栽植間隔の異なるクズ(Pueraria lobata OHWI)初年目群落の乾物生産ならびに葉面積展開の季節変化

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Seasonal Changes in Dry Matter Production and Leaf Area Expansion of First Year Stands of Kudzu-vine (*Pueraria lobata* OHWI) Differing in Spacing

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Synopsis

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The first year growth of kudzu plants grown at 40, 80 and 120 cm spacings was compared. Dry weights of the plant tops, roots and litter and leaf area were measured 8 times at three week intervals during the period from July 17 to December 11. Growth parameters were calculated using only plant tops. Plants and litter were harvested at planting (PS) and interplant (IS) sites, using a 20 × 20 cm quadrat.

Differences in top and root growth among spacings were small in IS throughout the growing season. In PS, however, there were significant differences in the seasonal trends of these dry weights among spacings. The greatest top and leaf dry weights, 475 g m^{-2} and 329 g m^{-2}, respectively, were obtained at 80 cm spacing. The highest value of maximum LAI was 5.2 at 40 cm spacing and maximum LAI was smaller at the wider spacings.

Seasonal trends in RGR, NAR, CGR and RLGR were similar in all spacings of IS. In PS, significant differences existed between 120 cm spacing and the other two spacings in RGR, NAR and CGR. This result was attributed to the difference in stem dry matter accumulation.

The highest maximum CGR, 6.2, was obtained at 80 cm spacing, with optimum LAI 2.9 and NAR 2.2.

Key words: Dry matter production, Growth rates, Leaf area, *Pueraria lobata*.

Introduction

Kudzu-vine was introduced into the southern USA as a forage and soil conservation crop in the 1940s. It was proven to be one of the best soil-conservation crops and was adapted to erosion control in gullies : where most other types of vegetation were inadequate[7]. In those days, few valuable scientific findings were obtained since practice was put before research and

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research techniques were less rigorous. Thus, little information is available on optimal planting density of kudzu-vine for field cultivation.

This study is an attempt to elucidate the characteristics of dry matter and leaf area production of kudzu-vine by monitoring dry weight, leaf area and growth rates in the first year kudzu stands differing in spacing.

Materials and Methods

1. Experimental designs and plant sampling

Kudzu seeds were collected from a natural kudzu stand in 2-chome, Tsurukabuto, Nada-ku, Kobe located at the southern foot of the Rokko mountains in January 1986. The seeds were scarified with an improved household mixer on May 14, 1986 and were immediately germinated in closed petri dishes in darkness at 25°C. The seeds were sown in 5 × 5 × 5 cm peat pots on May 16 when their radicles were about 1 cm long. Seedlings were raised in a glasshouse of the Faculty of Agriculture, Kobe University. They were provided with a 1/500 solution of Hyponex 5-10-5 fertilizer three times while being raised.

The seedlings were transplanted with a single plant per hill into the experimental plots comprised of 49 plants (7 × 7 plants) in a 40, 80 or 120 cm grid on June 26 (Fig. 1). The plot area was 7.84 m^2 for 40 cm, 31.36 m^2 for 80 cm and 70.56 m^2 for 120 cm spacing. Laneways (1 m width) were left between plots. Fertilizer was applied at the rate of 20 kg N, and 50 kg P_2O_5 and K_2O per ha.

Forty cm spacing has been conventionally adopted for the cultivation of *Centrosema* and *Desmodium* spp., tropical creeping forage legumes. At the present time, the optimum spacing has not been determined in field cultivation of kudzu-vine. Comparisons of plant growth were made among 40, 80 and 120 cm spacings in this study because kudzu-vine is a larger sized plant compared to the two above-described species. The experimental design was a randomized block with 4 replications.

Plant harvests were made 8 times at intervals of three weeks from July 17 to December 11, 1986. Sampling positions were in pairs, one at an original planting site (PS) and the other at an interplant site (IS). They were randomly pre-determined, as shown in Fig. 1. One paired position per plot was used for each sampling time. Plant tops, roots and litter were sampled within a 20 × 20 cm quadrat centered on each position. Roots were collected within 10 cm of the soil surface. Weeds were controlled by herbicide application and hand weeding. Irrigation was applied 12 times by overhead sprinklers from immediately after transplanting (June 26) until mid September.

2. Measurements and analysis

After sampling, plant tops were separated into stems, leaflets and petioles. Furthermore, these organs were separated into living and dead portions. Leaf area was measured with an automatic area meter (Hayashi Denko Co. Ltd., type AAM-7). Each plant part and litter were dried in an oven at 80℃ and weighed.

