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Planting Date and Soybean Cultivar Maturity Group Affect Population Dynamics of *Heterodera glycines,* and All Affect Yield of Soybean[1]

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Abstract: Five soybean cultivars, one each from Maturity Groups (MG) III, IV, V, VI, and VII, all susceptible to *Heterodera glycines,* were planted in *H. glycines*-infested soil in April, May, June, and July at multiple locations in Arkansas and Missouri. The purpose of the study was to determine whether planting early reduces yield losses due to *H. glycines.* The population levels of cysts, eggs, and second-stage juveniles of *H. glycines* were determined from soil samples collected at planting and harvest. Yields were measured from the two middle rows of 4.9 or 6.1-m four-row plots. The population dynamics of the nematode varied with planting date, cultivar, MG, and initial nematode population. Generally, the lowest reproductive factor (Rf = final population/initial population) for any year was on the MG III cultivar, regardless of planting date or field location. Also, the Rf was generally lower on each cultivar planted in April than in June or July. The highest Rf values were on cultivars in MG VI or VII planted in June or July. Yields were not consistently correlated with initial nematode population level. Early planting of late-maturing soybean cultivars may be profitable, but early planting of MG III cultivars, though supporting little if any increase in nematode numbers, did not result in high yields.

Key words: Glycine max, Heterodera glycines, planting dates, population dynamics, soybean, soybean cyst nematode, soybean maturity groups.

Soybean cultivars are divided into 12 maturity groups (MG) based on the relative time from germination to maturity. Generally, those with shorter life cycles are grown in northern areas where the growing season is shorter. However, cultivars in MG III and IV can be grown as far south as Arkansas and mid-Mississippi even though they may be better adapted farther north. Usually, MG V to VII cultivars are grown in Arkansas where they typically are planted in May or June and mature from early October to early November.

Soybean cyst nematode, *Heterodera glycines* Ichinohe, is present in 65–75% of the fields in which soybean is grown in Arkansas (Robbins et al., 1987) and 74% of the fields in Missouri (J. A. Wrather, unpubl.) and is one of the most destructive pests of soybean in the United States (Wrather et al., 2001). In the Southeast, overwintered eggs of *H. glycines* hatch in late April to early May (Ross, 1963; Slack and Hamblen, 1961). Some hatch may occur before soybean planting, particularly if the crop is not planted until June. If soil moisture and temperature are adequate, the second-stage juveniles (J2) will penetrate roots and reproduce on susceptible cultivars (Bonner and Schmitt, 1985). In Arkansas and southern Missouri, drought usually begins in June and may be severe in late July and August. When this occurs, nematode parasitism is likely to result in greater damage than if sufficient water were available. If short-season soybean cultivars could be planted in April, they might mature before the severe drought period in August and escape some damage from *H. glycines.* The practice of planting early-maturing cultivars earlier than normal has been referred to as the Early Soybean Production System (Heatherly and Bowers, 1998). There are some advantages and some disadvantages to the system (Wrather et al., 1996).

The objectives of this research were to determine the (i) effects of planting MG III to VII soybean cultivars in April, May, and June (May, June, and July when weather did not permit April planting) on the population dynamics of *H. glycines* and (ii) relative yields of the *H. glycines*-susceptible cultivars planted in *H. glycines*-infested soil.

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Materials and Methods

Location of plots and cultivars planted: Plots were located in different areas to determine the effects of different nematode populations and different weather conditions. Most of the tests were not irrigated. In 1991 to 1994, soybean cultivars in four to five different MG were planted in one to four different locations in April, May, and June or May, June, and July. Plots were four rows, 4.9 to 6.1 m long, replicated four times in randomized complete blocks. In 1991, Asgrow A3935 (MG III), Northrup King RA452 (MG IV), Hutcheson (MG V), and Asgrow A6785 (MG VI) were planted in April, May, and June on the Asgrow Farm at Marion, Arkansas (MAR) (30.8% sand, 64.0% silt, and 5.2% clay, silt loam soil). In 1992, the above cultivars plus Asgrow A7285 (MG VII) were planted in April, May, and June at MAR; on a farm near Conway, Arkansas (CON) (40.6% sand, 54.2% silt, 5.2% clay, 1.4% OM, silt loam soil); on the Pine Tree Station at Colt, Arkansas (PTS) (2% sand, 87% silt, 11% clay, 2.4% OM, silt soil); and in a field on the Delta Center Experiment Station near Portageville, Missouri (DCM) (34% sand, 50% silt, 16% clay, 1.2% OM, silt loam soil). In 1993, Asgrow A3733 replaced Asgrow A3935 and Asgrow A7986 replaced Asgrow A7285, and all were planted in April, May, and June at DCM and in May, June, and July at CON, MAR, and PTS. In 1994, the same cultivars planted in 1993 were planted in April, May, and June at the Cotton Branch Station at Marianna, Arkansas (CBS) (1% sand, 89% silt, 10% clay, 1.4% OM, silt soil), MAR, and DCM. The plots at CBS were planted on 47.5-cm (19-inch) centers rather than in standard wide rows (75 to 95 cm apart), which was used for all other plantings. Plots were four rows 4.9 or 6.1 m long and were replicated four times.

