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THE DEVELOPMENT AND ADOPTION OF INTEGRATED PEST MANAGEMENT OF THE POTATO TUBER MOTH, *Phthorimaea operculella* (Zeller) IN TUNISIA

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by

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I. INTRODUCTION

The management of crop pests takes a wide variety of forms. In traditional agriculture where most crop inputs originate from the farm, farmers manage crop pests and diseases through time-tested measures such as crop rotation and fallow, mixed cropping and other cultural practices. As agricultural production intensifies, farmers tend to make greater use of purchased inputs. There is often a strong economic incentive for them to substitute chemical pesticides for their traditional practices in controlling crop pests. Pesticides are relatively cheap, easy to use, and, at least initially, quite effective. By using chemical pesticides, for example, a farmer may be able to grow a high-valued cash crop continuously, abandoning his traditional practice of rotations with less profitable crops. In addition, chemical pesticide application is often seen as a kind of crop insurance. Farmers may apply regular treatments of chemical pesticides to guard against the possibility that severe pest damage might occur.[1]

It is becoming increasingly evident, however, that reliance on chemical pesticides alone for pest control may not be sustainable over time and can carry significant long-term environmental costs and health risks. However, even though farmers as a whole may benefit from a reduction in chemical pesticide use, individually they often have little incentive to consider the long-term consequences of their pest management decisions. Since environmental quality and the susceptibility of crop pests to pesticides are common property resources, it is

difficult for individuals (i.e. farmers) to control access to these resources by others. Nor are users usually required to pay the full social costs for their use.[2]

The growing recognition of these and other problems associated with pesticides has led to increased attention on integrated pest management (IPM) that does not rely on chemical pest control alone. IPM is based on a more complete understanding of insect ecology and plant-pest relationships.[3] In IPM a variety of complementary pest control measures, including varietal resistance, cultural practices, and biological control, are combined in such a way that is both environmentally sound and economically viable. The objective of integrated pest management in general is to reduce pest populations below an *economic or damage threshold*, and not necessarily to eliminate the pest completely.[4]

This study investigates the development and adoption of integrated pest management of the potato tuber moth *Phthorimaea operculella* (Zeller) in Tunisia. The potato tuber moth (also referred to in the paper as PTM) is the most significant insect pest of the potato in Tunisia, as well as in North Africa and in much of the Middle East. While it is principally a post-harvest pest damaging potatoes kept in rustic farm stores, it can be an important field pest as well.

The next section of the paper reviews the PTM research and extension program in Tunisia. This program is an interdisciplinary and collaborative effort between the International Potato Center (CIP) and the Tunisian National Agricultural Research Institute (INRAT). This is followed by two

sections which present evidence from farm surveys to show how farmers manage the potato tuber moth in their fields and stores. These results show a marked reduction in their application of chemical insecticides and an increase in the use of agronomic practices to control the PTM in potato fields. There also appears to have been substantial improvements in how farmers manage the PTM in potato stores, which has contributed to a significant decline in post-harvest losses during the late 1980s.

FOOTNOTES TO SECTION I

[1]For a theoretical model of pesticide application under production uncertainty, see G. Feder, "Pesticides, Information, and Pest Management under Uncertainty, American Journal of Agricultural Economics 61 (1979): 97-103. Examples of more applied models of farmer pest management can be found in G. A. Norton, "Analysis of Decision Making in Crop Protection," Agro-Ecosystems 3 (1976): 27-44.

[2]For a concise review of this issue, see U. Regev, "Economics of Sustainable Pest Control," in Biological Control: A Sustainable Solution to Crop Pest Problems in Africa, (J. S. Yaninek and H. R. Herren, eds.), International Institute of Tropical Agriculture, Ibadan, Nigeria, 1989. Social costs include health risks from exposure to toxic substances, the development of insect resistance to chemicals, ecological imbalances and the rise of secondary pests, and contamination of wildlife habitat and ground water. For an example of a "pesticide treadmill" in potato production in a developing country, see P. Ewell, et. al., "Farmer Management of Potato Insect Pests in Peru," Food Systems Research Series, No. 6, International Potato Center (CIP), Lima, Peru, 1990.

[3]See V. Delucchi (ed.), Integrated Pest Management: Quo Vadis? PARASITIS, Geneva, Switzerland, 1987; and V. Delucchi, "Integrated Pest Management vs Systems Management," in Biological Control: A Sustainable Solution to Crop Pest Problems in Africa, (J. S. Yaninek and H. R. Herren, eds.), International Institute of Tropical Agriculture, Ibadan, Nigeria, 1989, pp. 51-67.

[4]This issue is emphasized in J. C. Heady, "Defining the Economic Threshold," in Pest Control Strategies for the Future (R. L. Metcalf, ed.) National Academy of Science, Washington, D.C., 1972, pp. 100-8.

II. INTEGRATED POTATO PEST MANAGEMENT RESEARCH IN TUNISIA

The Potato in Tunisia

In Tunisia, potatoes are a high-cost, high-value crop produced on irrigated farms. The availability of irrigation year-round allows two potato crops per year, one in the Spring ("Saison") and a second either in the Fall ("Arriere Saison") or Winter ("Primeur"). Summer-time temperatures are generally too high to permit potato production, so much of the Saison crop is put into rustic farm stores for later market sale during this non-production period. Farmers also store a part of their Saison production for seed for the Arriere Saison. Figure II.1 shows the spatial and seasonal distribution of production in the major potato growing areas of Tunisia.

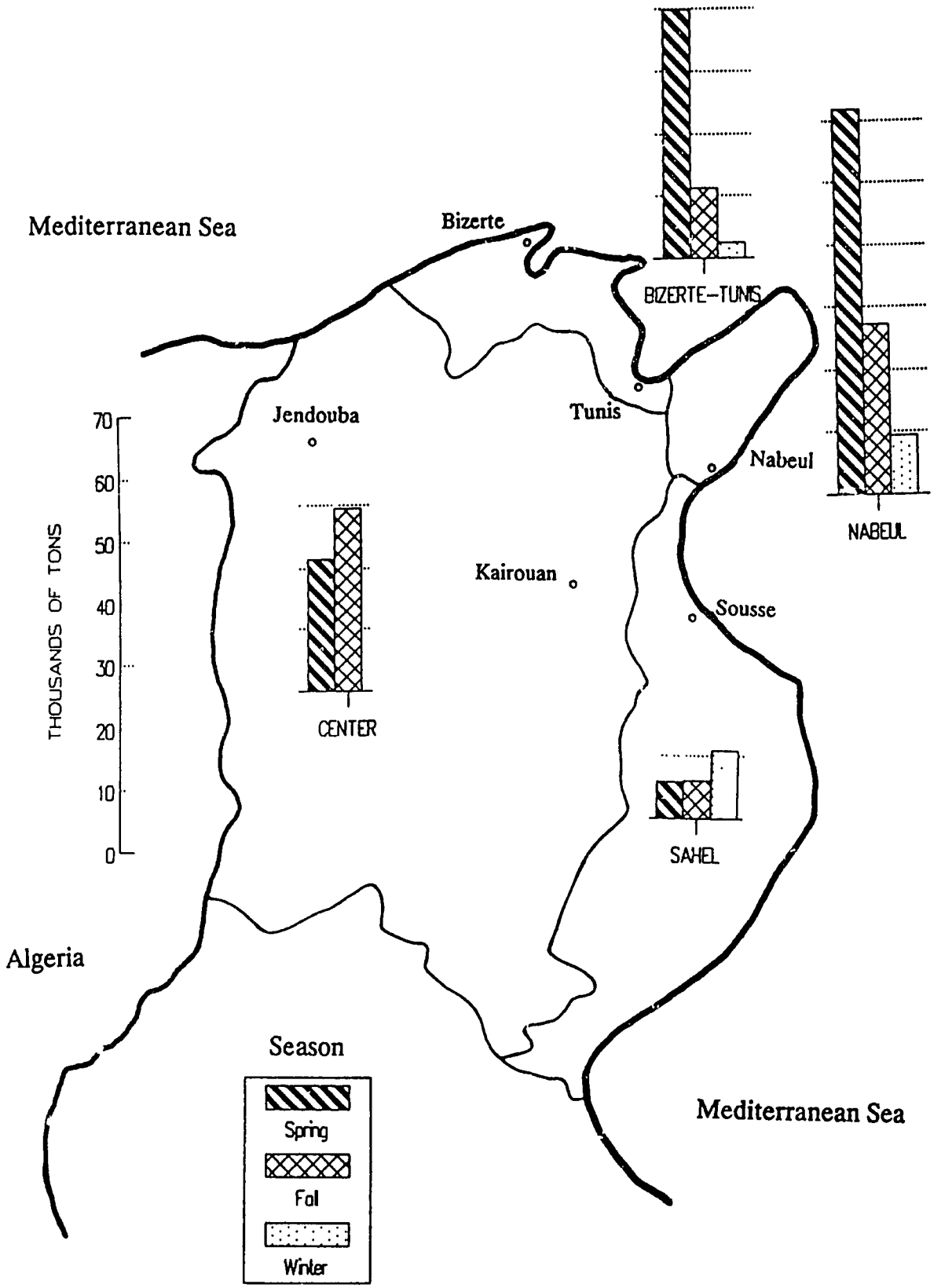
The potato tuber moth is both a field and post harvest problem. In fields, larvae bore into leaves, stems and tubers. While the damage caused to plant foliage usually does not reduce yields, infestation in tubers can lower or erase their market value. PTM larvae also infest tubers kept in rustic stores. If left untreated, damage to stores can be severe or total. The potato tuber moth poses a threat particularly to the Saison crop, both before harvest in the field and after harvest during storage.

