Plant damage and yield response to *Diatraea saccharalis*[*1] / and *Spodoptera frugiperda*[2] / in selection cycles of two tropical maize populations in Mexico[3] /

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Resumen

La importancia relativa de Diatraea saccharalis *(F) y* Spodoptera frugiperda *(J. E. Smith), el uso de la medida de sus daños en programas de mejoramiento vegetal y cambios en resistencia al ataque en relación al ciclo de plantas seleccionadas por rendimiento potencial fueron evaluados con dos poblaciones de maíz tropical (*Zea mays *L.) en dos ambientes de México.*

S. frugiperda *afectó significativamente el establecimiento de plantas y el daño a las hojas pero estos indicadores no correlacionaron significativamente con rendimiento. La selección por resistencia a esta plaga debería basarse en la reducción en rendimiento hasta que se encuentren otros estimadores de ataque más correlacionados con ese rendimiento.*

D. saccharalis *afectó significativamente el porcentaje de mazorcas podridas, mazorcas con túneles, mazorcas por plantas, ataque a las hojas, largo del túnel por planta, internudos con túneles por planta, salidas de túneles visibles por planta e internudos con salidas de túneles. Todos estos indicadores estuvieron, a su vez, correlacionados con el rendimiento en granos. Se sugiere usar como medida de resistencia a esta peste el porcentaje de mazorcas podridas, daño a las hojas, mazorcas por plantas e internudos con salidas de túneles.*

Introduction

Two important maize pests of the subtropical and tropical Americas are *Diatraea saccharalis* (F.), the sugarcane borer (SCB), and *Spodoptera frugiperda* (J. E. Smith), the fall armyworm (FAW) (9). Damage to maize in the U.S.A. by the sugarcane borer included leaf feeding, deadherat, lodging, broken shanks, and ear damage which permitted the entrance of weevils (1). Yield loss in Lousiana was attributed to increased barrenness, reduced ear size, reduced grain size, and interference with mechanical harvesting (5). Damage to maize by the FAW in Kansas included defoliation, killing of young plants, stalk and shank gouging and burrowing, and ear feeding (3). Tassel and silk feeding was reported in Florida (8). These authors could not demonstrate consistent yield loss to the FAW, but yield response to insecticides applied against this pest in Mexico was generally 1 to 2 tons of grain/ha (12, 2).

This study investigates: 1) The relative importance of these insects to yield of tropical maize; 2) How to measure damage and how to use damage measurements in breeding for plant resistance; 3) Changes in tolerance or resistance during selection for potential yield (reduced plant height and earlier maturity) in 2 populations of tropical maize.

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1 Lepidoptera: Pyralidae

2 Lepidoptera: Noctuidae

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Materials and Methods

Trials were planted at 2 stations of the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. Tlaltizapán, Morelos (experiments conducted from 5 May, 1976 to September, 1976) is subtropical at an altitude of 949 m. Poza Rica, Veracruz (experiments conducted from 24 May, 1 976 to 13 September, 1 976) is tropical at an altitude of 60 m. Natural FAW populations were moderate on young plants in Tlaltizapán and heavy until flowering in Poza Rica. Natural SCB populations were very low in Tlaltizapán and high in Poza Rica.

The plant materials used were Tuxpeño–1, a late-maturing tropical white dent and Mezcla Amarilla, an intermediate-maturing tropical yellow flint. Both are CIMMYT open-pollinated varieties. Selection cycles 0, 4, 8 and 12 of Tuxpeño–1 (Tx C_0, etc.) and 1, 2, 4, 6 and 8 of Mezcla Amarilla (MA C_1, etc.) were used. A 10th material, IDRN, was formed by random-mating 41 S_1 families of CIMMYT's Insect and Disease Resistance Nursery that were judged to be the best in agronomic appearance and resistance to the SCB in 1 975 at Tlaltizapán.

Plots were three five-meter rows arranged in a randomized complete block design with 4 replications. The center row was used for observations. Distance between rows was 75 cm. Plant spacing varied with selection cycles. Plant populations varied from 40 000 to 65 000 plants/ha.

