Differences in Growth and Starch Yield of Sago Palms (Metroxylon sagu Rottb.) among Soil Types in Sarawak, Malaysia

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Abstract The growth and starch accumulation process of sago palms cultivated on deep (DPS) or shallow peat soil (SPS) and mineral soil (MS) at Mukah and Dalat in Sarawak, Malaysia, were analyzed to examine the effects of the soil types on the growth and starch production. For the sago palms cultivated on DPS, longer years were required to reach the harvesting stage, while values for growth parameters including leaf emergence, trunk elongation and increase in trunk weight and volume were lower and resulted in lower trunk weight and volume at the harvesting stage compared with the sago palms cultivated on SPS and MS. On the other hand, the starch accumulation in the pith of trunk was monitored in the same way and a substantial starch accumulation started in the 3rd and 4th years after trunk formation in the sago palms cultivated on MS or SPS and DPS, respectively, while the trunk length and weight at that time were about 3m and 250-300kg, irrespective of the soil types. The soil types did not affect the average starch yield at the harvesting stage, i.e., 160-180kg per palm (dry weight basis). However, these results might be due to the higher starch percentage in the sago palms cultivated on DPS associated with the favorable light conditions in the garden because of the short duration of the period after the opening of the garden compared with the sago palms cultivated on MS and SPS.

Key Words: Growth rate, Growth stage, Metroxylon sagu, Starch accumulation, Years after trunk formation

Introduction

Sago palm (Metroxylon sagu Rottb.) is mainly distributed in swamp area with a high temperature and abundant sunshine located at latitude between 10° North and South, and it can grow up to an elevation of 700m (FLACH, 1977). The underground environment varies in terms of soil types, level of water table, frequency of sea water invasion, degree of flooding in the rainy season, etc. (YAMAMOTO, 1998). It was reported that sago palm is the only crop that can grow well on deep peat soil which is characterized by low pH values, a high water table all the year round, a

Received May 26, 2003
Accepted Aug. 30, 2003
deficiency in mineral elements, etc. without any improvement of these characteristics (SATO et al., 1979; TIE et al., 1977, 1991).

In Sarawak, Malaysia, where commercial production of sago starch is the most popular in the world, sago palms are planted over an area covering about 19,720ha with soil types consisting of peat soil (62%) and mineral soil (33%), respectively. Moreover, in 38% of the peat soil area, peat soil is more than 150cm deep, while the remaining 24% area consists of shallow peat soil (TIE et al., 1991). The growth and starch yield of the sago palms cultivated on different soil types in Sarawak, Malaysia were reported by SIM and AHMED (1978), TIE et al. (1991), YAMAGUCHI et al. (1994 and 1997), JONG and FLACH (1995) and KANEKO et al. (1996). According to these reports, for the sago palms cultivated on deep peat soil, longer years from sucker planting or emergence to trunk formation and harvesting stage were required and the values of growth parameters including leaf expansion and trunk elongation were lower. Starch productivity of sago palms cultivated on different soil types, however, is poorly documented and very few reports are available on the starch accumulation process in relation to the growth stages after trunk formation (LONG, 1995; YAMAMOTO et al., 2003).

This study was conducted to analyze the differences in the growth and starch productivity of sago palms cultivated on different soil types, i.e., deep and shallow peat soils and mineral soil in relation to the growth stages after trunk formation at Mukah and Dalat in Sarawak, Malaysia.

Surveyed Areas and Experimental Methods

Surveyed areas and methods

The surveys were carried out in farmers' gardens in the Mukah and Dalat Districts of Sarawak State, Malaysia in 1996-1998 (Table 1). In the Mukah area, the farmers' gardens were located in the Jebungan and Tellian villages east and south of Mukah town, respectively (YAMAMOTO et al., 2003). In the Jebungan village, soil types of the surveyed gardens consisted of shallow peat soil (SPS) 20-60cm and 70-120cm thick or mineral soil (MS). The soil type of the gardens surveyed in the Tellian village consisted of MS. In the Dalat area that is located about 20km southwest of Mukah town, the surveys were conducted in the farmer's sago palm garden of Balan village which is close to the Sungai Talau Peat Research Station (STPRS) (YAMAGUCHI et al., 1994) and the soil type of this garden consisted of deep peat soil (DPS) 300-450cm thick. All the sago palms surveyed belonged to the non-spiny type. Although the planting space of each surveyed sago palm garden was about the same (9-10m × 9-10m), the duration of the period after the opening of the garden in Dalat was about less than 20 years and the garden was younger than those in Mukah.