CIP-INRAT research collaboration on the potato tuber moth began in 1979 with some simple storage experiments. At that time farmers were applying DDT and Parathion directly on consumer potatoes kept in rustic stores. The persistence and toxicity of these chlorinated hydrocarbon and organophosphate pesticides

Figure II.1

POTATO PRODUCTION IN TUNISIA

Seasonal Averages 1984/85-88/89



posed a hazard to farmer applicators, potato consumers and to the environment generally. Experimental trials were carried out in rustic stores using synthetic pyrethroids insecticides whose chemical toxicity tends to break down in a short period. One application of a Pyrethroid insecticide was found to be as or more effective than Parathion in controlling the potato tuber moth in rustic stores for up to four months. With the availability of an effective and safer alternative, the Tunisian government restricted imports of DDT and Parathion in 1984 and recommended the use of the pyrethroid deltamethrin to potato farmers.

Research continued toward the development of a long-term solution to the potato tuber moth problem. In 1983, a research program in integrated pest management was initiated. This program involved not only biological research on insect ecology and pest control techniques, but also included participation from social scientists in studying farmer pest management decision-making and in evaluating new control components under realistic farm conditions.

Building a Biological Model of the Insect Pest

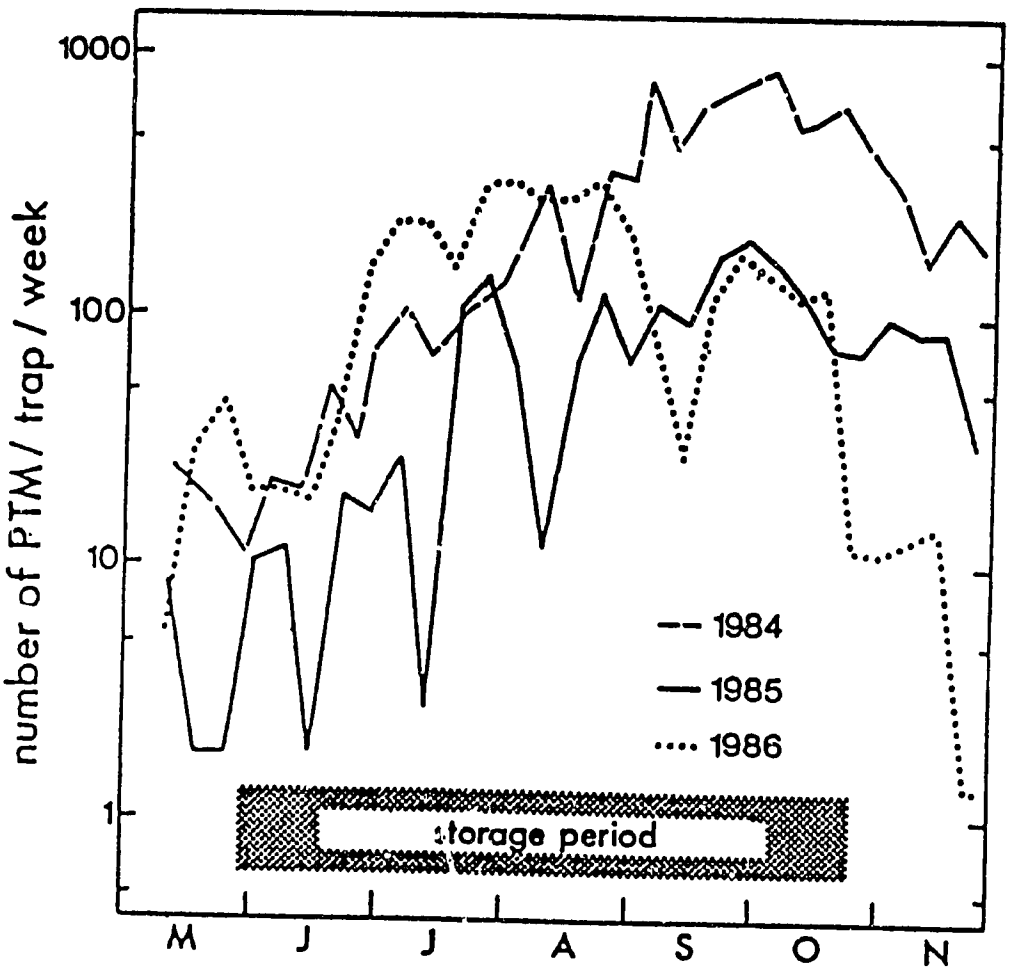
The basis of an integrated pest management approach lies with a more thorough understanding of insect ecology. The findings from basic research on insect population dynamics, natural insect mortality factors, and pest-plant relationships are probably the primary source of new pest management component technologies.[5]

Initial research on the biology of the potato tuber moth consisted of studies of pest population dynamics using sex pheromone baiting in open fields. These results clearly showed the seasonal cycle of potato tuber moth field populations in relation to the potato crop and storage calendar (see Figure II.2). During the cool season PTM populations remain low and do not cause significant damage to crops. However, insect populations develop quickly in May and June with the onset of hot and dry weather. The potato tuber moth then poses a threat to the main Saison potato crop, the harvest of which continues into July. The trapping surveys also showed that field populations of the PTM remain high even after harvest and into the post-harvest period.[6]

The simple trapping exercises were followed by more in-depth research on potato tuber moth ecology and population dynamics. In fields, pest-plant interactions were studied in detail, such as the relationship between PTM infestation and the physiological age of the plant. In rustic potato stores, age-specific life tables have been constructed in a cohort population study and the spatial dimensions of PTM population development have been examined. Studies of natural mortality factors have led to the identification of an indigenous strain of granulosis virus which infects the potato tuber moth and has demonstrated the importance of natural predators of the PTM in rustic farm stores.[7]

FIGURE II.2

Potato tubermoth (PTM) population densities observed by pheromone traps at a storage locality (Saïda, Tunisia) in three consecutive years.



Source: von Arx, R., et. al., "Integrated Control of Potato Tubermoth Phthorimaea Operculella (Zeller) in Tunisia," Insect. Sci. Applic. 8 (1987): 990.

Developing and Testing New Pest Control Components

Applied research to develop and test new pest management techniques in potato fields and stores has been the primary activity of the CIP-INRAT collaborative effort. Experimental trials have been carried out in laboratories, at experiment stations and with farmers to evaluate the effects of specific measures.

The PTM insect population cycle revealed in Figure II.2 demonstrates the importance of timely harvest of the Saison crop to avoid PTM infestation in fields. This has been verified through experimental field trials. Other agronomic techniques which have been tested are regular irrigation up to harvest to reduce soil cracking and extra hilling to increase soil coverage of tubers in the field. Both of these practices are designed to reduce the exposure of tubers to the potato tuber moth in the field.

In rustic potato stores, biological insecticides (including a formulation of the granulosis virus mentioned above) have been tested, along with mass trapping, insect growth regulators, and chemical insecticides. New potato varieties have been screened for host resistance. The effects of modifications in rustic store design have also been examined.[8]

One principal result of these experiments has been to demonstrate the need to integrate pest management in potato fields and stores. Insect damage in stores was found to be more easily controlled if PTM infestation in fields was kept to a minimum. Low infestation at harvest and rapid handling of the

potatoes going into storage established good initial storage conditions and decreased the likelihood of post-harvest losses. Biological insecticides in particular were more effective at preventing insect losses in stores in cases where the initial level of infestation was relatively low.[9]

Exploring Farmers' Pest Management Behavior

A thorough understanding of farmers' perceptions of pest problems and their pest management practices is as essential to integrated pest management as is a basic ecological understanding of the insect pest. The full benefit of pest management research is unlikely to be realized unless it leads to improved application of pest management technology by farmers.

Farmers generally chose pest management technology that is least costly and reduces production risk. Their decision to take pest control measures may be either *preventative*, in that they seek to avoid insect damages before they occur, or *curative*, in that they react to observed pest damage and seek to allay further losses. Preventative pest control measures are an important way for the farmer to reduce production risk. Furthermore, a farmer's pest management strategy is often composed of informal if-then rules: if certain conditions are present then certain actions are taken. For example, if climactic conditions known to be favorable to the pest occur, the farmer may decide to hill up extra earth over the tubers in the field to prevent insects from reaching them. Socioeconomic conditions also influence the choice of pest management techniques. During a period of peak labor demand, such as at harvest time, a farmer may avoid taking

actions that are labor-intensive such as hilling and instead spray insecticides in the field. Obviously, the level of farmers' knowledge about what conditions are favorable or unfavorable to a pest's development and what kinds of pest management measures are most appropriate under these conditions plays a central role in pest management decisions. The clarification of this decision-making process is a principal goal of the social science component on-farm pest management research.

