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Irrigation as a Factor Influencing the Management of Agricultural Pests [and Discussion]

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Irrigation as a factor influencing the management of agricultural pests

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Irrigation, probably more than any other single factor, has contributed to man's ability to manipulate and to increase the productive potential of agricultural systems. The main effect of improved water management has been to stabilize the crop habitat and overcome the vagaries of seasonality, with profound implications for pest population dynamics and disease epidemiology. The paper illustrates this thesis by reference to examples and discusses the ways in which such effects can be minimized.

Introduction

Agricultural pests are, by definition, a product of man's intervention in and manipulation of natural patterns of primary production. The development of agriculture has involved the redirection and concentration of primary production into a narrow range of domesticated crop plants with a dwindling gene pool, highly selected to maximize yield. These changes have been accompanied by remarkably successful techniques of crop husbandry and the net result has been to produce increasingly uniform and luxuriant stands of vegetation which provide an eminently exploitable resource for consumers other than man. Crop protection has assumed an ever more important role in the achievement of high levels of agricultural production as the cost of management inputs and the value of the produce has increased. It is perhaps worth noting at this point that most ecosystems, within the physical constraints imposed by environment, tend towards the production of a stable, climax vegetation within which production is balanced by consumption and diversity is the rule rather than the exception. Co-evolution and co-adaptation between producers and consumers lead to an essentially self-sustaining system at a more or less constant level of biomass. The levels of damage sustained by plants are often high and the partition of resources is often towards vegetative rather than reproductive production, to buffer the effects of consumption by herbivores. This is clearly the antithesis of agricultural production and it must be expected that the cultivation of crop plants requires high levels of input for its maintenance.

Irrigation and the crop habitat

Water availability has always been a major constraint to crop production and irrigation systems have a long history of association with agricultural intensification. Their primary role has been to stabilize the crop habitat, particularly for highly productive herbaceous annual plants, and overcome the constraints of seasonality. In extreme cases seasonality of cultivation is completely lost from the system and the habitat becomes a continuum throughout the year. This has a profound impact on pest population dynamics and disease epidemiology, particularly where the crop resource which such organisms are adapted to exploit is normally characterized by strong seasonality, relatively short duration and marked habitat disruption through extensive land preparation. Such characteristics require the pest to possess either the resilience to survive between periods of host availability or strongly developed migrant ability to move between habitats. The level of successful colonization is generally low and most pests of this type are therefore also adapted to rapid population increase and the production of large numbers of dispersive or diapausing stages. When the environmental rigours for such a pest are diminished through increased habitat availability, population explosion and severe crop damage can result. The present paper will illustrate some of the situations in which irrigation has influenced pest problems, with particular reference to insects and their role as disease vectors.

IRRIGATED RICE

Rice is a classic example of a seasonal crop and probably the chief beneficiary of improved water management, occupying between a quarter and a half of all irrigated land (Greenland & Murray-Rust 1985). The pest and disease complex associated with rice has been well studied and provides some excellent illustrations of both the impact of irrigation on pest problems and the need to modify management strategies. The brown planthopper, *Nilaparvata lugens* Stål, is probably the single most important pest of rice in Asia (Dyck & Thomas 1979). Complete crop loss can be caused through the direct plant damage inflicted by high insect densities or by transmission of virus diseases such as ragged stunt and grassy stunt, even in the presence of very low numbers of insects. *Nilaparvata lugens* is highly adapted to exploit its host plant, producing short-winged reproductive morphs early in the crop and long-winged dispersive morphs as the rice matures. It is a wind-borne migrant, capable of long-distance displacement under appropriate meteorological conditions and is carried annually from mainland China to infest rice crops in Japan (Kisimoto 1976). Seasonal northward and southward migrations enable it to colonize the summer expansion of rice cultivation in temperate Asia (Cheng *et al.* 1979). Recent studies in the Philippines (T. J. Perfect & A. G. Cook, unpublished results; Loevinsohn 1984) suggest that under tropical conditions, though long-distance migration occurs, most insects disperse within a few kilometres of their site of origin. In the tropics, seasonality of rice production is more a matter of degree than presence or absence. Temperature is not limiting but the available habitat normally declines dramatically during the dry season. Rice cultivation is severely restricted, and in some cases host plants may be limited to rattoon rice surviving in perennially damp localities. Nevertheless, short dispersive flights will generally be sufficient to ensure population survival. This situation can be illustrated by data collected in Laguna Province, Philippines (figure 1). Most farmers are able to produce two annual crops. At the upper end of the toposequence, where crops are primarily rain-fed with supplementary irrigation from streams, seasonality is quite strongly pronounced, while in fully irrigated lowland areas rice is present throughout the year. The influence on insect activity is shown by trap catches of *Nilaparvata lugens* at different elevations (Cook & Perfect 1985). Increased asynchrony of planting within irrigation systems, where institutional and logistic considerations play an important part in governing water supply, is a major factor contributing to the higher level and more protracted period of activity at the lowland sites. This has been elegantly researched within the framework of the Cropping Systems Programme of the International Rice

