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ALLOCATION OF ELEMENTS IN A CHRONOSEQUENCE OF SILVER BIRCH AFFORESTED ON FORMER AGRICULTURAL LANDS

Research on the effect of birch regeneration on changes occurring in the environment on former farmlands included a quantitative and qualitative analysis of the biomass growing on the research plots. Five experimental plots were selected in the Mazovia region: two in Dobieszyn and the Kampinos National Park and one in Kozienice. The analysis performed on each plot was concerned with the amount and chemical composition of biomass in four patches of vegetation, characterised by the different ages of the birch trees growing there. The vegetation patches were classified according to age group, i.e. I: 1–4 years old, II: 5–8 years old, III: 9–12 years old and IV: over 12 years old. Biomass samples were collected in the field and determined in kg DM/ha using the following components: roots, stem, bark, branches, assimilation apparatus, litterfall and the total biomass of the other (except birch) plants. For all the above-mentioned groups, the content of the elements N, C, S, Ca, K, Mg, Na, P, Mn, Cu, Fe, Zn, Pb, and Cd was determined. This allowed us to obtain both the values of the concentrations of particular substances and their allocation in both the organic matter and litterfall. The aim of the research was to discover whether the allocation of elements changes with the age of birch growing on former farmland.

Keywords: secondary succession, post-agricultural lands, silver birch, allocation of elements, chronosequence

Introduction

Silver birch (*Betula pendula* Roth.) is widely distributed in Eurasia, and it is one of the most abundant broad-leaved tree species in northern Europe [Hynynen et al.

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2010]. In Baltic and Nordic countries, the proportion of birch in the total volume of forest growing stock varies between 11% and 28% [Uri et al. 2012]. Silver birch is also an important tree species in Poland, where it occupies ca. 7.5% of the total area of forest [GUS 2011].

At the end of the 20th century in many countries of Central and Eastern Europe, a shift in land use was observed caused by economic changes. Large areas of post-agricultural lands have since been spontaneously and naturally afforested by fast-growing pioneer species, including silver birch [Karlsson et al. 1998]. Quantifying the amount and allocation of various elements is important for an understanding of the potential impact of newly-established forest ecosystems.

A review of literature on the element allocation of silver birch reveals that the replacement of field with forest brings about various changes in the species composition and biomass of the vegetation, as well as in soil properties. An estimation of the biomass and nutrient accumulation in relation to the foliar and root parameters is essential for understanding the structure and functioning of a new forest ecosystem formed on abandoned agricultural land. Such knowledge will provide an estimate of the resources and potential of young birch stands and their impact on the environment, e.g. on soil development, nutrient cycling and carbon sequestration [Uri et al. 2007]. These studies are the first ever in Poland to describe the allocation of elements on former farmland that has been afforested with birch of varying ages.

Previous studies focus mainly on the quantification of aboveground biomass of birch [Mälkönen 1977; Johansson 1999; Claesson et al. 2001]. In recent years, the scope of research has broadened to belowground biomass, and the allocation of carbon and nutrients in various components has been included in analyses [Uri et al. 2007b; Kuznetsova et al. 2011; Uri et al. 2012; Bijak et al. 2013; Varik et al. 2013]. In Poland, Bernadzki and Kowalski [1983] identified birch as a pioneer species adapting the ground for colonization by other trees on post-agricultural lands; Jakubowski and Sobczak [1999] analysed the possibilities of growing birch as intensive plantations established on post-agricultural lands; Glanc et al. [2000] investigated the content of Mn, Fe, Zn and Cu in birch juice and Kayzer et al. [2011] analysed the effect of trace elements on the state of birch foliage. Liepins [2007] also demonstrated the excellent performance of silver birch on former agricultural lands. This was also confirmed in a number of studies in Latvia.

The hypotheses of the presented study assumed that (I) the quantity of chemical elements (N, C, S, P, K, Na, Ca, Mg, Mn, Zn, Cu, Fe, Pb, Cd) changes with the age of birch, and (II) the quantity of the components varies between tree and ecosystem elements. To test these hypotheses, the objectives included: i) an assessment of the amount of biomass stored in the above and belowground parts of young birch trees, as well as the amount of litterfall on post-agricultural lands in central Poland; ii) an analysis of the effect of tree age on the allocation of elements.