In Tunisia, farmers' pest management practices were studied through field surveys carried out in 1986 and again in 1990.[10] Farmers were interviewed on their perceptions of insect pest problems and their pest management practices, and measurements were taken of insect damage in their fields and stores. Farms were sampled from the principal potato producing regions of the country. Most farms were sampled from the northeastern coastal provinces of Bizerte and Nabeul, were about 70 percent of the country's potatoes are grown. Potato farms are generally small with under 5 hectares of irrigated area and usually produce a variety of horticultural crops each year. Most farms are owner-operated, but around 30 percent of them are managed by tenants. Table II.1 details the nature and scope of these surveys.

Extending Results to the Farm Level

Since the mid 1980s, potato tuber moth management has been included in the curriculum of the annual potato production course given for agricultural technicians and extension agents. In 1987, improved potato storage, where the PTM poses a major

problem, was taken as the theme for the production course.[11]

In addition, radio and television spot ads have been prepared and distributed by the agricultural extension service. These discuss how to manage the potato tuber moth in fields through agronomic practices and in rustic stores through rapid handling and appropriate insecticide use. They are regularly featured on popular media channels.

TABLE II.1

FARM SURVEYS ON FARMER PEST MANAGEMENT

AND INCIDENCE OF POTATO TUBER MOTH INFESTATION

PRODUCTION ZONE	PROVINCE	NUMBER OF FARMS SURVEYED 1986	1990
North-east coastal	Nabeul	18	26
	Bizerte	20	34
Continental	Jendouba		16
	Kairouan		4
Sahelian	Sousse		7
	Monastir		6
TOTAL FARMS SURVEYED		38	93

SURVEY DESCRIPTIONS

1986 (1) continuous monitoring of pest damage on 6 farms from harvest to end of storage.
(2) formal questionnaire of 38 farms at end of storage on pest management practices.

1990 (1) informal interviews with 24 farmers on pest management practices during growing season.
(2) sampling for incidence of pest damage at harvest with formal questionnaire of pest management practices on 69 farms.
(3) sampling for incidence of pest damage in potato stores and interviewing on storage management and marketing practices on 40 of the 69 farms, including continuous monitoring of storage pest damage on 11 farms.

FOOTNOTES TO SECTION II

[5]V. Delucchi, "Integrated Pest Management vs Systems Management," in Biological Control: A Sustainable Solution to Crop Pest Problems in Africa, (J. S. Yaninek and H. R. Herren, eds.), International Institute of Tropical Agriculture, Ibadan, Nigeria, 1989, pp. 51-67.

[6]This finding contrasts with other studies of insect population dynamics which show a marked decrease in field populations of the potato tuber moth following harvest. In the Tunisian case, suitable host material remain available after harvest in nearby fields planted with other Solanacea crops such as tomatoes and peppers, and in the rustic potato stores. See R. von Arx, et. al., "Integrated Control of Potato Tubermoth *Phthorimaea Operculella* (Zeller)," Insect Science Applications 8 (1987): 989-994.

[7]Some results from pheromone trapping in fields are presented in R. von Arx, et. al., "Integrated Control of Potato Tubermoth *Phthorimaea Operculella* (Zeller)," Insect Science Applications 8 (1987): 989-994. The identification of new strains of granulosis virus is reported in K. V. Raman and J. Alcazar, "Biological Control of Potato Tuber Moth *Phthorimaea Operculella* (Zeller), Using a Granulosis Virus in Peru," a paper presented at the Second Triennial Conference of the Asian Potato Association, Kunming, Yunan, China, June 16-25, 1988. In-depth studies of PTM-potato plant relationships, age-specific cohort tables, and the activity of natural PTM predators in rustic stores are forthcoming in O. Roux, "Population Dynamics of the Potato Tuber Moth *Phthorimaea Operculella* (Zeller)," Ph.D. Thesis, Swiss Federal Institute of Technology (ETH) Zurich, Switzerland.

[8]The effect of harvest date on PTM infestation in the field and storage trials with a biological insecticide *Bacillus thuringiensis* are reported in R. von Arx, et. al., "Integrated Control of Potato Tubermoth *Phthorimaea Operculella* (Zeller)," Insect Science Applications 8 (1987): 989-994. Laboratory studies with viral and bacterial pathogens of the potato tuber moth are described in R. von Arx, and F. Gebhardt, "Effects of a Granulosis Virus, and *Bacillus thuringiensis* on life-table parameters of the Potato Tubermoth *Phthorimaea Operculella* (Zeller)," Entomophaga 35,1 (1990): 151-159. Results from experiments trials with storage design modifications can be found in R. von Arx, "Potato Tubermoth *Phthorimaea Operculella* (Zeller) Damage in Relation to Traditional Potato Storage Techniques in Tunisia," (unpublished manuscript). Results from varietal resistance trials are reported in "Résistance variétale contre la teigne de la pomme de terre *Phthorimaea Operculella* (Zeller) observeé en Tunisie," Proc Int Conf EAPR, 27-31 July, 1987, Aalborg, Denmark, p. 40-41. No varieties have been identified that offer significantly more resistance to PTM infestation than local varieties.

[9]R. von Arx, et. al., "Integrated Control of Potato Tubermoth *Phthorimaea Operculella* (Zeller)," Insect Science Applications 8 (1987): 989-994.

[10]While the present paper updates and synthesizes the findings from these farm surveys, results from the 1986 survey appears in R. von Arx, et. al., "Management of the Potato Tuber Moth by Tunisian Farmers: A Report of On-Farm Monitoring and a Socioeconomic Survey," International Potato Center (CIP), Lima, Peru, 1988.

[11]The lectures from the 1987 annual production course were compiled and published in "Amélioration de la Conservation de la Pomme de Terre en Tunisie," (A. J. Haverkort, M. Azzouz, and M. Fahem, eds.), C. P. R. A., 2031 Essaïda, Tunisia and C. I. P., 11 Rue Des Orangers, 2080 Ariana, Tunisia. This booklet has been widely distributed in annual potato production courses.

III. FARMER'S PEST MANAGEMENT IN THE FIELD

Farmers' Management of the Potato Tuber Moth in Fields

While agricultural research has identified several cultural and chemical means of reducing potato tuber moth infestation in potato fields, interviews with farmers in Tunisia have indicated four principal pest management measures that they have found suitable under local conditions. These are: (1) timely harvest before the onset of hot weather and increased pest populations; (2) irrigation up to harvest to keep the soil humid and to reduce cracking; (3) hilling up soil around tubers and plants; and (4) applying chemical insecticides to plants and soil.

These interviews have also revealed the level of knowledge farmers have concerning the ecological conditions that are favorable to potato tuber moth infestation. Farmers associate infestation in their potato fields with hot weather and delayed harvest. Dry fields with cracked soils which leave tubers exposed are also seen as favorable to infestation. However, farmers are generally not concerned about PTM infestation in foliage. Since infestation in plant stems and leaves occurs late in the growing season after tuberization is mostly complete, it is not seen as a factor which might reduce yields. Though this knowledge is widely held among potato farmers, it is not universal. About one-fifth of the farmers interviewed in 1990 were unable to describe field conditions that are favorable to PTM infestation.

Farmers rely on agronomic practices rather than chemical insecticides as the most important means of controlling insect

pests in their potato fields. In fact, it appears that in the late 1980s the reliance on agronomic practices increased and the use of chemical insecticides fell significantly. As Figure III.1 shows, the number of farmers using insecticides in potato fields fell from 46 percent in 1986 to only 14 percent in 1990. The average rate of insecticide application by users (at constant 1990 pesticide prices) also fell from 45.700 Dinars/hectare in 1986 to 31.500 Dinars/hectare in 1990, or by 30 percent. Averaged over all farms in the survey sample, the cost of insecticide used per hectare declined from 20.900 Dinars/hectare to only 4.600 Dinars/hectare, or by about four-fold. This represents a reduction in pesticide imports of around 150,000 Dinars annually for the country.

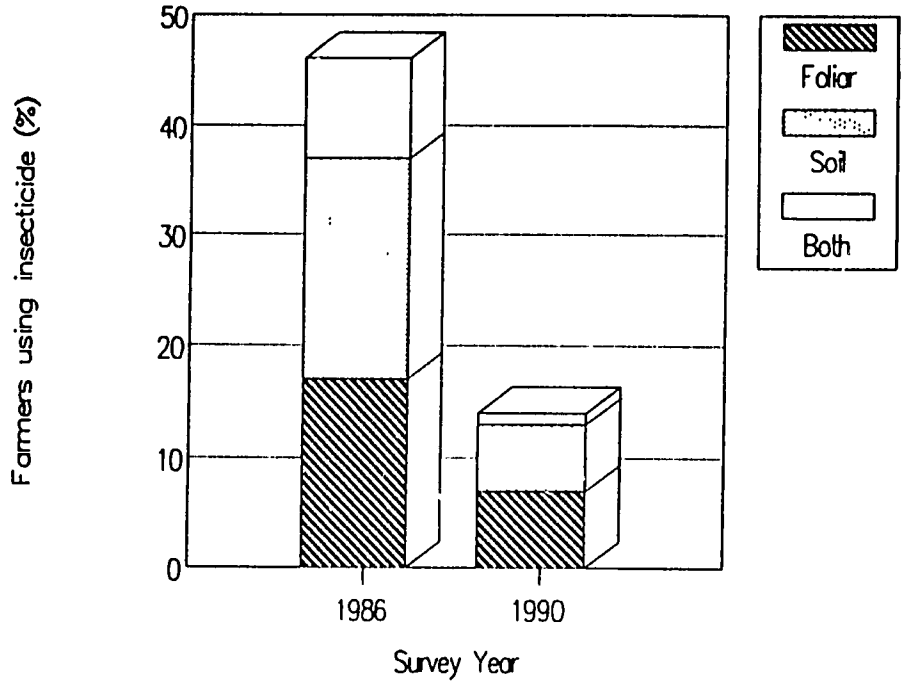
At the same time, farmers awareness and use of cultural practices such as timely harvest, regular irrigation up to harvest, and extra hilling have increased. The use of irrigation as a control measure increased significantly in the late 1980s. By 1990, four out of five farmers were using irrigation as a means of limiting PTM infestation. Over this period, there was also some additional use of extra hilling in fields to keep tubers better protected from insect damage, but this measure remains of secondary importance.

