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Wood Biomass Production of Twelve Tree Species in Coppice Plantations Managed Under 1-, 2- and 3-year Rotations*[1]

Young Il Hyun*[2] · Jae Hun Kim*[2] · Young Chang Han*[2] · Kyung Joon Lee*[2]

12樹種에 対한 短伐期 萌芽林의 Biomass生産*[1]

玄 榮 一*[2] 金 在 憲*[2] 韓 永 昌*[2] 李 景 俊*[2]

ABSTRACT

Wood biomass production at 1-year, 2-year, and 3-year rotations on both low and upper hills at 2m x 2m spacing (2,500 trees/ha) was studied for a six-year period with following 12 species: *Lespedeza cyrtobotrya, Amorpha fruticosa. Robinia pseudoacacia, Acer saccharinum, Platanus orientalis, Populus alba* x *P. glandulosa* F_1, *Salix alba, Pinus rigida, Alnus hirsuta* var. *sibirica. A. inokumai, A. glutinosa,* and *A. incana.* In one-year rotation, *Lespedeza cyrtobotrya* produced largest amount of biomass (2.6 t/ha/year, fresh weight) and *Populus alba* x *P. glandulosa* F_1 the second largest (2.2 t/ha/year) on low hill. In two-year rotation, the latter produced the largest amount (4.8 t/ha/year) and *Alnus hirsuta* var. *sibirica* second largest (2.8 t/ha/year) on low hill. In three-year rotation, the largest weight (11.2 t/ha/year) was produced by *Robinia pseudoacacia* and the second largest (6.2 t/ha/year) by *Alnus hirsuta* var. *sibirica* on low hill. *Amorpha fruticosa, Acer saccharinum, Platanus orientalis* and *Salix alba* were not suitable for biomass or fuelwood production due to poor growth. Biomass yield on upper hill was reduced considerably for all twelve species, with less than 4 t/year at maximum. Only nitrogen fixing species (*Robinia* and *Alnus* species) are recommended on upper hill for biomass production. Good sprouting ability of species was generally associated with good biomass production. Calorific values of ovendry wood ranged from 4,485 cal/g for *Salix alba* to 5,125 cal/g for *Alnus glutinosa.* For maximum biomass production, a three-year rotation with coppice is preferred to one-year and two-year rotations The best species appeared to be *Robinia pseudoacacia* and *Alnus hirsuta* var. *sibirica.*

Key words: biomass; 3-year rotation; Lespedeza cyrtobotrya; sprouting ability.

要 約

다음의 12樹種을 ha當 2,500本式 植栽한 造林地에서 短伐期萌芽林(1年, 2年, 3年伐期)을 利用하여 wood biomass生産量(줄기, 가지, 잎)을 6年間 測定하였다. 참싸리, 족제비싸리, 아까시나무, 은단풍, 버즘나무, 은수원사시(현사시), 알바버드나무, 리기다소나무, 물갬나무, 좀일산오리나무, 글루티노사 오리나무, 인카나 오리나무. 山麓部의 1年 伐期区에서 참싸리가 年間 ha當 2.6톤(生重量)으로서 가장 많은 biomass를, 현사시가 2번째로 2.2톤을 生産했다. 2年伐期区에서는 현사시가 가장 많은 年間 4.8톤을, 물갬나무가 2.8톤을 生産했으며, 3年 伐期区에서는 아까시나무가 年間 ha當 가장 많은 11.2톤을, 그 다음으로 물갬나무가 6.2톤을 生産

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* 2.林木育種研究所, Institute of Forest Genetics, Suweon, Korea.

