Jour. Korean For. Soc. Vol. 96, No. 5, pp. 520~527 (2007)

JOURNAL OF KOREAN FOREST SOCIETY

Fertilization Effects on Understory Vegetation Biomass and Structure in Four Different Plantations

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Abstract : Biomass and species diversity of understory vegetation after fertilization were studied for 28-year-old *Quercus acutissima* plantation (MQA), 29-year-old *Pinus densiflora* plantation (MPD), 8-year-old *Betula platyphylla* var. *japonica* plantation after coal reclamation (YBP), and 4-year-old *Pinus densiflora* plantation after forest fire (YPD) in central Korea. Nitrogen + phosphorus + potassium (6:4:1) fertilizer was applied for 3 years from 2004. Thereafter photosynthetically active radiation (PAR) and understory species richness and diversity were measured in late July-early August 2006. PAR (μmol m^{-2} s^{-1}) was higher at the fertilization treatment (100.9) than at the control (67.0) for MQA while was lower at the fertilization treatment (156.5) than at the control (268.7) for MPD. Total understory biomass (t ha^{-1}) was lower at the fertilization plot (1.8) than at the control plot (3.0) for YPD, however, there were no differences in biomass between fertilization and control plots for MQA, MPD and YBP. Total species number of understory vegetation was higher for fertilization than for control at MPD (47 vs. 45) and YPD (21 vs. 13), and was higher for mature plantations (33 vs. 37 for MQA and 47 vs. 45 for MPD) than for young plantations (16 vs. 16 for YBP and 21 vs. 13 for YPD). Species richness and diversity were higher at the fertilization treatment than at the control for MQA, YBP, and YPD while were lower at the fertilization treatment than at the control for MPD, however, the differences were not statistically significant. Our results indicate that there were no consistent patterns in light conditions, biomass and species richness and diversity of understory vegetation following fertilization. More detailed long-term studies with different fertilizer applications would be necessary to conclude the influence of fertilization on understory vegetation in the region.

Key words **:** Betula platyphylla *var.* japonica, *photosynthetically active radiation (PAR),* Pinus densiflora, Quercus acutissima, *species diversity, species richness*

Introduction

Even-aged plantations with a single species are widely established to maximize wood production in Korea. However, the plantation forestry is often criticized because the practice could not secure other forest values such as biological diversity and ecological functions of forests. The structure of understory vegetation would be one of biological diversities in forest ecosystems (Burton *et al.*, 1992; Seymour and Hunter, 1999). Fertilization is a common practice in commercial forests that are intensively managed for high production, and numerous studies reported increased tree growth after fertilizations (Binkley, 1986; Bowen and Nambiar, 1984; Chappell *et al.*, 1992). It has been also known that forest fertilization influenced wood quality, susceptibility to pest and pathogens, and non-target vegetation (Binkley, 1986). However, the influences of fertilization on production and diversity of understory vegetation are still conflicting in the literature (Canary *et al.*, 2000; Ceccon *et al.*, 2003; He and Barclay, 2000; Papanastasis *et al.*, 1995), and more detailed studies would be necessary with different combinations of species, age, and fertilizers. Furthermore, no research focused on the changes in light availability after fertilization even though light condition is critical for understory vegetation structure (Son *et al.*, 2004a).

Although currently forest fertilization is not a routine silvicultural practice in Korea, it is expected that more

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forest land areas would be fertilized to increase forest productivity in the near future. However, there is very limited information on production and diversity of understory vegetation following fertilization in the region (Son *et al.*, 2004a; 2004b). The objectives of the study were 1) to investigate light availability and 2) to estimate production and diversity of understory vegetation for four plantations after fertilization in central Korea.

