C-accumulation and allocation after afforestation of a pasture with Pin oak (*Quercus palustris*) and ash (*Fraxinus excelsior*)

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Abstract

The aim of the study is to investigate how afforestation of agricultural land effects the C-cycle. That is why the allocation and accumulation of carbon was quantified in 2 types of deciduous forest with 2 different ages on the one side and in unforested pasture on the other.

The total C-content of the pasture amounted to 128 ton C/ha. The total C-content in the young (29 years old) and old (69 years old) ash stand was 173 ton C/ha and 232 ton C/ha respectively. The young pin oak stand (27 years old) had a C-content of 117 ton C/ha, the old oak-beech stand (69 years old) one of 227 tonC/ha.

It was prooved that the young ash stand evolves to a higher C-content than the C-content of the pasture. In the young ash stand the aboveground and belowground C-pools are equally big. The older the stand, the more important the portion of the soil carbon becomes. The carbon in old stands is mainly stocked in the form of stable soil carbon.

After 27 years the pin oak stand has a lower C-content than the pasture. Furthermore, most of the carbon is situated aboveground. In the old oak-beech stand on the other hand the soil has been complemented. The soil carbon - as for the ash stand- takes the most important portion. This stable reservoir however is smaller than in the ash stand.

This study shows that when foresting a pasture the choice of tree species has an important impact on the accumulation, allocation, evolution and stability of carbon.

Key words: *C-accumulation, C-translocation, afforestation, Fagus sylvatica, Fraxinus excelsior, Quercus palustris, Quercus robur*

1. Introduction

For 20 years a discussion has been going on about wether terrestrial ecosystems are a source or rather a reservoir of carbon. Because of the complexity of biological C-accumulation, the big heterogeneity of vegetation and soils and because of the effect of human land use and land management it is difficult to assess the exact role of the terrestrial biosphere in the global C-cycle (Schimel 1995). Recent research goes to show that tropical forest is a source of carbon that causes an emission between 0.6 and 1.7 10^{15} g C/y. Outside the tropics the emission is much lower, figures of 0.1 10^{15} g C/y to -1.1 10^{15} g C/y are put forward.

In the forest, carbon is divided over different reservoirs: the tree biomass, the detritus and the mineral layer. The importance of forest soils especially should not be underestimated; forest soils contain more than 45 % (618 10^{15} gC) of all soil carbon (Watson et al. 1990). Of this 45 %, more than half (54%) is located in forest soils of temperate regions (Brown 1996). In the tropical rainforest on the other hand the most important carbon reservoir is the aboveground biomass (Melillo et al. 1988, Schlesinger 1977).

Via the chosen management mankind is able to influence the size of the pools and to direct the net carbon flux. To do this it is necessary to have knowledge of the size of the pools and their evolution through time- whether or not after management.
According to the model of Borman and Likens the size of carbon reservoirs evolves depending on the age of the stand (Borman and Likens in Kurz and Apps 1992). In the reorganization phase the total C-content in the ecosystem declines as a result of mineralization. Then there is a carbon increase in the aggradation phase. This rise is mainly due to a rise of the biomass carbon. These phases are ultimately followed by a permanent state in which the biomass carbon adopts a more or less constant value. The soil carbon keeps rising as a result of individual tree mortality, root dejection and litterfall. Because of this the amount of carbon in the whole ecosystem also experiences a rise. It follows that the total C-content can keep on rising despite the stagnation or even the small decrease of carbon in the living biomass.

