EnNa – A project for sustainable harvesting wooden biomass

Klaus v. Wilpert, Christian Vonderach and Dietmar Zirlewagen

Kurzfassung

EnNa – ein Projekt für die nachhaltige Ernte von Holzbiomasse

Der Bedarf an Biomasseernte im Wald steigt aktuell, wobei der Nährstoffexport mit Energieholz besonders hoch ist. Dadurch wird die Nährstoffnachhaltigkeit zu einem kritischen Problem. Jedoch ist die Holzernte nicht die einzige, und angesichts der Bodenversauerung durch Säuredeposition nicht die dominante Gefahr für die Nährstoffnachhaltigkeit.

Im vorliegenden Beitrag werden Ergebnisse aus Baden-Württemberg (Südwest-Deutschland) mit 1,4 Mio. ha Wald, einem Teil des deutschlandweiten EnNa-Projekts (Energieholzernte und Nachhaltigkeit) gezeigt. Biomasse- und Nährstoffexporte wurden aus der Bundeswaldinventur (NFI) abgeleitet. Nährstoffeinträge mit dem Regen und durch Mineralverwitterung stammen aus dem forstlichen Umweltmonitoring (FEM). Die FEM-Daten wurden mittels regionalisierten, auf multiplen Regressionsmodellen basierenden Karten auf die NFI-Punkte übertragen. Diese hatten eine Vorhersagegüte von rund 70 %.

Die Studie zeigte, dass bei den aktuellen Umweltbedingungen der vergleichsweise niedrige Nährstoffexport mit der Holzernte zur weiteren Verschlechterung der Bodenqualität beiträgt. Die Ergebnisse legen zwei Strategieansätze nahe:

- *Wenn die mit der Holzernte exportierten Nährstoffe durch Holzasche-Recycling zurückgeführt werden, können Defizite der Nährstoffbilanzen ausgeglichen werden. Dafür wäre ein Wiederholungsturnus von ungefähr 85 Jahren nötig.*
- *Die Ernteintensität könnte über alle Sortimente so lange reduziert werden, bis die Nährstoffbilanzen ausgeglichen sind. Das würde einen Nutzungsverzicht von rund 36 % bedeuten.*

Authors

Klaus von Wilpert

Christian Vonderach
Forest Research Institute Freiburg
Freiburg/Germany

Dietmar Zirlewagen
INTERRA, Bureau for Environmental
Survey and Research
Kenzingen/Germany

Introduction, problem and aim of the study

Nutrients circulate nearly without loss in natural, unmanaged forest ecosystems. Mineral weathering fully compensates the low losses [1]. Re-cycling and mobilisation of nutrients take place from comparably stable binding in organic substance or stable minerals of the bedrock (silicates, carbonates). Thus, nutrient export with seepage water gets minimised.

Human impacts, however, have substantially accelerated nutrient export in Central Europe since decades. Reasons are on the one hand acid deposition and subsequently increased element export with seepage. On the other hand intensified harvest intensity and new harvesting techniques extracting more nutrient – rich tissues (e.g. twigs or bark) result in increased nutrient export. Both, the load, caused by environmental change, and increased nutrient export, have to be quantified in order to judge nutrient sustainability of any harvesting strategy.

An increasing demand on biomass harvest for energy production and/or as raw material for the chemical industry, results from actual political efforts towards increasing the proportion of energy supply and chemical raw materials from renewable sources [2, 3]. Forest timber is the largest wood biomass pool accessible for renewable energy production.

The overall aim of the EnNa project (Energieholzernte und Nachhaltigkeit/energy wood harvesting and sustainability), funded by the German Ministry for Nutrition and Agriculture (funding code 22006512), is to determine the amount of wooden biomass which can be harvested without violating nutrient sustainability is to develop a methodical frame for the quantification of the fuel wood potential which can be mobilised in a sustainable way. The term "sustainability" is not restricted to the fuel wood amount, but mainly focussed on nutrient availability in that context. The overall aim of the project is to develop valid instruments for the spatially discrete determination of the fuel wood potential with synchronously maintaining or re-enabling nutrient sustainability.

The project is based on a pilot-study which was conducted in the pre-alpine glacial region in Baden-Württemberg, South-West Germany during the years 2007 to 2010. The pilot region is characterised by an over-proportionally wide range of soil qualities, from rich calcarious sediments to poor, heavily acidified sands. Thus, it provided a sound basis for transferring the results to the whole federal state of Baden-Württemberg with around 1.4 m ha forest area.

Methods

Biomass information has been quantified individually at each of the 13,000 sampling points of the National Forest Inventory (NFI), clustered in about 4,500 locations and spread over the whole Federal State of Baden-Württemberg in a 2 x 2 km grid. Assortment masses and biomass compartments have been determined by means of the computer software "Waldentwicklung und Holzaufkommens Modellierung" WEHAM (forest development and modelling of wood production) [4].

