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Response of germination and seedling growth to soil particle size of three herbaceous perennials on alpine zone of Mt. Fuji

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Abstract: *Polygonum cuspidatum, P. weyrichii* and *Artemisia pedunculosa* are herbaceous perennials in the alpine zone on Mt. Fuji. The effect of soil particle size on seed germination and seedling growth of these species was investigated. In the experiment three different particle size soils (large particle size LPS, medium particle size MPS, and small particle size SPS) were used. The other experiment was designed under three different watering intervals (every day, every two days, and every four days). Soil particle size had a great impact on seed germination and seedling growth. The highest percentage of seeds germinated in SPS and lowest in LPS soil, irrespective of the species. In the case of *A. pedunculosa* there was no significant difference of seed germination between SPS and MPS soils. However, the other two species had significantly reduced percentages of seed germination with increasing soil particle size. The maximum root length of seedlings was significantly longer in LPS and MPS compared to the SPS soil group, for all species. The number of root tips was increased with decreasing soil particle size, irrespective of the species. Further, larger above-ground biomass was found in seedlings of SPS than those of LPS and MPS.

A. pedunculosa showed a slightly different pattern of seed germination and seedling growth compared to the two *Polygonum* species. Seed germination of *A. pedunculosa* was comparatively independent of soil particle size, and it may have conservative water use strategy. On the other hand, seed germination of *Polygonum* species was highly affected by the soil particle size, and those species may adapt to the water deficit condition by taking up water from deeper soil.

key words: soil particle size, root growth, germination, soil water content, Mt. Fuji

Introduction

The reproductive success of an individual plant is dependent on its ability to pass through several selective filters during its life cycle: germination, establishment, growth to adulthood, and finally the reproduction and dispersal of viable seed (Harper, 1977). Studies of various species have shown that mortality is generally high in the seedling stage (Tazaki, 1960; Peterken, 1966; Cavers and Harper, 1967; Miles, 1972, 1973; Friedman and Orshan, 1975). Therefore, successful completion of initial stages of seedling establishment (seed entrapment, germination, growth and survival of seedling) contributes to an increase of plants living in a habitat.

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In the gravelly desert area on Mt. Hoei (the parasitic volcano of Mt. Fuji), where various sizes of scoria have accumulated, vegetation cover is low in the area with high content of large scoria (unpublished data). The size distribution of surface soil is expected to play an important role in seedling establishment through the effect on seed entrapment, on water holding capacity and on inter-space of soil particles which affects the elongation of roots. Though many studies have been conducted on seed germination and seedling growth of alpine plants, only a few works have concentrated on the effect of soil particle size (Chambers *et al.*, 1990, 1991; Chambers, 1995). The aim of the present study is to evaluate the effect of soil particle size on seed germination and seedling growth experimentally for three perennial herbs, *Artemisia pedunculosa, Polygonum cuspidatum* and *Polygonum weyrichii* var. *alpinum*. These species are co-dominant and occupy similar habitats in the desert area of Mt. Hoei, but they are different in seed size and in root morphology of adult plants: *A. pedunculosa* is shallow-rooted and produces small seeds, while the two *Polygonum* species are deep-rooted and produce large seeds. Therefore we expect that successful seedling establishment of these species is accomplished through a different strategy for each species, in response to the effect of various sizes of surface soil particles.

Materials and methods

Site and species description

Mt. Fuji (summit 3776 m above sea level), located on Honshu in central Japan, is the highest peak in the country. Mt. Hoei is a parasitic volcano on Mt. Fuji, formed by the latest volcanic eruption in 1707 (Tsuya, 1968). The vegetation of this area was completely destroyed by the eruption. The vegetation is in a progressive stage and has been recovering for 290 years (Hayata, 1929; Masuzawa, 1985). The study site was situated on the Hoei second crater, about 2400 m a.s.l. on Mt. Fuji.

