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Financial Analysis of Vegetation Control for Sustainable Production of Songyi (*Tricholoma matsutake*) in Korea*

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송이生產을 持續可能하게 하기 위한 소나무林內 植生整理 作業의 經濟性 分析*

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ABSTRACT

An economic study of vegetation control to increase production of Songyi (Korean name for pine mushroom, matsutake, *Tricholoma matsutake* (S. Ito & Imai) Sing.) in red pine (*Pinus densiflora*) stands in Korea was undertaken. In Korea, Songyi grows only in red pine stands. Harvest of this mushroom provides a significant income source to rural people in Korea yielding exports of US$20 million to US$80 million per year. However, hypogeous Songyi colonies and the mushroom production are declining, partly because shade tolerant species are succeeding the shade intolerant red pine. Past research says that it is possible to keep Songyi production increasing by controlling under-story vegetation. But few people are willing to invest in the necessary control. Our analysis found that the economics of vegetation control appear to be quite favorable, showing an internal rate of return (IRR) of 20.7 percent in 15 years. However, positive returns do not occur for at least eight years and even then, the returns may not appear to the landowner to be a result of vegetation control efforts only because the mushroom production has been greatly variable depending on weather conditions. In a sensitivity analysis, it was found that the number of circular mushroom colonies was critically important for the cash flow. Results of this analysis are also sensitive to assumptions about annual growth length(0.16m radial growth=1.0m/circular length growth) of Songyi colony. However, the primary goal of vegetation control should be to keep the young colonies growing. Further research in the behavior of hypogeous Songyi colonies after vegetation control would help to improve our confidence in the results.

Key words : Songyi, Tricholoma matsutake, *vegetation control, financial analysis, internal rate of return (IRR), project balance*

요 약

우리 나라에서 송이 (Songyi, pine mushroom, matsutake, *Tricholoma matsutake* (S. Ito & Imai) Sing.) 생산을 持續 可能하게 하기 위한 소나무림의 하층식생 정리작업에 대한 경제성을 분석하였다. 우리 나라에서는 소나무림에서만 발생하고 있는 송이는 日本에 수출되어 매년 2천만 달러~8천만 달러를 벌어들이는 산촌 농가의 중요한 소득원이다. 그러나 陽性인 소나무림이 耐陰性 樹種의

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林分으로 遷移되면서 송이생산은 차츰 줄어들 전망이다. 현재까지의 연구에 의하면, 소나무림내 하층식생을 정리하면 송이 생산이 계속 증가될 수 있지만 이 작업에 투자하려는 송이 생산자는 많지 않은 실정이다.

그렇지만 우리의 經濟性 分析에 의하면, 원형의 송이 菌環이 한 개 존재하고 있는 소나무림에 대한 하층식생 정리작업은 15년 동안 內部 收益率 (IRR=Internal Rate of Return)이 20.7%에 이를 정도로 收益性이 높다. 하지만 적어도 8년 동안은 이 투자에 대한 純現在價 (NPV=Net Present Value)가 마이너스이다. 이 작업의 經濟性에 대한 센시티비티 分析 결과로는 토양내 송이 菌環의 數가 純收益 변동에 크게 영향을 미쳤다. 한편, 송이 생산량은 기상조건에 따라서도 크게 변할 수 있으므로, 송이 생산자들은 이 內部收益率이 하층식생 정리 작업만의 결과라고는 생각지 않을 수도 있다. 또한 이 분석 결과는 이 땅속 菌環의 연간 신장량에 관한 가정 (菌環신장량, 0.16m/년=菌環의 원둘레 길이 생장량, 1.0m/년)에 따라서도 바뀔 수 있다.

결과적으로 송이를 持續的으로 생산하기 위한 植生整理 작업의 근본적인 목표는 어찌하여서든 땅속의 송이 菌環을 계속 자라게 하는 것이어야 한다. 우리는 植生整理 후에 땅속 송이 菌環의 行態에 관한 조사 연구가 이번 經濟性 分析의 信賴性을 높일 것이라고 생각한다.