했다. 족제비 싸리, 은단풍, 버즘나무, 알바버드나무는 生長이 아주 不良하여 biomass나, 燃料生産으로 不適當하였다. 山腹部에서의 生長은 12樹種 모두 低調하였다. 그中 窒素를 固定하는 樹種(아까시나무와 오리나무類 4樹種)만이 약간 優勢한 生長을 보여 주었으며, 山腹部에는 이 樹種들 만이 植栽가 可能하다고 생각된다. 萌芽力이 強한 樹種이 biomass生産量도 많았다. 이들 樹種의 乾燥된 木片의 發熱量은 4,485~5,125cal/g이었다. 最大의 biomass生産을 為하여 萌芽林에 依한 三年伐期가 一年 或은 二年 伐期보다 더 優秀하며, 아까시나무와 물갬나무가 가장 有望하다고 認定된다.

INTRODUCTION

Maximum crop yield in a given land appears to be one of the major issues in modern agriculture. Forests where economic return in a given period is much smaller than agronomic farm lands have recently received new attention in the course of maximization of forest productivity. In particular, wood biomass from forests has been proposed to have enormous potential as an alternative source of energy in future (Klass, 1981), because wood biomass is the most abundant, easily obtained, and renewable source of energy with no obvious danger of environmental pollution. The accelated exploitation and lavish consumption of fossil fuels from limited reservoir are destined to bring gradual decline in fuel production in near future. It is obvious that we should come up with new forms of energy before energy crisis hits us again.

Recently, many foresters in the world have started to pay attention to the ways of increasing wood biomass production with a relatively short rotation. For example, Schreiner (1970) proposed minirotation of 1 to 5 years with poplars, and McAlpine *et al.* (1966) recommended same scheme with sycamore for fiber production. These are extremely short rotations compared with conventional poplar management and still short compared with 10-year rotation proposed by Zsuffa (1973) with hybrid poplars. Recent innovations in the processing juvenile wood fiber (Dutrow and Saucier, 1976) and possibility of poplar farming for food and fiber (Anderson and Zsuffa, 1977) have given more prospect to the short rotation.

The objectives of this study were to investigate the potential of wood biomass production for fuelwood, and to select best species and best rotation period for maximum biomass production at two different sites (low hill and upper hill).

MATERIALS AND METHODS

The study area was located in Wangrimri, Bongdammyeon, Hwaseonggun, Gyeonggido. Of the total 3.2 ha, one area of 1.6 ha was selected on the low hill with relatively deep top soil. The other area with same 1.6 ha was about 2 km apart from the former area and located on upper hill with relatively shallow top soil. The following 12 species were planted in spring, 1975 at the spacing of 2m x 2m (2,500 trees/ha) in vertical rows for each species: *Lespedeza cyrtobotrya, Amorpha fruticosa, Robinia pseudoacacia, Acer saccharinum, Platanus orientalis, Populus alba* x *P. glandulosa* F_1, *Salix alba, Pinus rigida, Alnus hirsuta* var. *sibirica, A. inokumai, A. glutinosa,* and *A. incana.* The *Platanus. Populus,* and *Salix* were 1/1 cuttings at the time of planting, and other species were seedlings grown previously in 1974 in the nursery, except *Pinus rigida* which was 2-1 seedlings at the time of planting. Each tree received annual application of 30g of compound fertilizer (22-22-11 mixture of N, P, K).

One-year rotation (annual harvest), two-year rotation (alternate year harvest), and three-year rotation were employed in this experiment. At the end of growing season just before harvest (in October), aboveground biomass was determined after cutting shoots at the base of stems and measuring the fresh weight of entire shoots (with leaves attached) of ten sample trees each from each rotation. In addition, number of sprouts at the base of stems was also counted at the time of harvest. For determination of heat of combustion, entire wood pieces were oven-dried at 70°C, pulverized, and combusted using oxygen bomb calorimeter.

RESULTS

A) Biomass Production

considerable variation in the growth of these 12 species was observed during the experimental period. Table 1 shows biomass production on the low hill with three different rotations. In one-year rotation, steady increase in biomass production over 5

Table 1. Wood biomass production (fresh weight, kg/ha) during 6-year period and number of sprout per tree (in parenthesis) in 12 woody species on low hill at 1-year, 2-year, and 3-year rotation. Planting density was 2,500 trees/ha.

