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INFLUENCES OF SPECIES MIXTURE ON BIOMASS OF NORWAY SPRUCE (*Picea abies* (L.) Karst.) FORESTS IN THE DUSSELDORF DISTRICT IN GERMANY

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ABSTRACT

Norway spruce (*Picea abies* (L.) Karst.) is an important tree species for forest plantation in Germany. The planting tree has a very large area especially in Düsseldorf province. And pattern of growing is mixture of with Norway spruce and other tree species. The effect of tree diversity on productivity is poorly understood in subtropical forests in Germany. We investigated the biomass of tree, understory vegetation, coarse roots and fine roots with varying proportions of Norway spruce mixed other tree species at the stands in the same age. With an increase proportion of Norway spruce, biomass of tree and understory biomass increased at first, and then gradually decreased. As expected, biomass of fine roots decreased with soil depth. Stands with 40-60% of Norway spruce had the highest biomass, while stands with <20% of Norway spruce had the least biomass. Stands with <20% Norway spruce had the least understory biomass, while those with 20-40% Masson pine had the least fine root biomass.

Keywords：Norway spruce, mixed forest, biomass, arboreal stratum, undergrowth.

1.INTRODUCTION

According to economists and other observes of the energy scene, there is an impending shortage in the civilized world of petroleum and gas. Exhaustion of these nonrenewable fuels prompts consideration of alternative energy sources. One alternative source is forest biomass, which is defined as the quantity constituted by living organisms in the forest ecosystem in terms of mass. The aboveground portions of trees and shrubs transform solar energy in the form of vegetational substances. Because the forest is a renewable natural resource, plantations of trees and natural stands that were previously considered unmerchantable are now being examined as a new source of renewable energy. To help overcome a possible future energy shortage, methods of correctly managing and using forest biomass resources have to be developed now. The need for knowledge of the existing amount of standing timber and its growth in terms of mass, as measured and expressed by consistent methods and standards, is a part of this broad problem. The solution can be approached by producing biomass tables for tree species (Saraçoğlu, 2011).

The estimation of stem volume and tree biomass is needed for both sustainable planning of forest resources and for studies on the energy and nutrients flows in ecosystems. Planners at the strategic and operational levels have strongly emphasized the need for accurate estimates of stem volume, while Hall (1997) reviewed the potential role of biomass as an energy source in the 21st century. In addition, the United Nations Framework Convention on Climate Change and in particular the Kyoto Protocol recognize the importance of forest carbon sink and the need to monitor, preserve and enhance terrestrial carbon stocks, since changes in the forest carbon stock influence the atmospheric CO_2concentration. Terrestrial biotic carbon stocks and stock changes are difficult to assess and most current estimates are subject to considerable uncertainty (Zianis et al., 2005). The reliability of the current estimates of the forest carbon stock and the understanding of ecosystem carbon dynamics can be improved by applying existing knowledge on the allometry of trees that is available in the form of biomass and volume equations (Zianis et al., 2005). The biomass equations can be applied directly to tree level inventory data

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(the measured dimensions of trees; diameter, height), or biomass expansion factors (BEFs) applicable to stand level inventory data can be developed and tested with the help of representative volume and biomass equations (Jenkins et al. 2003, Zianis et al., 2005). On the other hand, the biological diversity has been significantly affected on production of biomass. The diversity productivity relationship has received considerable attention during the past two decades，largely because a long term pure stand production system is not sustainable due to soil fertility and productivity decline（Hoop *et al*. 2005）. Numerous empirical experiments have showed that diversity have positive relationships with productivity, also defined as biodiversity effect, i.e., polycultures have higher biomass production than the average production of monocultures (Loreau *et al.* 2001; Cardinale *et al.*2007; Isbell *et al.*2009). Polycultures have the advantages of species complementation, improved ecosystem and higher productivity. Rich experiences have demonstrated that a good mixed plantation can improve environmental conditions, increase the stability of forest and maintain high productivity. Because of that the presence of one species benefits the other by improving growing conditions, or niche differentiation, i.e. Coexisting species occupy different ecological niches that results in more complete resource use (Spehn *et al.* 2005; Marquard *et al.*2009). The niche complementarity hypothesis explained that biodiversity effect is due to increased resource use and nutrient retention via niche differentiation or partitioning and interspecific facilitation (Tilman 1999; Loreau *et al.* 2001; Hooper *et al.* 2005) has been the cornerstone of diversity productivity relationship studies. However, it is rare in influences of species mixture on biomass studies to directly demonstrate the link between the mixed ratio effect in biomass and productivity.

