Moisture Stress in the Screening of Maize Cultivars for Stalk Rot Resistance and Yield

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ABSTRACT

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A technique is described to screen cultivars under field conditions for stalk rot resistance and yield under a continuous range of rooting depths. The technique was tested from 1981 to 1983 using six hybrids. During the 1981–1982 season, stalk rot increased from 12.8 to 46.3% with decreasing rooting depth, while yield decreased by 23.4%. During the 1982–1983 season, rainfall was much lower from 1 wk before tasseling to harvest than during 1981–1982, and yield decreased by 97.7% with decreasing root depth, while stalk rot decreased from 40.8 to 17.9%. It was concluded that soil moisture stress increased stalk rot during 1981–1982, and that pretassel moisture stress during 1982–1983 reduced stalk rot during the latter season by reducing the photosynthetic sink, because plants subjected to the highest moisture stress did not produce grain. The technique permits the screening of hybrids for resistance to stress, taking both stalk rot and yield into account, and may have wider applicability.

To explain the host-pathogen-environment interaction of the stalk rot complex in maize, Dodd (4,5) introduced the photosynthetic stress-translocation balance (PS-TB) concept. According to this concept, a maize stalk becomes vulnerable to rot when photosynthesis is insufficient for both grain fill and the maintenance of a healthy root-stalk system. Consequently, stress factors such as leaf damage, shading, drought, mineral deficiencies, etc., that reduce photosynthesis will predispose the plant to stalk rot. It is, therefore, important that, in breeding programs, genotypes be stressed so that under variable environmental conditions selections may be made for stalk rot resistance and high yield. Further, in the production of adapted stalk rot resistant hybrids, cognizance needs to be taken of the prevailing environmental stresses in the locality for which these hybrids are destined. In South Africa, moisture stress resulting from drought is one of the major limitations to maize production and one of the most difficult factors with which to cope (3). Much research has been done worldwide on moisture stress effects. Recent reviews deal with the effect of moisture stress on maize development and yield (12), moisture stress as a predisposing factor in plant disease (11), and breeding strategies for stress and disease resistance (1). However, information about the effect of moisture stress on stalk rot of maize is limited (2,6,10), and as far as the authors could ascertain, no literature is available about the moisture-yield-stalk rot interaction.

Moisture stress experiments have usually been performed by means of plants in containers, or by withdrawal of irrigation water, or by erection of rain shelters in the field (11). Such studies have generally been characterized by constraints imposed by container culture, controlled environment conditions, and few levels of moisture availability.

In this paper, we describe a technique for screening maize cultivars in the field for yield and resistance to stalk rot under a continuous range of soil moisture conditions.

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MATERIALS AND METHODS

The technique employed in this study is similar to that described by Van der Wal (13). At Cedara, near Pietermaritzburg, at a site where no maize had been grown before, a wedge of soil of the dimensions indicated in Figure 1 was removed by grading. Topsoil was kept separate from subsoil. A heavy gauge polythene sheet was introduced to line the slope and vertical faces at the shallow end and the two sides, but not the vertical face at the deep end. A drain was laid at the deep end (Fig. 1) to remove excess drainage water. The graded subsoil and topsoil were carefully reintroduced and levelled.