Species	1-year Rotation (kg/ha/year)							2-year Rotation (kg/ha/2 yrs)				3-year Rotation (kg/ha/3 yrs)		
	75	76	77	78	79	80	Mean	76	78	80	Annual Mean	77	80	Annual Mean
Lespedeza cyrtobotrya	375 (3)	1,225 (3)	2,610 (9)	5,250 (9)	5,363 (16)	633 (6)	2,576 (8)	1,725 (6)	3,975 (8)	5,520 (14)	1,870 (9)	2,205 (8)	10,755 (6)	2,160 (7)
Amorpha fruticosa	165 (2)	688 (6)	890 (5)	908 (7)	738 (7)	250 (6)	607 (6)	1,000 (7)	1,385 (4)	640 (6)	504 (6)	530 (2)	360 (3)	148 (3)
Robinia pseudoacacia	255 (1)	950 (4)	2,088 (3)	2,350 (4)	5,838 (5)	1,375 (2)	2,143 (3)	1,750 (2)	5,875 (3)	2,635 (2)	1,710 (2)	12,210 (1)	55,313 (3)	11,254 (2)
Acer saccharinum	233 (2)	625 (5)	268 (3)	840 (5)	393 (5)	1,383 (7)	624 (5)	1,025 (1)	963 (3)	3,560 (4)	925 (3)	1,138 (1)	968 (4)	351 (3)
Platanus orientalis	318 (1)	625 (3)	290 (4)	840 (4)	288 (4)	513 (3)	479 (3)	1,050 (1)	353 (3)	2,063 (2)	578 (2)	1,468 (2)	4,625 (3)	1,016 (3)
Populus alba x *P. glandulosa* F_1	788 (2)	2,025 (8)	2,433 (6)	2,815 (7)	3,423 (11)	1,865 (8)	2,225 (7)	3,300 (2)	6,993 (6)	18,335 (7)	4,771 (5)	9,768 (2)	3,783 (5)	2,258 (4)
Salix alba	— —	175 (1)	2,325 (5)	3,188 (1)	780 (1)	1,038 (1)	1,251 (2)	— (1)	540 (1)	1,330 (1)	312 (1)	353 (1)	1,090 (1)	240 (1)
Pinus rigida	138 (1)	125 (1)	368 (2)	1,235 (7)	108 (6)	478 (3)	409 (3)	1,215 (1)	2,215 (6)	1,405 (6)	806 (4)	3,075 (1)	3,800 (4)	1,146 (3)
Alnus hirsuta var. *sibirica*	138 (1)	325 (2)	1,260 (4)	3,550 (6)	2,633 (9)	733 (6)	1,440 (5)	2,375 (1)	1,213 (4)	13,275 (5)	2,811 (3)	10,848 (1)	26,538 (4)	6,231 (3)
Alnus inokumai	130 (1)	125 (1)	880 (2)	1,695 (4)	2,800 (6)	503 (5)	1,022 (3)	648 (1)	975 (1)	10,563 (6)	2,031 (3)	5,413 (1)	12,888 (3)	3,050 (2)
Alnus glutinosa	130 (1)	678 (1)	1,000 (2)	2,325 (6)	4,743 (9)	733 (5)	1,601 (4)	635 (1)	3,010 (2)	4,288 (4)	1,322 (2)	5,570 (1)	26,375 (3)	5,324 (2)
Alnus incana	125 (1)	500 (2)	1,145 (4)	3,768 (7)	6,098 (10)	948 (5)	2,097 (5)	938 (2)	5,640 (5)	8,130 (7)	2,451 (5)	3,305 (1)	18,975 (4)	3,713 (3)

years was observed in *Lespedeza, Robinia, Populus,* and most *Alnus* species. *Lespedeza cyrtobotrya* produced in average of six years the largest amount of fresh weight (2.6 t/ha/year), *Populus alba* x *P. glandulosa* F_1 the second largest (2.2 t/ha/year) and *Robinia pseudoacacia* the third largest (2.1 t/ha/year). It should be mentioned that the biomass production in some species was markedly reduced in 1980 because of unusually cool and cloudy summer season which caused record-low poor harvest in most agricultural crops in 1980.