The following growth parameters[6] were used to describe the seasonal changes in dry matter and leaf area production : Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Crop Growth Rate (CGR) and Relative Leaf Growth Rate (RLGR). The growth

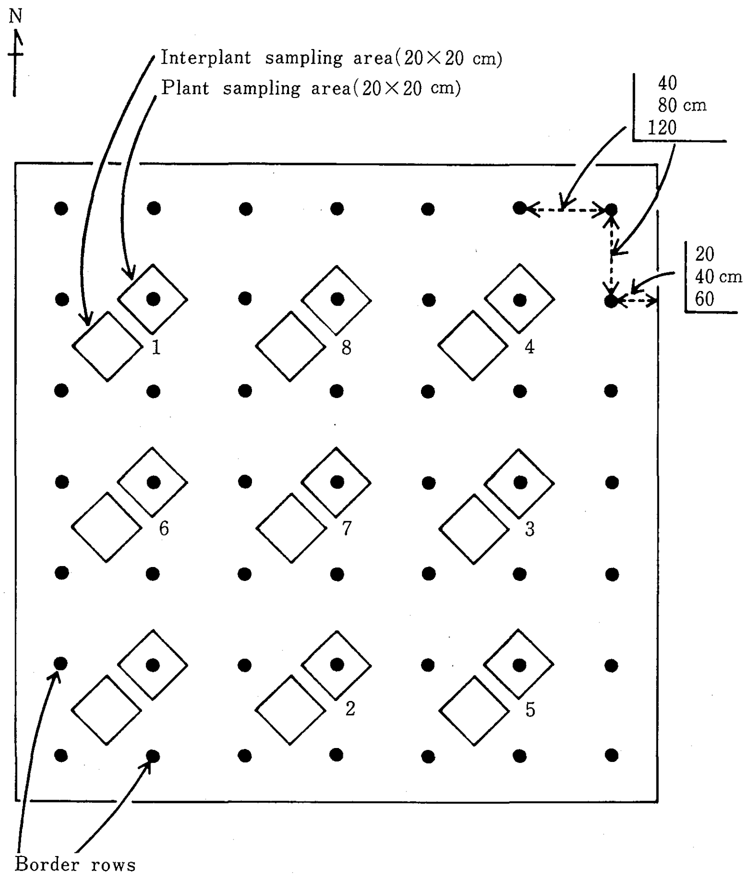

Fig. 1. Arrangement of kudzu plants (black dots) and sampling areas at 40, 80 or 120 cm spacing.
The distance between border rows and lane is 20, 40 and 60 cm in 40, 80 and 120 cm spacings, respectively. The numbers near the sampling areas show the sampling order in one plot.

parameters were calculated using only plant tops. Seasonal changes in Leaf Area Index (LAI) and Specific Leaf Area (SLA $cm^2\ g^{-1}$) were also determined.

The relationships between LAI and NAR or CGR were drawn according to the method by WATANABE[9,10].

Relevant climatic data were quoted from the monthly original records of Osaka District Meteorological Observatory situated about 25 km southeast of the study site and Kobe Marine Meteorological Observatory situated at the south foot of the Rokko mountains and about 9 km west of the study site (Table 1).

Results

1. Dry weight of plant tops, roots and litter

In each plant spacing, there is an apparent difference in growth between individual plants

Table 1. Weather data during the growing season.

Period (1986)	Daily mean temperature (°C)	Cumulative solar radiation (MJ/m²)	Cumulative precipitation (mm)
Jun. 26 - Jul. 16	23.5	291.1	126.0
Jul. 17 - Aug. 6	27.0	404.7	31.0
Aug. 7 - Aug. 27	27.8	392.5	2.0
Aug. 28 - Sept. 17	25.6	304.8	71.0
Sept. 18 - Oct. 8	21.5	313.5	33.5
Oct. 9 - Oct. 29	15.4	243.5	60.5
Oct. 30 - Nov. 19	12.6	176.9	16.5
Nov. 20 - Dec. 10	10.1	175.7	11.5

Temperature and precipitation data were quoted from the observations at Kobe Marine Meteorological Observatory and solar radiation data were quoted from the observations at Osaka District Meteorological Observatory.

for a brief period after transplanting due to the delay in the establishment of seedlings. However, from August onward, nosignificant difference in plant growth was observed in each spacing.

In the planting site (PS), total top dry weight of 40 and 80 cm spacings attained a maximum of 500 g m^{-2} on October 30 and 606 g m^{-2} on November 20, respectively ; whereas it continued to increase up to the final harvest at 120 cm spacing (598 g m^{-2}) (Fig. 2).

Stem dry weight decreased from October 30 onward at 40 cm spacing. At 120 cm spacing, however, it continued a rapid increase even during the late growing season. The ratio of stem dry weight to total top dry weight was larger at the wider spacings from August 28 onward. Petiole dry weight at 80 cm spacing was greater than that at the other two spacings from August 28 onward. Leaflet dry weight was also greatest at 80 cm spacing from August 28 onward. The maximum value of leaflet dry weight was 163 g m^{-2} at 40 cm spacing on October 30, 192 g m^{-2} at 80 cm spacing on October 9, and 141 g m^{-2} at 120 cm spacing on October 9. The proportion of leaflet dry weight was 33, 35 and 27% at these dates, respectively. The great differences in the seasonal trend of total top dry weight among the spacings were primarily attributable to the differences in dry matter production of stems.

In the interplant site (IS), total top dry weight increased until November 20 at 40 cm spacing and until October 30 at 80 and 120 cm spacings (Fig. 2). The highest values of top dry weight were smaller in the wider spacings, ranging from 370 g to 402 g m^{-2}. The proportion of stem weight was larger at the wider spacings throughout the growing season, while the reverse was true for the proportion of leaflet weight. The differences in the seasonal changes of total top dry weight among spacings in IS were not as large as those in PS.