These evidences above can be used for planning to fill the blanks inside the forest by target species so that tree productivity would be maintained. This will also help in maintaining the tree composition of the forest during the stand development (Pande 2005). Studies have shown that understory vegetation refers to all plants, including shrubs, herbes and liane, growing under the canopy in forest. It is an important component of forest ecosystem, plays an important role in improving soil, preventing water and soil loss, maintaining diversity and material recycling in a forest ecosystem. Understory vegetation is also an important component of forest carbon mass. Fine root biomass is closely related to the species and ages of trees in a stand. A mixed plantation generally has a higher standing biomass than a pure plantation. The biomass of fine roots (<2-5 mm in diameter) varies between 46 and 2805 $g \cdot m^{-2}$. The fine root biomass in a forest ecosystem depends on tress species, weather, site type, soil, community structure and tree age. Fine roots are the important dynamic component of nutritional pool. They play an essential role in energy flow and material cycling in forest ecosystem (Usman *et al.* 2000). In many stands, over 50% of the primary production is used in fine root maintenance and production (Grier *et al.*1981; Jackson *et al.*1997). Through the circulation and fine root, soil carbon and nutrient return may be equal to or greater than the above ground litter (Pregitzer *et al.* 1993; Arthur *et al* 1992). If the production of root biomass, especially the fine root biomass is neglected, the organic and nutrient turnover will be under estimated by 20% (Vogt 1986). Therefore, fine root is an important "currency" in forest primary production (Hendrick *et al.* 1993; Gill *et al.* 2000), and the key to the study of biomass in forest ecosystem.

The current study analyzed biomasses of different layers in mixed stands with Norway spruce comprising <20%, 20%-40%, 40%-60%, 60%-80%, >80%. The purpose of this study is to identify the optimal proportion of Masson pine in mixed stands in which maximal biomass can be obtained. This information is necessary for the establishment of commercial management of Masson pine carbon currency stands.

2. MATERIALS AND METHODS

2.1. Study area

Studying sites were located in southeast edge of Röttgenweg Forests-Düsseldorf (51°23′05″ N，6°32′20″ W), close to Düsseldorf district (Figure 1).

