THE SEASONAL GROWTH OF TROPICAL PASTURE GRASSES ON THE MID-NORTH COAST OF N.S.W.

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EXPERIMENTAL

The aims of this project were to measure the yields and seasonal growth curves of three tropical grass species - Kikuyu, Kazungula Setaria and Broadleaf Paspalum - and how these are affected by nitrogen, water supply and the climate of the mid-north coast. The grasses were also compared to determine if there are any differences between them that could be exploited in pastures.

Location.

The experiment site was located approximately 1 kilometre south of the Taree post office, along the Glenthorne road at Glenthorne. The experiment was situated on an alluvial soil. Full details of the site are presented in appendix 1.

Experimental design.

The basic experimental design was a factorial combination of three speciesxtwo nitrogen levels x two moisture levels x six replications. The treatments were related to commercial practice.

The three species involved were Kikuyu, Kazungula Setaria and Broadleaf Paspalum. To improve estimates of error there were twice as many Kikuyu plots as each of the other species.

The two nitrogen levels adopted were a low rate of 17 kg nitrogen per hectare per harvest and a high rate of 68 kg N per hectare per harvest. Nitrogen was applied after each harvest. The dates of application were the same as the harvest dates shown in appendix 3. Ten harvests were taken from each plot each year bringing the annual totals of applied nitrogen to 170 and 680 kg N ha^{-1} respectively. The low rate of nitrogen was selected to represent a low level of pasture production such as would be expected when a legume was the sole source of nitrogen (Jenzell, Fergus and Martin 1966, Smith 1962) or from an all grass pasture occasionally fertilized with nitrogen. The high rate of nitrogen (four times the low rate) was chosen as being a rate at which restriction of grass growth due to lack of nitrogen would not be large and yet not a rate greatly in excess of the maximum nitrogen rates that farmers consider to be economic on intensively managed Kikuyu pastures on the mid-north coast.

In addition to the two basic rates of nitrogen, 16 plots (8 Kikuyu, 4 Setaria and 4 Broadleaf) that received no nitrogen were included in the experiment to serve as controls and estimate the base soil level of "available" nitrogen.

The two moisture levels adopted were irrigated and non-irrigated. The irrigation treatment aimed at simulating a well irrigated pasture rather than a nil water stress situation.

The experiment site was split into two main plots with one plot being irrigated, the other not. There was no replication of the irrigation treatment. All other treatments were arranged in a randomized block layout within each main plot.

Replications were split into three series and harvested using the technique of Anslow and Green (1967) as discussed in the review of literature. Basically this approach involves cutting plots in a staggered sequence such that for anyone point in time there are three estimates of pasture growth rates, from which a mean pasture growth curve over time can be calculated. An appreciation of this approach can be obtained from examing the actual harvest dates for each series as shown in Appendix 3.

Harvest intervals were chosen to coincide with the frequency that good Kikuyu pastures are grazed on the mid-north coast. Such pastures are generally grazed every 3-4 weeks in summer and possibly once in winter. In the experiment plots were cut at intervals ranging from 3-4 weeks over summer to 10 weeks in winter.

Plots.

The plot size was 2.44m x 4.78m, and the area sampled from each plot 0.91m x 2.95m. To prevent invasion from neighbouring plots, particularly from Kikuyu, there was a space of 0.30m between plots on the long side and 1.00m space at the end of each plot. Each replicate covered an area of 10.67m x 38.91m and the whole experiment was situated within an area of 44m x 65m.

Irrigation.

A daily water balance was calculated to determine when to irrigate as explained later in the section on water balance models. In the first year plots were irrigated with a sprinkler system. Because such a system causes uneven distribution of water due to overlapping of sprays, this resulted in overwatering of some plots. In the second year, a specially designed irrigation plant was used that applied water more uniformly. (see illustrations 4 and 5) This plant consisted of two pipes, 120cm above ground, mounted on sleds that were drawn up the slight slope through the plots, by a wire attached to a slow moving electrically driven winch. Once started the equipment operated automatically, and had various cut out devices for safety and when irrigation was finished. Under tests, the application of water was reasonably uniform; at an output of 40mm (the most common application rate) the variation was from 37 to 43mm. Output could be changed by varying nozzle size or winch speed.

Irrigation water was drawn from a well sunk in the alluvial terrace approximately 100m from the Manning River. Initially the quality of the water was good, however, following several dry periods associated with heavy demands for water, salt influences were noted. Salt levels in the irrigation water were at times up to 2500ppm and conductivity levels up to 3mmhos/cm.

Pasture sampling.

All plots were sampled with an autoscythe with a 91cm cutter bar. First strips 91cm wide were removed from each end of the plot to be harvested, then a strip 91cm wide was mown down the centre of the plot, weighed green and a subsample of 450g taken for dry matter and chemical analysis. The remainder of each plot was then mown and all clippings were removed.

Kikuyu and Broadleaf Paspalum plots were harvested at a height of 7-8cm and Kazungula Setaria at 11-12cm. Previous observations had indicated that frequent low cutting of Setaria tended to make plants more susceptible to frost damage.

Samples were dried in a force draught oven at 80C for 20 hours. If samples could not be put into the oven within 2 to 3 hours of harvesting, they were stored in a cool room at -2 to -4C.

After drying, the samples from replicates and series were bulked into treatments for each harvest period and then forwarded for analysis of nitrogen content by the Chemistry Branch of the N.S.W. Department of Agriculture at Rydalmere. Nitrogen was determined by the Kjeldahl method. Facilities prevented an analysis of more samples.

Soil samples.

Samples of the surface soil were taken from the site prior to the commencement of the experiment and then in winter each year to assess the effects of the various treatments. The results of these soil analyses are presented in appemdix 2.

Species, seed bed and establishment.

Kikuyu cuttings obtained from near the experiment site were sown at 40-50cm spacing into a prepared seed bed. Kazungula Setaria and Broadleaf Paspalum were sown at 10 and 20 kg seed ha^{-1} respectively into a well prepared seed bed. Plots were sown on the 14th and 15th of November 1968. Over the summer and autumn of 1968/69 all plots were irrigated at intervals. All plots were well established by February 1969. Plots were then mown at intervals of approximately four weeks until July, 1969, when the experiment commenced.

Fertilizer.

The amount and time of application of fertilizer to each plot are shown in table 4. Nitrogen was applied as ammonium nitrate, phosphorus as single superphosphate and potassium as potassium chloride.

Table 4. Basal fertilizer applied kg element ha^{-1}

DATE	NITROGEN	PHOSPHORUS	POTASSIUM
November 1968	50	75	90
Feb-May 1969	120(i)		
1st August 1969	(ii)	43	60
July 1970		75	200
July 1971		75	200

(i) Three equal applications of 40kg nitrogen during establishment period.

(ii) Nitrogen treatments imposed and harvesting commenced. Plots were regularly topdressed with 0, 17 or 68kg N ha^{-1} on the dates shown in appendix 3.

<u>Weed control.</u>

The prevention of invasion of plots of one species by another was achieved by initially spraying the space between plots with a 30cm band of Bromacil to prevent root and rhizome growth, then periodically spraying the same area with 2,2-DPA. Broadleaf weeds and clover were controlled by hand cultivation or spot spraying with 2,4-D when required.

<u>Climatic data.</u>

At the field site screen temperature and relative humidity were recorded by a Casella type thermohygrograph and rainfall by a Lambrecht Hellmann type recording rain gauge. The thermohygrograph was checked for accuracy with an Assmann Aspiration Psychrometer when charts were changed. Soil temperature was only recorded during 1971-72 as the required thermograph was not available earlier.

The local meteorological station at Taree is situated 1.5km from the field site and an American Class A evaporation pan, and a Rimco type silicone cell integrating pyranometer for recording incoming solar radiation were located there. Data from these instruments were recorded daily by staff at the meteorological station. Regressions were established between temperature at the met. and field sites and these were used to fill in gaps in data when the recording instruments were undergoing maintenance. Fortunately such gaps were few.

A regression was also derived for solar radiation data recorded at Williamtown and at Taree. This equation was used to fill in a gap when the recording instrument at Taree was being repaired.

The regressions used are listed - all were derived from weekly data
(Y = field site, X= meteorological station Taree).

1. Maximum temperature (F) $Y = 0.71 + 0.96\ X$ (SD = 1.31 $r = 0.98$)
2. Minimum temperature (F) $Y = 7.44 + 0.87\ X$ (SD = 1.48 $r = 0.98$)
3. Solar radiation (cals cm^{-2} day^{-1}) $Y = 51.81 + 0.074\ X$ (SD = 54.11 $r = 0.93$)

X = Williamtown data as mW cm^{-2} day^{-1}.

Analysis of data.

Results were analysed for each irrigation treatment using standard analysis of variance techniques. The irrigated and unirrigated plots were analysed separately as there was no replication of the irrigation treatment. The errors for each irrigation treatment were similar at each harvest, enabling comparisons to be made.

Series were combined into "harvests" for analysis as shown in appendix 3. Along with the individual harvest yields the mean growth rate for each plot over each growth period was also calculated and analysed in the same way as the yields. This enables calculation of the errors associated with the growth curves at various points in time, ie. for each "harvest". The nil nitrogen plots were not included in the analysis as they were few and irregularly replicated. Harvest yields were totalled for each plot over each 12 month period and the yields analysed in an analysis of variance. The analysis of variance programme AGBANOV developed by the N.S.W. Department of Agriculture Biometry Branch was used for all the above analyses. An example of an analysis is given in appendix 4.

Once the individual harvests were analysed, and estimates of the variation at any one point in time obtained, the mean growth curves for each treatment were calculated. Growth curves were derived from the harvest data by a slight modification of the method used by Anslow and Green (1967). To illustrate the method used, a simplified example will be given. Figure 9 represents the growth curves of three series of plots harvested in an overlapping sequence - series 1 plots are harvested at days 10 and 40, and series 2 plots at 20 and 50 etc. The growth data are represented as histograms as the calculated mean growth rates apply to the whole of each growth period, ie. series 1 plots grew at a mean growth rate of 20kg dm ha^{-1} day^{-1} from day 10 to day 40. To derive the mean growth curve, points were taken at specified times; the general division of time was taken as that period from the harvest of one series of plots to the harvest of another series. In the example the time sequence would be split into the period from day 0 to 10, 10 to 20, 20 to 30, 30 to 40, etc. The mean growth rate is calculated as the arithmetic mean of the growth rates for each series over each period of time- for the period from day 10 to 20 the mean growth rate is $(20 + 15 + 18) \div 3 = 17.7$ kg DM ha^{-1} day^{-1}; similarly for the period from day 20 to 30 the mean growth rate is $(18 + 20 + 30) \div 3 = 22.7$ kg DM ha^{-1} day^{-1}. To be correct these mean growth rates should also be presented as histograms. However, bar graphs joining the mid point of each histogram are easier to interpret and the data are therefore presented as such. The mid point of each histogram is the mid point of the time period, eg. between day 10 and 20 the mean is day 15 and between 20 and 30 the mean is day 25. Therefore in plotting the mean growth curve, points in the example would be as below:

Mean Growth Rate	Day No.
14.3	5
17.7	15
22.7	25
31.7	35
36.7	45
40.0	55

Attempts were made to fit polynomial equations of high orders to the data to produce the growth curves. However these were not satisfactory due principally to the large errors at low harvest yields and the tendency to smooth out the curves removing real and significant fluctuations in sward

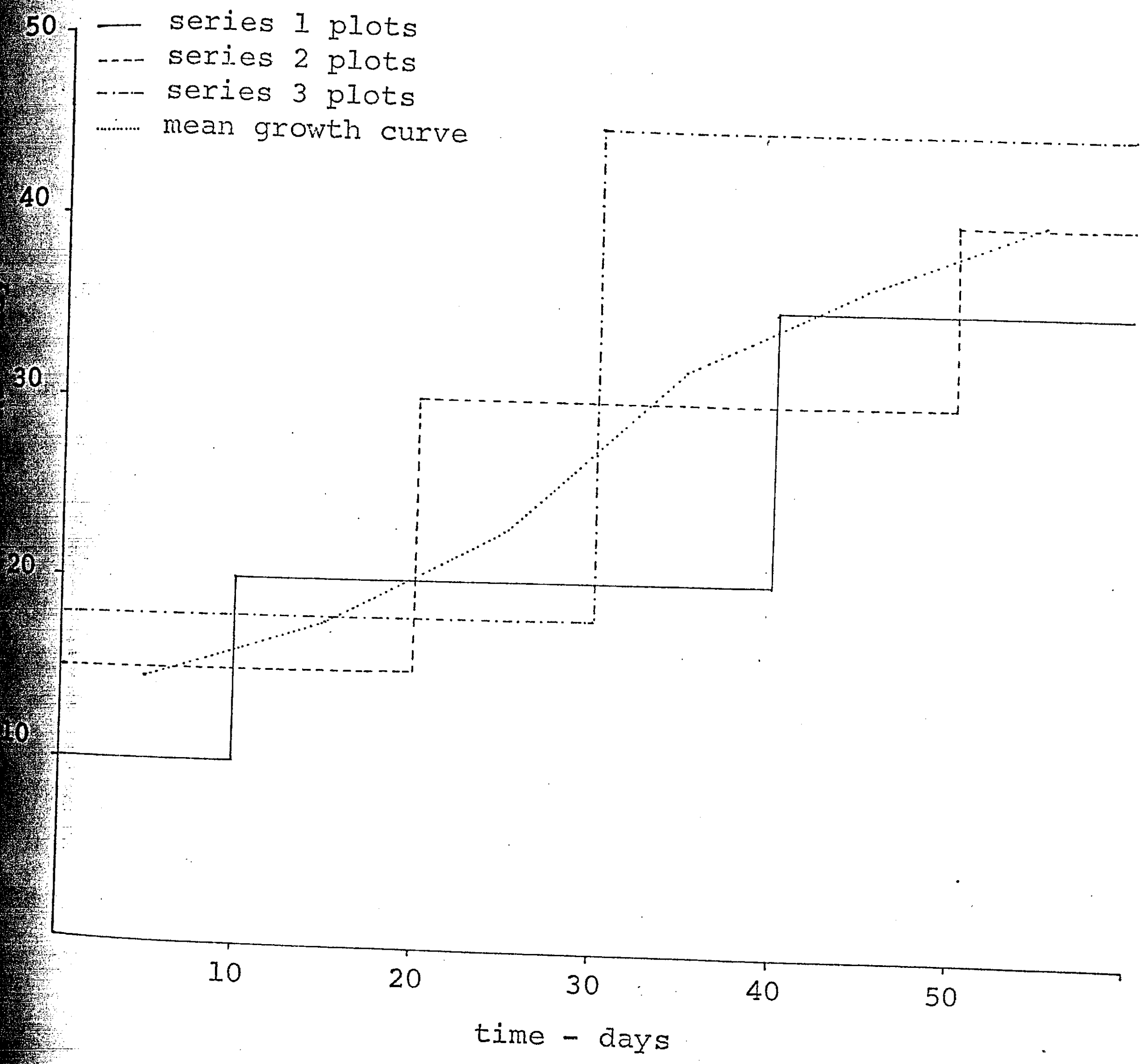


Figure 9. Derivation of mean growth curves.

Water Balance Models.

Water balance models were developed to estimate soil moisture levels and hence moisture deficits under the various treatments examined in this project. A general moisture budget was calculated for the irrigated plots to determine when to irrigate. A more complex water balance model was used for unirrigated plots. The aim was to obtain some measure of how soil moisture levels varied in relation to the growth rates of the swards. Direct soil moisture measurement on a regular basis was not possible because of limited facilities.

<u>Irrigated plots.</u>

A daily moisture balance for the irrigated plots was calculated using equation (i)

$$SM_n = SM_{n-1} + P + I - 0.8Ep \qquad (i)$$

SM_n = soil moisture level on day n (mm)

SM_{n-1} = soil moisture on previous day (mm)

P = rainfall (mm)

I = irrigation (mm)

Ep = evaporation from an American Class A pan (mm)

The maximum available soil moisture storage was assumed [illegible] be 75 mm and plots were irrigated whenever SM_n approached [illegible]. When SM_n was greater than 75mm the amount above 75mm [illegible] treated as surplus and removed from further calculations. This model was taken as representing maximum rates of [illegible] use in order to minimise moisture deficits on the irri[illegible] plots, even though this also meant that some treatments [illegible] be overwatered.

RESULTS.

Climate during the experimental period - August 1969 to July 1972.

The seasonal conditions over the three years of the experiment varied considerably. Figure 13 shows the mean monthly rainfall and evaporation values and figure 14 the mean monthly temperatures and incoming solar radiation for the years 1969 to 1972.

Moisture.

At the commencement of the experiment in August 1969 the soil was at field capacity and good rainfell during August (figure 13). Rainfall during spring 1969 was good. December was dry with low rainfall and high evaporation. Rainfall during January and March was adequate but then followed a severe drought from April until September 1970. Almost no rain was recorded during the winter of 1970.

In 1970 rainfall during spring was less than in 1969, then excellent falls of rain were recorded from December to March. April and May 1971 were dry months then good rain fell in June followed by dry conditions in July and August.

The spring of 1971 was the driest of the three years with very little rain falling until December. January recorded good rainfall then February was dry but March to June were wet months. July 1972 recorded almost no rain.

In summary, moisture conditions were good during the spring of 1969, intermediate in 1970 and poor in 1971. Summer of 1969-70 tended to be dry while in 1970-71 and 1971-72 moisture conditions were adequate. Autumn of 1970

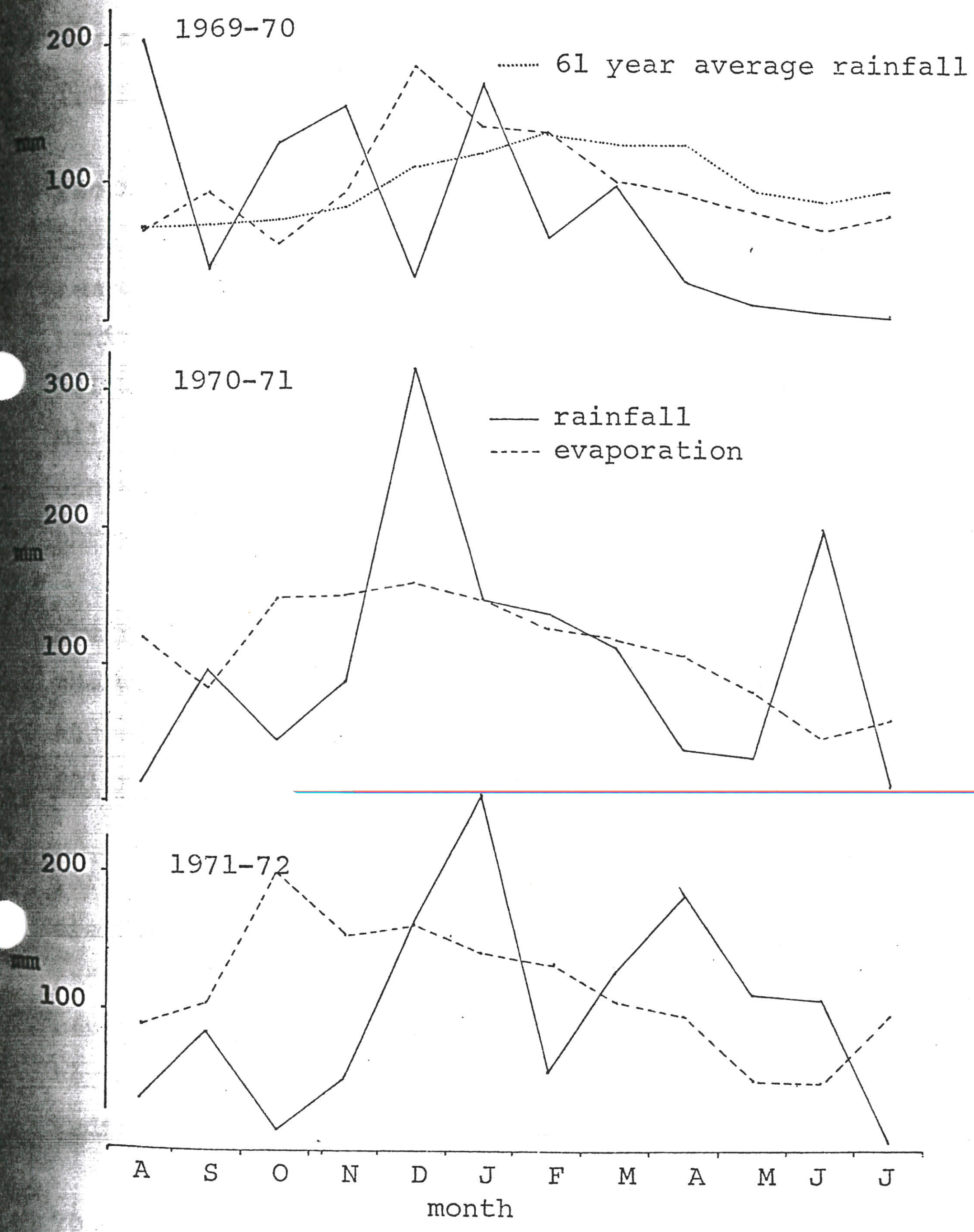


Figure 13. Rainfall and evaporation at Taree - August 1969 to July 1972.

was dry, 1971 intermediate and 1972 good.