INTRODUCTION

Recently, wild mushroom production in forests has been of great interest worldwide. Songyi (pine mushroom, matsutake, *Tricholoma matsutake* (S. Ito & Imai) Sing.) is a significant income source to rural people in Korea. The mushroom has been exported to Japan earning US$20 million to US$80 million per year (Kim, 1996) and its price is often US$110 to US$1,100/kg in Japan (Hall et al., 1994). The Pacific Northwest region of Canada and the USA is increasingly producing American matsutake (*Tricholoma magnivelare*) and 70 percent of the production is exported to Japan (Hosford et al., 1997). In Korea this mushroom fruits only in red pine (*Pinus densiflora*) stands (Lee et al., 1983), whereas American matsutake fruits under Douglas-fir, pines, hemlock and tanoak in Pacific Northwest America (Hosford et al., 1997).

The pine forests in Korea are currently declining because a variety of deciduous shade tolerant species are succeeding the highly shade-intolerant tree species (Ma, 1993). Korean Songyi production is also declining. Mycorrhizal fungal colonies of the invading species replace hypogeous Songyi fungal colonies which depend on pine roots (Ogawa, 1991). The underground Songyi colonies also disappear due to highly accumulated soil organic matter from deciduous trees (Ogawa, 1991). Fur-ther, artificial regeneration or transplanting of the fungal colonies has been unsuccessful in both Korea (Koo et al., 1993) and Japan (Hosford et al., 1997). Kyoto Forestry Research Institute (1982) argued that decreased Songyi production was related to reduction in charcoal production from under-story vegetation. These factors together may mean that without controlling the vegetation and soil organic matter, Songyi may disappear in the forest forever. While red pine forests and Songyi production are declining, research has shown that vegetation control increased the number of Songyi colonies and the resulting mushroom production (Ito and Ogawa, 1979).

Despite these implications, many forest owners are not willing to invest in vegetation management. Some owners who have controlled vegetation in the Songyi production forest have said that vegetation control did not seem to increase the mushroom fruiting[1]. At least some of the reasons may be due to the highly variable annual production of Songyi. Much wild mushroom production, including Songyi, has been extremely unpredictable (Ogawa, 1991 ; Hosford et al., 1997). For example, annual Songyi production in Korea has greatly varied from about 140 tons to 1300 tons since 1980. Some of the variability is related to rainfall patterns and temperature

1) Personal communication with Songyi harvesters in Kangwon and Kyungnam provinces, Korea

change (Park et al., 1995), and also to damage by forest pests like pine gall midge in Korea (Korean Forestry Research Institute, 1993) and pine wood nematode in Japan (Ogawa, 1991). In addition, Songyi colonies, radially growing out, die back when they reach an area that a previous colony passes by (Ogawa, 1991). Because of this behaviour, Songyi colonies may naturally dieback without any relation with vegetation, where many colonies are close together.

Finally, owners may not have noticed an increase in fruiting because the control operation should be done continuously at least for five years (Ogawa, 1991). The length of this investment suggests a financial analysis of the problem. But to date, no such analysis has taken place. To understand why the owners hesitate to invest in vegetation control as well as to help their decision-making, we did a financial analysis based on some assumptions of Songyi fungal growth, mushroom production and vegetation control costs.

METHODOLOGY

In order to undertake a financial analysis of the impact of vegetation control, we needed a Songyi production model. Important studies have been done by Ito and Ogawa (1979), Ogawa (1991), and Park et al. (1997). Unfortunately, none produced a model satisfactory for this analysis.

1. Ito and Ogawa's model of vegetation control effects on Songyi production in Japan

One of the first studies into the interaction of vegetation control and the Songyi production was done by Ito and Ogawa (1979) in Japan. Over 13 years they measured the changes of the number of fungal colonies after controlling vegetation in 25 year old pine stands which were producing the mushroom. They did this over four treatments : 1) no treatment ; 2) litter removal only ; 3) vegetation control only ; and 4) both litter removal and vegetation control.

