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EFFECT OF WHOLE-TREE HARVESTING ON SOIL FERTILITY[1])

EINO MÄLKÖNEN

TIIVISTELMÄ:

KOKOPUUN KORJUUN VAIKUTUS MAAN VILJAVUUTEEN

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The biomass production of forest ecosystems is very high, primarily due to the large amounts of nutrients which are involved in the biological cycle of organic matter. Timber harvesting has greater effects on the nutrient cycle, the more efficiently the biomass of the trees is harvested in connection with cuttings.

It has been considered that traditional stemwood harvesting does not lead to impoverishment of the soil because the nutrient content of the wood is quite low. In thinning cuttings the slash remaining in the forest has a manuring effect, which is lost when whole-tree harvesting is carried out. Particularly under cool climatic conditions thinning leads to an increase in the soil temperature, and may thus make nutrient mobilization in the humus layer faster. The nutrient loss occurring in connection with heavy thinnings and whole-tree harvesting has been considered as being of such a magnitude, however, that compensation for it through fertilizer application is necessary.

In comparison with harvesting unbarked stem timber, whole-tree harvesting has been found to increase the nutrient loss at the final cutting stage as follows: in the case of N 2 to 4 times, in the case of P 2 to 5 times, in the case of K 1.5 to 3.5 times and in the case of Ca 1.5 to 2.5 times. Depending on the conditions prevailing on the site, any one of these nutrients may be the limiting factor for tree growth during the next tree generation.

On the basis of our present knowledge we cannot calculate to what extent the soil is impoverished through whole-tree harvesting, but there is reason to believe that maintaining a certain fertility level will require a considerable increase in forest fertilization and other soil improvement measures.

1. INTRODUCTION

To meet the forest industry's demand for raw material, measures have been taken to increase timber production both by improving soil fertility and through the use of better varieties of trees. Nevertheless, estimates for the growth and drain, based

[1] The paper has been presented at the Symposium on the harvesting of a larger part of the forest biomass of Joint FAO/ECE/ILO Committee on Forest Working Techniques and Training of Forest Workers, held in Hyvinkää, Finland 14—16 June, 1976.

on inventories of the available timber resources and wood consumption, indicate that a lack of raw material will become a serious problem for the forest industry in the near future. The traditional raw material, stemwood, is already almost fully harvested in many countries; in Finland, for example, on average only as little as 1.5 kg dry matter is left in the forest in the topmost part of the stem (HAKKILA 1971). This means, however, that about 40 % of the total biomass of the trees is currently unused by the forest industries. Harvesting the reserve of raw material formed by slash has a number of biological consequences, one of them being the influence on the fertility of the soil, which is our most important natural resource.

Biomass production is considerably higher in forest ecosystems than in other plant communities growing on sites with an equal level of soil fertility. This is mainly due to the large amounts of nutrients that are involved in the biological cycle between the forest soil and its plant cover. Thus, the biomass production of forest ecosystems is highly dependent on the quantities of nutrients returning to the soil in the litter as well as on decomposition carried out by soil microbes. The amount of nutrients annually bound by the tree crop is of course dependent on the stage of stand development. In a Scots pine crop, for instance, the period of highest total production coincides approximately with maximum annual current increment of the stemwood (REMEZOV & POGREBNYAK 1965). As regards annual litter production, however, only small fluctuations have been observed after canopy closure (BRAY & GORHAM 1964).

Both as a result of leaching and nutrient losses in connection with logging operations, the fertility of forest soils is gradually decreasing. Nutrient losses through leaching from natural forest soils are largely compensated for by nutrients liberated by weathering and by those which enter the soil from the atmosphere, and consequently, the natural decrease in soil fertility is a relatively slow process.

Harvesting of stemwood only has not usually been considered to have a detrimental effect on soil fertility because the nutrient content of the wood is rather low. RENNIE (1957), however, states that timber harvesting on the siliceous *Calluna* moor soils in Britain, owing to their small calcium reserves, results in a need for appropriate fertilizer application if the timber-producing capacity of the soil is to be maintained. Maintaining the fertility of the soil is in fact a problem of the very greatest importance when decisions are being made about how extensively the biomass can be harvested in logging.