Temperature.

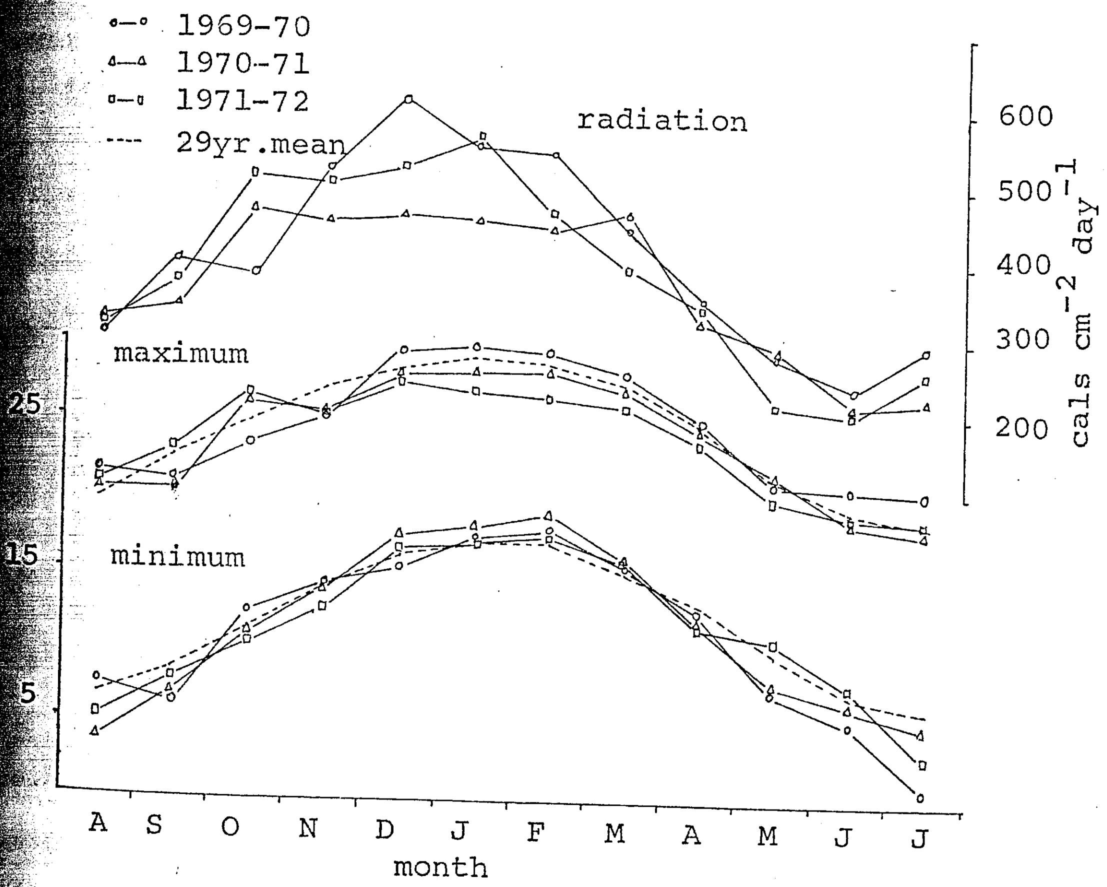
Temperatures during 1969-70 were amongst the highest recorded over the three years particularly during the summer, then during winter 1970 high maximums and very low minimum temperatures to - 6°C were recorded during the drought. Maximum temperatures during 1970-71 tended to be slightly below the average, and minimum above average, producing mild conditions. 1971-72 was characterised by mild temperatures with little fluctuation and was the coolest of the three years.

Over the three years temperatures did not show as large a variation as did the rainfall. The major exception was in the winter of 1970 when low minimum and high maximum temperatures were recorded.

Solar radiation.

Solar radiation levels varied considerably between years, particularly during the hotter months, when there were differences in rainfall and cloud cover. In late autumn, winter and spring there were few differences between years, the exception being when cloudless conditions occurred in the winter of 1970 and July 1972 allowing greater inputs of solar radiation.

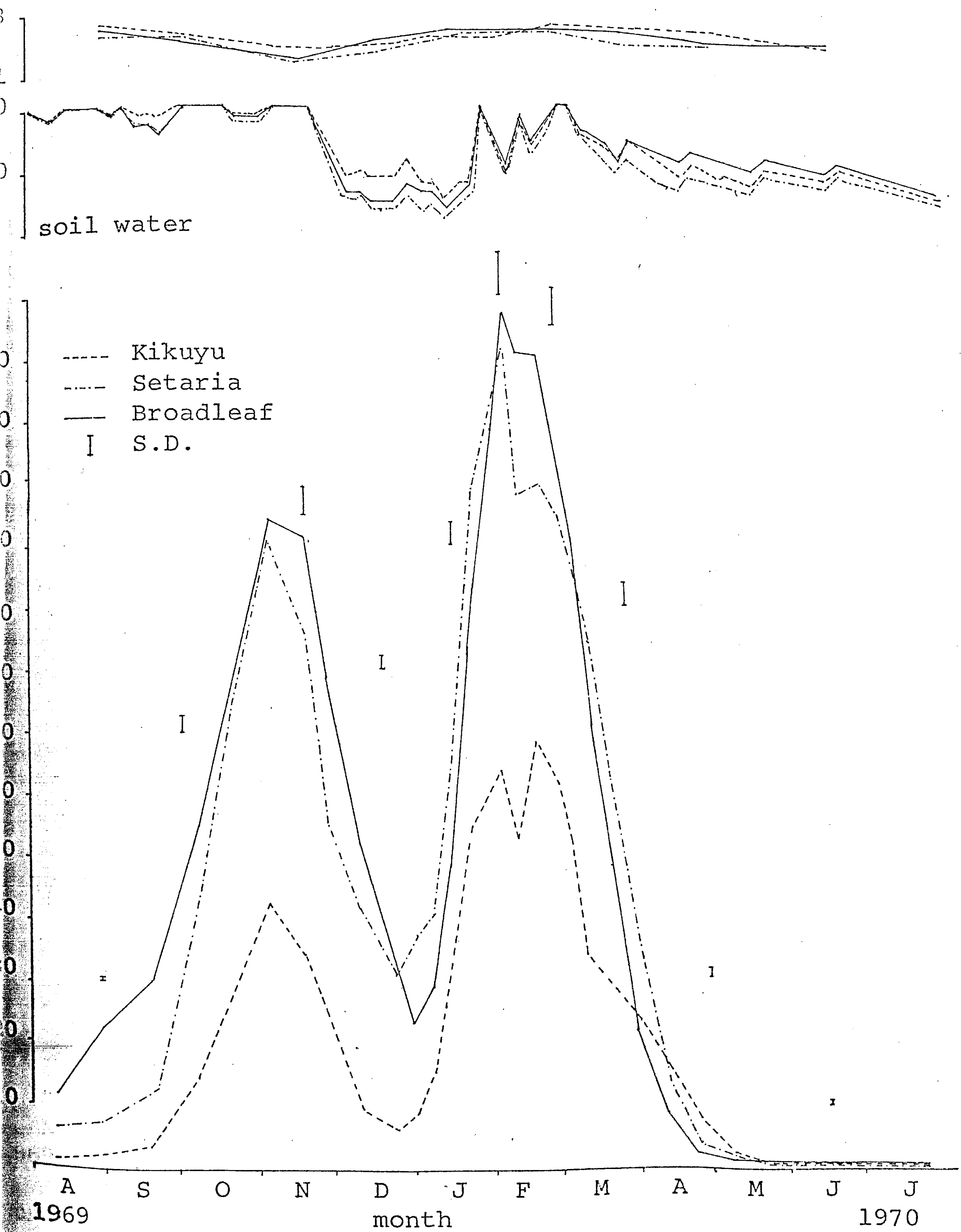
In summer differences were quite significant. In 1969-70 October recorded low inputs of radiation, but then radiation increased to a peak of 600 cals cm^{-2} day^{-1} in December. This is to be contrasted with 1970-71 when radiation levels over the period from October to March were quite uniform (see figure 14).



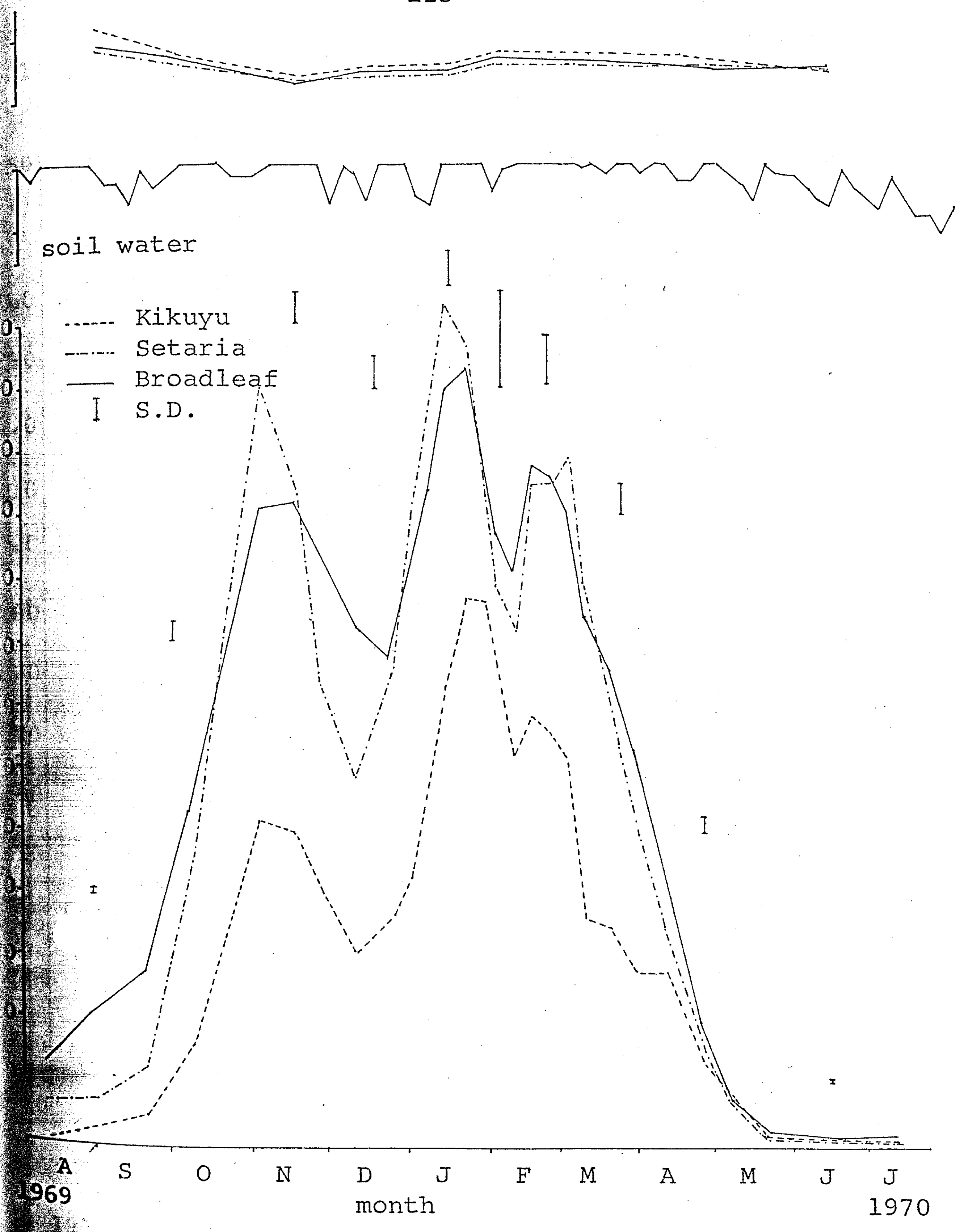
gure 14. Solar radiation and air temperature at Taree - August 1969 to July 1972

The mean input over this 6 months period is only 450 cals cm^{-2} day^{-1}. 1970-71 was characterised by heavy continuous cloud cover that caused the reduced radiation inputs and the mild temperatures previously referred to. Differences between these years is also apparent in the total energy input. In 1969-70 a total of 150 K cals cm^{-2} were received over the twelve month period compared with 136 K cals cm^{-2} in 1970-71.

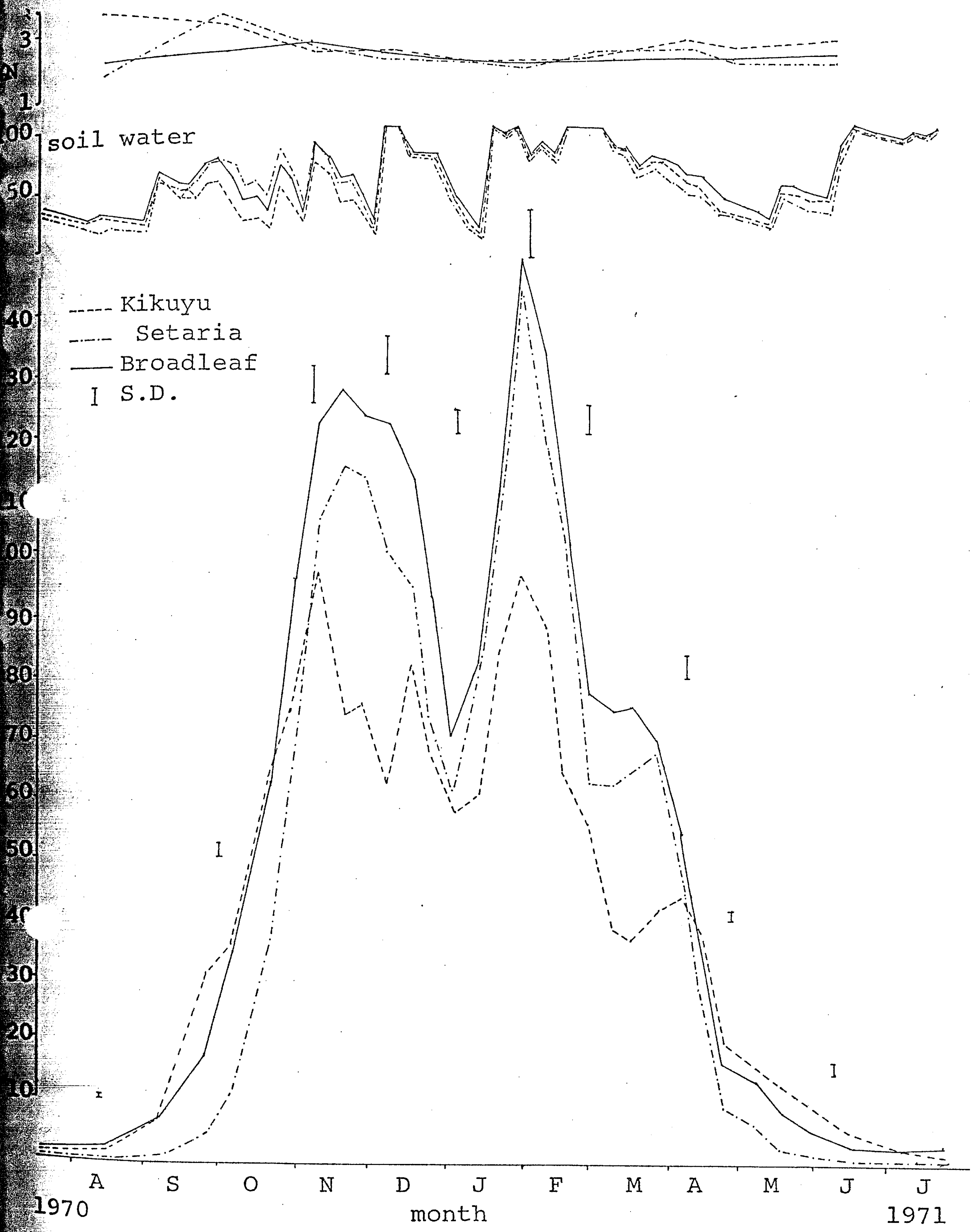
Radiation levels for the summer period in 1971-72 tended to fall between those of the other years. The major difference was in October which was dry and cloudless and high levels of radiation were recorded.