Materials and Methods

Four study plantations from four locations were included in this study; 28-year-old *Quercus acutissima* plantation (MQA), 29-year-old *Pinus densiflora* plantation (MPD), 8-year-old *Betula platyphylla* var. *japonica* plantation after coal reclamation (YBP), and 4-year-old *Pinus densiflora* plantation after forest fire (YPD) (Table 1). Based on the previous studies of fertilization trials, different combinations of fertilizers were applied manually for the plantations in April, 2004 (Table 1), and fertilization continued for 3 years. Nitrogen was applied as urea, phosphorus as superphosphate, and potassium as potassium chloride, respectively. The study plantations did not have any sort of overstory tree harvesting or tending within the last 10 years, however, brush cutting was applied to control understory vegetation in June, 2005. In late July and early August of 2006, six 10m×10m plots for MPD and YPD, and six 20m×20m plots for MQA and YBP were installed within each plantation; three plots for fertilization and the other three plots for control. There were buffer zones with at least 5m×10m among plots.

A Decagon Sunfleck Ceptometer (Model SF-80) was used to measure understory photosynthetically active radiation (PAR, 400-700 nm, in $\mu mol\ m^{-2}\ s^{-1}$) for only MPD and MQA in late July, 2006 because of low seedling height at YBP and YPD. The ceptometer was positioned horizontally 1m aboveground level, and five readings were taken at four cardinal directions within each plot. Species and frequency of understory vegetation were investigated in three 1m×1m subplots within each plot. Subplots were evenly distributed along alternating sides of diagonal transects across each plot. After identification (Nomenclature source: Lee, 1982), all aboveground understory plant materials were clipped and collected to measure biomass. Understory vegetation was separated into trees and herbs (Nagaike, 2002), and then oven dried at 65°C until the weight is constant. To characterize vegetation structure, species richness and diversity were quantified using the number of species and Shannon's diversity index (Ludwig and Reynolds, 1988; Son *et al.*, 2004a; 2004b). Differences in PAR and biomass, species richness and diversity of understory vegetation following fertilization were analyzed using *t* test (SAS, 1988).

Results and Discussion

1. PAR

PAR was significantly different between control and fertilization treatments for both MPD and MQA ($p<0.05$), however, the influence of fertilization on PAR was different for the both plantations. PAR ($\mu mol\ m^{-2}\ s^{-1}$) was significantly higher at the fertilized plot (100.9) than at the control plot (67.0) for MQA while lower at the fertilized plot (156.5) than at the control plot (268.7) for MPD (Figure 1). Geographic differences between two plantations might influence these absolute values (Hill, 1979). Tree growth was significantly increased after fertilization both at MQA and MPD while the increase rate was relatively higher at MPD (Byun, unpublished data).

Table 1. Selected site and fertilization characteristics of the study plantations. MQA denotes 28-year-old *Quercus acutissima*, MPD denotes 29-year-old *Pinus densiflora*, YBP denotes 8-year-old *Betula platyphylla* var. *japonica*, and YPD denotes 4-year-old *Pinus densiflora*.

Plantation	Location	Elevation (m)	Major species	Age (yr)	Density (No./ha)	Fertilizer (N:P:K)
MQA	Cheongwon, Chungbuk (36°35'40"N 127°35'43"E)	252	*Quercus acutissima*	28	283	200:133:33 kg/ha
MPD	Hwacheon, Kangwon (38°01'41"N 127°47'45"E)	328	*Pinus densiflora*	29	900	200:133:33 kg/ha
YBP	Jeongsun, Kangwon (37°12'6"N 128°53'47"E)	960	*Betula platyphylla* var. *japonica*	8	1825	100:67:17 g/tree
YPD	Samchuck, Kangwon (37°17'41"N 129°14'30"E)	341	*Pinus densiflora*	4	4584	60:40:10 g/tree

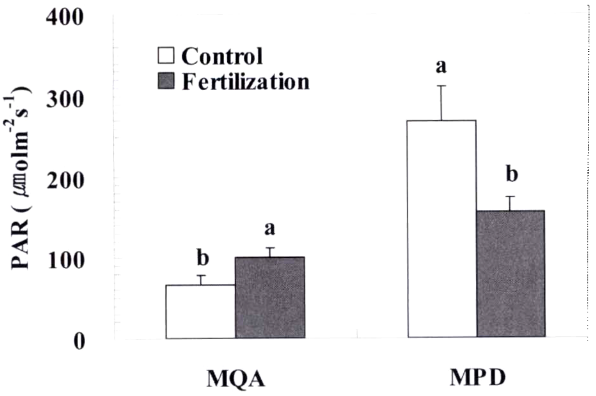

Figure 1. Photosynthetically active radiation (PAR) at 1m above ground level for 28-year-old *Quercus acutissima* (MQA) and 29-year-old *Pinus densiflora* (MPD) plantations. Vertical bars represent standard errors. Different letters indicate significant difference between treatments (p<0.05).

