A Characterization of Rice Tungro Epidemics in The Philippines from Historical Survey Data

SERGE SAVARY, Plant Pathologist and ORSTOM Visiting Scientist, NESTOR FABELLAR, Research Assistant, EMMANUEL R. TIONGCO, Assistant Scientist, and PAUL S. TENG, Plant Pathologist, International Rice Research Institute, P.O. Box 933, 1099 Manila, The Philippines

ABSTRACT

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We used historical survey data to compare patterns of rice tungro epidemics in two endemic areas and one nonendemic area in The Philippines. Four categorized variables—planting date, cropping season, vector population, and proportion of viruliferous vectors—were tested for their ability to characterize the variation in tungro incidence. Correspondence analyses indicated that high tungro incidence was associated with intermediate planting dates, whereas absence of tungro was associated with very early or very late planting dates. In the two endemic areas (North Cotabato and Sultan Kudarat, Mindanao; data from nine cropping seasons), increasingly higher tungro incidence was associated with increasing vector population and proportion of viruliferous vectors, but the relationships among the three variables differed in the two areas. In Sultan Kudarat, a high proportion of viruliferous vectors compensated for a moderate vector population size to produce high tungro incidence. In the nonendemic area (Central Luzon, 16 cropping seasons), moderate to high tungro incidence was associated with the presence of viruliferous vectors and moderate to very large vector populations. Further analysis indicated that epidemic years in Central Luzon are primarily associated with the occurrence of viruliferous vectors, with the size of the vector population playing a secondary role only. The analyses suggest that tungro outbreaks are more responsive to inoculum (represented by viruliferous vectors), when present, in the nonendemic area (Central Luzon) than in the endemic areas (North Cotabato and Sultan Kudarat).

Additional keywords: categorical data, endemicity

In some provinces of The Philippines, rice crops are affected by tungro disease every year, whether they are planted in the rainy season or the dry season. Such areas are commonly termed "hot spots" to distinguish them from other rice-growing regions that experience only sporadic but sometimes explosive epidemics (8). This contrast between endemic and nonendemic areas seems common in several countries in Southeast Asia (18), and both situations exist in The Philippines.

Few studies have compared areas where tungro occurs each season with areas where the disease occurs sporadically but causes considerable damage in some years. Much additional research is needed to understand the polyetic mechanisms that govern the carryover of the disease and its outbreaks and, therefore, the conditions that determine whether tungro is endemic or not.

We used historical survey data to describe and analyze tungro outbreaks in three rice-growing areas in an attempt to determine whether rice tungro "hot spots" can be defined by a set of stable characteristics. We also tried to answer the question of whether variation in rice tungro disease incidence can be adequately explained by a few key variables, such as the planting date, the size of the vector population, and the proportion of viruliferous vectors, that might be used in disease management.

Although methods using categorical data are seldom used in plant disease epidemiology (15) and crop loss analysis (16), they may prove very useful in ecosystem characterization. Because they handle data in the form of sets of a few discrete categories representing the variation in given environmental characteristics, these methods are conceptually compatible with decision making in agricultural systems. McCool et al (12) explain in detail some basic statistical indications for using categorical data: highly skewed distribution of the variable to be analyzed, heteroscedasticity, and unequal intervals within the rating or assessment scale used. Other reasons to consider the analysis of categorical data include the need to devise classes of observations in order to harmonize data sets from different origins and the desire to incorporate in the analysis variables that are qualitative by nature, such as the cropping season.

Log-linear analysis is one method for analyzing categorical data. However, because it is not practical when more than three variables are considered (12), we selected correspondence analysis (2,7,9) instead as an appropriate technique.

MATERIALS AND METHODS

Data collection. We considered three rice-growing areas of The Philippines: two provinces (North Cotabato and Sultan Kudarat) in the southern island of Mindanao with historical records of high tungro incidence (16,18) and the central part of Luzon Island, where tungro outbreaks occur occasionally. The two Mindanao provinces represent relatively well-delimited, irrigated rice-growing areas with two predominant cropping seasons per year and a range of traditional to improved cultivars. Central Luzon is a major rice production area of The Philippines, with very intensive rice cultivation in some parts and two cropping seasons per year.

