A long-term look at crop rotation effects on corn yield and response to nitrogen fertilization

Antonio P. Mallarino, Professor, Agronomy, Iowa State University

Enrique Ortiz-Torres, former Graduate Research Assistant, Agronomy, Iowa State University

Introduction

Increasing concerns about fertilizer nitrogen (N) cost, public awareness of effects of excess N use on water quality, and corn after corn production in Iowa require a better understanding of long-term effects of N fertilization and cropping sequences on corn yield. Therefore, continuous research and management adjustments are needed to improve economic benefits from fertilization and water quality. Growing corn in rotation with grain or forage legumes reduces the need of N fertilizer compared with continuous corn because soil after legume crops have higher potential N availability than after corn. Previous research has shown that optimum N fertilization rates for corn are highest for continuous corn and are followed by corn after soybean and corn after alfalfa. Yet, another benefit of including legumes in the rotation, mainly forage legumes, is that corn yield is higher than for continuous corn even at very high N rates because of often poorly understood beneficial effects of the legumes on soil quality, reduced incidence of corn pests, and other factors.

This presentation summarizes corn yield results from the two longest Iowa rotation studies experiments that have been evaluating effects of various cropping sequences and N fertilization rates on yield of several crops. These experiments provide very useful information for long-term implementation of cropping systems (such as continuous corn, corn after alfalfa, corn after soybean) and long-term fertilization strategies that short-term experiments on farmers' fields cannot provide. We focus the presentation on corn yield responses to N and stability over time. A unique piece of information provided by one of the experiments is the evaluation of yield and response to N of corn grown one, twice, or three times after a soybean crop, issues seldom investigated in other studies in Iowa and neighboring states.

Summary of Methods

The experiments are near Kanawha (Webster soil) and Nashua (Kenyon and Readlyn soils). Rotations in Kanawha are continuous corn with spring N, continuous corn with fall N, corn-corn-corn-oat, corn-soybean, corn-soybean-corn-oat, corn-corn-oat-alfalfa, and corn-oat-alfalfa-alfalfa. Rotations in Nashua are continuous corn, corn-soybean, corn-corn-soybean, corn-corn-corn-soybean, and corn-corn-oat-alfalfa. Hereon, an upper case letter in the rotation code indicates the crop being referred to. For example, cCs indicates we are referring to the second corn after soybean. Crops are managed with tillage. Oats was always undersown with alfalfa and no hay was harvested the seeding year after oat grain harvest. Therefore, hereon "oat" refers to grain from oat undersown with alfalfa and "alfalfa" refers to hay harvested in the second year at Nashua and the second or third years at Kanawha. The N fertilization rates are 0, 80, 160, and 240 lb N/acre applied for corn as granulated urea, which except for a fall application treatment at Kanawha is broadcast in spring and incorporated immediately after the application by disking. To simplify the presentation, we do not share results for the treatment that applies fall N for continuous corn at Kanawha. Also, we summarize all corn data available for the Nashua study (26 years, until 2004) but only corn yields from 1994 to 2004 for the study at Kanawha because is the most recent period without changes in rotations or N rates. Therefore, nine different corn crops were defined at Nashua and 10 at Kanawha according to the rotation and position of corn crops in the sequences. Table 1 shows rotations, crop sequence of each rotation, the defined corn crops and codes used.

The four widely spaced N fertilization rates used in both studies preclude a reliable modeling of corn response to N for accurately determine N rates that maximize yield or economically optimum N rates. Therefore, study of N effects emphasizes comparisons of observed yields for the N rates applied.

Results for the Nashua Site

Treatment effects for long-term averages

Figure 1 shows mean corn yield across the 26-year study period for Nashua. Yields and statistics indicated that corn crops could be grouped into four distinct groups according to yield level and response to N. The first corn after alfalfa yielded the highest across all N rates and responded the least to N application. Corn after soybean from all sequences (Cs, Ccs, and Cccs) ranked in a second group with lower yield for all N rates lower than 160 lb N/acre. Second corn after oats and 1 year of alfalfa (cCoa) ranked third in yield. The overall low yield of this corn crop is explained mainly by low yield in early years of the study, lately yield are much closer but still below yield of corn after soybean. Yields of continuous corn and first, second, and third corn after soybean (C, ccCs, cCcs, and cCs) did not differ and ranked the lowest. It is important to note that yields of the latter corn crops did not achieve the maximum yield levels of other crops even with the highest N rate applied.