It appeared that the increased tree growth resulted in high foliage area and then increased light interception for MPD. However, the reason for higher PAR at the fertilized plots for MQA was not clear. Differences in microenvironment including aspect and topography among plots might influence the measurements in this study. Although previous studies indicated light conditions influenced understory production (Harrington and Edwards, 1999; Martinez Pastur *et al.*, 2002), there were no relationships between light availability and understory biomass in this study; the relationship between PAR and understory biomass for MQA and MPD was not statistically significant (p>0.05).

2. Biomass

Total understory biomass for control and fertilization treatments (t ha^{-1}) was 0.8 and 1.2 at MQA, 1.4 and 1.3 at MPD, 0.9 and 1.0 at YBP, and 3.2 and 1.8 at YPD, respectively (Figure 2). Fertilization significantly decreased total aboveground biomass for YPD, however, there were no changes in biomass of understory vegetation following fertilization for MQA, MPD and YBP. The influence of fertilization on understory biomass seemed to be inconsistent in the literature; for example, Papanastasis *et al.* (1995) reported two to six-fold biomass increases in understory vegetation after NPK fertilization in *Pinus pinaster* plantations and Goodman and Hungate (2006) showed doubled understory biomass after nitrogen fertilization in a spruce forest while Canary *et el.* (2000) and He and Barclay (2000) reported no changes in understory biomass after relatively long-term fertilization treatments (16 years after urea fertilization and 27 years after nitrogen fertilization). The proportion of trees to total biomass ranged from 9.8% to 77.0% for control and from 17.7% to 69.0% for fertilization. *Festuca arundinacea* was planted to prevent soil erosion after planting *Betula platyphylla* var. *japonica* in 2000, and the species grew very fast. Consequently, relatively few species invaded the site and herbs (mainly *Festuca arundinacea* and *Dactylis glomerata*) occupied more than 80% of the total understory biomass at YBP.