In two-year rotation, biomass production increased considerably during the six-year period. The largest biomass production was observed in *Populus alba* x *P. glandulosa* F_1 with annual production of 4.8 t/ha/year. *Alnus hirsuta* produced the second largest biomass (2.8 t/ha/year) in two-year rotation. Two-year rotation resulted in more annual biomass production than one-year rotation in *Acer saccharinum, Populus alba* x *P. glandulosa* F_1, *Pinus rigida* and three *Alnus* species.

In three-year rotation, second harvest in 1980 was bigger than first harvest in 1977 in most species. Particularly *Robinia pseudoacacia* produced during

1978 to 1980 a total of 55.3t of biomass which corresponded to more than two times of second largest biomass production by *Alnus hirsuta* (26.5t) during the same three-year period. The annual biomass production by the former species was 11.2 t/ha which ranked number one in quantity among 12 species and among three rotation methods tested in this experiment. The second largest annual biomass production in overall methods was recorded in the latter species with a 6.2 t/ha/year in average.

Amorpha fruticosa, Acer saccharinum, and *Platanus orientalis* produced less than 1 t/ha/year regardless of rotation period. These three species including *Salix alba* do not appear to be suitable for biomass or fuelwood production even on low hill.

Table 2. Wood biomass production (fresh weight, kg/ha) and number of sprout per tree (in parenthesis) in 12 woody species on upper hill at 1-year, 2-year, and 3-year rotations. Planting density was 2,000 trees/ha.

Species	1-year Rotation (kg/ha/year)							2-year Rotation (kg/ha/2 yrs)				3-year Rotation (kg/ha/3 yrs)		
	75	76	77	78	79	80	Mean	76	78	80	Annual Mean	77	80	Annual Mean
Lespedeza cyrtobotrya	162 (2)	930 (4)	1,386 (6)	936 (4)	736 (4)	522 (4)	799 (4)	710 (4)	536 (5)	628 (8)	312 (6)	1,172 (1)	1,900 (4)	512 (3)
Amorpha fruticosa	78 (2)	308 (4)	614 (4)	480 (4)	622 (5)	1,180 (7)	547 (4)	230 (1)	540 (3)	540 (3)	218 (2)	362 (2)	412 (4)	129 (3)
Robinia pseudoacacia	122 (1)	274 (3)	908 (2)	936 (3)	1,940 (2)	2,780 (4)	1,160 (3)	1,060 (1)	1,060 (2)	5,820 (3)	1,323 (2)	2,824 (1)	12,840 (3)	2,611 (2)
Acer saccharinum	62 (2)	80 (3)	86 (2)	196 (2)	246 (2)	154 (3)	137 (2)	114 (1)	80 (1)	260 (2)	76 (1)	76 (1)	36 (1)	19 (1)
Platanus orientalis	82 (2)	98 (2)	58 (1)	68 (1)	102 (1)	108 (2)	86 (2)	74 (2)	98 (1)	40 (1)	35 (1)	84 (1)	— —	14 (1)
Populus alba x *P. glandulosa* F	430 (3)	710 (8)	1,216 (6)	1,296 (5)	1,504 (5)	602 (4)	960 (5)	1,810 (3)	1,692 (4)	1,452 (5)	826 (4)	1,702 (3)	4,740 (6)	1,074 (5)
Salix alba	— —	66 (1)	— —	100 (1)	— —	— —	28 (1)	28 —	— —	— —	5 —	— —	— —	— —
Pinus rigida	102 (1)	92 (1)	182 (3)	156 (2)	312 (10)	608 (2)	242 (3)	864 —	760 (2)	784 (5)	401 —	282 (1)	— —	47 (1)
Alnus hirsuta **var.** *sibirica*	80 (2)	252 (1)	1,496 (4)	4,040 (3)	2,952 (8)	814 (6)	1,606 (4)	1,136 (2)	4,980 (3)	4,580 (6)	1,783 (4)	5,052 (3)	12,970 (4)	3,004 (4)
Alnus inokumai	78 (2)	64 (2)	438 (3)	2,152 (3)	2,000 (5)	600 (7)	889 (4)	154 (1)	2,848 (2)	3,480 (5)	1,080 (3)	1,042 (1)	11,520 (2)	2,094 (2)
Alnus glutinosa	80 (2)	348 (1)	550 (3)	3,320 (2)	2,064 (7)	512 (8)	1,146 (4)	448 (1)	4,260 (2)	3,490 (5)	1,366 (3)	1,426 (1)	6,610 (2)	1,339 (2)
Alnus incana	70 (2)	222 (2)	760 (4)	3,320 (5)	2,930 (9)	1,216 (8)	1,420 (5)	810 (1)	3,186 (5)	9,000 (8)	2,166 (5)	3,912 (3)	10,340 (5)	2,375 (4)

