JOURNAL OF PLANT NUTRITION, 10(9-16), 1409-1417 (1987)

# NUTRIENT AND DRY MATTER ACCUMULATION RATES FOR HIGH YIELDING MAIZE

KEYWORDS: *Zea mays* L., maximum economic yield, N, P, K

D. L. Karlen, R. L. Flannery and E. J. Sadler

USDA-ARS
Soil & Water Conservation Research Center
Florence, South Carolina 29502 USA

New Jersey Agricultural Experiment Station
Rutgers University
New Brunswick, New Jersey 08903 USA

## ABSTRACT

The combined effects of improved hybrids, better water management, increased nutrient application rates, and higher plant populations have significantly increased maize (*Zea mays* L.) dry matter, grain yield, and nutrient accumulation when compared to benchmark data collected by Sayre in 1940 and Hanway in 1959. To evaluate the effects of those changes in management practices on seasonal rates of accumulation, aerial dry matter, N, P and K accumulation data from the benchmark studies, 2 recent field studies and a 1985 maximum economic yield (MEY) study were described with compound cubic polynomials. The equations were differentiated to determine rates and plotted as a function of growing degree units. Aerial accumulation patterns were similar for all 5 studies even though grain yields averaged 6.4 and 7.1 Mg $ha^{-1}$ in the benchmark studies, 9.7 and 14.0 Mg $ha^{-1}$ in recent studies, and 19.3 Mg $ha^{-1}$ in the MEY study. Peak daily N, P and K accumulation rates during vegetative growth were 3, 2, and 6 times higher with intensive management than in benchmark studies. During grain-fill, peak accumulation rates were doubled for N and P, but unchanged for K. Rate curves for all 5 data sets showed distinct peaks during both vegetative and reproduction growth stages. Double peaks suggest that for maximum maize yield a minimum stress environment must be provided during both vegetative and

reproductive growth stages. These results can be used to project optimum management strategies for profitable maize production.

## INTRODUCTION

Maize (*Zea mays* L.) yields have increased steadily because of improved hybrid yield potential, increased nutrient application rates, better water management practices, and higher plant populations. The Maximum Economic Yield (MEY) system is one integrated program that has encouraged higher yields by seeking to create a minimum stress environment and thus exploit the genetic potential within each seed. As a result of MEY maize research, grain yields ranging from 15.7 to 21.2 Mg $ha^{-1}$ have been achieved 20 times in just 5 years (4).

Total aerial dry matter, N, P and K accumulation have also increased as grain yields have risen. This is most evident when data collected at high yield levels (7,9,15) are compared with benchmark data published by Sayre (12) or Hanway (5,6). The objective of this study was to compare amounts and rates of N, P, K, and dry matter accumulation for maize yielding 6.4, 7.1, 9.7, 14.0 and 19.3 Mg $ha^{-1}$ and thus determine the effect of MEY and other intensive management systems on maize growth and nutrient accumulation.

## METHODS AND MATERIALS

Published dry matter, N, P and K accumulation data (5,6,7,9,12) were compared with data collected in a 1985 MEY study conducted on a Freehold sandy loam at the Soils and Crops Research Center near Adelphia, New Jersey, USA, to determine how management influences accumulation rates. Pioneer Brand 3192 hybrid maize was planted 1 May 1985, using an equidistant .3m x .3m spacing (107,600 plants $ha^{-1}$). The MEY practices included applying 152 mm of irrigation water, insecticides, herbicides, lime, and a fertilization rate of 560, 145, and 420 kg $ha^{-1}$ of N, P and K, respectively. Whole plant samples were collected at growth stages V4, V8, V12, VT, R1, R2, R5, and R6 (10).

Seasonal growing degree units (GDUs) were computed with a 10-30 C index (13) so that all studies could be compared on a physiological scale. The data were described with compound cubic polynomials (2) which were differentiated to determine the rates of accumulation. The curves were plotted using SAS (11) Graphics.