The maximum values of total top dry weight averaged across planting sites [(PS + IS)/2] were obtained on October 30 in all spacings, with 436, 475 and 444 g m^{-2} at 40, 80 and 120 cm spacings, respectively. No flower clusters were observed in the first year.

Senescence of leaves and unlignified stem tips progressed with rapidly decreasing air temperature after October. The proportion of dead dry weight to total top dry weight in both sampling sites was less than 4% until November 20 and ranged from 2 to 22% on

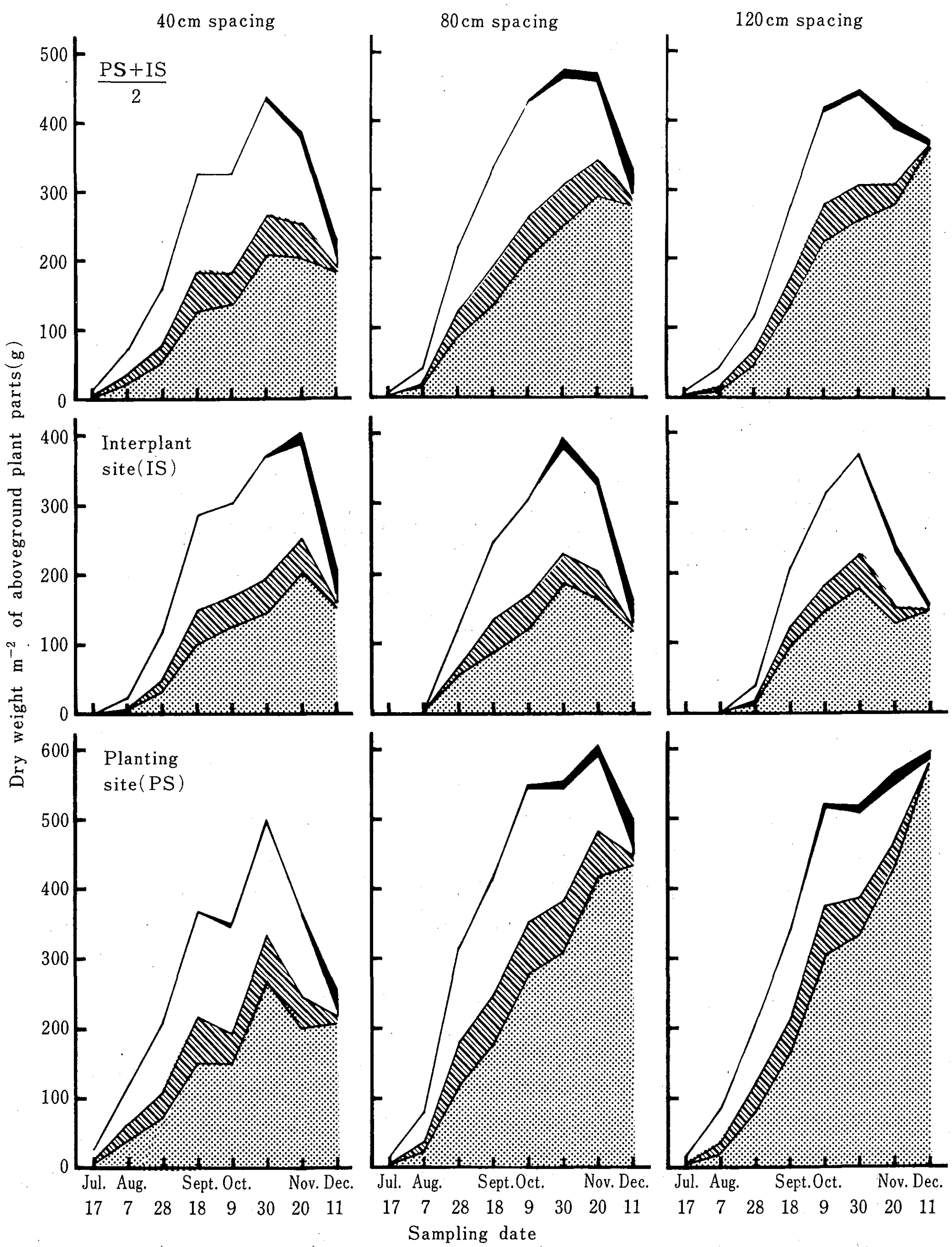

Fig. 2. Seasonal trends in dry matter partitioning of aboveground plant parts at planting and interplant sites and mean dry matter partitioning of both sites of kudzu plants grown at different spacings.
▒ : stem, ▨ : petiole, □ : leaflet, ■ : dead part.