Yield of corn after alfalfa increased significantly up to the 80-lb N rate and increased very little with higher rates. The response of corn following soybean to N did not differ among rotations (Cs, Ccs, and Cccs), and 160 lb N/acre were needed to produce near maximum yield. The cCoa corn crop, which ranked third in yield level, showed a very large response up to the 160-lb N rate and slightly more N was needed to produce near maximum yield compared with corn after soybean. Finally, a group made up by continuous corn and second or third corn following soybean (C, cCcs, cCs, ccCs), which yielded the lowest even for the highest N rate, clearly needed more than 160 lb N to produce near maximum yield. The finding that yield and response to N did not differ among continuous corn, second-year (cCs and cCcs), and third-year corn after soybean (ccCs) at both sites is an important result.

Use of only four widely spaced N rates does not allow for reliable modeling of N response and calculations of optimum N rates. These models estimated unrealistically high rates of N rates that maximized yield of corn after alfalfa, although rate estimated for other corn crops were reasonable. The rates producing maximum yield ranged from 152 to 172 lb N/acre for Cs, Ccs, and Cccs; and from 211 to 230 lb N/acre for continuous corn, cCcs, cCs, cCoa, and ccCs. Results confirmed that including legumes in rotation with corn frequently increase plant-available N in soils and that more N is available after alfalfa than after soybean. Crop rotation effects corn yield through improvements of growth factors other than N availability may explain higher corn yield level for rotations including oat and alfalfa even at the highest N rates used.

Treatment effects over time

To simplify presentation of rotation, cropping sequence, and N rate effects on corn yield over time we summarized results for four groups of corn crops showing similar responses for 26-year means. These groups were corn after corn (CC), corn after soybean (CS), first corn after alfalfa (Ccoa), and second corn after alfalfa (cCom). The CC group includes C, ccCs, sCs, and cCcs corn crops; and the CS group includes the first corn following soybean (Cs, Ccs, and Cccs).

Figure 2 shows the frequency by which each N rate produced the statistically maximum corn yield each year. The CC group had the highest response to N and responded up to the 80, 160, and 240-lb N rates 25, 67 and 8 % of the time. The CS group responded 58 % of the time to 80 lb N, 33 % of the time to 160 lb N, and never to 240 lb N. Corn after alfalfa responded 62 % of the time to 80 lb N and 12 % to 160 lb, but in 25 % of the time did not need N fertilizer. In contrast, cCoa responded up to 80, 160, and 240 lb N 42, 54, and 4 % of the time. This result confirms results for 26-year means in that there was little increased N availability due to alfalfa for a second corn crop compared with first-year corn. Probably a major proportion of native soil N not used by alfalfa or N fixed by alfalfa was mineralized and removed or immobilized by the first corn crop or was lost by leaching by the time the second corn was grown.

Figure 3 shows corn yields over time as affected by N fertilization. Very low yields in 1988 and 2003 for all corn crops and for Ccoa in 1989 some were the result of extreme draught or excessive rainfall. The yield of corn for the CC group without N fertilization declined from 1979 to 2004; which can be explained by depression of soil N supply over time, and on average yield decreased 1.4 bu/acre/year. No clear trend over time was observed for CC fertilized with 80 lb N and yields increased with rates of 160 and 240 lb 1.0 and 1.3 bu/acre/year, respectively. The result for the CS group shows that yield without N fertilization decreased 0.59 bu/acre/year, but increased over time with N fertilization 1.08, 2.04, and 2.28 bu/acre/year for 80, 160, and 240 lb N/acre. Second corn after alfalfa without N fertilization showed no significant trend over time, but yield increased 1.5, 2.8, and 2.1 bu/acre/year for the three N rates. For Ccoa there was a clear increasing yield trend for all N rates, and yield increased 2.3 to 3.8 bu/acre/year depending on the rate applied. An obvious increasing yield trend over time with high N availability may reflect genetic improvements in corn hybrids or better management practices.