In the investigation, three herbaceous perennials were used. These are pioneer plants of the early successional stage on volcanic gravel in alpine regions and dominate on the Hoei second crater on Mt. Fuji. *Polygonum cuspidatum* Sieb. et Zucc. is originated from the lowland of the temperate region of Japan, and is distributed up to the alpine region at 2500 to 2600 m a.s.l. on Mt. Fuji (Masuzawa and Suzuki, 1991). This species forms patches of vegetative growth. *Polygonum weyrichii* (F. Schmit) var. *alpinum* (Maxim) grows in sub-alpine and alpine environments in central Japan. It is distributed at 1400 to 3300 m a.s.l. on Mt. Fuji. *Artemisia pedunculosa* Miq. is a rosette form herbaceous perennial. This species mainly grows in alpine environments in central Japan and forms communities by vegetative reproduction (Masuzawa *et al.*, 1993). Each species has different root morphological characteristics and seed size. The two *Polygonum* species are deep-rooted (more than 1 m vertical penetration of roots) and large-seeded (6 to 10 times greater than seed of *A. pedunculosa*) species; however, *A. pedunculosa* is a shallow-rooted (less than 40 cm vertical penetration of roots) and small-seeded species.

Characteristics of study site soil

The soil particle distribution around the study area was investigated. Soil samples were collected at six places from the three depth increments of 0–2 (potential zone of seedling emergence), 2–5, and 5–10 cm. Samples were air dried under room temperature and were sieved to obtain three particle size groups, such as SPS (less than 1.0 mm in diameter), MPS (from 1.0 to less than 5.7 mm in diameter), LPS (from 5.7 mm in diameter or larger).

The percentage of soil particle size was calculated by the following formula,

$$\text{Percentage of soil particles} = \frac{DW_0}{DW} \times 100\ (\%), \qquad (1)$$

where, DW_0 is the dry weight of respective soil particle size and DW is the dry weight of the soil sample.

Water holding capacity was measured for each size of soil. Weighed dry soil sample was put in a drainage pot ($10.5 \times 9.0 \times 5.0$ cm; length, width and depth, respectively) and was saturated with water. Thereafter, the top of the pot was covered by aluminium foil to reduce evaporation and then the total weight of the pot was measured at intervals for three days (until the weight became constant) in a green house.

The percentage of soil moisture content was calculated by using the following equation:

$$\text{Percentage of soil moisture content} = \frac{FW - DW}{FW} \times 100\ (\%), \qquad (2)$$

where, FW is the weight of moist soil (fresh weight) and DW stands for the weight of dry soil (dry weight).

Response of seed germination to soil particle size

Plastic planters were filled with each particle size soil and saturated with water. Thereafter, ten treated (incubated in moist conditions at 5°C for 10 days) seeds of each species were scattered over the soil within each planter ($26.0 \times 13.0 \times 9.5$ cm). The planters were transferred to the chamber and maintained in 12L: 12D, 25°C/15°C (Light/Dark) temperature. Adequate water was supplied once a day at the beginning of each dark period. Six replications were used for each particle size group and germinated seeds were counted every day after watering.

Response of seedling growth to various particle size soils

In order to find the relationship between soil particle size and seedling growth, seedlings were planted in various particle size soils in late summer in 1997. Pots ($10.5 \times 9.0 \times 18.0$ cm) were filled with 3 types of soil, as was described earlier. Seeds of the study species were germinated at 20°C and 12L: 12D photoperiod in the incubator. Six seedlings of 5 to 15 mm radicle length each were planted in each pot (18 pots/treatment). The pots were kept in the greenhouse for 21 days and adequate water (50 ml/pot) was supplied daily during the experimental period. Then 30 seedlings were chosen randomly and removed carefully from the pots with minimum root loss and washed. Each seedling was separated into above and under-ground parts after measurement of maximum root length and the number of root tips was counted. Each part was dried at 80°C for 24 hours and weighed.

Maximum root length was defined as the root length from the hypocotyl to the tip of the longest root of the main or a lateral root.

