NMSU nitrogen use in cotton budget **calculator - lillywhi@nmsu.edu**) was used to determine the best management strategies for cotton profit optimization in the Mesilla Valley. Five irrigations with 80-lbs N/acre gave the highest profit (Carrillo et al. 2006c, Table 1). Insecticide, defoliation, excessive fertilizer and plant growth regulator expenses were deducted from the 80 and 50-lb N/acre treatments. Precision side-dress applications of nitrogen are expected to reduce nitrogen expenditures below those reported in Table 1.

Irrigations / lbs N	**Yield lbs/A**	**Profit-Loss $/A**
Five / 50 lbs	1092	+11.75
Five / 80 lbs	**1341**	**+117.00**
Five / 115 lbs	1391	+20.75
Five / 142 lbs	1492	+70.02
Five / 234 lbs	1421	+14.75

Table 1. Irrigation number, pounds of nitrogen, yield and profit of Acala 1517-95 cotton at Las Cruces, New Mexico, 2005. Five irrigations with 80-lbs of nitrogen gave the optimum profit.

Conclusions

The precision/conversation farming methods used here have been designated-Fast Agricultural Response Management System (FARMS). The FARMS uses tools of NDVI (stress) readings, improved insect sampling, and computer insect counting tools which result in lower nitrogen fertilizer, water, insecticide, plant hormone and defoliant use, sustains natural predator/prey ratios, requires fewer expenditures of time and money and improves profit margins. Essential elements of the FARMS can be applied to a wide variety of field and orchard cropping systems in the United States.

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