The results showed that the corn response to N (both the magnitude and up to what N rate) tended to increase over time for the CC and CS corn groups but not for cCoa or Ccoa. In spite of large yield variation from year to year, the absolute yield difference and the relative response (not shown) between fertilized and the non-fertilized plots of CC, CS, and cCoa increased with time. A regression of the N rates that produced statistically maximum yield of corn each year on time (not shown) indicated that the N needed to maximize yield for CC, CS, and cCoa groups increased slightly over time, but year-to-year variation was very large. One reason that could explain slightly increasing N needs over time is increasing N demand due to increasing yield levels. However, N rates needed to maximized yield of corn for the CA group did not change consistently. This result, and actually a small decreasing trend for Ccoa, could be explained by sustained or increased N supply by repeated alfalfa crops. Corn after alfalfa responded consistently up to the lowest N rate used during the first few years but responded only occasionally since 1989.

Results for the Kanawha Site

Treatment effects for long-term averages

Figure 4 shows average corn yields across the 20-year study period for Kanawha. The 10 corn crops can be grouped into five distinct groups according to yield levels without N fertilization. The highest yield was observed for corn after alfalfa (Ccoa and Coaa), followed by corn after oat (Csco and Ccco), both corn following soybean (csCo and Cs) and second-year corn after alfalfa (cCoa), second and third corn after oat, and finally, with the lowest yield, continuous corn.

Continuous corn, cCco, and ccCo showed very large yield increases up to the 160-lb rate, a smaller but still significant yield increase up to the 240 lb-N rate, but did not produce as high yield as corn of some other rotations even with the highest N rate applied. Corn after soybean or oat (Cs, csCo, Csco, Ccco) and second corn after alfalfa (cCoa) showed very large responses up to the 80-lb rate, and there was a smaller but significant yield increase up to the 160-lb rate. Corn after 1 or 2 years of alfalfa (Coaa, Ccoa) had the highest yield without N, and did not respond significantly to N fertilization. The results, as those for Nashua, show the benefits of including legumes such as soybean and alfalfa in rotation with corn. Data showed that first-year corn after oat and 2 years of alfalfa does not need additional N in most years compared with results for oat undersown with alfalfa followed by only one year of alfalfa.

Calculated N rates that produced maximum yield for corn after corn and corn after soybean were reasonable and useful for comparison purposes. For corn after corn these rates were 211, 221, and 237 lb N for cCco, continuous corn, and ccCo, respectively. This result agrees with results for Nashua in that continuous corn did not have larger N fertilizer requirements that corn after corn from other rotations. The N rates that produced maximum yield of corn after soybean were lower, and were 161 lb N for csCo and 193 lb N/acre for Cs.

Treatment effects over time

Six groups of corn crops were formed for the Kanawha site according to similarities in yield and response to N shown in Fig. 4. These were first corn after alfalfa (CA, which included Coaa and Ccoa); second corn after alfalfa (cCoa), first corn after soybean (CS, which included Cs and csCo); first corn after oat (CO, which included Ccco and Csco); second and third corn after oat (CCO, which included cCco and ccCo); and continuous corn.

Figure 5 shows the frequency by which each rate of N produced the statistically maximum corn yield for each year and corn crop. Continuous corn and corn of the CCO group responded more frequently to higher N rates than other corn crops. Continuous corn crop responded to rates of 80, 160, and 240 lb N/acre 44, 44 and 11 % of the time. The CCO group responded to those three rates 33, 50 and 11 % of the time; cCoa responded 56, 22, and 0 % of the time but did not respond to N 22 % of the time; while the CS group responded 78, 17 and 0 % of the time. Finally, the CO group responded to N only 50% of the time, and only to the 80 kg rate, while corn after alfalfa never responded significantly to N.