The T/R ratio was calculated by the following formula,

$$\text{T/R ratio} = \frac{\text{Top}_{(\text{Dry weight})}}{\text{Root}_{(\text{Dry weight})}}, \tag{3}$$

where, $\text{Top}_{(\text{Dry weight})}$ is the dry weight of the above-ground portion and $\text{Root}_{(\text{Dry weight})}$ is the dry weight of the whole root system.

Response of seedling growth to various watering intervals

In order to observe seedling growth under various watering intervals, ten seedlings (prepared by the same procedure as in the earlier experiment) were planted in each planter (27 × 13 × 13 cm), and filled with scoria (particle size of scoria was less than 5.7 mm in diameter). Adequate (field capacity) water was supplied for 7 days to all planters for rearrangement of the seedling's root by itself. Planters were then divided into three groups (10 planters/group), and 50 m*l* water was supplied every day, every two days and every four days in each treatment group. This procedure was continued for 21 days. All seedlings were harvested and the factors mentioned above were measured. All the experiments were done in the greenhouse in late summer in 1997. To check the moisture content of soil, samples were collected at three depth categories (soil surface to 2, 2–5 and 5–10 cm) from each planter, and weighed before and after drying at 105°C for 24 hours.

Differences in seed germination, maximum root length, T/R ratio, above-ground dry weight and number of root tips among treatments for individual species were examined with ANOVA. Mean comparisons were made using the Bonferroni/Dunn test least significant difference ($P < 0.05$).

Results

Characteristics of study site soils

The percentage of SPS soil increased with increasing soil depth up to 5 cm, but it was almost constant with further increase in soil depth (Fig. 1). In the 0–2 cm stratum, 37% LPS soil and 8.2% SPS soil were found, but in the stratum deeper than 2 cm, 25% LPS and 20% SPS soil were observed.

Smaller soil particles showed higher water holding capacity (Fig. 2). Water content at saturation was 5.9% in LPS, whereas SPS soil contained more than 15% even three days after water supply.

Response of seed germination to soil particle size

Highest percentage germination was obtained in the SPS group and minimum in the LPS group, irrespective of the species (Fig. 3). In the case of *A. pedunculosa*, similar percentages of seed was germinated in the MPS and SPS groups (83.3% and 86.7% respectively), in both cases more than the other species. In both *Polygonum* species, the MPS group showed significantly lower percentages of germination than the SPS group.

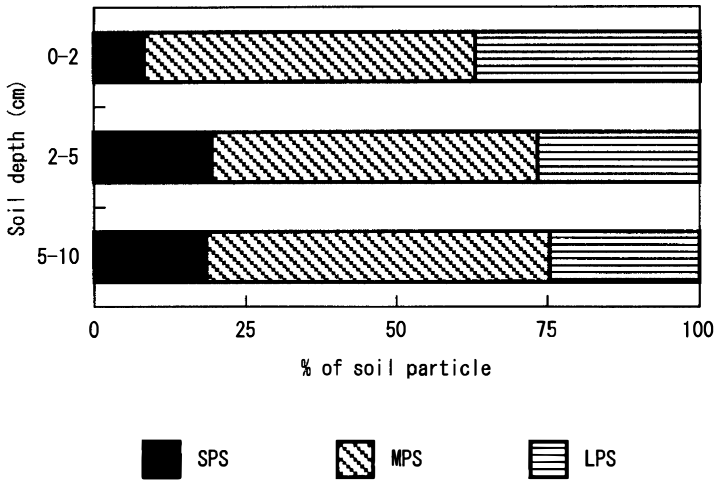

Fig. 1. Soil particle size distribution in different depth of study site soil. (large particle size LPS, medium particle size MPS, and small particle size SPS)

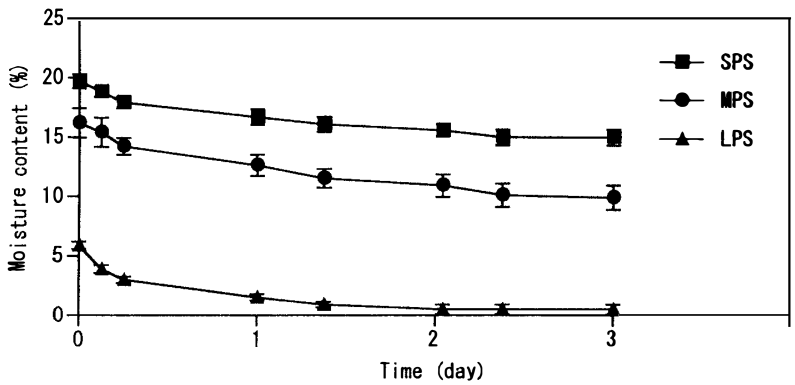

Fig. 2. Water holding capacity of three different soil types. Bar indicates SD.