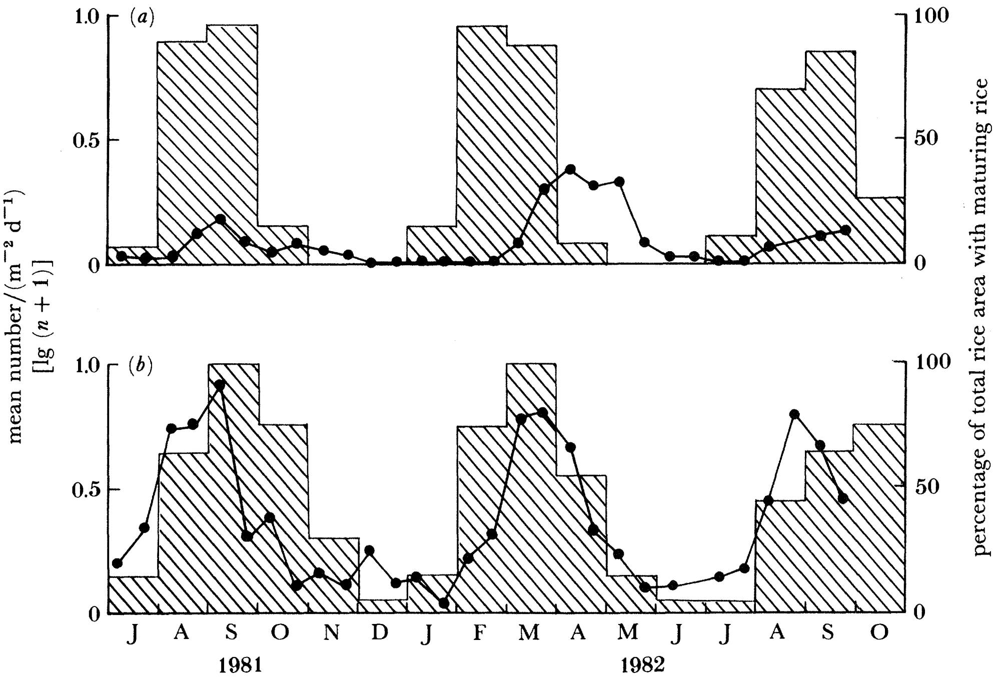

FIGURE 1. The distribution in time of mature rice (hatched) in relation to size and continuity of water-trap catches of *N. lugens* towards (*a*) the top and (*b*) the bottom of the toposequence in Laguna Province, Philippines. Water-trap catches are expressed per square metre of trapping surface.

Research Institute by Loevinsohn (1984) in Nueva Ecija, Philippines for a number of important rice pests. He showed that the logistics of water supply within a large irrigation system can impose a spread in planting dates that increases host plant availability, facilitates colonization by short dispersive flights and thereby increases the number of generations of the pest within the habitat. Asynchrony, expressed as variance in mean planting date within the normal dispersive radius of the pest, was significantly related to abundance in light-trap catches for six out of eight species studied, including Nilaparvata lugens, yellow stem borer (*Scirpophaga incertulas*), green leafhopper (*Nephotettix* spp.) and caseworm (*Nymphula depunctalis*). From the results of his study Loevinsohn designed a sequential planting strategy to minimize pest carryover and conducted trials in association with farmers and local and national institutions. Though it is difficult to assess the practical impact of the work on production, it represents a significant advance in providing data which substantiate the anecdotal belief that asynchrony increases pest problems, and in using ecological techniques to derive a solution.