Protection against FAW, SCB, and *Diabrotica* spp. natural infestations included carbofuran 3G (1 kg AI/ha) applied with the seed. Postemergence treatments varied with the artificial infestation schedule and location and consisted of foliar sprays of carbaryl 80WP (2.4 kg AI/ha) and methyl parathion 47EC (0.5 kg AI) in 400 l H_2O/ha until early whorl stage after which trichlorfon 2.5G (0.5 kg AI/ha) was used. In Poza Rica seeds were treated with chloroneb 65WP (5 g AI kg/seed) and Maneb zinc 80WP (0.8 kg AI/400 l H_2O/ha) was applied 8 times before flowering to attempt to control sorghum downy mildew, *Sclerospora sorgi* (Kulk.) and leaf blights, especially tarspot, *Phyllachora maidis* Maubl.

Controlled infestation methods described by CIMMYT (4) were used. Treatments were: 1) Insecticide check, 2) Controlled infestation with SCB during the mid-whorl and mid-silk stages, and 3) Controlled infestation with FAW during the 4 to 5 leaf stage. Mid-whorl SCB infestation levels were 130 and 65 newly-hatched larvae/plant in Tlaltizapán and Poza Rica, respectively. The mid-silk level was about 130 newly-hatched larvae/plant. In Tlaltizapán the FAW treatment plots received 2 applications of 50 newly-hatched larvae/plant, while in Poza Rica 1 application of 15 newly-hatched larvae/plant, supplemented with 15 more if the first infestation failed.

Data were collected on yield (kg/ha at 0% moisture), plant stand (plants harvested as % ideal number of plants), lodging, ears per plant, percent rotted ears, rot per ear, percent tunneled ears, leaf feeding, tunnel length per plant, tunneled internodes per plant, borer holes per plant and borer hole-bearing internodes per plant.

Results and Discussion

1. Yield Effects

Yield reductions due to FAW (Table 1) were significant when averaged over cycles of selection, but there were few significant reductions for individual cycles. This probably is a statistical effect indicating a need for more repetitions or larger plot sizes to measure effects of FAW on yield. Coefficients of variation in the 4 experiments varied from 13.1 to 22.7. Morril and Greene (8) also could not demonstrate consistent yield loss to FAW in Florida.

There was no difference in yield between MA and Tx or among cycles within a population in response to FAW.

Environment had little effect on response to FAW as mean yield reduction in Poza Rica was 13.6% and 12.8% in Tlaltizapán.

Yield response to SCB (Table 2) was more variable than with FAW. Mezcla Amarilla was less affected than either Tx or IDRN. Reductions were similar to those reported by Floyd **et al.** (5), 4.6% to 43.4%, for SCB in Louisiana. There was no obvious yield related pattern for loss or gain in resistance in either population, nor was IDRN (selected for SCB resistance) superior to the unselected populations.

Mean yield loss from SCB in Poza Rica was 20.8% and 6.8% in Tlaltizapán, indicating an environment effect. This could be due in part to greater stalk and ear rot intensity in Poza Rica. Sugarcane borer interacts with ear rots (Table 4) and stalk rots (10).

The relative importance of the 2 insects varied with selection cycle and environment. FAW caused loss more consistently over sites, but, where stalk and ear rot pressures were high, SCB appeared to have more damage potential.

2. Fall Armyworm Damage Estimates

FAW damage estimates were significantly different from the check (Table 3) but were not significantly correlated with grain yield. Foliar damage by FAW

Table 1. Yield response to the fall armyworm in selection cycles of Mezcla Amarilla and Tuxpeño–1. Mexico, 1 976.