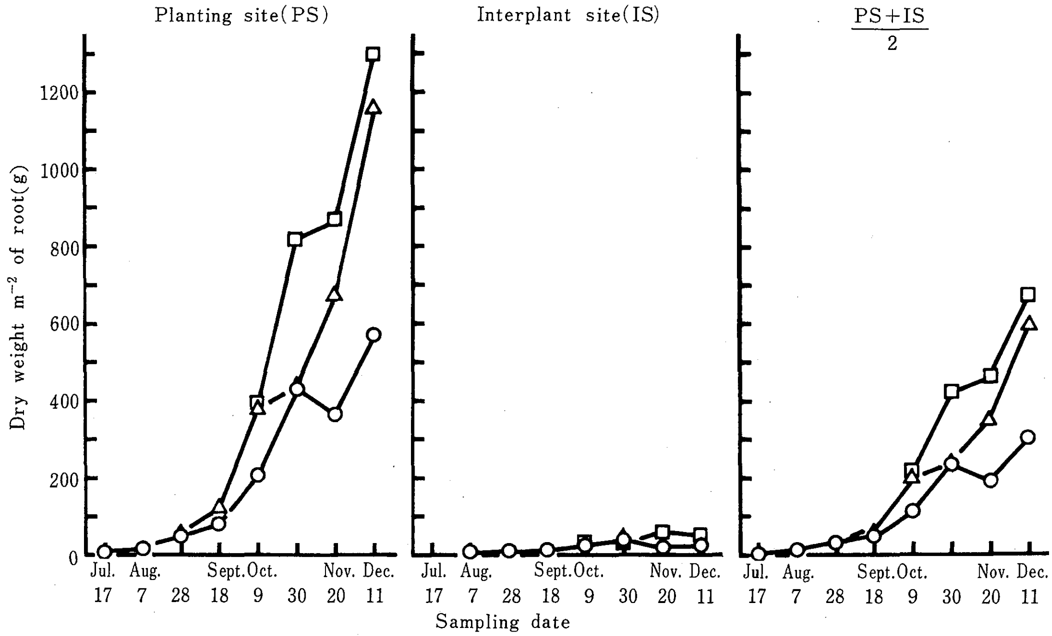

Fig. 3. Seasonal trends in root weights at planting and interplant sites and mean weights of both sites of kudzu plants grown at different spacings.
○——○ : 40 cm, △——△ : 80 cm, □——□ : 120 cm spacing.

December 11.

Root dry weight increased slowly until September 18 and rapidly thereafter in PS at all spacings (Fig. 3). The 120 cm spacing had a root dry weight of about 1.3 kg m^{-2} at the final harvest, whereas the 40 cm spacing had less than half of the value at 120 cm spacing. The increase in root dry weight in IS was very small in all spacings, and root dry weights of IS were 1/20 to 1/26 of those in PS on December 11.

Litter dry weights began to increase at both sampling sites at all spacings on August 28 and increased rapidly from October 30 onward, especially between November 20 and December 11 (Fig. 4). At the final harvest, litter dry weight was greater in the closer spacings in both sampling sites, and it was 13 to 58% greater in PS than in IS.

2. LAI, SLA and RLGR

Leaf area index (LAI) increased rapidly from July 17 in PS at all spacings and the highest values of LAI were 5.1, 5.1 and 3.5 at 40, 80 and 120 cm spacings, respectively (Fig. 5a).

The increase in leaf area occurred later in IS than in PS at all spacings, especially at 120 cm spacing. The highest values of LAI in IS at 40, 80 and 120 cm spacings were 5.4, 4.0 and 4.0, respectively. LAI in IS tended to be greater in the closer spacings over the growing season.

Specific leaf area (SLA) tended to decrease from early to late in the growing season, with a temporary slight increase on September 18, in PS of all spacings (Fig. 5b). On the other hand, in IS at all spacings, SLA increased until September 18, decreased to October 9 and then

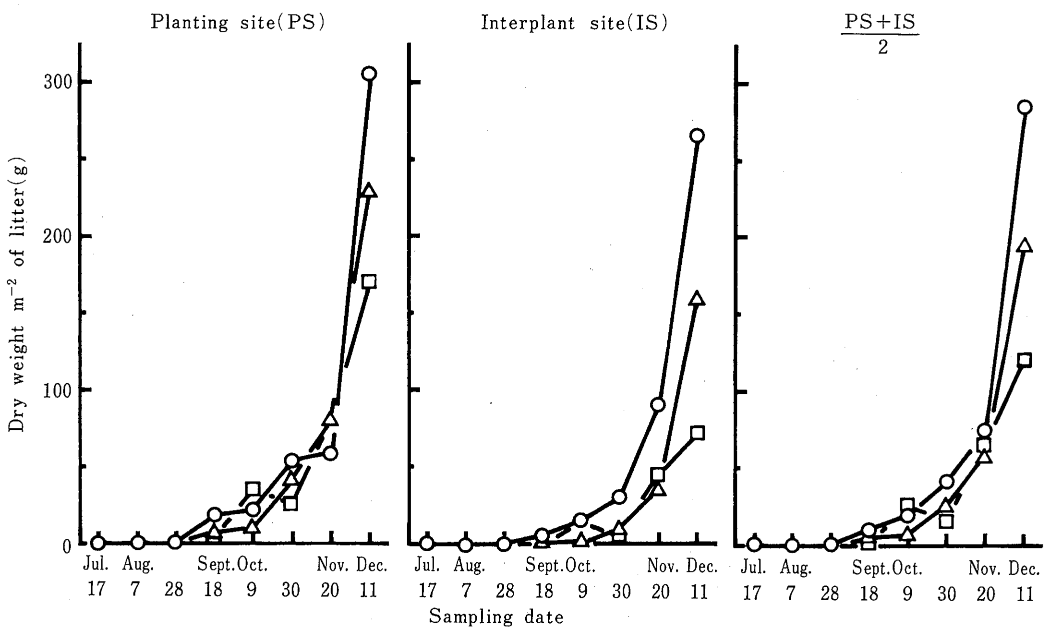

Fig. 4. Seasonal trends in litter weight at planting and interplant sites and mean weights of both sites of kudzu plants grown at different spacings.
○——○ : 40 cm, △——△ : 80 cm, □——□ : 120 cm spacing.

leveled off. SLA was greater at 40 cm spacing than the other two spacings at both sampling sites.