## RESULTS AND DISCUSSION

Aerial dry matter accumulation which averaged 31.8 Mg $ha^{-1}$ in a 1985 MEY study is compared to benchmark data averaging 13.9 and 17.3 Mg $ha^{-1}$ (12,5) in Fig. 1a and with recent accumulation

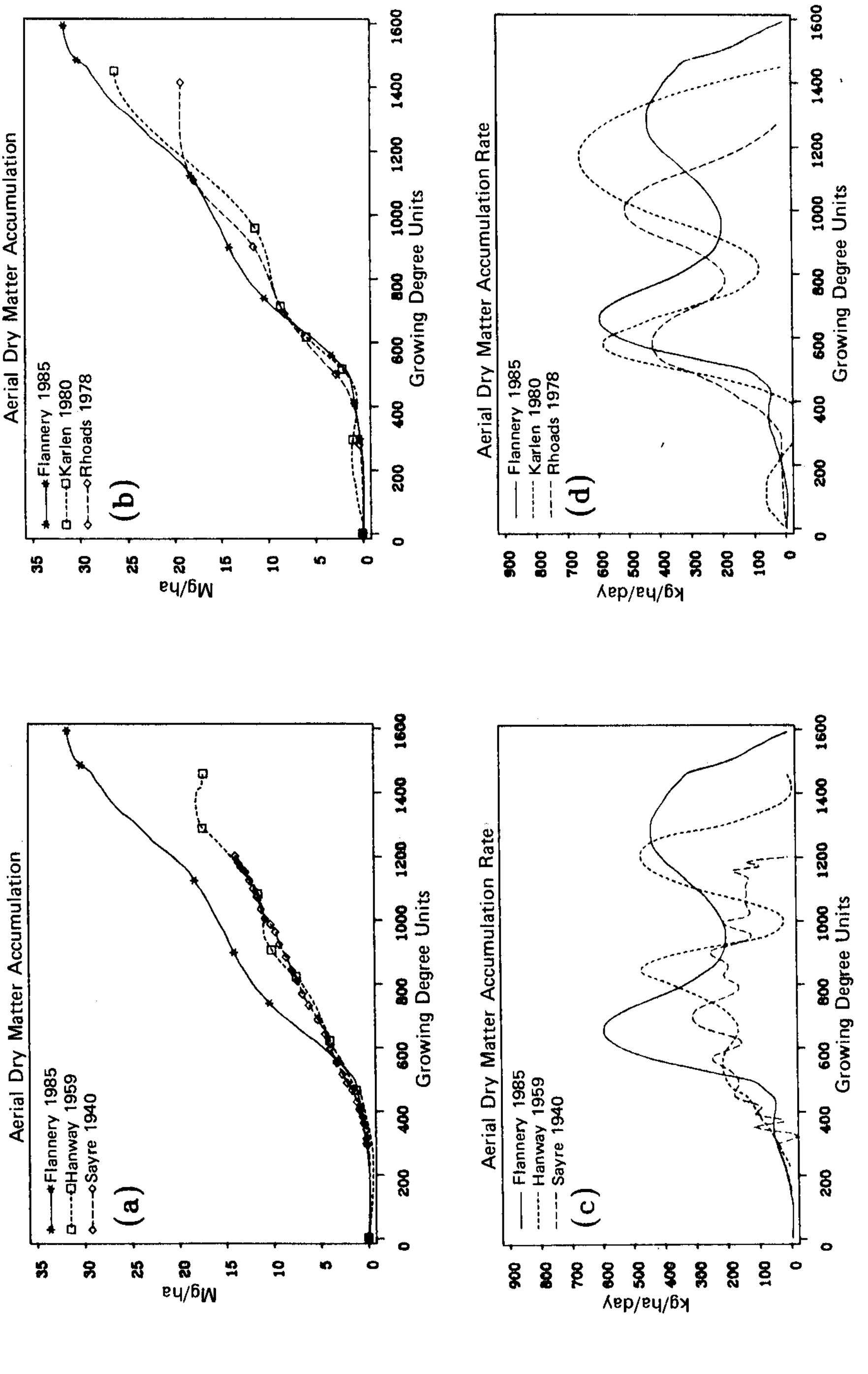
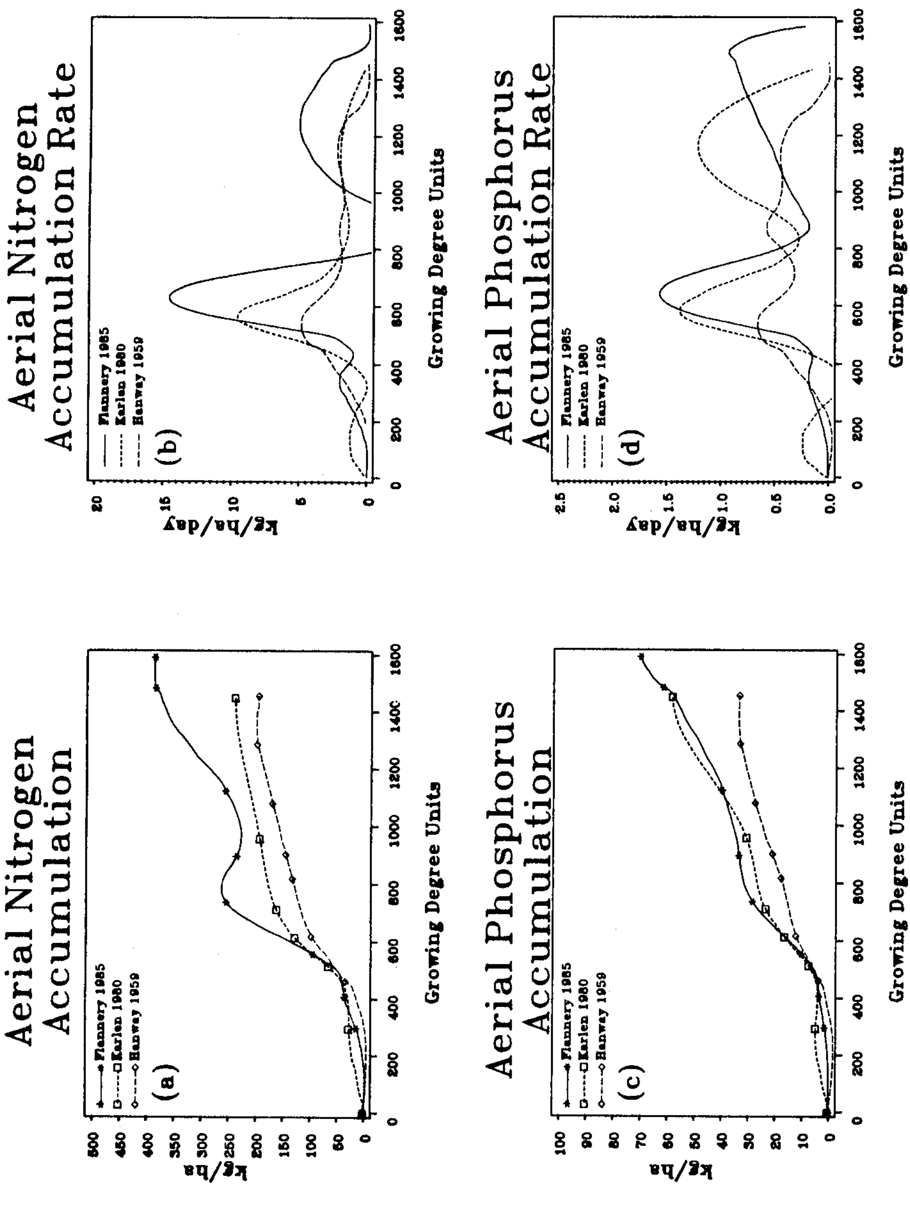