Materials and methods

The study included 20 stands growing on former agricultural lands in five locations in the Mazovia region of Poland (table 1). The plots were established in pure silver birch stands of successional origin. All the investigated stands originated from natural regeneration started after farming was abandoned, and remained free from any agri- or silvicultural treatments.

Experimental plots were selected in five stands: Dobieszyn (2), Kampinos National Park (2) and Kozienice (1). The analysis performed on each plot was concerned with the chemical composition and amount of biomass in four patches of vegetation, characterised by the different ages of the birch trees growing there. The vegetation patches were classified according to age, i.e. I: 1–4 years old, II: 5–8 years old, III: 9–12 years old and IV: over 12 years old.

Table 1. Locations and characteristics of study plots

Plot	Location	Soil types	Humus content
Dobieszyn 1	51°35′N, 21°10′E	Podzols & luvisols	0–1%
Dobieszyn 2	51°33′N, 21°09′E	Podzols & luvisols	1–2%
Kozienice	51°24′N, 21°26′E	Podzols & luvisols	2–3%
Kampinos 1	52°21′N, 20°43′E	Luvisols & cambisols	2–3%
Kampinos 2	52°19′N, 20°40′E	Luvisols & cambisols	3–10%

All the study sites were located within a transition zone from a maritime to continental climate [Martyn 2000] with annual average temperatures equal to 6–8°C and average annual rainfall equal to 550–600 mm. The coldest month (January) has an average temperature slightly below -2°C and the warmest (July) has a temperature ranging from 16 to 18°C. The study area has infertile soils developed on glacio-fluvial sand, glacial till, clay and peat.

At each of the five locations, four stands of increasing ages were selected. Ten trees were randomly chosen at each location according to the diameter range. A total of 181 trees were used for further analyses. All parts of the model trees (stem, foliage, branches and roots) were weighed in the field using portable scales with an accuracy equal to 0.01 g.

On each plot, five places were randomly chosen to determine the amount of organic matter on the ground. A 0.6 × 0.6 m sampler was used to collect all the organic components down to the mineral soil. The organic matter was further divided into litterfall and plants other than birch (mainly grass) and weighed using portable scales with an accuracy equal to 0.01 g.

Samples from each of the components from every model tree, litterfall and other ground organic matter were taken in order to determine the relationship between their fresh and dry biomass. The samples were oven-dried at 105°C and weighed. The dry biomass of the components was calculated for each tree on the basis of the corresponding fresh to dry mass ratios [Snowdon et al. 2000, 2002; Uri et al. 2007, 2012]. The dried components were further ground and homogenised. Of the next three samples, 50 g each were taken and mineralised in HNO_3. Then the content of K, Na, Ca, Mg, P, Fe, Mn, Cu, Zn, Pb and Cd in all parts of the trees was determined using an ICP-OES device. The content of C, N and S was determined using a LECO TruMac CNS device without mineralisation. The obtained biomass of the tree components (roots, stem, bark, branches, assimilation apparatus, litterfall and total biomass of the other (except birch) plants) and the content of the elements was further expanded to the plot level and expressed in kg DM/ha. The differences between the age classes were assessed using the Kruskal-Wallis test at 0.05 significance level.

Results and discussion

The major quantitative characteristics of the age groups are presented in table 2.

Table 2. Characteristics of age groups

Age class	Average age	Average biomass [m^3/ha]	Average biomass [kg/ha]			
			aboveground	roots	litterfall	other herbaceous plant
I	3	2	2 521.58^a	510.83^a	2 523.39^a	3 478.01^a
II	5	19	13 807.89^b	1 086.39^b	3 748.64^b	2 725.70^b
III	9	57	35 677.44^c	1 485.48^c	6 784.16^c	1 942.08^c
IV	12	126	78 082.05^d	1 475.87^c	9 643.49^d	1 306.86^d