Why have farmers adopted these means to manage insect pests in their potato fields? Improved farmer knowledge of pest management technology and the relative cost and effectiveness of agronomic practices over chemical insecticides have been the primary factors determining these choices. Below, we discuss each of the four principal means of reducing tuber moth infestation in

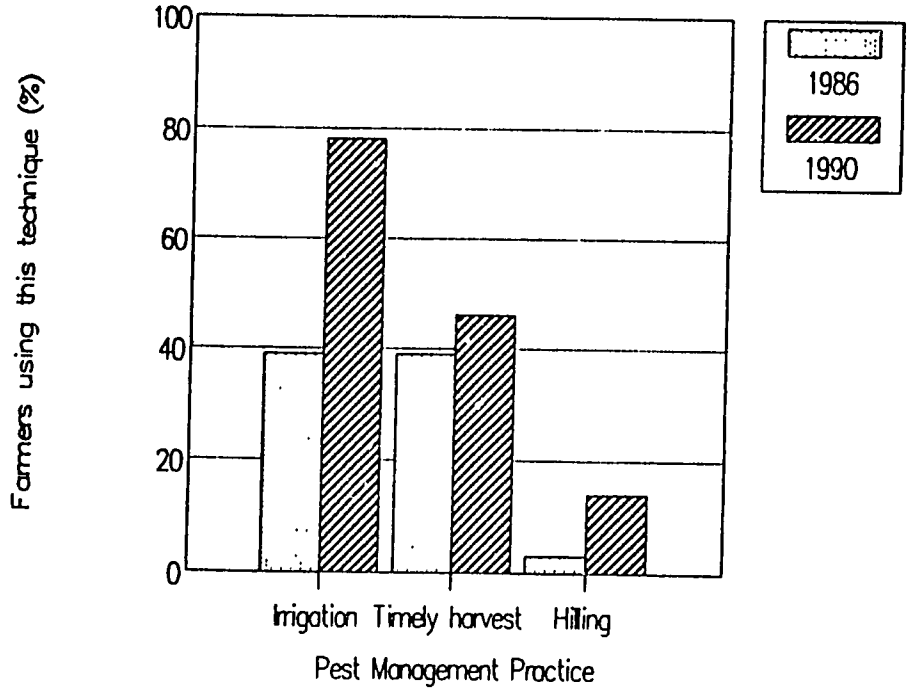
Figure III.1

CHANGES IN PEST MANAGEMENT PRACTICES IN POTATO FIELDS

REDUCTION IN INSECTICIDE USE



ADOPTION OF CULTURAL PRACTICES



potato fields and discuss in detail farmer's pest management decision-making.

The importance of harvest date in avoiding PTM infestation

Farmers clearly recognize the importance of timely harvest in keeping PTM infestation in the field to a minimum. But two primary reasons may preclude farmers from completing their potato harvest before the potato tuber moth begins to pose a substantial threat. The first reason is insufficient crop maturity. Since the bulk of the Saison crop is not sold immediately but put into rustic farm stores, farmers want the potato skins to be fully mature before harvesting. Improperly cured potatoes will have higher storage losses from transpiration and shrinkage[12]. At the other end of the crop season, planting date is constrained by environmental factors such as winter rains and the threat of frost.

The second factor constraining the completion of harvest is labor availability. In Tunisia, both potato planting and harvesting are done manually and are labor intensive. Planting one hectare of potatoes requires about 20 man-days of farm labor, and harvesting requires 40 man-days per hectare. Even small farms make substantial use of hired labor for these crop activities. It is often the case that some portion of the potato crop will not be harvested before the potato tuber moth begins to pose an important threat. Labor shortages are more severe when religious holidays, which follow the Lunar calendar, fall during the harvest period.

Irrigation to supplement insect pest management

Farmers often continue to irrigate their potato fields even after tubers have completed bulking in order to keep the soil cool and damp. This is especially the case for plots in which harvest is delayed. They may continue to irrigate these fields until one or two weeks before harvest. The last irrigations are principally seen as a way to maintain crop quality, and not to increase overall crop yield. Keeping the soil cool and damp reduces PTM infestation. Soft soil also makes harvesting less physically taxing.

Another advantage of irrigation is that it is relatively inexpensive. The variable cost of irrigating one hectare, including labor and water costs, is about 30 to 35 Dinars/hectare/irrigation. Farmers either obtain irrigation water by pumping from farm wells or through public irrigation systems where they are assessed water use charges. Water is distributed through pipes and field furrows, or in some cases by sprinkler systems. Each irrigation requires from 4 to 5 man-days of labor per hectare.

But there is also a danger from over irrigation. Waterlogging a field may create favorable conditions for the spread of bacterial and fungus diseases which increase rotting and reduce storability.

The apparent increase in the use of irrigation to control PTM infestation in the late 1980s is probably due to improved farmer knowledge about how to use this practice effectively and its relatively low cost.

Hilling as a complement in crop protection

Farmers typically hill up earth around plants once or twice during the potato crop season. The main hilling operation takes place after the potato plants are established, or about 30 to 40 days after planting, which is around 60 to 80 days before harvest. It is a labor intensive operation requiring about 10 man-days per hectare. One passage will be made with an animal-drawn plow followed by manual hoeing.

The main objectives in this operation are to make sure that the tubers will be properly covered and protected and to facilitate furrow irrigation. Keeping tubers well-covered is seen as a general means of protecting them from damages, including PTM infestation and greening from exposure to sunlight. As a pest management practice, the effectiveness of hilling is determined by not only when it is carried out (i.e., how close to harvest) but also in how well it is done (i.e., how thoroughly roots and tubers are covered).

Few farmers carry out an additional hilling close to harvest, although technically speaking this may be as or more effective than supplemental irrigation in reducing potato tubermoth infestation. Supplemental irrigation is cheaper and economizes on labor, which is at a premium at harvest time. Nevertheless, a thorough hilling operation is an important component of the farmers overall pest management and crop protection strategy.

Declining reliance on insecticides in fields

Chemical insecticide treatments are often recommended by farm input suppliers and agricultural extension agents as a modern means of controlling crop insect pests. In Tunisia, farmers may either spray liquid solutions to plant foliage (often mixed with fungicides) or apply granular soil insecticides. Farmers who use chemical insecticides see them as a preventative or curative measure against several insect pests, including potato tuber moths, aphids, wireworms and white grubs.

Nevertheless, the great majority of potato farmers have not found insecticide applications to be a cost-effective way of managing insect pests in the field. The farm survey evidence shows that as they have gained more experience with both agronomic practices and chemical insecticides, they have chosen to rely more heavily on cultural practices and less on insecticides to manage the potato tuber moth. Furthermore, few farmers judge the damage from other potato insect pests as being of sufficient significance to warrant costly treatment.

Lessons on the adoption of integrated pest management

Two important lessons emerge from the evidence on farmer adoption of new pest management methods. First, farmers adopt new practices based on their profitability and their ability to reduce or maintain low risk. The adoption of IPM in Tunisia occurred <u>not</u> because farmers were concerned about long-term environmental problems or even because of perceived health risks. Rather, IPM methods were adopted because they were found to be

cost-effective and convenient to use, while maintaining a sufficiently low likelihood that serious crop losses would occur.

Second, farmers adopted components of IPM according to their individual needs and circumstances, rather than pre-designed "packages". The success of extension efforts was probably due more to the dissemination of principles and concepts (including information on the agroclimatic conditions most favorable to the pest) rather than on a package of specific recommendations.