Response of seedling growth to various particle size soils

Seedlings grown in SPS were characterized by large above-ground biomass, high T/R ratio and very short roots, but, *P. cuspidatum* showed similar T/R ratios for the three soil types (Fig. 4). No significant differences were observed in these characteristics between MPS and LPS, except for maximum root length in the case of *P. weyrichii* (Fig. 4c). The number of root tips was increased with decreasing soil particle size (Fig. 4d). In the case of *P. cuspidatum* it was three times greater in SPS (49.3) compared to LPS (16.1).

Response of seedling growth to various watering intervals

The above-ground dry weight of *P. weyrichii* was larger with watering every day, than with watering every four days, whereas no differences were found for *A. pedunculosa* and *P. cuspidatum* among the treatments (Fig. 5a).

The T/R ratio decreased with increasing interval of watering (Fig. 5b). Maximum

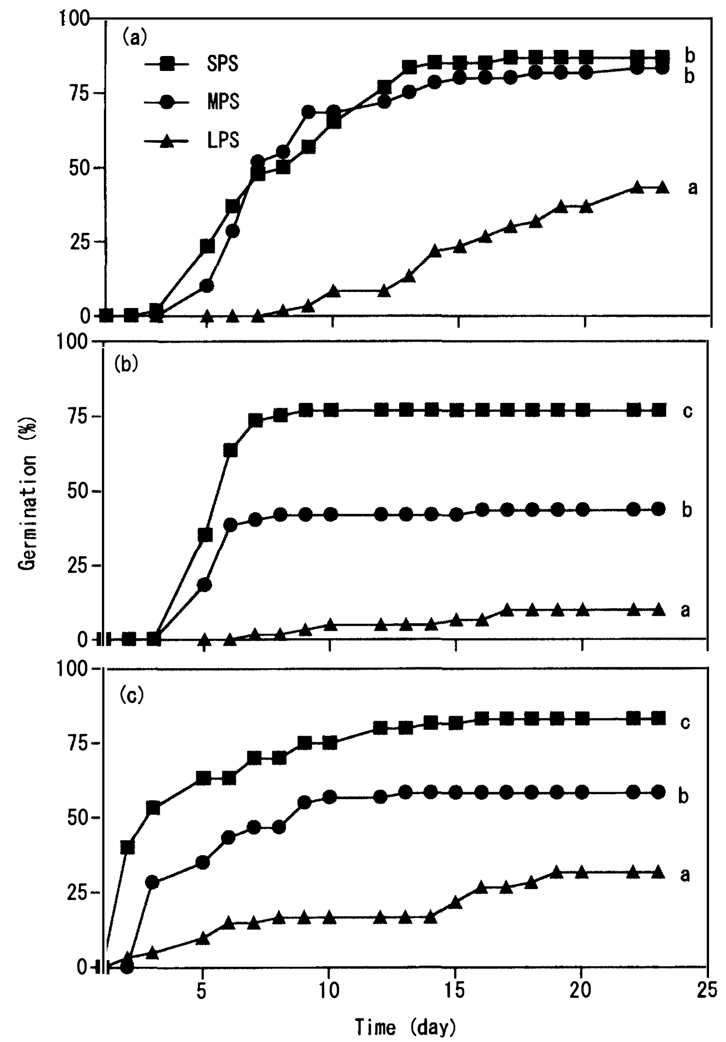

Fig. 3. Germination responses of three study species under various particle size of soils. (a) *A. pedunculosa*; (b) *P. cuspidatum*; and (c) *P. weyrichii*. Different letters indicate significant differences among treatments at 5% level by Bonferroni/Dunn test.

root length did not vary among the treatments for any of the species (Fig. 5c), though soil moisture content was different among the treatments at all depths (Fig. 6).

