# Summary – Results of the national soil inventory “BZE II” in Bavaria

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The data of 372 Bavarian plots of the national soil inventory (BZE II) gives an overview of the essential properties of the forest soils in Bavaria. The main focus is on the physical and chemical soil parameters which substantially affect forest growth. The results show not only the site specific distribution of values in soil profiles but also the diversity on an ecosystem level inside the forest growth regions of Bavaria. The data are the basis for further analyses on the relationship between soils and forest growth, crown condition, forest nutrition and forest vegetation.

As an inventory, the BZE aims to provide an unbiased estimate of the actual state of forest soils. Due to the regular sampling grid all over Bavaria, the BZE compliments other monitoring programs and experiments which are not able to cover the whole country. Another goal is to identify fundamental ecological principles and processes. Those findings might be able to be regionalized with the help of the BZE data. The surveys of forest nutrition within the scope of the BZE II also demonstrates how different monitoring programs interlock. For example, the long term time series of the Bavarian forest climate stations (WKS) show that the needle sampling of the BZE II in the years 2006-2007 satisfactorily represented the average condition of Bavarian forests. Dynamic forest nutritional changes over time can hardly be detected with surveys which only take place every ten or twenty years. Trends and effects that were detected within the monitoring programs, however, can be checked and verified by the BZE II data at a state wide level. The German wide harmonized investigative programs of the BZE II have a high value for science and praxis since the inventory allows for a wide range of analyses. The data describe the typical range of values for Bavaria and provide a solid base for comparisons during consultations (see „Ertrag und Nutzen der BZE II in Gegenwart und Zukunft“ in this volume).

## Possibilities to compare data from WBI and BZE II and results from merged inventory grids

The BZE II is a repeated sampling. In comparison to the antecedent forest soil inventory (WBI = BZE I) in 1987, which had a sampling depth of only 30 cm, the BZE II has a sampling depth of 1.5 m. Hence, a comparison between the two inventories is limited to the organic layer and the topsoil. Additionally, the soil texture and the soil density of the samples were determined within the BZE II up to the sampling depth of 1.5m. Therefore, it is now possible to calculate the water capacity and nutrient stocks for the BZE II sites. In the course of a harmonization between various surveys (the national forest inventory (BWI), the crown condition inventory (WZE) and the soil condition inventory (BZE)), the inventory grid was changed between the WBI and BZE II in order to have all surveys located at identical sites. This methodical change limits comparisons between both surveys in Bavaria. It is additionally known that soils are systems which react slowly. Hence, it is not surprising that no clear changes could be detected between both inventories in most cases.

The merging of inventory grids increased the possibility to use and analyze data as shown by the analyses in this report. Basically, the main focus of an inventory is to describe and evaluate the actual status and the spatial structure of the data and not to explain dependencies and correlations. Causal research (e.g. on crown condition, tree growth, or mortality) has to take place on intensely monitored plots with a high time resolution. One example are the Level II plots in Bavaria (Waldklimastationen or WKS) or long term experimental plots. Causal analysis on the basis of inventory data is possible with very high sample sizes (plot number) because this increases the number of environmental gradients. A good example is the data set of the federal soil inventory with large gradients which now has two repetitions. The BWI is another good example of a federal inventory since it already has three repeated measurements. In conclusion, it was the correct decision to merge the inventory grids since it allowed for the analyses which are presented in this report.

## Soil types

Most of the forest soils of Bavaria are in the group of the loamy Cambisols (according to WRB (2006) classification). This soil type has relatively favorable physical and chemical properties for growing trees. For example, Cambisols in Bavaria often have a well-balanced nutrient supply and enough plant-available water. The "brown forest soil" can be seen as the epitome of a forest soil. Soils with stagnic properties, which lead to water logging in winter and spring, occur on about one fifth of the BZE II plots and pose difficulties for forest management. The Gleysols are also widespread with high humus contents in valleys with high groundwater levels. The shallow Ah/C soils (e.g. Leptosols) appear at 12 % of the inventory sites and arise primarily on limestone