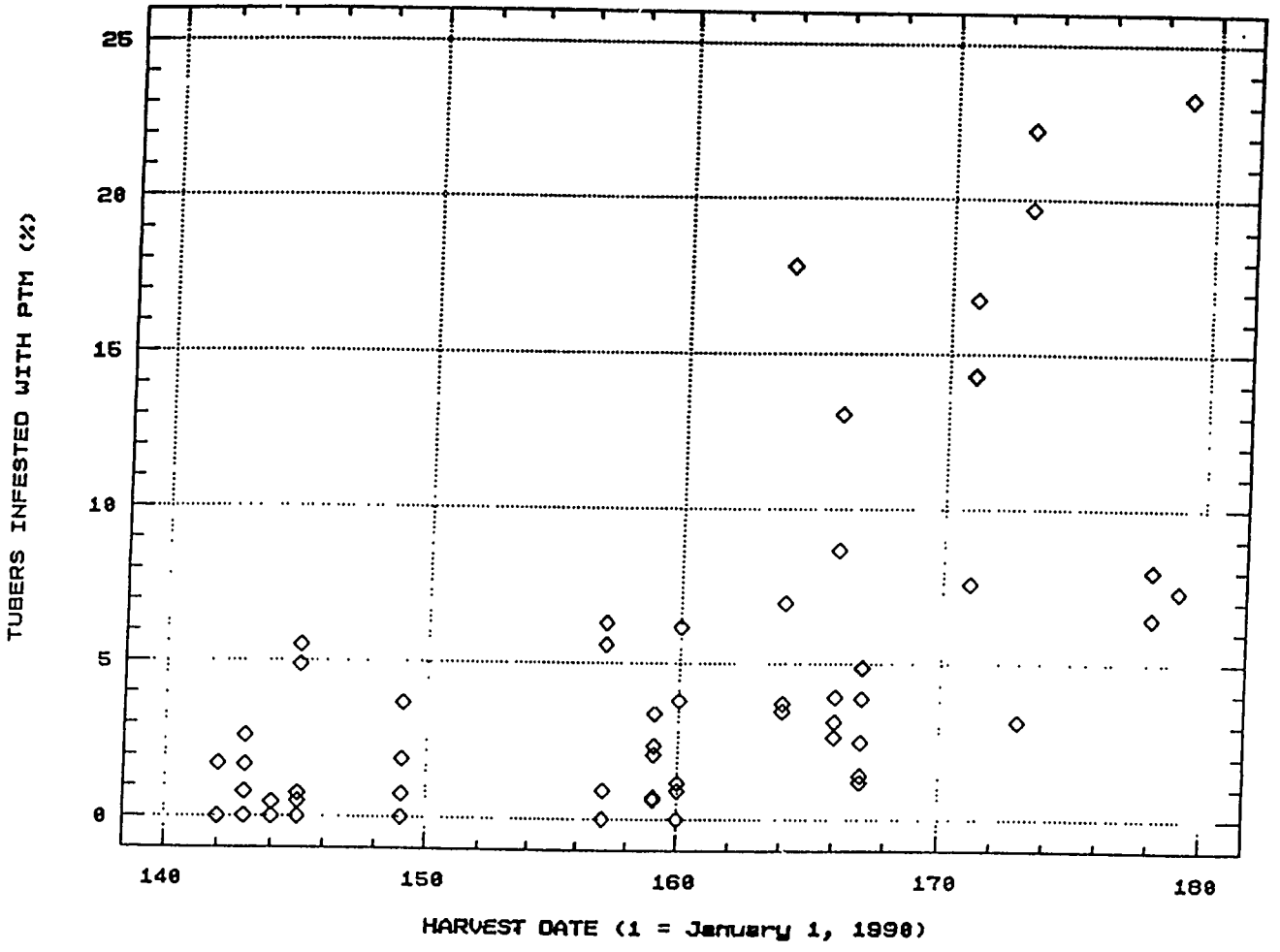
Both of these lessons carry important implications for the adaptation and testing of IPM technology, the design of extension programs, and for government policy. Farm-level testing of IPM should focus on one or two components at a time. In some cases, economic incentivies may be necessary to encourage the adoption of IPM where its components may only be marginally profitable but are nevertheless thought to be socially desirable.

Effectiveness of Farmers' Pest Management Practices in Fields

We have described how farmers seek to reduce potato tuber moth infestation in their fields. But just how effective are their management efforts? The 1990 farm survey not only gathered information about farmer practices, but also measured potato tuber moth infestation in the field at harvest time. Figure III.2 shows the level of PTM infestation in farmers fields as a function of time for observations taken from the farms in the northeastern coastal area (Nabeul and Bizerte) and the continental zone (Jendouba). The highest level of infestation observed on these farms was 23 percent of total tubers, although the average rate of infestation was only 5 percent. There was a

Figure III.2

POTATO TUBER MOTH INFESTATION IN FARMERS' FIELDS AT HARVEST



Each star shows the percentage of tubers infested with PTM larvae at harvest time from 59 potato farms. The farms were located in Nabeul, Bizerte, and Jendouba provinces.

In each field five sample units were selected at random, each unit comprising all plant growing in a 2-meter row. In each sample the number of plants, soil coverage, and plant maturity were recorded. Then the potatoes were harvested and the tubers were counted and weighed. Each tuber was then inspected for infestation by PTM larvae.

clear tendency for infestation to increase as harvest date was delayed. But it is also clear that some farms were able to harvest relatively late and still have low levels of infestation in their fields. In this section of the paper we test the hypothesis that farmer pest management practices helped reduce PTM infestation in fields where harvest was delayed.

To study the effect of irrigation, hilling, and insecticide use on the rate of infestation development, it is necessary to have sufficient variability in the farm survey data. First there should be observations from several farms at each of several harvest dates. Second, these farms should make different pest management decisions. Measurements are also necessary on other farm characteristics that may effect insect damage, such as soil quality. If these conditions are met, then the effect of their decisions of insect damage can be estimated.

We first transform the dependent variable, the percentage of PTM infestation measured in the field at harvest, into logits (a logit is $\log\{p/(1-p)\}$ where p is the proportion of tubers in a sample that were observed to be infested). The logit transformation models the development of infestation over time as a sigmoid curve. To find the rate of PTM infestation development we estimate an ordinary least squares regression of the logit of infestation as a function pest management practices, soil quality soil cover at harvest.

Harvest date is measured as the number of days between January 1 and the date when the harvest sample was taken in the field. Other pest management practices are modeled as dummy

variables according to the following definitions:

$$\text{IRRIGATION} = \begin{cases} 1 \text{ if farmer's last irrigation is } \leq 14 \text{ days before harvest} \\ 0 \text{ if farmer's last irrigation is } > 14 \text{ days before harvest.} \end{cases}$$

$$\text{HILLING} = \begin{cases} 1 \text{ if farmer's last hilling is } \leq 60 \text{ days before harvest} \\ 0 \text{ if farmer's last hilling is } > 60 \text{ days before harvest.} \end{cases}$$

$$\text{INSECTICIDE} = \begin{cases} 1 \text{ if farmer used a foliar insecticide in his potato field} \\ 0 \text{ if farmer did not use a foliar insecticide in his field.} \end{cases}$$

$$\text{SOILQUALITY} = \begin{cases} 1 \text{ for heavy clay soils} \\ 0 \text{ for light sandy and sandy-clay soils} \end{cases}$$

These variables are then entered as "slope-dummy variables" (i.e. interactions with harvest date) in the regression to see how they effect the rate of infestation development. An additional variable is included in the regression which measures soil shade (SOILSHADE) at harvest (the percentage of soil surface covered by haulms and weeds). It is hypothesized that shaded soils will have less tendency to crack, thus reducing the exposure of tubers to insect infestation.

Table III.1 shows the results of this regression. The results are interpreted graphically in Figure III.3. The relationship between harvest date and infestation is highly significant. Without taking any of the above pest management measures, infestation in a typical farmer's field reached 7 percent by June 15 and approached 20 percent by July 1. However, both hilling and irrigation were effective at reducing the rate of PTM infestation. By taking either one of these pest management steps, a farmer could reduce infestation to 4 percent by June 15 and 8 percent by July 1 (data limitations did not

permit us to determine the combined effect of any of these practices). An application of a foliar spray insecticide also reduced the rate of PTM infestation. But either of the two cultural practice was as or more effective as the insecticide treatment.

Soil quality was not found to have any significant effect on the rate of insect infestation. However, greater plant cover to shade soils did significantly reduce insect damage on tubers.

The most effective means of reducing PTM infestation in the field is to harvest as soon as possible, preferably by early June. But as it was pointed out above, it is not always possible for farmers to complete all of their harvest by this time. By following certain agronomic practices, a farmer can effectively extend the harvest period and avoid substantial crop losses from the potato tuber moth.

FOOTNOTES TO SECTION III

[12]R. H. Booth and R. L. Shaw, "Principles of Potato Storage," International Potato Center (CIP), Apartado 5969, Lima, Peru.

TABLE III.1

THE EFFECT OF FARMERS PRACTICES

ON PTM INFESTATION IN POTATO FIELDS

****

DEPENDENT VARIABLE: Logit of proportion of tubers found to be infested with PTM from a random sample taken from farmers' fields at harvest time.
Logit(p) = ln{1/(1-p)} where p is proportion of infested tubers.
Average level of infestation in fields at harvest = 5.4 percent.