Cycle	Location[1]	Check Yield (kg/ha)	FAW Yield (kg/ha)	Reduction (%)
MA C_1	PR	4 186	3 383	–19.2
	TL	4 365	4 122	– 5 6
MA C_2	PR	4 238	3 822	– 9.8
	TL	4 415	4 062	– 8.0
MA C_4	PR	4 409	4 628	+ 5.0
	TL	4 359	4 130	– 5.2
MA C_6	PR	4 388	3 745	–14 6
	TL	3 998	3 378	–15.5
MA C_8	PR	4 700	3 722	–20.8*
	TL	4 660	3 940	–15.4
MA	PR	4 384	3 860	–12.0*
Mean	TL	4 359	3 857	–11.5*
Tx C_0	PR	4 356	3 630	–16.7
	TL	3 839	2 729	–28.9
Tx C_4	PR	4 954	4 500	– 9 2
	TL	4 046	3 499	–13.5
Tx C_8	PR	5 260	4 163	–20.8*
	TL	4 431	3 430	–22.6
Tx C_{12}	PR	4 953	4 204	–15 1
	TL	4 977	4 287	–13 9
Tx	PR	4 881	4 124	–15.5*
	TL	4 163	3 486	–16.3*
IDRN	PR	3 908	3 340	–14 5
	TL	3 522	3 539	+ 0 5

1 PR = Poza Rica, TL = Tlaltizapán.
* Reduction significant at the 5% level.

to Tuxpeño–1 and other tropical maizes on small farms in Veracruz State, Mexico, had little effect on yield, but loss of plant stand to FAW was important*/.

3. Sugarcane Borer Damage Estimates

Damage estimates significantly affected by SCB (Table 4) were highly significantly correlated with grain yield in Poza Rica but rarely so in Tlaltizapán. Correlation coefficients were generally greater in Tuxpeño–1 than in Mezcla Amarilla.

* Galt, D.L. Economic weights for breeding selection indices: Empirical determinations of the importance of various pests affecting tropical maize. Ph.D. Thesis, Cornell University, 1 977. 407 pp.

Part of the yield loss to SCB in Louisiana was due to reduced number of ears per plant (5), a parameter also affected in these studies. The number of rotted ears was also affected, but rot per ear was not affected. This indicates that SCB provides an infection court for ear rots but is not involved in their spread within the ear. The surgarcane borer was involved in the spread of stalk rots (10).

The 4 measurers of stalk damage were well correlated with grain yield in Poza Rica. They were also well correlated among themselves, with holebearing internodes being the most rapid measure (11). Lodging, often associated with stalk borers (7), was not affected by SCB.

Table 2. Yield response to the sugarcane borer in selection cycles of Mezcla Amarilla and Tuxpeño–1. Mexico, 1 976.

Cycle	Location[1]	Check Yield (kg/ha)	SCB Yield (kg/ha)	Reduction (%)
MA C_1	PR	4 186	3 792	– 9.4
	TL	4 365	5 305	+21.5
MA C_2	PR	4 238	3 939	– 7.0
	TL	4 415	4 249	– 3.8
MA C_4	4PR	4 409	3 821	–13 3
	TL	4 359	4 226	– 3.0
MA C_6	PR	4 388	3 407	–22.4*
	TL	3 998	4 469	+11.8
MA C_8	PR	4 700	3 972	–15.5
	TL	4 660	3 566	–23.5
MA	PR	4 384	3 786	–13 6*
Mean	TL	4 359	4 363	+ 0.1
Tx C_O	PR	4 356	2 862	–34.3*
	TL	3 839	2 641	–31 2
Tx C_4	PR	4 954	4 839	– 2.3
	TL	4 046	3 843	– 5.0
Tx C_8	PR	5 260	2 836	–46.1*
	TL	4 431	3 815	–13.9
Tx C_{12}	PR	4 953	3 532	–28.7*
	TL	4 977	4 577	– 8.0
Tx	PR	4 881	3 517	–27.9*
Mean	TL	4 323	3 719	–14.0*
IDRN	PR	3 908	2 781	–28.8*
	TL	3 522	3 075	–12.7

1 PR = Poza Rica, TL = Tlaltizapán.
* Reduction significant at the 5% level

4. Changes Through Cycles of Selection

There was a trend for less damage by FAW through the cycles in both MA and Tx (Table 5). This was not reflected in the pattern of yield reduction. Such a trend emphasizes the need to include yield loss as a criterion for FAW resistance until damage estimates better correlated with yield are developed. No trend was discernible for SCB (Table 6) although the apparent superiority of Tx C_4 should be reevaluated.

