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CELKOVÁ DEPOZÍCIA DUSÍKA NA VOĽNEJ PLOCHE A POD KORUNAMI STROMOV VO VYSOKÝCH TATRÁCH

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Abstract:
Acidification has been serious environmental problem for decades. Although, emissions around Europe have been reduced in last decades, saturation of ecosystems with nitrogen and sulphur is gaining in importance. The bulk and throughfall nitrate and ammonium deposition was measured at the four research sites - Popradské pleso (PP), Vyšné Hágy (VH), Veľká Studená dolina (VSD) and Štart (ST) along the High Tatras, in the Tatra National Park in Slovakia during the years 2003 to 2006. Mixed conifer (spruce, larch, fir and cembra pine) and mixed deciduous stands (birch and rowan trees) were involved at the research sites to examine the interactions of nitrogen compounds in precipitation with the forest canopy. As suggested, throughfall deposition rates were few folds higher than the bulk depositions. The highest sum of nitrate and ammonium deposition was found in the larch throughfall at the VH site in 2003 with the value of 39.32 kg $N.ha^{-1}.year^{-1}$, 6.8 times greater than the bulk deposition. The four-year mean sum of nitrate and ammonium deposition was higher in throughfall than in open field at all the plots. Mean throughfall depositions of nitrate were mostly higher than the bulk depositions except the VSD and ST sites. At the VSD site, the birch and rowan throughfall and at the ST site the spruce and fir throughfall depositions were slightly lower than the bulk depositions. Four-year mean deposition of ammonium in throughfall was higher than the bulk deposition at all the sites. Greater mean depositions in throughfall indicate effective interception of the imissions by the forest canopy. On the other hand, the lower nitrate mean depositions in the spruce and fir throughfall at the ST site and in the birch and rowan throughfall at the VSD site compared to bulk depositions may indicate retention of nitrate by the canopy. Further investigation of the interactions of nitrogen compounds with canopy is needed.

Keywords: throughfall, bulk deposition, nitrate, ammonium, acidification

1. Introduction

The range of the High Tatra Mts. acts as a huge barrier in the way of air masses circulating in the Europe. Thus the mountain forest ecosystems in the High Tatras obtain considerable amounts of nitrogen due to long-range transport of air pollutants.

Even though emissions have decreased around Europe recently, nitrogen load still pose an important role in the acidification of environment. According to SHMI, emissions of nitrogen oxides in Slovakia have decreased since 1990 *(SHMI 2006)*. Emissions of ammonia decreased between 1990 and 2003 by 53.3% according to the web page of Slovak environmental agency. European Environment Agency also reports decrease of NH_3 between 1990 and 2006 by almost 22%, whereby two most important key categories of NH_3 are manure management and direct soil emissions *(EEA)*. Globally, the ammonia wasted to the atmosphere is about half of the global industrial production of ammonia whereby about 20% is of natural origin. However, estimates of global, regional and local ammonia emissions have high uncertainties, which increase with the smaller scale *(Erisman et al. 2007)*.

Continuous degradation of the forest health indicates synergistic effect of various dis-

turbance factors *(Fleischer et al., 2005)*. In addition after the windthrow disaster in Nov 2004, when the forest area of 12 600 ha on the south slopes of the High Tatras was thrown down by the wind, the forest health has declined rapidly. Consequently bark beetle population exploded and has posed a serious factor influencing the health of the trees suffering from acidification and other stress factors. Therefore it is of great importance to continuously monitor the degree of acidification.

The process of acidification and deposition of pollutants is well described in the literature. However, there are still some uncertainties in the process of canopy exchange of nitrogen compounds due to the complexity of the processes involved. Uptake of nitrate and ammonia by the canopy is reported in some of the studies *(Stachurski and Zimka, 2001; Malek and Astel, 2008)*. On the other hand, emissions from the clouds and dry deposited nitrogen compounds are trapped on the forest canopy and washed out by precipitation. Elevated nitrogen depositions in the throughfall and consequent soil acidification is the result with possible leaching to ground and surface water.

