AERIAL DRY MATTER AND NUTRIENT ACCUMULATION RATES FOR SOYBEAN AT DIFFERENT YIELD LEVELS

D. L. Karlen and E. J. Sadler

USDA-Agricultural Research Service
National Soil Tilth Laboratory, Ames, IA, and
Coastal Plains Research Center, Florence, S.C.

ABSTRACT

Managing plant nutrients in the most efficient and environmentally acceptable manner requires an understanding of when and at what rates they are accumulated by plants. To determine accumulation rates for soybean [*Glycine max* L. (Merr.)], mathematical splining was used to fit compound cubic polynomial equations through dry matter and nutrient accumulation data from five field experiments. Data from a maximum yield research (MYR) experiment that yielded 101 bu/a on Freehold sandy loam near Adelphia, N.J., in 1985 provided information for soybean grown with near-maximum dry matter and nutrient accumulation rates. The MYR results were compared to those determined for four non-MYR studies that yielded 35, 80, 50, and 32 bu/a in North and South Carolina. Accumulation patterns for determinate and indeterminate soybean cultivars were similar, although the determinate cultivars showed more fluctuation because plant growth conditions were not controlled as precisely as for the MYR study. Maximum aerial dry matter and nutrient accumulation rates for the MYR experiment were approximately twice that measured for the 80 bu/a crop, and three to four times greater than rates measured for the lower yielding crops. Results also suggest that soybean accumulates nutrients steadily throughout the growing season rather than during distinct vegetative and reproductive growth periods as previously shown by splining corn (*Zea mays* L.) data.

INTRODUCTION

Environmental and economic pressures on farmers and agribusiness emphasize the importance of applying plant nutrients in the most efficient and timely manner possible. To accomplish this goal, it is essential to quantify and understand effects of soil and crop management practices on amounts and rates of dry matter and nutrient accumulation by various crops.

One method for quantifying dry matter and nutrient accumulation rates is use of compound cubic polynomials (splining) to describe plant growth and nutrient accumulation data. This technique was introduced at a Foundation for Agronomic Research (FAR) workshop that emphasized corn (*Zea mays* L.) production (3), and has subsequently been used to describe aerial dry matter and nutrient accumulation patterns and rates for several corn data sets (4,5,6). Splining was also used to examine accumulation patterns for soft red winter wheat (*Triticum aestivum* L.) in the southeastern Coastal Plains (7). The advantage of describing accumulation data with compound cubic polynomials rather than with a least squares statistical approach, is that splining identifies periods of intraseasonal variation in accumulation rather than smoothing through those points. This requires an assumption that sampling variation is minimal and that the intraseasonal variation can be explained by changes in weather pattern, plant growth stage (ie vegetative vs reproductive), or by other factors affecting crop growth and development. If data are highly variable or have large standard errors at each point, intraseasonal fluctuations may be exaggerated.

The desire to examine rates and amounts of accumulation by soybean for this workshop provided an opportunity to use compound cubic polynomials to describe dry matter and nutrient accumulation patterns for a legume. We hypothesized that accumulation patterns for soybean might be different than previously identified for corn and wheat, because of their capacity for symbiotic N fixation and because they can have either a determinate or indeterminate growth pattern. Objectives of this study were to quantify and compare rates of dry matter and nutrient accumulation for five soybean data-sets that had yields ranging from 32 to 101 bu/a.

METHODS AND MATERIALS

Published information for 'Lee' soybean grown on Norfolk (fine-loamy, siliceous, thermic Typic Paleudult) loamy sand near Clayton, N.C., in 1966, 1967, and 1968 (2) and for 'Bragg' soybean grown on Goldsboro (fine-loamy, siliceous, thermic Aquic Paleudult) loamy sand near Florence, S.C., in 1979 (9,10,11,12) provided aerial growth and nutrient accumulation data for two determinate soybean cultivars. Fertilization, weed, and insect control were accomplished using recommended production practices for the North and South Carolina experiments. Seed yield for those experiments averaged 35, 80, 50, and 32 bu/acre, respectively.

Indeterminate 'Asgrow[1] A3127' soybean was grown on Freehold (fine-loamy, mixed, mesic Typic Hapludult) loamy sand in a maximum yield research (MYR) study near Adelphia, N.J. in 1985. A population of 205,000 plants/a was grown in 6-inch rows using a fertilization rate of (100-200-300-1-5-25-5 lb/ac, N-P_2O_5-K_2O-B-Cu-Mn-Zn, respectively), an insecticide [Diazinon (O,O-Diethyl O-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothiote)], a fungicide [Captan (cis-N-Trichloromethylthio-4-cyclohexene-1,2-dicarbosimide)], two herbicides [Treflan (2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine) and Scepter (2-{4,5-Dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl}-3-quinolin ecarboxylic acid)], supplemental irrigation, and a foliar fungicide [Benlate (Methyl 1-{butylcarbamoyl}-2-benzimi-dazole-carbamate)]. All of these were applied because the MYR objective was to remove as many physical, chemical, and biological constraints as possible so that the crop could express its genetic potential or biological optimum yield without consideration for economics, environment, or efficiency of nutrient use. Water stress was minimized by applying water through Chapin[1] double-wall tubing (Chapin Watermatics, Inc., Watertown, NY). A total of 9.0 inches of irrigation water was applied to supplement the 24.0 inches of rain that was received between 22 April and 15 October. Supplemental fertilizer was applied through the irrigation system when soybean were at early bloom and early pod-fill growth stages. Yield for this study averaged 101 bu/a.

Replicated, whole plant samples were collected from each experiment several times during the growing season. Samples were fractionated into leaves, stems, petioles, and pods + seeds; dried to determine aerial dry matter amounts; ground; and analyzed to measure N, P, K, Ca, and Mg

---

[1]Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA, and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

concentrations. Aerial accumulation was calculated for each sampling date, means were determined, and data were fitted mathematically using compound cubic polynomials (1). The interpolant polynomials were differentiated to determine rates of dry matter and nutrient accumulation. These values were plotted (8) as a function of days after planting.

RESULTS AND DISCUSSION

Seasonal weather patterns for the three locations (Clayton, N. C.; Florence, S.C.; and Adelphia, N.J.) and five seasons (1966, 1967, 1968, 1979, and 1985) are shown in Figs. 1 and 2. These data show that for the three North Carolina studies, the most favorable weather conditions for soybean production in occurred during 1967 when yield averaged 80 bu/a. In 1966 and 1968 when yield averaged only 35 and 50 bu/a, there were periods of water stress and temperatures were generally warmer. Higher yield in 1968 probably occurred because rainfall prior to flowering was greater. Management practices were similar each year, suggesting that water and heat stress were probably the most limiting factors in these studies.