Surveys were conducted by the Philippine Department of Agriculture (North Cotabato and Sultan Kudarat) and the International Rice Research Institute (Central Luzon). Fields were selected at random to cover the range of planting dates, cultivars, and field areas. Each field was represented by a set of five variables: cropping season (CS), planting date (PD), tungro incidence at tillering (IN), total vector population (V), and proportion of viruliferous vectors (VV). At each round, a new sample of fields was drawn, so that some fields could be visited several times. In the two Mindanao provinces, the survey was conducted during nine consecutive cropping seasons from 1983 to 1987, and information was gathered for 165 fields in North Cotabato and 379 fields in Sultan Kudarat. In Central Luzon, the same data were gathered on 530 fields, from the tillering stage until booting, over 16 consecutive cropping seasons (1973–1980).

Much of the data was collected during the tillering phase of the crop, when tungro symptoms are most conspicuous. We did not study the dynamics of tungro within a cropping season in a given field; the statistical analyses concentrated on the tillering phase, represented by 130, 118, and 420 fields in North Cotabato, Sultan Kudarat, and Central Luzon, respectively. In Central Luzon, however, two types of years were differentiated: those with tungro epidemics (with minimum prevalence of 40%) and those

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Table 1. Categorization of variables[a] used in the correspondence analyses

Variable	Classes				
Tungro incidence (%)	IN0 (0)	IN1 (0–2)	IN2 (2–5)	IN3 (>5)	
Number of vectors caught	V1 (0–5)	V2 (5–10)	V3 (10–15)	V4 (>15)	
Percentage of viruliferous vectors	VV0 (0)	VV1 (0–5)	VV2 (5–15)	VV3 (>15)	
Planting date	PD1 (very early)	PD2 (early)	PD3 (intermediate)	PD4 (late)	PD5 (very late)
Cropping season	RS (rainy)	DS (dry)			

[a] At the tillering phase.

Table 2. Contingency table for the analysis of data[a] from Sultan Kudarat

	Level of tungro incidence			
Variable[b]	IN0	IN1	IN2	IN3
V1	18	1	3	3
V2	25	9	8	4
V3	14	4	6	3
V4	10	4	3	3
VV0	16	0	1	0
VV1	28	8	2	6
VV2	20	7	4	3
VV3	3	3	13	4
PD1–PD2	17	1	2	2
PD3	18	3	11	9
PD4	14	14	7	1
PD5	18	0	0	1
RS	37	1	4	10
DS	30	17	16	3

[a] At the tillering phase. Entries are number of fields.

[b] Levels of vector population (V1–V4), proportion of viruliferous vectors (VV0–VV3), planting date (PD1–PD5), and cropping season (RS, DS) (see Table 1).

Table 3. Tungro prevalence in three areas in the Philippines

Area	Infected fields (no.)	Healthy fields (no.)	Percentage of fields infected
Central Luzon			
Tillering phase	118	302	28.1
Total	167	363	31.5
North Cotabato			
Tillering phase	110	20	84.6
Total	128	37	77.6
Sultan Kudarat			
Tillering phase	51	67	43.2
Total	321	58	84.7

without.

We first compared the temporal patterns of outbreaks in the three regions. For this comparison, we analyzed the Central Luzon data for the epidemic years only (1974, 1975, and 1976; 155 fields total), when 40% or more of the fields surveyed were affected by tungro at tillering. We compared the results of this analysis with the analyses of the North Cotabato and Sultan Kudarat data. A second analysis including all years of the Central Luzon data set was performed in order to introduce a polyetic perspective in the study.

Tungro incidence, defined as the proportion of field area affected, was assessed on an approximate grading scale with unequal intervals: 0, 1, 2, 3, 5, 10, 15, 20, 30, . . ., 100% of field area affected. Presence of tungro was confirmed using the iodine-starch test (3) on a few leaf samples.

The total vector population was represented by the number of leafhopper vectors (*Nephotettix virescens* (Distant)) caught in 10 sweep net strokes taken at random above the rice canopy. The proportion of viruliferous vectors (when vectors were present) was determined as the percentage of vectors (out of an average of 50 insects per sample) that induced a positive reaction in a transmission test, in which individual insects from the field were caged on a seedling of a susceptible rice cultivar (TN1).

Data categorization. Because of the nonnormal distribution frequencies of these three quantitative variables (IN, V, and VV) and the low precision (13) of assessments, we used nonparametric methods of analysis pertaining to categorized information. Two major steps may be distinguished in the handling of categorical data: the transformation of quantitative data into coded, qualitative data, and the building of contingency tables. In the first step, discrete levels are defined, so that each data unit falls into one level. The number of levels and their numerical boundaries should be chosen so that all levels are represented by similar counts (number of fields, in this case). In the second step, contingency tables are constructed to represent the bivariate distribution of fields according to two classifications (e.g., coded disease incidence and cropping season). The independence of the two frequency distributions can then be tested.