Relative leaf growth rate (RLGR) was greater at both sampling sites during the period when LAI showed a rapid increase. It fell to near zero as LAI peaked (Fig. 5c). RLGRs had large negative values from October 30 onward as LAI decreased rapidly.

3. RGR, NAR and CGR

In PS, relative growth rate (RGR) and net assimilation rate (NAR) at 40 and 80 cm spacings declined markedly from October 30 or November 20 to December 11, whereas those at 120 cm spacing tended to level off or increase during the same period. In contrast to PS, RGR and NAR in IS at 120 cm spacing, like at the other two spacings, declined noticeably and showed negative values from November 20 onward. RGR and NAR were higher in IS than in PS until September 18.

Crop growth rate (CGR) was very variable in both sampling sites at all spacings (Fig. 6c). Peak CGRs occurred during the period from August 7 to October 9 in PS and between August 28 and September 18 in IS. The mean value of CGR before October 9 was higher at 80 and 120 cm spacings (6.4, 6.0 g m^{-2} day^{-1}, respectively) than at 40 cm spacing (3.8 g m^{-2} day^{-1}) in PS, and it was higher at the wider spacings in IS (4.4 − 6.5 g m^{-2} day^{-1}). CGR between November 20 and December 11 was negative in IS at all spacings and in PS at 40 and 80 cm spacings, while maintaining a relatively large value of about 2 g m^{-2} day^{-1} at 120 cm spacing.

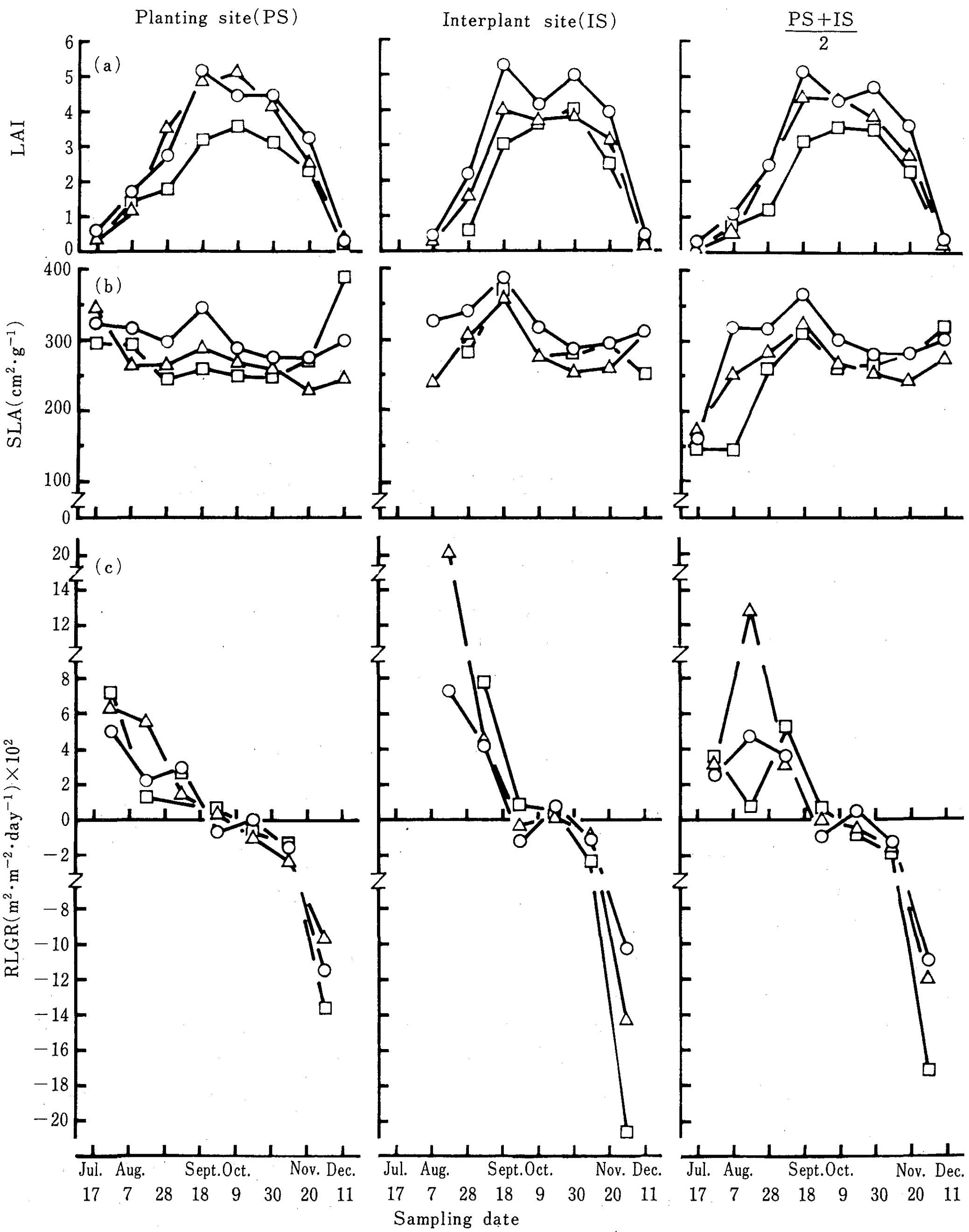

Fig. 5. Seasonal trends in (a) LAI, (b) SLA and (c) RLGR at planting and interplant sites and mean values of these growth parameters of both sites of kudzu plants grown at different spacings.