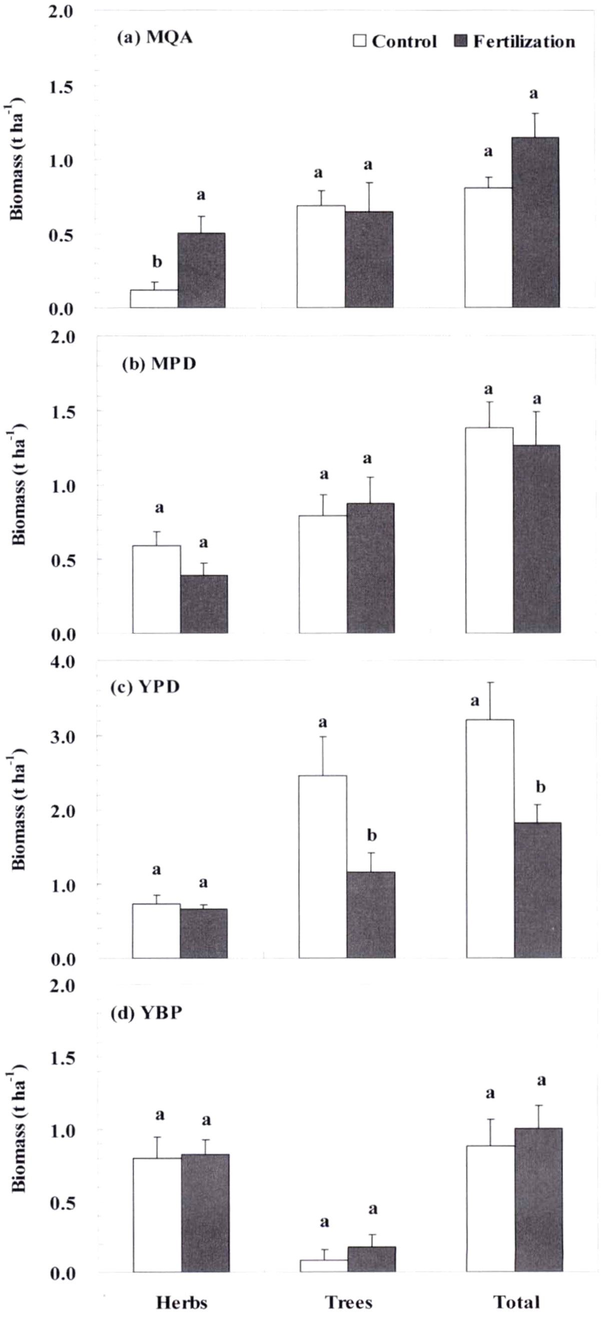

Figure 2. Understory aboveground biomass for 28-year-old *Quercus acutissima* (MQA), 29-year-old *Pinus densiflora* (MPD), 8-year-old *Betula platyphylla* var. *japonica* (YBP), and 4-year-old *Pinus densiflora* (YPD) plantations. Vertical bars represent standard errors. Different letters indicate significant difference between treatments (p<0.05).

3. Species richness and diversity

In general, total species number of understory vegeta-

Table 2. Understory plant species recorded in the four study plantations.

Species	MQA†		MPD		YBP		YPD	
	C*	F*	C	F	C	F	C	F
Trees								
Pinus densiflora			●					
Smilax china								●
Smilax sieboldii	●	●						
Quercus variabilis							●	
Quercus mongolica	●	●	●	●			●	●
Clematis mandshurica	●			●				
Clematis apiifolia	●	●						
Akebia quinata	●	●						
Lindera obtusiloba	●			●				
Sorbaria sorbifolia var. *stellipila*						●		
Spiraea prunifolia var. *simpliciflora*	●							
Stephanandra incisa			●	●				
Rubus crataegifolius			●	●	●	●		
Rubus parvifolius				●				
Rosa multiflora	●							
Prunus sargentii		●						
Lespedeza cyrtobotrya				●			●	●
Lespedeza bicolor		●		●	●	●		●
Pueraria thunbergiana	●							
Securinega suffruticosa	●		●	●				
Rhus chinensis				●				
Rhus trichocarpa				●				
Euonymus alatus for. *ciliato-dentatus*	●	●	●	●				
Euonymus alatus	●							
Tripterygium regelii				●				
Staphylea bumalda	●	●						
Acer ginnala		●						
Vitis amurensis var. *coignetiae*	●	●						
Parthenocissus tricuspidata	●	●						
Actinidia arguta	●			●				
Rhododendron mucronulatum			●				●	
Rhododendron yedoens var. *poukhanense*							●	●
Rhododendron schlippenbachii			●	●				
Symplocos chinensis for. *pilosa*			●	●				
Styrax obassia			●	●				
Ligustrum obtusifolium	●	●						
Callicarpa japonica	●	●		●				
Paederia scandens	●							
Sambucus williamsii var. *coreana*								●
Lonicera japonica		●						
Herbs								
Osmunda japonica			●					
Sphenomeris chusana			●					
Pteridium aquilinum var. *latiusculum*			●	●			●	●
Matteuccia orientalis			●					
Athyrium yokoscense			●	●				

tion was higher for fertilization than for control except for MQA, and was higher for mature plantations than for young plantations (Table 2); total species numbers for fertilization and control plots were 33 (19 for herbs (H)

Table 2. Continued.