Before leaving this question, it is worth emphasizing that the significance of pest population response to the continuous cultivation made possible in irrigated rice is very much scale and situation dependent. The extreme in asynchrony is exemplified by the 'rice garden', where farmers may plant small contiguous areas separated in time by as little as a week. This is a form of insurance practised particularly in areas of high risk, such as typhoon-prone parts of the Philippines, to safeguard against total crop loss. It also spreads the demand for labour, high-cost inputs such as pesticide and fertilizer, and maintains market prices through reducing seasonal gluts. Natural enemies play a very important role in the regulation of populations of *Nilaparvata lugens* in the absence of pesticide disturbance (Kenmore *et al.* 1984), and it has been argued that habitat continuity, such as that provided by the rice garden, should lead to a build-up of natural enemies and optimize population regulation by parasites and predators. There is reason to think that though this may be true for small plots isolated in a predominantly seasonal cropping environment, when translated to a larger scale the characteristics that have earned particular insects or diseases pest status will enable them to overcome natural regulation. Commercially operated systems in the Philippines have encountered major problems, particularly with *Nilaparvata lugens* and tungro virus, and large-scale rice production in the Solomon Islands has recently been abandoned because of the high levels of pest damage arising from continuous mechanized cultivation under irrigation. The situation was foreseen as early as 1967 (MacQuillan) and the maintenance of a rice-free period was recommended. This proved impossible in terms of the economic operation of the expensive capital equipment, which demanded the continuous use of fewer units rather than concerted use by many.

Continuity of host plants also has important implications for the use of varietal resistance, presently the most important strategy for the management of several rice pests. Selection pressure is intensified, and new, virulent, phenotypes emerge more rapidly. This phenomenon was observed in northern Sumatra in 1981 (Sogawa 1983) and southern Mindanao in 1982 with the variety IR36. Both are areas of virtually continuous cropping supported by irrigation. Much of what has been said above is relevant to the vector-borne diseases of rice such as rice tungro virus (r.t.v.), spread principally by *Nephotettix virescens*, grassy stunt and ragged stunt and vectored by *Nilaparvata lugens* and other important hopper-borne pathogens. The effect is compounded by the presence of continuous sources of virus in cases such as r.t.v., where the pathogen does not persist in the vector and thus the shorter the flight distance between habitat patches the greater the chance of disease spread (Ling *et al.* 1983).

Maize streak virus

Maize streak virus (m.s.v.), transmitted by leafhoppers of the genus *Cicadulina*, provides another example of the influence of irrigation on disease epidemiology through effects on vector ecology (Rose 1978). M.s.v. is a serious pest of irrigated maize in Zimbabwe, occurring in association with dense populations of *Cicadulina* which are not encountered under other circumstances. The phenology of the insect vectors is governed by their adaptation to exploit the seasonal growth of indigenous grasses, and the highest densities recorded under these circumstances reach only 2 m^{-2} (Rose 1973). This contrasts with more than 50 m^{-2} on pasture under irrigation. The flight season for *Cicadulina* occurs throughout the period from March to September as adults develop from nymphs surviving in drying grasses. Adults reared under these conditions are characterized as long fliers and this dispersive phase ensures survival, albeit at very low densities, during the dry season. Very few insects are carriers of m.s.v., which probably occurs at low density in indigenous resistant grasses expressing only mild symptoms, and survival is strongly influenced by rainfall patterns. During the wet season populations increase and the production of short-flying, non-dispersive forms is favoured by the availability of new growth of grasses. In the absence of irrigation m.s.v. is not apparent in susceptible grasses, nor is it a problem in maize crops planted after the end of the flight season. This is thought to be a result of the lack of availability of suitable host plants during the dry season when insects are dispersing and the low levels of dispersal during the wet season. The major source of m.s.v. derives from leafhoppers, which invade winter plantings of tolerant, irrigated cereal crops and create dense, relatively static populations within which the level of virus infestation is intensified (Storey 1936). The preponderance of short fliers then ensures infestation of subsequently planted maize crops and a 'compound interest' rate of increase within the crop (Van der Planck 1963). This compares with the low-density infestation of long fliers, mostly non-viruliferous and not remaining within the crop, that would normally originate from drying grassland away from irrigated areas.