In the literature, most of the studies were done in spruce, or beech stands. In our study, also other coniferous and broadleaved trees are involved. The goal of this study is to find some more information about the interactions between the canopy of different tree species and nitrogen compounds and bring comprehensive results.

2. Methods

2.1 Sites

Bulk and throughfall nitrogen loads were measured during the years 2003 to 2006 at the four research sites – Popradské Pleso, Vyšné Hágy, Veľká Studená dolina and Štart that are all located in the Tatra National Park within the altitude of 1150 to 1530 m a.s.l. Except Veľká Studená dolina site situated in mixed coniferous-broadleaved stand, other sites are situated in coniferous stands. The sites PP and VSD are in the forest untouched by the windthrow from 2004. The other two sites VH and ST are close to the windthrow area. The location of the sites on satellite map is shown in the Figure 1.

The research site **Popradské Pleso (PP)** is situated in the west part of the High Tatra Mts, in the Mengusovská dolina valley close to the lake Popradské Pleso, in the altitude of 1530 to 1540 m a.s.l. facing to S-SW. Spruce, larch and cembra pine throughfall (STF, LTF, CPTF) and bulk deposition (open field - OF) was measured.

The research site **Vyšné Hágy (VH)** is located west of the village Vyšné Hágy above the main road to Štrbské Pleso village in the elevation of 1134 to 1140 m a.s.l. with SE orientation. Spruce and larch throughfall and bulk deposition was measured here.

Veľká Studená Dolina (VSD) research site is situated at the feet of Veľká Studená dolina valley in the central part of the High Tatra Mts, below the ridge of Slavkovský štít facing to the east. Except bulk deposition and spruce throughfall, also rowan and birch throughfall (RTF, BTF) was measured at this site.

The research site **Štart (ST)** is located north of the village Tatranská Lomnica, in the altitude of 1150 to 1160 m a.s.l. on a moderate slope of Lomnicky štít peak foothill facing to SE. In the tree composition, spruce predominates over fir and larch. Open field is approximately 500 meters away from the other plots. Spruce, fir (FTF) and larch throughfall was measured. This site is involved in the European network of intensive monitoring in the framework of ICP forest.