## Soil carbon – humus

The content of the organic carbon in the soils of the BZE II plots represent the amount of humus in the forest soils in Bavaria. Humus is of special interest as a decomposable nutrient pool and as a stock for $CO_2$ with its high impact on climate. The comparison with the WBI shows that the humus stocks were stable all over Bavaria in the time from 1987 to 2008. Currently, more organic matter is stored in the soil (mineral soil and organic layer) than in the surface biomass (trees, soil vegetation, dead wood). The mean stock of organic carbon in the soil is 140 t/ha calculated with a soil depth of 1.5 m. Presently there is a shift in the types of organic layers to ones that are more favorable for nutrient availability ("Mull" and "Moder" according to German soil classification) and accordingly show narrower C/N ratios. The organic layer type "Rohhumus" with a wide C/N ratio was found only at 3 % of the BZE II plots in Bavaria.

Beside the geological substrates, the humus determines the properties of the forest soils. Humus is of high importance where the geology is rather unfavorable. On the one hand, 10 % of the soils of the BZE II have poor base saturation. On these sites the organic layers embody most of the cation exchange capacity and store the main part of base cation stocks. On the other hand, soils which are rich in base cations throughout the soil profile can be unfavorable for forest nutrition if they have a high pH value and, at the same time, very high amount of calcium. On such sites, the organic layer with its acid reactions is important for nutrient availability. For more than one fifth of the Bavarian forest soils the organic layer plays a central role in the nutrient cycle. On these soils sensitive forest management practices with a main focus on stabilizing humus is crucial. Situations with open land characters which stimulate humus degradation or promote soil erosion in steep mountain areas must be avoided. The stability of the stocks is of high priority in these situations. In addition, the survey of the BZE II proves the particular importance of humus with respect to phosphorus nutrition since organic layers contain the highest phosphorus contents. Besides the supply of nutrients, the humus plays an important role with regard to soil structure, water storage capacity, soil aeration and heat budget, filter and buffer functions as well as biological activity. Statements on soil fertility, and therefore forest productivity, cannot be adequately met without information on humus content and properties. Particular attention should be paid to the effects of a changing climate in order to adjust forest management practices accordingly.

## Nitrogen, phosphorus and sulfur

The high to very high mean nitrogen nutrition of the main tree species spruce, pine, beech and oak in Bavaria indicates that the atmospheric input of nitrogen is still high in this region. Nitrogen stocks in the organic layer and in the mineral soil are middle to high at nearly 90 % of the BZE II plots. Since the 1980s no appreciable decrease has appeared with respect to N-emissions. This is proven from measurements from the forest climate stations (WKS) as documented by Raspe et al. 2013. Consequences of nitrogen saturation can be an imbalanced nutrition, nitrate leaching with seepage water and a loss of base cations. Although the seepage water from forested areas is currently not significantly affected, the monitoring of nitrogen in forest ecosystems is of high importance (Falk and Stetter 2010). The results of the BZE II confirm other Bavarian nitrate inventories like the „Nitratinventur Bayern" and show that in spite of methodical differences there is, with high probability, undesired nitrate leaching on about one quarter of the forest soils in Bavaria. Forest ecosystems which can still absorb nitrate completely, or might have lower input and therefore no leaching, can be found on less than one fifth of the sites. That nitrogen deposition has become permanent is emphasized when comparing the data from WBI and BZE II. Between both inventories nitrogen contents and stocks have increased and the C/N ratios have accordingly become narrower. The results of the BZE II are yet another indicator for the fact that the N-deposition must be reduced. At hot spots of N-leaching forest management activities can be used to reduce nitrate in the seepage water in the medium to long term. For example, seepage water of beech or young spruce stands contain less nitrate than that of older pure spruce stands (ROTHE and MELLERT 2004; HUBER et al. 2008). Nevertheless, it is advisable to eliminate the cause than to simply treat the symptoms.