Pan evaporation totaled 23.8 inches for the South Carolina study, but a total of 25.8 inches of rainfall and 5.6 inches of subsurface irrigation were applied to meet this demand (9). There was a brief period of mild drought stress between August 10 and September 4, but generally the soybean were grown without significant water stress. The most probable cause for a relatively low yield (32 bu/a) was an 11-inch rainfall (not shown on Fig. 2) associated with Hurricane David on 4 and 5 September. This occurred during pod-fill and presumably increased abortion of pods and seeds.

Weather conditions at the Adelphia, N.J., site were more favorable for soybean than at other locations, primarily because ocean breezes resulted in cooler night temperatures (Fig. 2). We hypothesize that those conditions reduced respiration loss of carbohydrate, which coupled with intensive management practices, helped achieve a very high yield (101 bu/a) and water use efficiency (3.26 bu/inch of seasonal rainfall plus irrigation).

Amounts and rates of aerial dry matter accumulation by soybean grown in these five studies are presented in Figure 3. Maximum aerial dry matter accumulation for the 1966, 1968 and 1979 soybean crops ranged from 4.0 to 4.5 t/a. The 1967 crop in North Carolina that yielded 80 bu/a (2) had an aerial dry matter accumulation of approximately 6.5 t/a, while dry matter accumulation for the 101 bu/a MYR crop in New Jersey resulted in an aerial biomass accumulation of 8.5 t/a.

Accumulation patterns were similar for all five crops, although the determinate, southern varieties reached their peak approximately 120 days after planting (DAP), while the indeterminate cultivar reached its peak approximately 100 DAP. This was approximately growth stage 9 for the indeterminate cultivar and although the exact growth stage was not recorded would probably be the same for the determinate cultivars. Dry matter accumulation rates for determinate cultivars generally fluctuated more during vegetative growth stages than was observed in previous studies with corn or wheat (3,4,5,6,7). This suggests that early season soybean growth patterns were very responsive to rainfall and surface soil water content.

The dry matter accumulation pattern for the indeterminate cultivar was similar to that found for corn and wheat (3,4,5,6,7), including the slight decline as flowering began. Peak vegetative accumulation rates ranged from 110 to 160 lb/a/day for the 1966, 1968, and 1979 determinate crops. The 1967 determinate crop had two periods of rapid vegetative growth with rates

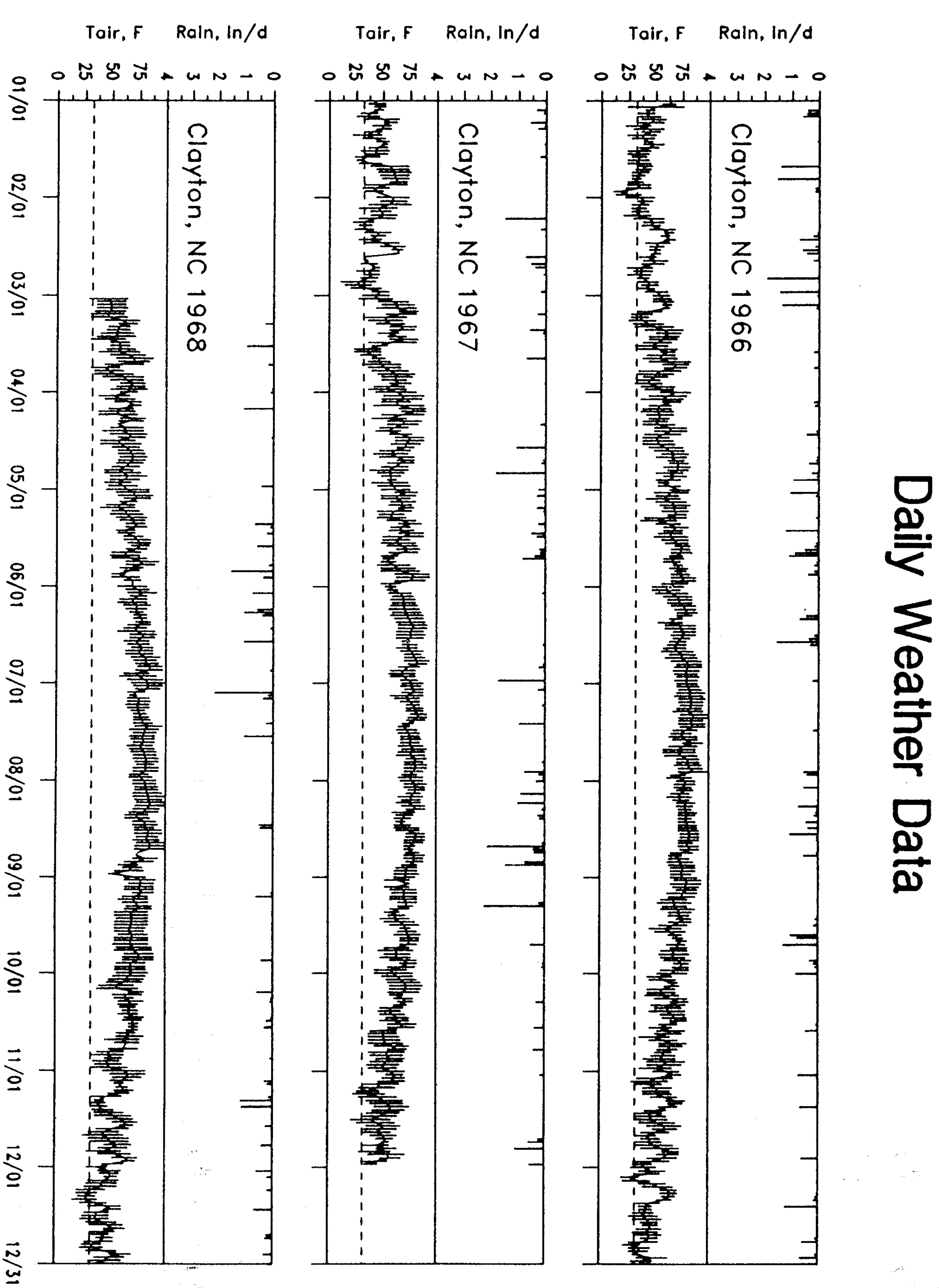


Figure 1. Temperature and rainfall for Clayton, N.C. in 1966, 1967, and 1968.