From the analysis of frequency distribution patterns, we defined boundaries and classes for each of the quantitative variables, transforming them into qualitative categories (Table 1). For instance, disease incidence percentages were encoded into the following disease classes: IN0, no disease (IN = 0); IN1, low incidence ($0 < \text{IN} \leq 2\%$); IN2, average incidence ($2\% < \text{IN} \leq 5\%$); and IN3, high incidence ($5\% < \text{IN} \leq 100\%$). This asymmetric coding, simultaneously with consideration of the tillering phase of the crop only, was intended to minimize the epidemic trend—that is, the tendency of disease to increase over time in a given field.

Five classes for planting dates (PD1–PD5), from very early to very late (Table 1), were considered within each cropping season. In the rainy season (RS), June–July was considered the midperiod for planting (PD3), and the planting dates were distributed among neighboring classes (early and very early, late and very late) with an approximately one-month step between classes. Planting dates in the dry season (DS) were distributed similarly, using December–January as a midperiod.

In some instances, groupings were made to reduce imbalance in the representation of some categories and to allow chi-square tests. For example, the early planting period PD2 was poorly represented (10 fields) in North Cotabato, and the data were pooled with those from the next planting period (PD3) in the analyses. In Sultan Kudarat, very early (PD1, four fields) and early (PD2, 18 fields) classes were combined. Similarly, only a few fields in Central Luzon fell into the medium (IN2, 14 fields) and high (IN3, seven fields) disease levels, so the two classes were pooled. Also in Central Luzon, the proportion of viruliferous vectors was never higher than 5%, so only two classes were present: VV0 and VV1. Similarly, the total vector population was usually low, so the three classes V2 (six fields), V3 (one field), and V4 (six fields) were pooled in the analyses.

Contingency tables. All three quantitative variables were encoded (Table 1) to build the contingency tables. Table 2 shows the contingency table representing the Sultan Kudarat data set. Each variable was categorized into classes, represented by frequencies (i.e., the number of fields falling into each class). Thus, the population of fields that belong to a given class (e.g., IN0) can be broken down into subpopulations associated with categories of other variables (e.g., the vector population). Table 2 shows, for instance, that among the fields with no tungro (IN0) in Sultan Kudarat, 18 had very small (V1), 25 had small (V2), 14 had large (V3), and 10 had very large (V4) vector populations. The series of figures 18, 25, 14, and 10 thus gives a profile of IN0 in terms of vector pop-

Table 4. Correspondence analyses (relative weights and contributions to axes) of rice tungro epidemics in three areas in The Philippines

Classes	Relative weight	Contribution to axes: Axis 1 Contribution	Axis 1 Sign	Axis 2 Contribution	Axis 2 Sign
North Cotabato ($n = 165$ fields)					
Columns					
IN0	0.154	80.9	+	3.5	+
IN1	0.469	2.4	−	34.0	−
IN2	0.215	6.4	−	0.0	
IN3	0.162	10.3	−	62.5	+
Rows					
V1	0.060	0.39	+	2.49	+
V2	0.077	0.10	+	3.64	−
V3	0.052	0.26	−	0.37	−
V4	0.062	0.24	−	9.02	+
VV0	0.025	43.27	+	2.49	+
VV1	0.050	1.60	+	3.63	−
VV2	0.156	9.42	−	0.37	−
VV3	0.019	0.65	−	9.02	+
PD1	0.027	18.18	+	0.03	−
PD2-PD3	0.054	4.73	−	17.91	+
PD4	0.140	5.28	−	8.03	−
PD5	0.029	15.39	+	0.42	+
RS	0.112	0.27	−	16.48	+
DS	0.138	0.22	+	13.27	−
Variation accounted for by axes		72.2%		25.3%	
Sultan Kudarat ($n = 379$ fields)					
Columns					
IN0	0.568	34.98	+	1.68	−
IN1	0.153	24.49	−	47.60	−
IN2	0.169	40.44	−	19.47	+
IN3	0.110	0.08	+	31.24	+
Rows					
V1	0.053	3.89	+	0.45	+
V2	0.097	0.42	−	2.79	+
V3	0.057	0.48	−	3.36	+
V4	0.042	0.17	−	26.17	+
VV0	0.036	9.63	+	1.26	−
VV1	0.093	2.63	+	1.42	−
VV2	0.072	0.03	+	0.41	−
VV3	0.049	26.34	−	0.04	+
PD1	0.008	3.33	+	0.32	+
PD2	0.038	2.72	+	0.35	+
PD3	0.087	1.14	−	22.89	+
PD4	0.076	11.46	−	24.43	+
PD5	0.040	14.36	+	0.29	+
RS	0.110	13.09	+	8.85	+
DS	0.140	10.31	−	6.98	+
Variation accounted for by axes		61.6%		30.5%	
Central Luzon (epidemic years) ($n = 155$ fields)					
Columns					
IN0	0.483	21.92	+	29.77	+
IN1	0.380	0.00		62.00	−
IN2-IN3	0.137	78.08	−	8.23	+
Rows					
V1	0.229	1.61	+	0.00	
V2-V3-V4	0.021	15.68	−	0.01	−
VV0	0.224	4.32	+	0.74	−
VV1	0.026	34.95	−	5.90	+
PD1	0.074	10.31	+	27.32	+
PD2	0.056	1.99	+	48.15	−
PD3	0.064	19.11	−	0.77	+
PD4	0.031	0.33	−	0.72	−
PD5	0.026	0.41	−	1.62	+
RS	0.135	4.94	−	6.91	−
DS	0.114	6.35	+	7.87	+
Variation accounted for by axes		71.7%		28.3%	