Quasi continuous maps (technical resolution 25 x 25 m) on soil properties were extrapolated from the 8 x 8 km grid points (304 sampling locations) of the soil survey by means of multiple linear regression models using landscape morphology, geologic and soil characteristics as transfer keys [5]. Thus, the soil information – needed for calculation of nutrient balances – to the NFI sampling points could be transferred. The nutrient amount exported with harvested wood biomass was calculated as product of assortment masses (or biomass compartment masses) calculated individually for different harvesting strategies with WEHAM and the nutrient concentrations determined by compartment-differentiated measurements on 1,035 trees sampled in the Federal States of Bavaria, Rhine-Palatinate, Baden-Württemberg and Lower Saxony from different precedent projects [6, 7].

Two different harvesting strategies were modelled on this basis. The nutrient effect of these strategies was dominated by the fact that nutrients will be "lost" for the nutrient cycle of the stand when biomass compartments and with them their nutrient content is exported or accumulated on skid trails, if they remain, well distributed on the stand area or their nutrient content re-cycled with wood-ash, they will remain in the nutrient cycle.

One of these scenarios was "substantial use max." where the harvest of substantial

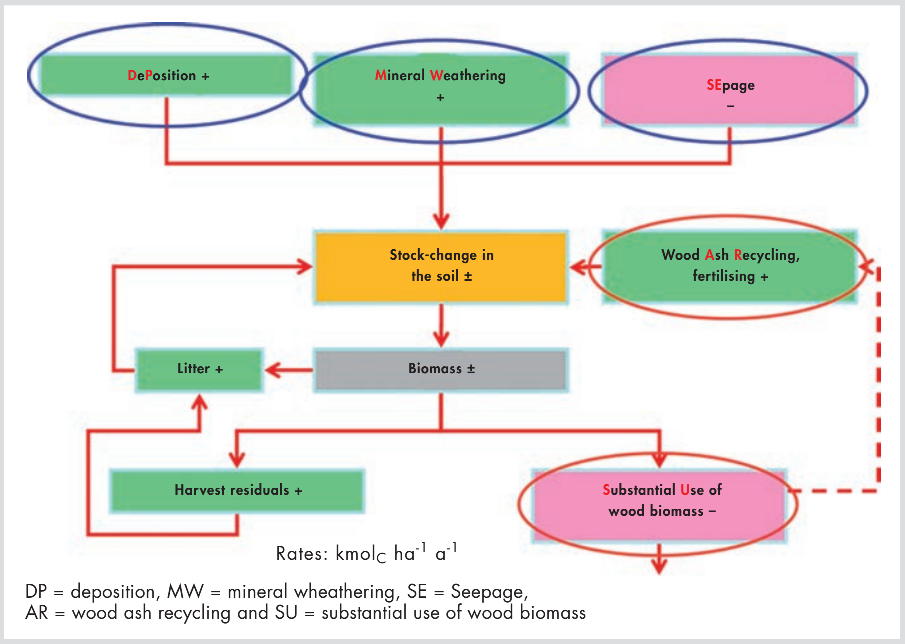


Fig. 1. Matter fluxes with timber harvest and compartments of element balances.

timber assortments have been maximised (trunk wood and industrial wood) and all non-timber biomass remained on the stand area – in case of fully mechanised harvesting technique the potentially harvestable crown biomass was accumulated on the skid trails. The other (“real harvest”) was to extract all harvestable biomass to use only the trunk wood and the coarser parts of industrial wood as timber, and to use all other biomass (including the smaller parts of industrial wood) as fuel wood where the wood ash can be re-cycled.

Quantification of the nutrient sustainability was achieved by spatially discrete calculation of nutrient balances. They were calculated individually at all NFI grid points. They comprise nutrient input with deposition, nutrient mobilisation with mineral weathering, nutrient export with seepage water and with wood biomass harvest (Figure 1).

According to Figure 1 the nutrient balance is the sum of five balance elements:

- nutrient balance =
  (DP + MW – SE) + (AR – SU)

There the first term (DP+MW-SE) represents the soil balance without the influence of harvest where nutrient input is generated by deposition (DP) and mineral weathering (MW) and nutrient export by seepage (SE). The latter is unnaturally increased in Central Europe through acid deposition and subsequent soil acidification. The second term in the formula represents the management impact consisting of nutrient export with substantial use of wooden biomass (SU) and nutrient input through wood ash re-cycling (AR).