Although selected for SCB resistance, IDRN performed no better than the unselected populations. It did appear promising for FAW resistance. This population displayed marked early plant vigor and at both sites, was the only material without stand loss due to FAW. Vigor could be due to heterosis gained from combining S_1 lines.

Conclusions

The relative importance of the 2 insects to grain yield varied with plant material and environment. Mean loss over sites and plant materials was 13.2% for FAW and 13.8% for SCB. Maximum losses were 28.9% and 46.1% for FAW and SCB respectively. Losses to FAW were similar in both environments, while losses to SCB in Poza Rica, where ear and stalk rot intensity was high, were twice those observed in Tlaltizapán.

Plant stand and leaf feeding ratings were the damage parameters significantly affected by FAW,

Table 3. Correlation coefficients of grain yield with damage estimates significantly affected (P = 0.05) by fall armyworm. Mexico, 1 976.

Variable	Variety	Location[1]	Check[2] Mean	FAW[2] Mean	Correlation Coefficient
Plant Stand (%)	MA	PR	97	89	0.1482
		TL	99	97	0 1349
	Tx	PR	98	89	0 0675
		TL	99	96	0 1093
Leaf Feeding[3] (PR = 4 days, TL = 8 days)	MA	PR	1.1	3 5	–0 1837
		TL	1.6	5 4	–0 1572
	Tx	PR	1 0	3 9	–0 0875
		TL	1 3	5 9	–0 0921
Leaf Feeding (PR = 8 days, TL = 15 days)	MA	PR	1 0	6 4	–0 1561
		TL	1 1	6 5	–0 1711
	Tx	PR	1 0	6 8	–0.0607
		TL	1 1	6 8	–0 1672
Leaf Feeding (PR = 19 days, TL = 22 days)	MA	PR	1 2	4 6	–0.0686
		TL	1 4	2 6	–0 0945
	Tx	PR	1 5	4 5	–0.0554
		TL	1 6	2 7	–0 2078

1 PR = Poza Rica, TL = Tlaltizapán.

2 Averaged over cycles of selection.

3 1–10 scale, 1 = no damage, 10 = dead plant, modified from Wiseman *et al.* (13).

but these were not significantly correlated with yield. Until estimates better correlated with yield are devised, selections for resistance should be based on least yield reduction.

Percentage of rotted ears, ears tunneled, ears per plant, leaf feeding, tunnel length per plant, tunneled internodes per plant, exit holes per plant and hole-bearing internodes were significantly affected by SCB and, at least in Poza Rica, significantly correlated with grain yield. Under conditions of artificial infestation and in environments where the SCB is important to yield, percent rotted ears, leaf feeding, ears per plant and hole-bearing internodes are recommended as criteria for breeding for resistance to SCB.

Summary

The relative importance of *Diatraea saccharalis* (F) and *Spodoptera frugiperda* (J. E. Smith), how to use damage measurements in a plant breeding program, and changes in resistance relative to plant cycles selected for potential yield were evaluated with two tropical maize populations in two environments in Mexico.

Plant stand and leaf feeding were significantly affected by *S. frugiperda,* but these were not significantly correlated to yield. Yield reduction should be used to select for resistance until estimates more correlated with yield can be found

Percentage of rotted ears, ears tunneled, ears per plant, leaf feeding, tunnel length per plant, tunneled internodes per plant, exit holes per plant and hole-bearing internodes were significantly affected by *D. saccharalis* and were correlated with grain yield. Percent rotted ears, leaf feeding, ears per plant, and hole bearing internodes are suggested for measuring resistance to this pest.

Table 4. Correlation coefficient of grain yield with damage estimates significantly affected (P = 0.05) by sugarcane borer. Mexico, 1 976.