Cannel (1992) records a carbon profit in the short term when foresting agricultural land with fast growing tree species. The C-accumulation is mainly situated in the mineral soil. However, if peat soils are forested the original C-content is never reached (Cannel 1992). According to Schlesinger (1972) in temperate regions, the C-content of the forest soil (118 ton/ ha) doesn't exceed the C-content of pastures. It follows that if pastures are forested, the soil C-content won't reach the original content either. The extent of the loss is dependent on the soil preparation that was executed.
To an important extent the tree species determines the type of detritus (Bonneau et al. 1973, Brueckner et al. 1987, Challinor 1968, Dupraz et al. 1986, Genssler 1959, Holstener-Jörgensen et al 1988, Muys et al 1992, Nys 1981 in Muys 1995). Detritus has an important influence on the generation of humus and on soil development (Howard & Howard 1990). Because of the long life span of trees the influence of the tree species on soil fertility is not to be underestimated (Muys 1995). Howard & Howard (1990) investigated the influence of the tree species on the acidity of humus and soil. They noticed that deciduous tree species produce humus that is less acid than that of coniferous species. Müller (1879, 1884 in Raulund-Rasmussen 1995) already proved that fundamental changes occur when oak (*Q. robur, Q. petraea*) is replaced by beech (*F. sylvatica*) on sandy soil in Jutland. Mull humus originating from oak was transformed into morhumus originating from beech. On the same site the rate of decomposition underneath oak is higher than underneath beech and Norway spruce (*Picea abies*) (Raulund-Rasmussen et al. 1995). Species such as conifers, beech and oak rather produce a slowly decomposing humus with few nutrients whereas poplar, ash, cherry and maple produce a fast decomposing humus that is rich in nutrients (*Muys 1995*).

This research compares the impact on the carbon balance of pasture being forested with different tree species; pin oak (*Q. Palustris)* and ash (*Fraxinus excelsior*). To investigate this the C-content of a young pin oak stand (27 years old) and of a young ash stand (29 years old) - both planted out on pasture- was compared with the C-content in a pasture (reference situation). So next to the influence of the tree species the impact of 2 forms of landuse (forestry-agriculture) on the C-content was studied. To work out wether the effect of the tree species is permanent, old tree stands of ash and oak-beech (Quercus robur-Fagus sylvatica) were also investigated.

2. Methodology

2.1. Site description

The research was carried out in the experimental forest Aelmoeseneie of the University of Ghent and on adjoining pasture. The C-contents of the pasture, 2 stands planted on pasture and 2 old stands are being compared.

The pasture is probably a few centuries old and has been used intensively during the last decades.

The young stands were planted on former pasture on the edge of the Aelmoeseie forest.

One stand consisting of ash (*Fraxinus excelsior*) was planted in 1968-69 over a surface of 1 ha. Before planting it a full soil preparation was executed with a rotary cultivator up to a depth of 15 cm. Elder (*Sambucus nigra*) has spontaneously settled in the shrublayer. In the herblayer Urtica dioica and Ranunculus repens have settled. The soil belongs to the wLep-serie, which means a strongly gleyic sandy loam soil with a reduction horizon between 80 and 120 cm and a clay substrate between 40cm and 80cm. The pH(H2O) of the A1-horizon is situated between 5 and 6.2. The humus belongs to the mull-type (Muys 1995). The amount and diversity of earthworms is notable which contributes to the fast decomposition and mixing of organic material with the mineral soil.

The second experimental plot (0.63 ha) was planted with pin oak (*Quercus palustris*) in 1970. No preceding soil preparation was executed. There is hazel (*Corylus avallena*) in the lower storey, planted in 1970 as well and cut twice until present. Elder spontaneously came into this shrublayer as well. The soil is of the wLdc type, a moderately gleyic sandy loam soil with a structure B-horizon and a clay substrate between 40 and 80 cm. The humus is described by Muys (1993) as moderlike mull. The earthworm biomass, like the Ca -content, is much lower here than in the ash stand. The prevalent species of the herbvegetation are also *Urtica dioica* and *Ranunculus repens*.