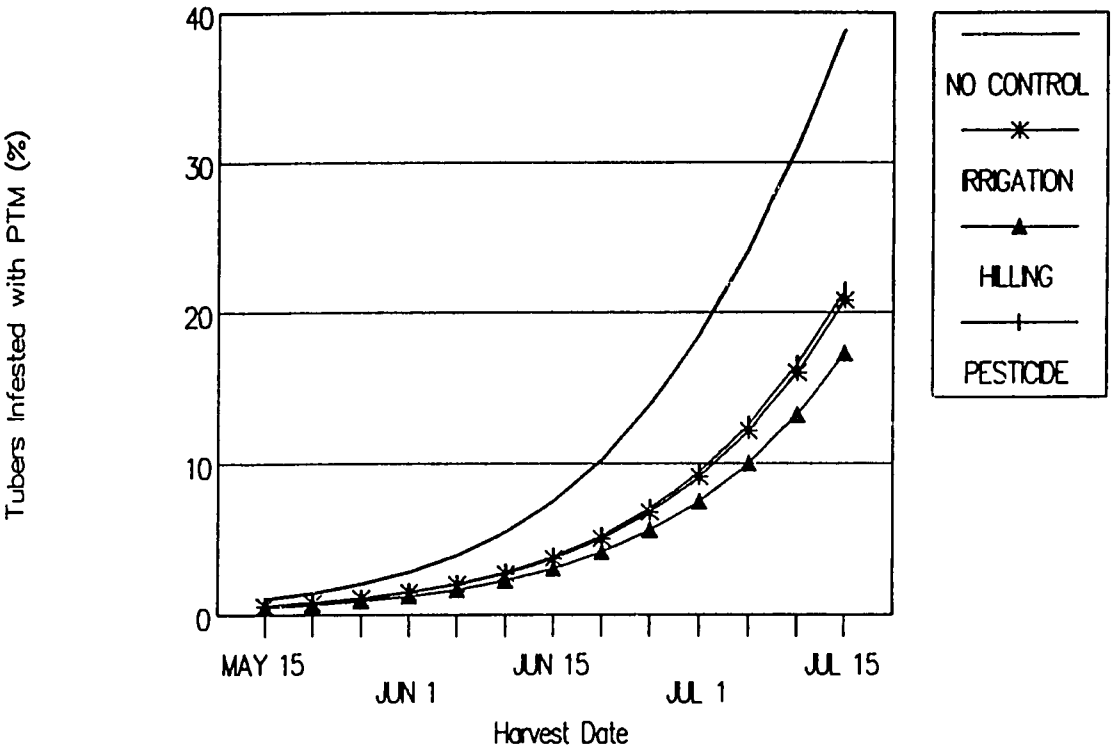
INDEPENDENT VARIABLES	DESCRIPTION	COEFFICIENT	STANDARD ERROR	T-VALUE	SIGNIF. LEVEL
CONSTANT		-13.694	1.460	-9.380	0.0000
HARVESTDATE	Harvest date: days between January 1 and harvest	0.07030	0.00910	7.728	0.0000
HARVESTDATE *IRRIGATION	Last irrigation not more than 10 days before harvest	-0.00473	0.00145	-3.267	0.0019
HARVESTDATE *HILLING	Last hilling not more than 60 days before harvest	-0.00509	0.00171	-2.978	0.0044
HARVESTDATE *PESTICIDE	Applied insecticide in field	-0.00237	0.00166	-1.422	0.1641
HARVESTDATE *SOILQUALITY	Heavy clay soil	0.00089	0.00124	0.717	0.4764
SOILSHADE	Soil covered by plants at harvest (%)	-0.01090	0.00485	-2.246	0.0290

R-SQUARED = 0.603
STANDARD ERROR OF THE REGRESSION = 0.726
DURBAN-WATSON STATISTICS = 1.805
59 OBSERVATIONS FITTED.

****

Figure III.3

EFFECT OF FARMERS' PEST MANAGEMENT ON INSECT DAMAGE IN POTATO FIELDS



IV. FARMER'S PEST MANAGEMENT IN RUSTIC POTATO STORES

Storing Potatoes in Tunisia

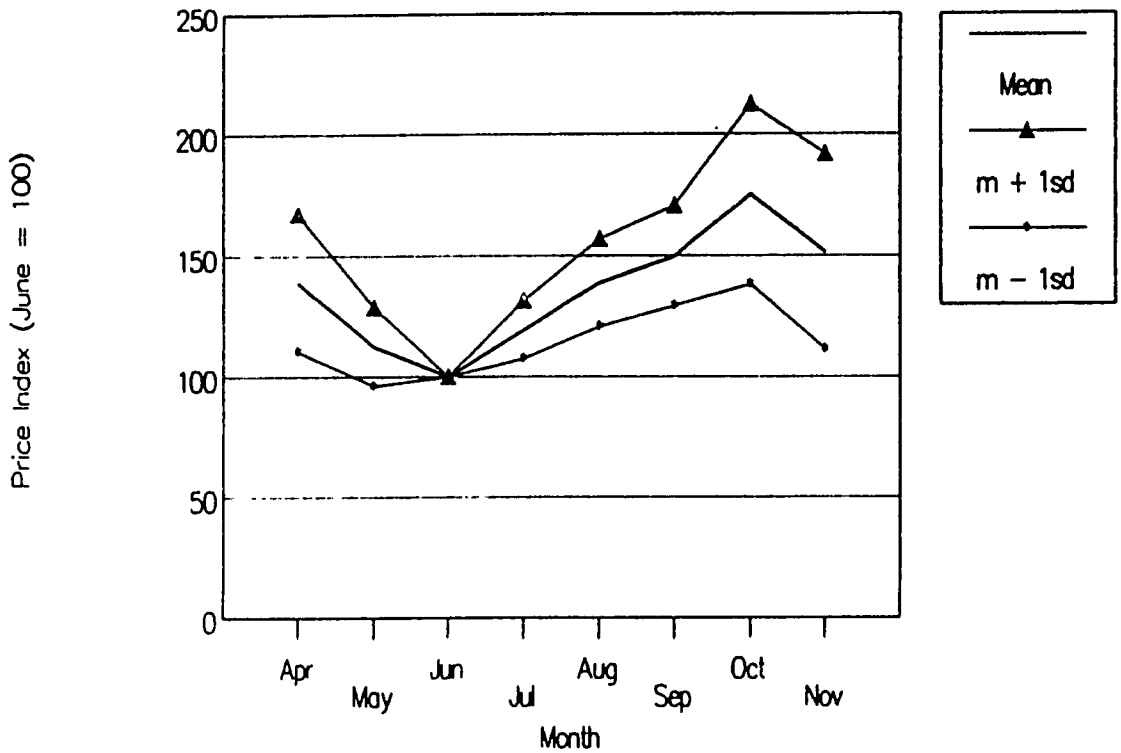
In total, around 60 to 70 percent of the Saison potato production is put into rustic farm stores. About 10 percent is for seed for the Arriere Saison crop (which is planted in August and September) and the rest of the store is for later market sale. Most of the potatoes available on the market between July and October originate from farmer's stores. During this period, potato wholesale prices typically rise by around 70 percent (see Figure IV.1). This seasonal price trend provides the primary motivation for potato storage.

Stores are low cost and unrefrigerated. Many farmers simply heap their potatoes under a tree and cover them with a thick layer of potato haulms. Other farmers build a temporary structure from wooden planks, straw bails, and tree branches. Potatoes may be covered with a layer of paper followed by a layer of loose straw, potato haulms, seaweed, reeds, tamarix branches, or other handy materials.

Throughout the summer the potato tuber moth poses a substantial threat to the potato store. PTM populations in the surrounding fields remain high and may penetrate the potato stores. Tuber moths may also be introduced from the field at harvest. Even tubers that are seemingly clean at harvest may in fact carry substantial numbers of tubermoth eggs and first instar larvae which are nearly invisible to the eye.

Figure IV.1

MONTHLY PRICE TRENDS IN TUNIS WHOLESALE MARKET (1980-1989)



The price trend is calculated using monthly potato prices reported at the Tunis wholesale market. The prices for each year were indexed with the June price being set to 100. The middle curve (solid line) shows the average price index for each month between April and November. The upper and lower curves represent high and low price tendencies. They show the mean monthly price plus or minus 1 standard deviation.

