RESEARCH

U.S. Wheat-Marketing System: An Insect Ecosystem

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ABSTRACT Wheat temperature, moisture, the flow of wheat through the marketing system, and insect control practices affect the population levels of lesser grain borer, *Rhyzopertha dominica* (F.), in the U.S. wheat-marketing system. We examined these effects and used marketing statistics and climatological data to characterize seasonal variation in wheat-marketing practices and the stored-wheat environment. These insights are incorporated into a computer simulation model that predicts the seasonal changes in average insect infestation levels marketwide. The predictions of computer simulations are compared with published data. The computer simulation model explained 96.5% of the month-to-month variation in lesser grain borer infestation levels reported in the literature for wheat that reaches U.S. ports for export. The close agreement between model predictions and actual data indicate that we have probably included the factors most important in determining the seasonal changes in lesser grain borer infestation levels.

EFFECTIVE MANAGEMENT of any species requires thorough knowledge of its biology and the ecosystem it inhabits. Such insight is particularly important for stored-wheat insect pests that move through the marketing system along with the wheat. In the United States, farmers own and store much of the wheat they produce and sell it at a rate similar to the rate at which wheat is milled, exported, used for seed, and fed to animals (Fig. 1). Wheat sold by the farmer is often moved and stored many times in the marketing process. Wheat temperature, wheat moisture, wheat flow through the marketing system, and insect control practices are important factors in determining whether insect populations will reach detectable levels.

In this study, we examine the way in which these factors influence average infestation levels of lesser grain borer, *Rhyzopertha dominica* (F.), in the marketing system. Marketing statistics and climatological data are used to characterize wheat-marketing practices and the stored-wheat environment. These details are incorporated into a computer simulation model that predicts seasonal marketwide changes in the average lesser grain borer infestation levels. The predictions of computer simulations are compared with published data not used in developing the simulation model. This simple model is an important first step in the development of a systems model that will help farmers, the wheat industry, and government officials anticipate when and where detectable insect infestations will occur. It will also help entomologists design improved insect pest management strategies.

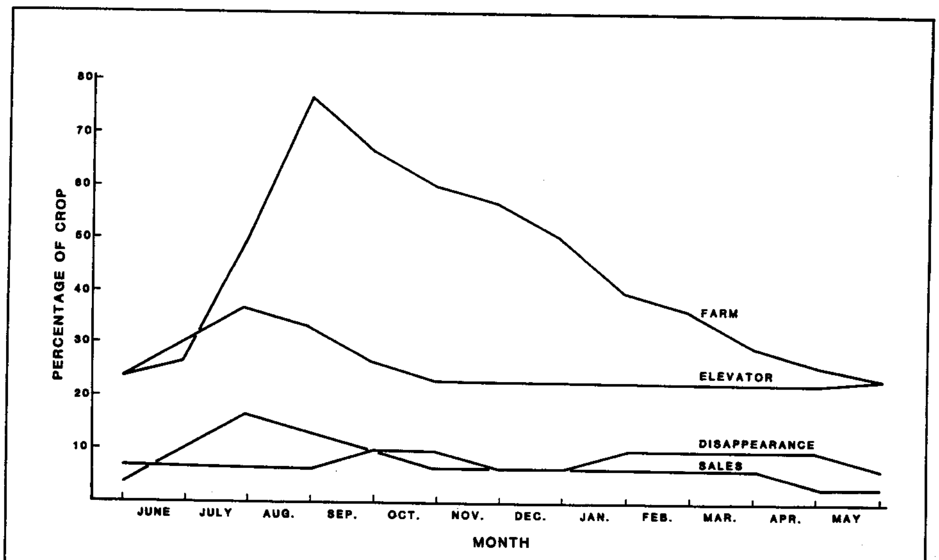

Fig. 1. *Average seasonal changes in wheat stock levels and transactions in the U.S. wheat-marketing system between 1967 and 1983.*

Wheat Marketing

The rate at which wheat flows through the marketing system determines the time in which insect populations can increase. Wheat flow through the marketing system can be characterized by seasonal changes in the wheat stock levels at various points in the marketing system. The changes in these stock levels, shown in Fig. 1, were derived from marketing statistics available for 20 states producing 93.5% of the wheat crop during years 1967–1983. Except for an average increase of approximately 4% per year in the volume of wheat marketed as a result of increased production, the seasonal changes in annual wheat stocks were similar.