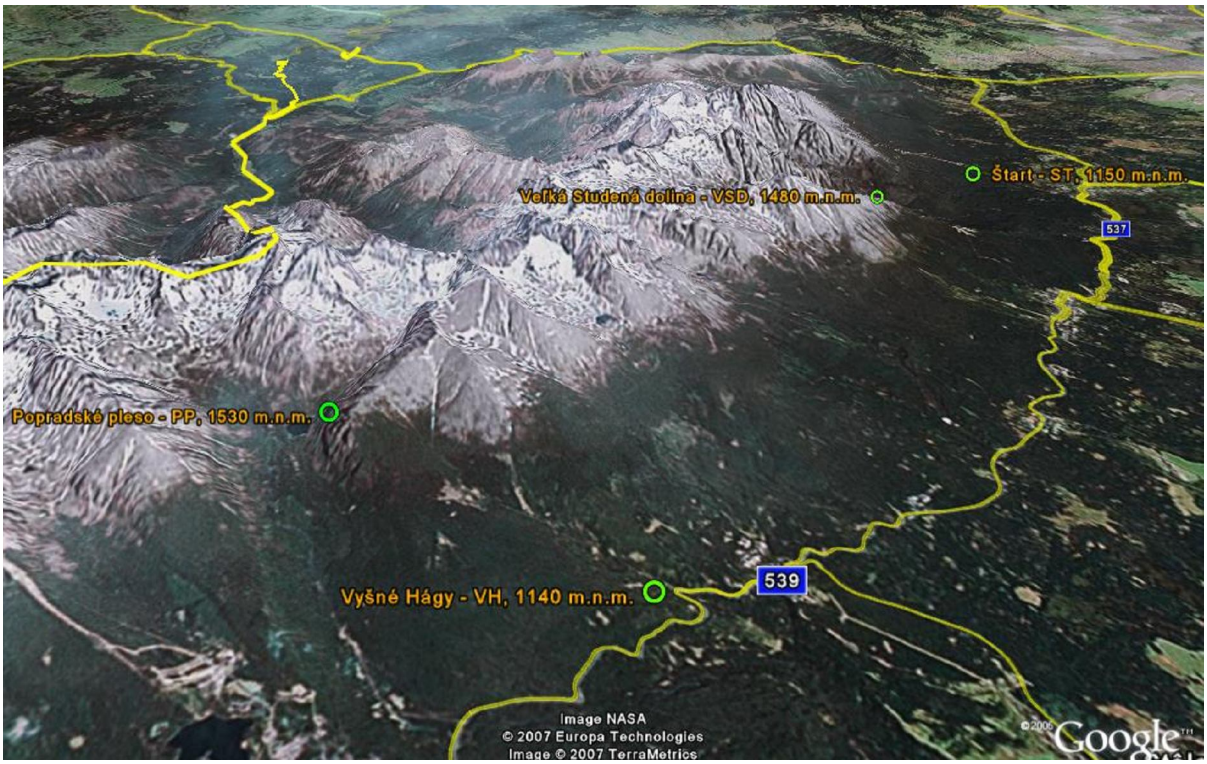

Fig. 1. Research sites (Google Earth)

2.2 Methods and chemical analyses

Open polyethylene collectors for trapping rain and snowfalls at the open field and under trees had been installed at the research sites. This material accommodates inert conditions against the snow and water, according to international forest monitoring requirements. Two kinds of collectors were used, one with larger funnel, thus catchment area for snowfalls (Nr.1) and the smaller one for rainfalls (Nr.2). We used diameter of the funnels to calculate the catchment area (Table 1).

Table 1 Diameters and catchment areas of appropriate funnels

Collector type	Diameter (cm)	Area (cm^2)
Nr.1	23.7	441.2
Nr.2	15.96	200

Each of the collectors Nr.2 contained also strainer to catch particles like needles, insect and dirt. After each take out of sample from the collectors, we washed them out with distilled water. We also cleaned the strainers.

Samples were analysed at the Research Station of the Tatra National Park. In the case of snow samples, they were let to melt by the room temperature and filtered before storage or analysis. Spekol 11 spectrophotometer (Carl Zeiss Jena) was used to analyse concentrations of NH_4^+ ions. To determine NO_3^- concentrations, isotachophoresis (ITP) on EA 102 was utilised.

2.3 Data handling

The data were collected from 7.1.2003 to 21.12.2006 on a two-week interval basis. Deposition rates were calculated by multi-

plying precipitation amount and concentration of a particular sampling period.

3. Results

3.1 Precipitation amount

Altitude and precipitation amount are of great importance. The precipitation in the mountains is considerably high, therefore deposition rates, depending on precipitation amount, and inputs of pollutants into ecosystems are significantly higher than in the areas with lower elevation and areas with smaller precipitation amount, even though the concentrations of pollutants in precipitation might be smaller. The four–year mean precipitation amount decreases in the order PP > VSD > VH > ST. These mean precipitation amounts correspond with the altitude of the sites, whereby the altitude of the sites is decreasing in the same order PP > VSD > VH > ST.

3.2 Nitrate deposition

The deposition of NO_3^- ions ranged from 0.4 kg.ha^{-1}.year^{-1} in the OF at the ST site (2006) to 8.09 kg.ha^{-1}.year^{-1} in the cembra pine throughfall at the PP site (2005).

At the **PP site**, as suggested, four year mean deposition in the open field was lower than throughfall mean depositions, whereat spruce throughfall mean deposition was almost double the mean deposition in the OF (Fig. 3).

At the **VH site**, the highest mean nitrate deposition was at the spruce throughfall plot (5.03 kg N.ha^{-1}.year^{-1}) and was 1.7 times greater than in the OF (Fig. 4).