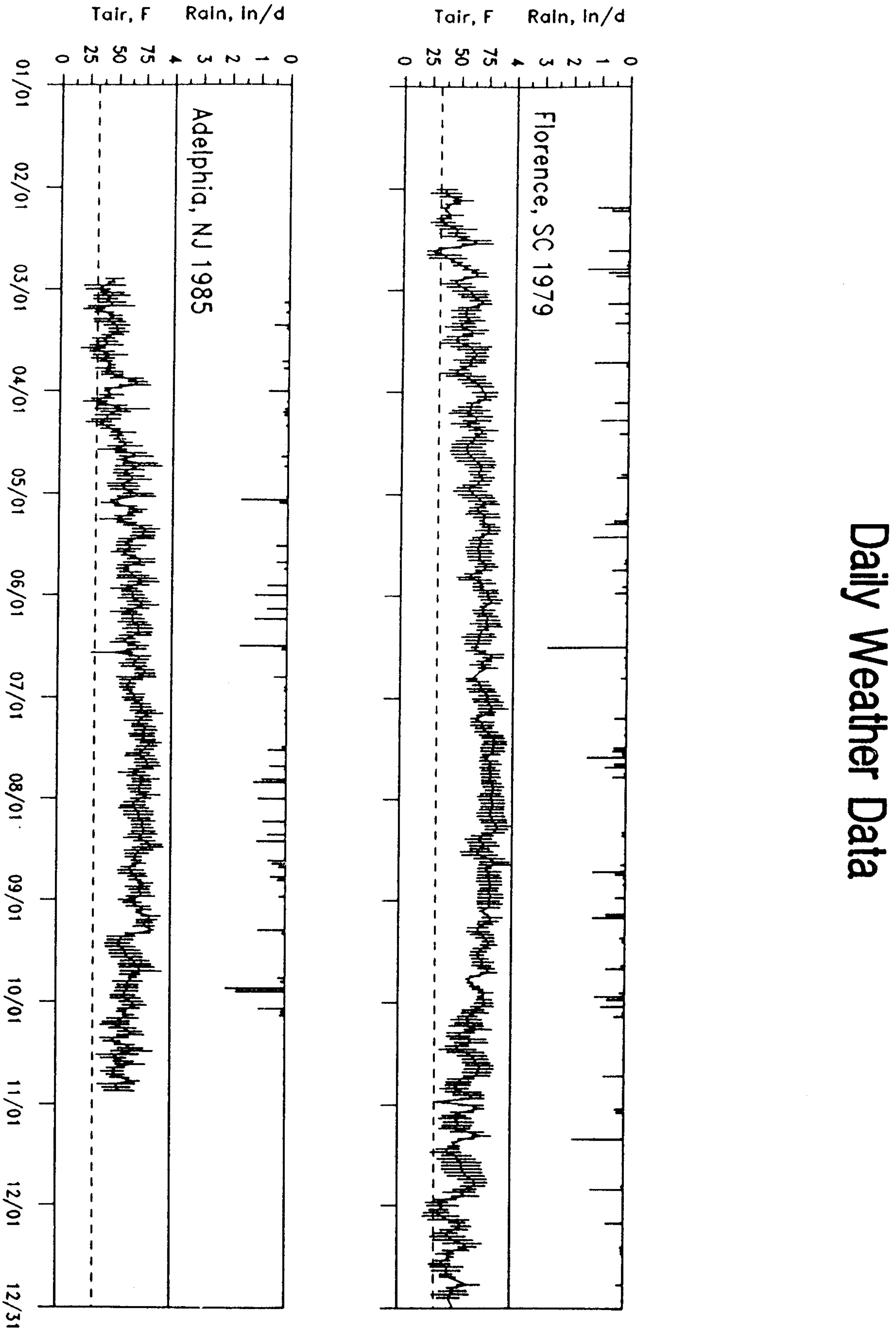
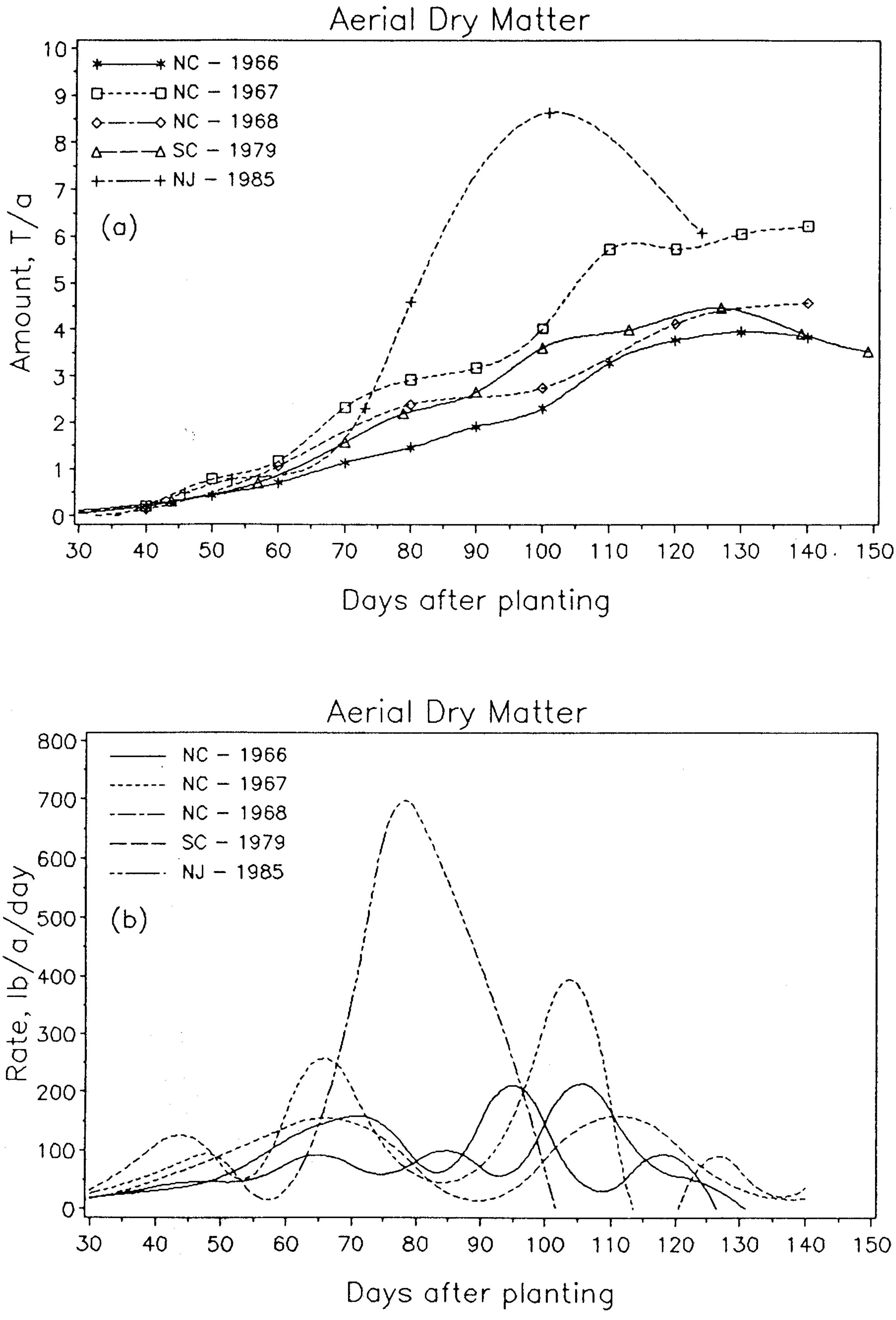


Figure 2. Temperature and rainfall for Florence, S.C. (1979) and Adelphia, N.J. (1985).

