PROTECTION OF FORAGE CROPS FROM INSECT PESTS: PROBLEMS AND SOLUTIONS IN RELATION TO STAND PERSISTENCE

W. O. Lamp

Department of Entomology, University of Maryland, College Park, Maryland 20742, USA

ABSTRACT

Pest management is the result of the generation and transfer of information on pest dynamics and pest-crop interactions. With emphasis on the role of pests on the persistence of forage legumes, I examine some of the problems associated with pest management research and education. Forage and grassland systems uniquely differ from most crop systems, and sharing of information among scientific disciplines, private industry, educators, and end-users is critical for the improvement of pest management. I provide an example of research on potato leafhopper *(Empoasca fabae*) and its injury to alfalfa (*Medicago sativa*). Feeding injury by this leafhopper disrupts normal translocation of photoassimilates and causes reduced photosynthetic rates. In one experiment, translocation to the stem tip is reduced for early vegetative plants, but not for reproductive plants. Phloem disruption on more mature plants is expected to affect root storage compounds, and therefore, plant survival and stand persistence. Nymphs and adults feed primarily on leaf and stem tissue, respectively, and in another experiment the photosynthetic rates of specific leaves differs depending on the type of tissue injured. The research of the physiological basis for alfalfa injury by potato leafhopper will aid in the development of new methods for alfalfa to withstand and recover from leafhopper injury. This example demonstrates the importance of defining pest management research and education needs as a result of communication among scientists, industry representatives, and producers.

KEYWORDS

pest management, alfalfa, information transfer, stand persistence, insect pests, potato leafhopper, physiological disruption

INTRODUCTION

Insect pests have existed in forage and grassland systems since the beginning of agriculture, and they will always exist as long as humans use plant foliage as food for animals. However, with time, we have developed our understanding of the dynamics of the insect pest life systems and their association with the grassland ecosystem, which in turn has expanded our ability to manage pest problems. Pest management is the result of two different but related approaches. One is research, or the generation of new information through scientific method and the development of new technology. The other is education, or the exchange of information among scientists, private industry, and producers. These two approaches are intimately linked in the extension of new information from researchers to producers. Less clearly acknowledged is the opposite flow of information: the identification of research and education needs (Fig. 1). Here, I describe pest management with regard to one of the major problems relating to forage production of legumes: the persistence of stands. I conclude by emphasizing the need to clearly define research and education needs for the future.

FORAGE LEGUME STAND PERSISTENCE

Forage legume crops are essential components of livestock production systems, with added value as contributors to soil improvement and conservation. Although forage legumes are capable of persisting in stands for many years, ecological and physiological factors act in concert with the pest community (e.g., weeds, pathogens, arthropods) to shorten the life of stands (Beuselinck et al., 1994; Marten et al., 1989). The resulting lack of persistence significantly reduces profitability and, in locations and periods of severe stress, effectively prevents the cultivation of specific crops. From the perspective of pest management, our goal is to improve persistence of forage legume stands through implementation of ecologically-based pest management (U.S. Congress, 1995; Frisbee and Smith, 1989).

Stresses imposed by such factors as unfavorable growing conditions, interference by weeds, and injury by pathogens and arthropod pests may significantly shorten stand life (Beuselinck et al., 1994). Although there are instances when single factors such as a key pest species may threaten production stand life (e.g., alfalfa snout beetle, *Otiorhynchus ligustici* L.; Manglitz and Ratcliffe, 1988), more typically loss of stands results from combined stresses imposed by several factors. For example, grass weed invasion may follow injury caused by alfalfa weevil, *Hypera postica* Gyll. (Berberet et al., 1987), or root feeding by clover root curculio, *Sitona hispidula* Fab., may increase the incidence of Fusarium root rot (Leath and Hower, 1993). Similarly, specific crop management practices affect not only crop persistence directly, but also indirectly through the interaction between pest populations and the crop. For example, early harvest may interfere with the cyclical increase in critical root storage compounds, yet help to reduce the impact of pests such as potato leafhopper, *Empoasca fabae* (Harris) at the same time (Simonet and Pienkowski, 1979). Thus, the problem of forage stand persistence is a clear example of the need for an integrated and interdisciplinary approach to crop and pest management for improving stand longevity.

PEST MANAGEMENT INFORMATION CONSTRAINTS

The development of our understanding and improvement of forage legume persistence depends on education of what we do know through information transfer and on research of what we don't know through science and technology. To identify some of the problems and possible solutions associated with pest management of forage crops, a workshop was held at the Third National IPM Symposium/ Workshop in April 1996, Washington, D.C., USA. A series of topics were discussed; a partial summary of that discussion is given in Table 1.