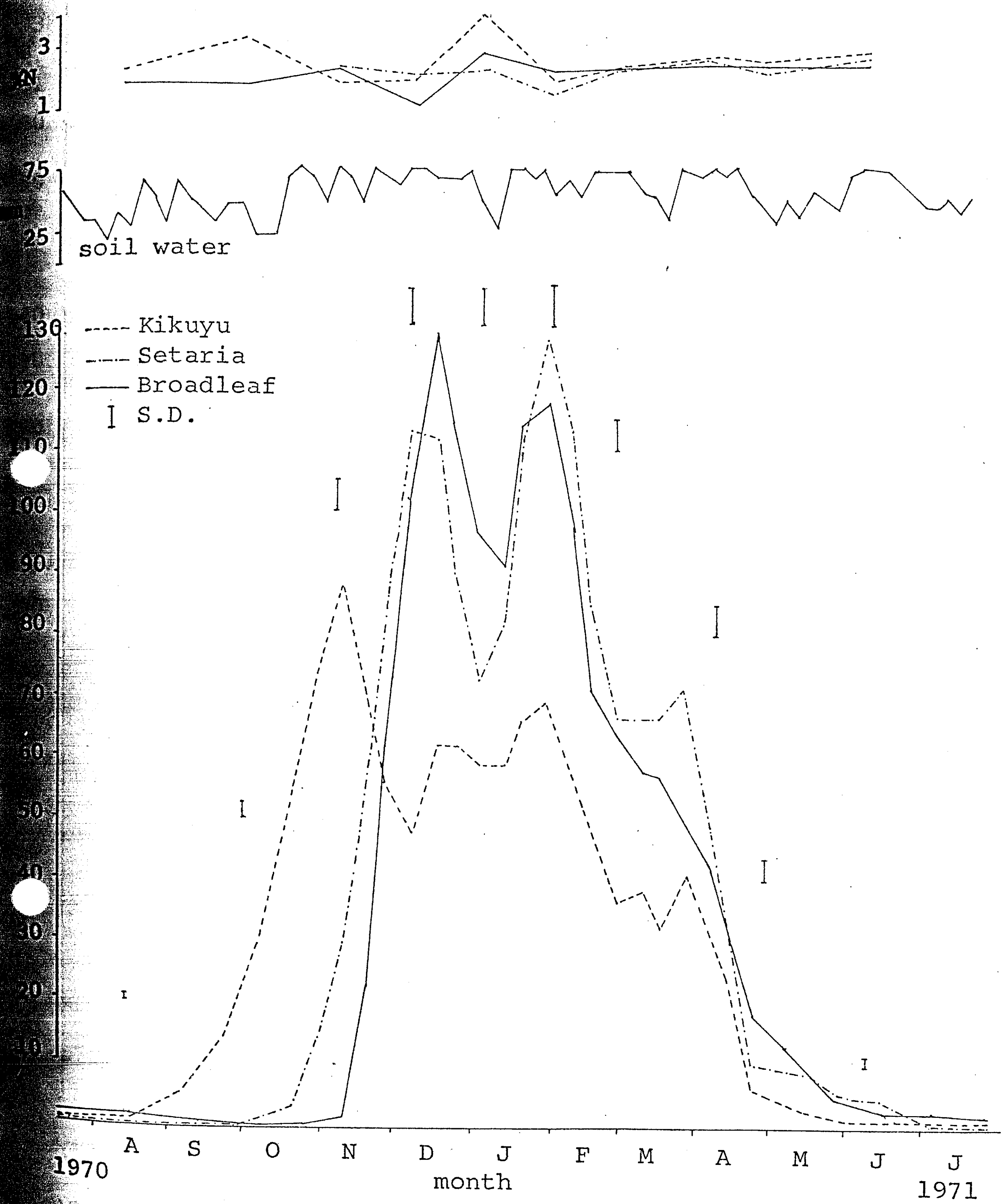
gure 16. Seasonal growth curves for high nitrogen unirrigated treatments 1969-70 plus percent nitrogen in the forage and estimated available soil water



ure 17. Seasonal growth curves for high nitrogen, irrigated treatments 1969-70 with percent nitrogen in forage and estimated available soil water.



8. Seasonal growth curves for high nitrogen unirrigated treatments 1970-71 with percent nitrogen in forage and estimated available soil water.



...ure 19. Seasonal growth curves for high nitrogen, irrigated treatments 1970-71, with percent nitrogen in forage and estimated available soil water.

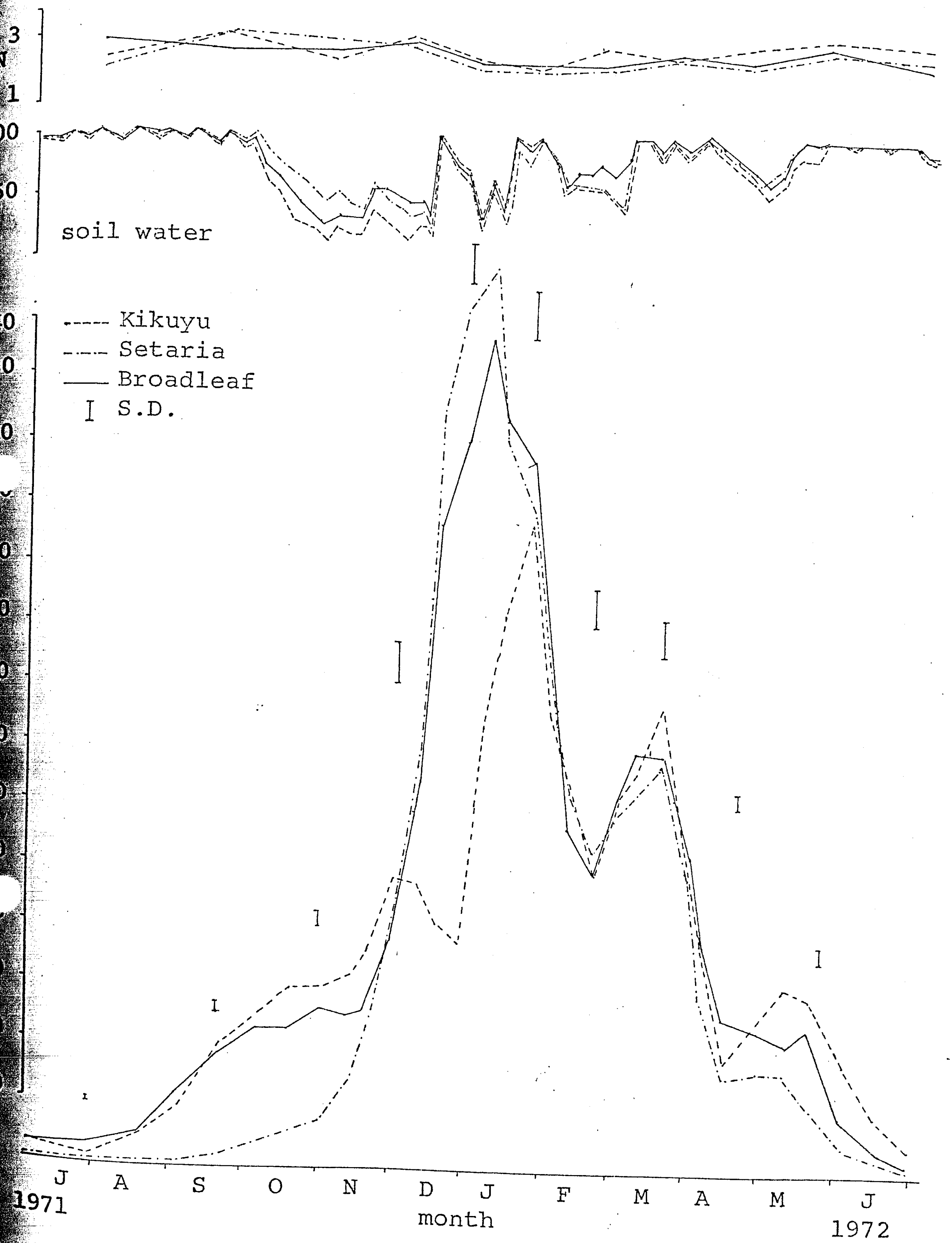


Figure 20. Seasonal growth curves for high nitrogen, unirrigated treatments 1971-72, with percent nitrogen in forage and estimated available soil water.

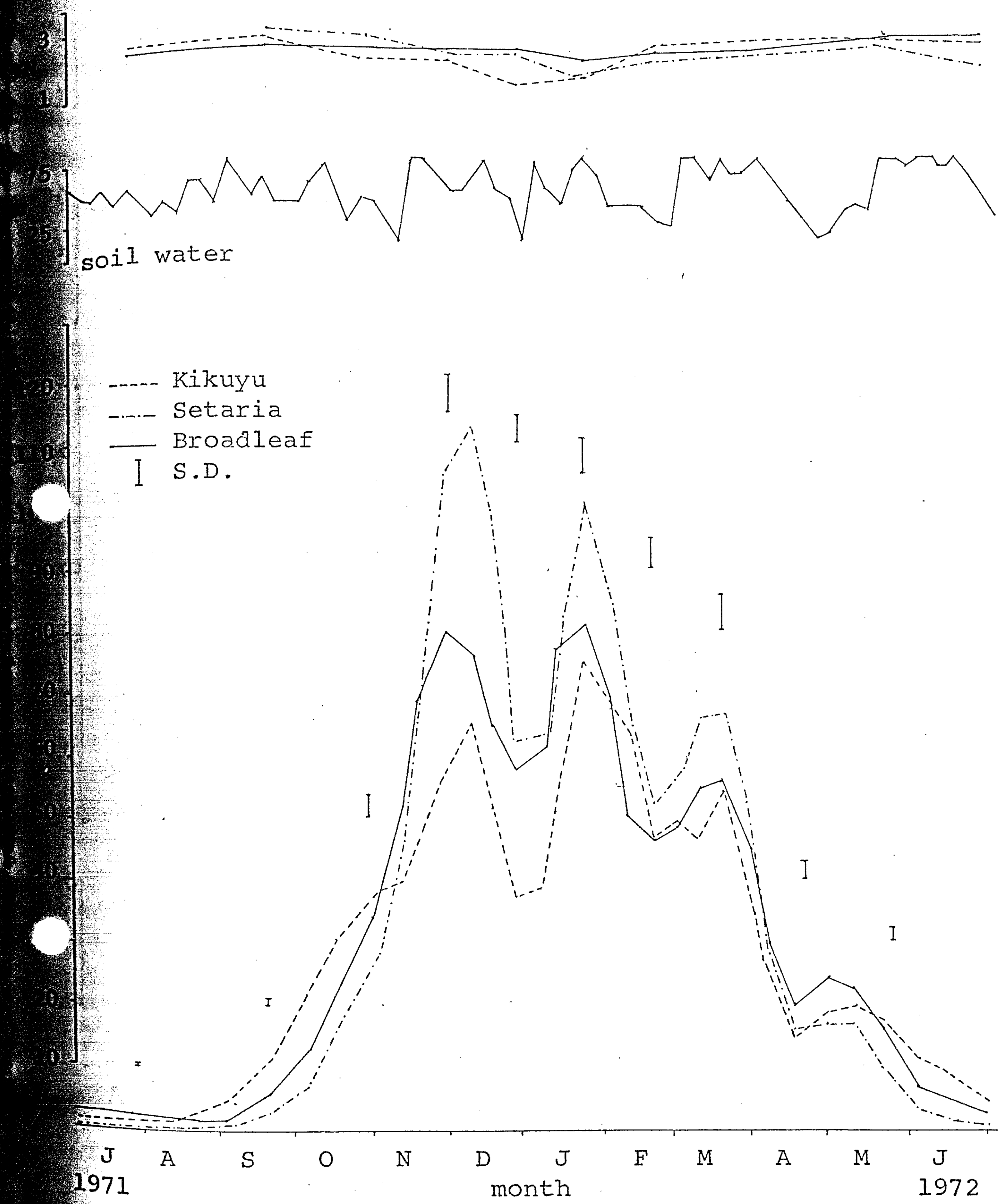
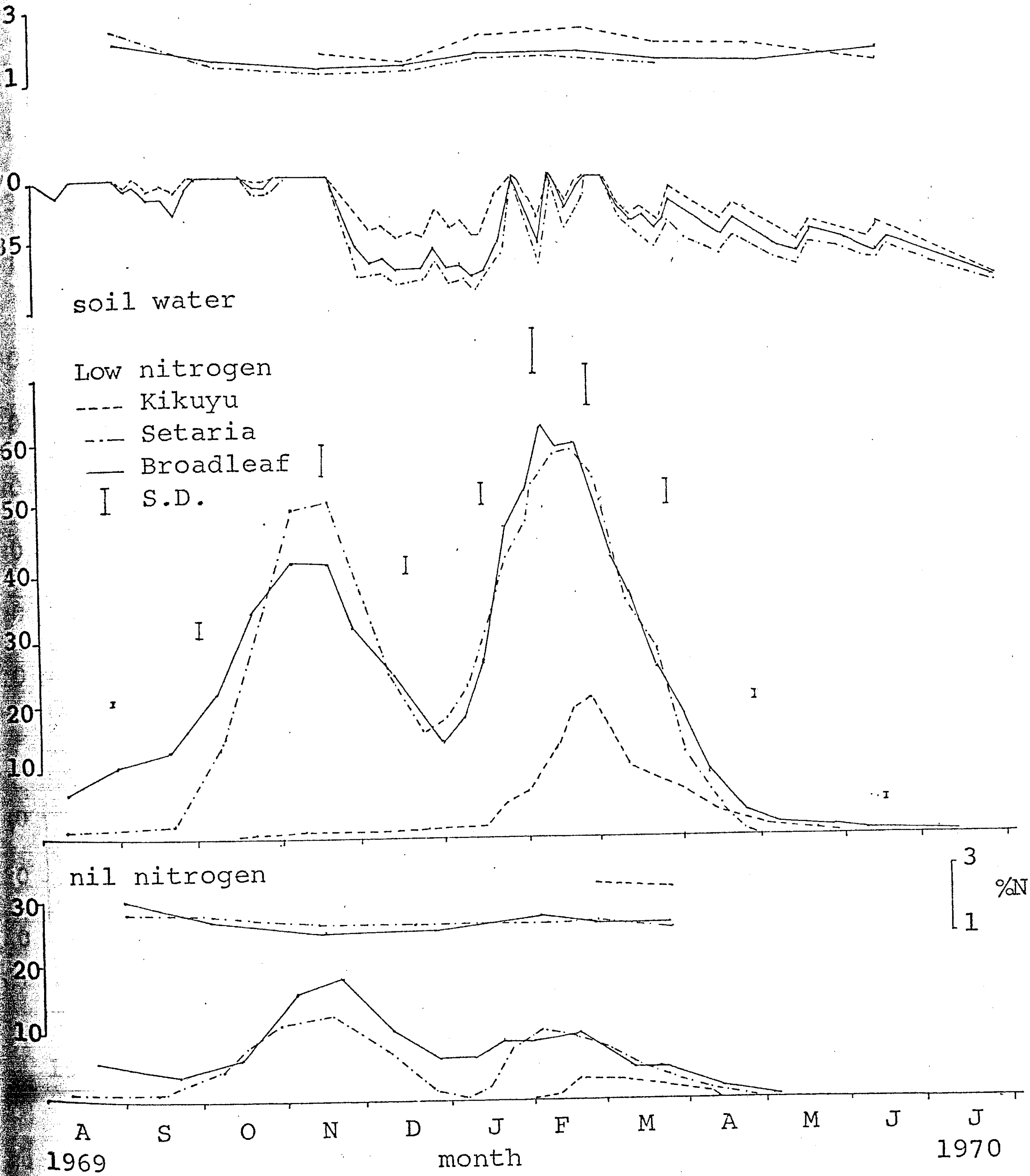


Figure 21. Seasonal growth curves for high nitrogen irrigated treatments 1971-72, with percent nitrogen in forage and estimated available soil water.



re 22. Seasonal growth curves for nil and low nitrogen unirrigated treatments 1969-70, with percent nitrogen in forage and estimated available soil water under low N plots.

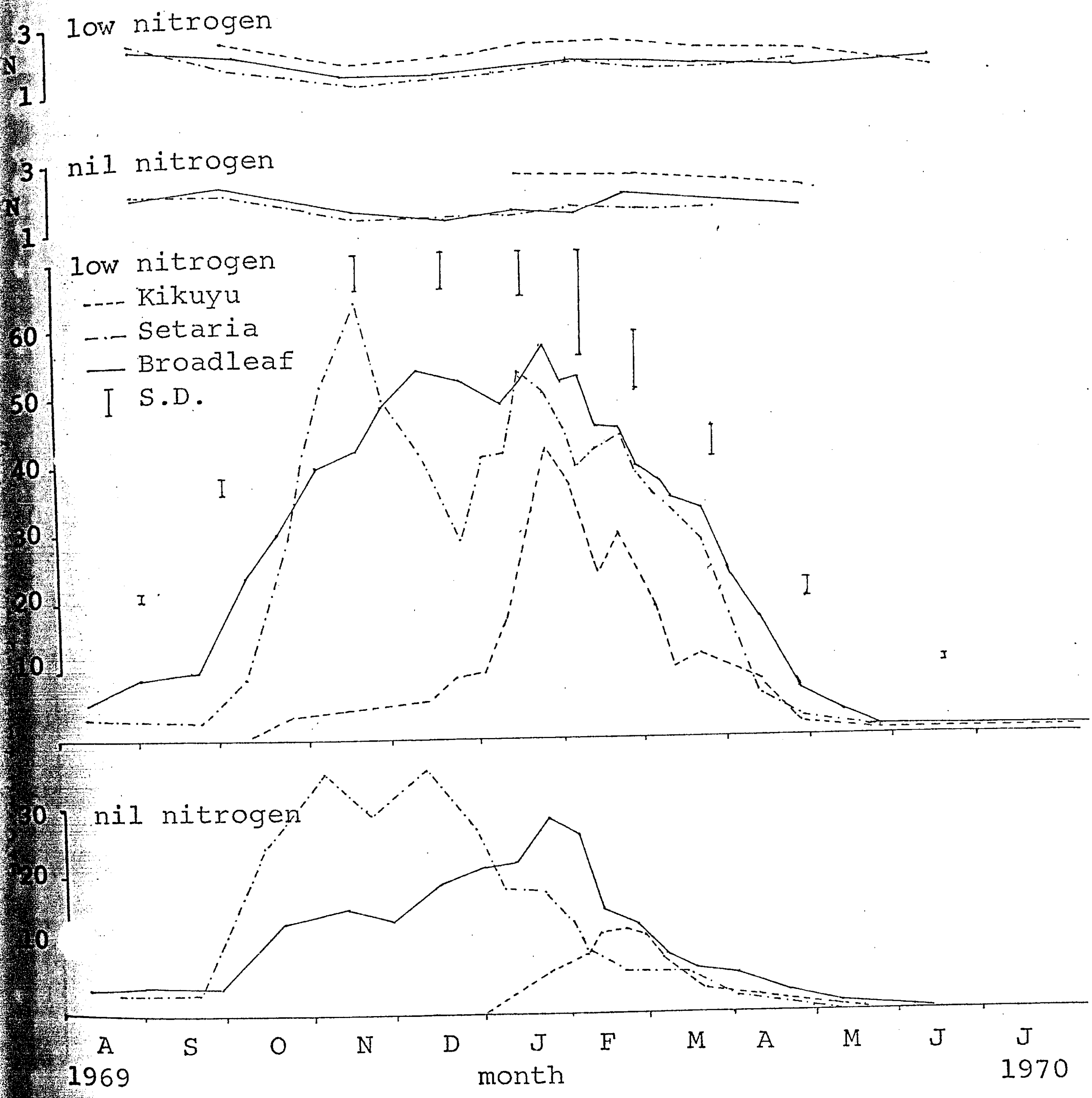


Figure 23. Seasonal growth curves for nil and low nitrogen irrigated treatments in 1969-70, plus percent nitrogen in forage.