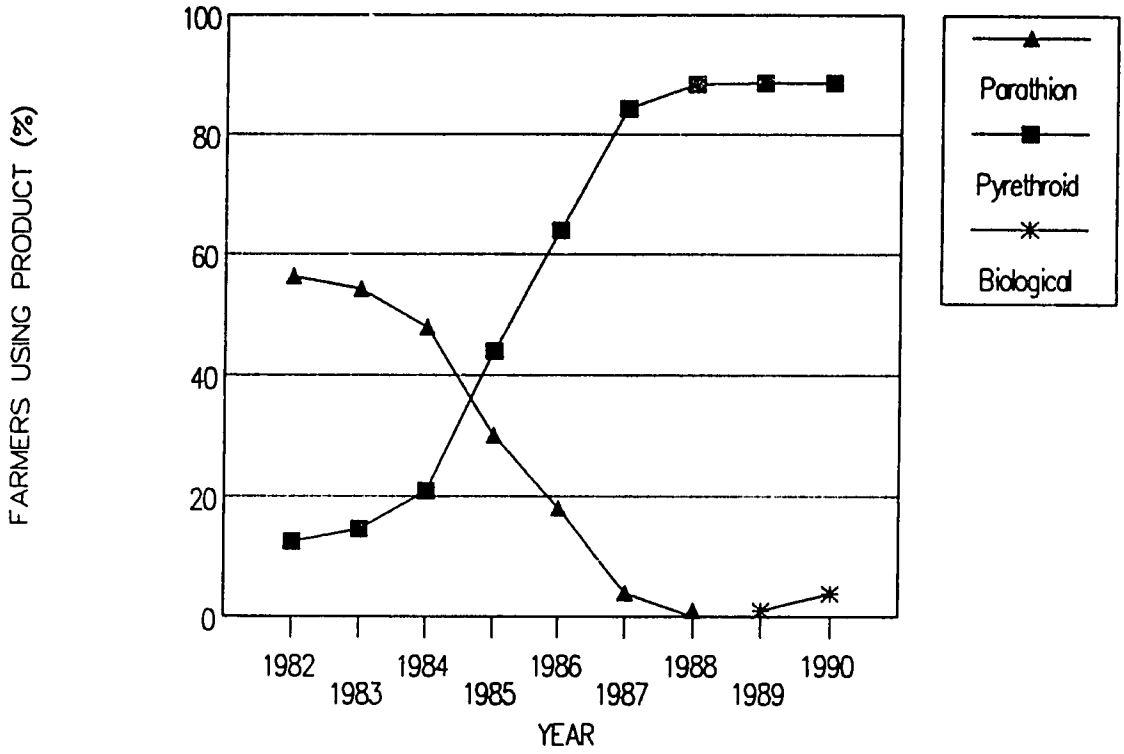
Farmers take several measures to keep insect damages in stores to a minimum. Their principal means of control are (1) handling and sorting, (2) treating with insecticides, and (3) monitoring and marketing. Immediately after harvest they will sort out damaged tubers, treat the remainder with insecticides, and put them in storage.[13] During the entire storage period they will also monitor the conditions in their stores closely, checking them for signs of rot and insect damage. If they find that the condition of the potatoes in their store is deteriorating, they may decide to sell immediately before losses become severe.

Insecticide Treatments in Stores

Figure IV.2 shows trends in insecticide use in rustic potato stores during the 1980s. The data are from the 1990 survey which asked farmers to recall their prior experience with insecticide applications in their potato stores. In 1982, about two-thirds of the farmers who were then storing potatoes were already using insecticides. The chemicals in use were either DDT or Parathion, both of which persist in the environment for a long period. Following government restricts on the importation of these insecticides, farmers switched to synthetic pyrethroid insecticides (especially the insecticide deltamethrin, under the brand names Decis and K-Othrine). By 1990, and the use of DDT and Parathion had been completely eliminated. Over the same period, the number of farmers applying insecticides in their stores increased from 66 to 90 percent.[14] The year 1990 also witnessed the first cases of farmers using a biological

Figure IV.2

ADOPTION OF NEW INSECTICIDES IN RUSTIC POTATO STORES



insecticide, Bacillus Thuringiensis. An important advantage of Bacillus Thuringiensis, which is a bacterial pathogen of the potato tuber moth, is that it poses no health risk to farmer applicators, consumers, or for that matter, other species of animals, fish, or wildlife. But the adoption of Bacillus Thuringiensis or other biological insecticides in the future is by no means a foregone conclusion, and will be driven by farmers' profit and risk considerations.[15]

Farm survey evidence shows that insecticide treatments are a rather small component of total storage costs. Insecticide application costs per ton of potatoes are shown in Table IV.1. On average, farmers spent about 3 Dinars/Ton on insecticides, which represented only 1 to 2 percent of crop value. The Table delineates insecticide treatment costs according to the mode of application. The most typical way of applying insecticides to potatoes going into storage is to spray or immerse them with a liquid solution of Decis. Farmers using this mode of treatment only used about 70 milliliters of chemical solution per ton, for a cost of about 2 Dinars/ton. These farmers stored their potatoes for an average of 80 days before selling them.

Other farmers used K-Othrine, a pyrethroid insecticide in powder form (Mode 2) or a combination of liquid and powder insecticides (Mode 3). For modes 2 and 3, the cost of insecticide treatment was almost three times higher, at 5 to 6 Dinars/ton. However, in nearly all cases in which a powder insecticide was used, it was applied together with an antisprouting agent. The antisprouting agent available to farmers

TABLE IV.1

INSECTICIDE COSTS BY MODE OF APPLICATION

IN RUSTIC POTATO STORES

Application Mode	Potatoes in Storage (% of total)	Storage Duration (days)	Insecticide per ton of potatoes		
			Decis (ml/ tn)	K-Othrine (g/ tn)	Total Cost (Dinars/ tn)
Mode 1 one treatment of Decis liquid at start of storage	67%	81	71	0	1.988
Mode 2 one treatment of K-Othrine powder at start of storage	20%	110	0	995	5.472
Mode 3 one treatment of Decis liquid at start of storage followed by second treatment of K-Othrine powder after 10-20 days	10%	79	55	794	5.907
WEIGHTED AVERAGE[1] (all farms)	100%	86	53	267	2.966

[1] About 3% of surveyed farms didn't apply insecticides.

("Stopgerm") is also a chemical powder and can be conveniently mixed with K-Othrine before application. Farmers using Stopgerm were apt to store their potatoes for a longer period, on average 100 days, before marketing them. As the seasonal price trend depicted in Figure IV.1 demonstrates, a longer storage period means a higher market price (up to a limit of about four months) so long as the quality of the stored potatoes can be maintained.

Farm Survey Evidence on PTM Damage in Farm Stores

The potato tubermoth may cause economic losses to farm stores in two ways. First, the actual infestation in tubers may lower or eliminate their market value. Second, if a farmer finds evidence of growing PTM infestation in his farm store, he may sell off his store prematurely (and thus at a lower price). Our farm surveys gathered evidence on the extent of these PTM-induced losses and sought to evaluate their economic cost. We report some of these findings below.

Sampling farm stores and measuring PTM infestation

Throughout the 1990 summer storage period, the survey team made over 50 farm visits and measured the level of actual PTM infestation from a samples of 3x100 tubers taken from the farm store. The highest level of infestation measured in a farm store of consumer potatoes was 19 percent (in a few cases higher levels of infestation were found in seed stores, usually ones that had not been treated with insecticides). The average level of infestation across all samples was 9 percent.

What is the economic cost of this degree of infestation?

Farm and market surveys conducted in 1986 and in 1990 show that wholesale and retail markets accept low levels of infestation in potato crates without imposing a price penalty. It is only when the total number of tubers damaged by the PTM in a store reaches 20 to 30 percent that the quality loss becomes noticeable enough to be reflected in its market price.[16] From the farmers perspective, the levels of infestation observed in their stores (below 20 percent) are tolerable and probably impose little economic cost to them.[17]

PTM infestation and premature storage sales

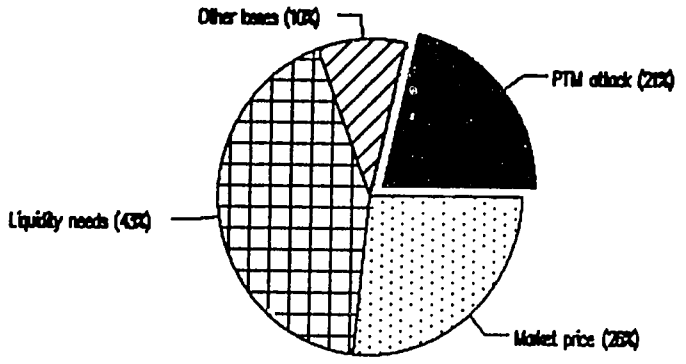
In 1986 and 1990 farmers were asked about the factors which influenced their marketing decisions to find out to what extent PTM infestation may have caused them to sell off their store prematurely. Using time series wholesale potato price data and farm survey evidence on storage costs we can also assess the degree of economic loss that may result from a premature sale.

Figure IV.3 summarizes these survey results. In 1986, 21 percent of storage sales were induced by farmers' concern about growing PTM infestation in their farm stores. In 1990, however, only 8 percent of farmers surveyed cited this as a factor influencing their marketing decision. The reasons mentioned most often by farmers as causing the sales decision were (1) a need for cash resources to finance farm operations, such as purchasing inputs for Arriere Saison planting, and (2) because they felt the seasonal potato price had peaked. Concerns about storage losses from germination, shrinkage, and rotting were also important

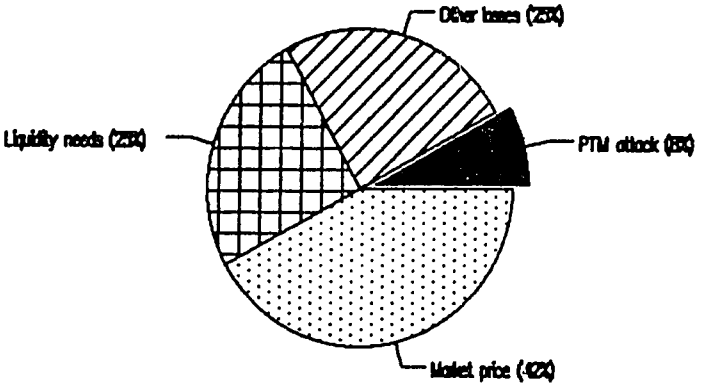
Figure IV.3

FACTORS DETERMINING MARKET SALES OF POTATOES FROM FARM STORES

1986



1990



considerations. Taken together, farmer concerns about PTM infestation and other storage losses induced about a third of potato storage sales in both 1986 and 1990.