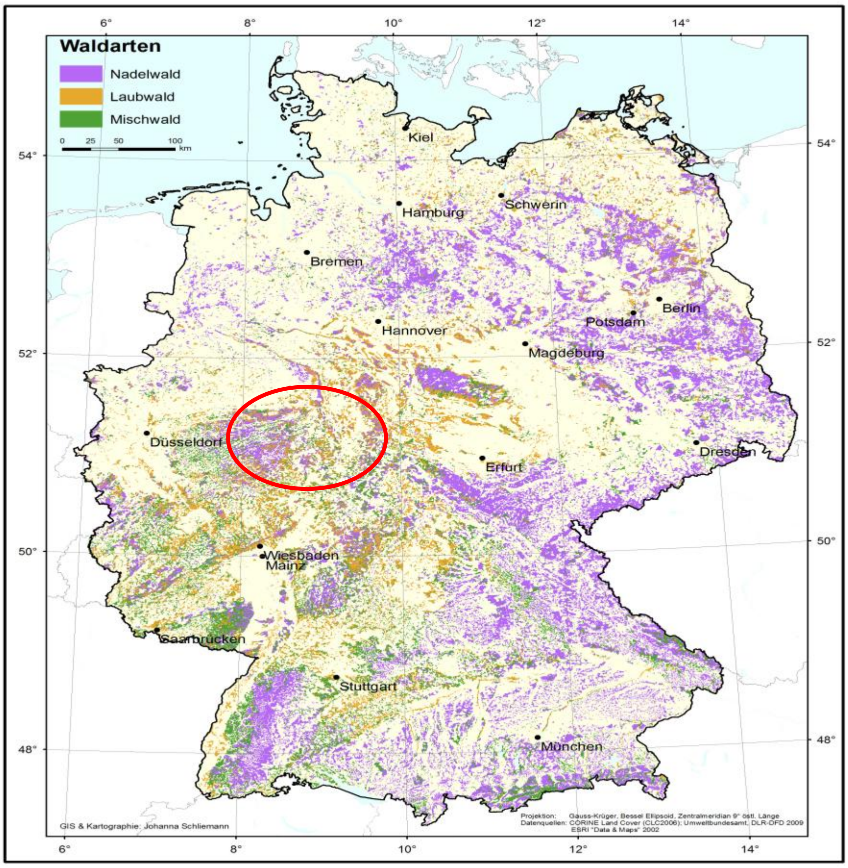

Figure 1. Research area

The mean annual temperature is 16.5 ºC and the mean annual precipitation is 582.5 mm. The rock base was mainly granite gneiss, and the soil was granite yellow brown soil, with a pH of 5.5-6.5. The barren soil has a weak capacity to hold water. In order to ensure that tree species diversity is the only factor influencing productivity, stands were allocated to be similar in growth and ecological factors but differ in the proportion of Norway spruce in this study. The general information of the plots was shown in Table 1 and Figure 2.

Figure 2. Mixed Norway spruce forest in the Röttgenweg in Düsseldorf.

Table.1 Characteristics of the sampling stands in different forest mixed ratio

Sample Plots	Mixed ratio* (%)	Altitude (m)	Slope	Slope position	Density (tree·ha^{-1})		Mean height (m)		Mean trunk diameter (cm)	
					Picea abies	Broad-leaved tree	*Picea abies*	Bbroad-leaved tree	*Picea abies*	Broad-leaved tree
1	<20	163	south	upside	150	450	8.3	7.6	15.9	15.2
2	<20	70	south	middle	75	775	7.0	7.3	17.5	15.1
3	<20	161	east	underside	175	700	5.9	7.7	11.9	16.4
4	20-40	62	north	middle	450	550	8.3	8.3	13.4	16.5
5	20-40	90	west	underside	375	775	9.0	7.5	14.1	14.0
6	20-40	162	south	middle	225	575	8.6	7.1	17.4	14.7
7	40-60	217	south	upside	275	175	8.7	8.3	15.7	17.8
8	40-60	102	south	middle	200	500	9.3	9.1	19.7	15.5
9	40-60	170	south	upside	425	400	8.5	7.3	16.3	16.0
10	60-80	96	east	underside	625	325	8.0	6.9	14.4	11.4
11	60-80	68	south	underside	600	350	9.8	7.1	13.9	12.7
12	60-80	156	south	middle	950	150	6.6	7.0	11.7	16.7
13	>80	217	south	upside	700	125	9.1	5.8	15.6	13.8
14	>80	157	south	middle	1425	100	8.7	5.7	13.9	10.4
15	>80	80	south	underside	1175	50	7.1	7.3	13.2	16.0

***Note: The actual percentages of Norway spruce were 15.2%、32.8%、48.5%、84.3%、95.7% in these stands.**

The vegetation was a mix of subatlantic and subcontinental deciduous to coniferous forest, mainly comprised of pure Norway spruce, scattered with broadleaf, *Fagus sylvatica* L.. There were few tree species, commonly seen were *Platanus orientalis*, *Fraxinus angustifolia*, *Ulmus glabra*, *Sorbus torminalis*, *Quercus petreae*, *Festuca arundinacea* and *Taraxacum officinale*. The stands selected had not been planted, irrigated, and disturbed for more than 30 years. Broadleaf species invasion occurred naturally.

2.2.Sampling Design

Away from the forest edge, fifteen plots with five different mixed levels of Norway spruce in mixed forest were selected for analyzing effect of mixed ratio on production of biomass. Except for mixed ratio, woodland habitat factors of these plots (including altitude, aspect, slope, slope position, soil properties, light, heat, and moisture, *etc.*) are basically same and stand age changed little. Values of mixed ratio of Norway spruce in 15 forest plots were measured based on survey in three 20m×20m standard areas of each plots, and it was classified into five levels, namely 20%, 21%-40%, 41%-60%, 61%-80% and >81%. Five levels were also briefly marked as I, II, III, IV, and V for convenience. Actual average value of each level was 15.2%, 32.8%, 48.5%, 84.3% and 95.7%, respectively.