○——○ : 40 cm, △——△ : 80 cm, □——□ : 120 cm spacing.

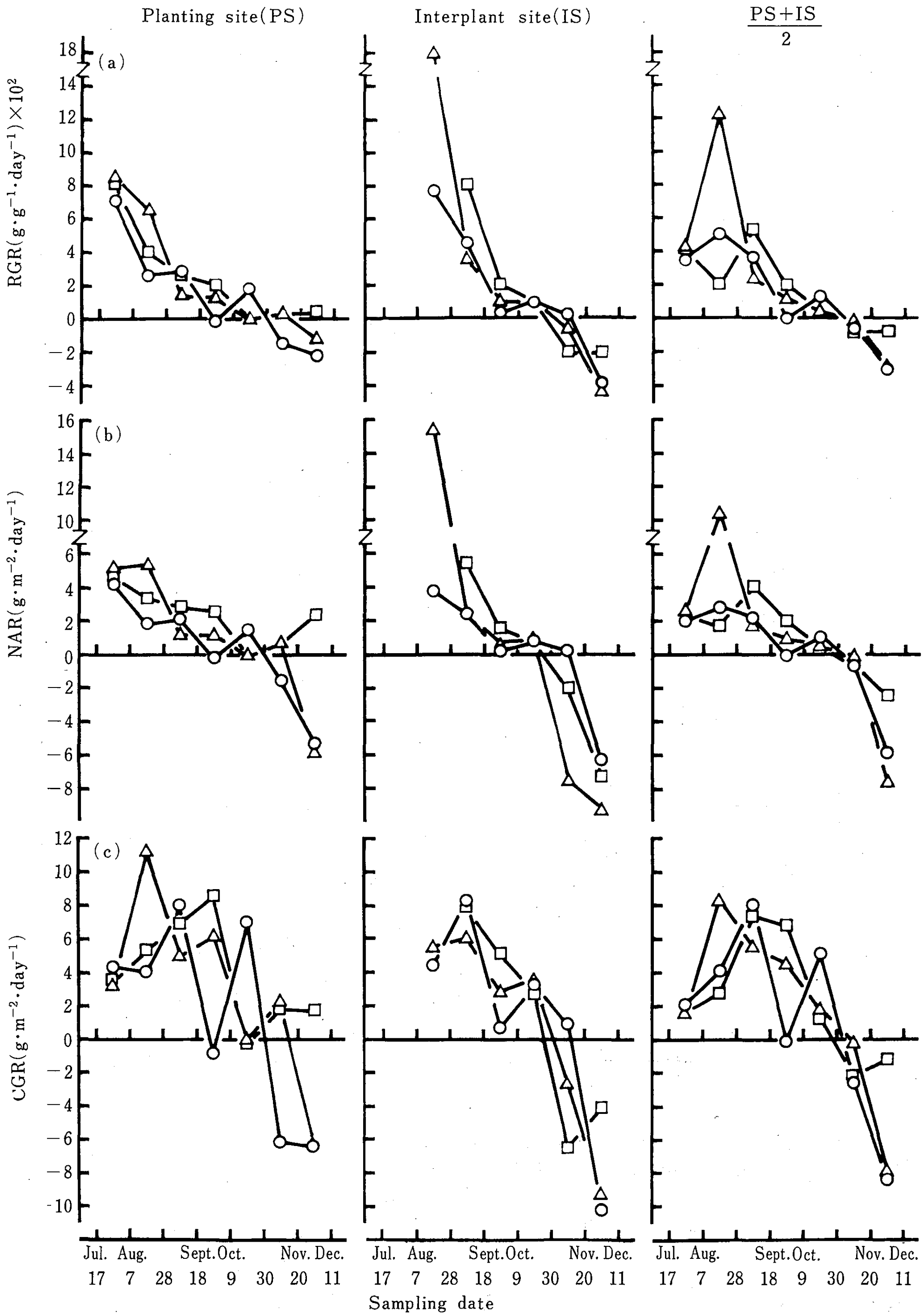

Fig. 6. Seasonal trends in (a) RGR, (b) NAR and (c) CGR at planting and interplant sites and mean values of these growth parameters of both sites of kudzu plants grown at different spacings.
○—○ : 40 cm, △—△ : 80 cm, □—□ : 120 cm spacing.

Table 2. Equations showing relationship between the number of weeks after transplanting(x) and total top dry weight(g), LAI or CGR(y) at different spacings.