Very small is the difference at the **VSD site** between STF (3.47 kg N.ha^{-1}.year^{-1}) and bulk (3.38 kg N.ha^{-1}.year^{-1}) mean depositions of NO_3^- ions. Interestingly, mean depositions of birch and rowan throughfalls are a bit smaller than the bulk deposition (Fig. 5).

There were only slight differences regarding mean nitrate depositions at the **ST site**. The highest mean deposition in the LTF amounted to 2.13 kg N.ha^{-1}.year^{-1} which is only 0.22 kg N.ha^{-1}.year^{-1} more than the bulk deposition. STF and FTF mean depositions were even smaller than the OF mean (Fig. 6). This might be due to a fact that the OF plot at the ST site is located about 0.5km away from other plots and is rather small forest opening than an open field, thus deposition rates might be influenced by surrounding trees. As well, chemical analyses of this plot are provided by Technical University in Zvolen, thus some differences might occur.

In general, nitrate depositions decreased from west to east-situated sites.

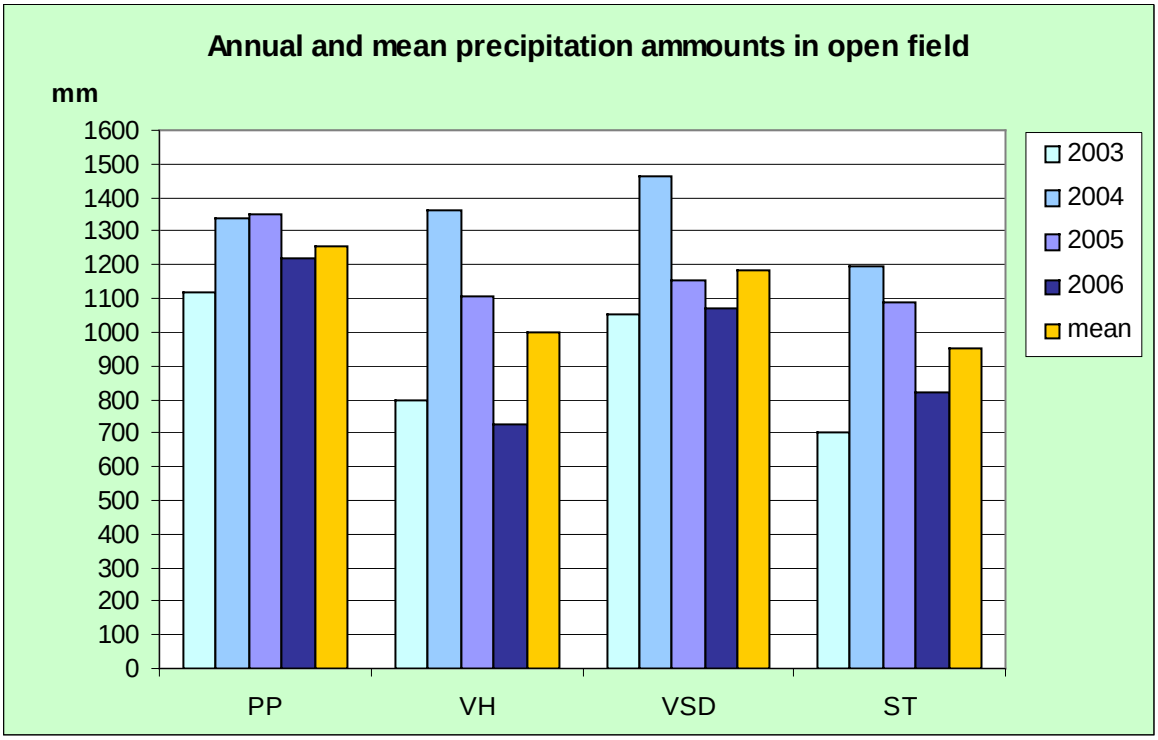

Fig. 2. Annual and mean precipitation amounts in the open field at the particular site