2.3.Data collection

From end of July and early August in 2012, in each selected mixed stand, one 0.04ha circular sample plot was established for investigating biomass and understory vegetation, understory plant diversity. To estimate the biomass in each sample plot, the following features were measured and examined in each plot.

2.4.Aboveground arboreal biomass

DBH (diameter at breast height) and tree height of individual tree in three 20m×20m standard areas of each plot were measured, and then standard tree of each plot was chosen based on information collecting from average value of DBH and tree height of whole plot. Three standard trees were cut down and divided into sections of 1 m and weighed fresh to obtain weights of truck, limbs, branches, leaves and barks, separately. Then samples were taken to a laboratory, dried at 70°C to a constant mass to determined oven-dried biomass and weighed to the nearest 0.01g. Water content and dry weight were calculated accordingly. Finally, biomass was calculated using average sample tree method.

2.5.Aboveground biomass of understory vegetation

In each sample plot, five 2×2 m subplots were randomly allocated to determine understory vegetation biomass. The aboveground biomass of all shrubs and herbs was clipped from each of the five randomly located 4 m^2 subplots. Understory vegetation within the plots were investigated. The shrubs were separated from the herbs, and each group was weighed fresh. These samples were then oven-dried at 70°C to a constant mass to determined oven-dried biomass and weighed to the nearest 0.01g.

$$\mathbf{Wu = \sum Wui / (A \times N) \times 10000}$$

Where;
Wu; the biomass per hectare;
∑Wui; the cumulative sum of biomass
A; the area of quadrats;
N; the number of quadrats.

2.6.Fine root biomass

Form June 2012 to September 2012, In each sample area, twenty points were randomly selected along an S line. At each point, soil samples were collected from three layers (0-10cm, 10-20cm, 20-30cm) using a soil drill of 6.8 mm inner diameter. A total of 270 samples were collected from 15 sample stands. Soil samples were numbered, put in plastic bags and taken to a laboratory. Then, they were soaked in water, washed over 0.5 mm in diameter soil screen set with flowing water. Cleaned roots were stored in bags, dried at 70°C to scale. Fine roots (<2 mm in diameter) were sorted.

2.7.Statistical analysis

To observe the relationships in biomass throughout stand development the field data for aboveground tree, understory and fine root biomass, Total biomass of the mixed forest was calculated for each sample site by summing together each of the samples for that site. Mean biomass was calculated for each of the mixed forest biomass for each developmental stage, allowing observation of how biomass varied between each of the stand development. T-test was used to test fine root biomass. We used the following models to represent;

Understory vegetation biomass:

$$\mathbf{Wu = \sum Wui / (A \times N) \times 10^4}$$

Where;
Wu; the biomass per hectare
∑Wui; the cumulative sum of biomass
A; the area of quadrats
N; the number of quadrats.

Fine root standing biomass estimates as follows:

R（thm^{-2}) = Average weight of soil core fine root × 10^2 / [$\pi\cdot(D/2)^2$]

Where;
R; fine root reserves
A; the average weight of soil core fine root
D; the diameter of soil drill.

3.RESULTS

3.1.Above ground tree biomass

The above ground tree biomass constitutes the largest portion of total biomass in these stands. Among stands, when the proportion of Masson pine gradually increased from <20% to >80%, the above ground biomass displayed an increase-decrease trend as shown in Table 2.

Table 2. The total aboveground biomass in Norway spruce mixed forest

Mixed ratio （%）	Tree layer biomass （t·ha）	Understory biomass (t·ha）	Above ground biomass (t·ha)
0-20%	216.663	1.39	218.053
21-40%	273.946	1.47	275.416
41-60%	281.583	1.52	283.103
61-80%	246.485	1.19	247.675
81-100%	232.657	1.13	233.787

The order of above ground biomass was III>II>IV>V>I. The difference between stands III and stand I were very significant (*P<0.01*). The above ground arboreal biomass in stand III was 281 t ha^{-1}, while it was 217 t ha^{-1}in stand I.