The seasonal changes in farmer-owned wheat stocks are based on annual wheat production (USDA 1968–1984a) and monthly open-market farm sales (USDA 1978, USDA 1978–1984). Most of this wheat has probably been stored on-farm or at local country elevators in each community. Farmer-owned wheat represents approximately 22% of the old crop when harvest of the new crop begins in June; the percentage increases from June to August as a result of the annual harvest, and then declines steadily over the remainder of a year. Wheat harvested in June, July, and August is 20, 40, and 40% of the crop, respectively. Disappearance of wheat stocks from the marketing system equals the sum of wheat milled (U.S. Department of Commerce 1968–1984), exported (USDA 1969, 1972, 1973, 1985), and used for seed or feed (USDA 1968–1984b, 1985). Both the sales of farmer-owned wheat and the disappearance of wheat stocks from the marketing sys-

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tem average 8% of the annual wheat crop per month. The elevator stocks refer to the difference between the wheat sold by the farmers and wheat stock disappearance. During harvest, elevator stocks rise only slightly above the levels generally maintained throughout the year. These consistent levels of elevator stocks are a result of sales of farmer-owned wheat being similar to the disappearance of wheat stocks from the marketing system.

Seasonal changes in wheat stock levels indicate that farmer-owned wheat might be viewed as a reservoir for long-term storage, while the elevator system is more like a pipeline that links wheat production with disappearance. Yet, the average time that the wheat crop spends in each of these two portions of the marketing system is remarkably similar. The average times that it took farmers to sell their wheat crops and the time it took the current elevator wheat stocks to disappear were 5.0 and 3.0 mo, respectively.

Wheat Moisture Content

Wheat moisture content is an important factor in determining how fast the insect population increases while the wheat is in the marketing system. As shown in Fig. 2, the variability in wheat moistures decreased as the wheat from different farms was mixed in the process of moving from farm (U.S. Wheat Associates 1982–1985) to port (Federal Grain Inspection Service, unpublished data). However, average moistures did not change much while wheat was in the marketing system. The average moistures of wheat delivered by farmers to the elevators at harvest and that of the wheat reaching the ports differed between three groups of states. The wheat grown largely under irrigation on the West Coast (14% of crop) was drier, and the soft wheat grown in the Midwest (8% of crop) was moister than the wheat grown in the Great Plains (78% of crop). The wheat exported from the West Coast probably had a higher average moisture than wheat grown on the West Coast, because of the wheat coming from the other states for export (Leath et al. 1981). For the model, wheat moisture was considered to average 12%.