Soil sampling: Soil samples were taken from each plot just prior to planting, regardless of the month planted, and at harvest of the MG VII cultivar to determine initial (Pi) and final (Pf) population densities of *H. glycines*. Samples were taken with a soil probe from the two middle rows of each plot. Each sample consisted of six 2.5-cm-diam. cores 15 to 20 cm deep. Soil was placed in labeled plastic bags for transport and cool storage until nematodes were extracted.

Sample processing: A 100-cm^3 subsample from each thoroughly mixed soil sample was suspended in water and sieved through nested 850-µm-pore (20-mesh) and 250-µm-pore (60-mesh) sieves, then through a 36-µm-pore (400-mesh) sieve. The nematodes on the 250-µm-pore and 36-µm-pore sieves were extracted by centrifugation-flotation, except that J2 were not extracted from soil from the Missouri samples. Cysts from the Missouri samples and cysts and J2 from the Arkansas samples were counted with a stereomicroscope. Cysts were broken with a ground-glass homogenizer, and eggs were extracted on a 25-µm-pore (500-mesh) sieve and counted with a stereomicroscope.

Soybean harvest: Plot combines were used to harvest each soybean cultivar at maturity. Yields were adjusted to 13% moisture and recorded as hectoliters/hectare (hl/ha = 1.15 × bu/A).

Data processing: Nematode numbers at planting (Pi) and harvest (Pf), reproductive factors (Rf = Pf/Pi), and yield were subjected to analysis of variance ($P \leq 0.05$), and correlation-regression analyses and figures were produced by a SAS program (SAS Windows Version 6.11, SAS Institute, Inc., Cary, NC).

Results

Initial nematode populations: Heterodera glycines Pi had a wide range when all locations and planting dates were considered (Table 1). The Pi for any location within any year were not significantly different among soybean cultivars, but they were different among planting dates at the MAR, CON, and CBS locations. In general, the *H. glycines* population density was greatest in samples collected in July, but the relative levels varied among the other planting dates.

Harvest population levels: Cultivars in MG V, VI, and VII usually had higher Pf than did the cultivars in MG III and IV (Table 2). In addition, cultivars in MG III, IV, and V gen-

TABLE 1. Initial (at planting) population densities (Pi) of eggs of *Heterodera glycines* per 100 cm^3 soil in soybean cultivar-date of planting tests at five locations[a] in Arkansas and Missouri in 1991 through 1994.

Month	Maturity group	Location[a]				
		MAR	CON	PTS	CBS	DCM
April	III	1,504	78	3,887	1,350	509
	IV	1,478	558	4,168	1,776	366
	V	1,444	135	3,006	1,674	384
	VI	1,130	354	3,943	2,340	427
	VII	938	150	4,199	2,292	
May	III	1,604	249	3,183	1,512	376
	IV	1,743	114	3,127	1,115	488
	V	1,646	522	3,678	1,257	282
	VI	2,065	84	2,537	770	393
	VII	2,589	155	1,975	1,194	
June	III	1,507	794	2,041	415	316
	IV	1,564	764	3,283	583	408
	V	2,225	2,083	2,206	551	255
	VI	3,064	1,195	3,216	279	363
	VII	1,361	321	1,845	493	
July	III	7,314	1,303			
	IV	3,534	1,445			
	V	5,784	1,780			
	VI	6,951	2,720			
	VII	5,649	964			

Numbers are means of five replications at all locations.