The two plots in the old stands are re-afforestations of forestparcels that were chopped during world war I (1914-1918) (Muys 1993). The first experimental plot (1ha) is an oak stand (69 years old) with an addition of beech (70%/30%). The soil is of the wLdc type, the same soil type as in the pin oak plot. The humus layer is of the moder type (Muys 1993). The prevailing species (57%) in the shrublayer is hazel (*Corylus avellana*) mixed with mountain ash (*Sobus aucuparia*), hawthorn (*Crataegus monogyna*) and maple (*Acer pseudoplatanus*). The herb layer is dominated by *Pteridium aquilinum and Rubus fructicosus.*

The prevalent tree species of the second experimental surface (0.8 ha) is ash of 69 years old. The soil type is Ldc; the same soil type as in the old oak stand without the clay substrate between 40 and 80 cm. Because of fast decomposition the humus type is active mull (Muys 1993). The earthworm diversity and activity is also notable here (Muys 1993). In the shrublayer hazel is the prevailing species (50%), maple (20%) and mountain ash (12%) also occur. The herb layer is dominated by *Anemone nemodrosa* and *Ranunculus ficaria*.

2.2 Description of the research

a. The pasture
To measure the C-content samples of the pasture's mineral soil were taken at 12 different places. Per sample place samples were taken between the following depths: 0-5cm, 5-15cm, 15-50cm and 50-100cm. The C-content in these samples was measured with the method of Walkley and Black. In a pasture, carbon reservoir of the biomass is negible compared to the carbon reservoir of the soil. For this reason it is not considered here.

b. The young forest stands
The C-content of the tree and shrub layer, of the detritus and of the mineral soil was measured.
The C-content of the tree layer was determined on the basis of model trees. Per stand three model trees were chosen; a tree with an average diameter and the two model trees of Hohenadl. These are 2 trees with a diameter equal to the average diameter plus and minus the standard deviation. To select these trees a full inventary was made. The aboveground biomass of all these trees was precisely measured. As a result of this, their dry matter was measured as well. According to Matthews (1993) 50% of dry matter consists of carbon. The C-content of the whole stand's aboveground biomass was calculated by means of extrapolation. Data on the C-content of dead wood and the belowground biomass were taken from literature (Duvigneaud 1984, Satchell 1971).
In both stands transects were made to estimate the C-content of the shrub layer. The ash and pin oak transect's dimensions were 5 x 50 m and 5 x 100m respectively. Within each transect the shrubs were counted and the average diameter at 1.30m height was defined. Again the C-content of 3 model shrubs was determined and an extrapolation for the whole stand was made.
The herb layer was not sampled supposing that it is fully taken up in the detritus.
In the humus layer samples were taken of the L-, F- and H-layer. In order to do this a 0.25m² surface of each layer was collected and weighed. The C-content was determined by means of ashing. Twelve repetitions were executed.
The C-content of the mineral layer was also determined with the method of Walkley and Black. For this purpose 12 soil samples were taken between 0-5cm, 5-15cm, 15-50cm and 50-100cm.

c. The old stands
Samples were taken per tree species. After a full inventory model trees were chosen for oak, beech and ash. For the oak population, which contributes 70% of the total population, the number of model trees was extended to 12. The 9 extra model trees were chosen from diameter classes in-between. The beech population is bimodal and was subdivided into an old and a young population. Of the young population the model trees of Hohenadl were sampled as well. Of the old population only the model tree with the average diameter was sampled. In the ash stand samples were also taken on the basis of the model trees of Hohenadl and the average model tree.

In order to obtain the C-content of the shrub layer in both the ash and the oak-beech 10 experimental surfaces of 5 x 5 m were sampled by means of destruction. The woody debris on the ground was collected in 5 experimental surfaces per stand. It was subdivided into diameter classes with the following dimensions: <1.5cm, 1.5-5cm an >5cm. Per experimental surface and for each of the above-mentioned diameter classes 1m², 5m² and 10m² were sampled respectively. The humus layer and the mineral soil were sampled in the same way as the young stands. However, the number of repetitions was much more extensive, 31 for the beech stand and 28 for the ash stand.

3. Results

a. The pasture

In 1956 and in 1995 the C-content of the pasture was measured. Table 1 reproduces the results of these measurements.