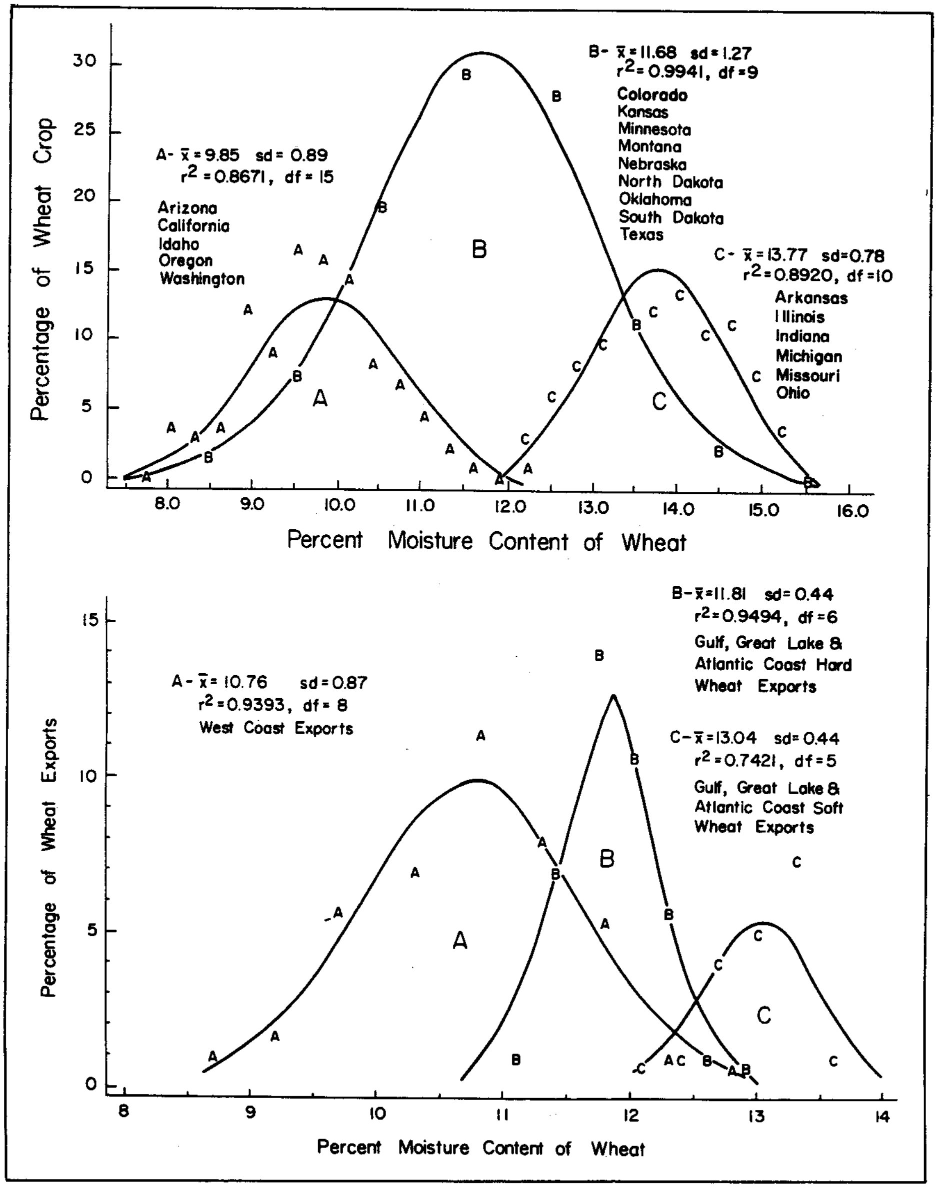

Fig. 2. *Distribution of moisture contents of newly harvested wheat sold at elevators for three subgroups of states weighted by their production and based upon a reanalysis of data presented in the 1982–1985 Crop Quality Reports of U.S. Wheat Associates (top), and ship lots at export based on unpublished data of USDA Federal Grain Inspection Service (bottom).*

Temperature

Seasonal changes in the storage temperature of wheat can influence the insect population growth rate. Studies on seasonal changes in wheat storage temperatures in Idaho (Halderson 1985), Kansas (Hagstrum 1987), and Oklahoma (Cuperus et al. 1986) indicate that wheat is harvested and stored during the summer at temperatures between 27 and 35°C and that stored wheat cooled in the fall at a rate of 1–2°C per week. Similar data are not available for warming of wheat in the spring.

The observed changes in the stored-wheat environment in the fall can be approximated from climatological data (NOAA 1967–1983). The maximum air temperatures at harvest given in the climatological data from the 20 major wheat-producing states predicted only small differences in summer storage temperatures between states or years. The maximum air temperature at harvest for all 20 states fits a single normal distribution with a mean of 30.72°C and a standard deviation of 4.68. For the model, the temperature of newly harvested wheat was considered to be 32°C, because the actual temperatures of wheat at harvest reported in the literature tended to be higher than maximum air temperature. Climatological data also predicted similar cooling rates in the fall of 1 or 2°C per week across these 20 states (Fig. 3). However, the central core of bulk-stored wheat will not begin to cool until after the outer layers begin to cool (Hagstrum 1987). Watters (1963) demonstrated that when wheat was moved during cool winter weather, mixing of the warm central core of the wheat bulk with the cooler outer layers equalized the temperatures of wheat throughout the bulk.

