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# Multiple effects of two drivers of agricultural change, labour shortage and water scarcity, on rice pest profiles in tropical Asia

Serge Savary<sup>a,\*</sup>, Nancy P. Castilla<sup>b</sup>, F.A. Elazegui<sup>b</sup>, Paul S. Teng<sup>c</sup>

<sup>a</sup>*Ecole Nationale Supérieure Agronomique de Rennes, UMR BiO3P, 65 rue de Saint-Brieuc, CS 84215, 35042 Rennes Cedex, France*

<sup>b</sup>*Entomology and Plant Pathology Division, International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines*

<sup>c</sup>*The Worldfish Centre, Jalan Batu Maung, Batu Maung, 11960 Bayan Lepas, Penang, Malaysia*

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## Abstract

The effects of shortage of agricultural labour, represented by direct-seeding technologies replacing transplanting, and of water scarcity, represented by limited water supply, on rice pests (pathogens, weeds, insects) were studied. The analysis was based on a field characterisation data set covering six sites in tropical Asia and several cropping seasons. Two-way ANOVAs and MANOVA were, respectively, used to test the effects of the two factors on individual rice pest injuries, and on the profile of injuries that an individual rice crop experiences over a cropping season. Fourteen injuries were considered, which individually were significantly ( $P < 0.05$ ) influenced by crop establishment (nine injuries), by water management (11 injuries), or their interaction (nine injuries). Multiple analysis of variance indicated that rice injury profiles, regionally, are altered by both factors. The results suggested that injuries caused by some pests would be enhanced (e.g., brown spot, planthoppers) or reduced (e.g., stem rot, sheath blight, rice whorl maggot) by crop establishment shifting from transplanting to direct-seeding. Water shortages, proxied in our data by poor water management, would favour some injuries (e.g., sheath rot, brown spot, neck blast, whiteheads) or suppress others (e.g., stem rot, sheath blight). Very strong increases in weed infestation were observed with both direct-seeding and poor water management. The results are discussed with respect to pest management in rice.

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**Keywords:** Pest management; Cropping practices; Rice diseases; Rice pests; Weeds; Pest injury profile; Crop establishment; Water management

## 1. Introduction

Water and labour are two major drivers of agricultural change worldwide, and in tropical Asia

in particular. These two factors have already profoundly affected the development of rice-based agricultural systems in the past (Greenland, 1997) and are hypothesized to be drivers of agricultural change in the future (Dowling et al., 1998). On the one hand, shortage of agricultural labour (Pingali and Hossain, 1998) favours the adoption of direct-seeding technologies, in replacement of traditional, labour-intensive

\* Corresponding author. Tel.: +33 2 23 48 51 81; fax: +33 2 23 48 51 80.

E-mail address: [Serge.Savary@rennes.inra.fr](mailto:Serge.Savary@rennes.inra.fr) (S. Savary).

transplanting (De Datta, 1986; Olofsdotter et al., 1998). On the other hand, global water scarcity, and especially scarcity of agricultural water (Vörösmarty et al., 2000) will result in water stresses occurring more frequently (Anon., 2000), but should also favour the development of water-saving irrigation technologies, including direct-seeding methods (Bhuiyan et al., 1995; Bhuiyan et al., 1998), as well as land levelling technologies, and intermittent irrigation.

A characterisation study was conducted at several sites of tropical Asia and several cropping seasons, which produced extensive information on rice pests, rice cropping practices and rice production environments in lowland rice ecosystems (Savary et al., 2000a). Multivariate analysis of this data set led to the identification of a limited number of combinations of production environments and cropping practices (production situations), and of a similarly limited number of combinations of levels of pest injuries (injury profiles), which a rice crop encounters during a given cropping season. A first result was thus to condense the highly diverse rice patterns of cropping practices and the rice environments in the lowlands of tropical Asia in a few production situations; these include, for instance, ‘direct-seeding’ in its very diverse forms (wet-seeding and dry-seeding) and ‘transplanting’ (with seedlings that may differ very much in age). It was also to cluster injury profiles of a very wide range of pests, depending not on their biological nature, but rather in terms of their harmful effects to the standing crops. Further, production situations and injury profiles were shown to be strongly linked, and to be good descriptors of the overall variation in levels of actual yields, i.e., of the effects of yield determining and limiting factors associated with any production situation, and of the effects of reducing factors, which pest injuries represent (Rabbinge, 1989). These findings were then used to specify from yield loss field experiments which pest injury profiles, and in some cases, which pests within a profile are most harmful to rice production (Savary et al., 2000b). This then led to consider priorities for management, in particular through slight alteration of cropping practices.