[a] Test plots were located at Asgrow Farm, Marion, Arkansas (MAR), near Conway, Arkansas (CON), on the Pine Tree Experiment Station near Colt, Arkansas (PTS), on the Cotton Branch Experiment Station near Marianna, Arkansas (CBS), and on the Delta Center near Portageville, Missouri (DCM).

erally had lower Pf when planted in April than when planted in May or June. The highest Pf were in July-planted cultivars, with June having the next highest and April the lowest. The Pf were significantly different among dates of planting at all locations and among cultivar MG at all locations except PTS. Only at CON was there an interaction between date of planting and MG.

Nematode reproductive levels: The mean Rf for cultivars in MG III were the same when they were planted in April and May and higher when they were planted in June and July but were higher in June plantings than in July (Table 3). The only combination in which the MG III cultivar had Rf above 1 in an April planting was at Conway in 1992 when the Pi were very low. The Rf was 1 or less in 9 of the 17 planting date-location combinations. In contrast, the Rf was over 2 in 6 combinations, and the highest Rf was 6.63. The Rf were significantly different among cultivars at CON, PTS, and DCM and among dates of plantings at MAR, CBS, and DCM. At no location was there an interaction between planting date and MG.

Soybean yields: Mean soybean yields ranged from 8.05 hl/ha in July plantings at CON to 50.6 hl/ha in May plantings at MAR and DCM (Table 4). Yields were significantly different among cultivars all years at all locations and among dates of planting in all locations except DCM. However, there was a significant interaction between planting date and MG at all locations except PTS. Significant correlations were found between Pi and yield at MAR in 1993 and for all tests combined, at CON in 1992, and for both years combined at CON and at PTS. The Pf were correlated with yield at MAR 2 of 4 years, at CBS in 1 year, at DCM all 3 years, and at PTS both years. The Pf were negatively correlated with yield when all locations, planting dates, and cultivars were combined in 1993 and 1994. The Rf were negatively correlated with yield in 1992 at CON and positively correlated with yield at DCM for cultivars and planting dates combined in 1992, 1993, and 1994. Overall, yields were highest in May-planted cultivars and lowest in July-planted cultivars. Yields were higher in April plantings than in June plantings.

Combination comparisons: Yield and Rf data were used to determine relationships with date of planting, maturity groups of the cultivars tested, and years the tests were conducted as conditions under which comparisons were made (Fig. 1A–C). Rf were not related to yield when any cultivar was planted in April (Fig. 1A). For cultivars planted in May, June, or July, Rf were negatively correlated with yield (Fig. 1A). The greatest negative correlation between yield and Rf was in July, but it was strong in May also.

The Rf were strongly negatively correlated with yield of four of the five maturity groups (Fig. 1B). For MG III cultivars, Rf were slightly positively correlated with yield, but the regression line was almost level, indicating that yield was not correlated with Rf (Fig. 1B). For MG VII cultivars, Rf were

TABLE 2. Final population densities (Pf) of eggs of *Heterodera glycines* per 100 cm^3 soil at harvest in soybean cultivar-date of planting tests at five locations in Arkansas and Missouri in 1991 through 1994.

Month	Maturity Group	Location[a] MAR	CON	PTS	CBS	DCM
April	III	124	1,029	1,333	34	437
	IV	422	1,445	5,508	196	593
	V	180	372	2,478	453	1,102
	VI	633	6,237	5,745	569	1,504
	VII	1,240	1,571	8,028	879	
May	III	275	293	628	51	299
	IV	1,292	1,077	3,979	200	708
	V	485	1,367	7,550	308	840
	VI	755	2,784	8,381	619	2,085
	VII	1,236	1,377	10,047	1,029	
June	III	1,425	1,826	3,395	1,104	616
	IV	574	938	3,116	451	1,051
	V	987	5,000	4,001	2,709	1,849
	VI	1,113	9,159	5,841	3,969	1,690
	VII	1,216	3,879	4,727	2,346	
July	III	3,903	656			
	IV	4,635	4,916			
	V	4,749	8,233			
	VI	5,035	19,738			
	VII	2,352	26,615			

Numbers are means of five replications at all locations.
[a] Test plots were located at Asgrow Farm, Marion, Arkansas (MAR), near Conway, Arkansas (CON), on the Pine Tree Experiment Station near Colt, Arkansas (PTS), on the Cotton Branch Experiment Station near Marianna, Arkansas (CBS), and on the Delta Center near Portageville, Missouri (DCM).