FIGURE 3. Total Amounts (a) and Daily Rates (b) of Accumulation.



ranging from 100 to 250 lb/a/day. The indeterminate cultivar had a maximum early-season dry matter accumulation rate of approximately 100 lb/a/day, which was less than for the 1967 determinate crop. After flowering began, however, aerial accumulation for the combined vegetative and reproductive growth was extremely high (averaging about 500 lb/a/day for 30 days). Peak dry matter accumulation rates for the determinate cultivars averaged about 200 lb/a/day during 1966, 1968, and 1979. The rates exceeded 400 lb/a/day for the 1967 crop, but for the MYR study they exceeded 700 lb/a/day.

Henderson and Kamprath (2) presented aerial dry matter and nutrient accumulation rates for the 1967 crop that were calculated by dividing the growing season into three periods (40-60, 60-100, and 100-110 days). Their data provide an opportunity to compare the splining method with a more traditional approach for determining accumulation rates. The 1967 rate curve (Fig. 3) shows three peak periods of dry matter accumulation. These occur at time periods similar to those identified by Henderson and Kamprath (2). Average dry matter accumulation for those periods, with a traditional approach, were 95, 145, and 339 lb/a/day, respectively. Splining predicted higher peak values (125, 250, and 425 lb/a/day), as expected, but midpoints for each peak (which would reflect integration across similar time periods) showed good agreement between the techniques. These results were similar to those shown previously for corn (3).

Nitrogen accumulation (Fig. 4) ranged from 240 to 260 lb/a for the 1966, 1968, and 1979 crops; peaked at about 420 lb/a for the 1967 crop, and exceeded 550 lb/a for the MYR study. Maximum N accumulation rates were less than 7.5 lb/a/day for the determinate crops, but exceeded 20 lb/a/day in the MYR study. Amounts and rate of N accumulation associated with very high soybean yield levels emphasize the importance of symbiotic N fixation and shows how soybean can consume more soil N rather than it contributes.

Phosphorus accumulation (Fig. 5) ranged from 14 to 21 lb/a for the 1966, 1968, and 1979 crops, exceeded 33 lb/a for the 1967 crop, and was greater than 58 lb/ac for the MYR crop. Maximum rates of P accumulation ranged from less than 0.5 lb/a/day to almost 2.0 lb/a/day for the MYR study and was in direct proportion to crop yield. As shown for dry matter and all other nutrients, peak P accumulation by the MYR crop occurred at about growth stage 9. Timely rainfall for the 1967 crop and prevention of plant water stress through surface irrigation in the MYR study probably increased diffusion rates and contributed to greater P accumulation by those crops. The 1979 soybean crop had lower P concentrations even though subirrigation was used to minimize water stress. This probably occurred because as water rose through the acid subsoil zone, most plant available P would be removed by relatively high Al and Fe concentrations. Furthermore, a well-managed subirrigation system probably would not wet the surface enough to increase diffusion.

Potassium accumulation (Fig. 6) ranged from 100 to 208 lb/a for all four determinate soybean crops, but exceeded 375 lb/a for the MYR study. Accumulation rates for K showed a much greater fluctuation for soybean than in either corn or wheat (3,4,5,6,7). The gramineous species consistently accumulated K primarily during vegetative growth stages with very low K accumulation rates during reproductive stages. Maximum K accumulation rates (5-17 lb/a/day) generally occurred when soybean pods and seeds were forming. This species difference was consistent with accumulation data presented by Henderson and Kamprath (2), probably reflecting interactions between K and nitrogen fixation as well as transport processes.

FIGURE 4. Total Amounts (a) and Daily Rates (b) of Accumulation.