FIG. 1. Seasonal amounts (a,b) and rates (c,d) of dry matter accumulation by maize.


Aerial Nitrogen Accumulation
(a)
Flannery 1985
Karlen 1980
Hanway 1959
kg/ha
Growing Degree Units
Aerial Nitrogen Accumulation Rate
(b)
kg/ha/day
Aerial Phosphorus Accumulation
(c)
Aerial Phosphorus Accumulation Rate
(d)

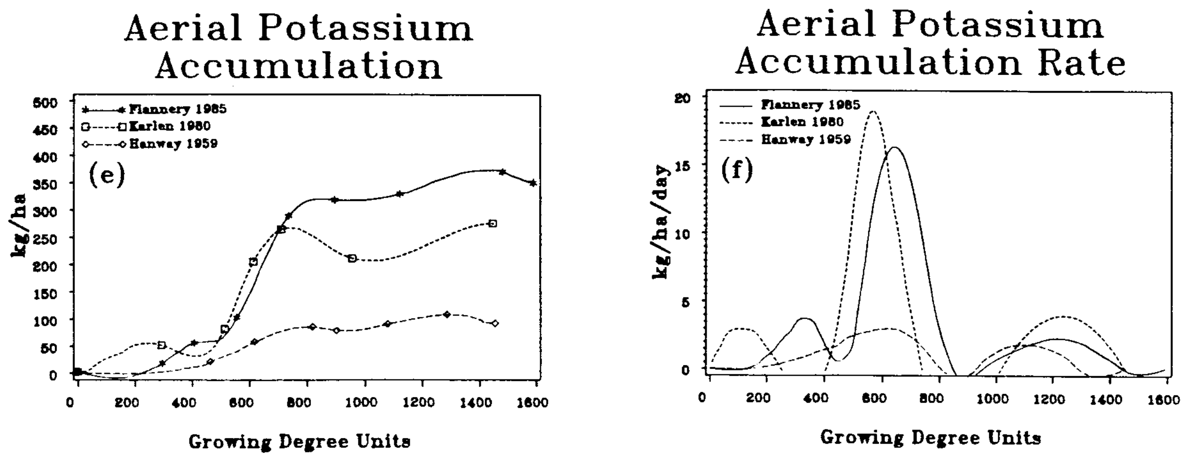



FIG. 2. Seasonal amounts (left) and rates (right) of N, P and K accumulation by maize.