The actual drop in average stored-wheat temperature might be expected to be less than 1 or 2°C per week and will depend on the average size of the bins in which the wheat is stored. Several surveys of bin storage capacity are available (Anonymous 1979, Mittleider & Scott 1985), but they do not provide a breakdown by actual size of bins or the

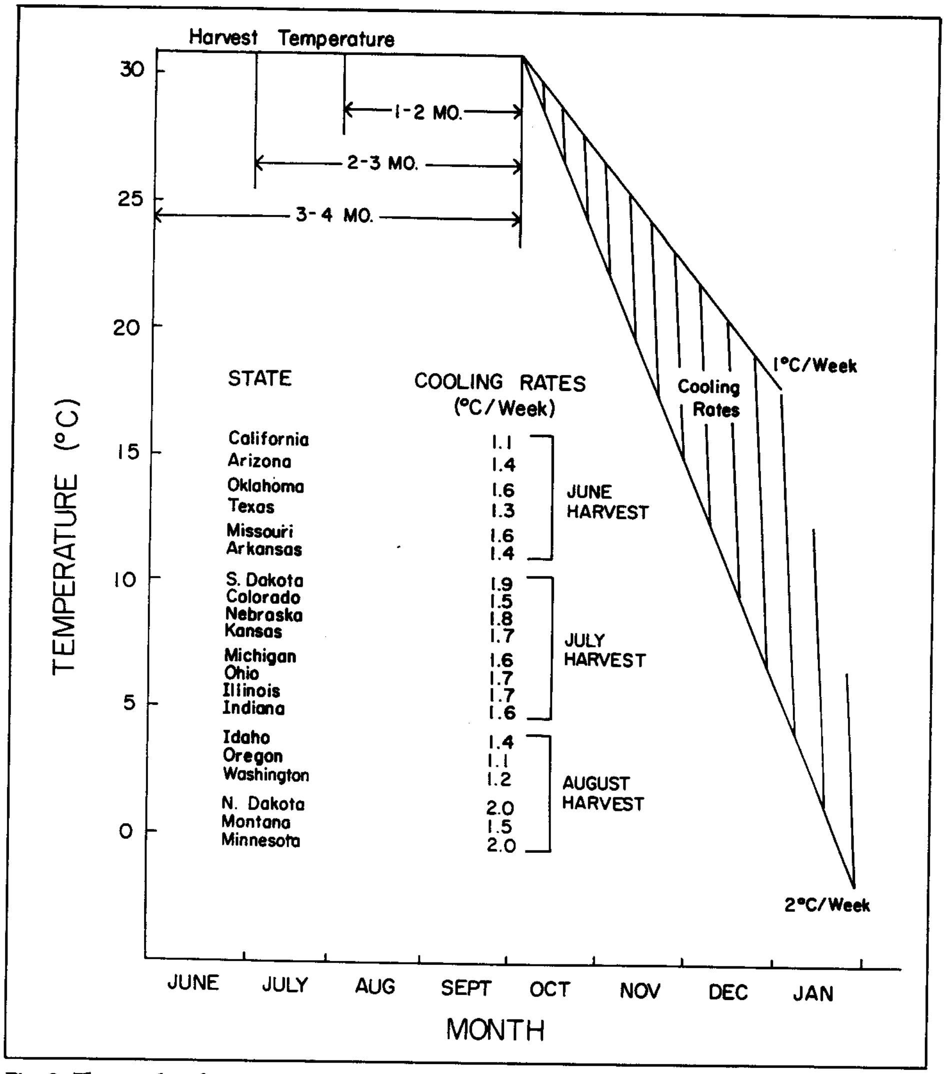

Fig. 3. *The results of Hagstrum (1987) expanded using NOAA climatological data to include the 20 major wheat producing states. Wheat harvested in June and July is stored 2–3 and 1–2 months, respectively, longer at harvest temperature than wheat harvested in August. Cooling rates varied 1–2°C and generally were not correlated with time of harvest.*

type of grain stored. Actual rates of cooling in fall and warming in spring will have to be estimated iteratively by fitting the model to actual published data for insect infestation levels in the wheat-marketing system.

Insect Populations

Insect infestation levels in the wheat-marketing system are determined by the rate at which insects can increase in numbers within the constraints of stored-wheat environmental conditions and wheat-marketing and insect control practices. The effect of the stored-wheat temperature and moisture on the lesser grain borer are simulated.