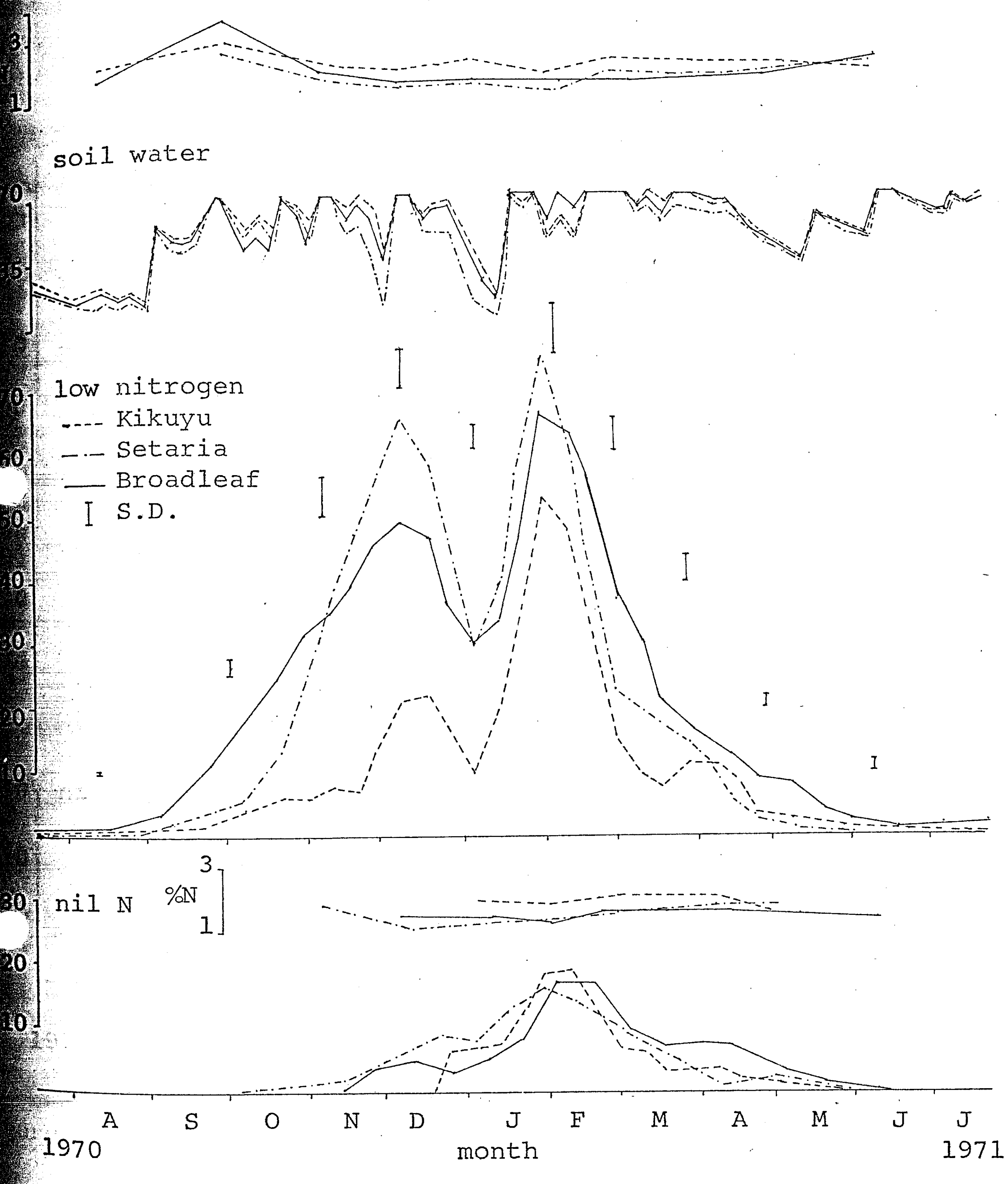


Figure 24. Seasonal growth curves for nil and low nitrogen unirrigated treatments 1970-71, with percent nitrogen in forage and estimated available soil water under low nitrogen plots.

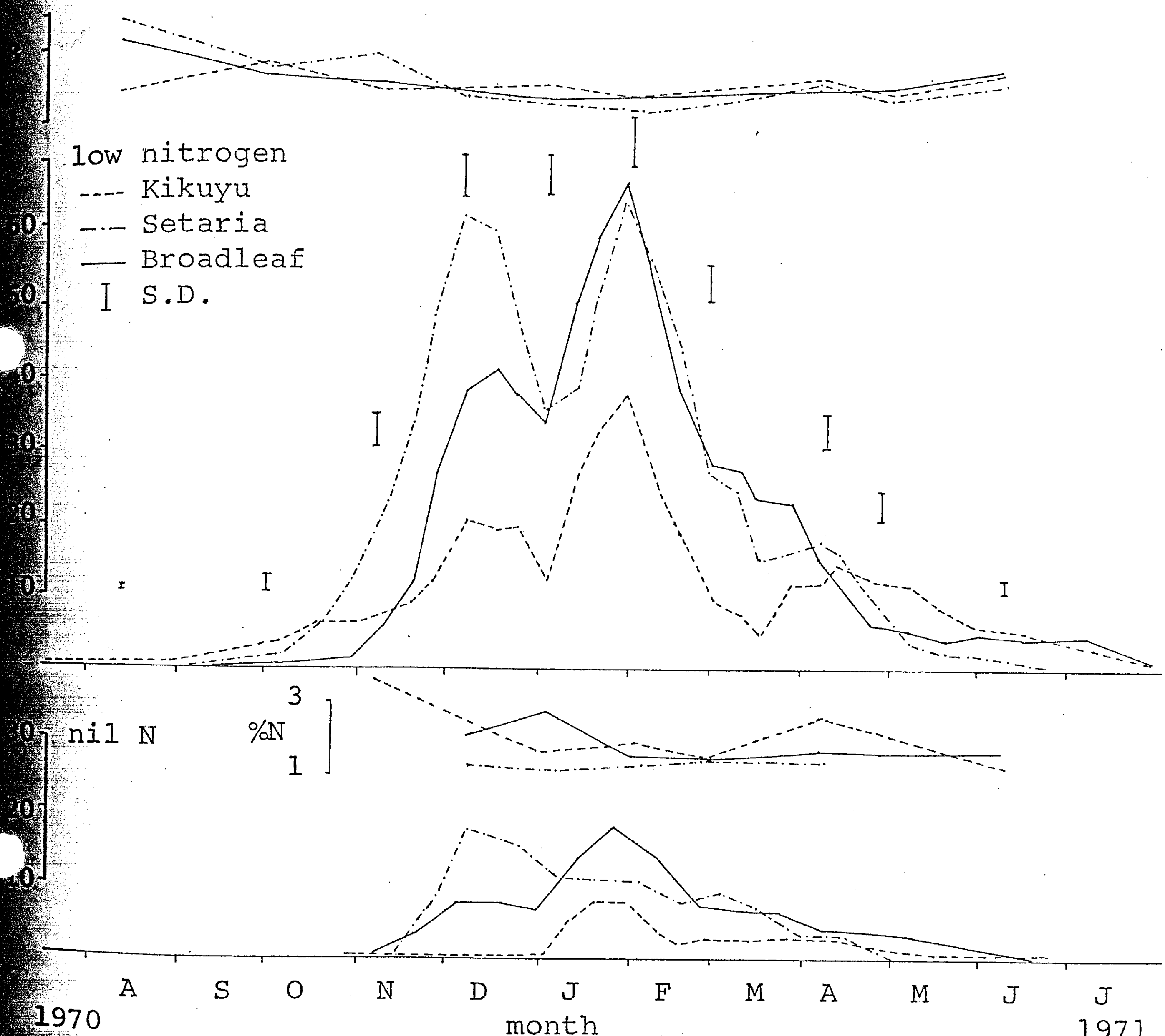


Figure 25. Seasonal growth curves for nil and low nitrogen irrigated treatments 1970-71, and percent nitrogen in forage.

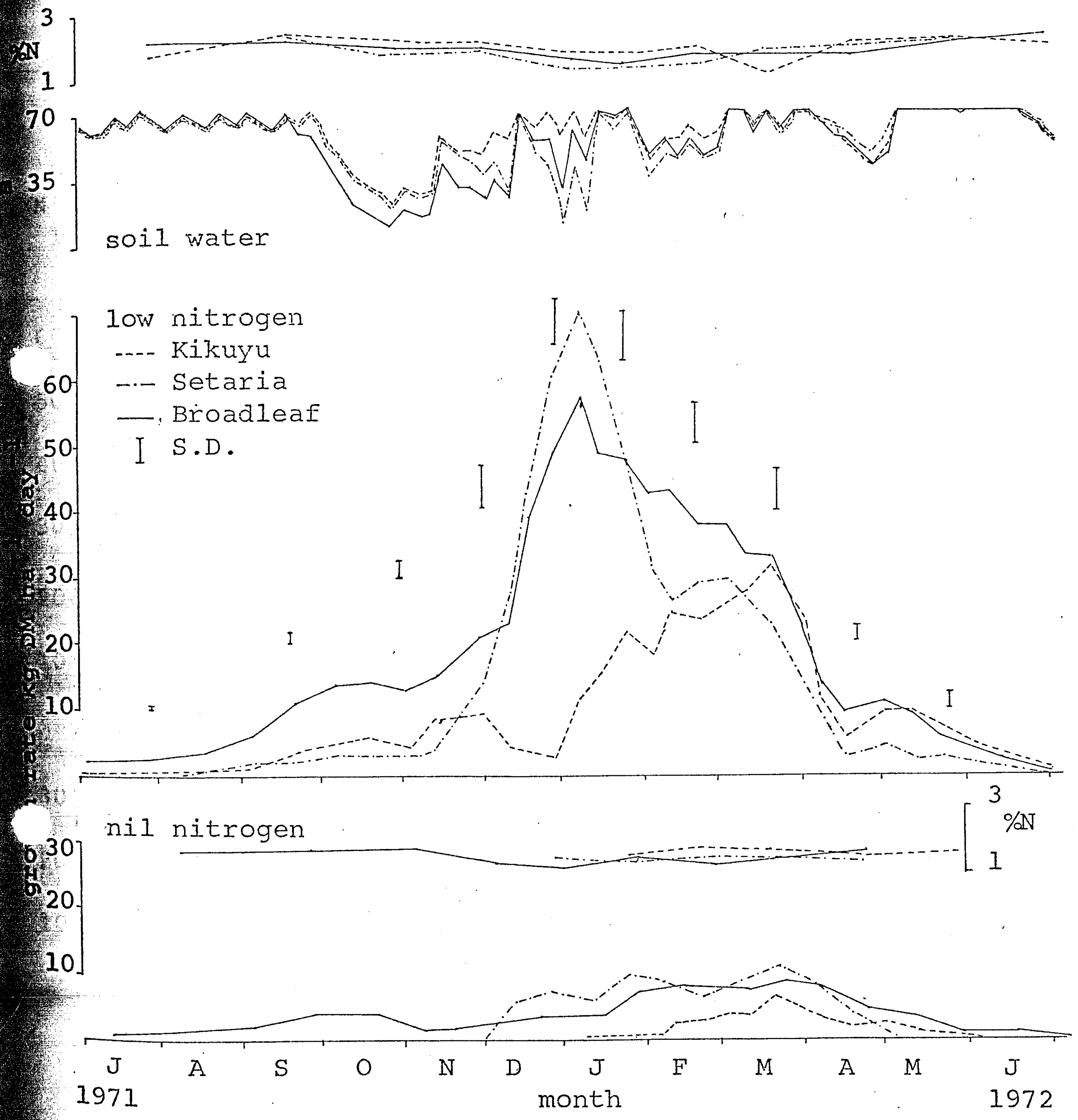


Figure 26. Seasonal growth curves for nil and low nitrogen unirrigated treatments 1971-72, with percent nitrogen in forage and estimated available soil water under low nitrogen plots.

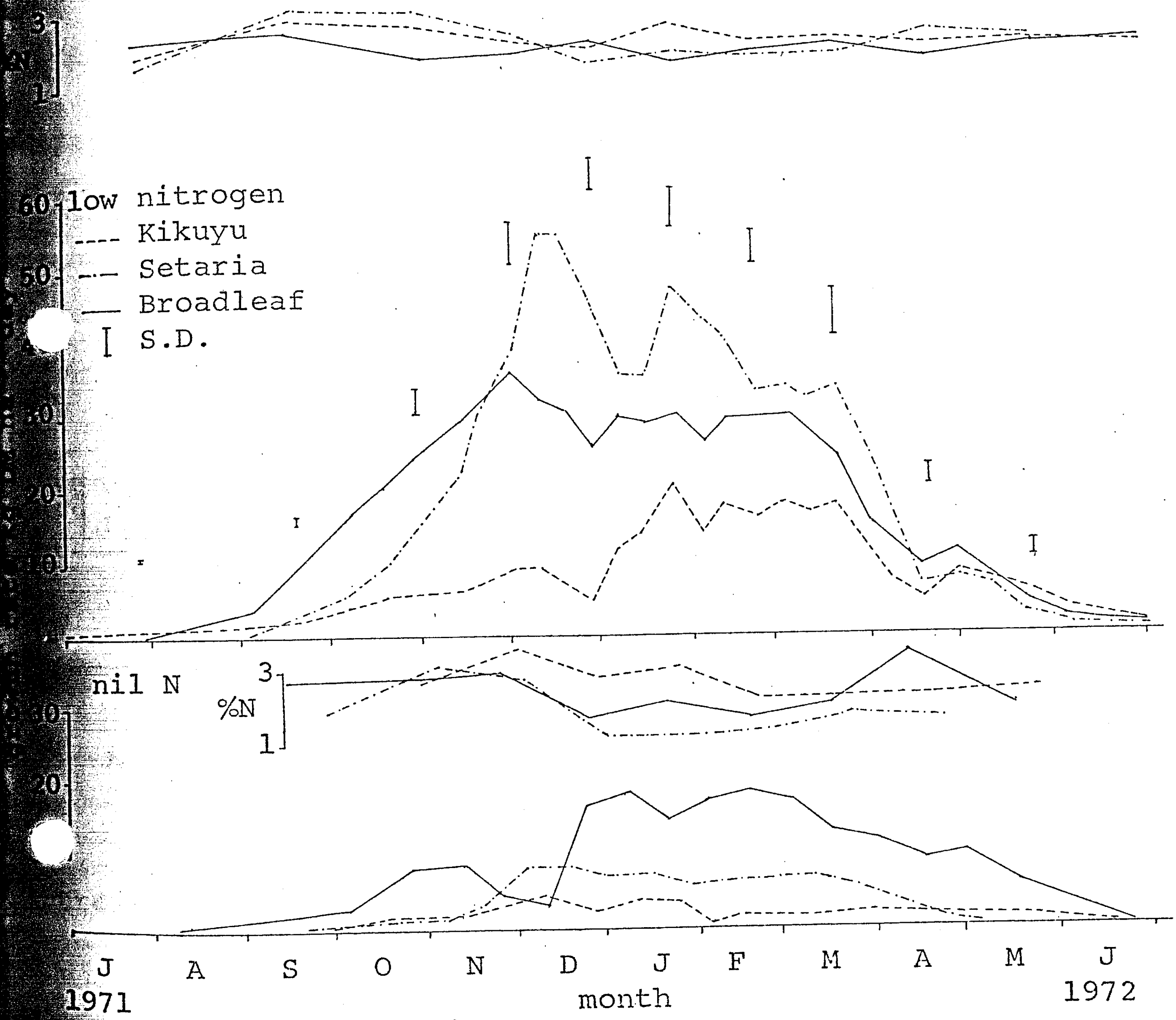


Figure 27. Seasonal growth curves for nil and low nitrogen irrigated treatments 1971-72, with percent nitrogen in forage.

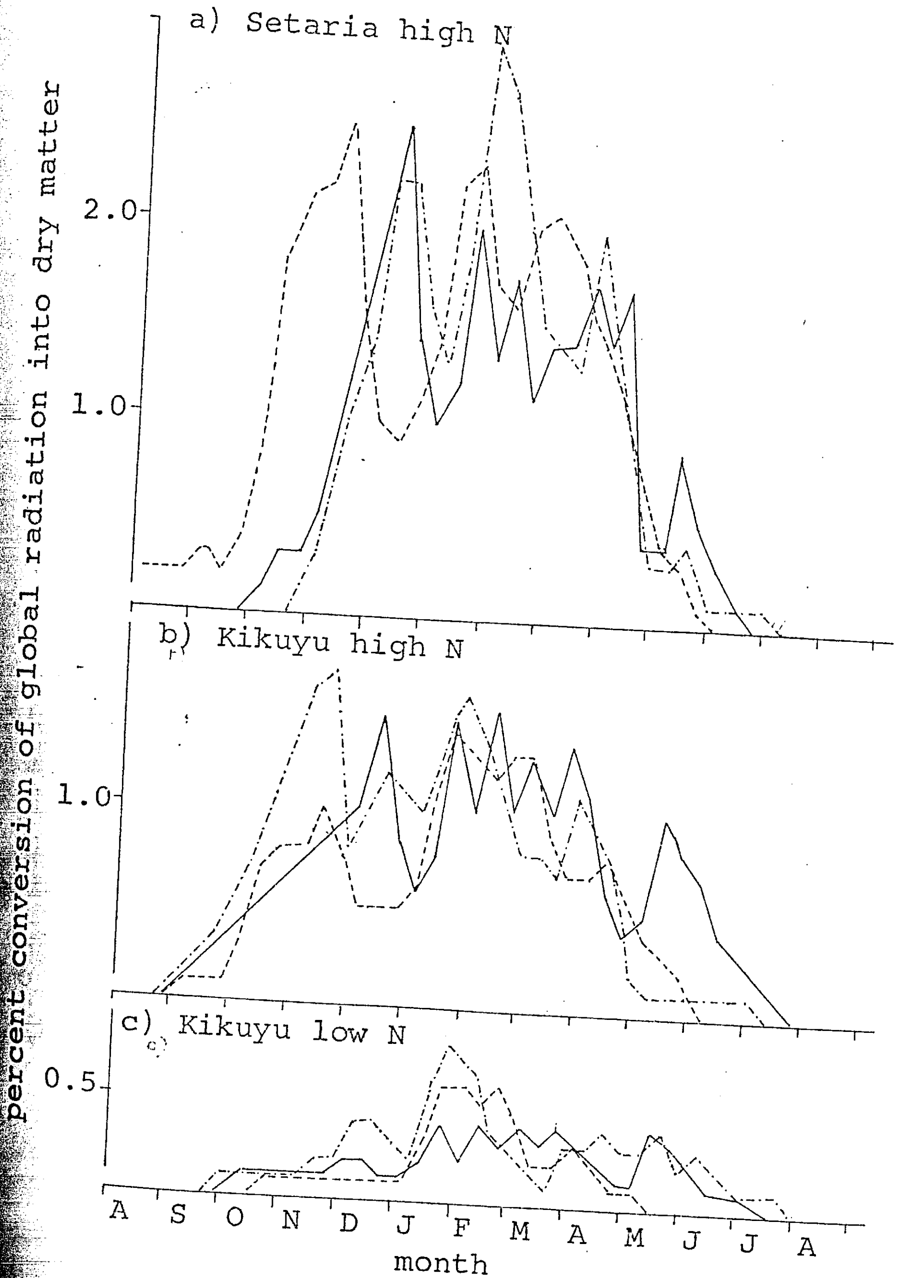
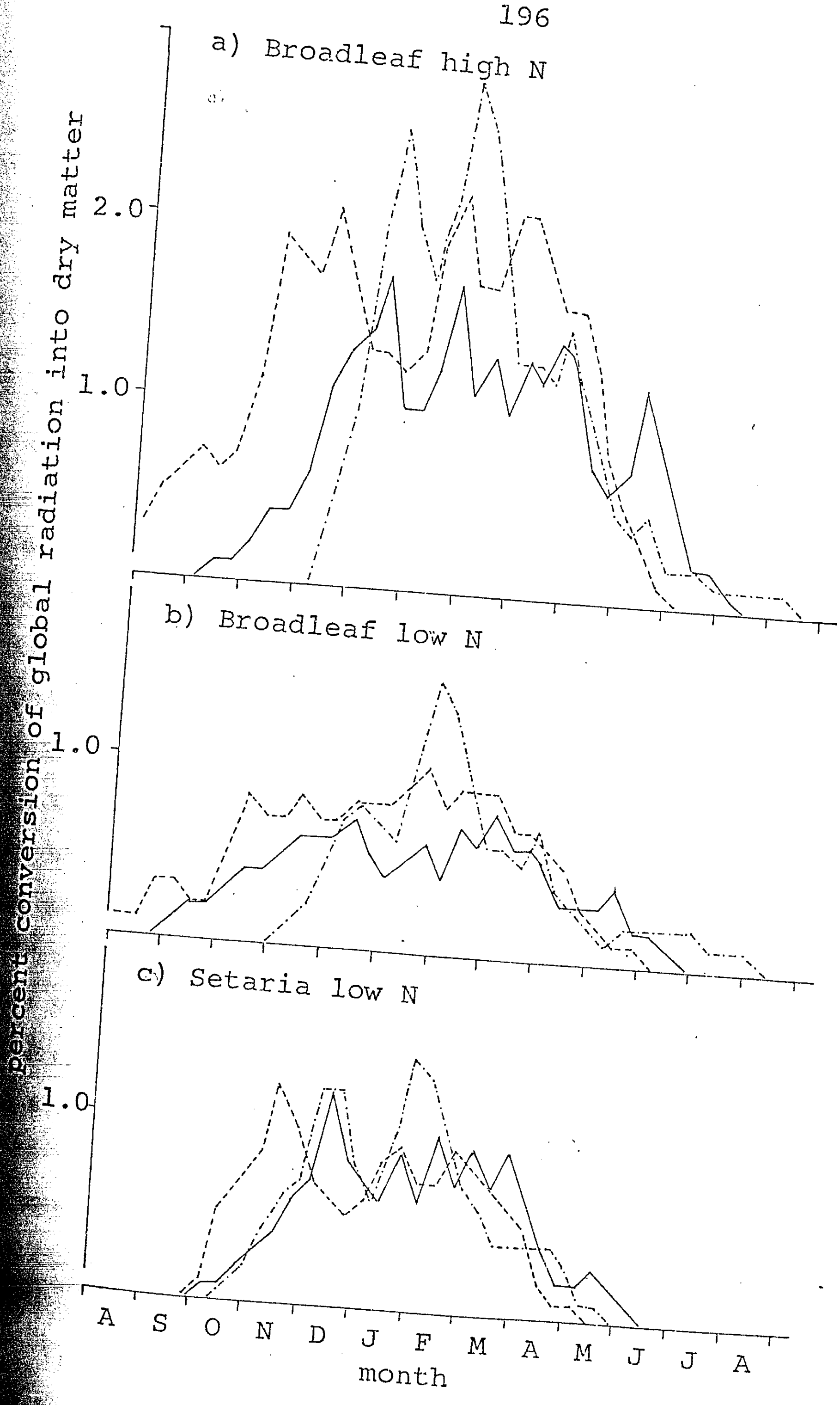


Figure 53. Efficiency of conversion of global radiation to dry matter - irrigated plots over three years-I.