Effects on the crop microclimate

There are few well documented direct effects of irrigation on pest problems. The presence of a stable water régime and consequent increased luxuriance of crop growth will affect the microclimate within the crop canopy, particularly through increasing humidity and reducing temperature fluctuations (Rosenberg 1974). This has been claimed to contribute, for example, to the success of *Nilaparvata lugens* and other pests under intensive rice production, though it is difficult to disentangle such an effect from the complex of other dominant influences such as fertilizer use and varietal shifts. An interesting example is provided by observations in the Sudan Gezira (R. C. Rainey, personal communication) on early dry-season irrigated cotton, where intense evaporative cooling was induced by the combination of dry northerly winds and high solar radiation acting on the wet soil surface of a freshly irrigated crop. This resulted in a very marked temperature inversion with the air in the crop canopy more than 10° cooler than recorded at 25 m above ground level. This situation is in direct contrast with the normal upward convection currents associated with heating of a dry soil surface and may well be a factor in the retention in the crop of dispersive stages of the whitefly, *Bemisia tabaci*, leading to very high and damaging infestations. Such a suggestion is consistent with the recent amelioration in the Gezira whitefly situation at a time when the area has been experiencing a shortage of irrigation water.

Irrigation as a management tool

Irrigation schedules can be designed to minimize their effects in promoting the build-up of pest populations. Such an approach is reported from the U.S.A. by Slosser (1980) for the management of the bollworm, *Heliothis zea* in cotton. The numbers of bollworm eggs and larvae have been shown to be highly correlated with the percentage of moisture in terminal shoots of the plant (Fletcher 1941) and infestations are largely confined to irrigated areas in dry years (Parencia *et al.* 1962). There thus appears to be a close association between establishment on the host plant and a favourable moisture régime. A computer model based on inputs from light-trap data was used to predict peak periods of moth oviposition and irrigation applied before, during, and after these periods, as different treatments in an experimental trial.

Irrigation during peak ovipositional activity resulted in an increase in the number of eggs laid and in increased larval survival. The author concluded that not irrigating during the 7–10 day period before and 3–4 days after peak oviposition provides an effective strategy for bollworm management. The pink bollworm, *Pectinophora gossypiella*, is another pest of cotton that has shown itself to be amenable to management by manipulation of irrigation practices (Bariola *et al.* 1981). *Pectinophora* overwinters in Arizona as diapausing larvae, the numbers of which are determined by the availability of late season bolls as a food source. Early season irrigation cut-off significantly reduced the number of green bolls occurring late in the crop and the numbers of diapausing larvae, though timing was critical to minimize the reduction in yield and the authors recommend that the technique be used in conjunction with application of growth regulators to chemically terminate boll production.

For some pests, irrigation *per se* can be beneficial. Cutworms, the larvae of the turnip moth *Agrotis segetum*, cause damage to vegetable and root crops throughout Europe and in parts of Africa and Asia. Damage is closely related to weather and can be severe in dry years. Cutworms occur sporadically and control measures must be timed to coincide with the presence of young larvae on the foliage of the host plant. A predictive model based on pheromone trapping is currently being developed for this purpose in the U.K. (Bowden *et al.* 1983). Recent studies (Taylor 1984) have shown that sprinkler irrigation applied over the period of larval emergence is as effective as pesticide treatment in reducing infestations, and suggest that larvae dislodged from the foliage are unable to regain their position on the host plant because they are only positively phototactic for the first two days after emergence.