The growth of 12 species on upper hill is shown in Table 2. *Salix alba* did not survive on upper hill and its biomass production was unable to measure since 1979. In general, biomass production on upper hill was much poorer than on low hill in all 12 species. Among 12 species planted on upper hill, only nitrogen-fixing trees (*Robinia* and *Alnus* species) produced more than 1 t/ha/year of biomass in all three rotation methods but it was less than 4 t/year. *Populus alba* x *P. glandulosa* F_1 performed relatively good (nearly 1 t/ha/year) which was better than *Lespedeza* and *Amorpha*. Other species, such as *Acer saccharinum, Platanus orientalis, Salix alba,* and *Pinus rigida* produced mere 0.1 to 0.2 t/ha/year regardless of rotation period.

B) Sprout Production

The number of sprouts produced in each rotation period is shown in the same Table 1, and 2 (numbers in parenthesis). The largest number of sprouts was recorded by *Lespedeza* with average sprouts of 8 shoots/year. *Populus alba* x *P. glandulosa* F_1 produced the second largest number of sprouts with 7 shoots/year in one-year rotation. Increased biomass production in many species was associated with, if not all the cases, increased number of sprouts in 1-year and 2-year rotations. Sprout production on upper hill was considerably reduced in *Lespedeza* and *Populus* compared with on low hill, while that of *Alnus* species showed little change with 4 to 5 sprouts per tree in 1-year rotation.

C) Heat of Combustion

Heat of combustion (carloric values) of ovendry woods is shown in Table 3. *Alnus glutinosa* wood produced 5,100 cal/g in 1-year rotation and 5,150 cal/g in 2-year rotation which was the highest caloric value among 12 species. Caloric values of other species ranged from 4,470 cal/g for *Salix alba* to 5,045 cal/g for *Alnus incana*. The difference in caloric values between 1-year rotation and 2-year rotation woods was very small and less than 100 cal/g in favor of 2-year rotation woods. The caloric values reported here are in well agreement with literature (Neenan and Steinbeck, 1979).

Table 3. Heat of conbustion (caloric values) of ovendry woods of 12 tree species used in biomass production study with 1-year and 2-year rotations.

Species	1-year-rotation (cal/g)	2-year-rotation (cal/g)	Mean (cal/g)
Lespedeza cyrtobotrya	4,985	5,015	5,000
Amorpha fruticosa	4,573	4,580	4,577
Robinia pseudoacacia	4,775	4,800	4,788
Acer saccharinum	4,705	4,750	4,727
Plantanus orientalis	4,610	4,630	4,620
Populus alba x *P. glandulosa* F_1	4,575	4,600	4,588
Salix alba	4,470	4,500	4,485
Pinus rigida	4,825	4,980	4,903
Alnus hirsuta var. *sibirica*	4,925	5,010	4,968
Alnus inokumai	5,011	5,010	5,061
Alnus glutinosa	5,100	5,150	5,125
Alnus incana	5,045	5,100	5,073

DISCUSSION

The present experiment was not intended to determine the optimum planting density for maximum biomass production, but the trees were planted at the same planting density of either 2,500 trees/ha on low hill or 2,000 trees/ha on upper hill. It would be possible to increase biomass production per ha by increasing planting density. Therefore, the present experiment should not be compared with high density poplar farming in terms of productivity.