data averaging 19.3 and 26.3 Mg ha-1 (9,7) in Fig. 1b. Accumulation patterns for all 5 maize studies are similar even though grain yields averaged 6.4 and 7.1 Mg ha-1 in benchmark studies, 9.7 and 14.0 Mg ha$^{-1}$ in recent studies, and 19.3 Mg ha$^{-1}$ in the MEY study. Similarity in growth curves among studies conducted over a period of 45 years suggests that cultural practices such as hybrid selection, water and nutrient management are primarily responsible for increased maize yields. Two hybrid improvements which have increased yields are better cold tolerance and the ability to produce grain at much higher plant populations. These growth and development characteristics have increased the effective growing season because of earlier planting dates and enabled populations to be increased as much as 400@%@ [26,300 plants ha$^{-1}$ in 1940 (12) vs 107,600 plants ha$^{-1}$ in 1985]. The ability to produce grain at high plant populations is especially important for intensive management systems such as MEY because after soil fertility, water, weed, and insect limitations are reduced, the arrangement and density of plants becomes the next most limiting factor affecting productivity (3).

Aerial dry matter accumulation rates (Figs. 1c and 1d) show distinct periods of peak accumulation during both vegetative and reproductive growth stages. Two peaks are present in all 5 maize data sets, although they are least evident in Sayre (12) data which was collected every 3 days. Recognizing 2 peaks is important because the first one occurs during vegetative growth stages V12-V18 (10) when ear size and number of ovules (potential kernels) are being established and while photosynthate reserves are being accumulated in the stalk and leaves. The second peak occurs during grain-fill when final kernel number and size are being determined. Traditional management concentrates on providing minimal stress during pollination and grain-fill (13), but for maximum yield, a minimum stress environment must also be provided during vegetative growth stages. The importance of the first peak may be greater for single-eared hybrids than prolifics, but most current commercially available hybrids are single eared.

Peak rates of dry matter accumulation in the MEY study were approximately 600 and 450 kg ha$^{-1}$ day$^{-1}$ during vegetative and reproductive growth stages, respectively. These rates were similar to those in recent maize studies (7,9) but greater than the benchmark studies. The most significant difference among the 5 studies, however, was the magnitude and duration of the first peak in the MEY study. This further emphasizes the importance of establishing a high potential yield and then achieving it.

Seasonal N, P and K accumulation for the Hanway (6), Karlen and Camp (7), and MEY studies are shown in Fig. 2. Total N accumulation in those studies averaged 197, 238, and 386 kg ha$^{-1}$, respectively, and was proportional to grain yield. Accumulation patterns were similar at the very early growth stages (@E@500 GDUs), but segregated according to yield between approximately 500 and 800 GDU. The MEY study showed significantly greater N accumulation during both vegetative (@E@800 GDUs) and reproductive growth. This probably occurred because of the greater fertilization rate, but may also reflect differences in hybrid ability to respond to increased N (14). Total P accumulation in the studies averaged 33, 58, and 70 kg $ha^{-1}$, respectively. The amount of P accumulation during vegetative growth (@E@800 GDUs) was also proportional to grain yield. High P accumulation is important because of its role in the formation of nucleic acids, phospholipids, and other energy compounds (14). Total K accumulation averaged 107, 274, and 370 kg $ha^{-1}$, respectively. Patterns of accumulation differed primarily during vegetative growth when most of the K was accumulated. This presumably reflected the higher plant populations which required more K for stalk strength. However, K accumulation during vegetative growth must be in balance with N and other nutrients (8).