---- 1969-70
-·-·-1970-71
——1971-72



54. Efficiency of conversion of global radiation to dry matter - irrigated plots over three years - II.

----1969-70
-·-·-1970-71
——1971-72

Appendix 1.

Site Characteristics

The experiment was located on the second terrace approximately 300m from the Manning River and 6m above the river. The site had a slope of approximately 10° in a south-east direction.

Native vegetation and land use.

The site was originally covered by brush forest, typical of alluvial flat areas along river banks on the north coast of N.S.W. The forest was cleared over one hundred years ago, and since then the land has been alternatively under crops and volunteer pasture grazed by dairy cattle. *Paspalum dilatatum* was the most common volunteer species until the 1950's, since then Kikuyu has been the dominant grass. Prior to the start of the experiment, the site had been cropped with vegetables and had then supported for one year a poor pasture of Kikuyu, that was occasionally grazed by dairy cattle.

Pa nt material. Alluvium deposited by floods - infrequent in recent times. The last flood to completely cover the site was in 1929.

Profile drainage. Unimpeded - some slight surface runoff likely but depends upon the vegetative cover.

Profile description.

In June 1970 three pits were dug down to 1m at points in and around the experiment in order to describe and sample the soil. These pits plus other observations suggested that the soil was uniform over the site. The principal profile form (Northcote 1971) was Um 1.44. Walker (1963) has described a similar profile at Kempsey.

Depth (cm)	Description
0-5	Very dark grey brown (10 Y R 3/2 moist) silt loam, earthy labile, many roots, diffuse to:
5-30	Dark brown (10 Y R 3/3 moist) loam, earthy, coherent, labile, few roots, changing to:
30-38	Dark brown (10 Y R 4/3 moist) sandy loam, friable, few roots, diffuse to:
38-100	Very dark grey brown (10 Y R 3/2 moist) clay loam, massive, coherent, labile, continuing......

The sandy loam zone from 30-38cms is probably due more to a past flood of fast flowing water depositing sand than to a cultivation effect. This zone appears to be too deep to be a plough layer or hard pan, and does not seem to be due to any soil forming process within the profile.

Physical characteristics.

Sampling pits were dug 48 hours after saturating the ea with water. Soil samples were taken every 7.5cms and analysed for moisture content and the apparent density was determined (see figure 1a). The mean gravimetric moisture content was 29.9% and the mean apparent density 1.47 g cm-2. A composite soil sample was used to determine the mean true specific gravity of soil solids (2.27 g cm^{-2}) and the drainage moisture characteristic (see figure 1b) using the method ofFawcett and Collis - George (1967). This indicated that the moisture content at field capacity (pF 2.5, - 0.3 bars) was 30%, in close agreement with the value derived from direct field measurements (figure 1a). The lower limit of "available" water was taken as pF 4.2 (-15 bars).

The moisture content at this tension was 15%.

Soil moisture storage (SMS, mm) was calculated from the formulae

$$SMS = D \times V \times M$$

where D = depth (mm)
V = apparent density ($g\ cc^{-1}$)
M = gravimetric moisture content ($\% \div 100$)

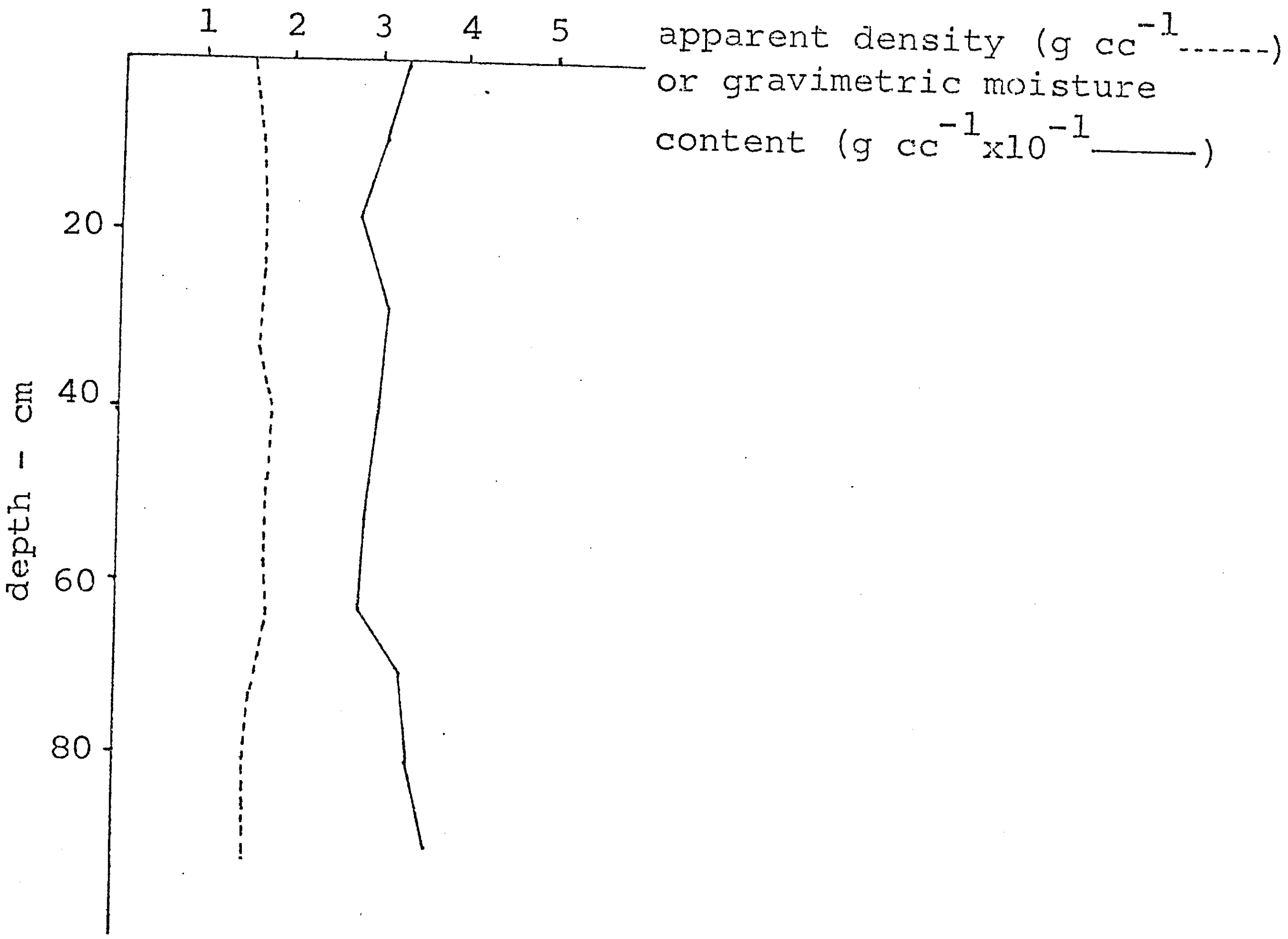
At -0.3bars. SMS - 132mm per 30cm depth and at -15.0 bars, SMS = 66mm per 30cm of soil depth. The "available" soil water is thus 66mm per 30cm of depth.

Chemical characteristics.

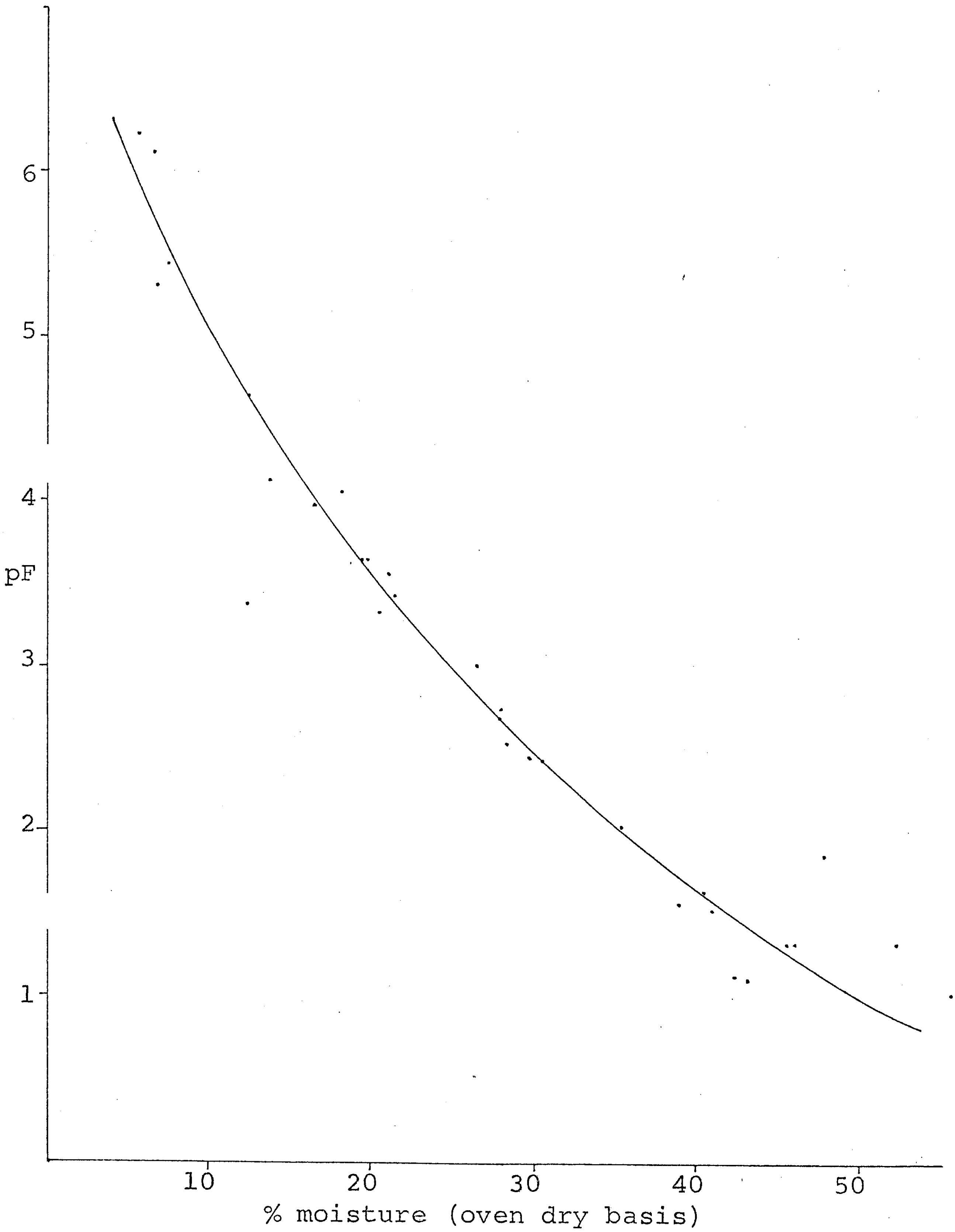
Chemical analysis of soil samples showed penetration of nutrients down the profile; figure 1c shows data for phosphorus, total nitrogen and pH and figure 1d shows the data for exchangeable calcium, sodium, magnesium, potassium and for soil water conductivity.

The effect of soil texture on chemical constituents can be clearly seen in figure 2d. Exchangeable bases are low in the zone from 30 to 38cms where the texture is sandy l m.

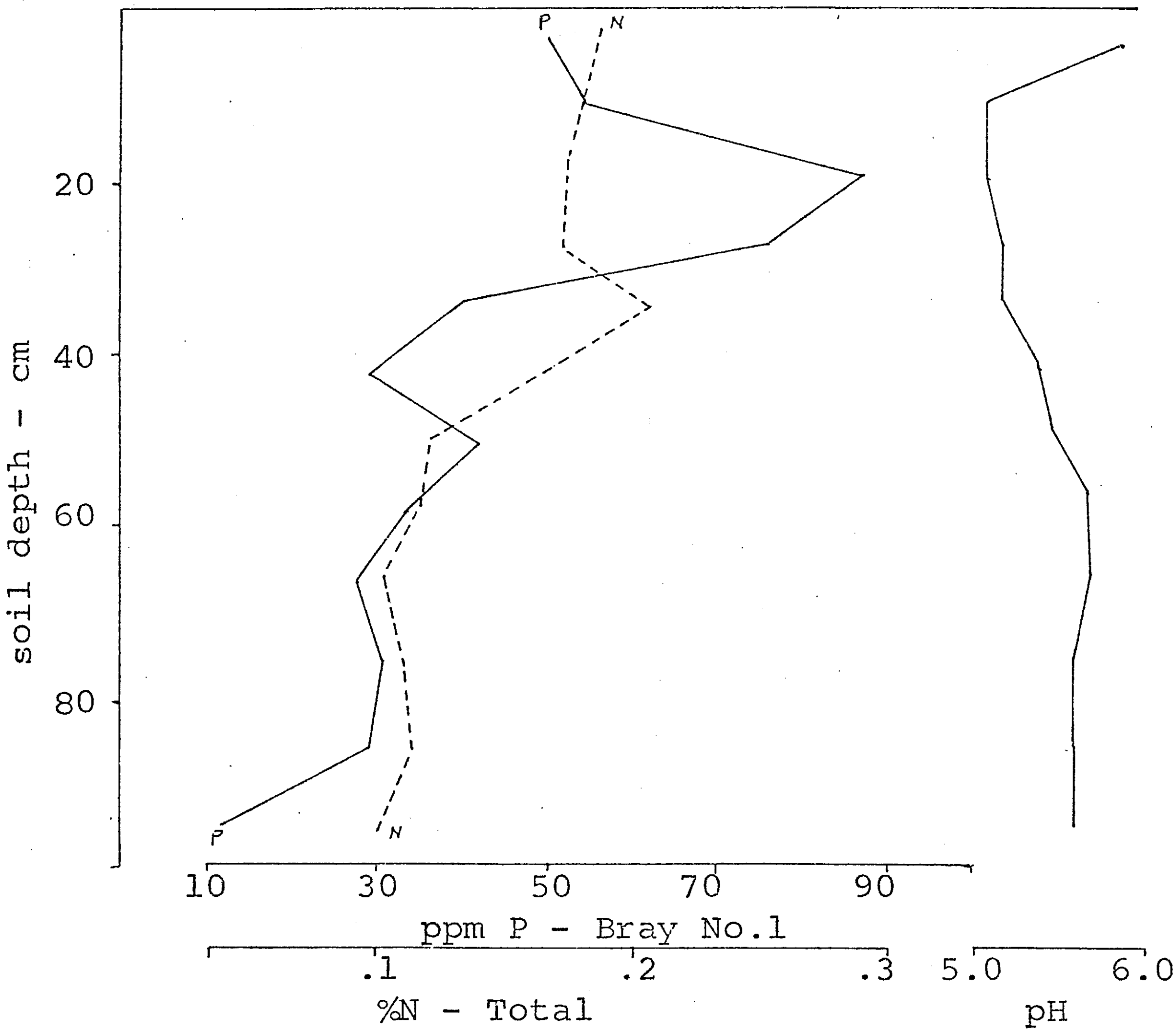
The high conductivity and sodium values are due to previous irrigation with salty water. Prior to this experiment, there had been several years of drought and low rainfall. This had caused an influx of salt from the Manning River into the water table and the well from which water for irrigation was taken.