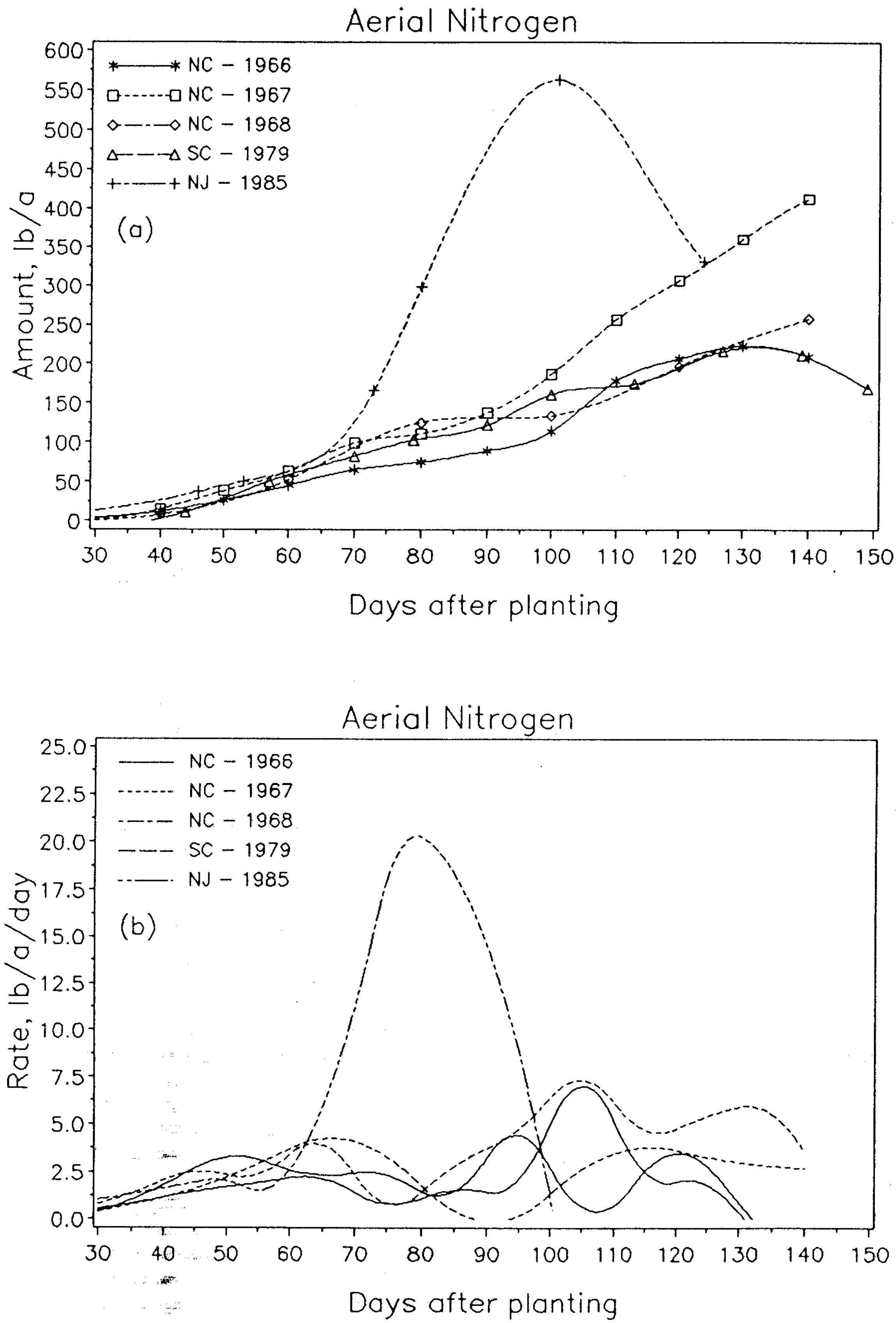
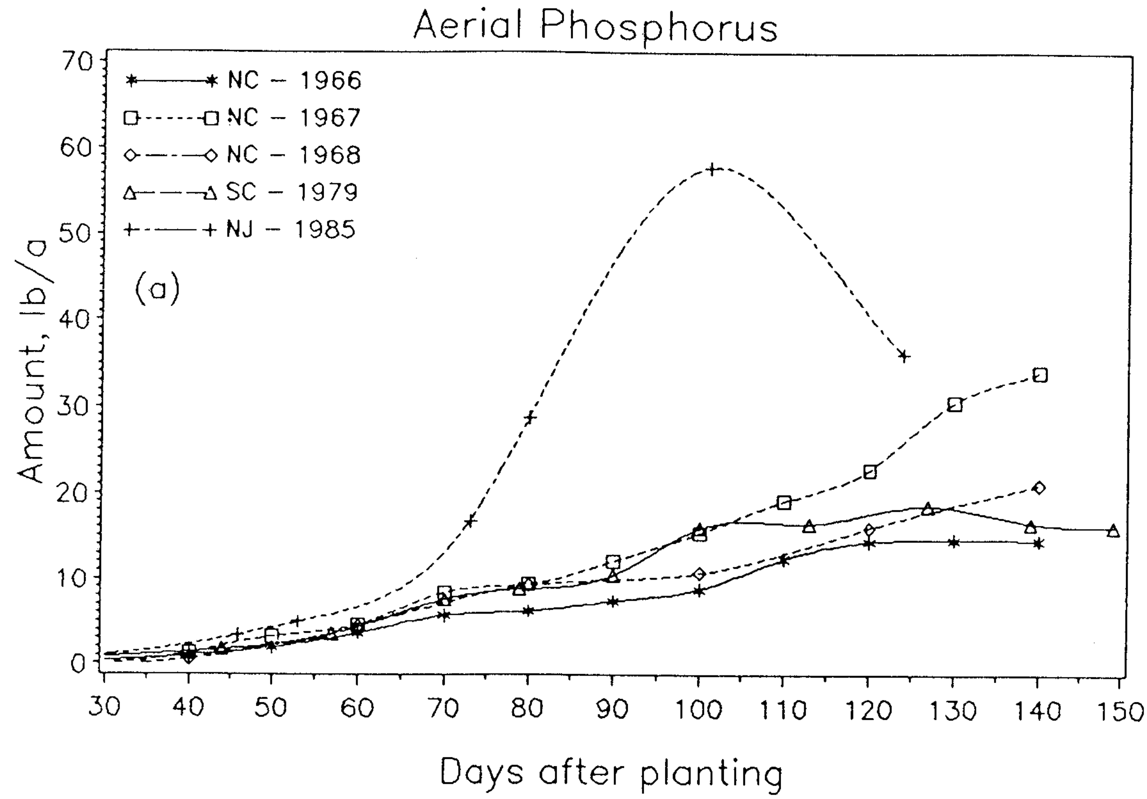


FIGURE 5. Total Amounts (a) and Daily Rates (b) of Accumulation.