The discussion provided a clear message that forage and grassland systems uniquely differ from most crop systems because of 1) their relatively low value per unit area, 2) the diversity of plant species used as crops, 3) their wide range of uses within farm systems (e.g., as monocultures or in mixtures, from closely-managed hay systems to relatively little managed prairie systems), 4) their integral use within sustainable farm systems for soil conditioning and crop rotation, and 5) their usual persistence in stands for several years, providing a consistent habitat for many pest species while frequent harvesting may disrupt other species. Thus, pest management within forage and grassland systems provides a special challenge to IPM (integrated pest management) implementation. The sharing of information among scientific disciplines, private industry, agricultural educators, and end-users is critical for the improvement of pest management.

PEST MANAGEMENT RESEARCH

Pest management research should be guided by the needs of producers to solve pest problems, yet based on the biology and ecology of the pest and its interaction with the crop. Here, I will describe research in progress on potato leafhopper and its impact on alfalfa physiology, and provide background on its importance in developing IPM programs for improving alfalfa stand persistence.

Potato leafhopper is the primary pest of alfalfa during the summer throughout northcentral and northeastern United States (Manglitz and Ratcliffe, 1988). Estimated leafhopper losses in Maryland averaged $32.11/ha to $66.12/ha annually over a six year period (Lamp et al., 1991). Injury to alfalfa is caused by probing and ingestion behaviors, and possibly salivary constituents, resulting in disruption of phloem tissue structure (Ecale and Backus, 1995a; Kabrick and Backus, 1990) and therefore reduced translocation of photoassimilates (Nielsen et al., 1990). Subsequently, injured plants have reduced photosynthesis and transpiration, and increased stomatal resistance (Flinn et al., 1990). Damage is expressed by reduced maturation, growth, and nutrient levels, as well as reduced root carbohydrate storage available for regrowth (e.g., Hutchins and Pedigo, 1990; Hutchins et al., 1990; Lamp et al., 1985). Insecticide applications remain the primary method for managing the pest; the need for application is determined from sweep net samples within fields (Cuperus et al., 1983; Hellman et al., 1995). Simulations of leafhopper management strategies as modified by tolerance mechanisms (i.e., reduced damage per insect) indicated significant savings not only as a result of reduced losses and less pesticide use, but also from a change in the optimum strategy for leafhopper management (Lamp et al., 1991). Thus, manipulating the response of the plant to leafhopper-induced injury has the potential of reducing pesticide input and increasing economic benefits for alfalfa production.

In general, carbon fixation and transport of carbon and nitrogen are primary physiological functions of crop plants which may be disrupted by sap-feeding insects, such as potato leafhopper (Raven, 1983). This disruption causes damage to the crop through a cascade of physiological reactions in response to feeding (Welter, 1989; Thomas and Stoddart, 1980). The degree of disruption, and thus the resultant stress to the plant, may be reduced by specific pest management practices (e.g., plant resistance, natural enemies, pesticide applications), or by manipulating the crop and its ability to compensate for injury. Crop manipulations are predicated on the knowledge of the physiological response of the crop to pest-induced injury.

The physiology of perennial herbaceous plants, including most forage crops, differ from annual and woody perennial plants because of the emphasis on cycling of carbon and nitrogen compounds between root and shoot tissues for survival and regrowth (Kust and Smith, 1961). In addition, forage legumes fix nitrogen through the symbiotic relationship with *Rhizobium* bacteria, which requires carbohydrates provided by its host (Vance et al., 1979). The role of vascular feeding by herbivores on root-shoot partitioning, as well as on nitrogen fixation, is poorly understood (Higley et al., 1993; Peterson and Higley, 1993; Welter, 1989). My goal is to improve our understanding of such a system: potato leafhopper whose injury to perennial alfalfa causes disruption of phloem translocation and reduction in photosynthetic rate. My research focuses on critical aspects of leafhopper-alfalfa interactions that affect crop growth, root-shoot relationships, and persistence.