ulation. This profile may or may not differ from those of other classes of tungro incidence (IN1, IN2, or IN3). Similarly, IN0, "absence of tungro," can also be profiled in terms of the proportion of viruliferous vectors (VV0–VV3), planting date (PD1–PD5), or season (RS or DS). Similarly, the profile of V1 in terms of tungro incidence is (following Table 2 in the horizontal direction) 18 (IN0), 1 (IN1), 3 (IN2), and 3 (IN3).

All the variables (IN0, . . ., IN3; V1, . . ., V4; VV0, . . ., VV3; PD1, . . ., PD5; RS and DS) were used in the analyses, and they were used to identify a few new variables (eigenvectors) that account for most of the information represented by the contingency tables. A series of eigenvectors and the corresponding axes were defined, each accounting for a proportion of the total inertia (variation) represented by the contingency table (the inertia of each class is the product of its frequency and the squared distance to the origin of the axes).

Correspondence analysis. Correspondence analysis (2,7,9) is a multivariate method that allows the pictorial representation of contingency tables in order to identify associations between two groups of variables. These two groups are the columns and the rows of Table 2, or the variable to be explained (IN) and the explanatory variables (V, VV, PD, and CS), respectively.

A correspondence analysis was conducted for each area (North Cotabato, $n = 165$ fields; Sultan Kudarat, $n = 379$; Central Luzon [epidemic years], $n = 155$) to characterize tungro disease incidence in the tillering phase of the crop. Before the correspondence analysis pertaining to each area was performed, the series of contingency tables (e.g., Table 2 for Sultan Kudarat) was combined into one single matrix, with tungro incidence categories as columns and vector population, percentage of viruliferous vectors, planting date, and cropping season categories as rows.

Correspondence analysis generates graphs where axes are used to plot categorized variables and examine their relationships. Because the variables used are represented by counts (in this case, numbers of fields), the metric used along the axes and in the graphs is a chi-square distance (2,6,7). The interpretation of the graphs (2,6,9) is based on the interpretation of axes (i.e., the proportion of variation they account for and the classes that contribute most to each of them), the proximity of points representing classes, and the progress along paths representing a succession of classes (e.g., from IN0 to IN3). Similarities in patterns or directions of paths indicate correspondences that can be tested further using the appropriate chi-square tests.

A fourth analysis was conducted on the entire Central Luzon data set ($n =$

530 fields) to characterize epidemic and nonepidemic years. In this analysis, the year was introduced as the columns of the contingency tables, with tungro incidence, vector population size, and proportion of viruliferous vectors as rows.

RESULTS

When data for all development stages were considered, overall disease prevalence was similar in the two Mindanao provinces, with 77.6% of 165 fields affected by tungro in North Cotabato and 84.7% of 379 fields affected in Sultan Kudarat (Table 3). When only the tillering phase records were considered, however, tungro prevalence in the two sites was very different, with 84.6% of 130 fields affected in North Cotabato versus 43.2% of 118 fields in Sultan Kudarat. The two figures for tungro prevalence in North Cotabato, 77.6 and 84.6%, are not significantly different. Because tillering was the earliest development stage considered, tungro therefore appears earlier in the course of crop development in North Cotabato than in Sultan Kudarat. The figures at the tillering stage for North Cotabato and Sultan Kudarat strongly contrast with those for Central Luzon, where 28.1% of fields were affected. In practice, tungro prevalence in Central Luzon ranged from less than 3% (1978) to 49% (1975).