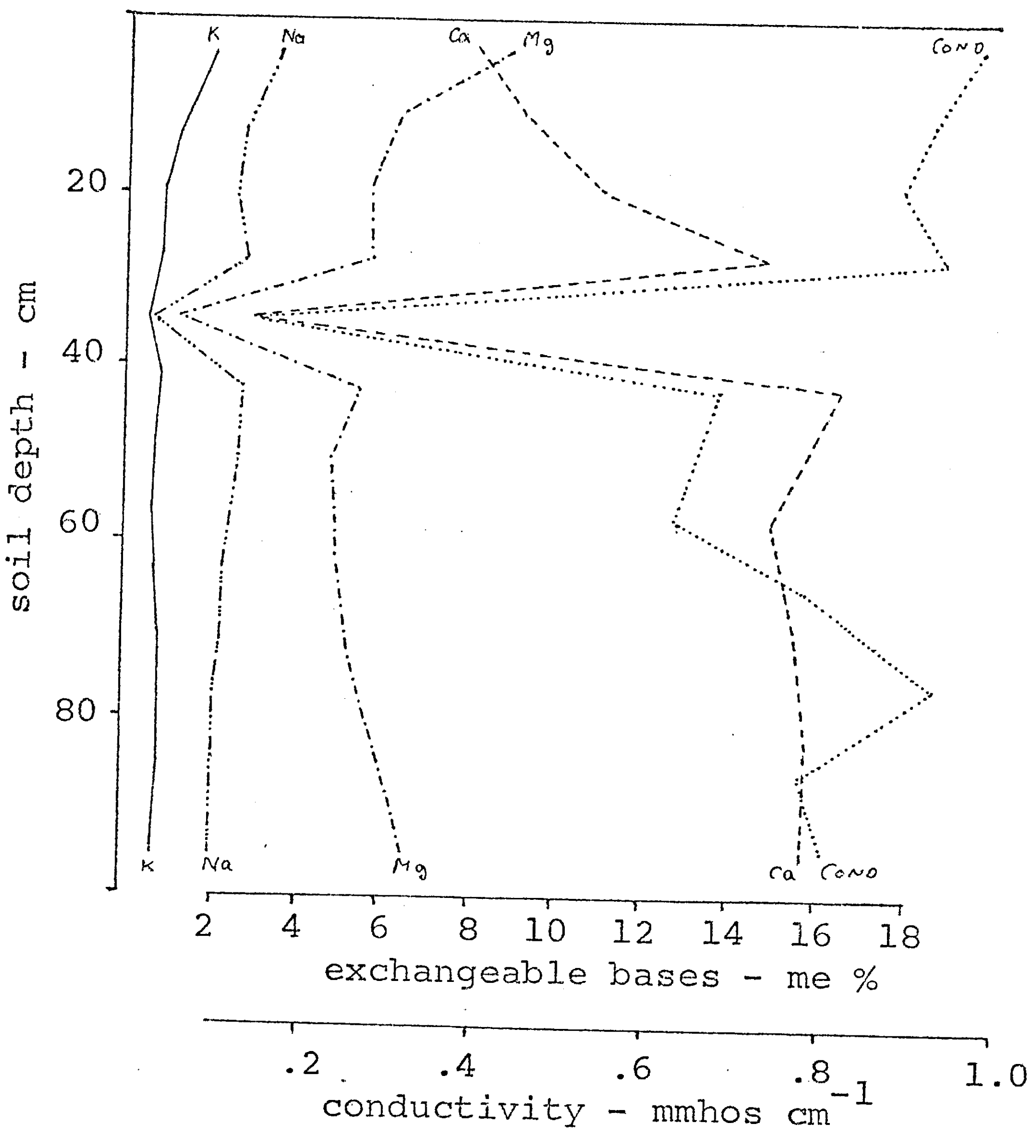
Appendix figure 1a. Moisture and density of soil with depth at experiment site.



Appendix figure 1b. Drainage moisture characteristic of soil at experiment site.



Appendix figure 1c. Soil phosphorus, nitrogen and pH with depth at experiment site.



appendix figure 1d. Soil bases and conductivity with depth at experiment site.

Appendix 3.

Harvest Dates

"Harvest No."	Series 1	Series 2	Series 3
0	1. 8.69	1. 8.69	1. 8.69
1	20. 8.69	10. 9.69	1.10.69
2	16.10.69	29.10.69	13.11.69
3	26.11.69	3.12.69	23.11.69
4	31.12.69	7. 1.70	14. 1.70
5	21. 1.70	2. 2.70	4. 2.70
6	11. 2.70	18. 2.70	25. 2.70
7	5. 3.70	11. 3.70	18. 3.70
8	1. 4.70	8. 4.70	22. 4.70
9	6. 5.70	20. 5.70	3. 6.70
10	24. 6.70	15. 7.70	6. 8.70
11	27. 8.70	16. 9.70	30. 9.70
12	14.10.70	28.10.70	4.11.70
13	18.11.70	25.11.70	2.12.70
14	17.12.70	23.12.70	30.12.70
15	14. 1.71	20. 1.71	27. 1.71
16	10. 2.71	17. 2.71	25. 2.71
17	10. 3.71	17. 3.71	24. 3.71
18	7. 4.71	14. 4.71	21. 4.71
19	5. 5.71	19. 5.71	26. 5.71
20	9. 6.71	30. 6.71	21. 7.71
21	11. 8.71	25. 8.71	14. 9.71
22	29. 9.71	13.10.71	27.10.71
23	10.11.71	17.11.71	24.11.71
24	8.12.71	17.12.71	22.12.71
25	5. 1.72	12. 1.72	19. 1.72
26	2. 2.72	9. 2.72	16. 2.72
27	1. 3.72	8. 3.72	15. 3.72
28	29. 3.72	5. 4.72	12. 4.72
29	26. 4.72	10. 5.72	17. 5.72
30	31. 5.72	15. 6.72	28. 6.72
31	12. 7.72	26. 7.72	2. 8.72

Appendix 5.

Light interception, leaf area, forage yield and growth rate

The relationships between light interception, leaf area index, forage yield and growth rate for Kikuyu, Kazungula Setaria and Broadleaf Paspalum were determined. The results were then used in the development of the water balance model.

Determination of leaf area

Leaf area of sampled leaves was determined by measuring length of the midrib, and width at the middle of the leaf and then using appropriate regression equations. The equations used were computed from leaf area and leaf length and width measurements of a sample of approximately 100 leaves of each species. Leaves of various ages and moisture and nutrient status were collected. Leaf areas were measured by tracing the leaf outline onto graph paper and cutting out the leaf shape. Then using known area: weight relationships for the graph paper leaf area was determined from the weight of the cut out paper. Several regressions were computed for each species and those with the largest R^2 and smallest standard deviations used when determining leaf areas. The equations used are listed below - all measurements are in centimetres.

Kikuyu

Leaf area = 9.14 + 0.59(length) + 14.36(width)
R^2 = 0.93 S.D.= 1.12

Kazungula Setaria

log(leaf area) = 0.13 + 1.03 log(length) + 0.83 log(width)
R^2 = 0.97 S.D. = 0.46

Broadleaf Paspalum

log(leaf area) = 0.19 + 1.10 log(length) + 0.64 log(width)
R^2 = 0.95 S.D. = 0.05

Determination of light interception

The amount of light intercepted by swards was determined by taking several readings with a Weston Master VI light meter held horizontally at the top and at the bottom of the sward within a 30cm square quadrat. Measurements were taken within 30 minutes of noon on several occasions during the year to cover a wide range of conditions. After taking the light readings the sward was then cut with hand shears to the height of the bottom light readings. Leaf area was estimated using the equations described previously then the sample dried to estimate forage yield. Samples were taken from a range of swards differing in age, yield, nutrient status and degree of moisture stress.

Light interception and leaf area index - The equations derived are presented below:

LI = light interception - expressed as a decimal
L = leaf area index ($\times 10^{-1}$)

Kikuyu

$$LI = 1.0 - e^{-9.50L}$$

$$R^2 = 0.93$$

Kazungula Setaria

$$LI = 1.0 - e^{-12.00L}$$

$$R^2 = 0.76$$

Broadleaf Paspalum

$$LI = 1.0 - e^{-8.50L}$$

$$R^2 = 0.80$$

Light interception and dry matter yield - Regressions were also derived for each species for the relationships between light interception and dry matter yield as dry matter was the principal measurement taken during the course of the experiments.

LI = light interception - as a decimal
Y = forage yield (-kg DM $ha^{-1} \times 10^{-4}$)

Kikuyu

$$LI = 1.0 - e^{-13.81\,Y}$$
$$R^2 = 0.75$$

Kazungula Setaria

$$LI = 1.0 - e^{-12.41\,Y}$$
$$R^2 = 0.68$$

Broadleaf Paspalum

$$LI = 1.0 - e^{-6.03\,Y}$$
$$R^2 = 0.74$$

Light interception and growth rate

Dry matter yields were determined over relatively long time intervals. This proved unsatisfactory in the water balance model as soil moisture changes can occur quickly. A high correlation was found between sward growth rate and forage yield for each treatment, despite the varied harvest interval - r^2 for Kikuyu, Kazungula Setaria and Broadleaf Paspalum were respectively 0.95 and 0.93 and 0.86. The relationship between sward growth rate and light interception for each species was then derived and is hown in table 5A. This enabled use of the growth curves to estimate changes in light interception. The data in table 5a is appropriate to this experiment only.

Table 5a: Estimated light interception at various growth rates.

Sward Growth rate kg DM ha^{-1} day^{-1}	KIKUYU	SETARIA	BROADLEAF
0-9.9	.10	.10	.10
10-29.9	.48	.46	.28
30-49.9	.76	.72	.46
50-69.9	.88	.87	.61
70-89.9	.94	.93	.72
90-109.9	.97	.97	.79
110-129.9	1.00	.99	.85
130-149.9	1.00	1.00	.88
>150	1.00	1.00	.93

Appendix 13.

Total yields for all treatments - kg DM ha^{-1}

Year		Species	Nitrogen Level nil	low	high	S.D.
1969-70	U	Kikuyu	1113	1008	6583	
		Setaria	1364	6279	13964	346
		Broadleaf	1991	7137	14881	(1000)*
	I	Kikuyu	588	2570	9370	
		Setaria	3760	6770	17130	480
		Broadleaf	3008	8110	18470	(1388)
1970-71	U	Kikuyu	1040	3380	13450	
		Setaria	1277	6610	15140	500
		Broadleaf	1340	7240	18330	(1446)
	I	Kikuyu	455	2960	11430	
		Setaria	1412	5870	12790	560
		Broadleaf	1406	5420	11940	(1619)
1971-72	U	Kikuyu	378	3110	11940	
		Setaria	1048	5080	12290	510
		Broadleaf	1310	6650	13870	(1475)
	I	Kikuyu	524	2380	9990	
		Setaria	1005	6110	11730	540
		Broadleaf	2830	5600	10850	(1561)

U - unirrigated
I - irrigated
* - L.S.D. (5%)

Appendix 14.

Percent nitrogen in forage samples

Species	Year	nil nitrogen mean	nil nitrogen range	low nitrogen mean	low nitrogen range	high nitrogen mean	high nitrogen range
Kikuyu	U 69-70	2.45	(1.99-3.41)	1.54	(1.37-2.44)	2.22	(1.69-2.59)
	70-71	1.91	(1.75-2.70)	2.07	(1.75-2.70)	2.74	(2.24-3.71)
	71-72	1.72	(1.47-2.32)	1.92	(1.16-2.32)	2.76	(2.14-3.30)
	I 69-70	2.25	(1.97-2.31)	1.74	(1.33-2.27)	2.31	(1.75-3.22)
	70-71	2.12	(1.23-3.61	1.91	(1.58-2.46)	2.51	(1.78-3.97)
	71-72	2.51	(1.27-3.47)	2.12	(1.71-2.62)	2.34	(1.36-2.91)
Setaria	U 69-70	1.32	(1.19-1.65)	1.23	(1.12-2.41)	2.00	(1.41-2.37)
	70-71	1.39	(1.18-1.85)	1.52	(1.30-2.37)	2.23	(2.04-3.71)
	71-72	1.44	(1.34-1.50)	1.77	)1.30-2.31)	2.58	(2.14-3.25)
	I 69-70	1.37	(1.12-1.93)	1.34	(1.01-2.20)	1.98	(1.61-2.48)
	70-71	1.27	(1.16=1.47)	1.98	(1.27-3.68)	2.17	(1.46-2.62)
	71-72	1.89	(1.22-3.05)	2.01	(1.46-2.91)	2.38	(1.58-3.16)
Broadleaf	U 69-70	1.34	(1.07-2.03)	1.59	(1.29-2.04)	2.15	(1.51-2.45)
	70-71	1.42	(1.26-1.57)	1.82	(1.43-3.44)	2.35	(2.17-2.79)
	71-72	1.51	(1.61-1.74)	1.84	(1.55-2.13)	2.68	(2.34-3.11)
	I 69-70	1.35	(1.11-2.04)	1.57	(1.22-2.13)	2.12	(1.60-2.52)
	70-71	1.82	(1.50-2.77)	1.91	(1.41-3.15)	2.11	(1.05-2.69)
	71-72	2.41	(1.71-3.43)	1.85	(1.53-2.38)	2.47	(2.03-2.83)

U - unirrigated
I - irrigated

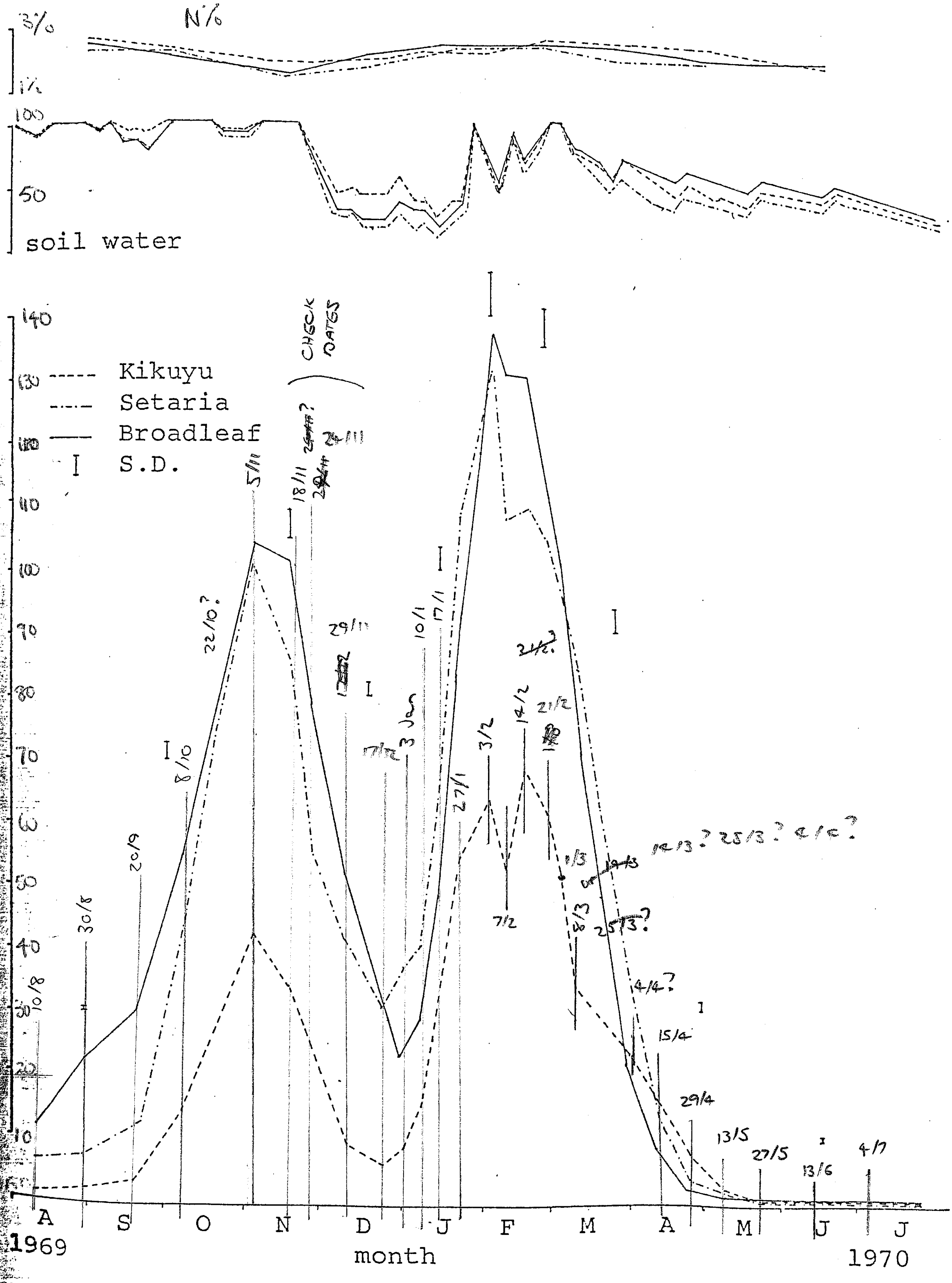


Figure 16. Seasonal growth curves for high nitrogen unirrigated treatments 1969-70 plus percent nitrogen in the forage and estimated available soil water

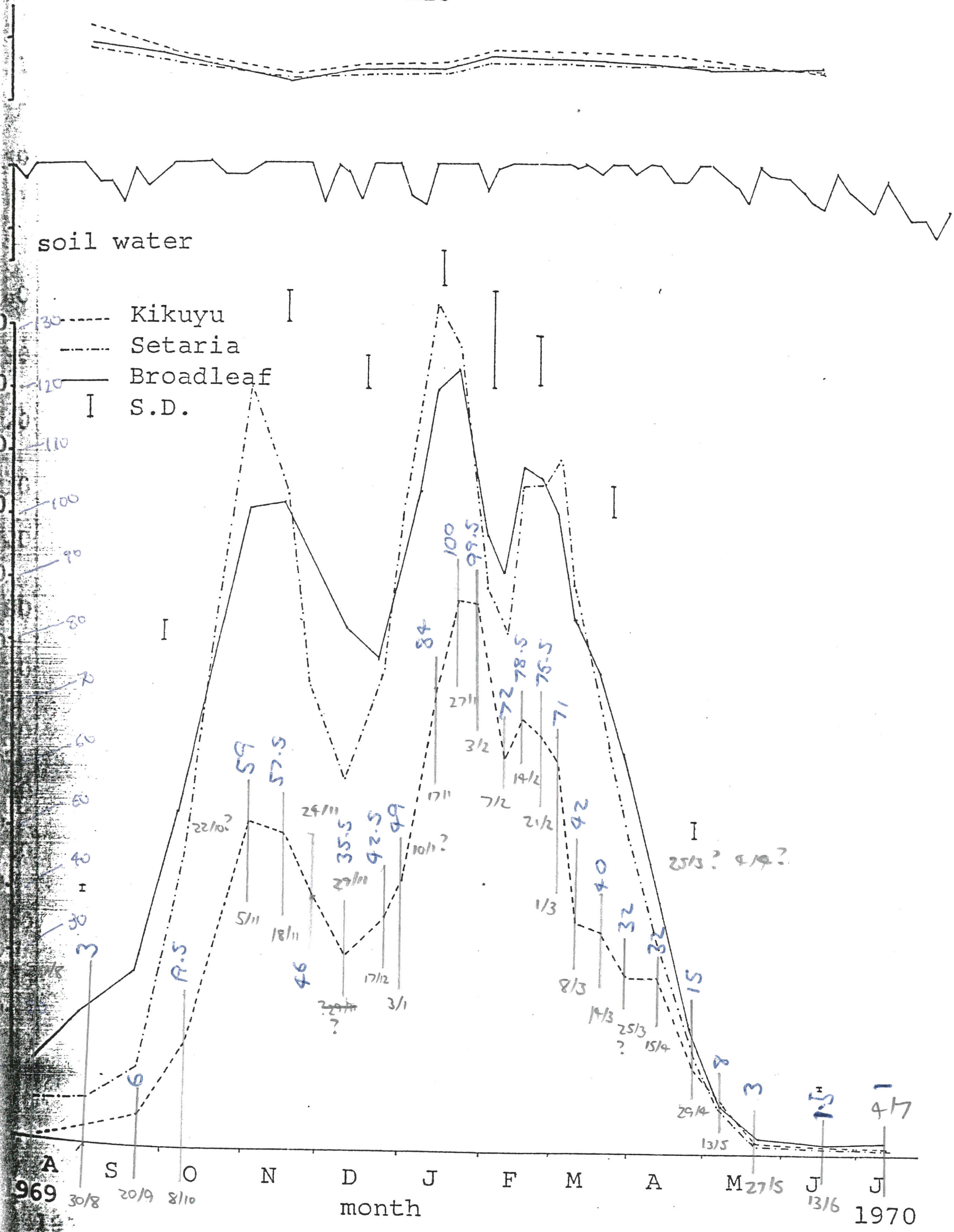
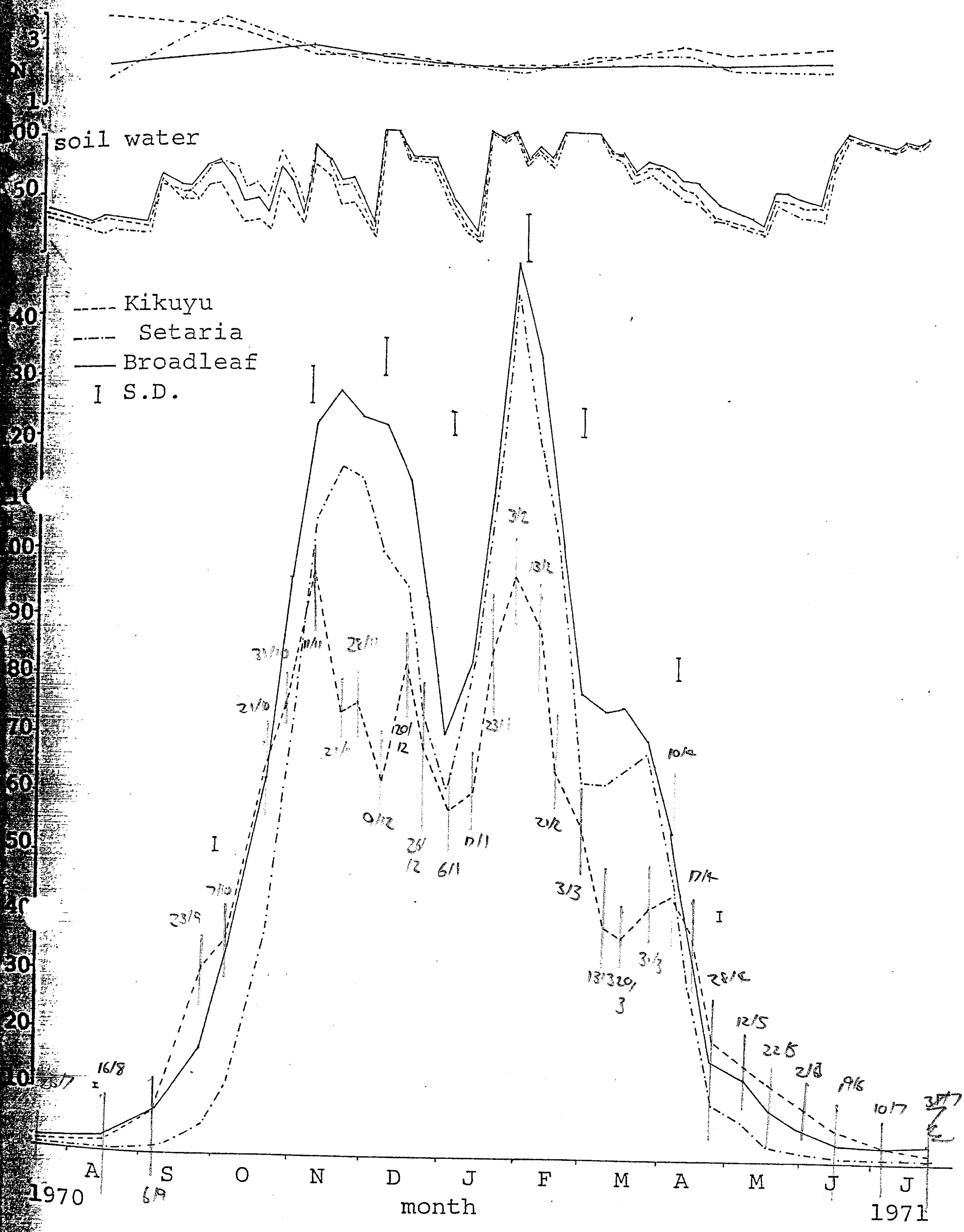