Experimentation with the lysimeter was carried out during two seasons (1981–1982 and 1982–1983). Each season, a total of 120 kg N, 60 kg P, and 170 kg K per ha was applied. Permethrin was applied at 100 ml (400 g/L a.i.)/ha at planting to control cutworm. Weed control was achieved by applying metolachlor (0.375 kg a.i./ha) and terbuthylazine (1.1 kg a.i./ha) at planting. At the first sign of stalk borer damage, monocrotophos at 0.75 L (400 g/L a.i.)/ha was applied. Rows of six hybrids of maize, PNR585, PNR473, PNR353, HL1, TX24, and SR52, were planted in a randomized block design with four reps (blocks) parallel to the length of the field. The length of the lysimeter was divided into four sections of equal size to compare the effects of soil depth on plant performance. During experimentation in the first season (1981–1982), a considerable plant response was obtained within section 1 and, for greater resolution of effects, this section was subdivided into 1a and 1b (Fig. 1). The calculated average soil depth for each section was: 0.25 m (section 1a), 0.38 m (section 1b), 0.68 m (section 2), 1.05 m (section 3), and 1.38 m (section 4). In 1983, the length of the lysimeter was divided into five sections of equal size (Fig. 1) with the following calculated soil depths: 0.34 m (section 1), 0.57 m (section 2), 0.83 m (section 3), 1.10 m (section 4), and 1.38 m (section 5). The population density throughout the study was 44,000 plants/ha, which is representative for this area, in 0.75-m rows. To compare plants in the lysimeter with those in undisturbed soil, row planting was extended 4.5 m beyond the end of the lysimeter, thus creating section 5 (1981–1982) or 6 (1982–1983). Around the periphery of the test site, 4.5-m borders of one hybrid were grown.

Rainfall was recorded daily during the growing season. To relate disease incidence to the stage of plant development of each hybrid, the percentage of plants shedding pollen was determined on three different dates, and the time at which 50% of the plants of a hybrid had shed their pollen was calculated. Stalk rot incidence was assessed on the basis of stalk softness by counting the number of plants that lodged after applying the squeezing technique described by Koehler (6). The degree of stalk softness of each hybrid at a particular soil depth was compared for significant difference with that of the other five, with six hybrids permitting 15 such paired comparisons.

After drying off in the field, plants

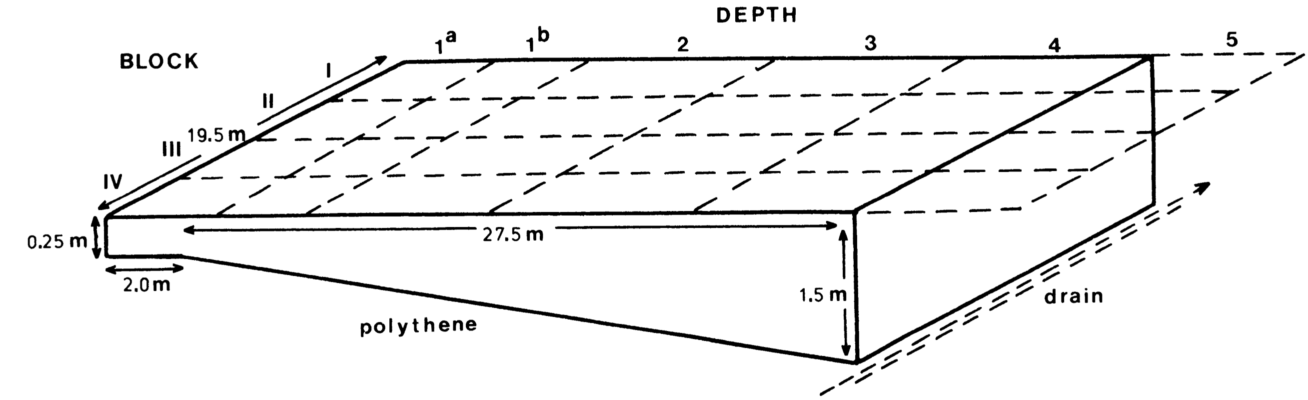

Fig. 1. Diagrammatic view of lysimeter used in the 1981–1982 season to evaluate hybrids for their response to stalk rot across a continuum of moisture stress.