One to three sago palms with different ages, i.e., different years after trunk formation which were selected by the owner of the garden in one to three area in each garden was felled using a chainsaw. The number of sampled sago palms and their age are shown in Table 1. After felling, growth parameters including palm height, trunk length, number of leaf scars and living leaves

Table 1. Outline of the surveyed sago palm gardens at Mukah and Dalat, Sarawak, Malaysia and number of sampled sago palms.

<table>
<thead>
<tr>
<th>Surveyed garden¹</th>
<th>Location</th>
<th>Soil type²</th>
<th>Thickness of peat layer (cm)</th>
<th>Water table³ (cm)</th>
<th>Age of sampled palms⁴</th>
<th>Total No. of sampled palms</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (J)</td>
<td>Mukah</td>
<td>Shallow peat</td>
<td>20-30</td>
<td>30-40</td>
<td>1.5-9</td>
<td>8</td>
</tr>
<tr>
<td>M (J)</td>
<td>Mukah</td>
<td>Shallow peat</td>
<td>70-120</td>
<td>20-30</td>
<td>2-4</td>
<td>6</td>
</tr>
<tr>
<td>H (J)</td>
<td>Mukah</td>
<td>Mineral</td>
<td>–</td>
<td>30-40</td>
<td>1.5-8</td>
<td>6</td>
</tr>
<tr>
<td>N (J)</td>
<td>Mukah</td>
<td>Mineral</td>
<td>–</td>
<td>30-40</td>
<td>1.5-7</td>
<td>5</td>
</tr>
<tr>
<td>S (T)</td>
<td>Mukah</td>
<td>Mineral</td>
<td>–</td>
<td>40-50</td>
<td>1.5-6</td>
<td>10</td>
</tr>
<tr>
<td>E (B)</td>
<td>Dalat</td>
<td>Deep peat</td>
<td>300-450</td>
<td>20-30</td>
<td>2-10</td>
<td>14</td>
</tr>
</tbody>
</table>

¹ J, T and B in the parenthesis indicate the Jebungan, Tellian and Balan village.
³ Depth from soil surface in dry season.
⁴ Yeas after trunk formation estimated by the owner of the garden.
were measured. Trunks were cut into sections about 0.9m long (hereafter referred to as "log"), i.e., the standard length of a log for selling in these areas and the weight of each log section was measured. The average diameter of the trunk was calculated based on the diameter of all the logs and that of the bottom, top and middle log when the number of logs was less and more than three, respectively. Samples of pith tissues weighing 50-100grams (unit of 0.1g) using an electronic balance (HL-200 type, Kagakukyoei Co., Ltd.) were taken radially from the center of a disk with 2-3cm thick in the middle of each log for which the diameter was measured.

Experimental materials and methods
The pith samples were dried in a ventilation-oven at 80°C for about 2 days, and brought to Japan, and again dried in a ventilation-oven at 65°C for 2 days to measure the dry weight. The contents of total sugar and starch were analyzed by the same methods as those described in the previous report (YAMAMOTO, et al., 2003). Total sugar and starch percentages were expressed as glucose and multiplied 0.9 to obtain glucose percentage per dry weight, respectively. The average values of pith dry matter, total sugar and starch percentages were calculated from the values of all the logs when the number of logs was three or less and according to the formula: $\frac{LL + UL + ML \times (\text{number of logs}-2)}{\text{number of logs}}$, where LL, ML and LL denote the values of bottom, middle and top logs when the number of logs more than three. The starch content (the amount of starch yield) of a trunk was calculated by the following formula; trunk fresh weight × 0.8 × average dry matter percentage of pith /100 × average starch percentage of pith /100. Since the weight of the bark accounted for about 20% of the trunk weight (YATSUGI, 1977), the value was multiplied by 0.8 in the formula.