The purpose of this earlier meta-analysis was to provide a general overview of rice production, rice pests, and approaches to manage them. The purpose of the present article is much more specific, focusing on

two particular production factors, their likely evolution, and their possible influence on rice pests. Here, our emphasis is on the description of effects of agricultural change, driven by water and labour availability, on rice pest injuries. This leads to suggesting possible trends in the evolution of rice pests in their importance, based on likely evolution of these drivers.

## 2. Field characterisation data set and analyses

The analysis is based on a field characterisation data set, which was generated from surveys conducted from 1990 to 2000 in several cropping seasons and sites (Faizabad, India; Hangzhou, China; Laguna, Central Luzon and Iloilo provinces, the Philippines; and Mekong Delta, Vietnam). The field work was conducted using the same protocol at all sites (Savary et al., 1996), which included environmental attributes, patterns of cropping practices, crop growth measurement and crop management status assessments, measurements of levels of injuries caused by pests, and direct measurements of actual yields from crop cuts. Some of the variables (crop management status and growth, levels of pest injuries) were assessed at four successive crop development stages (tillering, panicle initiation, booting and ripening), in order to provide a history of each individual field. Previous analyses (Savary et al., 2000a) indicated that this data set, consisting in summarised histories of 456 individual fields, provides a fair representation of current crop management practices, of production constraints, and of rice pest injuries in tropical Asia.

The two production factors, crop establishment method (CEM) and water management (WMGT) considered in this study are expressed with two levels each, direct-seeding versus transplanting, and ‘poor’ versus ‘good’ water management. Crop establishment was thus broadly categorised in two main types of practices: either transplanting (TR,  $n = 266$  fields), or direct-seeding (DS,  $n = 190$  fields). At each of the four visits in each field, the water supply to the rice crop was characterised using a 11-point grading scale (based on presence or absence of water, level of standing water and soil softness; Savary et al., 1996) as either insufficient (i.e., one instance when the supply was insufficient), adequate (i.e., neither any shortage

or excess of water), or excessive (i.e., occurrence of a water excess). The numbers of occurrences of the two modalities (water shortage or excess) during a cropping season (four visits) were then accumulated in two indices: accumulated water excess (AWE):  $0 \leq AWE \leq 4$ , and accumulated water shortage (AWS):  $0 \leq AWS \leq 4$ . Fields were then categorised according to water management (WMGT) in two groups, either 'good' ( $AWE < 2$  and  $AWS < 3$ ;  $n = 218$  fields) or 'poor' ( $AWE \geq 2$  or  $AWS \geq 3$ ;  $n = 238$  fields).

At each field visit, injuries caused by rice pests were assessed using the standardised procedure of the characterisation protocol (Savary et al., 1996). Fourteen different injuries were considered, including: bacterial leaf blight (BLB, caused by *Xanthomonas oryzae* pv. *oryzae*), stem rot (SR, caused by *Magnaporthe salvinii*), sheath rot (SHR, caused by *Sarocladium oryzae*) sheath blight (SHB, caused by *Rhizoctonia solani*), brown spot (BS, caused by *Cochliobolus miyabeanus*), leaf blast (LB, caused by *Magnaporthe grisea*), neck blast (NB, caused by *M. grisea*), planthoppers and leafhoppers (several species collectively referred to as PH, including *Nilaparvata lugens*), rice whorl maggot (RWM, caused by *Hydrellia philippina*), leaf folder (LF,

caused by *Cnaphalocrocis medinalis*), deadhearts (DH, caused by stem borers including *Scirpophaga incertulas*, *S. innotata*, *Chilo suppressalis*, *Sesamia inferens*), whiteheads (WH, caused by stem borers), weed infestation above the crop canopy (WA, many weed species able to outgrow the rice stand), and weed infestation below the crop canopy (WB, many weed species whose habit is underneath the rice stand). Levels of each injury (Zadoks, 1985) were computed as described in Savary et al. (2000a) using units aiming to measure injury at critical crop development stages, or the accumulation of harmful effects over a cropping season (Teng, 1987), and so, with units meant to reflect the amount of damage (yield loss, Zadoks, 1985) caused by each pest. Since injury mechanisms depend on the considered pest (Rabbinge and Vereijken, 1980; Boote et al., 1983), these units differ from one injury to another.