Figure 6 shows annual grain yields for the six corn groups as affected by N fertilization. Very low yields in 1988 and 1993 were the result of extreme drought (1988) or excessive rainfall (1993). The yield levels increased over time for all corn groups and N rates. These increasing trends over time agree only partly with results for Nashua, where yields of non-fertilized plots in continuous corn and corn after soybean decreased over time. In addition, and in contrast to results from

Nashua, regression analysis not shown indicated that the N rates that produced statistically maximum corn yield did not increase consistently over time for any corn crop. The difference between sites for non-fertilized plots for continuous corn and corn-soybean rotations may be explained by the fewer years without fertilization at Nashua (26 years) than at Kanawha (50 years). Perhaps non-fertilized plots at Kanawha had reached a low plateau for N supply. A lack of yield response to N by corn after alfalfa can be explained by many rotation cycles with alfalfa maintaining high enough soil N supply. Corn after soybean and cCoa responded up to the 80 lb rate in many years and showed a consistent response up to the 160-lb rate from 1998 to 2001, a result that could not be explained by rainfall or yield levels.

Summary and Conclusions

Comparison of yield of corn after corn and other corn crops indicated a clear rotation effect resulting in higher yield levels after legumes at both sites that could not be achieved by application of up to 240 lb N/acre. This yield difference ranged from 10 to 14% for the various rotations. First-year corn after alfalfa, oat undersown with alfalfa, or soybean had lower N requirements than continuous corn or second and third corn crops after these other crops. Another important result of this study was that continuous corn and second- or third-year corn after soybean had statistically similar yield and N fertilizer requirements.

Study of corn yields and yield responses to N over time indicated a large variation in responses. The frequency by which N fertilization (any rate applied) increased (statistically) corn yield each year across both sites was zero for first corn after oat undersown with alfalfa followed by 2 years of alfalfa (evaluated only at Kanawha), 46 % for first corn after oat undersown with alfalfa followed by one year of alfalfa, 50 % for first corn after oat undersown with alfalfa (only at Kanawha), 93 % for first corn after soybean, 91 % for second- or third-year corn after any other crop, and 100 % for continuous corn. The N rate needed to attain statistically maximum corn yield did not change consistently over time, although yield levels of corn fertilized with near optimum or higher N rates and of corn after alfalfa tended to increased over time.

Table 1. Crop rotations and codes for corn crops for experiments at Nashua and Kanawha.

Site	Crop sequence	Corn crop studied	Code†
Kanawha	corn-corn-corn-corn	continuous corn with spring N	C
	corn-corn-corn- oat	1st corn after oat	Ccco
		2nd corn after oat	cCco
		3rd corn after oat	ccCo
	corn-soybean-corn-soybean	corn after soybean	Cs
	corn-soybean-corn-oat	corn after oat	Csco
		corn after soybean	csCo
	corn-corn-oats-alfalfa	1st corn after 1 year of alfalfa	Ccoa
		2nd corn after 1 year of alfalfa	cCoa
	corn-oats-hay-alfalfa	corn after 2 years of alfalfa	Coaa
Nashua	Corn	continuous corn	C
	corn-soybean	corn after soybean	Cs
	corn-corn-soybean	1st corn after soybean	Ccs
		2nd corn after soybean	cCs
	corn-corn-corn-soybean	1st corn after soybean	Cccs
		2nd corn after soybean	cCcs
		3rd corn after soybean	ccCs
	corn-corn-oats-alfalfa	1st corn after alfalfa	Ccoa
		2nd corn after alfalfa	cCoa.

† a, alfalfa; C or c, corn where a capital letter refers to continuous corn or the corn crop studied within the sequence; o, oat undersown with alfalfa without hay harvest; s, soybean.