The single balance elements are derived from regular environmental monitoring data: the nutrient input with deposition from deposition measurements in the Level II network, the mobilisation of nutrients from mineral weathering from the base saturation of soil monitoring data, the nutrient export with seepage water from mean element concentration measured in the water extracts derived from soil monitoring which are multiplied with mean water fluxes as assessed by means of pedotransfer functions based upon primary soil physical parameters of soil monitoring. Nutrient exports with timber harvest are the product of assortment masses from NFI and nutrient content in biomass-compartments measured at 474 spruce- and 561 beech trees. The compartment-wise measurements of nutrient contents were provided by additional measuring campaigns, from projects complementing routine monitoring data. All five balance elements displayed a comparable mean amount in the project region and thus were comparably important for nutrient sustainability: nutrient deposition (calcium, magnesium and potassium) in the average 0.7 kmol$_c$/ha/a, mineral weathering 1.2 kmol$_c$/ha/a, export with seepage 0.8 kmol$_c$/ha/a and export with timber harvest respectively to harvesting scenarios, as well as assumed wood ash re-cycling between 0.8 and 1.2 kmol$_c$/ha/a [8].

A simplified balance approach, based only on soil stock and nutrient-export with harvest was used for trace nutrients, particularly phosphate as export with seepage is minimal.

Multiple linear regression functions have been fitted to the statistical material of wood biomass assortment data and nutrient balance data at the 523 NFI sampling points in the pilot-region in order to transfer this information from the discrete sampling points to the whole forest area, where they are needed as decision support tools for sustainable forest management. Transfer keys for the biomass data were stand parameters (tree species, age, height and stand density) from local forest inventory data, as well as landscape morphology characteristics derived from a digital height model. The same stand parameters as for assessment of wood biomass pools were chosen as transfer keys for extrapolation of nutrient deficits caused by timber harvest. The same applies to the parameters on landscape morphology and additionally to those parameters from soil and geological maps. These regressions for the assessment of fuel wood potentials and nutrient balances (here presented for potassium) showed no assessment bias and could explain between 60 and 70 % of the parameter variance (Figure 6). The data for derivation of those transfer functions have been split into a training-data set for model development and a second data set for validation of the model quality. The proportion of explained variance decreased with the model application to the validation data set only by 3 to 5 %. Thus, in all stands or forest enterprises, where sufficiently detailed inventory data are available the information on biomass pools and nutrient balances can be transferred applying those transfer functions.

Results

The spatial variability of nutrient-balances is substantially high and depends much on stand and soil properties. The main predictor of those target variables is the harvested wood biomass, and the soil properties or the age of stands play a secondary role. The balance elements “mineral weather-

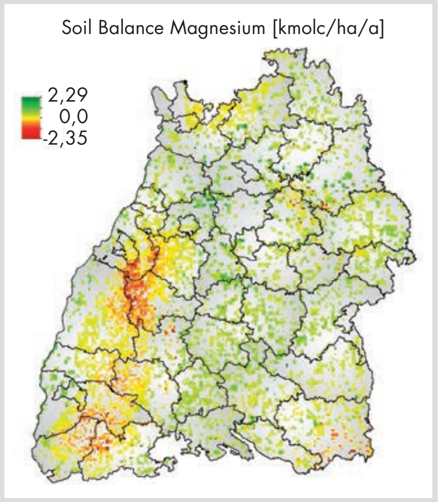


Fig.2. Amount of the soil balance for magnesium in Baden-Württemberg. At loamy areas the balance between mineral weathering, deposition and seepage is positive (green colours) and in the stony, sandy areas on poor bedrocks in the Black Forest, the southern part of the pre-alpine moraine region and the sandy parts of Keuper hills it is negative (red colours).

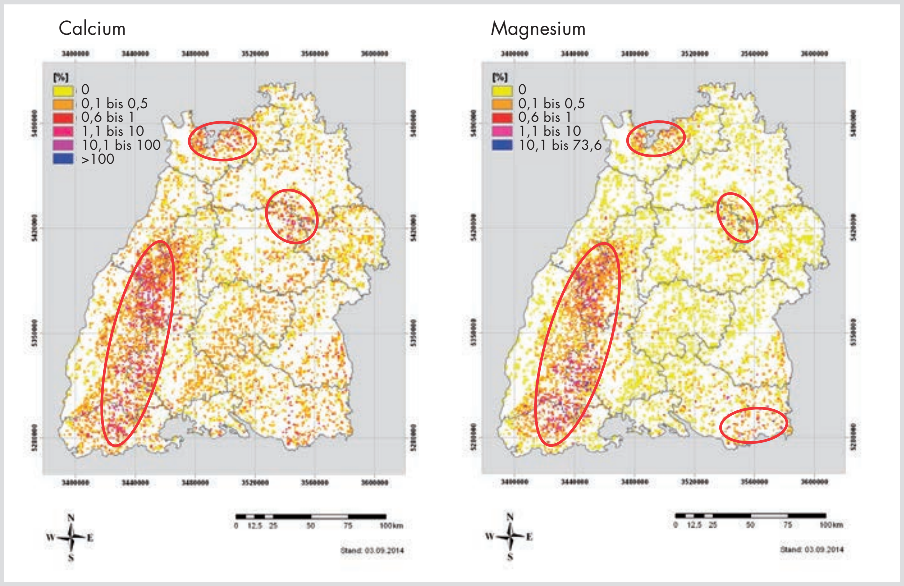


Fig. 3. Total nutrient balances for calcium (left) and magnesium (right) in relation to the element stock in the soil (%). Nutrient export with harvest has been calculated for the harvesting regime “real” where trunk wood, industrial wood and fuel wood were harvested.