3.2.Understory biomasses

Understory biomasses differed with changes in the proportion of Norway spruce (Table 2). The order of shrub biomasses was III>II>I>V>IV. Among these, the difference between stand III and stand IV was significant (*P<0.01*). The lowest was 0.98 t.hm^{-2}, the highest was 1.36 t·hm^{-2}. The difference between them was 0.38 t·hm^{-2}. The order of biomass in herb layer was IV>III>II>V>I. Among these, the herb biomasses were 0.21 and 0.07 t·hm^{-2}, respectively, in stands IV and stand I. The former was 3 times more than the latter. The difference between these two proportions was very significant (*P<0.01*). Stand III had the largest arboreal biomass but not the largest herb biomass. Stand I had the least herb biomass but relatively large arboreal biomass. These indicate that arbores influence the availability of light to herbs, thus influence the development of herb layer.

3.3.Above ground total biomass

Above ground total biomasses was increasing in the order of stand type III>II>IV>V>I (Table 2). The difference between stands, III and I was significant (*P<0.01*). The above ground total biomasses were 283.103 and 218.053 t·hm^{-2} in stand III and I, respectively. The difference between them was 65.05 t·hm^{-2}. Arboreal biomass is the major part of all above ground strata. The differences in the understory biomass among different stands were small. The arboreal and understory biomasses in III stand were the largest. Therefore, the above ground biomass of III stand was also the largest.

3.4.Fine root biomasses

Fine root biomasses displayed a trend decline as the depth of soil increased (Figure 3).