Result
Determination of age of sago palms
It is necessary to estimate the palm age exactly for a comparison of the effects of soil types on the growth and starch yield in sago palms. As for the growth stages of sago palm, it was suggested that the growth period from sucker planting or emergence to trunk formation was more affected by the soil types than that from flower bud formation to flowering, i.e., the duration of the former period was usually 4-6 years in the case of MS and 6-8 years in the case of DPS, while that of the latter period was about 2 years, irrespective of the soil types (JONG and HILARY, personal communication). In sago palms, since starch accumulated in the trunk is utilized, the growth and starch accumulation process of sago palms cultivated on different soil types after trunk formation should be compared.

Therefore, the palm age in this study was expressed by the years after trunk formation (YATF) estimated by the owner of the garden. The ages of the sampled palms in this study ranged from 1.5-8 in MS, 1.5-9 in SPS and 2-10 YATF in DPS, and those in the 7th and 8th years in MS, 9th year in SPS and 10th year in DPS attained at the flower formation or bolting stage (Table 1). The number of mature sago palms that had reached the harvesting stage beyond the full trunk length stage (JONG, 1995) were 5 in MS (6-8 YATF), 4 in SPS (6-9 YATF) and 4 in DPS (8.5-10 YATF).

Growth after trunk formation
Relations between YATF and the growth parameters of sago palms cultivated on different soil types were analyzed to compare the differences in the pattern of growth progress after trunk formation associated with the soil types as follows. Plant length of the sago palms cultivated on different soil types was not appreciably different immediately just after trunk formation, ranging from 10-12m and reached values of 15-18m at the harvesting stage. Number of living leaves ranged from 15 to 20, irrespective of the soil types and growth stages, although the number in the 10th year palms in DPS was much higher. Annual rate of increase of expanded leaves on a palm calculated by adding the number of leaf scars and living leaves after trunk formation was higher in the order of sago palms cultivated on SPS (10.6 leaves) > MS (9.2 leaves) > DPS (8.1 leaves) (Fig. 1). This rate is considered to indicate the average leaf emergence rate after trunk formation.

Changes in the trunk length and average trunk diameter of the sago palms cultivated on the different soil types after trunk formation was shown in Fig. 2. The trunk length increased at a rate of 90-130cm per year on the average in the order of sago palms cultivated on SPS ≥ MS > DPS, and the length of the trunks cultivated on DPS was shorter than cultivated on SPS and MS.
compared at the same YATF. Trunk length at the harvesting stage, however, did not show appreciable differences among the sago palms cultivated on different soil types, ranging from 6-8m, except for the 9th year palms cultivated on SPS. The average trunk diameter of sago palms ranged from 35 to 55cm, with a maximum value immediately after trunk formation and tended to decrease with YATF in the order of sago palms cultivated on MS followed by SPS and DPS.

Changes in the trunk weight and volume of the sago palms cultivated on different soil types after trunk formation are shown in Fig. 3. Yearly growth rates of the trunk weight and volume were higher in the order of sago palms cultivated on MS (152kg) > SPS (121kg) > DPS (74kg) and MS (0.166m³) ≥ SPS (0.142m³) > DPS (0.09m³), respectively, and the rates of sago palms cultivated on MS were about two times higher than those of the palms cultivated on DPS. The trunk

Fig. 1. Relation between years after trunk formation and number of leaf scars and leaves in sago palms cultivated on different soil types. *Estimated by the owner of the garden. ○, mineral soil; □, shallow peat soil; ●, deep peat soil.

Fig. 2. Relation between years after trunk formation and trunk length (A) or trunk diameter (B) in sago palms cultivated on different soil types. *Estimated by the owner of the garden. ○, mineral soil; □, shallow peat soil; ●, deep peat soil.

Fig. 3. Relation between years after trunk formation and trunk weight (A) or trunk volume (B) in sago palms cultivated on different soil types. *Estimated by the owner of the garden. ○, mineral soil; □, shallow peat soil; ●, deep peat soil.
weight and volume at the harvesting stage ranged from 600 to 1100kg and from 0.7m³ to 1.3m³, respectively, and the values of the sago palms cultivated on DPS tended to be considerably lower than those of the palms cultivated on MS and SPS. Regardless of the soil types, a highly significant and positive correlation was observed between the trunk weight and volume (MS; r=0.983***, SPS; r=0.980***, DPS; r=0.957*** and the trunk weight per m³ volume was higher in the order of sago palms cultivated on MS (887kg) > SPS (822kg) > DPS (767kg). A highly significant and positive correlation was observed between the trunk length and trunk weight as well and the trunk weight per m calculated from the regression line was heavier in the order of the sago palms cultivated on MS (125kg) followed by SPS (91kg) and DPS (84kg) (Fig. 4).