It was demonstrated in the present experiment that 11 t/ha/year biomass production was possible with *Robinia pseudoacacia* at 3-year rotation. Three-year rotation increased annual wood production (compared with one-year and two-year rotations) in *Robinia pseudoacacia*, *Platanus orientalis*, *Pinus rigida*, and four *Alnus* species, indicating that for maximum wood production rotation period should be long enough to accumulate on above ground large photosynthesizing area during the growing season. From the psysiological point of view, early spring growth of trees in three-year rotation treatment will be stimulated much faster with large number of photosynthesizing leaves early in the growing season (originated from many winter buds) than growth of trees in one-year rotation whose early spring growth will start slow due to small number of total leaves on the new shoots. Therefore, a rotation of three years is recommended for maximum wood biomass production for these species.

Large biomass yield with short rotation period was also reported by some researchers. For example, Kennedy (1975) working with sycamore (*Platanus occidentalis*) showed that two- to four-year rotation gave more biomass than one-year rotation. Two-year rotation appears to be satisfactory for *Populus euramericana* giving 30 t/ha/year (Frison, 1974) and for *P.* x *canadensis* with acceptable pulp quality (Anderson and Zsuffa, 1975). Even one year rotation of *P. euramericana* cv. I-45/51 gave about 48 t/ha of wood plus bark with intensive management (Zsuffa and Balatinecz, 1975). Some researchers, however, are skeptical on the prospect of short rotation. Ek and Brodie (1975) stated that extremely short rotation of less than 15 years was undesirable for aspen management. Steinbeck *et al.* (1974) preferred rotation of 5 to 10 years for sycamore coppice to shorter rotations which required fertilization and were not economical in conservation of nutrients in the stand.

The poor growth of all 12 species on upper hill presented us new problems of how we should manage the poor soil on upper hills in many parts of this country. Shallow soil, low fertility, and low water availability in upper hills are major limiting factors for good tree growth. In the present experiment, *Lespedeza* performed very poorly on upper hill compared with the good growth on low hill. The five species that grew reasonably well on upper hill were all nitrogen-fixing trees (*Robinia peudoacacia* and four *Alnus* species). This fact suggested that nitrogen availability is one of the limiting factors in upper hill. Authors of this paper strongly suggest that nitrogen-fixing trees mentioned above are the only tree species that can successfully be planted on upper hills for biomass production and for soil improvement before major reforestation. These tree species in the present experiment contained 3 to 4% of nitrogen (dry weight basis) in the leaves and accumulated 1 to 1.5 t/ha of fallen leaves annually on the forest floor (Unpublished data).

According to Fege *et al.* (1979) forests in the world will provide wood for energy at competitive prices in the future through "silviculture energy farms". There is no doubt that high price of fossil fuels will put in near future much pressure on foresters in Korea to produce cheap alternative sources of energy from forest lands which occupy two-thirds of total land area in Korea. The authors have found plenty of poorly stocked open forest lands near farm villages. We strongly suggest that these less productive forest lands which have been abandoned for many years without adequate care and proper long-term management plans should be brought into attention for urgent soil improvement. The long-term soil improvement plan in these poor lands can be initiated by planting nitrogen-fixing tree species as a preliminary step toward introduction of economical tree species in later stage. In the mean time, these forests with nitrogen-fixing trees will give enough fuelwoods and extra incomes to the village farmers through sprout harvest and thinning.

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