The two axes generated first by the correspondence analyses accounted for a very large proportion of total inertia (97.5, 92.1, and 100% for North Cotabato, Sultan Kudarat, and Central Luzon, respectively) (Table 4). Therefore only these axes, which captured a large proportion of the information represented by the contingency tables, were used to draw the graphs and interpret the results.

The three graphs in Figure 1 share some common features, including the pattern of tungro incidence classes, from no disease (IN0) to increasingly higher incidences (IN1–IN3). The successive classes are linked in the graphs, and the lines showing paths of increasing tungro incidence can be compared to patterns of other variables. The paths of increasing tungro incidence show two phases: disease establishment (IN0–IN1) and disease intensification (IN1–IN2–IN3). In the graphs for North Cotabato and Sultan Kudarat, disease establishment is associated with the first axis (in projection, this axis accounts for most of the movement from IN0 to IN1, in the negative direction). Disease intensification is primarily associated with the second axis (the movement from IN1 to IN2 and from IN2 to IN3 primarily takes place along this axis, in the positive direction). The graph representing Central Luzon (Fig. 1; see also Table 4) shows a combined contribution of both axes to disease appearance and further

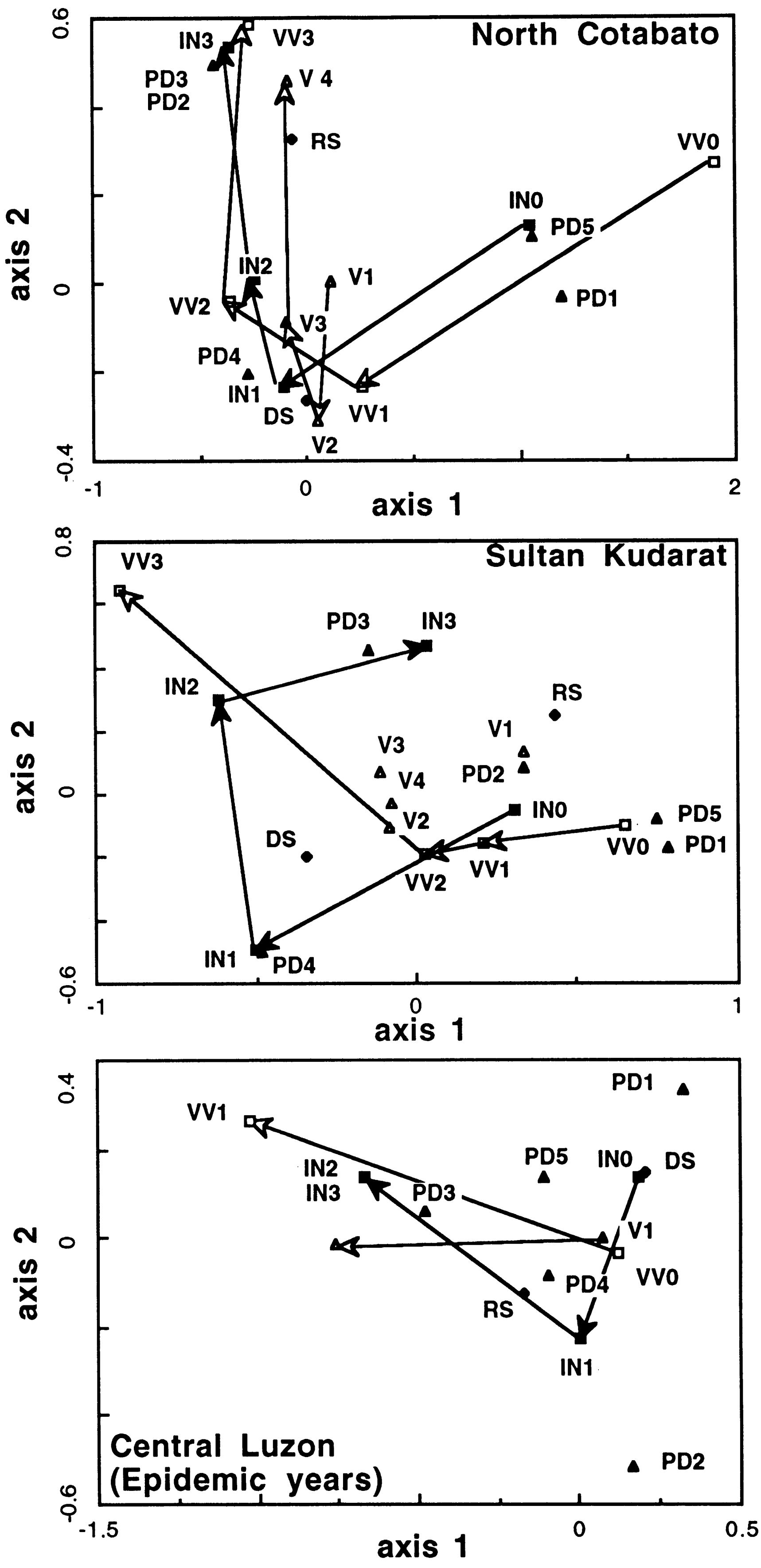

Fig. 1. Correspondence analyses of tungro epidemics in three areas in The Philippines. The first and second axes are the horizontal and vertical ones, respectively. The scales on the axes represent chi-square distances between classes. The categorized variables are tungro incidence in the field, from none to high (IN0–IN3); total vector population size, from small to very large (V1–V4); proportion of viruliferous vectors, from null to large (VV0–VV3); planting date, from very early to very late (PD1–PD5); and cropping season, rainy or dry (RS and DS).