Species	MQA[†]		MPD		YBP		YPD	
	C*	F*	C	F	C	F	C	F
Athyrium niponicum		●	●					
Dactylis glomerata					●	●		
Festuca arundinacea					●	●		
Oplismenus undulatifolius	●	●						
Miscanthus sinensis			●	●			●	●
Spodiopogon sibiricus	●	●	●	●				
Humulus japonicus		●						
Pilea peploides		●						
Asarum sieboldii				●				
Persicaria perfoliata		●						
Pseudostellaria heterophylla	●							
Cerastium holosteoides var. *hallaisanense*					●			
Thalictrum filamentosum				●				
Actaea asiatica				●	●			
Corydalis turtschaninovii							●	●
Duchesnea chrysantha		●						
Fragaria nipponica							●	●
Potentilla fragarioides var. *major*	●	●	●	●				
Sanguisorba officinalis						●		
Agrimonia pilosa	●							
Vicia angustifolia					●	●		
Amphicarpaea edgeworthii var. *trisperma*	●	●			●	●		
Impatiens textori	●	●						
Trifolium repens					●			
Geranium thunbergii					●	●		
Viola variegata				●				
Viola phalacrocarpa			●	●				
Viola rossii	●		●					
Viola albida			●					
Viola hirtipes				●				
Viola verecunda	●				●			
Pimpinella brachycarpa				●				
Lysimachia clethroides	●	●	●	●				●
Scutellaria insignis	●							
Salvia chanroenica			●	●				
Mosla punctulata	●	●						
Isodon inflexus		●		●				
Clinopodium chinense var. *parviflorum*						●		
Melampyrum roseum			●					
Plantago asiatica					●	●		
Rubia akane	●	●						
Asperula odorata	●							
Patrinia scabiosaefolia								●
Patrinia villosa								●
Valeriana fauriei								●
Codonopsis lanceolata	●	●						
Atractylodes japonica			●	●			●	●
Ainsliaea acerifolia			●					

Table 2. Continued.

Species	MQA†		MPD		YBP		YPD	
	C*	F*	C	F	C	F	C	F
Aster scaber			●				●	●
Erigeron annuus				●	●	●		
Petasites japonicus		●	●					
Petasites saxatilis			●					
Syneilesis palmata			●	●				
Artemisia japonica					●	●		
Artemisia feddei							●	●
Artemisia stolonifera	●		●	●	●	●		
Artemisia princeps var. *orientalis*	●			●	●	●		
Saussurea pulchella								
Taraxacum officinale						●		
Lactuca indica var. *laciniata*		●			●			
Youngia denticulata								●
Carex humilis	●	●	●	●			●	●
Carex lanceolata			●					
Carex siderosticta			●	●				
Commelina communis		●	●					●
Convallaria keiskei				●				
Disporum sessile				●				
Disporum smilacinum			●	●				
Polygonatum odoratum var. *pluriflorum*			●	●				
Smilax riparia var. *ussuriensis*			●	●				
Veratrum maackii var. *parviflorum*			●					
Hemerocallis fulva			●	●				●
Lilium distichum			●					
Dioscorea batatas			●	●				
Dioscorea quinqueloba				●				

* C denotes control and F denotes fertilization.
† MQA denotes 28-year-old *Quercus acutissima*, MPD denotes 29-year-old *Pinus densiflora*, YBP denotes 8-year-old *Betula platyphylla* var. *japonica*, and YPD denotes 4-year-old *Pinus densiflora.*

and 14 for trees (T)) and 37 (18 for H and 19 for T) for MQA, 47 (29 for H and 18 for T) and 45 (35 for H and 10 for T) for MPD, 16 (13 for H and 3 for T) and 16 (14 for H and 2 for T) for YBP, and 21 (15 for H and 6 for T) and 13 (8 for H and 5 for T) for YPD, respectively. Twenty species (10 for H and 10 for T) at MQA, 27 species (19 for H and 8 for T) at MPD, 12 species (10 for H and 2 for T) at YBP, and 11 species (8 for H and 3 for T) at YPD were found on both treatments within each plantation. Except for *Pinus densiflora* at MPD, all of the understory trees were hardwood species, and most of them were shrubs or vines. *Lespedeza bicolor* was found at all fertilization treatment and control plots for four plantations. Proportion of trees to total species number were higher for mature plantations (22-51%) than for young plantations (13-38%). In general, *Festuca arundinacea* shows rapid growth and the species was the dominant understory species at YBP while *Dactylis glomerata* was the next dominant understory species by ground coverage. Son *et al.* (2004a; 2004b) reported that shade tolerant understory species were dominant under improved light conditions after thinning in a *Larix leptolepis* plantation. However, there were no apparent patterns in species characteristics such as life forms or shade tolerance among plantations and between treatments in this study.