While there was some useful information produced from the study, we are suspicious of the conclusions. They said the litter removal treatment was not effective even though it increased the number of fungal colonies by over 200 percent at the second year. This increase in itself is questionable given Ogawa's (1991) conclusion that new colony formation takes three to five years. In addition, there were some conditions in Ito and Ogawa's study (1979) which limited its usefulness to us. They did not define the fungal colony in terms of size and mushroom production potential and did not count the mushroom production separately on each treatment. In North America, vegetation control effects on American matsutake (*Tricholoma magnivelare*) of which hypogeous colony is very similar to Songyi (*T. matsutake*) are not yet available[2].

2. Park et al.'s (1997) environmental control study for Songyi production in Korea

Park et al. (1997) argued that environmental control effect on Songyi production was short-term only. In their ten year study, vegetation control treatment effect on Songyi production started from the next year by increasing production from 200 percent to 400 percent of the pre-treatment level and lasted three years. We did not directly incorporate their results into a model, however, because they did not supply the data of actual Songyi production itself as well as the number and size of Songyi colonies at the study site.

3. A model for this analysis

A) Basic assumptions

Ito and Ogawa's study (1979) showed the presence of a fungal colony before vegetation control is critical for vegetation control to increase Songyi production in pine forests. However, they did not explain the relationships between the size of a fungal colony and mushroom production. For this analysis, we assumed that length of fungal colony is absolutely related to the amount of the mushroom production and that fungal colony

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2) Personal communication with Dr. Randy Molina, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, Oregon, USA.

growth is seriously hindered by dense vegetation. Songyi can be produced on a stand aged from 20 years to 90 years, and good yields can be obtained from stands 30 years to 60 years old (Ogawa, 1991). Thus, we also assumed vegetation control started when the stand is 30 years old. We calculated the revenues for 15 years after the operation although the mushroom production may continue further 40 years. While we recognize the variability of Songyi production, we believe that given the conservatism of our assumptions and the improved habitat provided by vegetation control, our results are meaningful.

B) Input assumptions

Our input assumptions are shown on Table 1A.

(1) Number of circular colonies : according to Ogawa (1991), typical underground Songyi colonies are circular. We assumed one full circular colony per hectare. Presence of a number of colonies in a stand may mean that vegetation may not be a problem. In addition, Ito and Ogawa (1979) mentioned that vegetation control did not induce fungal colonies to grow at the site where there had been no preexisting fungal colonies.

(2) Radial growth of Songyi colony : Songyi starts to fruit in pine forests when trees are about 20 years and the colony radially grows out about 0.15m to 0.20m per year (Ogawa, 1991). After fruiting, the inside of the colony is in the process of dieback. If the fungal colony is fully circular and its radial growth is 0.16m per year, then its circumference growth is calculated into about 1.0m (Fig. 1). And thus, the length growth of 1.0m is constant every year, regardless of the colony size.

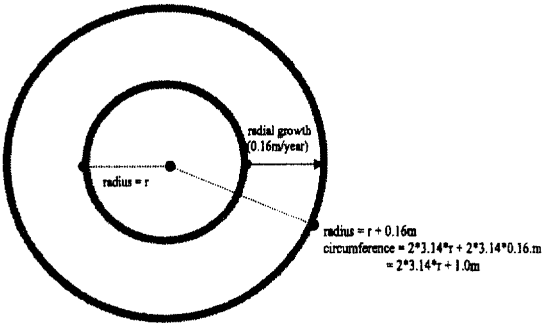

Fig. 1. A hypogeous circular Songyi (*Tricholoma matsutake*) colony radially grows out by 0.15m to 0.20m per year (See Appendix 1). If we assume the growth is about 0.16m, then it equals to about 1.0m long circumferential length growth. This length growth is the same regardless of the size of a circular colony.

(3) Initial colony length : we started with a 10m. This is based on our assumptions that the colonies begin growing when the pine trees are about age 20 (Ogawa, 1991), that the colonies grow about 1m/year (see above) and that the stand to be treated is now age 30. Therefore, in 10 years, in a 30-year-old red pine stand, the circumference of the colony will be about 10m long.