ing” and “nutrient export with seepage”, obviously depend more on geological and soil factors. This high spatial variability of nutrient balances can easily be equalised via soil protective liming which should be combined with wood-ash re-cycling in order to supplement the nutrient content of dolomite lime with the essential trace nutrients potassium and phosphorous.

Due to the environmental conditions in Central Europe and the deposition history there, even the soil balance without any impact of harvest is substantially negative in some distinct areas of Baden-Württemberg as presented in Figure 2 for the example of magnesium.

The negative soil balance result from the deposition-driven soil acidification and the unnaturally high nutrient export with seepage water. This example demonstrates that the problem of nutrient sustainability of harvest mainly gets crucial through deposition- and acidification history of sites.

The total nutrient balances, including nutrient export with harvest, are negative for calcium for nearly the whole state of Baden-Württemberg with high-deficit areas in the Black Forest, Oden Forest and the sandy regions of the Keuper Hills. Only on a few sampling points, scattered around the state without clustering, the soil calcium stock is not depleting. For magnesium in more or less the same hot-spot areas high deficits could be detected, but in all other parts of the state magnesium balances are levelled or positive (Figure 3). This means that only in the areas with high actual magnesium deficits the soil magnesium stock must be claimed to level the magnesium balance.

A need for nutrient re-cycling does only exist where the total nutrient balances are negative. On these sampling points, the frequency distributions of soil balance values are with about half of the values in the negative range in the case of calcium and with about two thirds negative for magnesium. The soil balances for potassium are with very few single exceptions in the positive range (Figure 4). Harvest with the actual intensity causes for all elements nutrient exports with the highest losses for calcium and the lowest for magnesium.

The medians of the frequency distributions in Figure 4 are summarised in Table 1. The medians of the soil balance are slightly positive for calcium and potassium and slightly negative for magnesium. Nutrient export with harvested wooden biomass, including all assortments according to the actually real harvesting intensity is for calcium with the median of 0.66 kmol$_c$/ha/a

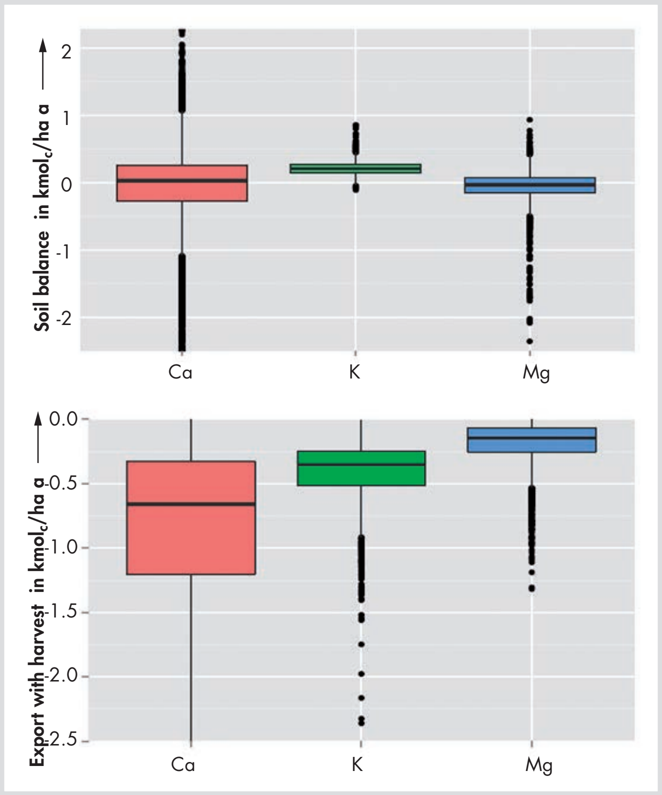


Fig. 4. Nutrient recycling need for all sampling points with total balances below zero. Soil balances for calcium, potassium and magnesium (above) and nutrient export with harvest (harvesting regime “real”) for the same elements (below). Boxes comprise median and 25 to 75 % percentiles, whiskers 5 to 95 %, dots extreme values. The sum of soil balance and export with harvest indicates the compensation need.