Comparisons of injury levels across types of crop establishment methods and levels of water management were sought. These comparisons should enable addressing individual injuries, as well as the entire profiles of injuries rice stands may experience during their cropping history. In a first stage, levels of injuries were normalised and made relative to a maximum potential (Table 1). Potential injury levels were

Table 1  
List of injuries caused by rice pests, units, and potential levels

Injury	Abbreviations	Units	Potential injury values
Bacterial leaf blight	BLB	% dsu <sup>a</sup>	5000
Stem rot	SR	% <sup>b</sup>	100
Sheath rot	SHR	% <sup>b</sup>	100
Sheath blight	SHB	% <sup>b</sup>	100
Brown spot	BS	% dsu <sup>a</sup>	5000
Leaf blast	LB	% dsu <sup>a</sup>	5000
Neck blast	NB	% <sup>c</sup>	100
Planthoppers	PH	Number dsu <sup>d</sup>	1000
Rice whorl maggot	RWM	% dsu <sup>e</sup>	5000
Leaf folder	LF	% dsu <sup>e</sup>	5000
Deadhearts	DH	% <sup>b</sup>	100
Whiteheads	WH	% <sup>c</sup>	100
Weed infestation above the rice crop canopy	WA	% dsu <sup>f</sup>	5000
Weed infestation below the rice crop canopy	WB	% dsu <sup>f</sup>	5000

<sup>a</sup> Area under incidence (at the leaf level) progress curve over development stage units (dsu), with: dsu = 100: harvest stage.

<sup>b</sup> Maximum incidence (at the tiller level) observed over four field assessments.

<sup>c</sup> Maximum incidence (at the panicle level) observed over four field assessments.

<sup>d</sup> Area under progress curve of the number of planthoppers and leafhoppers (brown or whitebacked planthopper, and zigzag leafhopper) per sampled hill (or 10 cm × 10 cm quadrat).

<sup>e</sup> Area under leaf injury incidence progress curve over development stage units (dsu).

<sup>f</sup> Area under progress curve of percent ground covered by weeds over development stage units (dsu).

derived from conservative maximum estimates. For instance, bacterial leaf blight injury (BLB) accumulates during the crop cycle and may extend over the 100 development stage units (dsu) a cycle consists of. It was considered that the area under BLB severity progress curve could not possibly exceed 5000% dsu (equivalent to a linear increase from 0 to 100% severity at 100 dsu). In the case of injuries such as stem rot (SR), it was considered that the maximum incidence (percent injured tillers) at tillering stage could not exceed 100. Two-way ANOVAs were used to compare levels of individual injuries across crop establishment methods and levels of water management. The effects of the two production factors on injury profiles (the possible combination of levels of 14 injuries) were analysed through MANOVA.

### 3. Results

Comparison of overall, normalised levels of injuries suggests that some injuries generally achieved much higher levels than others (Fig. 1). For instance, actual bacterial leaf blight (BLB) and leaf blast (LB) injuries were generally low, compared to sheath blight (SHB), and weed infestation above or below the rice crop canopy (WA or WB), the latter three reaching higher levels, irrespective of water management and crop establishment. This would suggest that a better control of BLB and LB, than of SHB, WA and WB, was generally obtained in farmers' fields. The levels of other injuries (e.g., stem rot SR) very much varied with levels of water management and of crop establishment.

In many cases, significant effects ( $P < 0.05$ ) of crop establishment (CEM), water management (WMGT), or their interaction on injury levels were found in two-way ANOVAs. One example is weed infestation, represented by WA and WB (Table 2), the two variables being significantly influenced by both CEM, WMGT and CEM  $\times$  WMGT. Fig. 1 shows WA and WB increased with shifts from transplanted (TR) to direct-seeded (DS) rice, and from 'good' to 'poor' water management, the increase between 'good' and 'poor' water management being larger in direct-seeded crops.

We briefly describe here results pertaining to injuries caused by rice diseases (Fig. 1A and Table 2).

SR injury was strongly reduced in the direct-seeded (DS) compared to the transplanted (TR) crops, and SR was also strongly reduced in the transplanted crops when poor water management occurred. SHR was significantly increased when poor water management occurred. SHB was significantly decreased in the DS compared to the TR crops, and was also decreased by poor water management. BS was significantly increased when poor WMGT occurred, and this increase was significantly more pronounced in the TR compared to the DS crops. NB was significantly increased when poor WMGT occurred, and NB was significantly higher in the TR compared to the DS crops.

