Original Paper

Fluctuation in size and weight of acorns and in the amount of acorn production with *Quercus variabilis* Blume

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Fluctuation of acorn production by *Quercus variabilis* was investigated in five trees for five years from 1975 to 1979 (group A) and two others for three years from1998 to 2000 (group B) in the campus of Nagoya University, Aichi Prefecture, Japan. All fallen acorns were collected every day from early September to the middle of October. All investigated individuals showed large variation in acorn production, but seemed not to show any particular synchronization in either group. In group B, the sizes of acorn were measured and wet and dry weights were determined to give an estimate of acorn mass. The results showed that the total dry weight produced fluctuated approximately in paralled with the number of acorns.
Keywords: acorn production, fluctuation of acorn production, *Quercus variabilis*, size and weight of acorns, synchronization of acorn production

Introduction

As *Quercus variabilis* Blume is one of main components of secondary forests in the warm temperate zone, it is important to determine the ecological properties of the species, particularly in the early stage of the life history. Investigations have already been conducted into the term of seed falling, the relation between germination properties of seeds and establishment of the seedling in fields (Hiroki and Matsubara 1977, 1982). The relation between seed characteristics and species distribution, as well as seedling growth relative to reserve materials (Matsubara and Hiroki 1985), have also been studied (Matsubara and Hiroki 1980). However, the relation between size and weight of acorns and fluctuation in acorn production has not yet been determined.

It is known that many tree species show large fluctuation in seed production (Tagawa 1979; Norton and Kelly 1988; Koenig *et al*. 1994; Hiroki and Matsubara 1995; Hiroki 2000). Acorn production of *Quercus* species has received attention, because it is closely related to their regeneration (Kanazawa 1975, 1982; Imada *et al*. 1990), and is important in providing food for animals (Down and McQuilkin 1944; Christinsen 1955; Gysel 1956; Koenig *et al*. 1994).

Acorn production is generally assessed in terms of number but dry mass may be important. The present study aimed to determine the relationship between number and mass of *Q. variabilis* acorns, in terms of yearly fluctuation.

Materials and Methods

Collection of acorns

For collection of acorns of *Q. variabilis*, two sites were selected in the campus of Nagoya University in Nagoya City, Aichi Prefecture (35°9′ N, 136°58′E, about 50 m in altitude). There is a fragmented secondary forest mainly comprised of

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Pinus densiflora, Quercus serrata and *Q. variabilis* in one site, and there are two remnant trees of *Q. variabilis* in an open area in another site. The annual mean temperature is 14.9°C and the annual mean precipitation is 1535 mm (National Astronomical Observatory 1993).

All fallen acorns were picked up every day under the crowns of the *Quercus* trees from early September to the middle of October from 1975 to 1979 in the secondary forest site, and from 1998 to 2000 in the open site. The numbers were counted, and they were checked for soundness and insect attack. The number of sampled trees was five (A–E) in the former site and two (F and G) in the latter. The size of the trees was 20 to 30 cm DBH (diameter at breast height) and about 14 to 16 m in height for A–E. The size of the trees was 38–44 cm DBH and 16 m in height for F, and 39–48 cm DBH and 17 m in height for G. The crown size was larger in F (10×13 m) than in G (10×10 m), presumably because F was solitary but G was touched by individuals of *Castanopsis* and *Cyclobalanopsis* species. The distance between F and G was about 50 m.

In the former site, individuals D and E suffered heavy damage by insects in 1977 and 1978, and also for E in 1979. In 1980, as the damage by insects spread to individuals A and B, the investigation was stopped. Considering that *Castanopsis* nuts remain uneaten on the surface of soil under the trees in the same campus until winter, we did not take into consideration the possibility of rodents and other animals having a strong influence by eating acorns. Immature and small acorns remaining in cupule were not included in the collection.

Measurement of volume, size and weight of acorns

The following measurements were carried out from 1998 to 2000 for the two individuals (F and G) in the open area. Length (excluding the style at the tip of the acorn) and width of 100 acorns from each individual each year were measured, and their volumes were estimated cubically by multiplying the length by the square of the width as demonstrated for fagaceous nuts or acorns by Hiroki and Matsubara (1982). Fresh acorns were weighed soon after the collection, and they were weighed after drying at 80°C for 48 hrs in an oven, then the water content (%) was calculated using these data. To determine relationships among volume, wet weight and dry weight, 100 acorns in 1998 were marked by numbering. In 2000, as