Species richness ranged from 4.8 at the control plot for YPD to 14.6 at the control plot for MPD and species diversity ranged from 1.19 at the control plot for YPD to 2.15 at the control plot for MPD (Table 3). These values were lower than 5.0-7.4 and 15.4-23.9 of species richness and 1.33-1.70 and 2.33-2.75 of species diversity reported for a *Larix leptolepis* plantation in Yangpyeong (Son *et al.*, 2004a; 2004b). Overall there were no significant changes in understory species richness and diversity between fertilization treatment and control plots, only species richness of herbs was higher at the control plot (10.6) than at the fertilization treatment plot (7.0)

Table 3. Understory species richness and diversity for the four study plantations. Values in parentheses are standard errors. Means followed by the different letters indicate significant differences between fertilization and control. MQA denotes 28-year-old *Quercus acutissima*, MPD denotes 29-year-old *Pinus densiflora*, YBP denotes 8-year-old *Betula platyphylla* var. *japonica*, and YPD denotes 4-year-old *Pinus densiflora*.

Plantation	Treatment	Species richness			Species diversity*
		Trees	Herbs	Total	H'
MQA	Control	5.0(2.8)	3.4(2.7)	8.4(5.3)	1.24(0.90)
	Fertilization	4.4(2.6)	5.7(2.4)	10.1(4.5)	1.74(0.47)
MPD	Control	4.0(1.1)	10.6(2.7)a	14.6(3.4)	2.15(0.23)
	Fertilization	4.4(2.2)	7.0(3.9)b	11.4(4.4)	1.84(0.55)
YBP	Control	0.4(0.7)	4.6(1.7)	5.0(1.9)	1.14(0.43)
	Fertilization	1.0(0.5)	4.8(1.0)	5.8(1.0)	1.20(0.26)
YPD	Control	1.7(1.0)	3.1(0.9)b	4.8(1.9)	1.19(0.33)
	Fertilization	2.1(0.9)	4.2(2.4)a	6.3(2.3)	1.34(0.39)

*Based on the equation of Ludwig and Reynolds (1988)

$$H' = -\sum_{i=1}^{S}\left[\left(\frac{ni}{n}\right)\ln\left(\frac{ni}{n}\right)\right]$$

where S is the number of species observed in the sample, ni is the number of individuals belonging to the ith of S species in the sample, and n is the total number of individuals in the sample.

for MPD (Table 3). Except of MPD, species richness and diversity were slightly higher at the fertilization plots than at the control plots, however, the differences were not statistically significant. Some previous studies predicted species richness would decrease after fertilization because fertilization would promote dominance of a few abundant species (Prescott *et al.*, 1993; Thomas *et al.*, 1999), while He and Barclay (2000) reported that after 27 years fertilization showed no significant effects on understory species richness. It is possible that the effect of fertilization on understory might be different at different growing stages (He and Barclay, 2000). Based on our short-term observations the influence of fertilization on species richness and diversity might be marginal at the early stage. In general, species richness was higher for herbs than for trees.

Conclusion

Our study indicated that there were no consistent patterns in light conditions, biomass and species richness and diversity of understory vegetation following fertilization. However, these results were obtained from relatively short-term measurements after fertilization, and there might be a lag between environmental changes after silvicultural treatment and light conditions and understory vegetation (Hill, 1979; Thomas *et al.*, 1999). Also there is a possibility that non-resource-based mechanisms such as physical disturbance and toxicity effects and differences in species-specific edaphic requirements would influence the relationship between fertilization and understory vegetation (Ceccon *et al.*, 2003; Thomas *et al.*, 1999; Vanderschaaf *et al.*, 2004). Therefore, more long-term studies including different fertilization treatments would be necessary to find changes in understory vegetation structure and production after fertilization.

Acknowledgements

This study was supported by the Korea Forest Research Institute and A3 Foresight Program of KOSEF.

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(Received April 23, 2007, Accepted May 18, 2007)