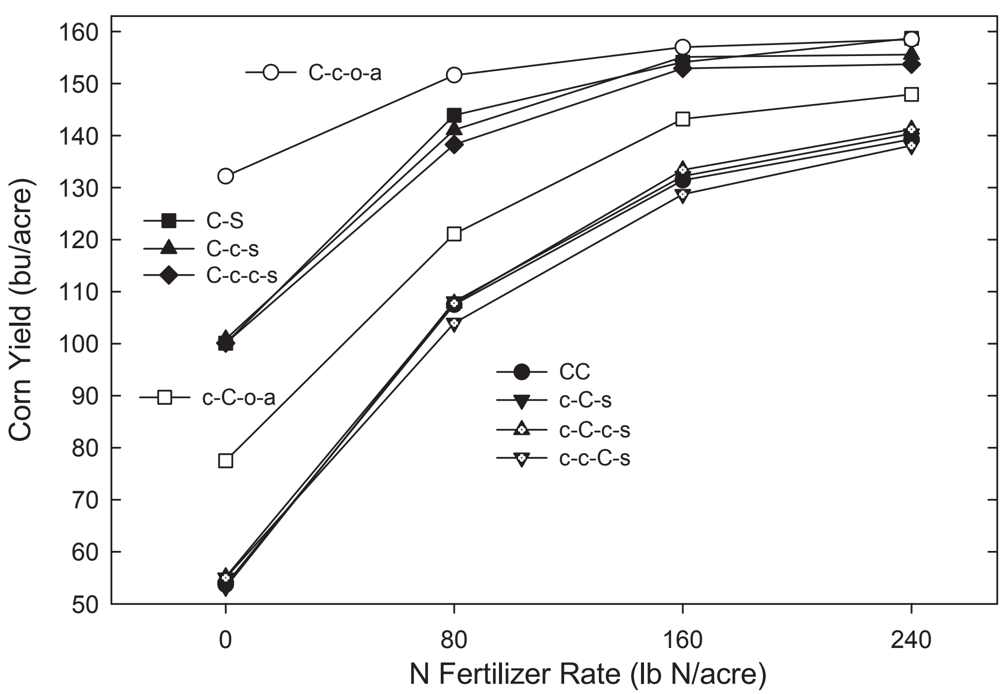

Figure 1. Rotation and N rate effects on corn yield during 26 years for Nashua (1979-2004).

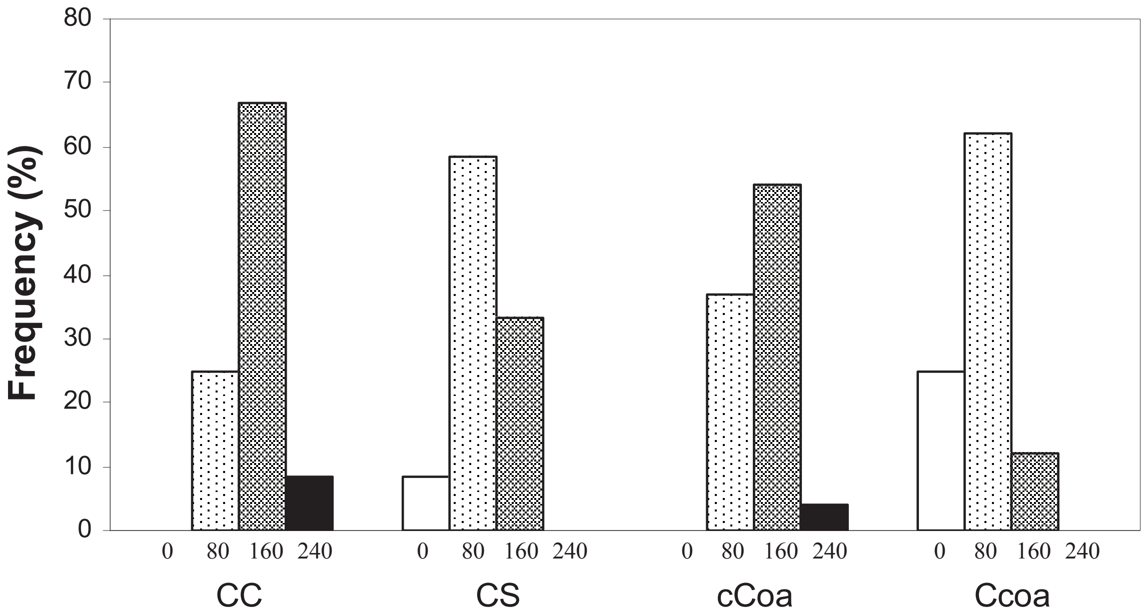

Figure 2. Frequency at which each N rate applied in the trial produced the statistically maximum yield response over time at Nashua for four crop groups (CC, corn after corn; CS, corn after soybean; cCo, second corn after alfalfa; Ccoa, first corn after alfalfa).