Table 1. *C-content (%) of the pasture in 1956 and 1995*

1956		1995	
depth (cm)	*C%*	*Depth (cm)*	*C%*
0-5	1.5	0-5	5.7
11-20	1.0	5-15	3.09
61-80	0.2	15-50	1.03
101-150	0.1	50-100	0.14
total C(ton/ha)	69.4	total C(ton/ha)	128.5

b. The forest stands

The C-content (ton/ha) in the different compartments of the 2 young and 2 old stands are represented in Table 2.

Table 2. *The C-content (ton/ha) in the different compartments of the forest stands*

	Young stands		old stands	
	pin oak	Ash	oak-beech	ash
tree layer	37.7	80.2	85	73.8
shrub layer	12.1	0.2	2.4	4.2
dead wood	0.8	1.3	2.5	3.0
total aboveground	*50.6*	*81.7*	*98.9*	*81*
Roots	9.9	16.1	*17.6*	*14.4*
L-layer	1.2	1.2	0.4	0.04
F-layer	5.4	-	11	0.2
H-layer	-	-	13	0.2
total humus layer	*6.6*	*1.2*	*24.4*	*0.4*
0-5 cm	9.4	11.9	29	31
5-15 cm	10.1	17.8	24	31
15-50 cm	20.8	33.8	31	44
50-100cm	9.9	10.7	11	30
total mineral layer	*50.1*	*74.2*	95	136
total belowground	*66.6*	*91.5*	*137*	*150.8*
Total	*117.25*	*173.2*	*236*	*232*

Fig. 1 represents the distribution of carbon over the various compartments. In Fig. 2 the evolution of the C-content from pasture to old forest is shown.