a, b, c, d – homogenous groups determined at 0.05 significance level

The dry biomass of the aboveground tree components increased significantly with age ($p = 0.0000$) and was on average equal to 2.5 t/ha for age class I (average age 3 years), 13.8 t/ha for age class II (average age 5 years), 35.7 t/ha for age class III (average age 9 years) and 78 t/ha for age class IV (average age 12 years). In experiments performed by Uri et al. [2012] in Estonia, biomass equal to 25.7 t/ha was reported in a 6-year-old stand, 67.6 t/ha in a 13-year-old stand, and 39.9 t/ha in a 14-year-old one. Johansson [1999] reported the biomass of birch on post-agricultural areas in Sweden amounted to 5.7–55.7 t/ha at 7–11 years. The biomass of the 8-year-old birch assessed in the experiment by Uri [2007b] was equal to 31.2 t/ha, and in research from Uri et al. [2007] varied from 6 to 22.8 t/ha. The results obtained are similar, and the differences are mainly due to different soil conditions. It should be noted that the slightly lower values coming from Estonia and Sweden may have been caused by shorter vegetation periods.

Table 3. Nutrient accumulation in plant biomass components [kg/ha]

Age class	N	C	S	P	K	Ca	Mg
Foliage							
I	19.05^{a}	367.29^{a}	1.55^{a}	2.56^{a}	5.56^{a}	4.57^{a}	2.22^{a}
II	48.83^{b}	939.35^{b}	3.87^{b}	6.92^{b}	13.53^{b}	12.76^{b}	4.98^{b}
III	152.70^{c}	2886.33^{c}	11.72^{c}	18.74^{c}	54.30^{c}	27.47^{c}	9.80^{c}
IV	372.70^{d}	7626.91^{d}	27.60^{d}	38.65^{d}	121.57^{d}	97.61^{d}	34.96^{d}
Branches							
I	4.35^{a}	268.67^{a}	0.36^{a}	0.70^{a}	2.11^{a}	2.08^{a}	0.46^{a}
II	11.78^{b}	950.13^{b}	1.07^{b}	1.80^{b}	4.63^{b}	7.77^{b}	1.14^{b}
III	29.64^{c}	2561.88^{c}	2.72^{c}	4.15^{c}	12.70^{c}	14.87^{c}	2.20^{c}
IV	70.32^{d}	5665.98^{d}	6.49^{d}	9.42^{d}	28.64^{d}	39.54^{d}	5.33^{d}
Stem							
I	2.63^{a}	411.08^{a}	0.22^{a}	0.46^{a}	1.25^{a}	1.34^{a}	0.35^{a}
II	14.29^{b}	3786.27^{b}	1.26^{b}	2.39^{b}	7.48^{b}	7.45^{b}	1.33^{b}
III	35.77^{c}	11453.53^{c}	3.63^{c}	4.99^{c}	15.93^{c}	19.99^{c}	3.51^{c}
IV	65.84^{d}	26086.65^{d}	5.89^{d}	9.90^{d}	30.88^{d}	53.23^{d}	8.39^{d}
Bark							
I	2.02^{a}	125.90^{a}	0.14^{a}	0.17^{a}	0.58^{a}	1.35^{a}	0.18^{a}
II	7.89^{b}	979.89^{b}	0.58^{b}	0.80^{b}	2.08^{b}	7.23^{b}	0.66^{b}
III	17.84^{c}	2379.96^{c}	1.33^{c}	1.31^{c}	4.03^{c}	12.98^{c}	1.04^{c}
IV	34.55^{d}	4862.30^{d}	2.56^{d}	2.06^{d}	5.33^{d}	30.02^{d}	1.80^{d}
Aboveground part of trees							
I	28.05^{a}	1172.94^{a}	2.27^{a}	3.89^{a}	9.50^{a}	9.34^{a}	3.21^{a}
II	82.79^{b}	6655.64^{b}	6.78^{b}	11.91^{b}	27.72^{b}	35.21^{b}	8.11^{b}
III	235.95^{c}	19281.70^{c}	19.40^{c}	29.19^{c}	86.95^{c}	75.31^{c}	16.55^{c}
IV	543.41^{d}	44241.84^{d}	42.54^{d}	60.03^{d}	186.42^{d}	220.40^{d}	50.48^{d}
Roots							
I	5.57^{a}	478.83^{a}	0.71^{a}	1.23^{a}	3.12^{a}	3.77^{a}	0.75^{a}
II	15.92^{b}	1302.14^{b}	2.51^{b}	3.20^{b}	6.78^{b}	11.45^{b}	1.51^{b}
III	37.49^{c}	3085.71^{c}	5.02^{c}	6.70^{c}	15.74^{c}	16.19^{c}	2.80^{c}
IV	59.67^{d}	6429.23^{d}	9.84^{d}	13.44^{d}	33.09^{d}	40.55^{d}	6.39^{d}
Litter fall							
I	10.31^{a}	280.81^{a}	0.99^{a}	0.80^{a}	1.04^{a}	3.60^{a}	0.47^{a}
II	82.81^{b}	1754.80^{b}	7.53^{b}	6.04^{b}	6.09^{b}	34.64^{b}	6.66^{b}
III	143.01^{c}	3279.47^{c}	14.69^{c}	9.60^{c}	8.18^{b}	56.74^{c}	8.17^{b}
IV	197.35^{c}	4511.78^{d}	19.76^{c}	12.98^{c}	10.53^{b}	66.29^{c}	10.31^{b}