The author wishes to acknowledge the comments of professors Pentti HAKKILA and P. J. VIRO.

2. NUTRIENT LOSSES IN LOGGING

21. Thinning cuttings

During the development of a tree crop from a seedling stand to a closed forest, the amount of ground vegetation diminishes. The resulting gradual death and decomposition of the ground vegetation releases large amounts of nutrients which become available to the trees at the very time when their nutrient requirement is at its greatest (OVINGTON 1959).

At this stage of stand development further growth of the stand is regulated by thinning cuttings, the effect of which on the remaining trees has usually been considered to be favourable as long as traditional stemwood harvesting methods are used. On the basis of thinning experiments it has been found that even relatively heavy thinning cuttings do not lead to a decrease in the total yield of stemwood (CARBONNIER 1974). This result may be interpreted in such a way that the increase in growth of the remaining trees is partly due to a manuring effect caused by the slash. Particularly in regions having a cool climate, thinning operations may raise the soil temperature, which in turn leads to an increase in microbial decomposing activity and to the mobilization of nutrients

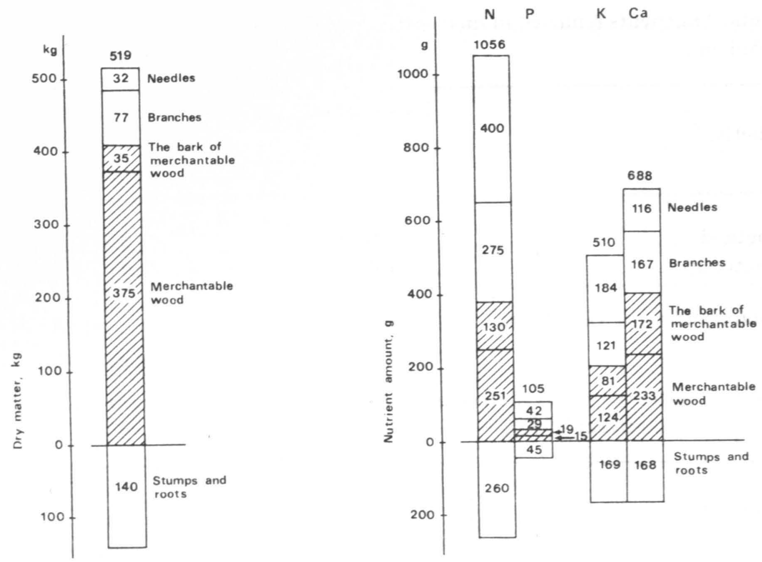

Fig. 1. The distribution of dry matter and nutrients in different tree compartments per cu.m. of mechantable wood including bark in a 45-year old Scots pine stand in South Finland.

bound by the relatively inactive layer of raw humus (WRIGHT 1957). The relatively high nitrogen content of the material reaching the ground as slash is important for the nutrient cycle because the low nitrogen content of coniferous litter limits the biological activity of the soil.

In Scots pine and Norway spruce stands at the thinning stage the tree crowns usually represent about one third of the dry matter of the trees, but contain about two thirds of the total amount of nutrients. Therefore, the nutrient situation after thinning in which whole-tree harvesting is carried out is less favourable.

On the basis of Fig. 1, for example, it can be concluded that the magnitude of the nitrogen loss incurred during logging in a thinning stand of Scots pine in South Finland is about 15 kg/ha when 40 m³/ha of wood is removed by the shortwood method, and about 42 kg/ha when the same volume is removed using the whole-tree method. Although the quantities mentioned do not seem very high, it will be necessary, under Scandinavian conditions, to compensate for the nutrient losses caused by heavy thinning and whole-tree harvesting by fertilizer application, particularly in stands growing on poor sites (TAMM 1969).

22. Final cuttings

With increasing age, an ever-greater part of the mobilized nutrient resources of a tree stand is bound in the biomass of the tree crop. Clearcutting therefore leads to a sudden change in the nutrient cycle as large amounts of organic matter and plant nutrients are returned to the ground. As the ground vegetation of a cutover area is not able to utilize as large an amount of nutrients as the removed tree crop, there is a strong increase in leaching (TAMM et al. 1974). So, for example, the increase in nitrogen leached out one year after a cutting operation may correspond to the annual nitrogen requirements of the tree crop (BORMANN et al. 1968).