Discussion

Porous scoria has low water holding capacity. Therefore, surface soils, which absorb more solar radiation, dry up rapidly, especially in the potential zone of seedling emergence (0–2 cm), which contains relatively high proportion of large particles (Fig. 1). Moisture and thermal conditions are considered to be primary regulators of seed germination in alpine regions. According to Billings (1974), alpine seed do not germinate well on dry surface soil or at low temperature. In our experiment, the percentage of germination was lowest in seeds sown on LPS (Fig. 3). This may be

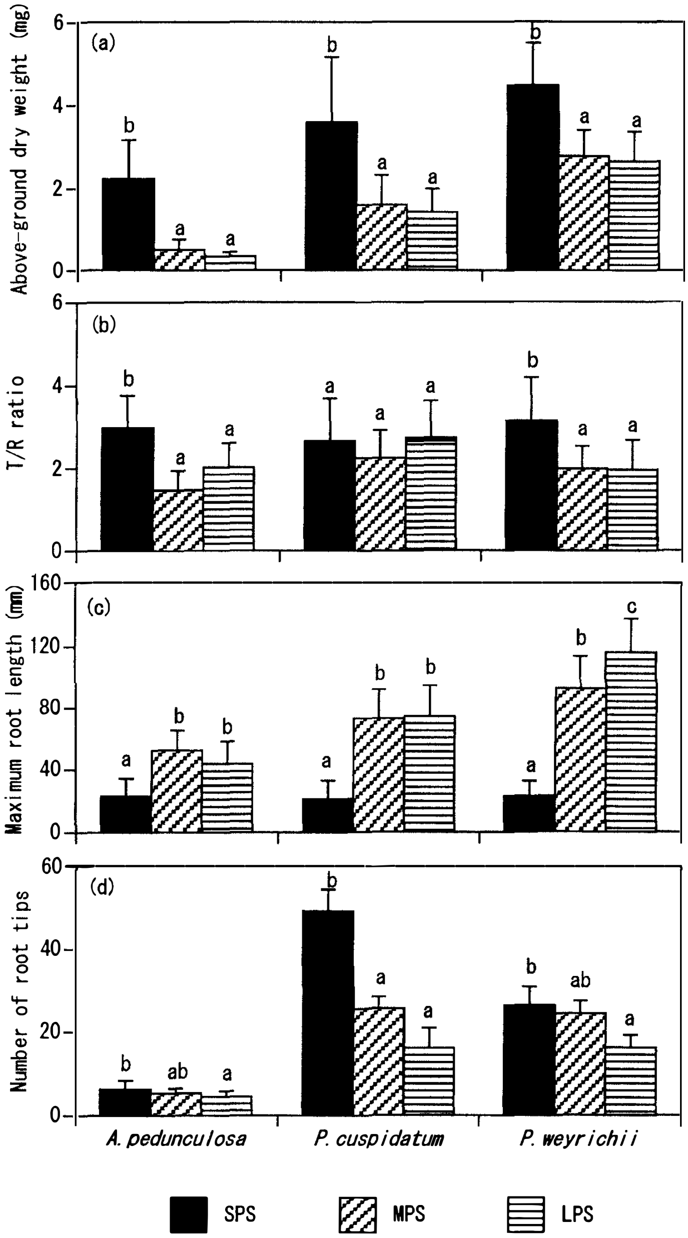

Fig. 4. Seedling growth under different particle size soils. (a) above-ground dry weight of seedling; (b) T/R ratio; (c) maximum root length; and (d) number of root tips. Different letters indicate significant differences among treatments at 5% level by Bonferroni/Dunn test. Bar indicates SD.