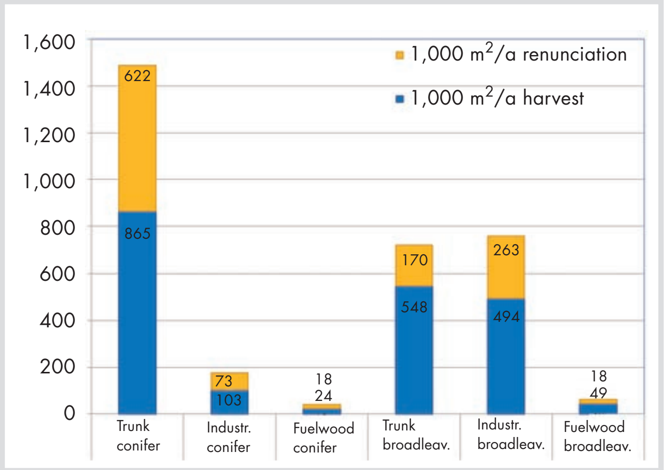


Fig. 5. Amount of harvesting reduction in order to level out deficits of nutrient balances for the state forest Baden-Württemberg and the actual harvesting intensity. The harvest renunciation is not restricted to the less valuable assortments rather than is distributed to all assortments more or less equally.

Tab. 1. Average need of compensation for the macro-nutrients calcium, potassium and magnesium in ion-equivalents (kmolc/ha/a).

	Calcium	Potassium	Magnesium
Soil balance	+ 0.03	+ 0.21	– 0.03
Harvest export	– 0.66	– 0.35	– 0.14
Sum = need for compensation	– 0.63	– 0.14	– 0.17

highest and about double the value of potassium and quadruple for magnesium.

Since calcium has the highest balance deficit in the total nutrient balance and as most of the areas showed calcium deficits, the balance deficit of 0.63 kmol$_c$/ha/a can be taken as indicator for the assessment of the mean compensation need in Baden-Württemberg. This is supported by the fact that the areas with high balance deficits are mostly congruent for all three nutrients (Figure 3). For the whole forest area of 1.4 m ha the compensation need then would be 882,000 kmol$_c$/ha/a Ca+Mg+K, which corresponds to 65,725 t/a dolomite/wood ash mixture with a total carbonate content of 75 % being the quality bench mark for the practical use of this mixture in Baden-Württemberg. The usual dosage in practise is 4 t/ha resulting in a yearly amount of 16,430 ha where dolomite/wood ash mixture has to be spread. This would cause costs of about 320 €/ha, including material, logistics and distribution in the forest. Thus, the compensation costs would be in the average of about 5.3 m €/a for Baden-Württemberg. The repetition period on individual forest sites can be assessed, if the yearly compensation area is related to the whole forest area of 1.4 m ha and amounts to about 85 years. Thus, roughly one campaign of nutrient re-cycling with 4 t/ha dolomite/wood ash mixture has to be foreseen per forest rotation period in order to guarantee nutrient sustainability of the actual harvesting intensity under given environmental boundary conditions.

There is an alternative discussed in the public to reduce the actual harvesting intensity until the deficits of nutrient balances would be levelled out. This approach shows the evident shortcoming that already the soil balances for all three elements, but mainly for calcium and magnesium, are in some areas substantially negative without any harvesting impact (Figure 2). Nevertheless the harvest renunciation is presented in Figure 5, which would be necessary to equilibrate deficits in nutrient balances. Reflecting partially negative soil balances this is a statistical and average-oriented information. When soil balance was negative or zero, no harvest was allowed. In all cases with positive soil balances the amount of renunciation was derived by reducing the harvested biomass stepwise at each of the about 13,000 sampling points, beginning with the least valuable assortment fuel wood. The presentation is related to the state forest of Baden-Württemberg where the most complete overview over harvest intensity is available from a consistent booking system.

Figure 5 shows the highest amount of renunciation for coniferous assortments as compared to broad leaved ones. But for both tree species groups the renunciation needed to equilibrate negative nutrient balances is unexpectedly high, also for the most valuable assortment trunk wood. For coniferous trees the trunk wood renunciation would be 622,000 m^3/a, of the potential harvest of 1.49 m m^3/a, and for broad leaved species 170,000 m^3/a, of potentially 718,000 m^3/a. These findings result from the fact that coniferous tree species are growing mostly on poorer sites with lower soil nutrient stocks as broad leaved tree species. The relative proportion of renunciation to the actual harvesting intensity, and the allowable harvest with respect to nutrient sustainability are summarised in Table 2. The over-all result is that roughly 36 % of the actual harvesting intensity as an average over all assortments and tree species would be needed, if nutrient balances should be equilibrated by means of reduction of harvesting intensity.