Daily rates of N, P and K accumulation for the Hanway (6), Karlen (7), and MEY studies are also shown in Fig. 2. Peak N accumulation rates for the 3 studies averaged 5, 10, and 15 kg $ha^{-1}$ $day^{-1}$, respectively, during vegetative growth and were directly proportional to grain yield. The N accumulation rate during grain-fill in the MEY study averaged about 5 kg $ha^{-1}$ $day^{-1}$ or approximately twice as high as in the other 2 studies. Peak P accumulation rates during vegetative growth were approximately 0.7, 1.4, and 1.6 kg $ha^{-1}$ $day^{-1}$, respectively, and were also proportional to grain yield. Peak rates of P accumulation during grain-fill averaged approximately 0.55, 1.25, and 0.95 kg $ha^{-1}$ $day^{-1}$, respectively, but were not proportional to grain yield. Peak K accumulation rates in the Karlen (7) and MEY studies averaged 18 kg $ha^{-1}$ $day^{-1}$ and were approximately 6 times higher than in the Hanway (6) study. This K accumulation rate was not unusual for current high yield maize (15), presumably because of increased plant population.

## SUMMARY AND CONCLUSIONS

The amounts and rates of dry matter, N, P, and K accumulated by maize yielding 6.4, 7.1, 9.7, 14.0, and 19.3 Mg $ha^{-1}$, respectively, were compared to evaluate how the combined changes in factors such as hybrid characteristics, water management, and fertilization rates have influenced maize growth and nutrient accumulation during the past 45 years. Dry matter and grain yield appear to have increased with intensive management programs such as MEY because slightly higher daily growth rates are sustained for a longer period of time during both vegetative and reproductive growth stages. Peak N, P, and K accumulation rates during vegetative growth have increased 3, 2, and 6 times, respectively, compared to benchmark rates. Peak rates of accumulation during grain-fill have doubled for N and P, but were not significantly different for K. This presumably occurred because maize accumulates most of its K during vegetative growth. The most important observation, however, is recognizing that during the maize life-cycle, there are 2 periods when dry matter and nutrient accumulation occur at peak rates. The first peak occurs when potential yield is being established, and the second occurs when final yield is being determined. This information can be used to optimize maize management practices such as irrigation scheduling or fertilization. It suggests that for maximum yields, a minimum stress environment must be provided during both vegetative and reproductive growth stages. It can also be used as an aid in selecting hybrids which "peak" during generally favorable weather and thus make maize production more profitable.

## REFERENCES

1. Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agr., the N.J. Agr. Expt. Stn., or the S.C. Agr. Expt. Stn. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

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

3. Downey, L. A. 1971. Plant density-yield relations in maize. J. Aust. Inst. Agric. Sci. 37:138-146.

4. Griffith, W. K. and D. W. Dibb. 1985. Research...The Future...and PPI. Better Crops with Plant Food. 69:34-37.

5. Hanway, J. J. 1962a. Corn growth and composition in relation to soil fertility: I. Growth of different plant parts and relation between leaf weight and grain yield. Agron. J. 54:145-148.

6. Hanway, J. J. 1962b. Corn growth and composition in relation to soil fertility: II. Uptake of N, P and K and their distribution in different plant parts during the growing season. Agron. J. 54:217-222.

7. Karlen, D. L. and C. R. Camp. 1982. N, P and K accumulation by high-yielding irrigated maize grown on a Typic Paleudult in the Southeastern U.S. In A. Scaife (ed.). Proc. 9th Intl. Plant Nutri. Colloq., Warwick Univ., England. 1:262-267.

8. 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.

9. Rhoads, F. M. and R. L. Stanley, Jr. 1981. Fertilizer scheduling, yield, and nutrient uptake of irrigated corn. Agron. J. 73:971-974.

10. Ritchie, S. W. and J. J. Hanway. 1984. How a corn plant develops. Special Rpt. No. 48. Iowa State Univ. Coop. Ext. Ser., Ames, IA.

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

12. Sayre, J. D. 1948. Mineral accumulation in corn. Plant Physiol. 23:267-281.

13. Shaw, R. H. 1977. Climatic requirement. In G. F. Sprague (ed.). Corn and Corn Improvement. Agronomy 18:591-623.

14. Tsai, C. Y., D. M. Huber, H. L. Warren and L. Lyznik. 1986. Corn physiology and genetics as they interact under nutrient stress. In R. D. Munson (ed.). Proc. Physiology, Biochemistry, and Chemistry Associated with Maximum Yield Corn. Foundation for Agron. Res., Atlanta, GA.

15. Welch, L. F. and R. L. Flannery. 1985. Potassium nutrition of corn. In R. D. Munson (ed.). Potassium in Agriculture. Am. Soc. Agron., Crop Sci. Soc. of Am., and Soil Sci. Soc. Am., Madison, WI.