TABLE 3. Mean reproductive factor (Rf, at-harvest population density/at-plant population density) based on eggs + J2 of *Heterodera glycines* in soybean cultivar-date of planting tests in five locations in Arkansas and Missouri in 1991 through 1994.

Month	Maturity group	Locations[a] MAR	CON	PTS	CBS	DCM	Mean Pf/Pi
April	III	0.11	12.20	0.26	0.03	0.94	0.27
	IV	0.26	2.27	1.41	0.17	1.80	0.98
	V	0.22	0.55	0.85	0.46	2.11	0.69
	VI	0.49	10.45	1.53	0.30	2.12	1.79
	VII	0.81	7.70	0.96	0.41		1.55
May	III	0.60	0.98	0.19	0.06	1.13	0.22
	IV	0.86	5.38	1.27	0.51	1.76	1.10
	V	0.47	1.60	1.06	0.22	2.56	1.43
	VI	0.52	0.73	1.00	0.93	3.13	2.50
	VII	0.61	2.30	1.25	0.50		2.33
June	III	0.78	0.15	0.78	1.27	1.87	1.65
	IV	0.58	2.50	1.06	1.05	2.38	0.91
	V	0.53	1.00	1.42	6.34	2.85	1.99
	VI	0.64	3.25	1.31	3.18	2.32	2.68
	VII	1.03	2.73	1.03	3.00		3.03
July	III	1.06	0.56				0.53
	IV	0.58	2.42				1.92
	V	0.64	2.51				2.20
	VI	1.01	4.50				2.56
	VII	0.43	10.70				4.38

Numbers are means of five replications at all locations.
[a] Test plots were located at Asgrow Farm, Marion, Arkansas (MAR), near Conway, Arkansas (CON), on the Pine Tree Experiment Station near Colt, Arkansas (PTS), on the Cotton Branch Experiment Station near Marianna, Arkansas (CBS), and on the Delta Center near Portageville, Missouri (DCM).

TABLE 4. Mean yields (hectoliters/hectare[a] = 1.15 X bu/A) of soybean cultivars in cultivar-date of planting tests at five locations in Arkansas and Missouri in 1991 through 1994.

Month	Maturity group	Locations[b]				
		MAR	CON	PTS	CBS	DCM
April	III	24	9	20	14	21
	IV	39	22	48	43	41
	V	40	20	35	47	45
	VI	51	15	42	41	49
	VII	33	19	37	41	
May	III	34	16	24	38	48
	IV	48	15	29	46	38
	V	47	25	29	54	43
	VI	48	29	33	40	45
	VII	44	23	36	34	
June	III	33	12	24	29	34
	IV	40	20	25	33	38
	V	44	12	25	30	40
	VI	42	26	30	27	39
	VII	36	18	27	20	
July	III	25	3			
	IV	26	10			
	V	31	5			
	VI	26	13			
	VII	13	6			

Numbers are means of five replications at all locations.
[a] Hectoliter/hectare = 1.15 bu/A.
[b] Test plots were located at Asgrow Farm, Marion, Arkansas (MAR), near Conway, Arkansas (CON), on the Pine Tree Experiment Station near Colt, Arkansas (PTS), on the Cotton Branch Experiment Station near Marianna, Arkansas (CBS), and on the Delta Center near Portageville, Missouri (DCM).

strongly and negatively correlated with yield and the correlations were only slightly lower for MG IV, V, and VI (Fig. 1B). The Rf were strongly correlated with yield in 2 of the 4 years in which tests were run (Fig. 1C). In 1992, the correlation was strongly negative, and in 1991 it was strongly positive; as in 1993 the relationship was slightly negative, and in 1994 it was slightly positive (Fig. 1C).

DISCUSSION

Initial nematode populations: The higher Pi in samples taken in July compared with samples taken in April might be expected if Pi were based on numbers of J2 in the soil. However, when all eggs and J2 are considered, that is an unusual situation. No reproduction should have occurred in plots that were fallow between April and July. In fact, because temperatures were high enough for egg hatch, the Pi logically would be lower because of hatch and starvation of the J2 during that period. The only practical explanation appears to be that cysts in samples taken in July were more readily extracted than those in samples taken in April; therefore, a more accurate count was obtained.