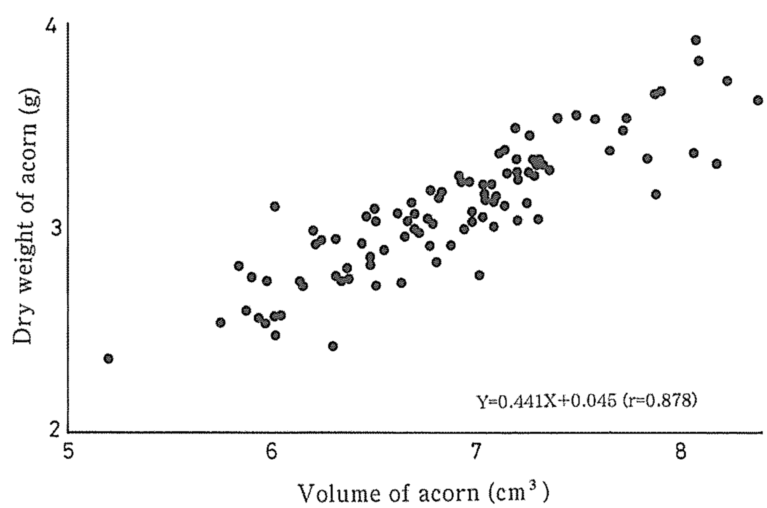

Fig. 1. Relationship between estimated volume and dry weight of acorns of *Quercus variabilis*.

measurement of dry weights was not made, values were estimated as follows. The estimation of dry weight of acorns in 2000 was made in two ways, in the first from wet weight and mean water content for F and G in 1998 and 1999, and in the second from the relation between volume and dry weight (Y=0.441X+0.045) in Fig. 1.

Results

Acorn production of *Quercus variabilis* fluctuated 2.5 to 3.1 fold in three individual trees (A, B and C) over the five years from 1975 to 1979 (Table 1). Individual D produced a large number of acorns in 1979, amounting to 21.3 times the production in 1976, though observation was not conducted for this tree in the intervening two years due to attack by insects. The proportion of sound acorns was 21.0% to 89.4%, with means for the five years of 52.5% to 70.7%.

The correlation between volume, estimated from length and width, and dry weight of acorns was low (r=0.878, Fig. 1), compared with that between wet and dry weights (r=0.955, Fig. 2).

The two individuals F and G showed quite contrasting pattern of fluctuation of acorn production from 1998 to 2000, the number produced by the former decreasing constantly, while in the latter, decrease was observed from 1998 to 1999, followed by increase in 2000 (Table 2). Dry weights of single acorns in 2000 were 3.27 and 5.73 g for F and G, respectively estimated from wet weight and mean water content in 1998 and 1999 (34.7%), and 3.18 g for F and 6.33 g for G when estimated from volume and the correlation formula (Y=0.441X+0.045, in Fig. 1). The values with the two estimations were approximately coincident for F but not G. Weights of single acorns for G demonstrated larger yearly fluctuation (from 4.37 g to 5.73 g) than for F (from 3.05 g to 3.27 g). Total dry weight of acorns fluctuated in parallel with the number of acorns but not with the variation in acorn weight. Similar patterns of yearly fluctuation were observed between the numer of acorns and the total dry weight, though synchronization fo acorn production was not recognized between these two individual trees for the three years from 1998 to 2000.

Table 1. Acorn production by five individual *Quercus variabilis* trees (A～E) from 1975 to 1979.

		Year					Mean ± Standard deviation
		1975	1976	1977	1978	1979	
A	Total	481	195	521	348	493	408 ± 136
	Sound	415	110	253	272	322	274 ± 111
	Ratio of sound acorns to the total (%)	86.3	56.4	48.6	78.2	65.3	67.0 ± 15.4
B	Total	1502	663	592	904	903	913 ± 358
	Sound	1336	139	281	608	538	580 ± 463
	Ratio of sound acorns to the total (%)	88.9	21.0	47.5	67.3	59.6	56.9 ± 25.1
C	Total	1165	1172	713	399	371	764 ± 293
	Sound	1041	725	454	307	247	555 ± 329
	Ratio of sound acorns to the total (%)	89.4	61.9	63.7	76.9	66.6	70.7 ± 11.5
D	Total	452	89	—	—	1897	813 ± 956
	Sound	269	30	—	—	1219	506 ± 629
	Ratio of sound acorns to the total (%)	59.5	33.7	—	—	64.3	52.5 ± 16.5
E	Total	1566	1347	—	—	—	1457 ± 155
	Sound	1041	550	—	—	—	796 ± 347
	Ratio of sound acorns to the total (%)	66.5	40.8	—	—	—	53.7 ± 18.2

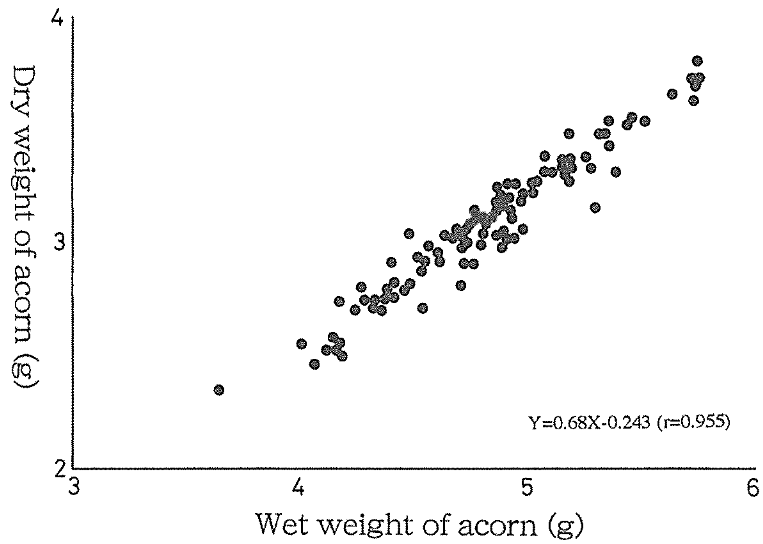

Fig. 2. Relationship between wet and dry weights of acorns of *Quercus variabilis*.