The results of an accompanying study to the BZE II point to the fact that particularly the phosphorus nutrition of spruce and pine is suboptimal to low in many German forests (KHANNA et al. 2007). This cannot be confirmed for both species in Bavaria. However, the P nutrition of beech is deficient in one quarter of the sites and only sufficient at another 46 % of the investigated stands. Shortages in phosphorus nutrition is found not only with beech but also with spruce in the Alps due to certain soil-chemical conditions. Especially stands on shallow limestone soils are endangered because they practically lose the entire phosphorus stock when the organic layer is lost. For the protection of such sites, a careful management with the aim of humus conservation is necessary. All together, the further development of the phosphorus supply and nutrition of the forests should be carefully observed. The phosphorus stocks in the organic layers and mineral soils are predominantly sufficient in Bavaria (only 8 % are categorized as very low or low). However, low P availability sometimes seems to cloud this positive picture. The fact that weak phosphorus nutrition has negative effects on growth could be shown for a subsample of spruces using the national forest inventory data (BWI). Optimal growth is only possible if there is no shortage of P and holds true for nitrogen as well. Particularly with regard to phosphorus, a methodical improvement is needed since up to now a uniform method for the analysis of plant-available phosphorus in the forest soil is still missing.

Since the beginning of the 1990s, decreasing sulfur deposition has been measured at the forest climate stations (WKS) (RASPE et al. 2013). Fortunately, this trend is also reflected in the results of the BZE II. The nutritional concentrations of spruce needles indicate for that for most parts of Bavaria only a weak sulfur contamination persists. Compared to the forest soil inventory of 1987, mean sulfur concentrations of spruce and pine needles declined about 10 %. But even if deposition decreases it can take decades, depending on the soil properties, until the sulfur stocks originating from deposition are removed again. The deposition pattern from the time before the flue-gas desulfurization is still observable in the soil data. Sulfur concentrations are highest in the organic layers of eastern Bavaria.

## Soil reaction, base cations of the soils and forest nutrition

The pH is an indicator of the acidity of the soil solution as well as the acid accumulation in the soils; this allows for conclusions on biological and chemical processes in the soil. The soils in the lower mountains of eastern Bavaria with their acidic bedrocks (granite and gneissic rock) and the high amount of conifers exhibit mostly low pH values. This is also true for regions with sandstones and acidic sands as found in Spessart. High values are found in areas with calcareous substrates like the Alps. The comparison of pH between WBI and BZE II shows a slight trend towards increasing values. This means that at least in the upper soil layers, pH has ceased to decrease.

The base saturation is defined as the portion of the basic cations potassium, calcium, magnesium and sodium in comparison to the whole cation exchange capacity of the soil. Together with the corresponding acidic cations, it indicates the state of soil acidification in the soil profile. In combination with the size of the cation exchange capacity it enables a way to estimate the speed of soil acidification induced by acid deposition. The highest base saturation values averaged all over Bavaria equal more than 70 % in the organic layers and 80 % in the deeper soil horizons. High levels of base saturation with values of more than 90 % are found in regions with marls and limes in such geologic substrates from the Fränkische Platte or the Bavarian Alps. Very low levels of base saturation (< 20 %) are found in eastern Bavaria (Fichtelgebirge, Bayerischer Wald) as well as in the Spessart and Röhn regions which are dominated by red sandstone. On these locations the base saturation of the organic layer reaches at most the category "weak to medium basic" (20 – 50 %).

In order to characterize the entire soil profile with regard to base saturation, the profile is assigned one of five categories which describe the base saturation gradient from the upper to lower soil layers. Type 1 has a high base saturation in the entire soil profile whereas type 5 is the other extreme in which soils exhibit very low base saturation throughout the profile. The remaining three types are in between. Averaged for Bavaria, 77 % of the BZE II plots consist of the base saturation types 1, 2 and 3 and clearly dominate in comparison to types 4 and 5. Type 5 is critical for trees with regard to nutrient supply, however, this type is not dominant due to the large geologic variety of Bavaria. It is limited to a few regions like eastern Bavaria or areas with nutrient-poor, sandy substrates.