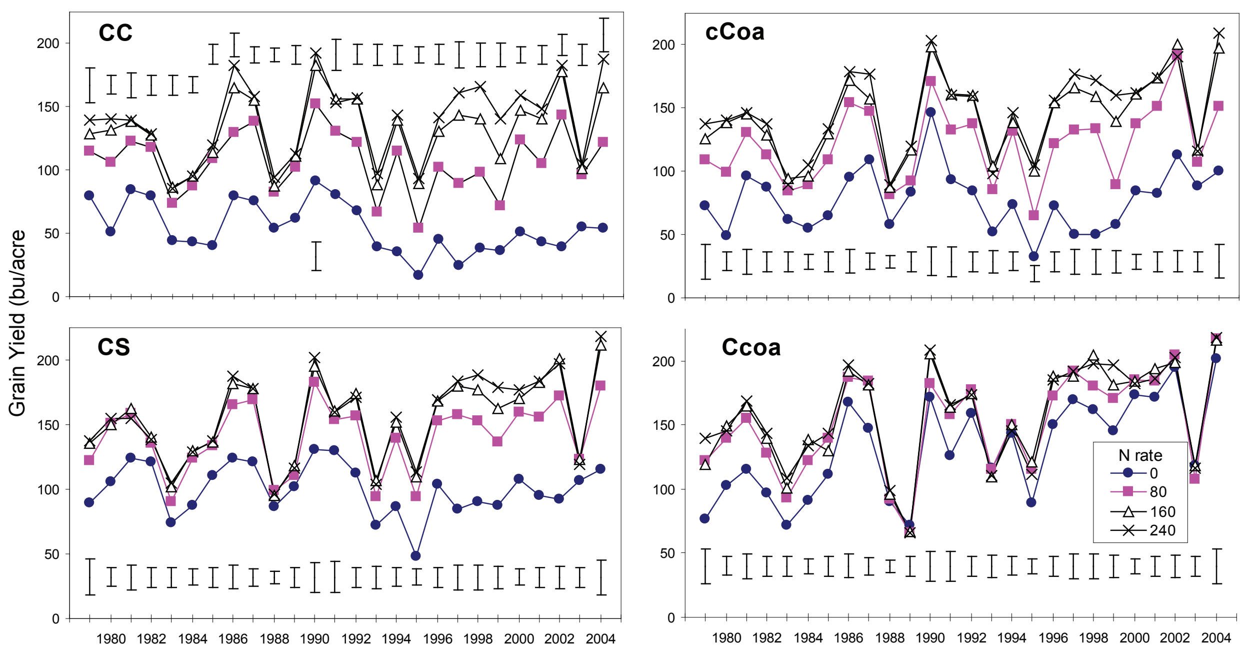

Figure 3. Rotation and N fertilization effects on corn yield over time at Nashua. Vertical lines represent least significant differences appropriate for comparing yield at the same N rate each year (CC, corn after corn; CS, corn after soybean; cCoa, second corn after alfalfa; Ccoa, first corn after alfalfa).