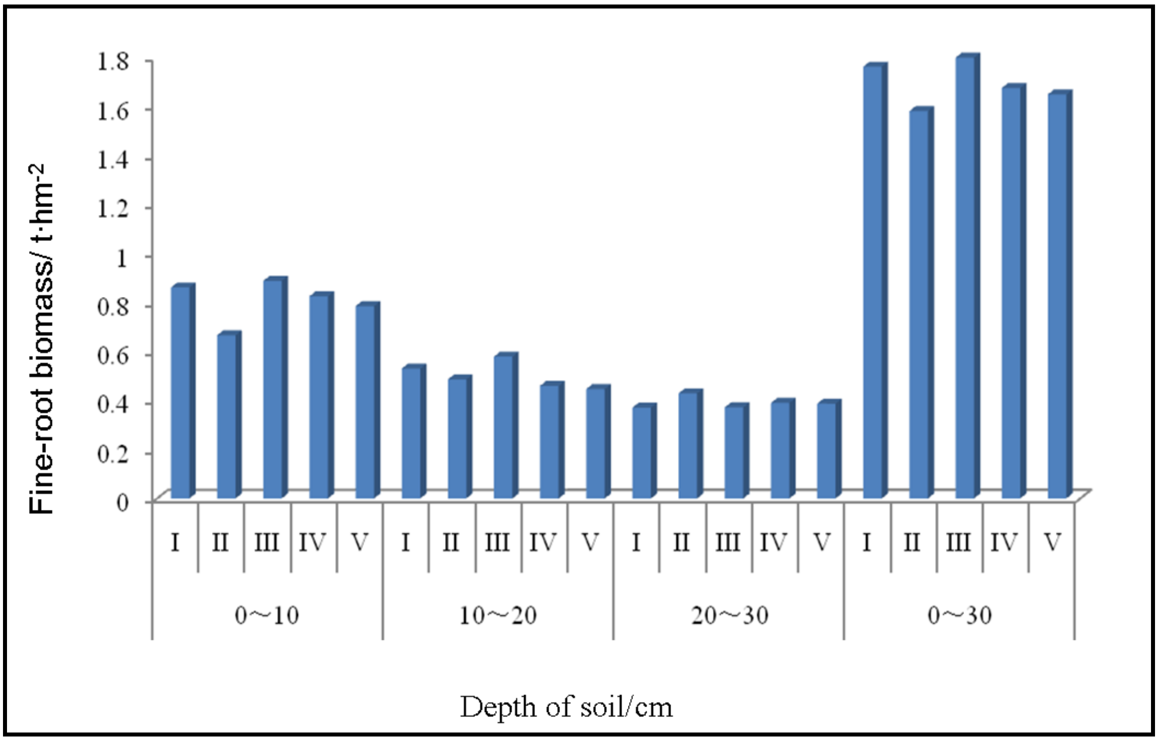

Figure 3. Fine-root biomass distribution in 0~30cm soil layer of mixed forest

The majority of fine root biomass was within the 0-10 cm layer. Within 30 cm depth, the highest fine root biomass was found in the top 10 cm of soil, being 49.4%. In stand III, soil strata 0-10cm and 10-20cm had the largest fine root biomass. In II stands, the 20-30cm soil stratum had the largest fine root biomass. The difference between III and II was very significant (*P<0.01*). Compared among stands, the fine root biomass was the largest in III, may reach 1.799 t·hm^{-2}, while it was the least in II, being only 1.581 t·hm^{-2}. The order of fine root biomass was III>I>IV>V>II. In each stand type, fine root biomass in the 0-10cm soil stratum was significantly different from that in the other two strata. In stand III, fine root biomass within 10-20cm soil stratum had a significant difference. Fine root biomasses in stand II within the 20-30cm soil layer were significantly different. The total fine root biomasses were significantly different between stands III and II. By T-test tested the independent samples,we found that III stands with I,II,III and V were very significant differences within the 0-10cm layer (Table 3).

Table 3. Fine-root biomass paired-sample T test in different soil layer of mixed-forest

Mixed Ratio		0-20%	21-40%	41-60%	61-80%
1~10cm soil layer	0-20%				
	21-40%	–1.507(0.150)			
	41-60%	2.334(0.032)	3.498(0.003)		
	61-80%	–3.740(0.002)	–3.273(0.004)	4.108(0.001)	
	81-100%	–1.403(0.179)	–2.057(0.050)	3.462(0.003)	3.345(0.004)
10~20cm soil layer	0-20%				
	21-40%	–0.102(0.920)			
	41-60%	1.261(0.224)	2.119(0.049)		
	61-80%	–2.779(0.013)	–2.878(0.010)	2.456(0.025)	
	81-100%	0.058(0.954)	0.230(0.821)	2.252(0.038)	3.345(0.004)
20~30cm soil layer	0-20%				
	21-40%	–0.610(0.551)			
	41-60%	0.939(0.361)	3.115(0.006)		
	61-80%	0.442(0.678)	0.332(0.774)	2.267(0.037)	
	81-100%	–0.551(0.589)	–0.159(0.876)	2.509(0.023)	–0.421(0.037)

Note: Table in brackets indicates the p-value

In stand III, the results of T-test were very significant different with other stands, within the 10-20cm layer (Table 3). In the 20-30cm layer, III. stands with I,II,III and V were very significant differences (Table 3).

4.DISCUSSION

Stands with 45.6% Norway spruce had the largest above ground tree, understory and fine root biomass. Such a mix level positively influences the growth of stands. It can be seen that the level of mix is an important influential factor upon biomass. Among the five Norway spruce stands, the order of above ground arboreal biomasses was (according to proportion) III>II>IV>V>I. In this context, similar results were found a research was made on oriental beech (*Fagus orientalis* Lipsky.) (Saraçoğlu, 1998). Among these, the above ground arboreal biomass in stands with 45.6%. Norway spruce was the largest, while that in stands with 92.3%. This value is 87.4% of European alder (*Alnus glutinosa* L.) stands (Saraçoğlu, 1991). Understory biomass was largely comprised of the shrub stratum. Although herbs occupied surface area and were abundant, their biomass was the smallest portion. As the proportion of Norway spruce increased, understory biomass first increased and then decreased (the maximal shrub biomass was 1.36 $t{\cdot}hm^{-2}$ seen in stands with 45.6% Norway spruce). The fine roots of Norway spruce and broadleaved trees were mainly found in the 0-10cm soil layer. The deeper into the soil, the less the fine roots were. The largest fine root biomass was seen in stands with 45.6% Norway spruce, while the least fine root biomass was seen in stands with 35.6% Norway spruce. The differences between the two stands were significant.

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