Harvest population levels and reproductive factors: The lower Pf and Rf in plots planted in April, regardless of cultivar MG, also are unusual. The growing season of cultivars in all MG should be longer when planted in April than May or June, thus providing this nematode more time to feed on roots and reproduce. In a previous study, cultivars in MG III, V, and VI required 78 days, 108 days (average of two cultivars), and 128 days (average of three cultivars), respectively, from emergence to maturity when planted on May 13, and 74, 104, and 121 days, respectively, when planted on June 3 in Beltsville, Maryland (Johnson et al., 1960). That test did not cover the range of planting dates in our test but it illustrates the effect of planting date on length of growing season. Soybean development is related to latitude, temperature, maturity, and date of planting (L. Purcell, pers. comm.). Generally, soybean seedlings are not subject to day-length effects for about 3 weeks after emergence (juvenile phase). In addition, they require a certain number of degree-days (350 for MG 00) to induce flowering. Therefore, temperature probably controlled the initiation of flowering, and ultimate maturity, for the cultivars in MG III and IV planted in April. The juvenile phase may have affected flower initiation for cultivars planted in May. Otherwise, day length controls flowering and that varies with latitude. In our study the latitude may not have varied enough to affect the start of flowering or length of growing season and, ultimately, increase in nematode population.

Population densities of *H. glycines* should increase throughout the growing season on susceptible soybean cultivars, and the number of generations in a year should be related to the time from germination to death of the soybean plant (Bonner and Schmitt, 1985). In studies in Kansas, Rf for the same *H. glycines*-susceptible soybean cultivars