MANOVA of the multiple injury response to varying levels of water management (WMGT) and crop establishment (CEM) enabled the testing of the hypothesis of independence of injury profiles with these two factors (Table 3). Significant ( $P < 0.01$ ) effects of crop establishment and water management (and their interaction) on combined levels of injuries were found, indicating that injury profiles significantly vary depending on these two factors.

### 4. Discussion

#### 4.1. Comparison among injuries

Fig. 1 suggests that some rice pests are, in general, checked under current crop management practices. The situation concerning bacterial leaf blight and leaf blast, however, is very recent in the history of rice cultivation. These two diseases were extremely damaging, even in favourable irrigated agrosystems, 30–40 years ago only (Mew, 1992), and their current levels should be seen as the result of considerable breeding efforts (Mew, 1991; Bonman et al., 1992).

#### 4.2. Effect of water management and crop establishment on injuries caused by diseases

The effects of water management on rice diseases have been unevenly documented. Our results are however in agreement with published results in this respect. By contrast, very few studies are available to support hypotheses concerning the effects of crop establishment methods on rice diseases.

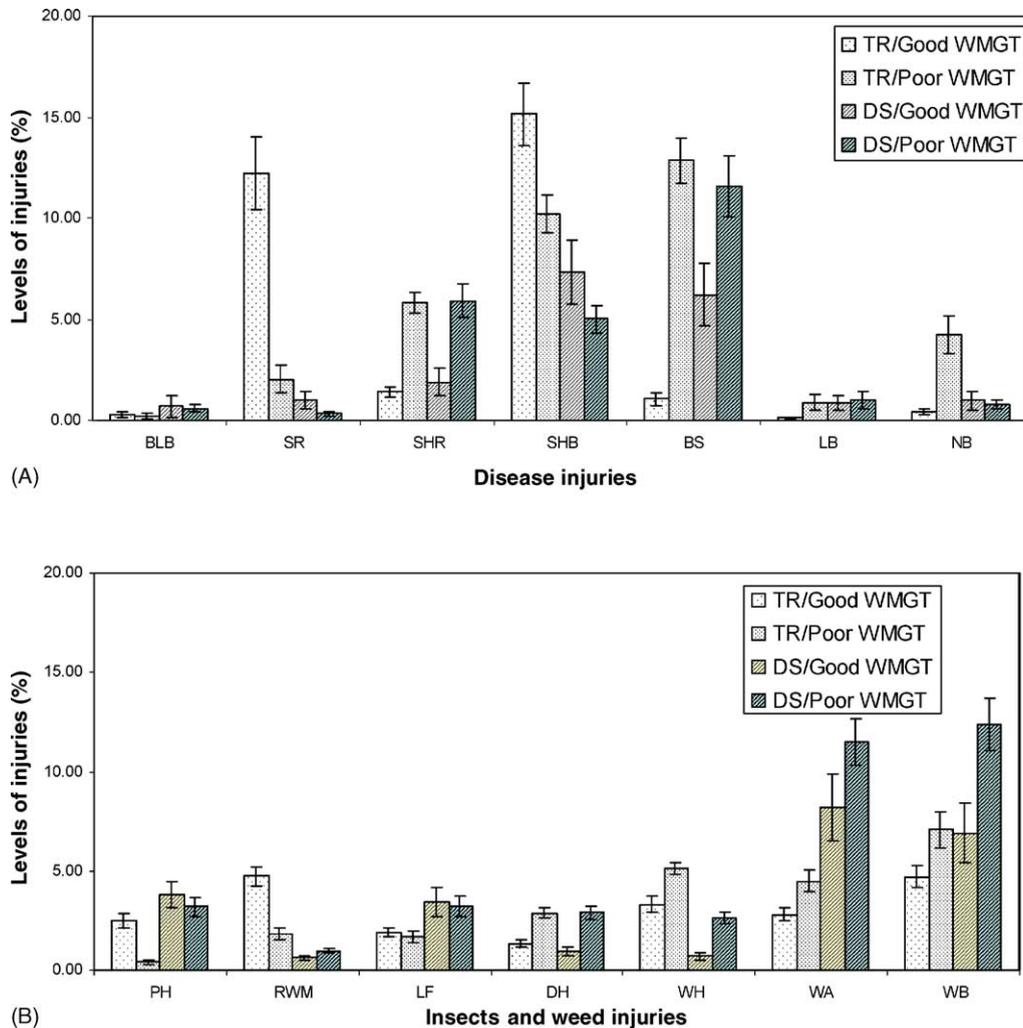


Fig. 1. Variations of normalised injury levels with varying levels of water management and of crop establishment. Abscissa: injuries caused by rice bio-aggressors: BLB: bacterial leaf blight, SR: stem rot, SHR: sheath rot, SHB: sheath blight, BS: brown spot, LB: leaf blast, NB: neck blast, PH: planthoppers, RWM: rice whorl maggot, LF: leaffolder, DH: deadhearts, WH: whiteheads, WA: weed infestation above the rice crop canopy, WB: weed infestation below the rice crop canopy. Ordinates: levels of injury normalised to their potential maximum level (%). Levels of crop establishment: TR: transplanted, DS: direct-seeded. Levels of water management: 'good' (occurrence of a water shortage in no more than two visits out of four, and occurrence of a water excess in no more than one visits out of four) or 'poor' (occurrence of a water shortage in more than two visits out of four, or occurrence of a water excess in more than one visit out of four). Vertical bars indicate standard errors of means.

'Poor' water management leads to poor crop growth, and a poor stand to fewer contacts among host tissues within the canopy. Opportunities for the sheath blight (SHB) pathogen to spread within and between rice plants are thus reduced (Savary et al., 1995; Castilla et al., 1996). This may explain the apparent SHB reduction under poor water management (Fig. 1). This difference in SHB level between levels of water