(4) Colony dieback rate : the growth of Songyi colonies can be hindered or partly killed by the dense roots or organic litter of vegetation other than red pine and the colony dieback is also due to the decline of red pine forests infested with diseases or pests (Ogawa, 1991). Further, Songyi production has varied with weather conditions in Korea (Park et al., 1995). However, to simplify, we assumed that decrease in mushroom production absolutely depends on fungal colony dieback. We calculated a dieback rate of the mushroom production based on a smoothed production decline (from about 400 tons in 1958 to about 140 tons in 1973) in Kyoto Japan (Kyoto FRI, 1982). The dieback rate was calculated to about 7 percent per year for 15 years. From the Songyi production data (Korean Forestry Administration, 1996) we could also calculate a similar dieback rate in Korea during 1985 (1,313 tons, the maximum record) to 1995 (654 tons, the recent maximum).

(5) Songyi production per unit length of colony : the productivity of a fungal colony was estimated from the study on Songyi circular colony of Kyoto FRI (1982) and Ito and Ogawa (1979). From their 10 years of observations (Appendix 1 ; yearly fruiting greatly varied in the colony), we estimated that a one-meter-long Songyi colony produced an average 5.8

Table 1. Financial analysis of investment in vegetation control for Songyi production in Korea for 15 years

A) Assumptions

No. of circular colony(>0)/ha=	1.0	Colony radial growth(m/yr)=	0.159
Initial colony length(>0)(m/ha)=	10.0	Colony dieback rate=	7.0%
Songyi production rate(kg/m)=	0.50	Songyi price ($/kg)=	100
Labour ($/people/day)=	30	ARR=	10.0%
Finance for 1st yr cost(repaid for 15 yrs ($)=	1200	Finance interest rate (i) =	12.0%
1st yr labour requirement(people/ha)=	40		

B) Formulae

Colony length(m/ha)	
Vegetation control =	Initial colony length + 2*3.14*No. of circular colony*colony radial growth*yrs
No control=	Initial colony length*(1-colony dieback rate)^yrs
Songyi production (kg/ha)=	Colony length*Songyi production rate
Yearly repayment of finance ($/ha) =	Finance*{i*(1+i)^15)/(1+i)-1}
Revenue ($/ha)=	Songyi production*price
Project Balance ($/ha)=	Beginning balance + interest + net revenue (loss)

C) Summary Statistics

Analysis	Without finance	With finance
NPV	$1,724	$1,584
IRR	20.7%	31.5%
Break-even figures		
Songyi production rate(kg/m)	0.27	0.28
Labour($/people/day)	57	53
Colony dieback rate(%)	-1.7%	-1.2%
Songyi price($/kg)	53	57

D) Project balance by year with the most likely assumption variables

Activity		Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Colony length (m/ha)	Vegetation control	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	No control	10.0	9.3	8.6	8.0	7.5	7.0	6.5	6.0	5.6	5.2	4.8	4.5	4.2	3.9	3.6	3.4
Songyi production (kg/ha)	Vegetation control	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5
	No control	5.0	4.7	4.3	4.0	3.7	3.5	3.2	3.0	2.8	2.6	2.4	2.3	2.1	1.9	1.8	1.7
Revenue ($/ha)	Vegetation control	500	550	600	650	700	750	800	849	899	949	999	1049	1099	1149	1199	1249
	No control	500	465	432	402	374	348	323	301	280	260	242	225	209	195	181	168
	Rev. diff.	0	85	167	248	326	402	476	549	620	689	757	824	890	954	1018	1081
Labour (people/ha)		40	10	5	2	2	2	2	2	2	2	2	2	2	2	2	2
Cost ($/ha)		1200	300	150	60	60	60	60	60	60	60	60	60	60	60	60	60
Without finance																	
Net Rev(Rev.Diff.-Cost) ($/ha)		-1200	-215	17	188	266	342	416	489	560	629	697	764	830	894	958	1021
Beginning balance ($/ha)		-1200	-1200	-1535	-1671	-1651	-1550	-1363	-1084	-703	-214	394	1130	2008	3038	4236	5618
Interest ($/ha)		0	-120	-154	-167	-165	-155	-136	-108	-70	-21	39	113	201	304	424	562
Project Balance ($/ha)		-1200	-1535	-1671	-1651	-1550	-1363	-1084	-703	-214	394	1130	2008	3038	4236	5618	7200
With finance																	
Finance+interest ($/ha)		-1200	176	176	176	176	176	176	176	176	176	176	176	176	176	176	176
Net Rev(Rev.diff.-cost-Finan-interest) ($/ha)		0	-391	-159	11	89	166	240	312	383	453	521	588	654	718	782	844
Beginning balance ($/ha)		0	0	-391	-589	-637	-611	-506	-317	-36	343	831	1435	2166	3037	4058	5246
Interest ($/ha)		0	0	-39	-59	-64	-61	-51	-32	-4	34	83	143	217	304	406	525
Project Balance ($/ha)		0	-391	-589	-637	-611	-506	-317	-36	343	831	1435	2166	3037	4058	5246	6615