a, b, c, d – homogenous groups determined at 0.05 significance level

The share of foliage biomass within the whole tree biomass decreased with age (p = 0.0001), while the share of the trunk increased significantly (p = 0.0012). After an initial moderate increase, the share of bark and branches stabilized, starting from age class II. The share of roots initially decreased and then levelled off [Bijak et al. 2013].

An average nutrient accumulation in the biomass of the plants across the analysed chronosequence is presented in table 3.

The carbon accumulation in the aboveground parts of the researched trees increased from 1.2 t/ha in age class I (average 3-year-old) stand, to 6.7 t/h in age class II (average age 5 years) and 19.3 t/ha in age class III (average age 9 years), to 44.2 t/ha in class IV (average 12 year-old part) (table 3). In the Estonian research by Uri et al. [2012], the carbon accumulation in the aboveground parts of the 6-year-old birch, equalled 12.5 t/ha and in the 13-year-old birch – 32.4 t/ha. Uri et al. [2012] reported carbon equal to 40–45 t/ha only in the 18–28 year--old samples. This indicates a much larger carbon uptake in the conditions of the Mazovia region. The author of the Estonian research also indicated that a silver birch stand growing on a fertile site had a high capacity for C accumulation, both in the biomass and in the soil. At the same time, the author pointed out that in the younger age classes, much depended on tree density. In the case of loosely wooded patches, part of C was accumulated in herbaceous vegetation so that the accumulation in birch was lower. According to this study, the root systems of the 5 year-old birches accumulated 1.3 t C/ha, and in the 13 year-old – 6.4 t/ha. In the case of the Estonian research, the accumulation amounted to 3.8 t/ha at 6 years of age and 7.6 t/ha at 13 years of age, respectively, while it should be noted that in this particular study the amount of belowground biomass was estimated. Lower biomass, and thus lower carbon accumulation, could be explained by the higher site fertility, because the studied birch stands grew on fertile soils and, according to an intensive fine root strategy, there was no need for the tree to grow a large number of fine roots for more sufficient nutrient uptake [Varik et al. 2013].

Nitrogen content in the aboveground parts of the birch trees in the investigated chronosequence increased from 28 to 543 kg/ha. In the Estonian research on the 8 year-old birch, the accumulation of biogenic elements was equal to 192.6 kg N/ha, 24.9 kg P/ha and 56.6 kg K/ha [Uri et al. 2007]. These values were much lower than those obtained in the present study on the 9-year old birch, which amounted to 235.95 kg N/ha, 29.19 kg P/ha and 86.95 kg K/ha (table 3). The N:P:K ratio, which in the first case was 70:9:21 and in the second was 67:8:25, was very similar with a slight shift of the nitrogen content towards potassium, which may have been the result either of the soil conditions or the seasonal vegetation, in which the samples were taken. In yet another Estonian research study [Uri et al. 2007], it was found that the average content of biogenic elements in the aboveground parts of 8 year-old birch trees was equal to 110.44 kg N/ha, 15.30 kg P/ha and 46.74 kg K/ha, which confirmed that under less fertile site conditions and a shorter vegetation season, the accumulation of elements in plants was definitely lower. In the roots, it was assessed that the content of nitrogen was equal to 5.57 kg/ha in the first age class, 15.92 kg/ha in the second age class, 37.49 kg/ha in the third class and 59.67 kg/ha in the fourth one. Estonian researchers reported that the content of nitrogen was equal to 39.3 kg/ha in the 6 year- old stand and 53.2 kg/ha in the 14 year-old one [Varik et al. 2013]. The reported results from Estonia and central Poland are comparable and there is no evidence of differences in climate and soil on the nitrogen content, which were visible in the case of carbon. The distribution of various biogenic elements (especially NPK) in the separate parts of the plants is shown in table 3. In the investigations by Uri et al. [2007], the content of NPK was noticeably lower in the branches, stems and bark, but definitely higher in the leaves. This varying allocation of the investigated elements was caused by the collecting of the samples in different phases of the vegetation season.