management should only be considered as a trend ( $F = 2.23$ ,  $P = 0.11$ ). Lower SHB intensity in direct-seeded compared to transplanted rice has been experimentally documented (Willcoquet et al., 2000), and is attributable to lower accessibility of healthy tillers to the pathogen in a direct-seeded crop. Spread of the disease (1) has a short range, and (2) depends on mycelial strands growing within a canopy,

Table 2

Summary of two-way analyses of variance of the effects of crop establishment method, water management level, and their interactions on injury levels

Injury <sup>a</sup>	CEM <sup>b</sup>		WMGT <sup>c</sup>		CEM × WMGT	
	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
BLB	2.76	0.10	0.68	0.51	1.13	0.33
SR	28.4	<0.001	14.8	<0.001	11.8	<0.001
SHR	0.93	0.34	27.4	<0.001	1.08	0.34
SHB	27.8	<0.001	2.23	0.11	0.86	0.42
BS	3.22	0.07	24.1	<0.001	23.3	<0.001
LB	1.41	0.24	0.95	0.39	3.10	0.05
NB	6.49	0.01	4.50	0.01	3.61	0.03
PH	22.5	<0.001	5.17	0.006	1.05	0.35
RWM	54.6	<0.001	9.34	<0.001	14.0	<0.001
LF	11.0	0.001	3.08	0.05	4.36	0.01
DH	0.001	0.99	25.7	<0.001	2.97	0.05
WH	47.8	<0.001	19.2	<0.001	2.17	0.12
WA	54.2	<0.001	6.01	0.003	5.84	0.003
WB	17.0	<0.001	7.01	0.001	9.26	<0.001

<sup>a</sup> See Table 1 for abbreviations.

<sup>b</sup> Crop establishment method: transplanted or direct-seeded rice.

<sup>c</sup> Water management level: 'good' or 'poor' (see text for detail).

from leaf to leaf, tiller to tiller, and plant to plant. In a direct-seeded crop progress of the disease is hampered, as healthy tissues are not clustered as they are in a transplanted one. This difference in SHB intensity in direct-seeded versus transplanted crops accounts for the large and significant ( $F = 27.8$ ,  $P < 0.001$ ) crop establishment effect on this injury (Fig. 1 and Table 2).

The observed effect of a 'poor' water management associated with higher brown spot corresponds to earlier studies showing that this disease is favoured by a reduced water supply, which increases both the infection efficiency and the rate of lesion expansion (Su, 1938; Herrera and Seidel, 1978; Ou, 1987). This effect appears more pronounced in transplanted than in direct-seeded crops, resulting in a strong CEM × WMGT interaction. An increase in brown spot intensity is also suggested by the analysis (Fig. 1 and Table 2) in the case of direct-seeded crops. This

may be attributed to rice plants having a shallower root system, and thus being more sensitive to water stresses in a direct-seeded compared to a transplanted crop (Castillo, 1962).