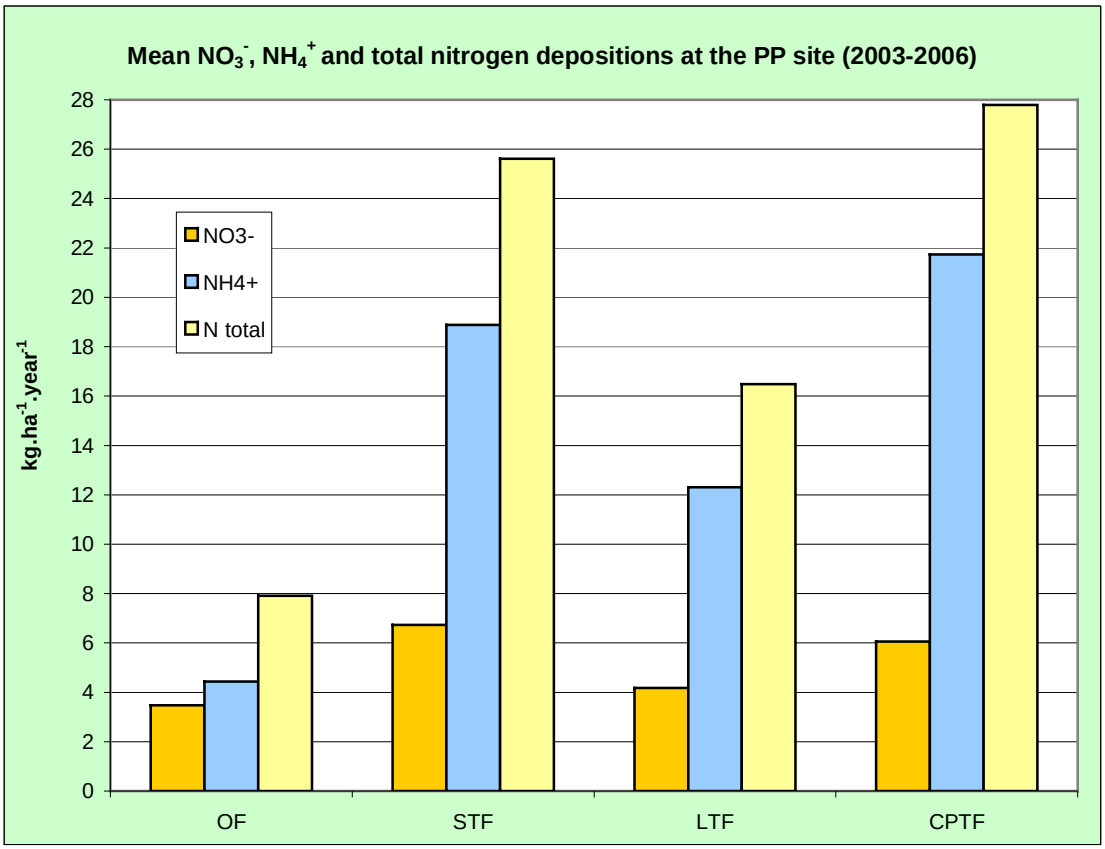

Fig. 3. Mean NO_3^- and NH_4^+ deposition at the PP site

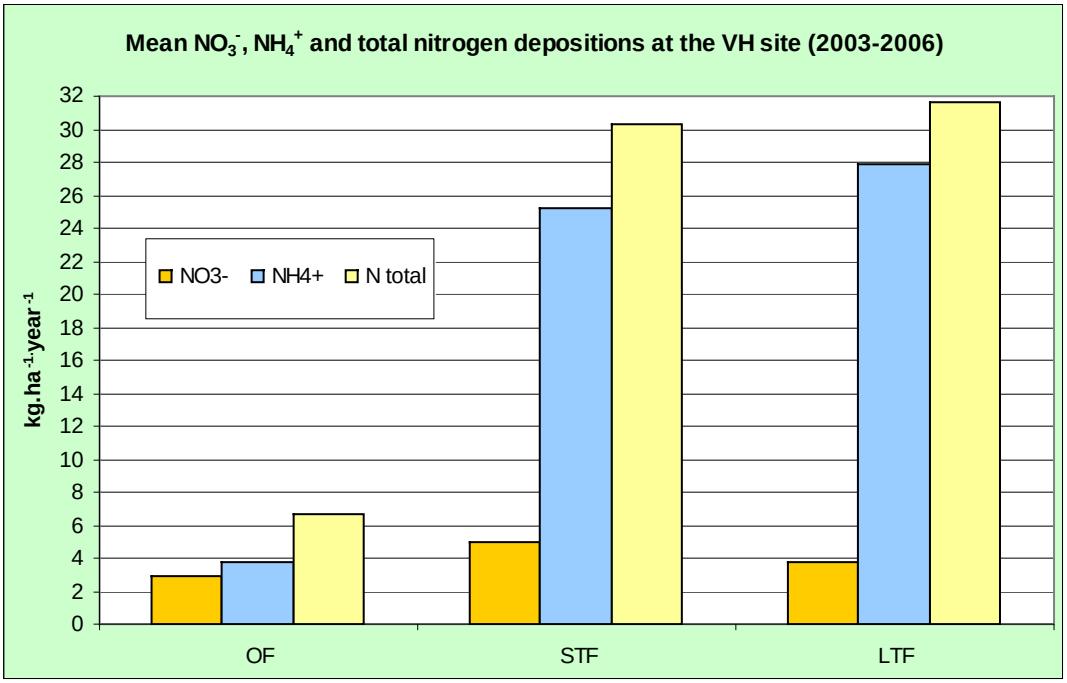

Fig. 4. Mean NO_3^- and NH_4^+ deposition at the VH site

3.3 Ammonium deposition

Deposition of NH_4^+ ions ranged between 1.78 kg N.ha^{-1}.year^{-1} in the open field at the ST site (2006) and 37.09 kg N.ha^{-1}.year^{-1} in the larch throughfall at the VH site (2003).

The highest mean depositions were at the **VH site** (Fig. 4) at the larch TF (27.87 kg N.ha^{-1}.year^{-1}) and spruce TF (25.23 kg N.ha^{-1}.year^{-1}) plots followed by cembra pine TF mean deposition (21.74 kg N.ha^{-1}.year^{-1}) at the **PP site** (Fig. 3). The highest mean deposition of ammonium at the larch TF plot was 7.4 times the open field mean. At the PP site, cembra pine TF mean deposition was 4.9 the open field deposition.

At the **VSD site**, the highest mean ammonium deposition was at the spruce TF plot (8.11 kg N.ha^{-1}.year^{-1}) and was double the open field value (Fig. 5).

At the **ST site**, it was larch TF mean deposition with the highest value (10.58 kg N.ha^{-1}.year^{-1}) 2 times greater than in the open field (Fig. 6).

There is evidence in these results, that ammonium deposition plays a major role in contribution to the total nitrogen deposition in the High Tatras.

3.4 The sum of nitrate and ammonium deposition

We considered the sum of N-NO_3^- and N-NH_4^+ depositions as total nitrogen deposition.

The highest total nitrogen deposition was that of the larch TF at the **VH site** in 2003 with the value 39.32 kg N.ha^{-1}.year^{-1}, 6.8 times greater than the open field value. The four-year mean deposition at this plot was 31.65 kg N.ha^{-1}.year^{-1}. Spruce TF mean deposition was close to this value (30.25 kg N.ha^{-1}.year^{-1}).