Research completed in my lab has demonstrated that leafhopper injury has a marked impact on translocation of photoassimilates as measured by ^{14}C movement following fixation in leaves and subsequent export to the vascular system (Nielsen, et al. 1990; submitted). Because of the cycling of carbon and nitrogen compounds between roots and shoots in alfalfa (Avice et al., 1996; Barber et al., 1996; Graber et al., 1927), the time of leafhopper feeding during alfalfa development will impact the physiological response of the plant to injury. Studies to date on alfalfa response to leafhopper have focused on the larger effects of leafhopper injury without consideration of the profound changes during alfalfa development (Flinn et al., 1990; Womack, 1984). For example, I expect that injury to stems during the first half of the growth cycle (with carbon and nitrogen compounds generally moving upward) will especially affect stem growth, while injury during the second half of the growth cycle (with carbon and nitrogen compounds generally moving downward) will especially affect root storage and nitrogen fixation. These predictions have important implications for the timing and long-term impact of pest management tactics.

We performed a preliminary test of this hypothesis by comparing the distribution of translocated ^{14}C within injured and uninjured alfalfa plants at one of three stages of development (Nielsen et al., submitted). We exposed "injured" plants to three adult leafhoppers for 20 h before measuring phloem translocation from the leaf at the fourth node to the growing tip (methods similar to that described in Nielsen et al., 1990). We found, as expected, that ^{14}C translocation to the tip was significantly reduced especially on the early vegetative plants, but not on the reproductive plants (Table 2). Note that translocation, shown in log scale, is reduced nearly 100-fold in the injured early vegetative plants. Current IPM practices (i.e., economic thresholds, Hellman et al., 1995; Cuperus et al., 1983) focus on short-term, above-ground effects of injury within a given growth cycle. Thus, our research expands knowledge of the long-term effects on the persistence of the stand. The research will provide a basis to revise thresholds in light of subtle, below-ground effects of leafhopper injury.

Different leafhopper stages may have different impacts on alfalfa physiology. We have observed that while adults feed primarily on stem tissue, nymphs feed primarily on leaflets. For example, we carefully observed the locations of nymphs on plants within an alfalfa field during July, 1996 (Lamp *unpub. data*). Of the 75 1st-2nd instars and the 127 4th-5th instars, 96% and 85% were on leaf tissue, respectively. Locations of adults are more difficult to observe in the field, however in a laboratory test 64% of 42 independently caged adults were observed on stem tissue (Fuentes and Lamp, *unpub. data*). This adult preference for stems is also supported by a laboratory study by Backus et al. (1990) and the observed preference for oviposition in stems (Simonet and Pienkowski, 1977). Thus, nymphs are expected to more directly cause reductions in the export of photoassimilates from individual leaves, while adults disrupt translocation within the stem. However, our recent data show that when forced to feed on stems, only larger stadia (4-5th instars) and not smaller stadia (1st-2nd) were capable of disrupting translocation of ^{14}C-labeled photoassimilates to stem tips (Nielsen et al., submitted).

In another recent study to compare leaf and stem injury (Nielsen & Lamp, *unpub. data*), we confined 5th instar nymphs to either one leaf (third fully-expanded leaf from the top) or to one internode stem section (between the second and third leaves) for 24 h, and measured the effect of injury on the rate of photosynthesis for the top three leaves. Leaf feeding reduced photosynthesis only on the injured leaf, whereas stem feeding reduced photosynthesis for leaves above the feeding site (Fig. 2). Because adults and nymphs usually feed on different tissues, their impact on the plant differs. Thus, economic thresholds should distinguish between adult and nymph injury.

Furthermore, little is known of the ability of alfalfa to recover from feeding injury. Nielsen et al. (1990) found no evidence of recovery of phloem translocation from a 6 or 12 h feeding pulse 4 d after leafhopper removal. Yet, histological studies following injury suggest that phloem tissues do regenerate (Ecale and Backus, 1995b). Based on morphological symptoms of injury at the cellular level, they observed that sieve elements had bypassed the injured, nonfunctional tissue 8 d following an injury pulse. No morphological recovery was observed after 3 d, and physiological functioning (such as translocation and photosynthetic rates) was not documented. In our study of photosynthetic rates, photosynthesis was reduced for at least 3 d after feeding, but had recovered by 7 d (Fig. 2). Further documentation of the rate of physiological recovery is planned. The research of the physiological basis for alfalfa injury by potato leafhopper will aid in the development of new methods (e.g., genetically or environmentally-based tolerance) for alfalfa to withstand and recover from leafhopper injury.