The content of the remaining biogenic elements, such as S, Ca, Mg, also increased with age. These elements reached the highest content in the leaves, and their share, in comparison to the rest of the plant in many cases exceeded 50%. It is worth mentioning the relatively low content of magnesium (Mg) in the woody parts of the plants and in the bark, as opposed to calcium (Ca) with its high amount in the stem, reaching nearly 25% of the total Ca content stored in the aboveground parts of the trees.

When analysing the allocation of microelements in the separate parts of the plants (Table 4) it is visible that the content of the majority of the analysed microelements in the biomass increased with age, with the exception of the roots where the amount of sodium (Na) and iron (Fe) clearly stabilized in the older age classes. Similar trends can be observed in the case of heavy metals in the litterfall. The content of cadmium (Cd) was lower than that of lead (Pb) in almost the whole plant, with the exception of the bark, where the results were the opposite. A high content of sodium, lead and iron in particular was observed in the roots. In the second age class, over 80% of the iron was located in the roots. The sodium content in the roots significantly decreased with age and increased in the stems. Similar patterns of element transfer from the roots to the shoots could be seen for copper and, to a lesser extent, for lead. There was a relatively low level of Pb accumulation in the foliage of the trees. This is why there was no significant influence of the presence of trace elements in the environment on the size of the assimilation apparatus [Kayzer et al. 2007].

The highest content of copper and zinc could be found in the bark of the trees.

For the litterfall, a significant drop in most elements could be observed in the initial phase, followed by a relatively stable moderate increase. However, the amount of litterfall increased more or less linearly. In addition, for the litterfall, the content of the majority of the analysed elements increased in the young ages and then decreased. Reverse tendencies could be observed for the foliage.

Table 4. The allocation of microelements in plant biomass components [kg/ha]