The amount of nutrients removed with the stemwood depends to some extent on the age of the tree stand. At the beginning of heartwood formation, mobile nutrients such

Table 1. Amounts of nutrients removed in final cutting of a 70-year-old Norway spruce stand on a *Myrtillus* site in South Finland.

Harvesting method	Dry matter	N	P	K	Ca
	kg/ha				
Shortwood method	121 500	95	8.4	47	184
Whole-tree method[1])	197 500	372	40.6	161	409

[1]) Incl. stumps and roots Ø > 5 cm.

Table 2. Amounts of nutrients removed in connection with timber harvesting from a spruce stand during a rotation of 80 years (Kreutzer 1975).

Harvesting method	Total yield	N	P	K	Ca
		kg/ha			
Shortwood method	974 m³ merchantable wood with bark	480	42	300	570
Whole-tree method[1])		1 570	163	870	1 020

[1]) Incl. slash in thinning cuttings and slash, stumps and large roots in final cutting.

as nitrogen, phosphorus and potassium are transferred to other parts of the tree by the action of the internal nutrient cycle, whereas calcium accumulates in the stem. Consequently, the quantities of nitrogen, phosphorus and potassium removed per unit volume of wood are greater in young wood than in old.

Estimates for the nutrient losses in connection with various harvesting methods can be made, for instance, on the basis of Table 1 where the amounts of nutrients removed in final cutting under Finnish conditions are presented (Mälkönen 1973).

It is worth while comparing the maximum amounts (Table 2) removable from a fertile site in connection with thinning and final cuttings during the course of the whole rotation with the nutrient amounts presented in the preceding Table 1.

When the results from different coniferous stands are summarized, the nutrient losses in whole-tree harvesting are 2 to 4-fold in the case of N, 2 to 5-fold in the case of P, 1.5 to 3.5-fold in the case of K and 1.5 to 2.5-fold in the case of Ca in comparison to the losses in harvesting of stemwood with bark (Weetman & Webber 1972, Mälkönen 1973, Young 1973, Nykvist 1974, Kreutzer 1975). In addition, it must be pointed out that a change in favour of harvesting unbarked timber increased the nutrient loss by 1.5 to 2 times as compared with harvesting barked wood. In practice the nutrient loss is slightly smaller because, for example, the needles can not be harvested completely.

Already at the present time the whole-tree method is widely used in the Soviet Union, where off-road extraction takes place mainly in the form of skidding whole trees or stems. Whole-tree extraction has come into use for technical reasons because only small amounts of slash are used by the forest industries. Attention has been paid to the impoverishment of the forest soil caused by this harvesting method (Table 3), and compensation for the nutrient loss by the application of a corresponding quantity of nutrients is considered to form the basis for future fertilization requirements (Shumakov 1971).

Table 3. The average amounts of nutrients removed in connection with final cuttings in the European part of the Soviet Union (Shumakov 1971).

Stand category	N	P	K	Ca
	kg/ha			
Coniferous stands	356	53.6	240	388
stems	204	33.2	157	277
slash	152	20.4	83	111
Hard-wood desiduous stands	991	47.5	308	1 158
stems	750	30.5	191	858
slash	241	17.0	117	300
Soft-wood desiduous stands	757	69.8	381	798
stems	552	54.1	272	581
slash	205	15.7	109	217

3. DISCUSSION OF NUTRIENT LOSSES

In order to try and find an answer to the question of how whole-tree harvesting affects the nutrient resources in the soil, we have usually taken the amounts of nutrients bound in the biomass as the point of departure. Such an examination should be based on the nutrient balance of the forest soil, that is, on a comparison between the amounts of nutrients received by the vegetation and those removed from the soil. In this respect, however, our knowledge is rather limited; we do not know accurately enough the amounts of nutrients that are mobilized and leached during the course of the rotation.