attributable to low moisture content of the soil (Fig. 2). *A. pedunculosa* germinated equally well on MPS and on SPS, while the two *Polygonum* species showed significantly lower percentages of germination on MPS than on SPS (Fig. 3). The relationship between seed morphology and soil particle size determines the movement of seeds (Chambers *et al.*, 1991). Seeds of *A. pedunculosa*, 1/6 to 1/10 the size of *Polygonum* seeds, might be trapped in deeper layer of the MPS soil where moisture content might

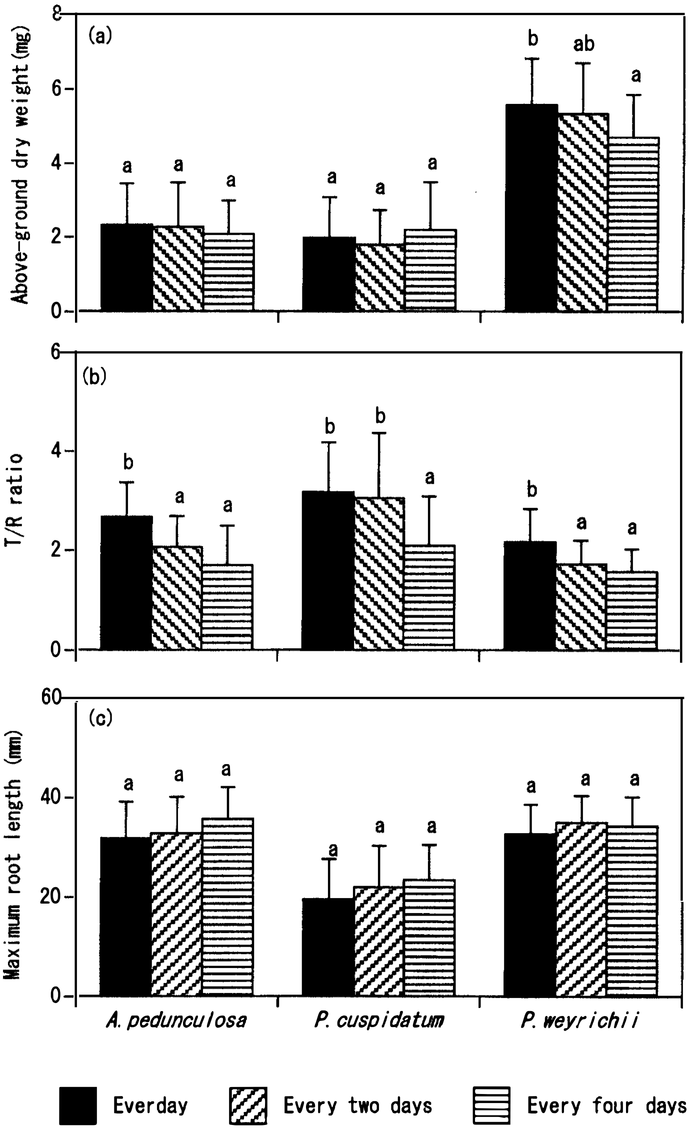

Fig. 5. Seedling growth under various watering intervals (a) above-ground dry weight; (b) T/R ratio; and (c) maximum root length. Bar indicates SD.

be favorable for germination due to less evaporation than at the top surface.

Although the root branching pattern is genetically determined, environmental factors can modify some root morphological characteristics (Zobel, 1975). There are several reports on the relationship between root growth and water stress (Osonubi and Davies, 1981; Molyneux and Davies, 1983; Sydes and Grime, 1984; Sharp and Davies, 1985; Park, 1989; Yura, 1989; Fitter, 1991; Reader *et al.*, 1993). Some of these authors have reported that roots grew deeper or longer under water stress conditions than under watered condition. In our experiment, seedlings grown on LPS and MPS, where moisture contents were lower than SPS, had longer roots (Fig. 4). This result is consistent with the reports above. Though large particle soils have poor water holding