SUMMARY AND CONCLUSIONS

The examples selected above have been chosen to illustrate rather specifically the influence of irrigation on crop pest problems. However, the real issue is agricultural intensification, and irrigation has its most important impact in creating the background against which high levels of inputs and management become economically viable through removal of the risks inherent in rain-fed cultivation. Varieties are bred to maximize yield, emphasizing reproductive at the expense of vegetative production and thus increasing their vulnerability to herbivores. The application of fertilizer increases their nutritional status leading to higher survival and population growth of pests. This has been exacerbated by the shift towards continuous cultivation and the consequent reduction of host-free periods which act as a brake on population development and reduce carryover under seasonal planting régimes. Loevinsohn (1984) concluded from an analysis of long-term light-trapping data in relation to cultivation records that the shift from single to double cropping of rice with the advent of institutionalized irrigation systems was the most important factor influencing a steep rise in yellow stem borer abundance at sites in both Malaysia and the Philippines. The historical solution to this problem has been the use of chemical pesticides, a strategy that has been increasingly shown to be subject to the law of diminishing returns. Many pest species have now been recorded as possessing resistance to one or more of the common insecticides, with cross-resistance widely reported. Perhaps more importantly, misuse of insecticides is widespread and it is becoming increasingly clear that their role in crop protection should be more akin to that of the scalpel than the sledgehammer. Incorrect timing and application have been strongly implicated by Kenmore *et al.* (1984) in the rise to prominence of the brown planthopper as a pest of tropical rice. It seems clear that agricultural intensification, with irrigation as a central feature, acts to reduce the impact of natural regulatory mechanisms on pest populations. The current trends in pest management that emphasize the exploitation of a thorough understanding of pest biology and ecology in cultural, biological, chemical, and genetic components in an integrated approach present the only realistic means of substituting for this loss.

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Discussion

J. M. THRESH (*East Malling Research Station, Maidstone*). Will Mr Perfect and Dr Evans comment on the extent to which pests and diseases should be controlled in plant breeders' selection plots?

T. J. PERFECT. The question presumably refers to the loss of resistance factors through screening for desirable agronomic traits, high yield in particular, under maximum pesticide protection. The other side of the coin is to risk the loss of important agronomic characters because the genome in which they are contained lacks the appropriate resistance characteristics to combat the specific pest pressure at the time and place of screening. Pest pressure varies greatly in both time and space and the absence of pest control probably increases this risk to an unacceptable level. Even so, excessive levels of prophylactic pesticide use are always to be avoided. The fact that they continue to be used probably reflects a lack of confidence in plant protectionists to provide an effective alternative. Few plant breeders are concerned by a moderate level of damage, but plant loss is anathema.

L. T. EVANS (*Division of Plant Industry, Canberra*). The answer surely depends on the plant breeder's objectives. If he is selecting for performance and stability under conditions where particular pests and diseases are serious or frequent, it is desirable that the breeding materials be exposed to significant, or even intensified, pressure from those organisms. On the other hand, if the breeding programme is oriented primarily towards selection for yield, quality or some other characteristics in crops to be grown in areas where pests and diseases are not a problem, or will be controlled, it would be more efficient to control them in the selection plots also. Otherwise, progress towards the primary objectives will be slowed.

T. W. Tanton (*Institute of Irrigation Studies, University of Southampton*). I find this paper most enlightening and with important implications for the rehabilitation of existing rice irrigation projects. Because peak water demand occurs at the time of land preparation, there is a need to increase the time available for land preparation to the longest period possible. The result is that cropping can become highly staggered and ideal for the breeding of insect pests. How far are the entomologists from giving us clear guidelines on how much stagger in planting may be used before we might expect it to create major pest problems? Although I recognize that the data may not necessarily be adequate to make such clear recommendations, failing to do so could result in millions of pounds being invested in unsound design, which could result in projects having the same problems as the highly organized rotational rice projects in Guadalcanal.

T. J. Perfect. Useful guidelines require a detailed understanding of pest population dynamics in relation to exploitation of a particular crop resource. A knowledge of dispersal characteristics and variations in susceptibility to colonization and infestation with crop age are particularly important. This information makes it possible to model the spread and population development of the pest within the habitat and identify critical factors, such as the degree of continuity that would permit development of an additional generation. The only attempt at such a systematic approach, so far as I am aware, is the work of Loevinsohn (1984), referred to earlier. This has resulted in definite recommendations for rice which should soon become more widely available and similar studies in other cropping situations should certainly be undertaken.