Downscaling functions which allow for the transfer of fuel – wood potentials and nutrient balances from NFI sampling points to the area, where practical forest management takes place, are exemplarily presented for a 8,300 ha wide forest district in Figure 6 for the spatial distribution of the need for potassium compensation. The figure displays a latent potassium deficiency (purple) in the model area with a subordinate proportion of positive balance values in its northern part (green). Thus, the need

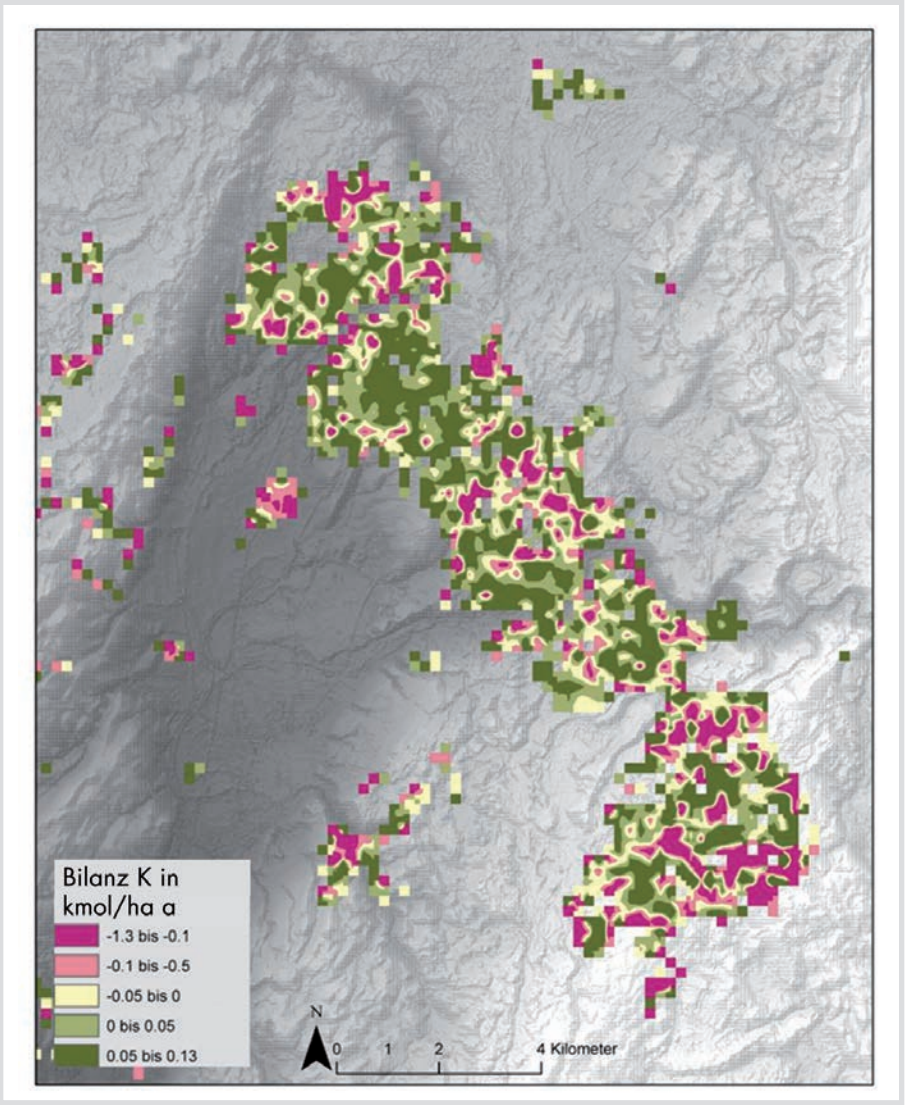


Fig. 6. Spatially discrete assessment of the nutrient balances for potassium by means of multivariate regression modelling, for an 8,200 ha wide test stand. Data have been transferred from NFI grid points to the whole area by multiple linear regression technique. The technical resolution in space is 25 x 25 m.

Tab. 2. Distribution of harvest renunciation (% of the actual harvest intensity) over the assortments trunk wood, industrial wood and fuel wood for broadleaved and coniferous tree species.

Assortment	Renunciation [%]	Sustainable harvest [%]
Broad leved fuelwood	28.3	71.7
Coniferous fuelwood	42.9	57.1
Broad leaved industrial wood	34.8	65.2
Coniferous industrial wood	41.5	58.5
Broad leaved trunk wood	23.7	76.3
Coniferous trunk wood	41.8	58.2
Weighted average	35.9	64.1

for nutrient compensation is quantified in small scaled spatial patterns.

With the example of downscaling of potassium compensation needs, it could be demonstrated that with the stochastic downscaling models including forest inventory data, practical decision support instruments could be derived at a small-scaled range being relevant for forest management decisions. Wood ash should be added to conventional soil protective liming at the areas where potassium deficiencies are indicated.