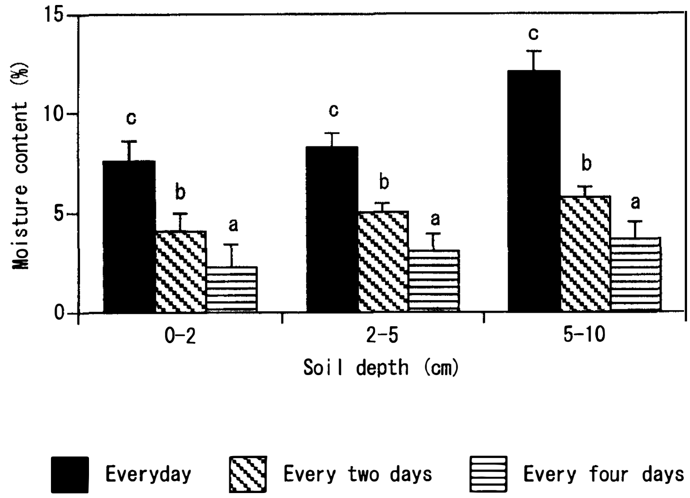

Fig. 6. Soil moisture contents at various depths in planter of watering interval experiment. Soil samples were collected after the experiments period of 21 days. Bar indicates SD.

capacity, they generally have higher water availability in the deep layer because of deeper penetration of water and lower rate of evaporative water loss (Chapin and Bliss, 1988). Therefore, root elongation may be an adaptive response in order to uptake water from the deep layer of large particle soil. On the other hand, seedlings may not need to elongate roots much in small particle soil with relatively high water holding capacity. However, the short roots of seedlings in SPS may also be due to the physical constraint of the compact soil. Generally, fine soil is compact and inhibits downward penetration of roots (Iijima *et al.*, 1991).

Some studies have reported that shoot dry weight was decreased with increase of water stress, while root weight was increased, resulting in a decrease in the T/R ratio (Cutler and Rains, 1977; Lawlor, 1969). In the present study, *A. pedunculosa* and *P. werichii* showed this kind of response in the experiment with varied soil particle size (Fig. 4). A great reduction of above-ground biomass in *A. pedunculosa* in less soil moisture conditions (LPS and MPS) suggests that this species has a conservative water use strategy. There are other reports showing reduced T/R ratio in response to water stress, with above-ground biomass being constant (Davidson, 1969; Read and Bartlett, 1972; Furuhata and Monsi, 1973; Sharp and Davies, 1979; Markhart, 1985). A similar result was obtained in our experiment with changing watering interval (Fig. 5a, b). The T/R ratio was significantly higher when plants were watered every day than when they were watered every four days, but above-ground biomass was relatively constant. Seedlings might accumulate reserve in roots in response to water stress.

The present study showed that soil particle size played an important role in seed germination and seedling growth of three dominant species on the volcanic gravel of Mt. Hoei. Low vegetation cover in the large soil particle dominated area might be explained by low germination due to the low water holding capacity of the soil (Figs. 2, 3). *A. pedunculosa* showed a slightly different response to soil particle size from the two *Polygonum* species. Seed germination of *A. pedunculosa* is comparatively independent of soil particle size (Fig. 3a). In addition, reduction in above-ground biomass in response to increased soil particle size was most conspicuous in *A. pedunculosa* (Fig. 4a), while root elongation was less conspicuous than in the two *Polygonum* species (Fig. 4c). This species may survive in an area dominated by large particle soil by reducing water loss from the above-ground part. On the other hand, seed germination of the two *Polygonum* species is reduced greatly with increasing soil particle size (Fig. 3b, c). According to Chambers (1995), large-seeded species had higher overall seed entrapment in large soil particles. We also found a similar result for the two *Polygonum* species (unpublished data). Therefore, total seedling emergence of these species may not be very poor in a large particle soil dominated area. After seedling emergence, these species may survive by increasing water uptake from the deep layer of the soil using long roots (Fig. 4c).

We conclude that, two different strategies were adopted by the dominant species on Mt. Hoei for seedling establishment to be successful. Small-seeded *A. pedunculosa* adopted a conservative water use strategy, while the large-seeded *Polygonum* species adopted a water up-take strategy.

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