The weekly rate of increase of the lesser grain borer is described by the following equation, which is based on the data of Birch (1953):

$$\text{rate} = 4.71 - 0.15\ \text{temperature} - 0.39\ \text{moisture} + 0.0168\ \text{temperature moisture}$$

This equation predicts that lesser grain borer populations will increase exponentially in the absence of insect control measures. The actual seasonal trends for lesser grain borer populations in wheat reaching the ports for export (reported by Storey et al. [1982] and shown in Fig. 4) indicate that average systemwide lesser grain borer infestation levels in the wheat moving from farm to port do not increase exponentially. Insect control within the wheat-marketing system must have been sufficient to have prevented an exponential increase in insect populations.

The current use of insect control practices has been surveyed by Cuperus et al. (1986), Harein et al. (1984), Reed (1986), and Storey et al. (1984). However, none of these studies provides a measure of how effective these control practices are at reducing the average marketwide insect infestation level. In addition, insect infestations in wheat sold by the farmer can be diluted as the wheat is mixed in the elevator system with the wheat from other farms. Insect infestation levels also can be reduced by insect mortality occurring as a result of handling the wheat (Bailey 1962, Joffe 1963, Joffe & Clarke 1963, Bailey 1969, Bryan & Elvidge 1977, Loschiavo 1978, Watters & Bickis 1978) during the marketing process. Insect control in the wheat-marketing system also will have to be estimated iteratively by fitting the model to the actual data for the lesser grain borer infestation levels shown in Fig. 4.

Simulation Model

The preceding characterization of wheat flow through the marketing system, of insect control practices, of the stored-wheat environment, and of insect population growth under such conditions is incorporated into a computer simulation model that predicts the seasonal marketwide changes in average lesser grain borer infestation levels. For the purposes of modeling, the wheat-marketing system is divided into two compartments, farmer-owned wheat stocks and elevator wheat stocks. Just before harvest in June (week 1 of simulation), roughly 20% of the old wheat crop was still owned by the farmer and roughly 20% of the old wheat crop was still in the elevator system. The average insect infestation was four insects per bushel. The 20, 40, and 40% of the new crop harvested in June, July, and August, respectively, was added to the farmer-owned stocks in weekly increments of 5, 10, and 10% of the crop. The newly harvested wheat and the old wheat

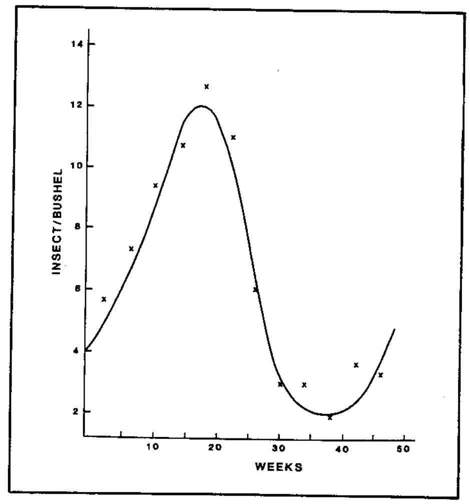

Fig. 4. *Seasonal changes in lesser grain borer infestation levels in wheat reaching ports for export. The data of Storey et al. (1982) were converted from percentage of samples infested to the number of insects per bushel by assuming that the annual average number of lesser grain borers was 6.5 insects per bushel and that the number of insects per bushel was proportional to the percentage of samples infested. The actual data (x) are plotted along with model predictions (—).*

were 32°C and 12% wheat moisture content. The stocks moved from farmer-owned stock to elevator stock and disappeared from the elevator at rates of 8% of the annual wheat crop per month or in weekly increments of 2%. The lesser grain borer population grew exponentially, according to the equation.

The model best predicted actual seasonal trends in lesser grain borer infestation levels (Fig. 4) when insect control equaled 30% of the insect population per week and when the wheat temperature dropped 0.5°C/wk in the fall (week 13 of simulation) and rose 0.5°C/wk in the spring (week 29 of simulation). The model explained 96.5% of the seasonal variation in the lesser grain borer infestation levels. The close agreement between the model and the actual data indicates that we have probably included the factors most important in determining the seasonal changes in the insect infestation level. ■

Acknowledgment

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