Technique of nutrient re-cycling through wood – Ash re-cycling

Wood ash is predominantly suited for supplementing the buffer capacity of forest soils because of its high base content. Relevant components for forest nutrition are the macro nutrients calcium and magnesium and the trace elements potassium, which is predominantly relevant at loamy soils and phosphorous, being of high relevance at sites with biologically inactive raw – humus sites. The latter can replace the relatively expensive addition of raw phosphate which was usual at these sites in the past. But also heavy metal contaminations are accumulated in wood ashes like the other useful mineral components. Critical elements are cadmium, chrome and lead. Heavy metal concentrations are decisively influenced by the kind of burning material. Span plates, impregnated wood and wood with coloured paint cover lead to by orders of magnitude higher heavy metal loads as untreated natural timber.

Precondition for the re-cycling nutrients with wood – ash to forests is a clearly organised regulation of wood ash – re-cycling and secure quality assurance rules. The following rules have been fixed in Baden-Württemberg:

- Only wood ash from natural, untreated wood biomass is allowed for re-cycling in the forest.
- No filter dust is allowed to be used, because they are much more contaminated with heavy metals and must be treated as dangerous waste.
- The heavy metal thresholds of the fertiliser regulation laws have to be met, checked and the checks documented.
- Wood ash re-cycling should normally be combined with soil protective liming and the proportion of wood ash should not exceed 30 % in the mixture with dolomite lime.

An important aim of the project is to identify the technical options for wood ash re-cycling. Together with two limestone works the technical process of mixing dolomite rock powder with wood ash has been optimised where physical homogenisation of wood ash was the most critical task. Thus, dolomite/wood ash mixture was developed as a new, well standardised product for soil protective liming. This product was distributed during a pilot project in 2008 and 2009 at about 1,561 ha with a dosage of 4 t/ha. The results on the project and accompanying quality checks showed that thresholds prescribed in environmental regulations and laws can be met without problems. The following product properties have been proven to be realistic: 75 mass% total carbonate, 12 mass% MgO equivalents, 1.5 mass% K_2O equivalents and 0.5 mass% P_2O_5 equivalents.

The costs for production of the new product are about 15 to 20 % higher than conventional dolomite rock powder. This is mainly due to the technical effort for homogenisation of wood ash which tends to build clods because of their hydraulic property (Figure 7). Thus, mean realistic costs for re-cycling the nutrients, exported by harvest, have been identified for the project region with about 4 €/ha/a. With that measure Ca and Mg deficits will be totally resolved but for the trace elements K and P only about 80 to 90 % of the exported nutrient amount will be re-cycled since the content of these trace elements in the dolomite/wood ash mixture is low. But full re-cycling of the trace elements is not forcing, since their effect for forest nutrition is more dominated by plant availability as by their soil stock amount and plant availability is in acidified forest soils enhanced with soil protective liming.

Conclusions

Finally we can state that under the influence of deposition-driven nutrient depletion and acidification of forest soils in Central Europe the actual harvesting intensity will be not sustainable at many sites on the long-run. Additionally the actual, highly mechanised harvesting techniques extracts more nutrients as would be exported with motor manual harvesting techniques where more nutrient-rich biomass compartments like bark and twigs would remain quite well distributed on the stand area. The main factor is the export of the over-proportionally nutrient-rich bark with trunk wood harvest. Mechanisation was introduced in forest management during the last 20 to 40 years. This took place in coincidence with the phase of highest acid deposition in Central Europe resulting in heavy soil acidification with subsequent nutrient leaching. Setting aside and ignoring this latent load for nutrient sustainability in Central European forests, and a "business as usual", which is oriented mainly on short-term economic prosperity, will contradict the postulate for resource sustainability in forest management. Harvesting strategies have to be identified and judged in a trans-disciplinary way, which combine sustainability in terms of forest, products, nutrient resources and economic suitability in the sense of an optimised compromise. Thus, maximisation of the politically sensible fuel wood harvest could be pursued and soil quality maintained and/or developed at the same time. The EnNa

Fig. 7. The tendency of wood – ash to generate clods because of its hydraulic properties (left), mechanical homogenisation and mixing with dolomite rock powder in limestone – works (centre), distribution of the mixture with helicopter (right).

project could demonstrate that the assessment of fuel wood potentials and compensation needs at the basis of routine forest monitoring data is possible in a statistically reliable way, and can be transferred to small scaled forest enterprises and forest stands. Thus, a reliable instrument for sustainability management as well as for supporting economic management decisions is available, which meets the demand of [10] for "good practice guidance of the use of residual wood biomass in the forest". Responsible fuel wood harvest opens the technical option to re-cycle nutrients to forests – predominantly to forests with artificially acidified soils and comparably high harvest intensities.