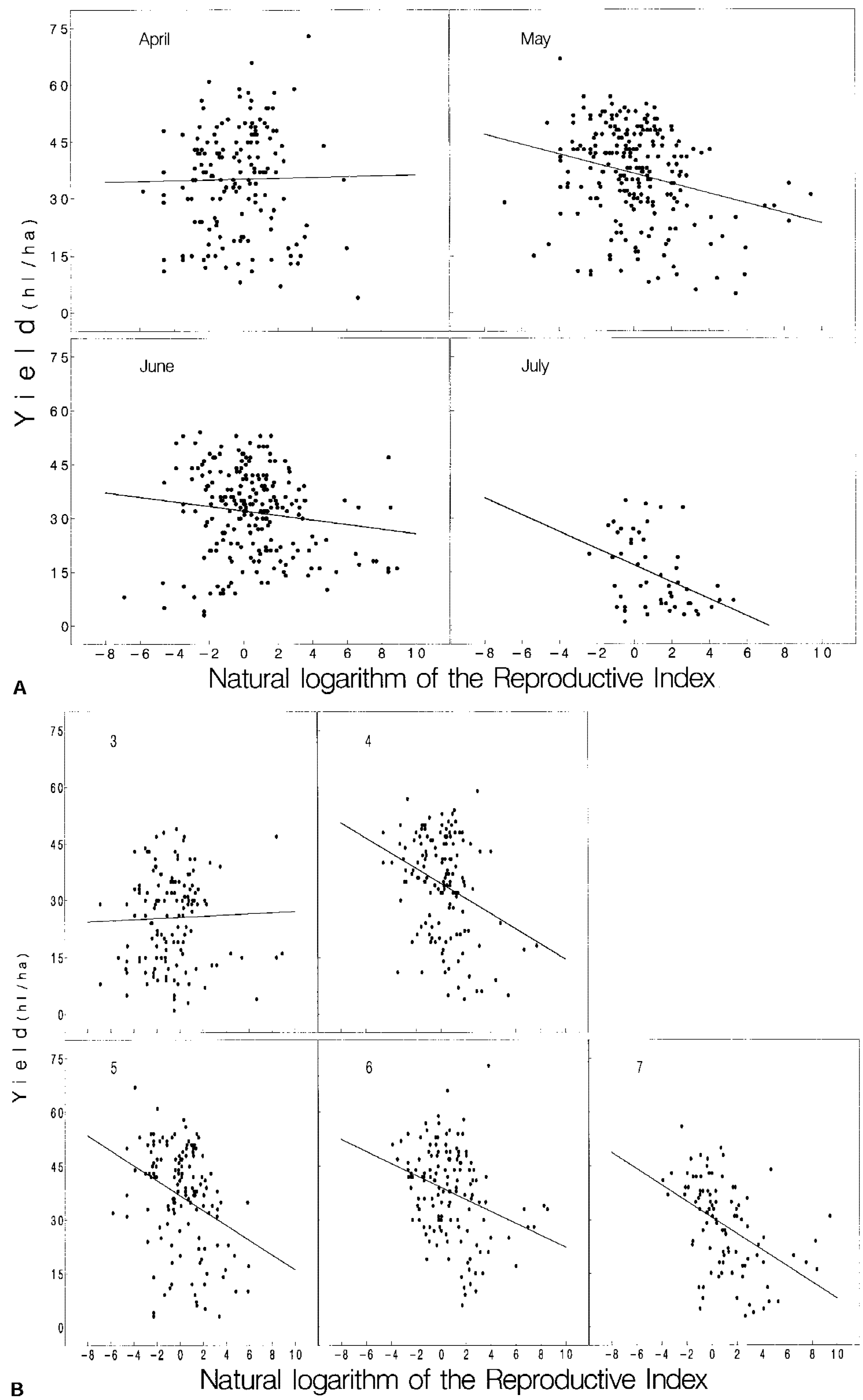

Fig. 1. Regressions of yield against the natural logarithm of the reproductive index (Rf = harvest nematode population density/at-plant nematode population density) of *Heterodera glycines* compared by A) date of planting, April, May, June, and July for all Maturity Groups, locations, and years; B) soybean cultivar Maturity Group for all locations, planting dates, and years; and C) year of testing for all Maturity Groups, planting dates, and locations.