Based on the results obtained, the growth rates of sago palms in terms of leaf number and trunk elongation, weight and volume after trunk formation that were cultivated on different soil types are listed in Table 2, which shows that these growth rates were lower in the sago palms cultivated on DPS than in those cultivated in SPS and MS.

**Starch accumulation process and starch yield**

Changes in the percentages of dry matter and starch in the pith of trunk after trunk formation are shown in Fig. 5. Only a slight increase in these percentages was observed until the 3rd and 4th years after trunk formation in the sago palms cultivated on MS or SPS and DPS, respectively, but thereafter the values rapidly increased to the 6th and 8th years after trunk formation in the palms cultivated on MS or SPS and DPS, respectively. Irrespective of the soil types, the percentages of dry matter and starch were mostly distributed within the range of 40-50% and 60-70%, respectively, at the harvesting stage, although these percentages tended to be slightly higher in the sago palms cultivated on DPS than those in the palms cultivated on MS and SPS. A closer relation was observed between the percentages of dry matter and starch and their relation was regressed by a logarithmic equation, however, the starch percentage tended to be higher in the order of sago palms cultivated on DPS followed by SPS and MS at more than 30% of dry matter (Fig. 6).

Total sugar percentage in the pith of trunk showed an extremely high value, 40-50%, in the 1st and 2nd years after trunk formation, but thereafter the values exponentially decreased.
and finally reached 2-5% at the harvesting stage, irrespective of the soil types (Fig. 7). A closer negative correlation was observed between the total sugar and starch percentages ($r=0.969^{***}$).

Changes in the amount of starch accumulated in the pith (starch content) of trunk are shown in Fig. 8. The starch content did not increase appreciably until the 3rd and 4th years after trunk formation in the sago palms cultivated on MS or SPS and DPS, respectively, but thereafter the content linearly increased, irrespective of the soil types. The coefficients of regression lines showed that the starch accumulation rate per year was higher in the order of sago palms cultivated on MS (48kg) followed by SPS (39kg) and DPS (32kg) (Table 2).

Correlations between the trunk length or weight and starch content in the pith of trunk are shown in Fig. 9 to analyze the relation of the growth parameters to starch accumulation. Before the trunk length reached value of 3m or the trunk weight reached values of 250 (DPS) -300kg (MS and SPS), only a small amount of starch accumulated in the pith. However, thereafter, starch accumulated in parallel with the trunk elongation or trunk weight, irrespective of the soil types (Fig. 9A, B). Based on the coefficients of regression lines shown in Fig. 9A, the starch accumulation rate per 1m trunk elongation was higher in the order of sago palms cultivated on MS (40kg) followed by DPS (35kg) and SPS (31kg). The coefficients of the regression lines in Fig. 9B which lists the ratios of the starch amount (dry weight) to the trunk weight (fresh weight) were higher in the order of sago palms cultivated on DPS (36%) followed by MS (31%) and SPS (29%).

Starch yield and related growth parameters of sago palms at the harvesting stage are shown in Table 3. Although for the sago palms cultivated on DPS, it took 2-3 years longer from trunk formation to harvest and the palms showed a
Table 2. Differences in growth and starch accumulation rates of sago palms cultivated on the different soil types.

| Soil type   | Leaf emergence rate (No./year) | Trunk growth rate in terms of | Starch accumulation rate (kg/year) | YATF  
|-------------|--------------------------------|-------------------------------|------------------------------------|------
|             |                                | elongation (m/year)           | weight (kg/year)                   | volume (m²/year) |  
| Mineral     | 9.2                            | 1.18                          | 152.0                              | 0.166           | 47.8            | 3  
| Shallow peat| 10.6                           | 1.34                          | 121.0                              | 0.142           | 38.5            | 3  
| Deep peat   | 8.1                            | 0.87                          | 73.9                               | 0.090           | 32.4            | 4  

1) Dry starch.
2) Years after trunk formation at the beginning of rapid starch accumulation. The starch accumulation rates were calculated after that year.