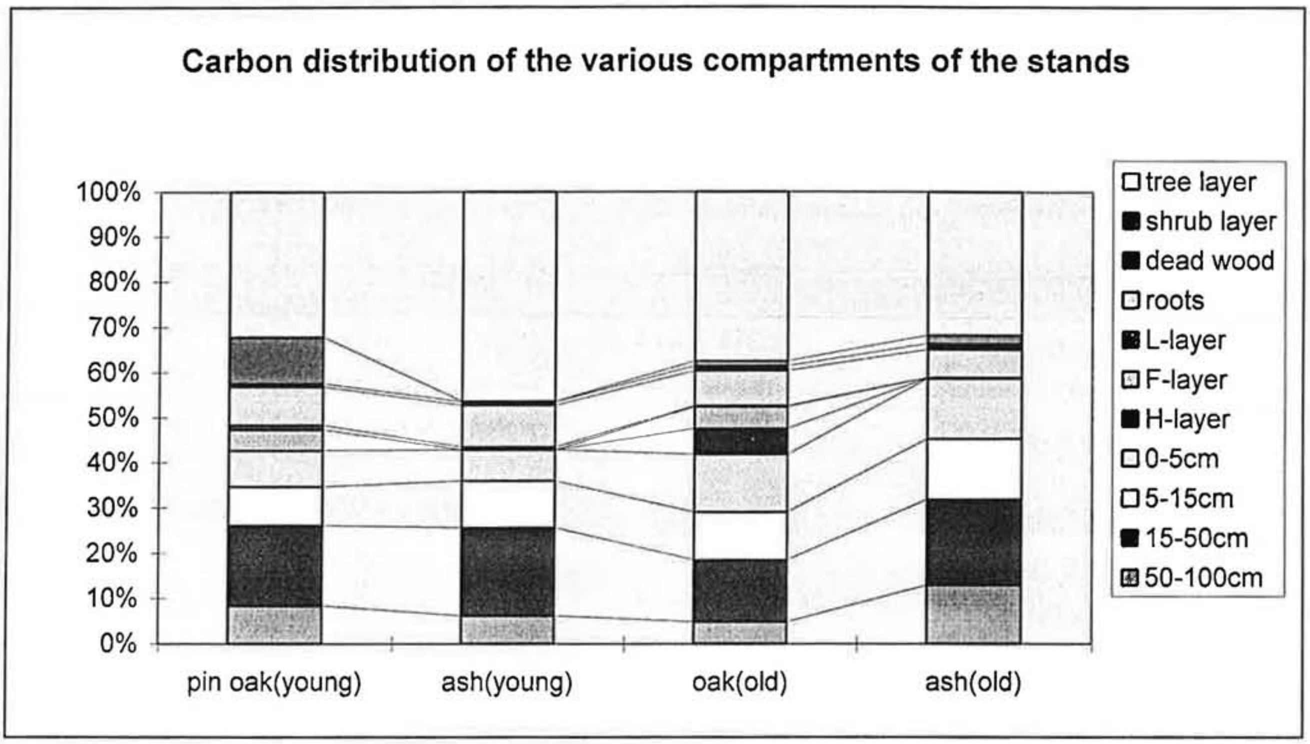

Figure 1. *The distribution of carbon over the various compartments in terms of percentage.*