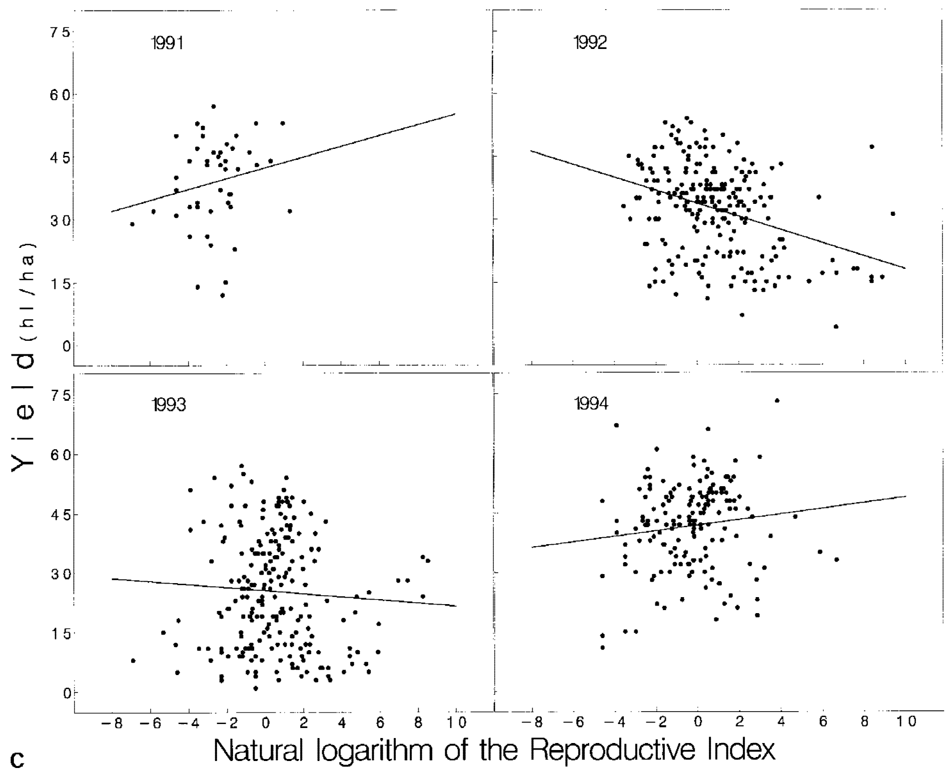

FIG. 1. *Continued.*

planted in July were less (0.9) than when planted in June (1.8) (Todd, 1993). However, a year later, when the soybean cultivar was planted in May and June, the Rf was not significantly different (7.7 vs. 10.0). In 1990, Rf from MG III and IV cultivars were significantly higher than those of an MG V cultivar (1.5 vs. 1.0), but in 1991 Rf of cultivars in MG III (4.9), IV (8.6), and V (13.0) were not significantly different. In studies in Missouri, Rf for a single cultivar was May 7 < May 27 < June 21 planting dates (Koenning and Anand, 1991). However, a year later, again for a single cultivar, Rf was May 7 < May 27 > June 21 planting dates. In a comparison of planting date and maturity group effects on *H. glycines* population dynamics, cultivars in MG V and VII had lower Rf when planted late than when planted early when averaged over 4 years (Koenning et al., 1993). Interestingly, for all of the 4 years and two MG combinations except one, the Pf of the late planting was higher than that of the early planting. That is similar to our results and, under these circumstances, a lower Rf would be expected.

If the population level increased uniformly from seed germination to plant death, the cultivars with the longest growing season should have the highest population densities at the end of the growing season, assuming equal susceptibility. According to the pedigrees of the cultivars tested, only the MG VI cultivar (Asgrow A6785) had resistant ancestors, but it showed no signs of resistance to the nematode populations in these tests. However, the females that are in the roots as the plant nears maturity will not all be at the same stage of development, so even a few days' difference would allow the production of additional eggs by the females. One explanation for the low Pf on April-planted soybean cultivars is that the soil in April is cool enough to slow root growth. The high numbers of J2 penetrating the roots may cause extensive damage from which the roots never recover; therefore, the food supply for nematodes is too low to support extensive population level increases. However, evidence indicates that *H. glycines* reproduced more on pod-producing plants than on those on which no pods were allowed to form and the plants remained vegetative (Hill and Schmitt, 1989). The high soil temperatures in late July and August when the April-planted MG III cultivars were filling pods may have adversely affected nematode reproduction. However, the low Rf may be due to the amount of damage done by the nematodes penetrating from which these cultivars never recovered. The MG III cultivars planted in April never yielded well. The slight positive correlation between Rf and yield of MG III cultivars normally would indicate that the nematode numbers were high and the yield was high. However, in 10 of 14 experiments with MG III cultivars, the Rf was less than 1.0, indicating that nematode reproduction was low; therefore, yield would be low in a positive correlation. The early nematode damage may have been high, resulting in a poor root system and, ultimately, low nematode reproduction and low yield.

No explanation is evident for the higher Rf values for MG VII cultivar planted in June than for those planted in April in the present studies. The shorter growing period, even for an MG VII cultivar planted in June, should result in a lower nematode Rf. The root system may expand more rapidly at the higher soil temperature typical of June and July, thus providing abundant feeding sites. If the moisture is low but sufficient for egg hatch and J2 movement, root penetration would be at a higher level and nematodes would be more likely to establish a feeding site within the stele than if moisture were sufficient (Johnson et al., 1993a, 1993b). However, the increased penetration would not necessarily result in increased reproduction because this damage should reduce root growth and the food supply could become limiting. Therefore, no explanation appears to adequately explain the higher Pf and Rf on MG VII cultivars planted in June or July.

In summary, when soybean plants are growing in soil infested with *H. glycines,* other factors contribute to the effect of the nematode on soybean growth and yield. The present study over a 4-year period and five locations seems to indicate that early planting (mid-April or slightly later) results in lower increases in population levels of *H. glycines* during the growing season, regardless of cultivar MG. The lower numbers of nematodes did not improve yields of the MG III soybean cultivars, but cultivars in MG IV to VII yielded as well as or better than when planted later. Soybean cultivars in MG V to VII had greater nematode population levels when planted in June or July, and that appeared to be reflected in the yield. Therefore, April planting of soybean cultivars in MG IV to VII in fields infested with *H. glycines* appears to be a good practice, even if the cultivars are susceptible to *H. glycines,* in the latitudes where these tests were conducted. However, planting cultivars in MG III in these latitudes or planting *H. glycines*-susceptible cultivars in May to July in these latitudes probably will not result in optimum yields because of damage from *H. glycines.*

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