**Discussion**

It was reported that the sago palms cultivated on MS reached harvesting stage after 10-12 years (JOHNSON and RAYMOND, 1956) or 8-12 years after planting (JONG and FLACH, 1995), while for those cultivated on DPS, it took 12-15 years (JONG and FLACH, 1995; YAMAGUCHI et al., 1997) or 15-17 years (JOHNSON and RAYMOND, 1959). These reports clearly revealed that the growth duration from planting to harvest varied depending on the soil types and was longer in the sago palms cultivated on DPS than in those cultivated on MS. Moreover, the growth duration from planting to trunk formation in the former took about 6-8 years (JONG and HILARY, personal communication) and this duration was 2-4 years longer compared with 4-6 years in the latter. In this study, we tried to compare the growth and starch accumulation process of the sago palms cultivated on MS, SPS (thickness of peat soil layer; 150cm<) and DPS (ibid.; 150cm>) to analyze the effects of the soil types on the sago growth and starch productivity (Table 1).

The growth duration from trunk formation to harvesting (over full trunk length stage, JONG, 1995) was longer in the order of sago palms cultivated on DPS (8-10 years) followed by SPS (6-9 years) and MS (6-8 years) and the growth duration including years to trunk formation was 10-14 years for MS and 14-18 years for DPS. These results were in agreement with those of the above-mentioned reports. It also took 6-8, 9 and 10 years to the flower-bud formation stage after trunk formation for the sago palms cultivated on MS, SPS and DPS, respectively.

The results of the correlation analysis between YATF and growth parameters which revealed the presence of a highly significant and
positive correlation in the number of leaf scars and living leaves, trunk length, weight and volume, etc., irrespective of the soil types were linearly regressed on these growth parameters (Fig. 1 - 3). The growth rates expressed by the coefficients of regression lines were remarkably lower in the sago palms cultivated on DPS than in those cultivated on MS and SPS (Table 2). In particular, the trunk elongation rate of the former was 87 cm per year and this value was 35 and 27% lower compared with the values for MS (134 cm / yr) and SPS (118 cm / yr), respectively. Moreover, the growth rate of the trunk weight per year was higher in the order of the sago palms cultivated on MS (152 kg) > SPS (121 kg) > DPS (74 kg), and the rates of palms cultivated on DPS were 51 and 39% lower than those of the palms cultivated on MS and SPS, respectively. This was also true for the average trunk diameter after the 4th year of trunk formation (Fig. 2B). These results were consistent with the findings reported by KANEKO et al. (1996) and YAMAGUCHI et al. (1997) who compared the trunk growth rate of the sago palms cultivated on DPS with the rate of the palms cultivated on MS at Dalat in Sarawak. KAKUDA et al. (2000) suggested that one of the factors responsible for poor growth of the sago palms cultivated on DPS was the lower mineralization of nitrogen per unit volume of DPS. On the other hand, although TIE et al. (1991) and KUEH et al. (1991) reported that the trunk length at the harvesting stage was longer in the sago palms cultivated on DPS than in those cultivated on MS, in our study, no significant differences were observed among the soil types. Trunk elongation may be affected by the light conditions, such as mutual shading in the sago palm garden (FLACH and SCHULING, 1989). Therefore, better light conditions in the garden of DPS due to the short duration of the period after the opening were considered to have inhibited the trunk elongation. Moreover, the trunk weight and volume at the harvesting stage were also lower in the sago palms cultivated on DPS in spite of their longer growth duration compared with those cultivated on MS and SPS (Table 3).

No differences were observed in the starch accumulation process of the sago palms cultivated on MS, SPS and DPS (Fig. 5B). Total sugar percentage in the pith immediately after trunk formation which was remarkably high, ranging from 40 to 50%, tended to increase from the base to the top of the trunk (Fig. 7). The total sugar percentage, however, decreased with YATF as starch accumulation proceeded from the base to the top (YAMAMOTO et al., 2003). Finally at the harvesting stage, the total sugar and starch percentages in the pith did not show appreciable differences among the positions on the trunk (SIM and AHMED, 1978; JONG, 1995; YAMAMOTO et al., 2003). These results suggested that the starch syntase activity in the pith of sago palms of the early stage of trunk formation was low, but that the enzyme was rapidly activated in some YATF and led to the promotion of transformation from sugar to starch (SATO et al., 1979; YAMAMOTO et al., 2003). The higher starch percentage in the pith of the sago palms cultivated on DPS at the harvesting stage compared with that of the sago palms cultivated on MS and SPS (Fig. 5B) might be due to the favorable light conditions in the garden associated with the short duration of the period after the opening, as mentioned above. TIE et al. (1991) and KUEH et al. (1991) reported that the starch percentage in the pith of the palms cultivated on DPS was lower than that of the palms cultivated on MS at the harvesting stage.