disease development.

In all three areas, off-season plantings (PD1 and PD5 in North Cotabato; PD1, PD2, and PD5 in Sultan Kudarat; PD1 and to some extent PD5 in Central Luzon) are graphically associated with (close to) absence of tungro (IN0), whereas plantings at more intermediate, regular periods (PD2 and PD3 in North Cotabato, PD3 in Sultan Kudarat and Central Luzon) correspond to high tungro incidence (IN3). This association between planting date and tungro incidence is significant at $P < 0.01$ in all three cases ($\chi^2 = 58.7$, 38.8, and 28.4 for North Cotabato, Sultan Kudarat, and Central Luzon, respectively).

Similarly, the successive categories of vector population size (from very small, V1, to very large, V4) and of proportion of viruliferous vectors (from null, VV0, to large, VV3) may be linked together and the resulting paths compared to that of incidence levels. The results indicate differences in the disease-vector-virus relationships in the three areas. In North Cotabato, the path of increasing proportion of viruliferous vectors follows a stepwise pattern, in close correspondence with increasing tungro incidence ($\chi^2 = 62.8$, $P < 0.01$). Absence of viruliferous vectors (VV0) is associated with absence of disease (IN0), and high proportion of viruliferous vectors (VV3) is associated with high disease incidence (IN3). In contrast, disease intensification (from IN1 to IN3)—but not disease appearance—is associated with increasing total vector population ($\chi^2 = 4.16$, $P < 0.05$).

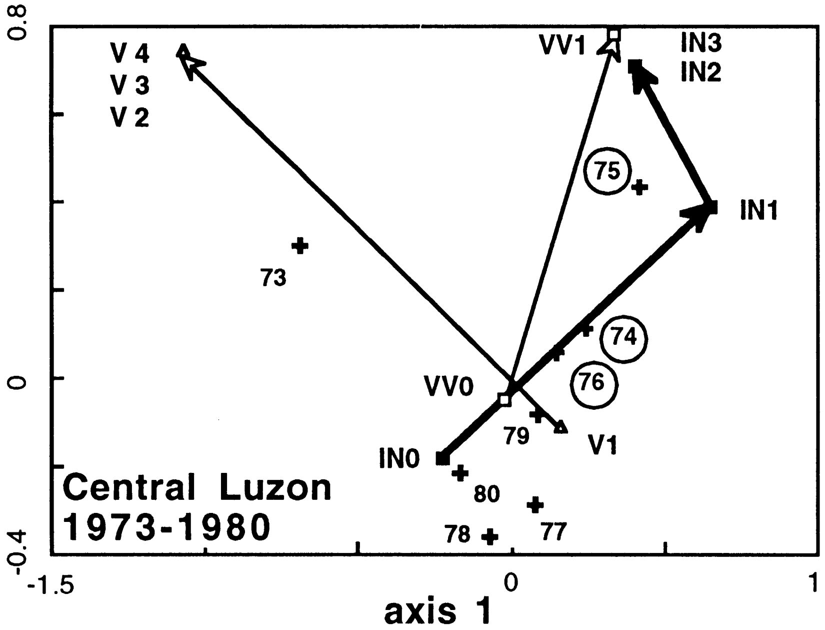

Fig. 2. Correspondence analysis of tungro outbreaks in Central Luzon, 1973–1980. Epidemic years (1974, 1975, and 1976) are circled. The categorized variables are tungro incidence in the field, from none to high (IN0–IN3); total vector population size, from small to very large (V1–V4); and proportion of viruliferous vectors, from null to large (VV0–VV3).