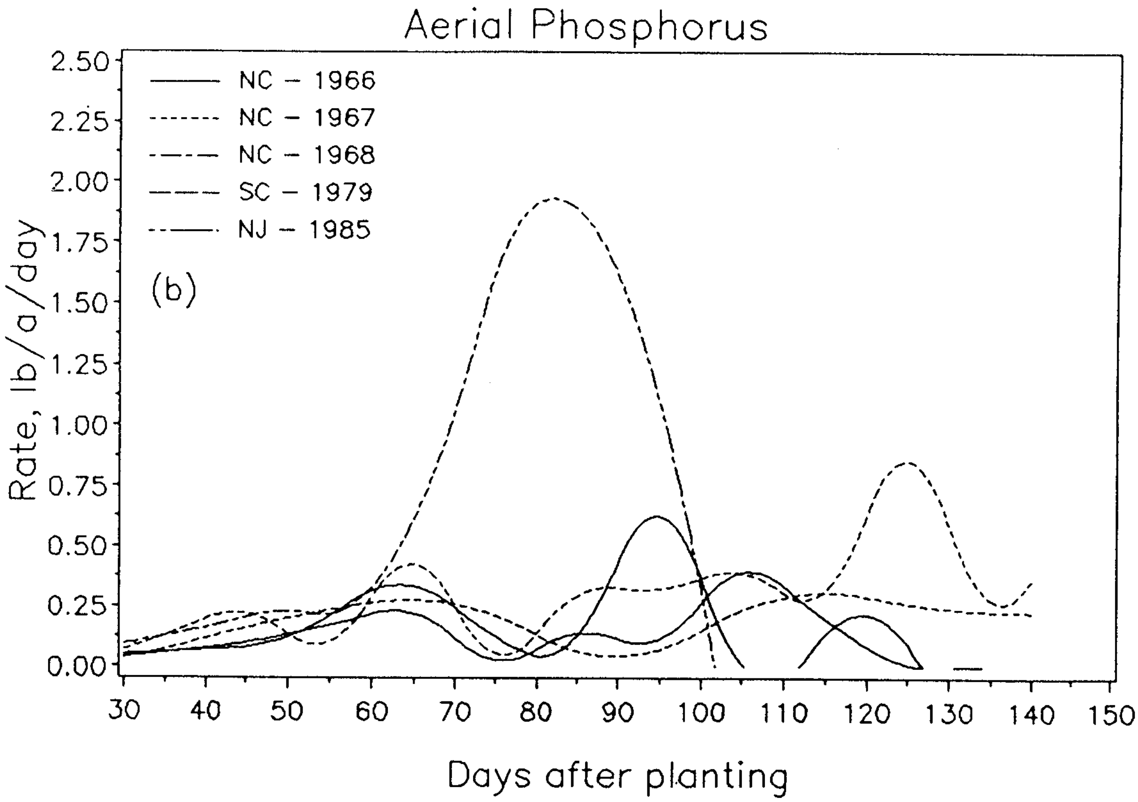
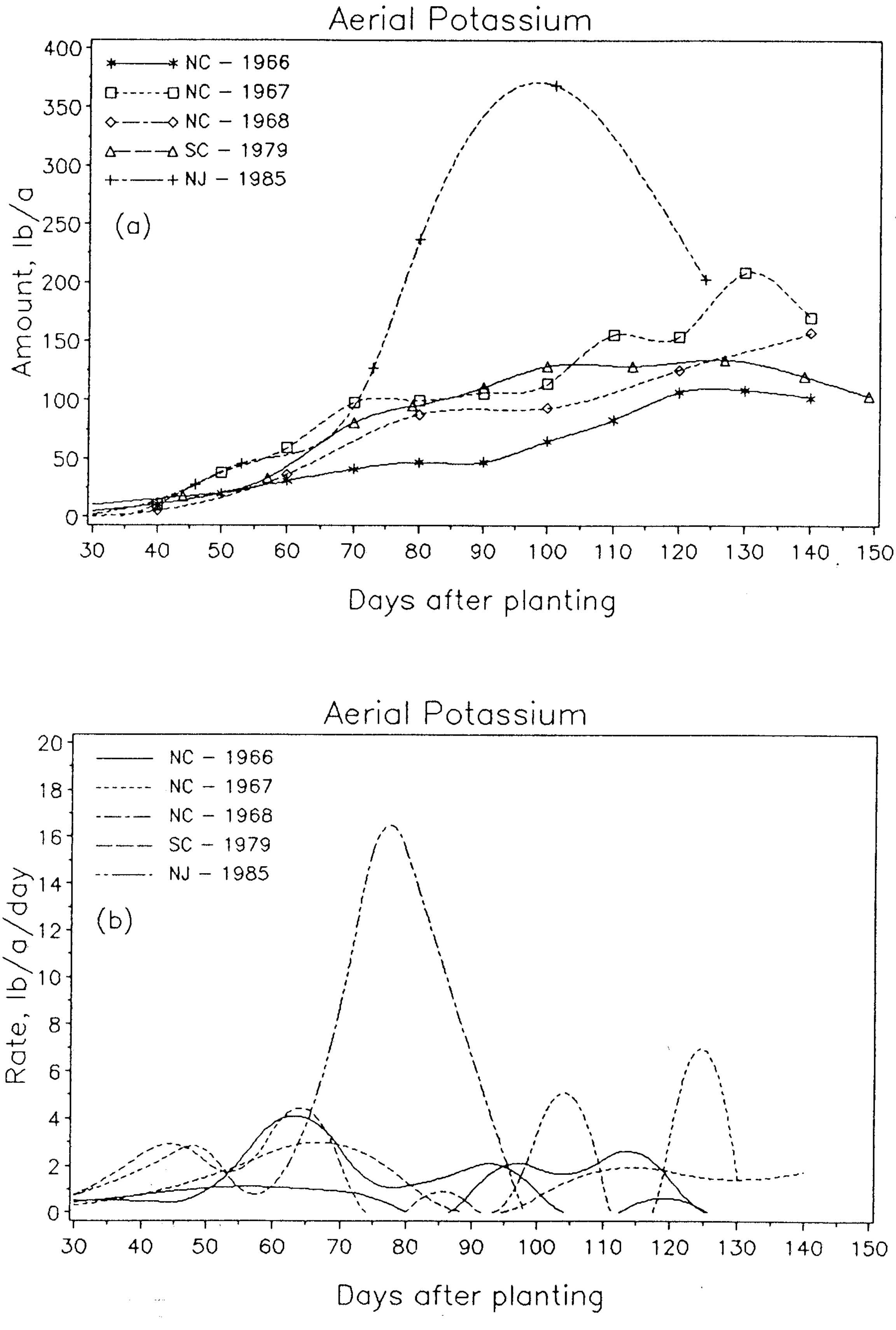


FIGURE 6. Total Amounts (a) and Daily Rates (b) of Accumulation.



Aerial accumulation patterns for Ca by soybean differed from those for corn because of a generally steady accumulation during pod fill (Fig. 7). Total accumulation ranged from 50 to 70 lb/a for the determinate cultivars, but exceeded 150 lb/a in the MYR study. Rates of Ca accumulation ranged from about 0.5 to 2 lb/a/day during the early season or vegetative growth stages, and from less than 0.5 to more than 6 lb/a/day during reproductive growth. Accumulation patterns for Ca except for the MYR study, appeared to fluctuate more than for other nutrients. This may have reflected periods of plant growth and differential amounts of Ca being moved to the plant root with transpirational water following rainfall events.

Magnesium accumulation patterns were similar to those for Ca with steady accumulation throughout the growing season (Fig. 8). Total aerial accumulation ranged from 20 to 30 lb/a except for the MYR study where it exceeded 58 lb/a. Rates of Mg accumulation were generally the highest when pods and seeds were forming. Rates for the southern data sets ranged from 0.5 to 1.0 lb/a/day, while Mg accumulation in the MYR study occurred during pod fill at a rate in excess of 2 lb/a/day. High Mg accumulation during pod fill was similar to that shown for MYR corn during grainfill (6).

SUMMARY AND CONCLUSIONS

The splining technique helped identify intraseasonal variation in dry matter and nutrient accumulation by soybean, especially the determinate cultivars that were exposed to greater environmental fluctuation. Aerial dry matter and nutrient accumulation patterns for determinate soybean generally did not show distinct peaks associated with vegetative and reproductive growth periods. The indeterminate cultivar grown in a MYR experiment did have two accumulation periods. The first occurred prior to flowering and was similar to that shown for determinate cultivars. When vegetative growth, flowering, and pod-fill began, accumulation rates for the MYR experiment were much greater than for non-MYR experiments. Maintaining adequate water and nutrient supplies throughout the season appears to be very important to prevent yield reductions and fluctuations in growth and nutrient accumulation.