An idea of the increasing impoverishment of the forest soil as a consequence of biomass harvesting can be gained by considering the present situation in the field of silviculture: the natural timber producing capacity of the soil is considered insufficient, and forests are fertilized on a large scale. Thus, all measures leading to an impoverishment of the soil require effective soil improvement measures in order to keep the soil fertility at its former level at least.

NITROGEN

The loss of nitrogen caused by timber harvesting is not very large in comparison with the nitrogen resources of forest soils. Forest soil usually contains several thousand kilograms of nitrogen per hectare in the form of different organic compounds. As far as forest fertilization is concerned, however, our interest has been focused on the use of nitrogen alone or combined with other nutrients. Nitrogen application has increased the yields of different tree species even on soils of varying fertility. Particularly in the northern coniferous zone nitrogen is the limiting factor with regard to the nutrient status of the soil owing to its slow mobilization (Viro 1967, Weetman & Webber 1972, Shumakov 1975). In Finland, for example, a close correlation has been found to exist between the nitrogen content of the topsoil and the site type (Table 4). Most of nitrogen present in the humus layer, however, is in the form of relatively stable compounds which break down at a slower rate than the bulk of the slash. During the initial phase of development of a new tree generation a substantial part of the exchangeable nitrogen comes from decomposing slash. Thus, the nitrogen occurring in slash is of considerably greater importance for the nutrient status of the site than is indicated by a mere comparison between the nitrogen content of slash and the topsoil. The loss of

Table 4. Amounts of organic matter, total nitrogen, easily soluble phosphorus, exchangeable potassium and calcium in various site types in South Finland (VIRO 1969).

Site type	Org.	$N_{tot.}$	P	K	Ca
	t/ha	kg/ha			
Vaccinium type	85.4	2 341	26.5	125.3	236.7
Myrtillus type	99.4	2 836	27.3	141.8	297.1
Oxalis-Myrtillus type	111.2	3 492	22.8	165.1	588.9

organic matter and nitrogen caused by whole-tree harvesting may consequently be of much greater importance particularly in the case of infertile mineral soils.

Depending on both climatic and edaphic factors the extent of nitrogen replacement may vary very much. Under the conditions prevailing in Central Europe, for instance, the nitrogen balance of the soil may still be positive even after whole-tree harvesting has been carried out, as a result of fast nitrogen mobilization and of heavy nitrogen pollution (KREUTZER 1975). In these circumstances the nitrogen resources of forest soil can be enriched by cultivation of lupine, too.

PHOSPHORUS

As was earlier explained, a change from stemwood harvesting to whole-tree harvesting leads to the greatest losses in the case of phosphorus. Under conditions in which nitrogen fixation and mobilization are effective, the whole-tree system has the greatest effect on the phosphorus balance (BINNS 1975).

In the conditions prevailing in Finland evidence of phosphorus deficiency has been observed after nitrogen application, particularly on fertile sites (VIRO 1967), and this gives reason for the assumption that the phosphorus resources of the forest ecosystem are utilized to in a high degree. There is a considerable variation in the phosphorus content of the soil, but slight negative correlation has been found to exist between the phosphorus content and the site type (Table 4).

POTASSIUM

Of the total amount of mobilizable nutrients in the forest, potassium accumulates in the biomass in relatively the greatest amounts (e.g. MÄLKÖNEN 1974). Binding of potassium ions with organic substances is so loose that stable organic potassium compounds do not occur. Owing to its high water solubility, the potassium cycle is very rapid and most of the total potassium in humus is in an exchangeable form. After whole-tree harvesting the replenishment of potassium is greatly dependent on weathering.

CALCIUM

It has not been established whether there is any real deficiency of calcium as a plant nutrient in forest soil, although it has been found that there is a close correlation between the calcium content and the site index (VIRO 1951, LINTEAU 1955). The favourable effect of calcium is due in the first place to the fact that it speeds up nitrogen mobilization in the humus layer. For this reason nitrogen probably becomes a limiting factor earlier than calcium in the case of sites poor in nutrients.

4. ORGANIC MATTER

The nitrogen cycle in the soil is to a large extent part of the so-called biological system (JANSSON 1971), that is, of the process of organic matter formation and decomposition. Moreover, the quantity and quality of humus is of importance both for the nutrient- and water-holding capacity and for the structure of the soil. Nutrient losses can be compensated for by fertilizer application, but the decrease in the humus supplies caused by whole-tree harvesting may under certain conditions be a more severe problem.