Item	Plant spacing	Equation	R^2
Total top dry weight	40 cm	$y=-36.67x+45.774x^2-4.6855x^3$	0.976**
	80 cm	$y=-46.77x+52.541x^2-5.1924x^3$	0.993**
	120 cm	$y=-53.96x+48.223x^2-4.4882x^3$	0.981**
LAI	40 cm	$y=-0.229x+0.5887x^2-0.06939x^3$	0.945**
	80 cm	$y=-0.252x+0.5517x^2-0.06490x^3$	0.965**
	120 cm	$y=-0.506x+0.5315x^2-0.05820x^3$	0.975**
CGR	40 cm	$y=-36.67+91.549x-14.0563x^2$	
	80 cm	$y=-46.77+105.081x-15.5773x^2$	
	120 cm	$y=-53.96+96.446x-13.4646x^2$	

** significant at 1% level.

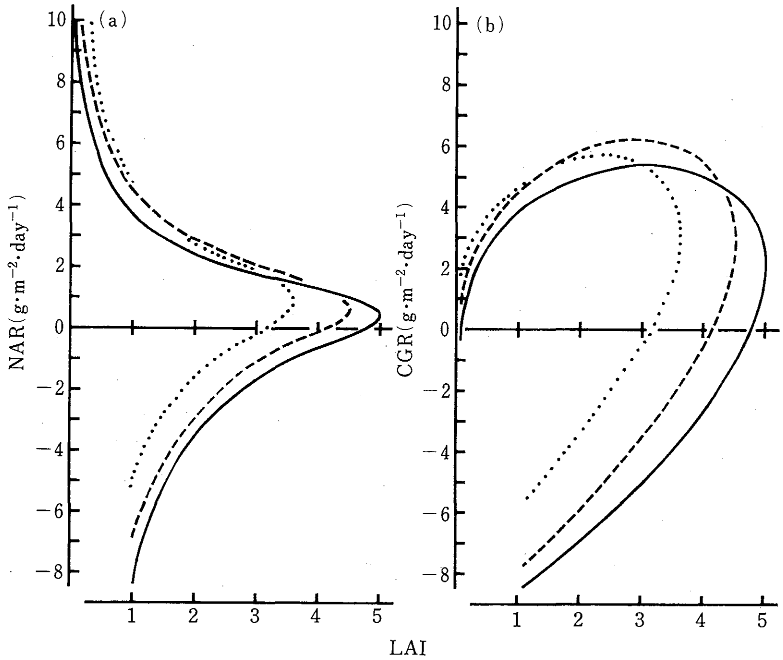

Fig. 7. Relationships between LAI and (a) NAR or (b) CGR calculated by averaging across planting and interplant sites in kudzu plants grown at different spacings.
—— : 40 cm, ---- : 80 cm, ········ : 120 cm spacing.

4. Relationship between LAI and NAR or CGR

Equations for total top dry weight, LAI and CGR are listed in Table 2, and were used to create the LAI-NAR and LAI-CGR graphs shown in Fig. 7. NAR decreased with increasing LAI in all spacings and was not greatly different among spacings before maximum LAI was attained (Fig.7a). Maximum LAI ranged from 3.6 at 120 cm spacing to 5.0 at 40 cm spacing.

NARs reached zero immediately after maximum LAIs and had negative values thereafter.

CGRs increased with increasing LAI toward peaks ranging from a maximum of 6.2 at 80 cm spacing to a maximum of 5.4 at 40 cm spacing (Fig. 7b). Optimum LAI ranged from 2.4 at 120 cm spacing to 3.1 at 40 cm spacing. CGRs of all spacings showed negative values immediately after maximum LAI was attained.

Discussion

The highest of top dry weight, 4.7 t ha^{-1}, was obtained at 80 cm spacing (15,625 plants ha^{-1}) on October 30. HABU *et al.*[1] transplanted kudzu seedlings at a rate of 3,021 plants ha^{-1} in Tottori Pref. (35°31′N, 133°38′E) on March 12 and harvested them on August 4. Forage dry matter yield was 1.9 t ha^{-1} with an application of 11.3 t ha^{-1} of barnyard manure and 0.6 t ha^{-1} without manure. The lower yield in the study by HABU *et al.* is probably due to the lower planting density which is less than one fifth of ours (Forty and 120 cm spacings are equivalent to 62,500 and 6,944 plants ha^{-1}, respectively).

Two-year-old kudzu seedlings were transplanted at a rate of 12,085 plants ha^{-1} in Tochigi Pref. (36°50′N, 139°58′E) and fresh forage yield without fertilizer was 21 t ha^{-1} in KURIYAMA's study[4]. In Iwate Pref. (39°14′N, 141°03′E), kudzu plants were grown in the same manner as in Tochigi Pref. and yielded 23.8 t ha^{-1} of fresh weight[4]. Dry matter yield was estimated to be 5.3 t ha^{-1} in the former study and 6.0 t ha^{-1} in the latter study. In spite of the lower planting density, these experiments had higher yields than the 80 cm spacing in our study. This is probably because larger sized seedlings were used in KURIYAMA's experiments.

As commonly observed in many plant species[2], including a study on *Centrosema* and *Desmodium* spp. in which a similar sampling method to the present study was used[8], RGR and NAR of kudzu-vine decreased through time (Fig. 6a, b). Both growth parameters had positive values in PS at 120 cm spacing, but had large negative values in IS at 120 cm spacing and in both sites at the other two spacings from October 30 or November 20 onward. An increase in top dry weight in PS at 120 cm spacing after November can be attributed to a fairly large NAR and therefore large RGR.