ARR=alternative rate of return; IRR=internal rate of return; NPV=net present value; PV=present value; Rev.diff.=revenue difference mushrooms. Ito and Ogawa (1979) also showed that there are about twelve Songyi mushrooms in one kilogram. Thus, we assumed 1.0m of Songyi colony produces about 0.5kg mushrooms.

(6) Songyi price : in Korea, Songyi export prices varied from US$101/kg to US$189/kg (Kim, 1996) and were highly negatively correlated with production (r=0.93) for last 10 years (Koo's unpublished data). That is, the price was high when the production was low. From Kim's data (1996) the average export price of Songyi of last 5 years was calculated into US$125/kg. Because this price includes a commission for exporting of about 23 percent (Jeong, 1993), we assumed US$100/kg as Songyi price for the harvesters.

(7) Number of labourers : Kim (1996) recommended 40 people per hectare for controlling vegetation in Songyi producing stands. So, we assumed 40 labourers were needed for the first year. The next year 10 people were needed for removing new shoots and more specific work like root extracting. After that we assumed two people are needed every year for routine work to maintain the normal colony growth.

(8) Labour charge : we assumed the labour charge is US$30 per worker per day that is generally accepted in rural areas in Korea. Because the operation required only simple tools like scythe, spade, rake etc, the cost for the tools was included in the personal labour charge.

(9) ARR : we applied a pre-tax nominal rate of 10 percent as the alternative rate of return (ARR). The percentage is close to the interest for savings accounts in Korea before its economic crisis in 1997.

(10) Finance : we assumed that the owners who received loans for the first year vegetation control had to pay back the loan annually for 15 years at 12 percent annual interest rate.

Formulae used to calculate the changes of colony length, Songyi mushroom production and revenue are on Table 1B.

C) Analysis

Net present value (NPV), internal rate of return (IRR) and break-evens for the input assumptions were calculated with the Microsoft Excel (Microsoft, 1993). Net revenues of the vegetation control were calculated by subtracting both the controlling costs and revenue for no-control from revenue for the vegetation control. Project balance each year was calculated by adding the current net revenue to the compounded net revenues or costs of previous years. Because the first year cost for the control was a great burden to the forest owners, we also analysed NPV, IRR and break-evens for the assumption variables in case of loaning the first year labour cost for 40 people.

Kaen (1995) said that sensitivity analysis cannot be used for decision-making but may be used for understanding the importance of some factors. To understand how the changes of the assumption values affect the IRR of vegetation control project for sustainable Songyi production, sensitivity analysis was used. Sensitivity of IRR was calculated for combination changes of both initial colony length and the number of circular colonies under different colony dieback rates. However, we did not include the Songyi price because it is highly negatively correlated with the mushroom production.