Figure 17. Seasonal growth curves for high nitrogen, irrigated treatments 1969-70 with percent nitrogen in forage and estimated available soil water.



8. Seasonal growth curves for high nitrogen unirrigated treatments 1970-71 with percent nitrogen in forage and estimated available soil water.

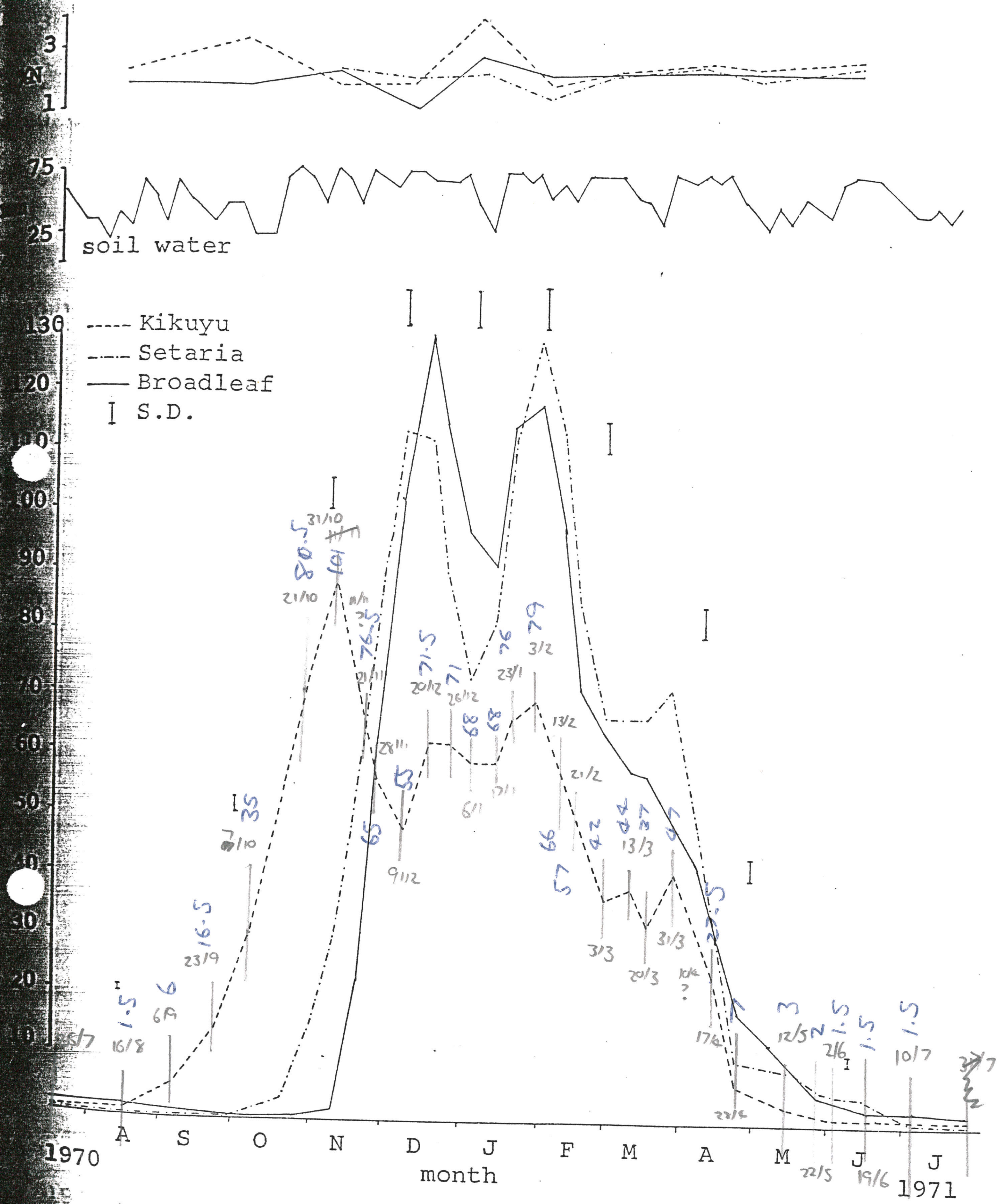
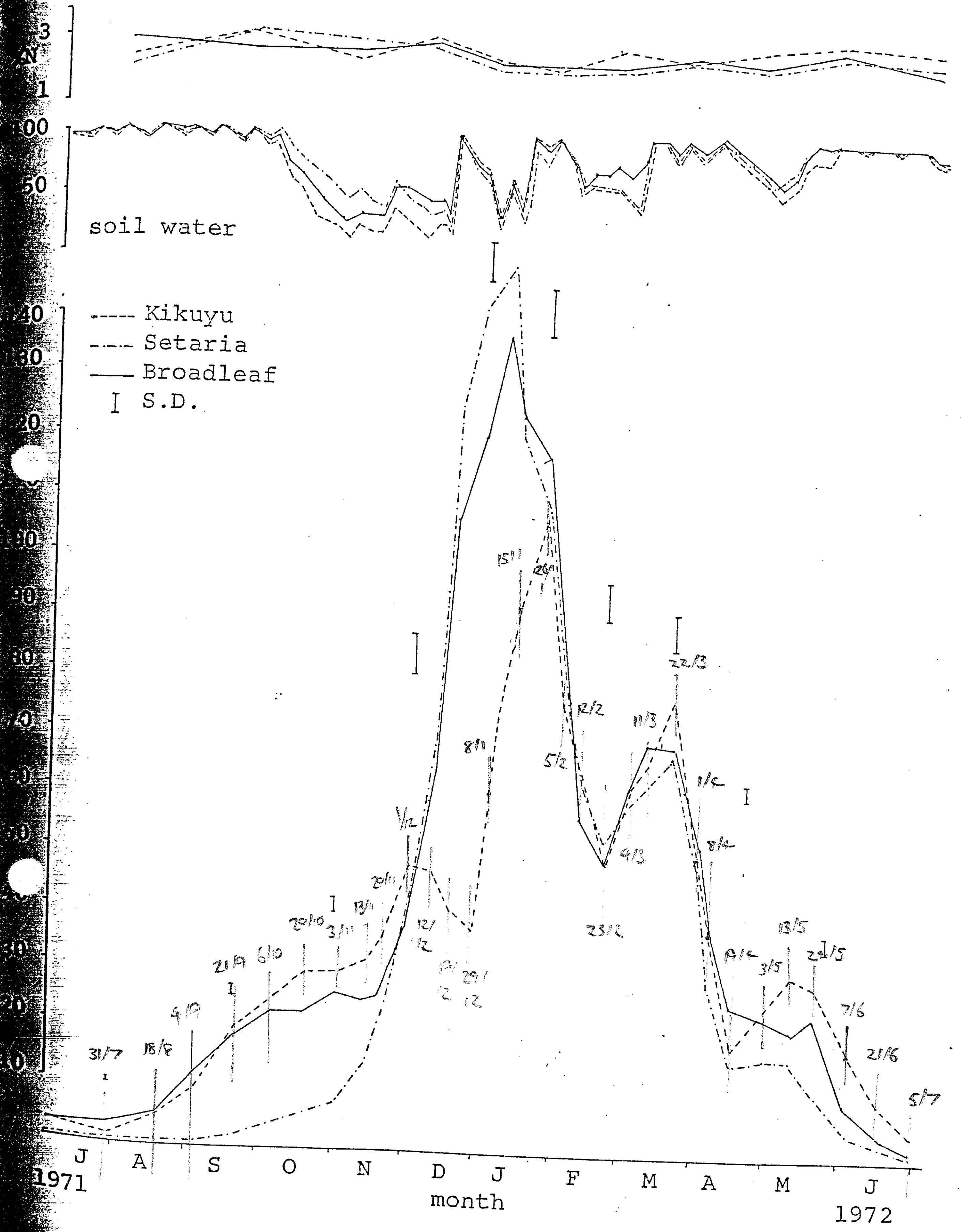


Figure 19. Seasonal growth curves for high nitrogen, irrigated treatments 1970-71, with percent nitrogen in forage and estimated available soil water.



ure 20. Seasonal growth curves for high nitrogen, unirrigated treatments 1971-72, with percent nitrogen in forage and estimated available soil water.

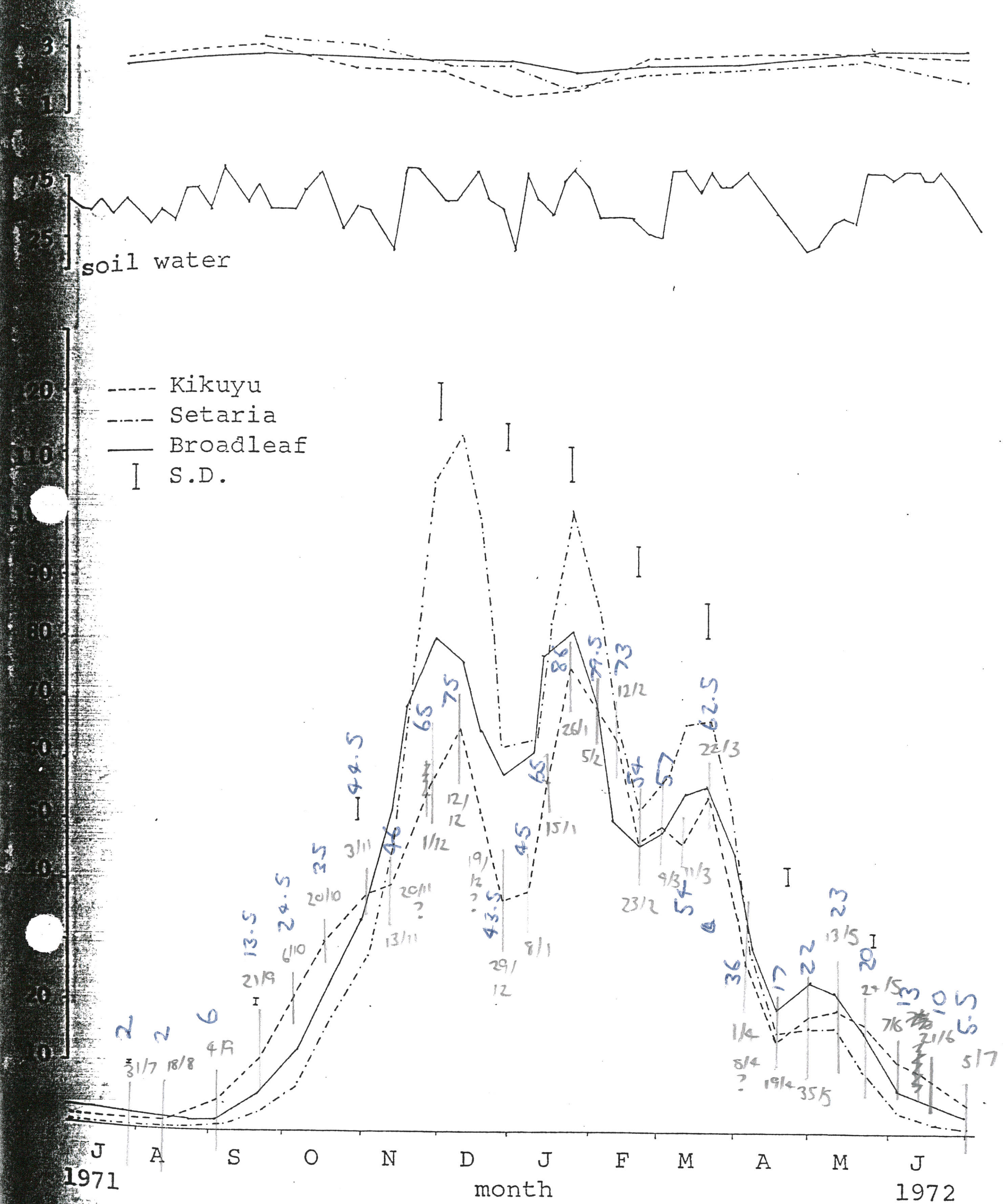
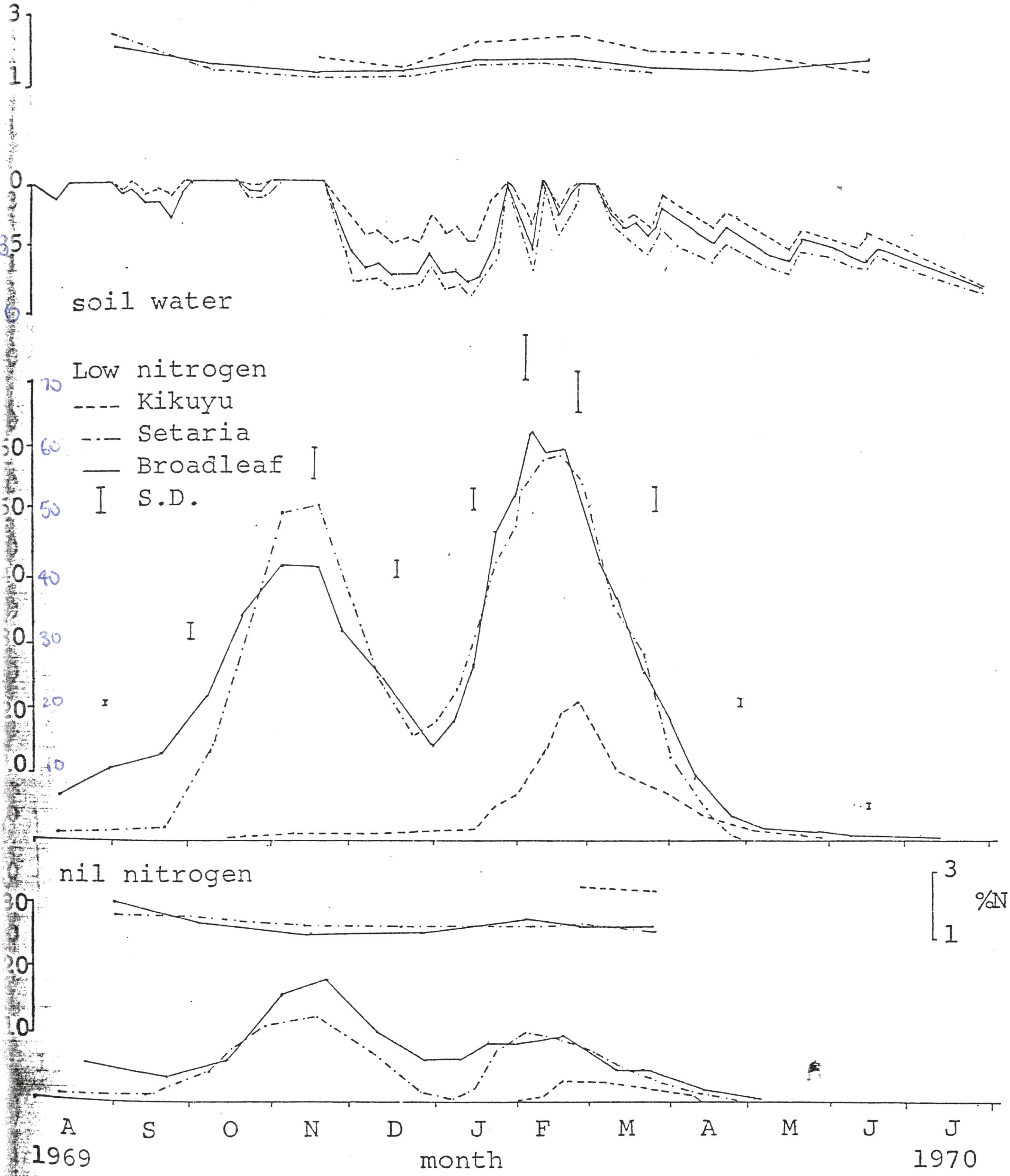


Figure 21. Seasonal growth curves for high nitrogen irrigated treatments 1971-72, with percent nitrogen in forage and estimated available soil water.



22. Seasonal growth curves for nil and low nitrogen unirrigated treatments 1969-70, with percent nitrogen in forage and estimated available soil water under low N plots.