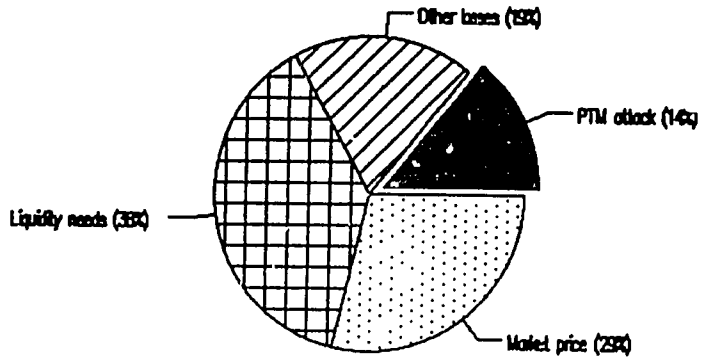
The 1990 survey included more detailed information on farmers' marketing decisions. In particularly, we are able to relate the factors influencing the marketing decision to the timing of the sale. Recalling that storage begins after harvest in May and June, we have divided storage sales into those occurring in July and August (early sales) and those occurring in September and October (late sales). The reasons for marketing storage potatoes during these periods are summarized in Figure IV.4. Early sales were mainly motivated by liquidity needs and concerns over storage losses. In fact, all of the PTM-induced sales occurred in July and August. Farmers who did not have pressing needs for cash resources and whose stores stayed relatively clean of PTM infestation kept them until they felt the market price had peaked for the season. By selling in September or October, they were able to receive a price that was 80 percent above that which prevailed at harvest and about 40 percent above the July/August wholesale market price.

Suppose a farmer had intended to keep his potatoes until October in order to get the best possible price, but then was forced to sell them in July or August because he observed increasing PTM infestation in his store. What is the economic cost of this premature sale? In Table IV.2, we present a simple storage-cost exercise using farm survey data and the wholesale seasonal price data from Figure IV.1. First, we index the quantity put into storage and the price at harvest as 1.00.

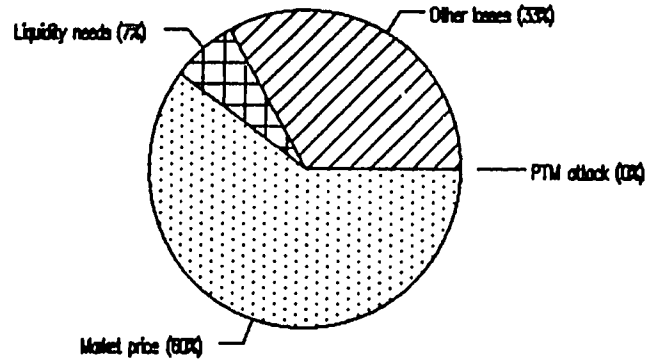
Figure IV.4

CAUSES OF PREMATURE STORAGE SALES IN 1990

JULY/AUGUST
PREMATURE SALES



SEPTEMBER/OCTOBER
OPTIMAL SALES



Using indices makes the calculations independent of a particular choice of units. The initial value of the store is thus also 1.00. After two months of storage the farmer can expect to lose about 4 percent of his store to transpiration and shrinkage. Weight losses after 4 months are estimated to be about 7 percent.[19] At the same time, prices typically rise around 40 percent between harvest and July/August (to 1.40) and by about 70 percent between harvest and September/October (to 1.70). Thus, after accounting for weight losses, the value of the farmer's store will increase from 1.00 to 1.34 and then to 1.58 during the storage season. We also subtract 10% for the costs of labor, materials, and insecticides, and 2% per month for the opportunity cost of holding his store, since the farmer is forgoing the use of the money-value of his potato crop it is in storage. The net value of his store is then 1.00 at harvest, 1.20 in July/August, and 1.40 in September/October.

The storage cost-exercise demonstrates that a premature sale can be quite costly. A farmer who intended to keep his store till October but had to sell in August because of his concerns about PTM infestation will lose 20 percent of the potential value of his crop (he receives 1.20 instead of 1.40). This is the case even though the market may not discount anything for the actual infestation he has in his potatoes when he sells them. In fact, it appears that the main cost to the farmer from PTM infestation (or at least from the potential of infestation) is *not* from actual potato damages but rather from forced premature sales.

TABLE IV.2

COST OF RUSTIC POTATO STORAGE

	MAY/JUNE harvest time	JULY/AUGUST 2 months of storage	SEPT/OCT 4 months of storage
Initial Quantity (index)	1.00	1.00	1.00
Storage Losses[1]		-0.04	-0.07
Net Quantity	1.00	0.96	0.97
Market Price[2] (index)	1.00	1.40	1.70
Current Value	1.00	1.34	1.58
Direct Costs[3] (labor and materials)		-0.10	-0.10
Opportunity Cost[4] (2% per month)		-0.04	-0.08
Real Value	1.00	1.20	1.40
Percent Gain		20 %	20 %

Notes

[1]The decline in quantity stored over time is attributable to shrinkage and transpiration.

[2]The increase in the market price reflects actual seasonal trends recorded in the Tunis wholesale market during a typical storage season (see Figure IV.1).

[3]Direct storage costs include the costs of labor, storage construction materials, chemical insecticides and germination suppressants used in a typical rustic farm store. These costs total to about 20 Dinars per ton of potatoes, or about 10 percent of the average market price at harvest (200 Dinars/ton).

[4]The opportunity cost of storage reflects the foregone use of the cash that could be obtained by selling the crop at harvest.

FOOTNOTES TO SECTION IV:

[13]Some farmers who plan to store their potatoes for three or four months will sort out damaged potatoes a second time 10 to 30 days after harvest. They will first set up a temporary store in the field and then after resorting they will move the store to a more protected and shady area. This practice of "pre-storage" is typical of the Bizerte area.

[14]Farmers who by 1990 were not applying insecticides in their potato stores were mainly those who were only storing seed potatoes for their second *Arriere Saison* potato crop. These tended to be small stores and altogether probably only account for about 3 percent of all potatoes in storage (see Table IV.1).

[15]See Ben Salah, H., et. al., "Developpement d'une nouvelle bioinsecticide dans la lutte integree contre la teigne de la pomme de terre, Phthorimaea Operculelle Zeller, dans les exploitations agricoles de Tunisie," Annals de l'INRAT, 1992 (forthcoming) for evidence from on-farm trials on the performance and profitability of new biological insecticides in rustic potato stores.

[16]Market surveys showed that lightly infested tubers could be passed off in the market place at no loss to the farmer. Moderately infested tubers (i.e. two or more insect galleries per tuber) would be sorted out and sold separately at a discounted price. Moderate infestation doesn't set in until at least 20% of a potato store is infested. See Fuglie, K., "The Demand for Potatoes in Tunisia," Working Paper, Social Science Department, International Potato Center, Lima, Peru, December, 1991, and also Ben Salah, et. al., 1992.

[17]These losses are absorbed by consumers. A few infested tubers will be mixed in with clean tubers and bought by consumers at the prevailing retail price. Consumers will then be obliged to cut away damaged parts from tubers or discard them.

[18]These weight loss figures calculated from observations taken in farmers stores in 1990. Sacks of potatoes which initially weighed 10 kilograms were placed in the several farm stores and weighed at monthly intervals.

V. SUMMARY

This report has documented how Tunisian potato farmers have learned to manage an important field and post-harvest insect pest, the potato tuber moth, and how research on integrated pest management has contributed to this process. The research effort has included both basic and applied entomological studies and interdisciplinary, on-farm surveys and trials to develop economically viable and environmentally sound methods of potato tuber moth management in potato fields and rustic stores.

Interviews with farmers revealed the sometimes complex pattern of pest management decision-making. Farmer pest management often consists of a series of if-then decision rules. Ideally they try to complete the potato harvest early enough before the seasonal increase in field insect populations brought about by hot and dry weather. Baring that, they will irrigate their fields frequently up to harvest or hill up earth around the base of plants to protect tubers in the ground from exposure to the insect pests. In rustic potato stores, insecticide treatments are an important part of pest management to avoid post-harvest losses. Farmers will also monitor the condition of their store carefully and sell the store if they find evidence of increasing insect damage.

During the 1980s, new pest control technology and better farmer awareness led to changes in how farmers manage the potato tuber moth in their fields and stores. Farmers reduced their use of insecticide treatments in potato fields and instead made more use of agronomic management methods to avoid crop losses from the

insect pest. On average, farmers reduced their chemical insecticide costs from 20 Dinars/hectare in 1986 to under 5 Dinars/hectare by 1990 (at constant 1990 prices), saving about 150,000 Dinars annually in pesticide imports. In rustic potato stores, government pesticide regulations caused farmers to adopt synthetic pyrethroid insecticides and to discontinue use of environmentally harmful chemicals such as DDT. Research is continuing on non-mammalian toxic biological insecticides and some farmer adoption of these products has occurred.

Farm survey evidence suggests that the adoption of improved storage management during the late 1980s may have reduced the incidence of premature crop sales due to insect infestation. By being able to store potatoes for the full storage period, a farmer can increase the net value of his crop by 20 percent.

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