The concept presented, is open for different strategic approaches and normative settings. It can serve to define the nutrient compensation demand as well as a quantitative data base for the definition of a harvesting threshold above which nutrient sustainability will be endangered, like [11] and [12] suggest to be observed through harvesting renunciation. In that case it has to be clarified that harvesting renunciation cannot be restricted to fuel – wood harvest rather has to be applied on all harvested assortments. But we have to keep in mind that with substantial reduction of harvesting intensity not only crucial economic losses would occur rather than losses of environmental services like carbon fixation in forest products and avoidance of fossil energy sources through substitution with wooden biomass [13]. If we compare the additional costs for nutrient re-cycling amounting to about 4 €/ha/a with the economic loss by reduction of the harvesting intensity by in average 36 % in relation to the actual harvesting intensity, the harvesting reduction would cost about 230 €/ha/a [14]. This would be about 58-times the compensation costs. Only the renunciation of trunk wood – the most valuable assortment – has been considered in this calculation. Thus, the real economic loss would be even slightly higher because of renunciation of industrial and fuel wood.

References

[1] Ebermayer, E.: *Naturgesetzliche Grundlagen des Wald- und Ackerbaus*, 1882.

[2] Bündnis90/Die Grünen und SPD Baden-Württemberg: Koalitionsvertrag BÜNDNIS 90/DIE GRÜNEN und der SPD Baden-Württemberg. 92 pp., 2011.

[3] German Bioeconomy Council: *Bioeconomy Policy, Synopsis and Analysis of Strategies in the G7 A report from the German Bioeconomy Council*. 58 pp., 2015.

[4] Bösch, B.: *Fachkonzept WEHAM II, Modelle und Algorithmen*. Forest Research Institute Baden-Württemberg: Internal research report, 77 pp.

[5] Zirlewagen, D., and v. Wilpert, K.: *Upscaling of environmental information – Support of land-use management decisions by spatio-temporal regionalisation approaches*. Environmental Management, 2010; http://dx.doi.org/10.1007/s00267-010-9468-4.

[6] DBU-Project: B64,B65,B67, NW-FVA: *Möglichkeiten und Grenzen der Vollbaumnutzung*.

[7] EnBW: *Biomasse-Aufkommensprognose und Kreislaufkonzept für die Wiederverwertung von Holzaschen*.

[8] v. Wilpert, K., Bösch, B., Bastian, P., Zirlewagen, D., Hepperle, F., Holzmann, S., Puhlmann, H., Schäffer, J., Kändler, G., and Sauter, U.H.: *Biomasse-Aufkommensprognose und Kreislaufkonzept für den Einsatz von Holzaschen in der Bodenschutzkalkung in Oberschwaben*. Freiburger Forstliche Forschung, Berichte, Heft 87.155 pp., 2011.

[9] v. Wilpert, K. (Hrsg.): *Holzascheausbringung im Wald – ein Kreislaufkonzept*. FVA Kolloquium in Freiburg vom 5. – 6. März 2002. Freiburger Forstliche Forschung, H. 43, 166 pp.

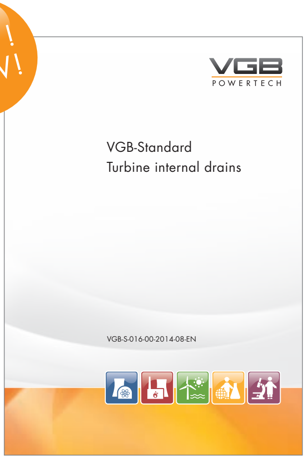
[10] Meiwes, K.J., Asche, N., Block, J., Kallweit, R., Kölling, C.. Raben, G., and v. Wilpert, K.: *Potentiale und Restriktionen der Biomassenutzung im Wald*, AFZ-DerWald, 10-11 2008, 598-603.

[11] Göttlein, A., Ettl, R., and Weis, W.: *Energieholznutzung und nachhaltige Waldbewirtschaftung – ein Zielkonflikt? In: Rundgespräche der Kommission für Ökologie*, Bd. 33 „Energie aus Biomasse", 87 – 95., 2007.

[12] Kölling, CH., Göttlein, A., and Rothe, A.: *Energieholz nachhaltig nutzen – Biomassenutzung und Nährstoffentzug*. LWF aktuell, 61, 32-37, 2007

[13] Pistorius, T.: *Die Bedeutung von Kohlenstoffbilanzen im Diskurs über die Einbindung der Forstwirtschaft in die nationale Klimapolitik*. Dissertation Univ. Freiburg. 252 pp., 2007.

[14] Möhring, B.: *Die wirtschaftliche Lage der privaten Forstbetriebe 2012 im forstlichen Betriebsvergleich Westfalen-Lippe*; www.waldbauernverband.de/2010/cms/upload/pdf-files/betriebsvergleich_2012.pdf



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