In the coniferous zone the decomposition of humus, and simultaneously, the nutrient cycle, is slow, and hence organic matter may accumulate in large quantities in the soil. Increased decomposition of the humus is thus the aim of various soil improvement measures.

In the temperate zone as much as 30 to 50 % of the humus may be broken down after clearcutting and soil preparation (ULRICH & WACHTER 1971). As there is a decrease in the humus formation as a result of slash harvesting, mineralization of such an intensity may lead to nitrogen deficiency in addition to other negative effects on soil properties in general. For example, in Wisconsin HABERLAND and WILDE (1961) obtained high water losses and appreciably lower amounts of organic matter and total nitrogen in the topsoil due to accelerated litter decomposition after heavy thinning. Thus, some of the biological consequences for soil which may be detrimental in one situation may be innocuous (cf. BOYLE et al. 1973) or beneficial in another.

5. CONCLUSION

On the basis of the data at present available it is not possible to calculate to what extent the soil is improverished as a result of whole-tree harvesting, but there is reason to believe that at least in the case of poor soils the decrease in fertility is considerable. As the aim of present day forestry is to achieve the most effective and long-lasting utilization of nutrient resources in forest soils, whole-tree harvesting does not seem to be an attractive idea. The detrimental effect of fuller biomass harvesting will naturally be smaller if only stump and root wood is harvested or if harvesting methods can be developed so that needles or leaves will remain in the forest. In any case, an increase in the extent of biomass harvesting requires more detailed studies of the need for fertilization and basic improvement measures than have been carried out so far.

REFERENCES

BINNS, W. O. 1975. Whole tree utilization — consequences for soil and environment — experience and opinion in Britain. Whole-tree utilization — consequences for soil and environment, pp. 18—25. Elmia 75. Jönköping. Mimeograph.

BORMAN, F. H., LINKENS, G. E., FISHER, D. E. & PIERCE, R. S. 1968. Nutrient loss accelerated by clear-cutting of a forest ecosystem. Science, 23: 882—884.

BOYLE, J. R., PHILLIPS, J. J. & EK, A. R., 1973. Whole tree harvesting: Nutrient budget evaluation. J. For., 71: 760—762.

BRAY, J. R. & GORHAM, E. 1964. Litter production in forests of the world. Adv. Ecol. Res. 2: 101—157. Akad. Press. New York — London.

CARBONNIER, C. 1974. Preliminära resultat från ett gallringsförsök i planterad granskog. Summary: Preliminary results from a thinning experiment in a Norway spruce plantation. Rapp. Uppsats. Instn. Skogsprod. Skogshögsk., 29.

HABERLAND, F. P. & WILDE, S. A. 1961. Influence of thinning of red pine plantation on soil. Ecology 42: 584—586.

HAKKILA, P. 1971. Coniferous branches as a raw material source. Commun. Inst. For. Fenn. 75.1.

JANSSON, S. L. 1971. Use of ^{15}N in studies of soil nitrogen. Soil Biochemistry 2: 129—166. Marcel Dekker. New York.

KREUTZER, K. 1975. Der Einfluss de Wirtschaftsführung auf den Nährstoffhaushalt mitte-