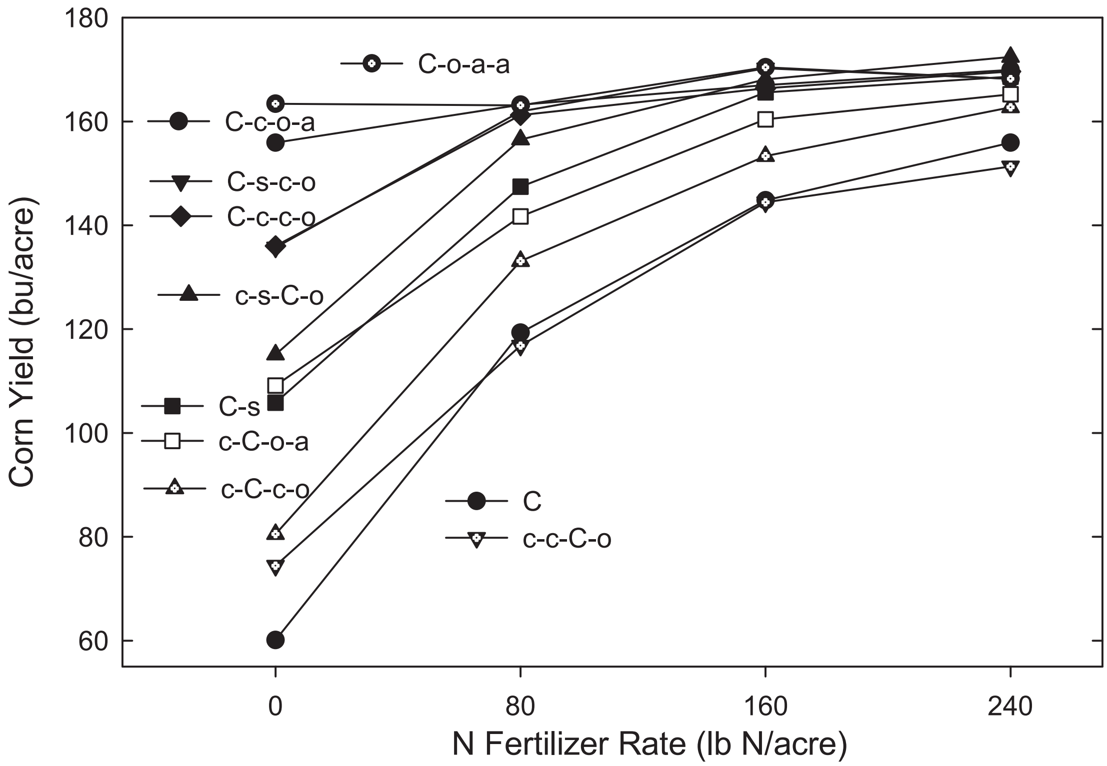

Figure. 4. Rotation and N rate effects on corn yield during 20 years for Kanawha.

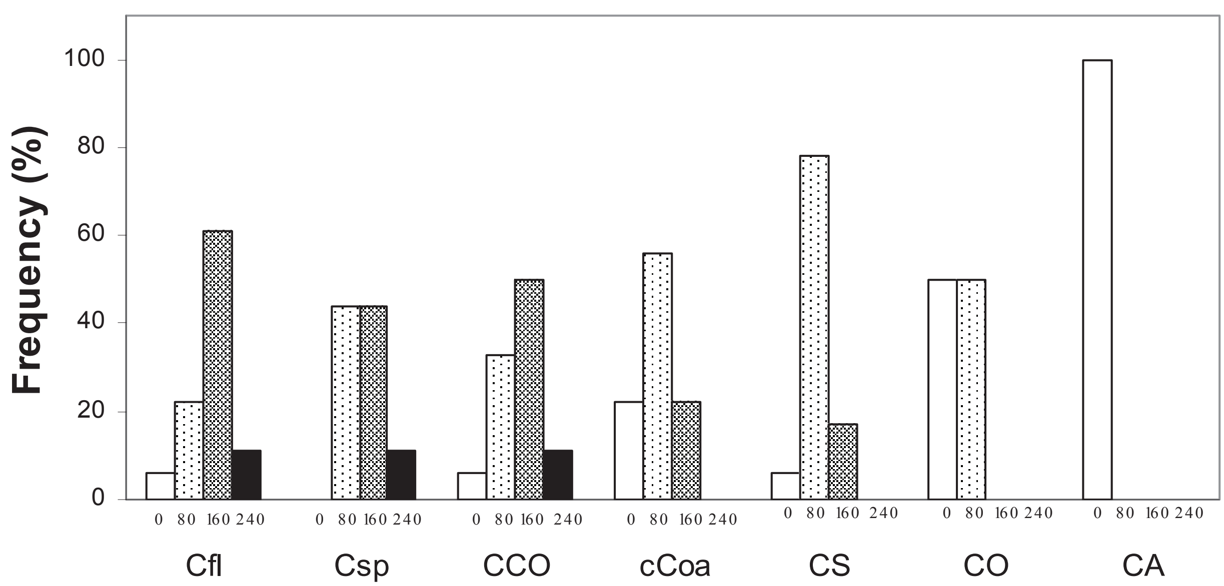

Figure 5. Frequency at which each N rate applied produced the statistically maximum yield response at Kanawha for six crop groups: C, continuous corn; CCO, second and third corn after oat; cCoa, second corn after alfalfa; CS, first corn after soybean; CO, corn after oat; and CA, first corn after alfalfa.