Table 5. Correspondence analysis (relative weights and contributions to axes) and comparison over years in Central Luzon ($n = 418$ fields)

		Contribution to axes			
		Axis 1		Axis 2	
Classes	Relative weight	Contribution	Sign	Contribution	Sign
Columns (years)					
1973	0.144	64.30	−	18.17	+
1974	0.123	7.37	+	2.12	+
1975	0.120	20.45	+	31.55	+
1976	0.130	2.92	+	0.61	+
1977	0.113	0.74	+	13.59	−
1978	0.137	0.56	−	25.99	−
1979	0.135	1.16	+	1.30	−
1980	0.099	2.49	−	6.68	−
Rows					
IN0	0.240	11.62	−	11.44	−
IN1	0.069	27.35	+	14.91	+
IN2–IN3	0.024	3.70	+	17.29	+
V1	0.290	7.10	+	5.02	−
V2–V3	0.020	18.03	−	15.28	+
V4	0.023	29.95	−	18.37	+
VV0	0.314	0.129	−	1.02	−
VV1	0.019	2.108	+	16.67	+
Variation accounted for by axes		58.8%		39.2%	

In Sultan Kudarat, the relationship between tungro incidence and proportion of viruliferous vectors can be seen in two phases ($\chi^2 = 59.6$, $P < 0.01$). In the first phase, a stepwise increase in the proportion of viruliferous vectors from zero to medium (VV2) is associated with disease appearance (IN0–IN1). In the second phase, medium to high disease incidence is associated with a high proportion of viruliferous vectors (VV3). The relationship between tungro incidence and total vector population is represented by an overall trend ($\chi^2 = 3.00$, $P < 0.1$): a very low vector population (V1) corresponds to the absence of disease, whereas disease appearance and further increase are associated with any vector population size from small (V2) to very large (V4).

In Central Luzon (Fig. 1), the changes in virus population size and in the proportion of viruliferous vectors are depicted by the vectors V1-(V2-V3-V4) and VV0-VV1, respectively. The two vectors have similar directions along the first axis, both of them pointing at IN2-IN3. IN0 and IN1 are equally close to V1 and VV0 and equally distant from V2-V3-V4 and VV1. These associations indicate that moderate to high tungro levels are associated with any vector population size larger than V1 and with the presence of viruliferous vectors. Both relations are significant (IN and V: $\chi^2 = 8.1$, $P < 0.05$; IN and VV: $\chi^2 = 20.3$, $P < 0.01$).

The areas also differ with regard to the cropping season. In North Cotabato, disease prevalence (percentage of fields affected) was similar in both seasons (RS and DS are equally distant from IN0), but incidence was frequently higher in the rainy season ($\chi^2 = 12.6$, $P < 0.01$) (RS is close to IN3, and DS is close to IN1). In Sultan Kudarat, tungro prevalence is higher in the dry season; however, tungro incidence is usually higher when epidemics occur in the rainy season than during the dry season ($\chi^2 = 14.2$, $P < 0.01$). In Central Luzon, both prevalence and incidence are higher in the rainy season ($\chi^2 = 8.25$, $P < 0.05$).

The fourth analysis (Fig. 2) represents the Central Luzon data over the period 1973–1980. Two main axes were found, accounting for 58.8 and 39.2% of total variation. The contributions to both axes (Table 5) of the successive classes of tungro incidence, vector population size, and proportion of viruliferous vectors were high, especially for axis 2. On this axis, increases in all three variables are associated. Axis 1 represents contrasting combinations of vector population size and proportion of viruliferous vectors. The graph (Fig. 2) indicates that the direction of the path of increasing level of tungro is associated with increasing vector population and, more strongly, with increases in the proportion of viruliferous vectors (along axis 2). The eight points representing the successive years are indicated on the graph. Three of them (1974, 1975, and 1976) are plotted along the path of increasing tungro level and correspond to the epidemic years.

DISCUSSION

The small set of variables and the procedure used to analyze the data in this review yielded encouraging results and produced simplified epidemiologic characterizations. Only a few variables representing information collected by plant protection services were used. This information was processed in a manner that took into account the way in which it was collected and the aim of the study. Tungro may be considered endemic (in the sense of Vanderplank [19]) in North Cotabato and Sultan Kudarat.

The technique of correspondence analysis allowed us to characterize change in tungro intensity as paths of increasing incidence, with two main phases: disease appearance and disease intensification. In all three areas, tungro appearance was opposed to off-season planting. Tungro appearance in North Cotabato was also associated with the appearance of viruliferous vectors (VV1), regardless of vector population size or cropping season, whereas in Sultan Kudarat, it was associated with an increased proportion of viruliferous vectors up to medium (VV2), any increase in vector population size above V1, and the dry season.