Starch yield per trunk is determined by the
pith (dry) weight and its starch percentage. The increase in the starch yield was limited until the 3rd year for MS and SPS or the 4th year after trunk formation for DPS, but thereafter the yield increased linearly with YATF (Fig. 8). This starch accumulation process of sago palm was proposed by SATO et al. (1979) and experimentally confirmed by YAMAMOTO et al. (2003). Yearly starch production rate could be estimated from the regression lines after the 3rd or the 4th year after trunk formation and the values were higher in the order of sago palms cultivated on MS (48kg) followed by SPS (39kg) and DPS (32kg) (Fig. 8). These results revealed that the starch production rate of the sago palms cultivated on DPS was 33 and 18% lower than that of the palms cultivated on MS and SPS, respectively. Remarkable starch accumulation in relation to the trunk growth parameters started when the trunk was about 3m long and weighted 250-300kg, irrespective of the soil types (Fig. 9).

According to the report of JONG (1995), the suitable stage for harvesting in sago palm is from full trunk to the flowering stage, and within these stages starch yield does not differ appreciably. Average starch yield of the sago palms within these stages that were cultivated on each soil type in this study was 164-180kg per palm (dry weight basis) and differences among the soil types were not conspicuous (Table 3). These results agreed well with those reported by TIE et al. (1991) and YAMAMOTO et al. (2003) who failed to observe significant differences in starch yield between the sago palms cultivated on MS and DPS or on MS and SPS at Mukah and Dalat in Sarawak, respectively. The starch yield level obtained in this study was close to the values of 189kg for MS and 179kg for DPS reported by Sim and AHMED (1978), 155-214kg for MS (average; 192kg) and 166-244kg for SPS (average; 199kg) by YAMAMOTO et al. (2003) at Mukah in Sarawak and 203-219kg for DPS at Dalat in Sarawak by JONG (1995). However, in the current study, the higher percentage of starch and reduced trunk growth of sago palms cultivated on DPS compared with the values of the palms cultivated on MS and SPS did not result in any difference in the starch yield among soil types, while TIE et al. (1991) reported that the lower starch percentage but the increased trunk growth of sago palms cultivated on DPS did not bring about any differences in starch yield. This discrepancy may be due to the difference in the light conditions and nutrient status of the soil and underground water in the sago gardens of DPS where the sago palms were sampled (FUNAKAWA et al., 1996; KAKUDA et al., 2000). On the other hand, KUEH et al. (1991) reported that the starch yield of the sago palms cultivated on DPS (277kg) was higher than that of the palms cultivated on MS (219kg) at Mukah in Sarawak.

It could be concluded that for the sago palms cultivated on DPS longer years were required for reaching the harvesting stage, but that their trunk weight and volume were considerably lower than those of the palms cultivated on MS and SPS due to the lower growth rate and the start of remarkable starch accumulation in the pith of trunk was about one year late, although the starch accumulation process was similar, irrespective of the soil types. Although no differences in starch yield were observed in the sago palms cultivated on different soil types, these findings might be closely related to the higher starch percentage in the pith of the sago palms cultivated on DPS due to the favorable light conditions in the garden because of the short duration of the period after the opening of the garden. It was eventually suggested that starch productivity of sago palms cultivated on DPS was slightly lower than that of the palms cultivated on MS and SPS for about the same starch percentage under about the same light conditions in the sago garden.

Acknowledgement

We thank the staff of the Land Custody and Development Authority (LCDA), CRAUN, Sarawak, Malaysia, for their kind assistance in the field research. The research was financially supported by the Japan Society for the Promotion of Science in 1996 and the Toyota Foundation in 1997 and 1998.

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