Table 2. Estimated volume, wet weight, dry weight and water content of acorns, the number of acorns, and total dry weight of acorns of two individuals (F, G) of *Quercus variabilis* in three years from 1998 to 2000.

		Year		
		1998	1999	2000
F	Estimated volume (cm^3)*	6.90 ± 0.65	6.71 ± 0.72	7.07 ± 0.71
	Wet weight (g)	4.83 ± 0.44	4.68 ± 0.54	5.01 ± 0.52
	Dry weight (g)	3.09 ± 0.31	3.05 ± 0.39	3.27 ※
	Water content (%)	36.0	36.0	—
	Number	7748	2668	1073
	Total dry weight (kg)	23.9	8.1	3.5
G	Estimated volume (cm^3)*	9.92 ± 1.25	10.89 ± 1.48	12.68 ± 1.58
	Wet weight (g)	6.85 ± 0.92	7.51 ± 1.02	8.78 ± 1.13
	Dry weight (g)	4.37 ± 0.61	5.12 ± 0.71	5.73 ※
	Water content (%)	34.8	31.8	—
	Number	679	339	934
	Total dry weight (kg)	3.0	2.0	5.4

* Estimated by multiplying length by the square of the width of acorns.
※ Estimated from wet weight and mean water contents for F and G in 1998 and 1999.

Discussion

From the present results, dry weight of acorns of *Q. variabilis* can be estimated from both volume and wet weight, though more accurately from the latter in terms of the correlation coefficients. Considering this fact and the laborious nature of measurement of volume, dry weight may best be estimated from the wet weight. However, attention should then be paid to conditions of ground or duration of time after falling. The value for water content reported earlier (42.3%, Hiroki and Matsubara 1982) differs from the present results (31.8 to 36.0%, mean 34.7%).

Though size and weight of *Quercus variabilis* acorns showed yearly variation, particularly in individual G (9.92 cm^3 to 12.68 cm^3 in size and 4.37 g to 5.73 g in dry weight), total dry weight of acorns varied almost independent of these variables but in parallel with the fluctuation in acorn number (Table 1). It can be concluded, therefore, that the fluctuation in number approximately reflects the fluctuation mass of production.

Three individuals (A, B and C) in the present study seemed not to show any synchronized pattern in acorn production in five years, though the data could not be tested statistically. Two other trees (F and G), which were similar with each other in the size and location, exhibited a remarkable difference in pattern of fluctuation of acorn production, in contrast to earlier report of synchronization within species in *Quercus* (Imada *et al*. 1990; Sork *et al*. 1993; Koenig *et al*. 1994). It must be noted that there was almost no crop failure in *Q. variabilis* (the only one exception, in which acorn production was low but not nul, was individual D in 1976). Crop failures synchronized within species have been reported by Koenig *et al*. (1994) between individuals and by Imada *et al*. (1990) between stands. This suggests that some climatic factors may trigger depression of acorn production. However, the Konara oak (*Q. serrata*) did not show synchronization between stands in one study (Hashizume 1987). Koenig *et al*. (1994) recognized a similar fluctuation pattern of acorn production between the species in the same section requiring the same number of years to mature acorns. But close taxonomic species do not necessarily show the same ecological properties, as *Q. crispula*, closely related to *Q. serrata*, showed large crop failure and synchronization of acorn production within species (Imada *et al*. 1990). Considering that *Q. crispula* is distributed in cooler regions than *Q. variabilis* and *Q. serrata*, climate may be one important factor that triggers synchronization of acorn production, although other influences must also have an impact (Kelly 1994).

Acknowledgements

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アベマキの堅果の大きさ，重量および生産量の年変動

広木詔三

アベマキの堅果生産量の年変動を調べるために，名古屋大学構内の二次林において5個体のアベマキを選び，1975年から1979年の5年間，個体ごとの堅果の落下数を数えた。また，同構内の孤立しているアベマキ2個体を選び，1998年から2000年の3年間にわたって，同様に堅果の落下数を数えた。その結果，アベマキでは，堅果生産が個体間で同調する傾向が認められなかった。堅果の大きさや湿重から堅果の乾重を推定することが可能であり，堅果の湿重量の方が大きさよりも乾重との相関は高いが，より正確に乾重を推定するためには，大きさと湿重量の両方を用いることが望ましいことが示された。1998年から2000年にかけての生産された堅果の数と乾重による生産量の変動はほぼ対応することが認められた。

キーワード：アベマキ，堅果生産，堅果生産の同調性，堅果生産の変動，堅果の大きさと重量