Maximum disease incidence (IN3) was associated in all three areas with plantings during the peak period (PD3). In North Cotabato, disease intensification was associated with increasing vector population and percentage of viruliferous vectors. Disease intensification in Sultan Kudarat appeared primarily and strongly dependent on the occurrence of a high percentage of viruliferous vectors. In Central Luzon, there were no such relations between disease level and vector population characteristics: the appearance of viruliferous vectors and any vector population size larger than V1 was associated with moderate to high tungro levels. Thus, in contrast to the similar effects of planting periods, the three areas differed in the relationships between tungro incidence and the size of the vector population and the proportion of viruliferous vectors.

Two features appear to differentiate the two "hot spot" areas, North Cotabato and Sultan Kudarat. First, the contingency table relating the total vector population and the percentage of viruliferous vectors (*not shown*) shows that at low vector populations (V1), the percentage of viruliferous vectors is higher in North Cotabato than in Sultan Kudarat ($P < 0.05$). This difference could not be related to differences in planting schedules in the two areas. It may account partly for the earlier disease development in North Cotabato. Second, the disease-vector relationships appear to differ. In North Cotabato, any increase in the percentage of viruliferous vectors is linked with a corresponding, stepwise increase in tungro incidence; in Sultan Kudarat, only high percentages of viruliferous vectors are associated with medium to high incidences. In other words, North Cotabato seems more directly responsive to inoculum than Sultan Kudarat. In the third area, Central Luzon, a more obvious relationship is indicated for epidemic years: high tungro levels are observed only when the vector population exceeds V1 and viruliferous vectors are present.

The analysis of Central Luzon data for 1973–1980 provides further information on the occurrence of tungro outbreaks in a nonendemic area. The resulting graph (Fig. 2) can be interpreted as follows: The two variables, size of vector population and proportion of viruliferous vectors, are both favorable to tungro outbreaks; however, the presence of viruliferous vectors is the only factor that should be considered necessary. The three epidemic years, 1974 (prevalence 47%), 1975 (70%), and 1976 (39%), are distributed along the direction of increasing tungro level, which is superimposed on the vector representing viruliferous vector appearance. The nonepidemic year 1973 is associated with an increased vector population but not with the appearance of viruliferous vectors.

The level of tungro incidence depends on many interacting factors (14), including vector population and composition, availability of virus sources, and host plant susceptibility. Some of these components were represented in the analyses, where their relationships were visualized and compared. The rice cultivars grown in North Cotabato and Sultan Kudarat were not found to differ markedly. Another factor that must be considered in studying the establishment of tungro in a given area is the deployment of cultivars over time. In Central Luzon, the successive epidemic years coincided with the disappearance of cultivar IR20 and the spread of cultivars such as IR26 and IR30; the end of these epidemic years was associated with the widespread adoption of cultivar IR36. Because the available data do not provide information on other environmental factors or on their possible effects on vector and virus variation, the direct consequences of such cultivar changes are difficult to assess.

The analyses for North Cotabato and Sultan Kudarat support the assertion of Ling et al (11) that forecasting the absence of or low levels of disease is easier than forecasting severe tungro outbreaks. Conversely, they also indicate that all variables that contribute to tungro epidemics need not be at optimum levels for epidemics to be severe (17). In fact, compensation mechanisms (1) may come into play, as illustrated in the Sultan Kudarat analysis, where moderate vector population size was compensated for by a high proportion of viruliferous vectors to result in severe epidemics.

Although North Cotabato and Sultan Kudarat may be considered similar in many respects, relatively minor environmental differences may explain the differing patterns of relationships among epidemiologic components. For example, differences in the availability of alternative hosts (14) might account for differences in initial inoculum. Differences in vector ecotypes (4,5), species diversity of secondary hosts (10), weather conditions, and environment-cultivar interactions may contribute to the difference between the two areas in the dose-response relation (proportion of viruliferous vectors to tungro incidence).

The occurrence of tungro outbreaks in Central Luzon seems essentially determined by the appearance of viruliferous vectors. In this area, disease intensification at field level in epidemic years appears to be governed by the existence of viruliferous vectors in a population large enough to ensure spread. Figure 2 indicates that the threshold size of the vector population is small. These analyses therefore suggest that any factor that keeps the proportion of viruliferous vectors below the minimum level will prevent the disease from becoming endemic. Conversely, the data also imply that tungro in the nonendemic area in Central Luzon is much more responsive to inoculum, when present, than in the endemic areas.

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