RESULTS

1. NPV, IRR and project balance

With the input assumptions and without finance (Table 1A) NPV was US$1,724/ha in 15 years and IRR was 20.7 percent (Table 1C), but the project balance was not positive for eight years (Table 1D and Fig. 2). Whereas the revenue of the vegetation control site was US$1,249/ha at the 15th year, the value of the uncontrolled was only US$168/ha. The difference of these revenues, US$1,081, could be calculated into US$1,021/ha after the control cost. With the finance of the first year cost, NPV was US$1,584 and IRR was 31.5 percent but the project balance was not positive for seven years (Table 1C). However, this high IRR value decreases as a finance interest rate increases (data are not shown).

2. Break-even

Without finance, the break-evens were 0.27kg/m for Songyi production rate and US$57/worker/day for labour (Table 1C). The negative break-even of colony dieback rate, -1.7 percent, means that if the Songyi in the nocontrolled stands is growing at the rate of less than 1.7 percent per year, the NPV of vegetation control is positive. If the fungal colonies are growing faster than this rate, no vegetation control is warranted. The break-even Songyi price was US$53/kg.

The break-even values with finance were slightly lower than the values without finance in production variables, such as mushroom production rate and Songyi price, but higher for cost such as labour charge. This means that, although IRR (31.5 percent) is much higher than the interest of the loan (12 percent) the owners have some burden for repaying the loan.

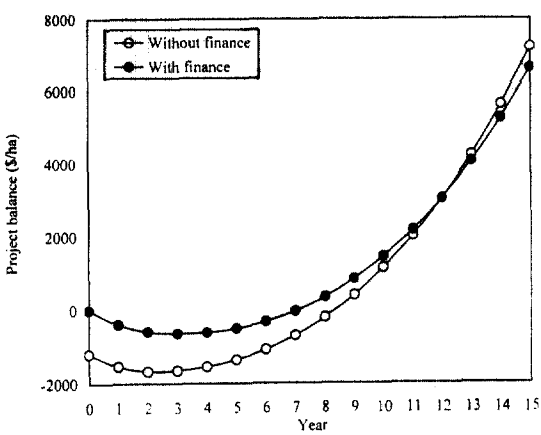

Fig. 2. Project balance of a vegetation control project in a pine stand for Songyi (*Tricholoma matsutake*) production. The value is based on input assumptions in Table 1A.

3. Sensitivity of IRR

IRR increased as the number of circular colonies, colony length or colony dieback rate increased (Table 2). The IRR change was greater with the change in the number of circular colonies than with the change in initial colony length. For example, at 7.0 percent dieback rate, IRR of 20.7 percent for one circular colony with 10m initial colony length changed to 26.2 percent for 1.5 circular colonies without changing colony length, while it changed to 24.0 percent for 15m colony length with one circular colony. Further, as the colony dieback rate increased from 3.5 percent to 10.5 percent, the effect of changes in initial colony length on IRR increased. That is, at 3.5 percent dieback rate with one colony per hectare, IRR increase due to colony length change from 10m to 15m was 2 percent (from 17.6 percent to 19.6 percent), while it was 4.3 percent (from 23.1 percent to 27.4 percent) at 10.5 percent dieback rate. At first this latter result may seem counterintuitive, however, as dieback is related to competing vegetation, the higher the initial dieback rate, the greater the potential impact of vegetation control.

DISCUSSION

Through this financial analysis, we could understand biologically and financially why the owners of Songyi production forests are hesitating to invest in controlling vegetation in their forests. First, in the biology of Songyi, the radial fungal colony extension, 0.15m to 0.20m per year (Ito and Ogawa, 1979) increase fungal length only by about 1m per year, which can directly contribute to the increase in Songyi production.

Table 2. Sensitivity of IRR (%) of a 15-year-long vegetation control project for Songyi production with combination changes of assumption variables : colony dieback rate, initial colony length and the number of circular colonies.