The stocks of exchangeable potassium on more than 70 % of the BZE II plots are classified as middle to very high. With regard to calcium and magnesium it is more than 80 %. The lowest potassium stocks are found in the Bavarian Alps with their stony and shallow soils. The lowest calcium and magnesium stocks are found in the Bavarian Forest on crystalline bedrock. The nutrient stocks in the Bavarian forest soils are all together predominantly high.

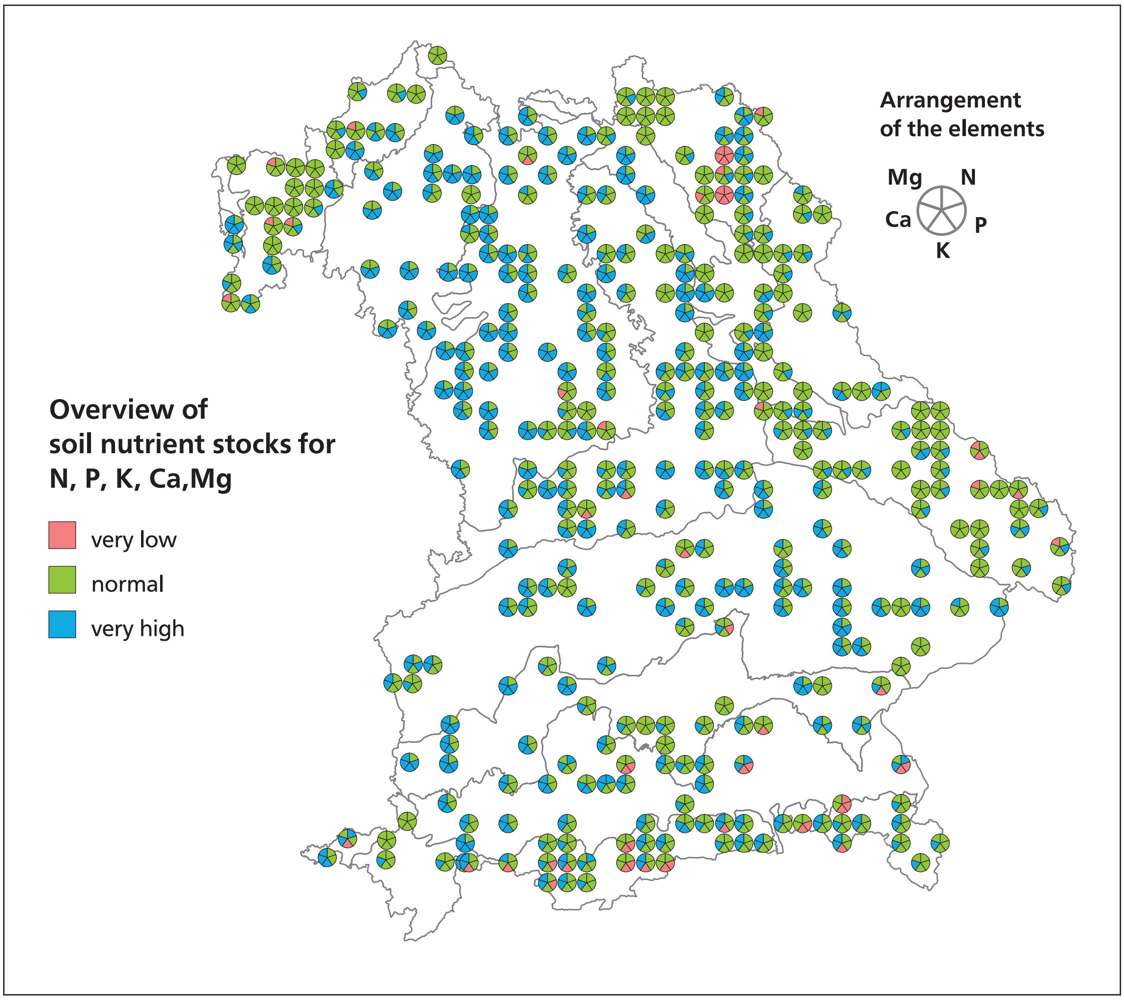


*Figure 1: Overview of the soil nutrient stocks of nitrogen, phosphorous, calcium and magnesium. Total evaluated stocks for N and P are illustrated where as for K, Ca and Mg, the evaluated exchangeable stocks are illustrated. Evaluation as per FSA (2003). BZE II plots on shallow soils stand out with regard to their low nutrient stocks, however, the plots in Bavaria generally have middle to high levels of nutrients stocks.*

The data of the BZE II plots for Bavaria show that forest nutrition with regard to macronutrients is essentially good for the main tree species. Except for isolated cases, the supply with the most important micronutrient elements iron, manganese, copper and zinc is at least sufficient. Nutrition deficiency with potassium, calcium and magnesium appears only in a few cases. The mostly optimal calcium nutrition and the generally sufficient and seldom deficient magnesium nutrition of the main tree species reflects the soil conditions in Bavaria. The data of the crown condition inventory indicate a similar tendency with chlorosis rates of less than 5 % for all main tree species during all years of the BZE field campaign. The few spruce trees with chlorosis in 2007 were found in the lime-dominated Alps and in the mountainous regions with highly acidified soils and correspond with the nitrogen and magnesium deficits which appear there. As a result, there is no need to correct the principles regarding forest liming in Bavaria. The proven cases of magnesium and calcium deficiency on strongly acidified soils, (e.g. in the Bavarian Forest or Spessart) can be compensated for by the use of limes rich in magnesium.