Noticeable differences existed only in stem dry weight among spacings in PS from October 30 onward (Fig. 2). This is because kudzu plants grew favorably and their stem bases thickened vigorously at 120 cm spacing because of less severe interplant competition ; whereas at 40 cm spacing plant size was smaller and the stem base thickened less as a result of severe interplant competition. RGR and NAR maintained positive values in PS at 120 cm spacing during the late growing season because the increase in stem dry weight exceeded the decrease in leaf dry weight (including petiole dry weight) due to leaf fall. In PS at the other two spacings, however, stem dry weight did not compensate for the decrease in leaf dry weight. Hence RGR and NAR showed negative values.

There is no growth analysis information available for kudzu-vine and other prostrate forage legumes with large sized, horizontal leaves like kudzu-vine. In ladino clover (*Trifolium repens*), a forage legume with a stoloniferous habit, OKUBO observed a maximum CGR of 14.4 g m^{-2} day^{-1} and a maximum LAI of 5.8, accompanied by a NAR of 2.5 g m^{-2} day^{-1}[15]. Kudzu plants at 80 cm spacing had estimates of maximum CGR 6.2 g m^{-2} day^{-1} and optimum

LAI 2.9, accompanied by NAR 2.2 g m^{-2} day^{-1} (Fig. 7). The maximum CGR of kudzu-vine was less than half that of ladino clover, although NARs of the two species were nearly equal. This may be due to the smaller optimum LAI in kudzu-vine. The smaller optimum LAI of kudzu-vine compared to ladino clover seems to be associated with the large-sized and horizontal leaves of kudzu-vine.

The influence of interplant competition was also observed in root dry weight (Fig. 3). Root dry weight differed between 120 cm spacing and the other two spacings on October 30 and among all three spacings in PS from November 20 onward, suggesting that plant size was smaller and thickening growth of the tap root was much more depressed in the closer spacings.

Vegetation ground covers help prevent falling raindrops from scattering topsoil[3]. PSs at all spacings were covered with a leaf canopy of kudzu-vine within 6 weeks after transplanting (August 7). However, it took about 9 weeks for the leaf canopy to cover IS at 40 and 80 cm spacings and a longer period in IS at 120 cm spacing. There were no great difference in LAI between 40 and 80 cm spacings in PS, while in IS the LAI at 40 cm spacing was greater than those at the other two spacings (Fig. 5). Thus, 40 cm spacing is superior to the other two spacings when it is desirable to cover the soil surface with kudzu-vine as soon as possible in the first year of growth. The LAI of natural kudzu stands ranged from 2 to 3 in Maryland to 4 to 5 in Georgia USA[11]. These LAI values seem to be in general agreement with the results of our study.

RLGRs in both sampling sites at all spacings decreased to nearly zero between September 18 and October 9, presumably because leaf loss by senescence on the main stems and lower order branches balanced gains from new leaves in higher order branches. Rapid decline in LAI after October seems to be associated with decreasing temperature.

The elongation of horizontal stems along the soil surface, rooted node formation and the structure of tap and nodal root systems, as well as leaf canopy formation in kudzu-vine, are important characteristics involved in soil conservation, and also have important roles in the persistence and expansion of kudzu stands. Thus, these factors, which should be evaluated when conducting comparative studies on planting density, will be discussed in a series of papers dealing with planting density of kudzu-vine.

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栽植間隔の異なるクズ（*Pueraria lobata* OHWI）初年目群落の乾物生産ならびに葉面積展開の季節変化

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要　　約

本研究では異なる3段階の栽植間隔で栽培したクズの地上部ならびに地下部の1年目の生長を比較した。1986年6月26日に40，80および120 cmの栽植間隔でクズ実生を移植し，7月17日から12月11日にかけて3週間間隔で8回にわたり植物体各器官の乾物重およびリター重を測定するとともに，植物体地上部のみを用い生長解析を行った。植物体の採取には20×20 cmのコドラートを用い，植物体を植付けた位置（planting site : PS）と，隣接する4個体に囲まれた正方形の対角線の交点の位置（interplant site : IS）を中心に，両者を対にして採取した。

ISでは，全生育期間を通じて，3栽植処理区間の地上部および地下部生長差は小さかった。PSでは茎基部と主根の肥大生長に大きな差が生じたため，地上部ならびに地下部乾物重の季節変化に顕著な処理区間差が現われた。両採取位置を平均した m^2 当りの最大全地上部乾物収量ならびに最大葉収量は80 cm間隔が最高で，それぞれ475 g/m^2，329 g/m^2 であった。最大LAIは40 cm間隔の5.2が最高で，疎植ほど低下した。

RGR, NAR, CGRおよびRLGRの季節変化はISでは3栽植間隔とも同様であった。PSでは生育終期のRGR，NARおよびCGRに120 cm間隔と他の2栽植処理区の間で顕著な差が生じた。これは茎の乾物蓄積の差に起因した。

両採取位置を平均した最大CGRの最高値6.2 g/m^2/日は80 cm間隔で得られ，最適LAIは2.9，そのときのNARは2.2 g/m^2 葉面積/日であった。

キーワード：乾物生産，クズ，生長速度，葉面積.

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