The amounts and rates of aerial dry matter and nutrient accumulation by 101 bu/a soybean grown in an MYR study were approximately twice that reported for an 80 bu/a yield, and three to four times greater than the rate measured for other lower yielding determinate soybean crops. These results quantify potential rates at which nutrients can be accumulated by high-yielding soybean plants. However, MYR studies utilized extremely high fertilization rates, so to be economically or environmentally acceptable, profitability and sustainability of each factor will need investigation.

REFERENCES

1. Burden, R. L., J. D. Faires, and A. C. Reynolds. 1981. Numerical analysis. Prindle, Weber, and Schmidt. Boston, MA. 598 pp.

2. Henderson, J. B. and E. J. Kamprath. 1970. Nutrient and dry matter accumulation by soybeans. Tech. Bul. No. 197. North Carolina Agri. Expt. Stn., Raleigh, N.C.

FIGURE 7. Total Amounts (a) and Daily Rates (b) of Accumulation.

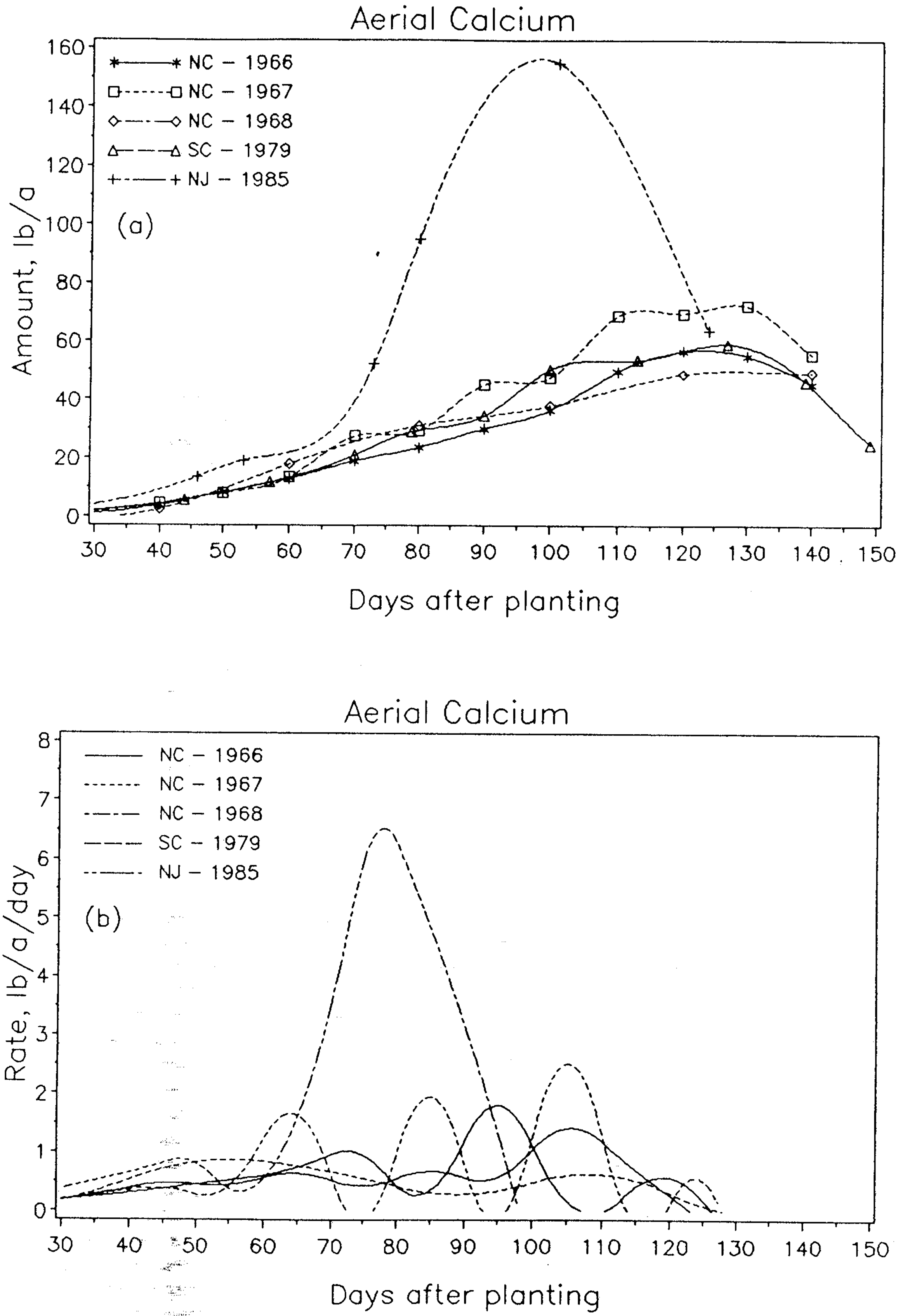
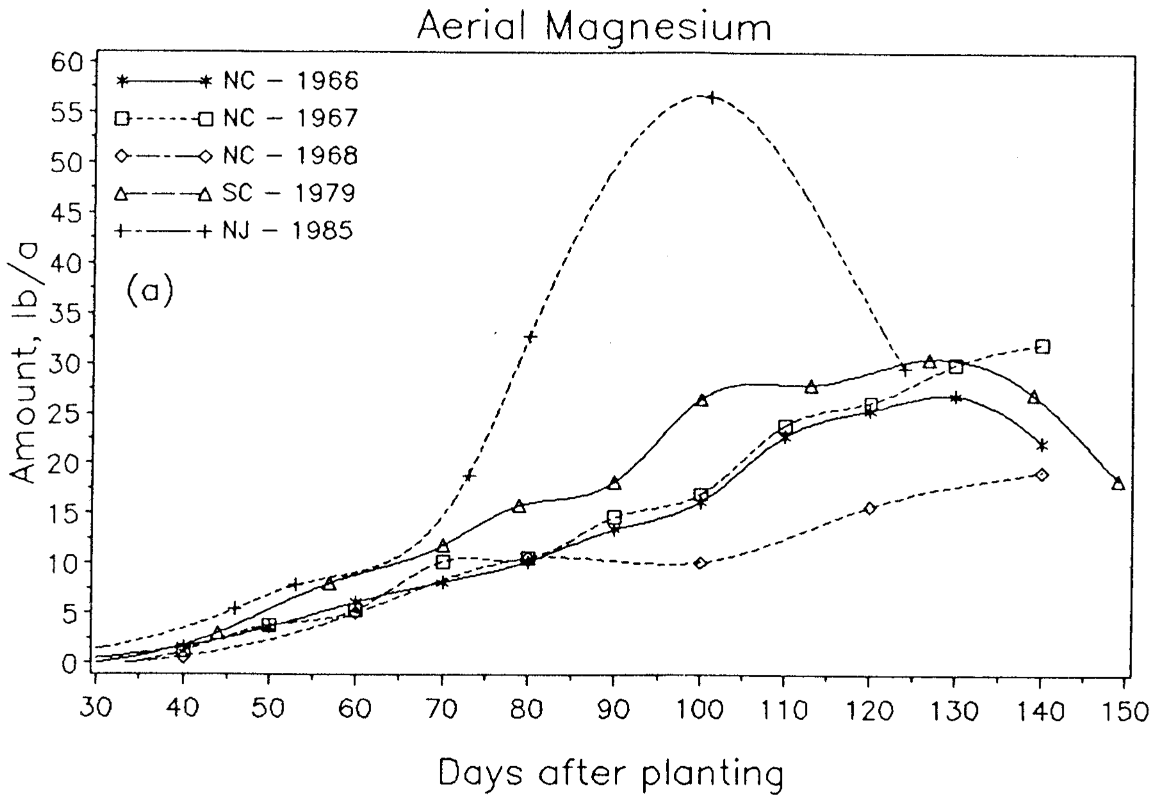
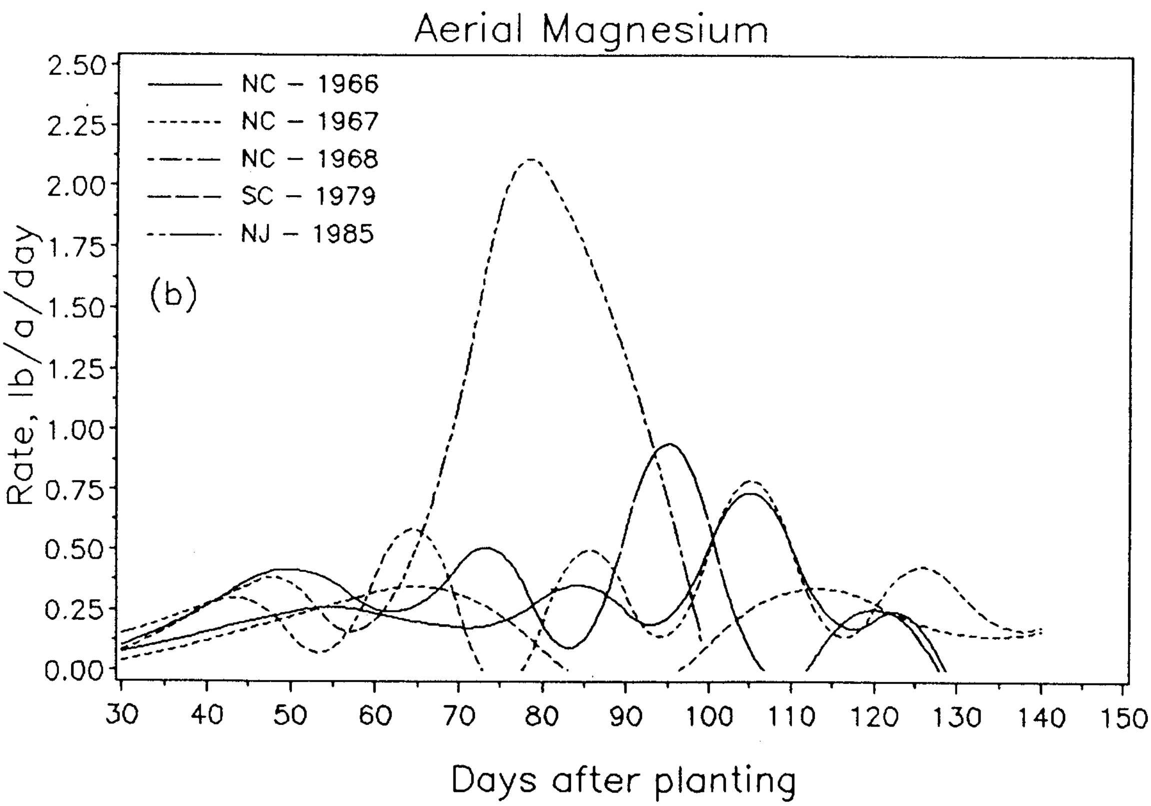