Variable	Variety	Location[1]	Check[2] Mean	SCB[2] Mean	Correlation Coefficient
Leaf Feeding[3] (1 week)	MA	PR	1.6	3 8	−0.3563**
		TL	1.4	3.9	−0.0945
	Tx	PR	1.8	3 8	−0.5270**
		TL	1.6	3.9	−0.2078
Leaf Feeding (2 weeks)	MA	PR	1.2	4.6	−0.3482**
		TL	1.0	1.4	−0.3969**
	Tx	PR	1.1	5.0	−0.5667**
		TL	1.0	1.8	−0 3096**
Ears per Plant	MA	PR	0.994	0.923	0.4484**
		TL	1.002	0 973(a)	0.4618**
	Tx	PR	0.929	0 830	0.5149**
		TL	0.976	0.849	0.2787*
Rotted Ears (%)	MA	PR	27-25	56	−0.5520**
		TL	13	30	−0.2260
	Tx	PR	33	60	−0.6108**
		TL	16	33	−0.1094
Tunneled Ears (%)	MA	PR	46	82	−0.4750**
		TL	9	53	−0.0048
	Tx	PR	50	85	−0.4892**
		TL	2	37	−0.1335
Tunnel Length per Plant (cm)	MA	PR	18.8	28.7	−0.5211**
		TL	8.1	30.3	0.0215
	Tx	PR	21.9	34 0	−0.6202**
		TL	1.1	35.8	−0.2562*
Tunneled Internodes	MA	PR	2.3	3.8	−0 5252**
		TL	1.1	3.9	−0.0261
	Tx	PR	2.8	4.6	−0.5936**
		TL	1 0	4.1	−0.2437
Borer Holes per Plant	MA	PR	2.0	4.8	−0.3630**
		TL	0.8	5.0	−0.0564
	Tx	PR	2.3	5.9	−0.6313**
		TL	0.4	5.2	−0.2012
Hole-Bearing Internodes	MA	PR	1 5	3.1	−0 4126**
		TL	0.5	3.1	−0.0463
	Tx	PR	1.8	3.7	−0 6393**
		TL	0.3	3.2	−0.1963

1 PR = Poza Rica, TL = Tlaltizapán.

2 Averaged over cycles of selection.

3 1-9 scale of Guthrie *et al* (6) (a) Not significantly different

* Significant, P = 0.05.

** Significant, P = 0.01.

Table 5. Over-all damage estimates of fall armyworm to selection cycles of Mezcla Amarilla and Tuxpeño–1, Mexico, 1 976.

Mezcla Amarilla			Tuxpeño–1		
Cycle	Damage[1] Estimate	Yield[2] Rank	Cycle	Damage[1] Estimate	Yield[2] Rank
IDRN	–0.5568	2	IDRN	0 0790	1
8	–1.1458	6	12	–0 5046	3
6	–1.3160	5	8	–0.6515	4
4	–1.4237	1	0	–0.8651	5
1	–1.5138	4	4	–1.0040	2
2	–1.6298	3			

1 Correlation from Table 1 were weighted for performance relative to other cycles and then combined to give overall damage estimates

2 Relative yield loss to FAW, 1 = least affected.

Table 6. Over-all damage estimates of sugarcane borer to selection cycles of Mezcla Amarilla and Tuxpeño–1, Mexico, 1 976.

Mezcla Amarilla			Tuxpeño–1		
Cycle	Damage[1] Estimate	Yield[2] Rank	Cycle	Damage[1] Estimate	Yield[2] Rank
1	–5.2729	1	4	–4 9970	1
4	–5 7238	4	IDRN	–7.3595	3
8	–6.2835	5	12	–7.4989	2
2	–6.4113	3	0	–10.5776	5
6	–7.6587	2	8	–11.4333	4
IDRN	–11 1802	6			

1 Correlations from Table 2 were weighted for performance relative to other cycles and then combined to give over-all damage estimates.

2 Relative yield loss to SCB 1 = least affected.

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