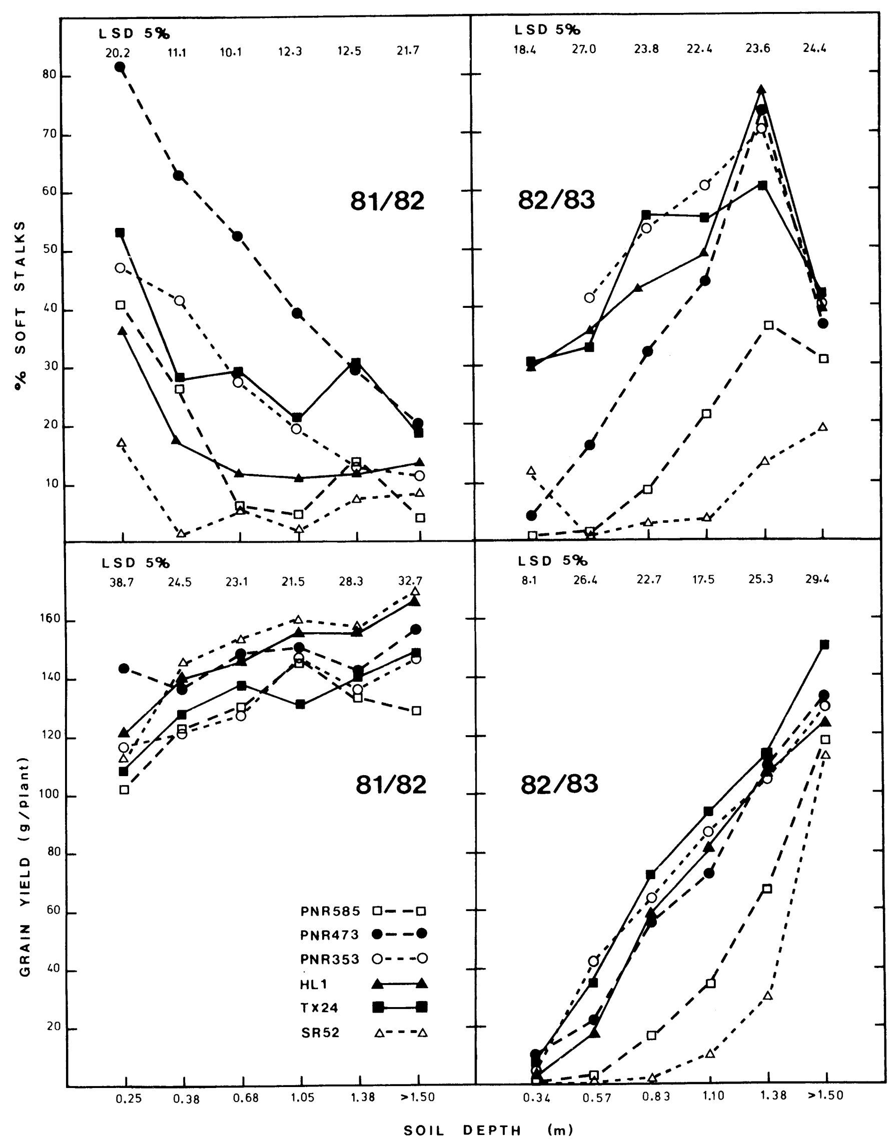

Fig. 2. Percentage stalk softness and grain yield for calculated average soil depth per section of lysimeter in the 1981–1982 and 1982–1983 seasons.

were counted and ears were weighed per section for each row, and the grain moisture percentage was assessed. From this, the kernel dry weight per plant was calculated.

RESULTS

During the 1981–1982 and 1982–1983 seasons, the total rainfall from planting to 1 wk before pollination was approximately the same (184.0 and 185.5 mm, respectively). From 1 wk before pollination to 1 wk after, rainfall was much lower during 1982–1983 (13.6 mm) than in the previous season (51.0 mm). This trend persisted during the period from 1 to 8 wk after pollination, viz. 200.0 mm during 1981–1982 and 124.9 mm during 1982–1983. During both seasons, drought stress symptoms were observed before pollination at the shallow end of the lysimeter; plants were smaller and often looked wilted. Plant development also was delayed in shallow soil. Compared with plants in deeper sections of the lysimeter, pollination occurred 5 days later at a depth of 0.25 m during 1981–1982 and 3 days later at a depth of 0.34 m during 1982–1983.