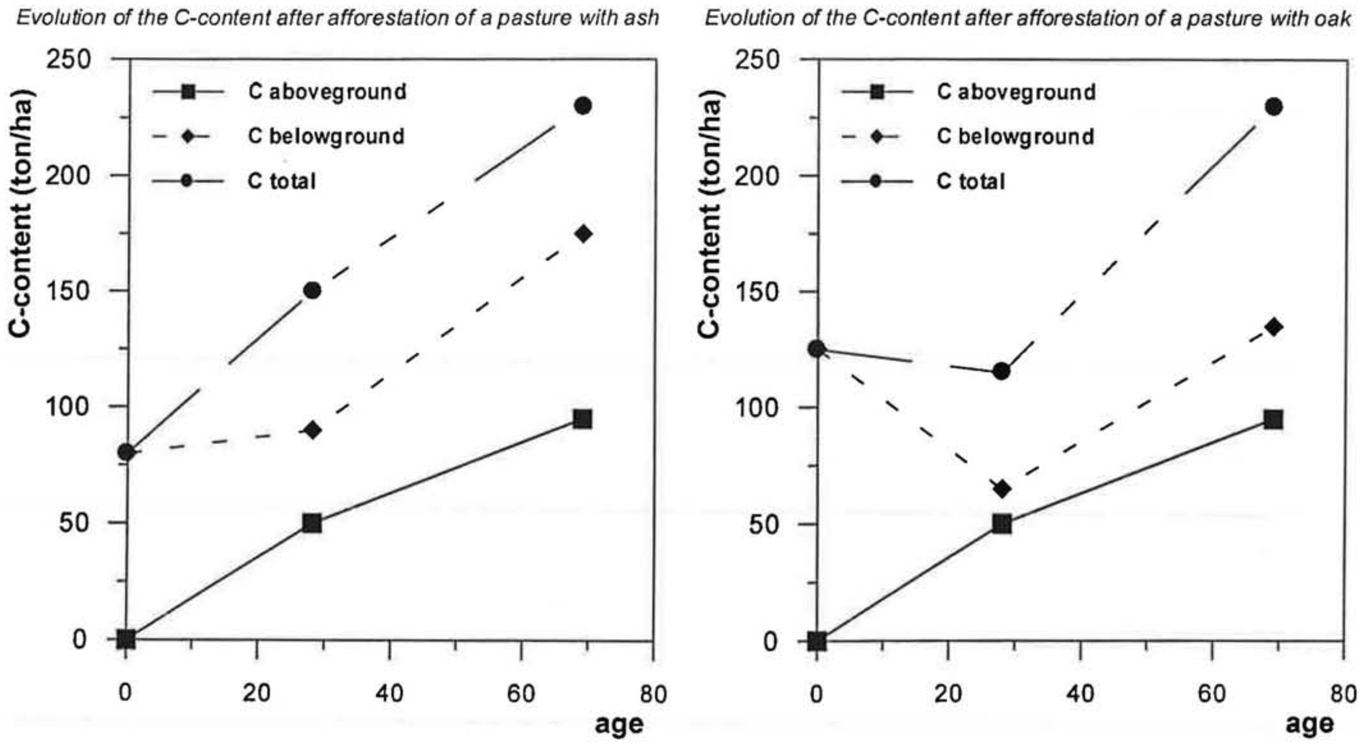

Figure 2: *The evolution of the C-content from pasture to old forest.*

4. Discussion

During a life span of 39 years the belowground C-content of the pasture has risen 59.1 tonC/ha (85%). This rise is mainly situated in the upper 5 cm of the mineral layer. There is no increase in the deeper layers. This rise is probably due to an increase in fertilisation in Flanders' agriculture.
In literature however, no figures were found about the influence of intensified agriculture on the C-content of pasture. In farmland on the other hand the C-content of the upper 36 cm has risen 25 % during the last 40 years (Van Meirvenne et al 1996). It is not clear whether this rise also applies for pasture. According to Hawing (1992) the C-content doesn't change when there is a rise in fertilisation of 250 to 700 kg N/ha/year.
Werger (1983) and also Brouwer (1962 & 1983) assert that the shoot/root-ratio of grasses rises when there is an increase of available nutrients. It is supposed that with an increased availability of nutrients more energy is invested into the development of the aboveground biomass, causing light to be the limiting factor instead of nutrients. According to Brouwer (1962) the size of the root system hardly changes. Because it is mainly the rootage that is responsible for the carbon accumulation (Schlesinger 1977) the soil carbon will not rise according to these statements.

When the C-content in the 2 young stands is compared with the C-content in the pasture it is striking that the C-content of both stands is lower than the current one in the pasture.
It is believed that at the moment of planting in 1968 and 1970 the C-content value was closer to that of 1956 than to the value of 1995, which was heightened by intensified fertilisation. After 28 years the value of 1956 is already exceeded by the ash stand. Inspite of the fact that there was a soil preparation, which caused the soil's carbon supply to be mineralised partially, the soil's C reservoir has been restored and even enlarged within a time span of 28 years.
The belowground C-content of the young pin oak stand is comparable to the value of the pasture in 1956. This conclusion is remarkable since there was no soil preparation before the planting which normally implies a smaller loss of C than the ash stand.

In comparison with the C-content of the young ash stand (29 years old) the belowground C-content in the old ash stand (69 years old) is 60 ton/ha higher. In the oak-beech stand a higher C-content was assessed as well. It is assumed that the substantial rise for ash and the doubling of the C-content for oak has not occurred within a time span of 30 years. Knowing that the soil is an old forest soil, it must already have contained a substantial C-content before the reafforestation.

If the aboveground carbon is considered in the comparison of the different C-contents, then the C-content of the young ash stand is higher than that of the pasture for both the situations in 1956 and 1995. The pin oak stand on the other hand still contains a lower C-content than the pasture in 1995, but it has already exceeded the value of 1956.

If the total C-content of the young and old stands is compared, the higher C-content obviously attracts attention. This increase is due to both a rise in aboveground and belowground C-content. Even though a higher aboveground C-content was expected initially, it is the belowground C-content that is decisive. The C-distribution changes in function of the age of the stand. In the young ash stand 46.5 % of the carbon is situated aboveground. For pin oak this is 42%. Only 35% of the C in the old ash stands is situated belowground, for an oak-beech stand this adds up to 39.5%. As the age of a stand advances, the portion of the soil carbon increases as compared to the aboveground C.