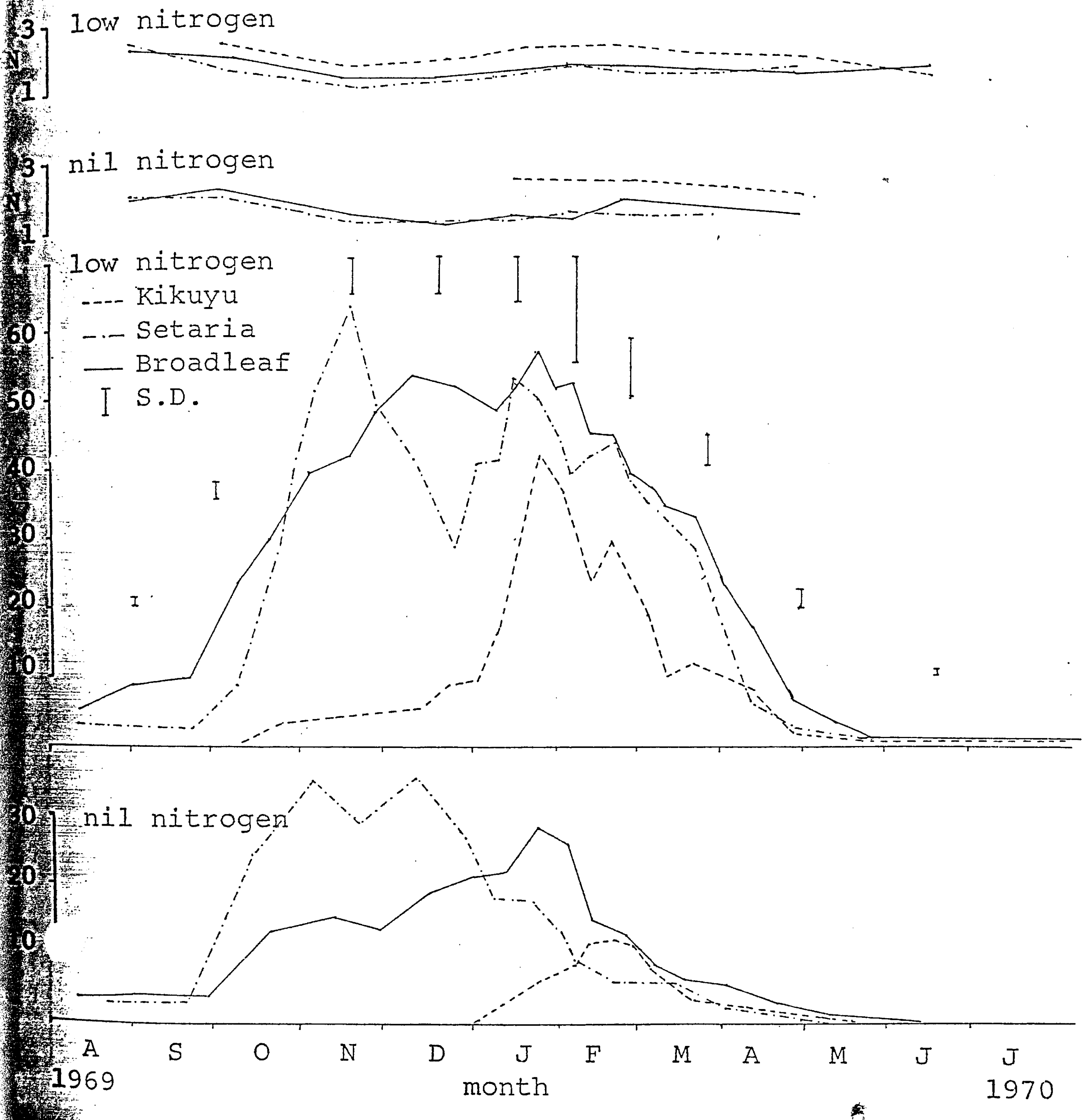


Figure 23. Seasonal growth curves for nil and low nitrogen irrigated treatments in 1969-70, plus percent nitrogen in forage.

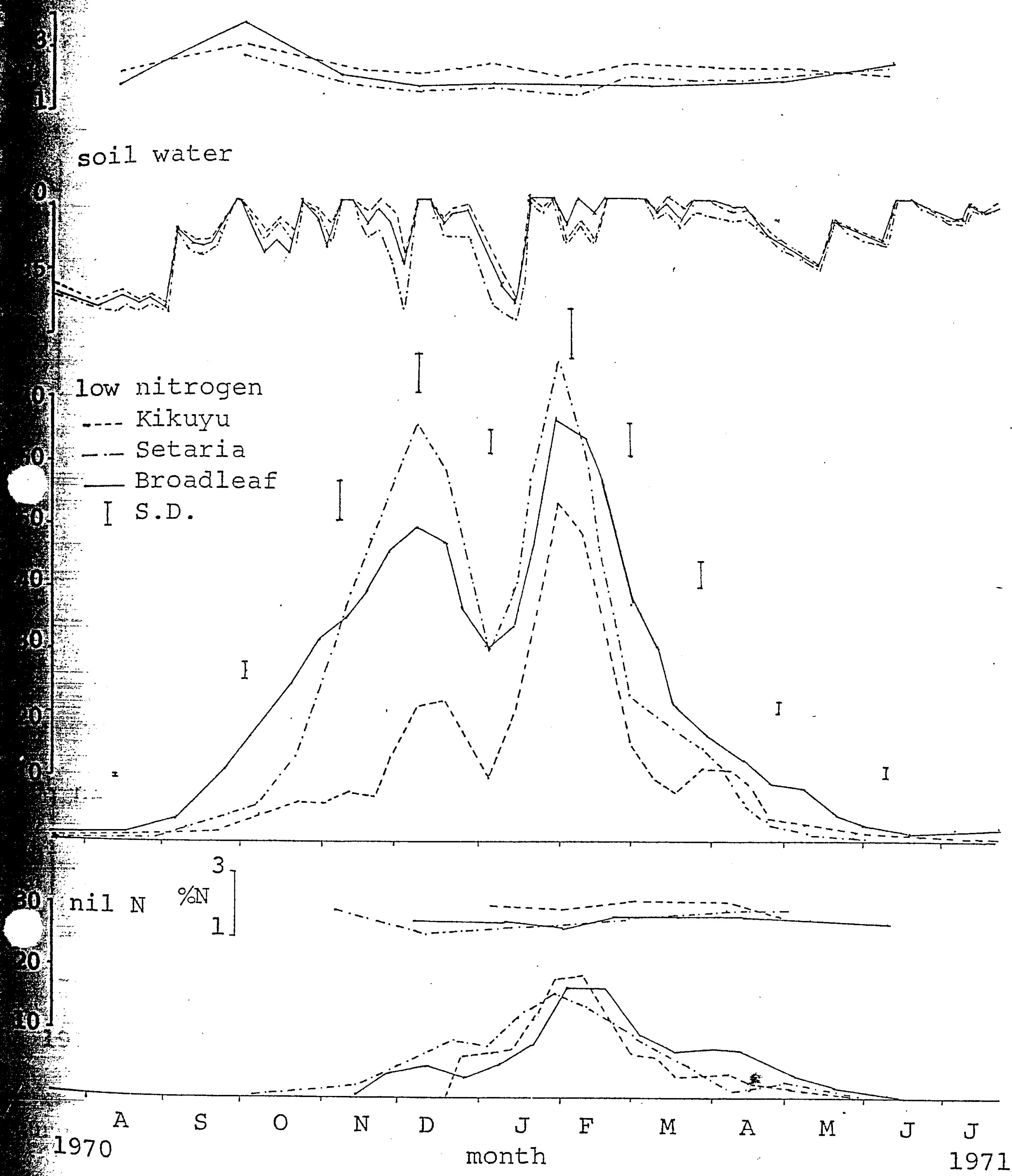


Figure 24. Seasonal growth curves for nil and low nitrogen unirrigated treatments 1970-71, with percent nitrogen in forage and estimated available soil water under low nitrogen plots.

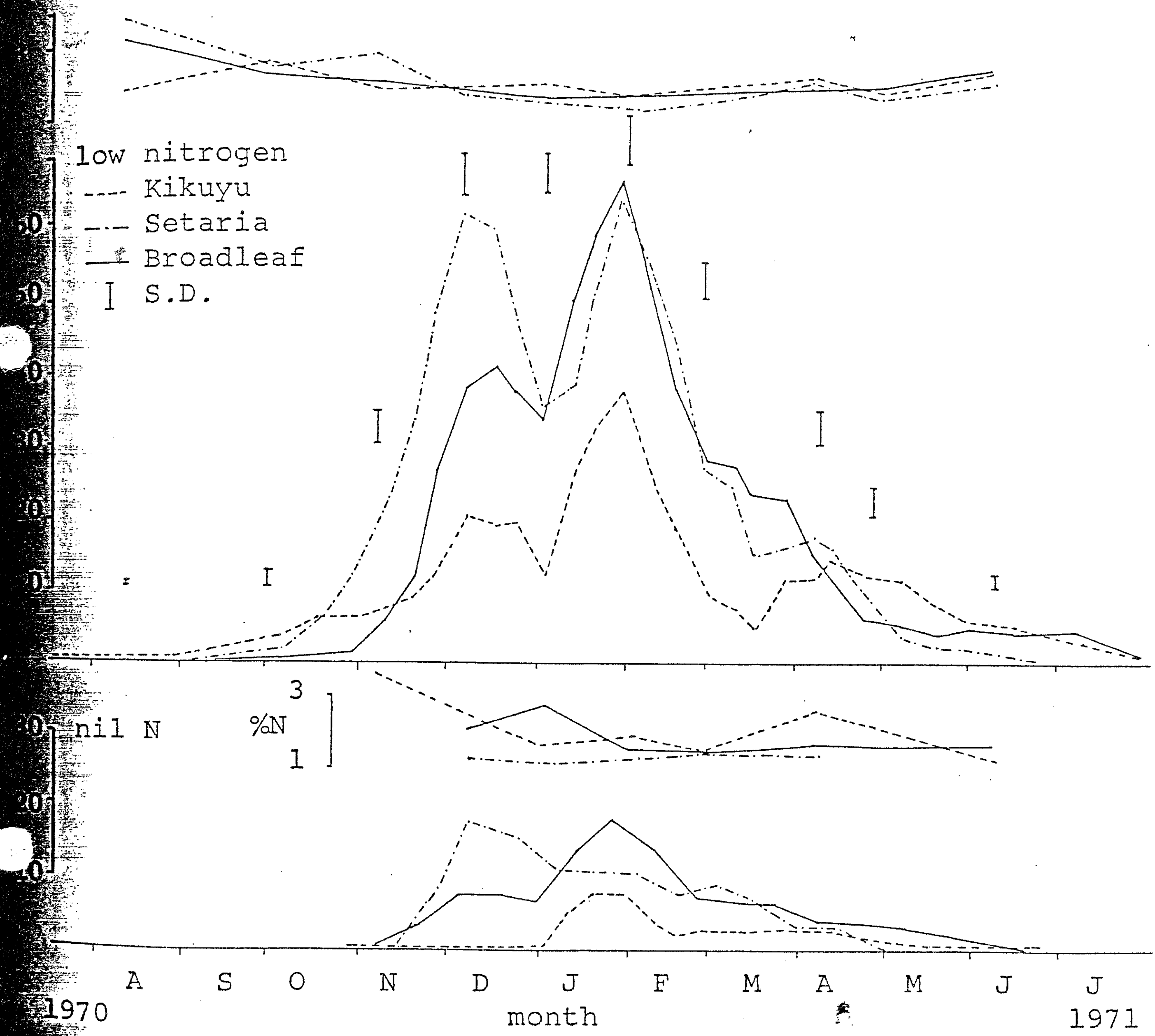


Figure 25. Seasonal growth curves for nil and low nitrogen irrigated treatments 1970-71, and percent nitrogen in forage.

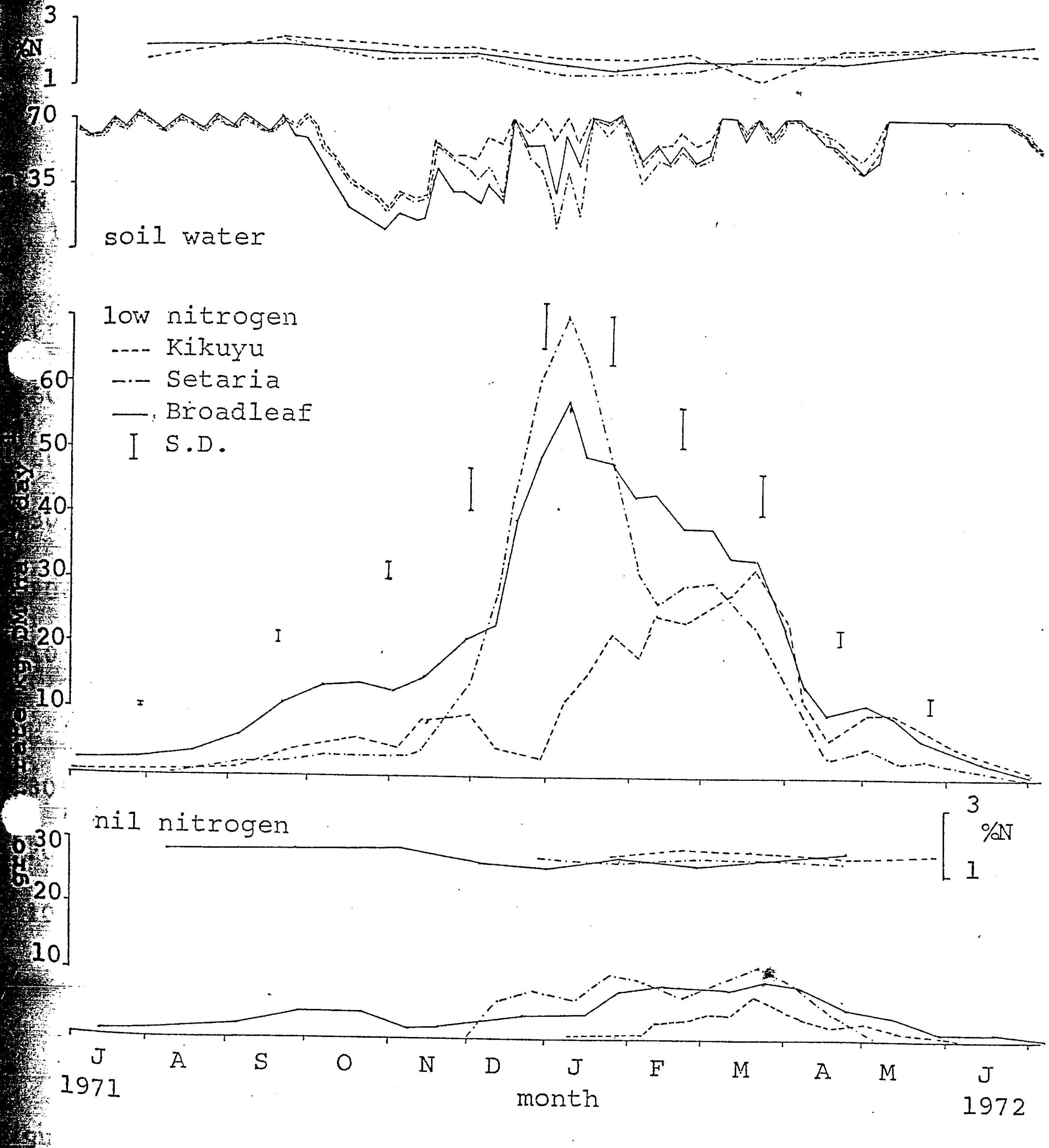


Figure 26. Seasonal growth curves for nil and low nitrogen unirrigated treatments 1971-72, with percent nitrogen in forage and estimated available soil water under low nitrogen plots.

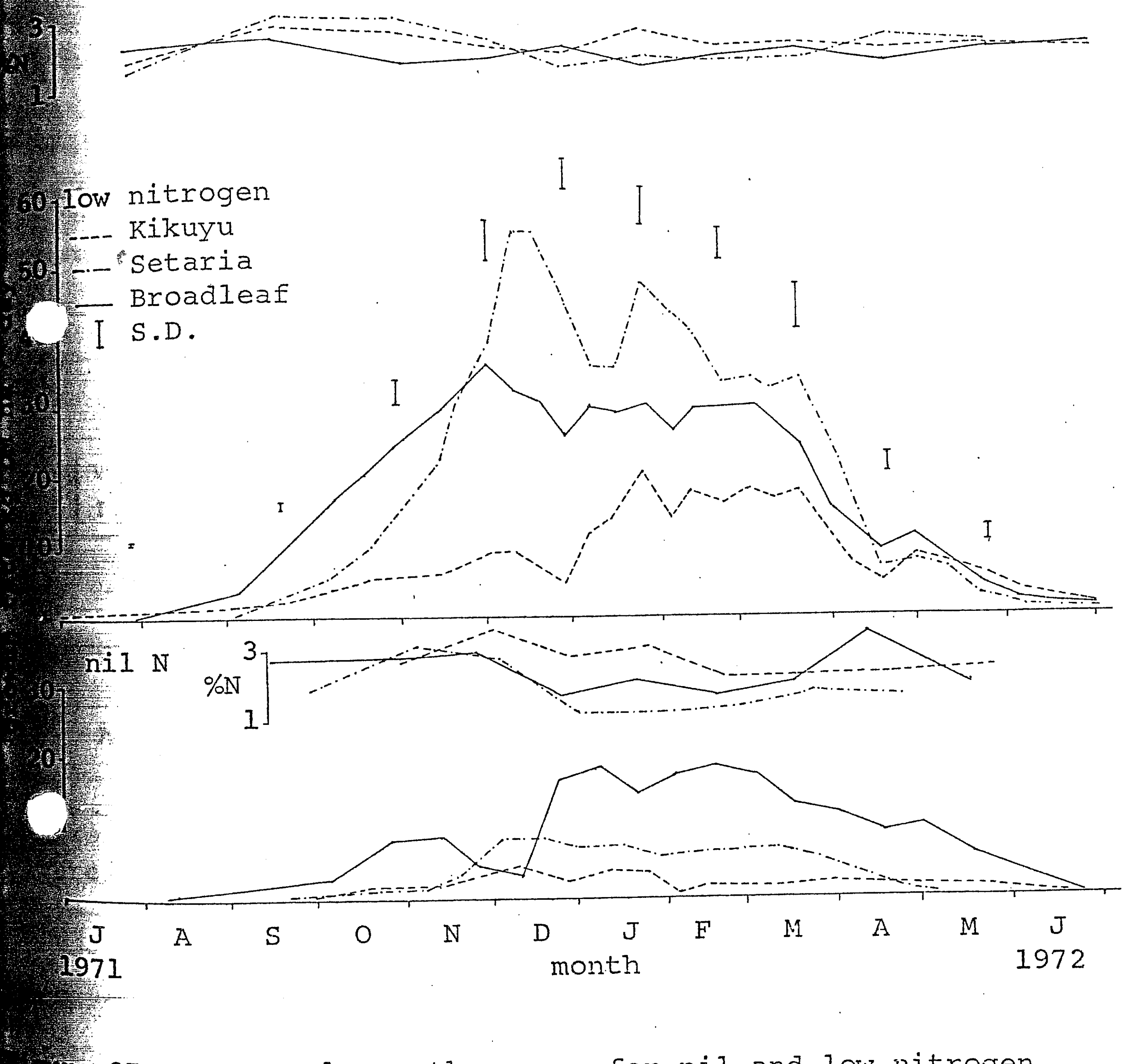


Figure 27. Seasonal growth curves for nil and low nitrogen irrigated treatments 1971-72, with percent nitrogen in forage.