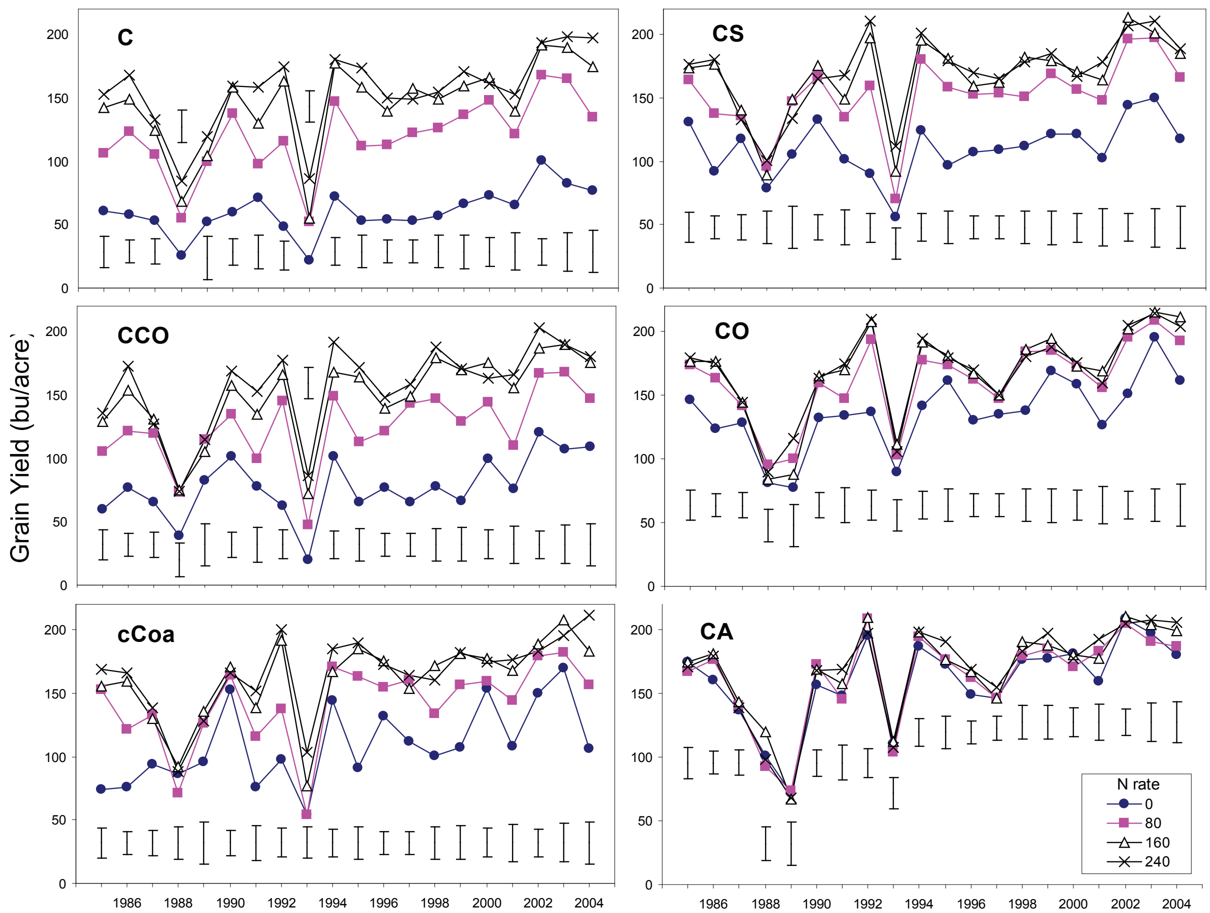

Figure 6. Rotation and N fertilization effects on corn yield over time at Kanawha. Vertical lines represent the least significant difference appropriate for comparing corn yield for each N rate each year (C, continuous corn; CS, corn after soybean; CO, corn after oat; CCO, second corn after oat; CA corn after alfalfa group; cCoa, second corn after alfalfa).