		Colony dieback rate								
		3.5%			7.0%			10.5%		
Initial colony length/ha		5m	10m	15m	5m	10m	15m	5m	10m	15m
	0.5	6.7	9.8	12.5	9.1	13.9	17.9	10.8	16.8	21.8
Number of circular	1.0	15.4	17.6	19.6	17.1	20.7	24.0	18.5	23.1	27.4
colonies/ha	1.5	21.8	23.5	25.2	23.2	26.2	29.0	24.3	28.4	32.2

This slow length growth is probably not widely known to Songyi growers. And this growth increase may not be easily recognised as a vegetation control effect, when comparing a very large natural yearly variation in Songyi production. In addition to this small annual increment in the colony length, the vegetation control could increase the number of fungal colonies only in 7 years (Ito and Ogawa, 1979), although it could significantly affect NPV and IRR values.

Second, the project balance from the vegetation control was negative for eight years with our input assumptions. This long period of time may not justify the first year investment because most of the rural people may not have accumulated financial resources. If a harvester has to pay tax on the income from Songyi, the wait for a positive project balance will be even longer. Because of these factors, the vegetation control may not be expected to be done by the harvester even in state forests in which a Songyi harvesting right has been conceded at no charge to the local people, on the condition that they should protect the forest from fire and pest[3].

Further, there are some other reasons why the owners are not willing to invest in the vegetation control. In this study we basically assumed that Songyi production is absolutely related to its fungal colony length and that the colony dieback is due to dense under-vegetation. In nature, Songyi colony growth itself can be affected by various soil conditions like depth and moisture, weather patterns, various pests, and relationship with near Songyi colonies. However, the hypogeous fungal colony growth may be less affected by the weather, because soil environment is less changeable. In contrast, the continuing growth of Songyi primordia formed in soil is fully exposed to unpredictable weather conditions such as air temperatures during the fruiting season (Ito and Iwase, 1997). Thus, the weather variables, e.g., minimum temperature in September can significantly affect Korea's annual Songyi production (Park et al., 1995). Due to these factors the owners may not consider the dense vegetation as a unique factor of declining Songyi production and Songyi colony dieback.

3) Personal communication with Korean Forestry Administration

Nevertheless, vegetation control in Songyi production forests may be very profitable. Even with one circular colony, vegetation control promises a positive project balance in eight years and its benefits increase when the fungal dieback rate due to heavy vegetation increases. Our study showed that it is extremely important not to lose any fungal colony in Songyi producing forests and that vegetation control cost in the first year is the biggest burden to the owners of Songyi producing forests. Therefore, we suggest that one of the economical and efficient ways to managing the Songyi colonies is to survey the location of colonies and partially control the vegetation near the existing colonies every year. This partial control may dramatically reduce labour costs for the first two years. While our analysis suggests vegetation control efforts would be cost-effective, further research on the behavior of belowground Songyi colonies after vegetation control would improve our confidence in our model.

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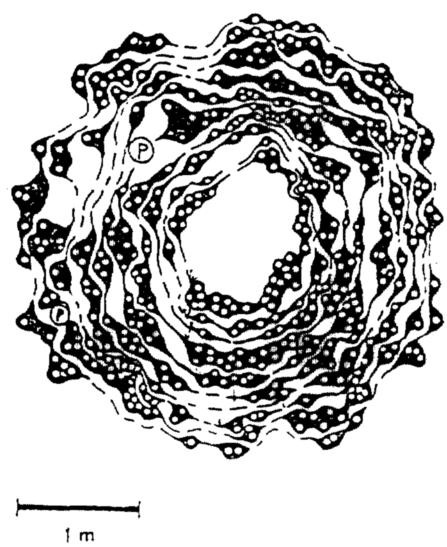

Appendix 1. Annual Songyi mushroom (*Tricholoma matsutake* (S. Ito & Imai) Sing.) colony growth recorded in Kyoto, Japan for ten years since 1970 (Kyoto Forest Research Institute, 1982). The innermost circle is the colony of 1970 and the outermost is of 1979. This figure shows that Songyi colony radially grows out 0.15m to 0.20m annually. The small open circles in each circular colony are the positions of Songyi fruiting. From this record we could calculate a 1-m-long Songyi colony produces an average of 5.8 mushrooms per year.