leuropäischer Wälder. Helträdsutnyttjande — Konsekvenser för mark och miljö, pp. 20—30. Elmia 75. Jönköping. Mimeograph.
LINTEAU, A. 1955. Forest site classification of the north-eastern coniferous section of the boreal forest region, Quebec. Can. Dep. North. Aff. Nat. Resour, Bull 118.
MÄLKÖNEN, E. 1973. Effect of complete tree utilization on the nutrient reserves of forest soils. IUFRO Biomass Studies, pp. 377—386. Univ. Mine. Orono.
— » — 1974. Annual primary production and nutrient cycle in some Scots pine stands. Commun. Inst. For. Fenn. 84.5.
NYKVIST, N. 1974. Växtnäringsförluster vid helträdsutnyttjande. Rapp. Uppsats. Instn. Skogstek. Skogshögsk., 76: 74—93.
OVINGTON, J. D. 1959. The circulation of minerals in plantations of Pinus sylvestris L. Ann. Bot. 23.90.
REMEZOV, N. P. & POGREBNYAK, P. S. 1965. Лесное почвоведение. Изд. Лесная пром. Москва.
RENNIE, P. J. 1957. The uptake of nutrients by timber forest and its importance to timber production in Britain. Quart. J. For., 51: 101—115.
SHUMAKOV, V. S. 1971. Применение минеральных удобрений в лесах. Summary: Application of mineral fertilizers in forests. Лесоведение, 4: 71—79.
— » — 1975. Применение минеральных удобрений в лесах СССР. Лесное хозяйство, 10: 37—40.
TAMM, C. O. 1969. Site damages by thinning due to removal of organic matter and plant nutrients. Thinning and mechanization. Proc. IUFRO meet., pp. 175—177. Stockholm.
— » — , HOLMEN, H., POPOVIC, B. & WIKLANDER, C. 1974. Leaching of plant nutrients from soils as a consequense of forestry operations. Ambio, 6: 211—221.
ULRICH, B. & WACHTER, H. 1971. Bodenkundliche Gesichtspunkte zur Frage der Bodenbearbeitung im Wald. Summary: Some aspects of soil preparation in forests. Allg. Forstu. Jagdztg. 142: 257—265.
VIRO, P. J. 1951. Nutrient status and fertility of forest soil. I Pine stands. Commun. Inst. For. Fenn. 39.4.
— » — 1967. Forest manuring on mineral soils. Medd. Norske Skogforsøksv., 85.23.
— » — 1969. Prescribed burning in forestry. Commun. Inst. For. Fenn. 67.7.
WEETMAN, G. E. & WEBBER, B. 1972. The influence of wood harvesting on the nutrient status of two spruce stands. Canad. J. For. Res., 3: 351—369.
WRIGHT, T. W. 1957. Some effects of thinning on the soil of a Norway spruce plantation. Forestry 30: 123—133.
YOUNG, H. E. 1973. Biomass, nutrient elements, harvesting and chipping in the complete tree concept. Tenth Res. Conf. API-TAPPI College Relation Groups, 1—20.

TIIVISTELMÄ: KOKOPUUN KORJUUN VAIKUTUS MAAN VIJAVUUTEEN

Metsikön biomassan tuotos on muihin kasviyhdyskuntiin verrattuna huomattavan korkea lähinnä sen suuren ravinnemäärän ansiosta, joka metsikössä sisältyy biologiseen kiertokulkuun orgaanisen aineen mukana. Puunkorjuu aiheuttaa ravinteiden kiertokulkuun sitä suurempia seurannaisvaikutuksia mitä tarkemmin puun biomassa otetaan talteen.

Perinteisen runkopuun korjuun ei ole yleensä katsottu köyhdyttävän metsämaata, koska puuaineen ravinnepitoisuus on huomattavasti alhaisempi kuin puun muiden osien. Harvennushakkuussa maahan jäävällä hakkuutähteellä on tietty lannoitusvaikutus, joka menetetään kokopuun korjuuseen siirryttäessä. Voimakkaasta harvennuksesta ja kokopuun korjuusta aiheutuva ravinteiden menetys saattaakin olla niin suuri, että ravinteiden korvaaminen lannoitteilla on tarpeellista.

Päätehakkuun yhteydessä kokopuun korjuun on laskettu lisäävän typen menetyksen 2—4, fosforin 2—5, kaliumin 1.5—3.5 ja kalsiumin 1.5—2.5 -kertaiseksi kuorellisen ainespuun korjuuseen verrattuna. Riippuen kasvupaikan olosuhteista mikä tahansa näistä ravinteista voi osoittautua puuston kasvua rajoittavaksi tekijäksi seuraavan puusukupolven aikana.

Nykyisten tietojen perusteella ei ole mahdollista laskea, miten paljon metsämaan viljavuus kokopuun korjuun takia heikkenee, mutta on syytä epäillä, että viljavuuden ylläpitäminen tulee edellyttämään lannoituksen ja muiden maanparannustoimenpiteiden huomattavaa lisäämistä.