FIGURE 8. Total Amounts (a) and Daily Rates (b) of Accumulation.





3. Karlen, D. L. and E. J. Sadler. 1986. Seasonal N, P, and K uptake rates associated with high yield corn. *In* R. D. Munson (ed) Proc. Physiology, Biochemistry, and Chemistry Associated with Maximum Yield Corn. Foundation for Agron. Res., Atlanta, GA.

4. Karlen, D. L., R. L. Flannery, and E. J. Sadler. 1987a. Nutrient and dry matter accumulation rates for high yielding maize. J. Plant Nutrition 10:1409-1417.

5. Karlen, D. L., E. J. Sadler, and C. R. Camp. 1987b. Dry matter, nitrogen, phosphorus, and potassium accumulation rates by corn on Norfolk loamy sand. Agron. J. 79:649-656.

6. Karlen, D. L., R. L. Flannery, and E. J. Sadler. 1988. Aerial accumulation and partitioning of nutrients by corn. Agron. J. 80:232-242.

7. Karlen, D. L., and E. J. Sadler. 1990. Nutrient accumulation rates for wheat in the southeastern Coastal Plains. Comm. Soil Sci. Plant Anal. 21:000-000 (In Press).

8. SAS Institute. 1985. SAS User's guide: Statistics. Version 5 Edition. SAS Institute, Inc. Cary, N.C.

9. Scott, H. D., R. E. Sojka, D. L. Karlen, F. B. Arnold, V. L. Quisenberry, and C. W. Doty. 1983. Bragg soybeans grown on a southern Coastal Plains soil I. Dry matter distribution, nodal growth analysis, and sample variability. J. Plant Nutrition 6:133-162.

10. Sojka, R. E., H. D. Scott, and D. L. Karlen. 1985. Bragg soybeans grown on a southern Coastal Plain soil II. Seasonal changes in nodal K, Ca, and Mg concentrations. J. Plant Nutrition 8:751-785.

11. Sojka, R. E., D. L. Karlen, and H. D. Scott. 1986. Bragg soybeans grown on a southern Coastal Plain soil III. Seasonal changes in nodal Fe, Zn, and Mn concentrations. J. Plant Nutrition 9:1353-1390.

12. Sojka, R. E., D. L. Karlen, and H. D. Scott. 1989. Bragg soybeans grown on a southern Coastal Plain soil IV. Seasonal changes in nodal N and P concentrations. J. Plant Nutrition 12:939-972.