CONCLUSIONS

The research described herein provides an example of the importance of defining research needs. Producers and scientists alike have repeatedly stated the need to improve persistence of forage legumes (e.g., Table 1; Beuselinck et al., 1994; Marten et al., 1989). Although past research of potato leafhopper has focused on above-ground impact of injury, such as reduced growth, development, and quality of forage (Hutchins and Pedigo, 1990), evidence suggests that leafhopper injury may affect root tissue, and therefore, plant survival and stand persistence (Shaw and Wilson, 1986). Research of the more subtle, below-ground effects of leafhopper injury requires cooperative efforts of scientists who understand insect biology, plant physiology, and forage crop management. Each experiment must be carefully designed and implemented to ensure proper hypothesis testing, and collectively the experiments must develop knowledge of key processes, including feeding injury to plant tissues, disruption of translocation, reduction of photosynthesis, and tissue recovery from injury. This knowledge can then be used to modify decision-making guidelines and to develop novel means of reducing leafhopper injury, such as cultivars with improved tolerance of injury or the ability to recover faster subsequent to injury. Thus, pest management has, and will, require continuing communication and cooperation among scientists (private and public), industry representatives (e.g., from seed companies), and producers.

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Table 1
Summary of discussion of the development and delivery of IPM programs for forage crop producers at the Third IPM Symposium/Workshop, 1996, Washington, D.C.

Topic	**Discussion points**
Identification of research needs	* Integrate forage IPM from the perspectives of crop growth and animal requirements; move towards integrated crop management (ICM) and integrated farm management (IFM). * Improve understanding of "stand decline"; yet persistence is a result of complex interactions of crop genetics, management practices, abiotic factors, as well as biotic factors (especially pests). * Provide clearly defined thresholds and easily implemented control alternatives, including the use of crop management practices for managing pests. * Provide economic data to support decision-making by producers.
Enhancement of communication among scientists, private industry, and producers	* Place more emphasis on regional or national approaches to forage crop IPM research and education because of shifting foci at universities. * Provide local expertise in forages to address local problems and needs. * Develop more holistic approaches to planning of research and education needs through a team approach involving multiple disciplines and/or industry/university partnerships. * Understand that not all producers are willing to listen to new information.
Adoption of new technology for pest control	* Recognize that most new technologies are too expensive for use on forages. The major exception is the development of new crops and new varieties. * Develop information for new crops. Producers need to know the pests and how they can be managed. Regional differences are critical since problems will vary locally and regionally. * Develop IPM in light of new intensive grazing technology.
Improvement of education of pest management	* Improve communication among all participants in understanding the forage system. * Focus education on specific issues and provide recommendations with regard to economic costs and benefits. * Provide answers to specific producer problems and questions. * Understand the audience to market information successfully.

Table 2
Distribution of radiolabelled carbon subsequent to translocation to the tip of stems on injured or uninjured alfalfa

Alfalfa stage	Mean±SE ^{14}C disintegrations (log_{10} dpm/mg)	
	No injury	Injured
Early vegetative	4.03±0.14	2.08±0.35
Mature vegetative	3.67±0.22	2.59±0.67
Reproductive	2.89±0.36	3.20±0.37

Figure 1
Paradigm for problem-solving and the development of understanding within forage and grassland pest management.

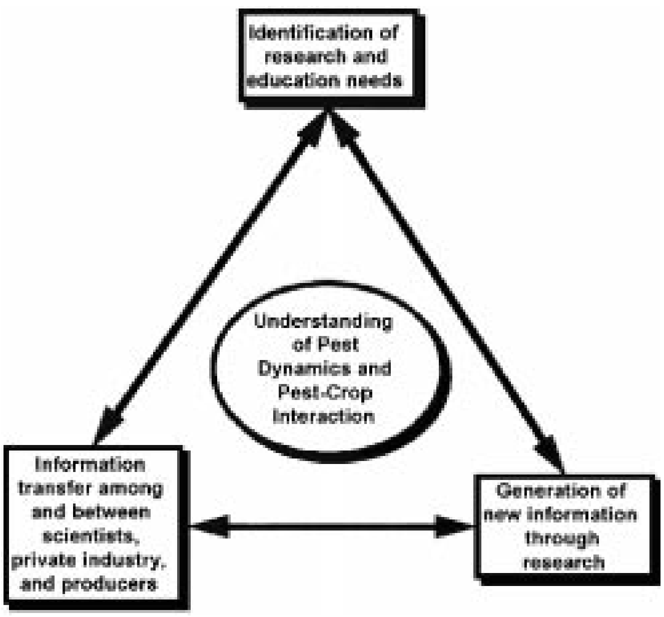

Figure 2
Photosynthetic rates for specific alfalfa leaves subsequent to caging of leaf or stem tissue, either with or without leafhoppers for 24 h. Leaf number is from the uppermost, fully-developed leaf on the stem.