The differences in development among hybrids were marked also. During 1981–1982, pollination of the earliest pollinating hybrid (TX24) and the last PNR353) was 7 days apart; during 1982–1983 the difference was 4 days. However, the disease assessment was done at the same time for all soil depths and all hybrids because it was not feasible to take differences in developmental stages into account.

During 1981–1982, stalk softness (Fig. 2) decreased with increasing soil depth from 46.3 to 12.8%, averaged for all hybrids. The number of pairs significantly different from shallow to deep soil was: 7, 12, 10, 9, 3, 0. Thus, at the shallow end, differences in stalk softness between hybrids were more marked than at the deep end. An exception was the most shallow depth (0.25 m), where the LSD at the 5% level was 20.2, and much higher than that at the other depths. The pattern of stalk softness during 1982–1983 (Fig. 2) was the reverse of that during 1981–1982. During 1982–1983, stalk softness increased with increasing soil depth up to 1.38 m, from 17.9 to 49.9%, and then decreased in the deepest section (outside the lysimeter) to 40.8%. The number of pairs significantly different at the 5% level, from shallow to deep soil, was 10, 6, 7, 8, 9, 0.

During 1981–1982, the average oven-dry grain weight per plant was 117.5 g at the soil depth of 0.25 m, and this increased to an average of 153.3 g for soil outside the lysimeter. During 1982–1983, grain weight per plant increased considerably with soil depth, from 3.0 g (at 0.34 m) to 128.3 g (at >1.50 m) (Fig. 2). During 1982–1983, barren plants decreased from 88% (at 0.34 m) to 5.6% in soil outside the lysimeter. During 1981–1982, these figures were 5.5% (at 0.25 m) and 1.8% (at >1.50 m).

Total correlation coefficients between stalk softness (S), soil depth (D), and grain yield (Y) are presented in Table 1. Of the variables measured, soil depth explained most of the variation in stalk softness during 1981–1982: $S = 58.4 - 72.2\,D + 29.3\,D^2$ ($R^2 = 0.30$) ($P < 0.01$).

During 1982–1983, the best estimation of stalk softness was observed with grain yield as a variable: $S = 5.5 + 1.0\,Y - 52.0\,Y^2$ ($R^2 = 0.57$) ($P < 0.01$).

DISCUSSION

During the two seasons of investigation, plants at the shallow end of the lysimeter were more stressed than those at the deep end. This was evident from the wilting symptoms that were already observed early in the season, from stunted growth, and from a delay in development. Because plants were evenly distributed over the field, and the same depth of topsoil was available to each, effects from nutrient stress and shading can be largely excluded, and moisture stress may, consequently, be regarded as the factor mainly responsible for observed effects.

During the 1981–1982 season, the lysimeter imposed moisture stress successfully and distinguished between hybrids on a basis of their stalk rot resistance. From a soil depth of over 1.50 m to an average depth of 0.38 m, the number of hybrid pairs with significant stalk softness differences increased from 0 to 12. The number of paired comparisons, in which one hybrid had significantly more stalk softness than the other, provides an indication of both the stalk rot-inducing potential of a particular soil depth, and the efficacy of lysimeter methodology in differentiating between relative stalk rot susceptibilities of maize hybrids.