Age class	Na	Cu	Zn	Mn	Fe	Pb	Cd
Foliage							
I	0.028^{a}	0.005^{a}	0.237^{a}	0.929^{a}	0.124^{a}	0.0009^{a}	0.0005^{a}
II	0.071^{b}	0.013^{b}	0.525^{b}	3.053^{b}	0.299^{b}	0.0025^{b}	0.0015^{b}
III	0.173^{c}	0.031^{c}	1.053^{c}	8.353^{c}	0.682^{c}	0.0065^{c}	0.0020^{b}
IV	0.410^{d}	0.040^{c}	2.554^{d}	20.689^{d}	2.046^{d}	0.0126^{d}	0.0077^{c}
Branches							
I	0.017^{a}	0.003^{a}	0.176^{a}	0.206^{a}	0.038^{a}	0.0008^{a}	0.0006^{a}
II	0.054^{b}	0.008^{b}	0.601^{b}	0.787^{b}	0.067^{b}	0.0026^{b}	0.0020^{b}
III	0.150^{c}	0.022^{c}	1.069^{c}	3.141^{c}	0.182^{c}	0.0073^{c}	0.0037^{c}
IV	0.364^{d}	0.046^{d}	2.184^{d}	6.015^{d}	0.441^{d}	0.0137^{d}	0.0079^{d}
Stem							
I	0.023^{a}	0.002^{a}	0.100^{a}	0.149^{a}	0.045^{a}	0.0014^{a}	0.0004^{a}
II	0.111^{b}	0.021^{b}	0.497^{b}	0.853^{b}	0.186^{b}	0.0084^{b}	0.0025^{b}
III	0.220^{c}	0.053^{c}	1.268^{c}	3.496^{c}	0.806^{c}	0.0331^{c}	0.0051^{c}
IV	0.588^{d}	0.137^{d}	2.259^{d}	7.700^{d}	2.206^{d}	0.0556^{d}	0.0108^{d}
Bark							
I	0.019^{a}	0.002^{a}	0.094^{a}	0.075^{a}	0.026^{a}	0.0002^{a}	0.0003^{a}
II	0.071^{b}	0.015^{b}	0.374^{b}	0.586^{b}	0.143^{b}	0.0010^{b}	0.0013^{b}
III	0.125^{c}	0.035^{c}	0.606^{c}	1.775^{c}	0.363^{c}	0.0030^{c}	0.0022^{c}
IV	0.175^{d}	0.073^{d}	1.211^{d}	2.873^{d}	0.664^{d}	0.0049^{d}	0.0040^{d}
Aboveground part of trees							
I	0.087^{a}	0.012^{a}	0.607^{a}	1.359^{a}	0.233^{a}	0.0033^{a}	0.0018^{a}
II	0.307^{b}	0.057^{b}	1.997^{b}	5.279^{b}	0.695^{b}	0.0145^{b}	0.0073^{b}
III	0.668^{c}	0.141^{c}	3.996^{c}	16.765^{c}	2.033^{c}	0.0499^{c}	0.0130^{c}
IV	1.537^{d}	0.296^{d}	8.208^{d}	37.277^{d}	5.357^{d}	0.0868^{d}	0.0304^{d}
Roots							
I	0.104^{a}	0.007^{a}	0.171^{a}	0.228^{a}	1.375^{a}	0.0087^{a}	0.0008^{a}
II	0.286^{b}	0.018^{b}	0.521^{b}	0.549^{b}	17.478^{b}	0.0628^{b}	0.0035^{b}
III	0.480^{c}	0.041^{c}	0.865^{c}	2.843^{c}	10.138^{c}	0.1047^{c}	0.0054^{c}
IV	0.497^{c}	0.084^{d}	1.500^{d}	4.478^{d}	18.559^{b}	0.2139^{d}	0.0095^{d}
Litter fall							
I	0.013^{a}	0.005^{a}	0.096^{a}	0.670^{a}	0.236^{a}	0.0024^{a}	0.0003^{a}
II	0.214^{b}	0.042^{b}	1.249^{b}	6.245^{b}	2.538^{b}	0.0213^{b}	0.0041^{b}
III	0.314^{c}	0.072^{c}	2.432^{c}	13.738^{c}	5.002^{c}	0.0463^{c}	0.0101^{c}
IV	0.412^{c}	0.099^{c}	2.245^{c}	17.438^{c}	6.714^{c}	0.0599^{c}	0.0090^{c}

a, b, c, d – homogenous groups determined at 0.05 significance level

Summary and conclusions

A significant accumulation of elements, including particularly biogenic ones, such as carbon (about 50% of the dry aboveground biomass), nitrogen, phosphorus, potassium, calcium and magnesium occurred in the spontaneous birch afforestation on post-agricultural lands. Biomass increments, and consequently the accumulation of elements recorded in this study, were significantly higher than the increment described for Sweden and Estonia. This was probably due to the longer growing season and better habitat conditions that characterize sites located in the Mazovia region. The fertility of the habitat is probably also the reason for a somewhat weaker root development. This is because there is less need for such a significant penetration of the soil environment where there is a higher availability of nutrients.

The allocation of biogenic elements in particular parts of trees was surely affected by the phase of the vegetation season in which the samples were collected. To confirm this hypothesis it would be desirable to investigate whether the given elements existed in the mobile or bound fraction. This could be done by an analysis of the chemical composition of the juices from the analysed birches. It can be indisputable, however, as the highest content of biogenic elements was located in the foliage, with the exception of carbon, which was mainly allocated to the growing stems.

The content of microelements in various parts of the trees varied, and their location depended on their physiological role. The highest content of these elements existed mainly in the leaves, but some of them (sodium, lead and iron) were to a large extent allocated to the roots while copper was located in the stems and bark.

Based on the presented results, after supplementing them with a soil analysis and taking into account litterfall and herbaceous vegetation, it should be possible to make an introductory balance of the matter flow that takes place in the process of the initiated transformation of the former agricultural area into forest land. Such an analysis of the spontaneous birch afforestation could help answer the question if such a process is beneficial to the environment in terms of ecosystem protection, biodiversity, habitat conservation, as well as the economy and sustainable environmental management.

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