Numerous studies (e.g., Kim, 1987) indicate that the level of water supply influences several processes in rice blast epidemics (spore liberation, spore germination and infection). Water management directly translates into variation in the crop microclimate (especially, dew deposition; Asai et al., 1967; El Refaei, 1977), and indirectly, in the crop physiology. The former affects the life cycle of the pathogen and the latter influences host susceptibility (Bonman et al., 1988). A 'poor' water management, when leading to moist or dry soil (instead of flooded or wet) favours dew deposition, enhances host susceptibility, and thus blast. This may account for the higher neck blast incidence under 'poor' water management.

Table 3

Multiple analysis of variance of injury profiles for effects of crop establishment method and water management<sup>a</sup> and their interaction

Effect	Wilk's lambda	<i>F</i> -statistic	d.f. <sup>b</sup>	<i>P</i>
Crop establishment (CE)	0.62	19.62	14, 439	$0.99 \times 10^{-15}$
Water management (WMGT)	0.71	12.69	14, 439	$0.99 \times 10^{-15}$
CE × WMGT	0.89	3.85	14, 439	$3.35 \times 10^{-4}$

<sup>a</sup> With two levels each (see text).

<sup>b</sup> Numerator degrees of freedom, denominator degrees of freedom.

The relative increase in neck blast incidence in transplanted compared to direct-seeded stands suggests that direct-seeding generates a crop environment which might be unfavourable to the disease.

Literature on the epidemiology of stem rot (SR) and sheath rot (SHR) is scarce. Strong numerical (Fig. 1) and statistical (Table 2) effects of the two factors indicate that much might be gained from better knowledge of SR for its control through water management and crop establishment. Sheath rot is one disease commonly encountered in crops where nutritional, water, or health (virus infection, stem borer injuries) occur (Ou, 1987), and so poor water management associated with increased SHR injury is expectable. Epidemiological understanding, however, is lacking.

#### 4.3. *Effects of crop establishment and water management on other rice pests*

Our data also indicate, for instance, that planthopper (PH) densities are decreased with poor water management (especially in transplanted crops), that rice whorl maggot (RWM) injury is decreased with poor water management, and that weed (WA and WB) infestation is increased in direct-seeded crops, and is also increased with poor water management. These trends conform to the literature concerning rice planthoppers (Pathak and Dyck, 1973; Das and Thomas, 1977), rice whorl maggot (Ferino, 1968; Viajante, 1985) and rice weeds (Navarez et al., 1979; Moody, 1991), respectively. These results also suggest that the data used here are representative of commonly described disease, insect, and weed patterns in Asian rice production, and that the double classification used (transplanted versus direct-seeded, and 'good' versus 'poor' water management) is relevant, in spite of its simplicity.

#### 4.4. *Implications for rice pest management in the future*

Multiple analysis of variance indicates that rice injury profiles, regionally, are significantly altered by the method of crop establishment and the level of water management. The effects of the two factors however differ in their direction depending on rice pests, and especially, rice diseases: direct-seeding

increases PH, LF, WA, WB, while SR, SHB, RWM, WH are decreased; and poor management of water increases SHR, BS, NB, DH, WH, WA and WB, while SR, SHB, PH and RWM are decreased. This suggests that, in the context of increased agricultural labour and water resource constraints, translated into widespread use of direct-seeding technologies and restricted water inputs, diseases such as SHR, BS and NB might become more important, together with some insect injuries (LF, DH and WH), and weeds in general (WA and WB). On the other hand, diseases such as SR and SHB would be negatively affected by these two factors.

This analysis only provides an overview of complex, interlinked, processes; the trends it suggests could arguably be attributed to limited sampling intensity; and it only offers circumstantial evidence of ongoing, or yet-to-come agricultural changes, based only on current pattern diversities observed in farmers' fields. Strong trends however are indicated, which pertain not to individual pests only, but also to injury profiles, which appear driven by factors that are likely to play increasing roles in the future. Such issues are related to effects of global climate change on plant diseases (Scherm and Van Bruggen, 1994b; Scherm and Yang, 1995). Studies on climate change effects on plant diseases have primarily addressed specific diseases, e.g., downy mildew of lettuce (Scherm and Van Bruggen, 1994a), or potato late blight (Zwankhuizen and Zadoks, 2002). Ecological studies (e.g., Shaw et al., 2002) have addressed the multiple effects of climate change-related variables on systems' performances. In a similar way, effects of global changes (climate, trade and labour) on crop pests could also be addressed at the systems level and so be explored through multifactorial approaches (experimental and modelling) in order to quantify interactions, understand, and predict the behaviour of agricultural systems.

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