This evolution corresponds with what Kurz & Apps (1992) propose in their model. In this model they state that C of the detritus or mineral layer is released during the re-organisation phase- after cutting a forest, after a fire or a storm. The release of C from the detritus and the soil is bigger than the absorption of carbon by the growing vegetation. This phase lasts 10 to 20 years. The aggradation phase is the second phase, it can last longer than a century. The living biomass of the young growing wood experiences a substantial increase that is at it's maximum at the end of the period. The belowground C-content hardly comes down, it even evolves towards a rise at the end of the phase. The C-content of the whole ecosystem rises enormously. During these phase all forests function as carbon reservoirs, including those that arose on forestland or pasture. In the phase of the permanent state the total carbon quantity in the living biomass reaches a more or less constant value that is specific to the ecosystem. Very often this constant is submaximal because there is a transitional phase between the aggradation phase and the permanent state. In this transitional phase the C-content of the living biomass decreases. During the permanent state and as a result of individual tree death, root rejection and leaffall there is a continuous flow of carbon from the living biomass to the soil. The portion of the soil carbon increases as the stand becomes older.

Since the C-content of the young pin oak stand is lower than the current C-content of the pasture, it can be assumed that the pin oak stand experienced a long reorganisation phase, during which a lot of carbon was lost. This phase finished more quickly for the ash stand. The aggradation phase, which is characterised by an enormous growth of biomass, is passed through at this moment.

In both old stands the portion of soil carbon is considerably higher than the portion of the aboveground carbon. Consequently deforestations of old stands have a double effect. Not only is the accumulated aboveground biomass taken into use so that carbon is brought into the atmosphere more rapidly. There also is the fact that an unknown and immense pool (depending on the previous history of the forest soil) is exposed to mineralization. If carbon emission is to be restricted, the conservation of old forests is essential.

The difference in C-content between the tree varieties is remarkable. Ashes, which produce an easily decomposable detritus (Muys 1993), bring carbon more quickly into the soil than pin oaks. According to Muys (1993) the oak-beech detritus is hard to decompose. Because of this a thick detritus develops in these stands. The decomposition of the detritus comes about tardily as a result of which the carbon only finds its way into the mineral soil. This is still cleanly visible in the old stands. In the old ash stand there is a very thin to almost no detritus. Carbon quickly finds its way into the mineral layer. The C-content is much higher in the mineral layer of the ash stand. This difference is partly due to the tree species.

The mixing of carbon with the deeper layers is closely related to the presence of endogeic and anecic earthworms. In Flanders these species are the only biological agents that are capable of airing the soil and of mixing it intensively with organic materials. The absence of these species causes inadequate airing and mixing of the organic material (Muys 1993). In his research Muys discovered that these earthworms are chiefly found in forests with secondary tree species and poplar. The higher C-contents in the deeper layers of the examined ash stands can be explained by the presence of these earthworms.

5. Conclusions

The belowground C-content of the investigated pasture has rised 59 ton/ha over 39-year period. This rise is probably due to an intensification of agriculture. In literature no explanation for this rise can be found.

When comparing the belowground C-content in the 2 young stands with the C-content of the pasture in 1956 and 1995 it attracts attention that there is a decrease of the pin oak stand's C-content. The C-content in the ash stand exceeded the C-content of the pasture in 1956, but not in 1995.

The soil carbon expands as the age of the forest advances. The C-content in the old oak stand is more than twice as big as the C-content in the young oak stand . The same trend occurs in the ash stand. In the long term the C-content in the forest soil will certainly rise in comparison with the C-content of the pasture.

The distribution of the C-content between the various compartments of a forest stand changes according to its age. In the young stands the C-content, that is assessed aboveground and belowground, is almost just as big. In the old stands the portion of soil C is much bigger. C migrates from the aboveground to the belowground, where it is accumulated. The storage capacity of the forest soil is underestimated.

The kind of tree species plays an important role in the C storage capacity of a forest. Ashes, which have an easily decomposing detritus, bring C into the soil more quickly. As a consequence this spicies brings more C into the soil. Oaks produce a detritus that is hard to decompose. Because of this a thick detritus develops in the old stand and the C migrates less easily to the soil.

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