The highly significant negative correlation coefficient between soil depth and stalk softness, and the highly significant regression of soil depth on stalk softness, reflect the importance of soil moisture in stalk rot expression. Koehler (6) and Christensen and Wilcoxson (2) summarized literature about moisture effects on stalk rot and concluded that, generally, suboptimal soil moisture conditions make maize more vulnerable. Furthermore, dry weather early in the season, combined with high rainfall later on, appeared to be most favorable for stalk rot development. Schneider and Pendery (10) reported a stalk rot incidence of 60.3, 25.3, and 7.7% with a mild plant-water stress during pretassel, postpollination, and grain-filling, respectively, whereas nonstressed (irrigated) plants had 24.7% disease. Their stress treatments were so mild that no symptoms of wilting were visible. However, studies that involve the modification of rainfall/irrigation regimes to some degree confound the effects of soil moisture and atmospheric moisture on the physiologic processes of plant and pathogen. In our study, different levels of soil moisture associated with uniform atmospheric moisture conditions for all plants were obtained, and it was possible to assess the effect of soil moisture on stalk rot. The high LSD in stalk softness at the shallow end of the lysimeter is probably due to severe moisture stress causing irregular plant development and a resultant high variation in the progress of stalk rot development. Irregular plant development under moisture stress has long been recognized (12).

Although differences between hybrids during the 1982–1983 season were not as clear as during 1981–1982, there were still remarkable differences in the amount of stalk rot between different soil depths. During the 1982–1983 season, rainfall immediately before and after pollination was lower than that during the previous season, and moisture stress drastically decreased ear formation and grain yield. The effect of moisture stress on grain yield has been studied by a number of researchers. The most critical stage has been found to be around tasseling and silking, because the number of ovules that will be fertilized is then determined. On the average, it has been found that, during this time, one stress day causes a yield reduction of 7% (12). In our study, stress days are assumed to have occurred sooner and more often at the shallow end than at the deep end of the lysimeter. Stress occurred throughout the field only after times of very low rainfall. Our data show a reduction in grain weight of 23.4% in shallow soil compared with deep soil during 1981–1982, whereas during 1982–1983 the reduction was 97.7%, mainly as a result of the high number of barren plants in shallow soil. This, no doubt, was a direct consequence of the very low rainfall shortly before and during pollination. Consequently, stalk rot was primarily affected by yield during 1982–1983, and the correlation coefficient between grain yield and stalk softness was higher than between soil depth and stalk softness. The best estimate of stalk softness was achieved with grain yield as a variable. This effect of yield on stalk rot has been observed by other authors (7–9) and is an essential element of the PS-TB concept (4,5).

Taking the 1981–1982 and 1982–1983 data together, it is clear that as long as moisture stress does not impair seed set, it enhances stalk rot. When moisture stress becomes more severe, or is experienced at a critical stage during plant development, yield potential is decreased and less or no carbohydrate is required for grain filling. Under such conditions, moisture stress may indirectly reduce stalk rot incidence. These findings provide clear support for Dodd's theory that the PS-TB plays an important role in the development of stalk rot.

Table 1. Total correlation coefficients between stalk softness, depth, and grain yield during the 1981–1982 and 1982–1983 seasons

Variable[a]	1981–1982	1982–1983
D-S	−0.53**[b]	0.45**
D-Y	0.53**	0.86**
Y-S	−0.41*	0.65**

[a] S = stalk softness, D = depth, Y = grain yield.
[b] * = Significant at 5% level, ** = significant at 1% level.

Whereas more studies of moisture effects at different stages during plant development are required to elucidate the effect of moisture on stalk rot further, with the aid of the present data it is possible to point out some drought characteristics of the hybrids used. PNR585 and SR52 were most resistant to moisture-stress induced stalk rot, but yielded very poorly under these conditions. Of the hybrids that yielded relatively well under conditions of moisture stress, PNR473 appeared most sensitive to stress-induced stalk rot. HL1, TX24, and PNR585 were moderately sensitive to moisture stress in terms of both stalk rot and yield.

In many countries, maize varieties are tested for yield and disease at many locations under a wide spectrum of environmental conditions. A lysimeter similar to the one used in this study could, feasibly, reduce the number of test locations considerably, because it provides a continuous range of moisture levels and enables a large-scale comparison of genotypes on a basis of stalk rot and yield under optimal and suboptimal moisture conditions in an environment that is, in other respects, natural.

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