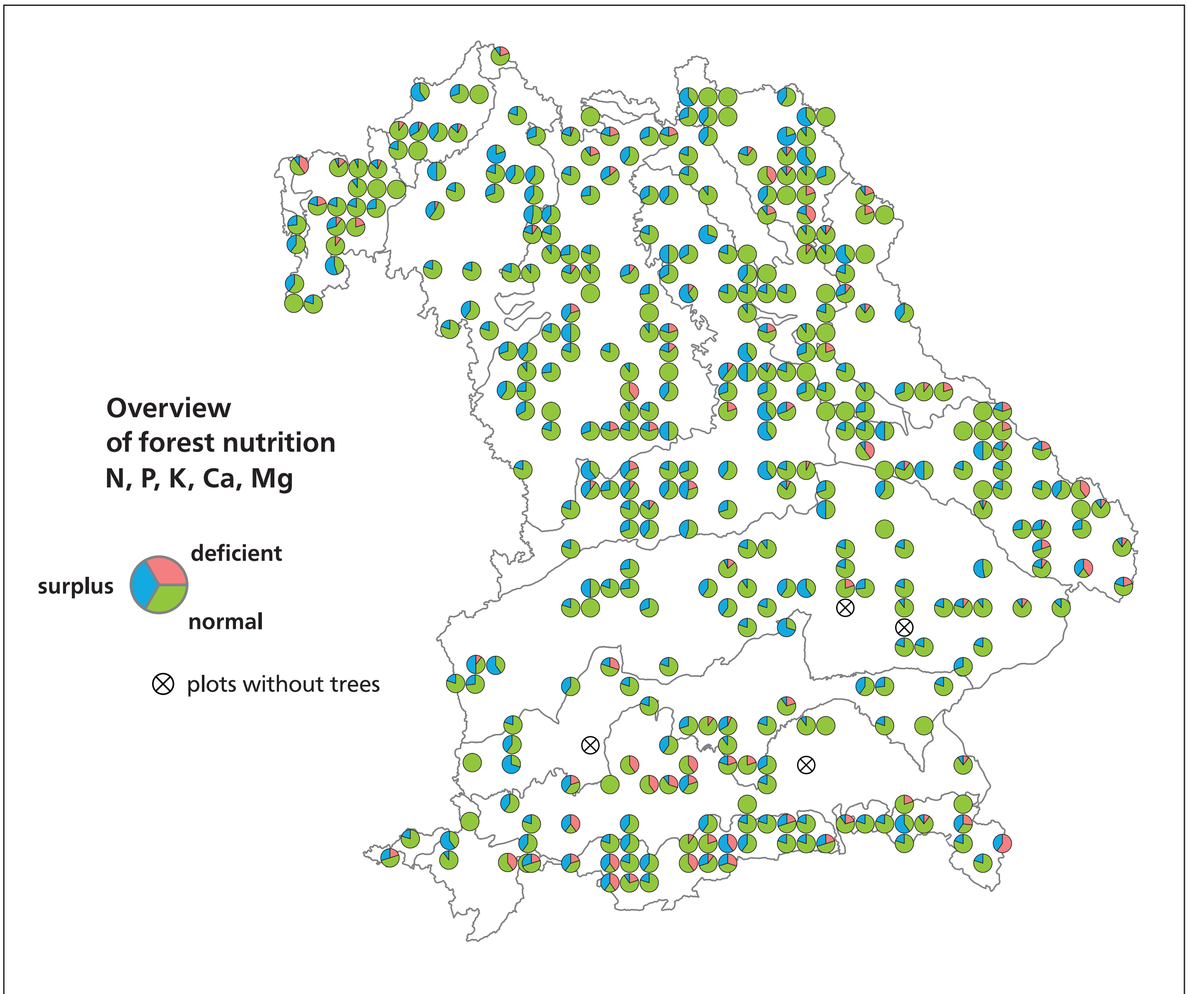


*Figure 2: Overview of the forest nutrition in Bavaria. The size of the segments represents the summarized proportions of deficient, normal and surplus nutrition for all macroelements (N, P, K, Ca and Mg) and all tree species which occur on the individual plots. For the distribution of the tree species please see Figure 1 of the article „Waldernährung in Bayern – Ergebnisse der BZE II". The evaluation scheme for the individual tree species are specified in the respective text.*

## Pollutants

The effects of air pollution control can be seen not only with sulfur but also in the case of lead, which was an environmental problem of the 1980s that was derived from motor vehicle traffic. In the spruce needles and beech leaves of the permanent soil monitoring plots (BDF), decreasing lead contents were observed since end of the 1980s. The data of the BZE II confirm this finding. The lead content measured in the needles and leaves in Bavaria are, for the moment, clearly below a critical threshold that would lead to negative effects on trees. A clear decrease in lead content can be found in the organic layers. As a result, the lead stocks have only slightly increased in the soil profile. It can be assumed that there is a relocation of the pollutant into deeper soil horizons. Due to the fact that heavy metals are not degradable, it is vital to avoid input altogether. The heavy metal contents measured at BZE II plots in the forest soils can be classified as uncritical since they are generally in a normal natural-anthropogenic background range. There are only very few exceptions in Bavaria; high heavy metal content in soils are limited to geologic substrates comprised from rare minerals (e.g. high zinc, chrome and nickel contents on soils derived from diabase which posses high amount of chlorite and serpentine minerals).

## Results

In conclusion, it can be stated the condition of Bavarian forests is predominately good as seen from the results of soil, forest floor vegetation, crown condition and forest nutrition inventories. The sites which are problematic from a pedological or tree nutritional point of view and produce poor growth or weak crown conditions are limited to a few „difficult" regions. In addition, the sites are also influenced by the climate, but this was not a consideration of the inventory. It cannot be forgotten, however, that the buffer function of soils is clearly limited on a considerable number of sites (e.g. with regard to nitrogen on a wide selection of Bavarian forests). Bavaria is a state with a high proportion of forests where forestry plays a significant role. The high productivity of the forests here can substantially be attributed to the relatively high number of favorable forest soils. It is important to preserve these soils and to exercise caution with their management.