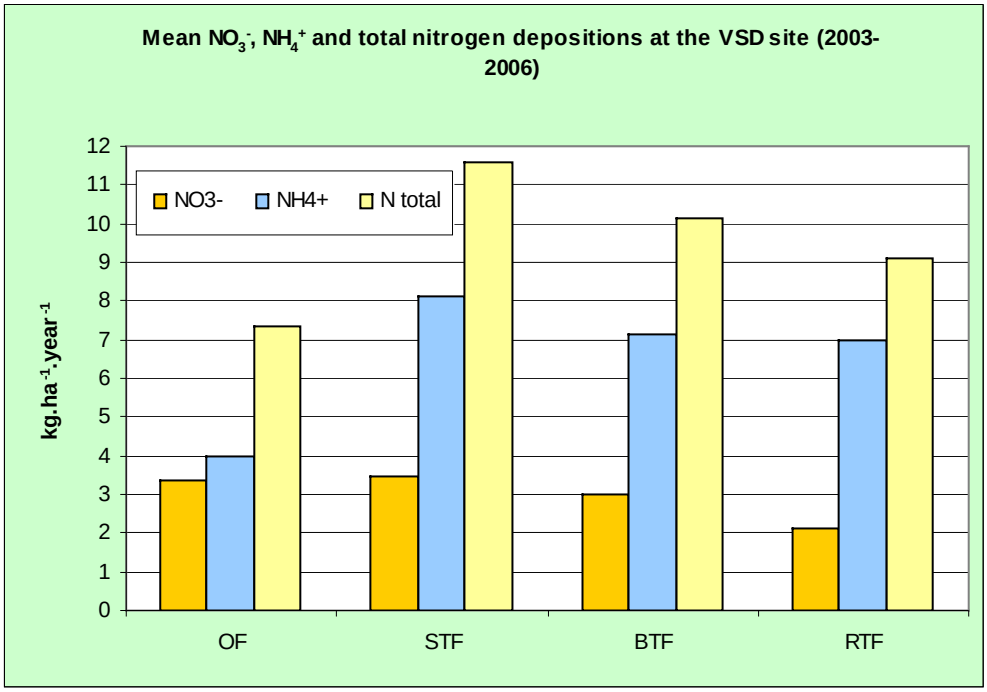

Fig. 5. Mean NO_3^- and NH_4^+ deposition at the VH site

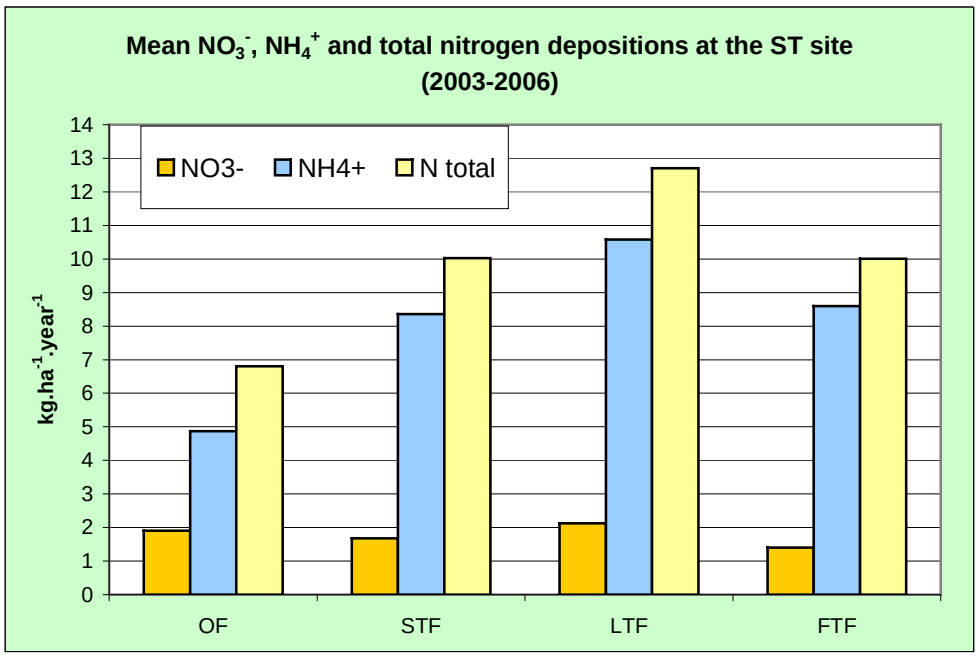

Fig. 6. Mean NO_3^- and NH_4^+ deposition at the ST site

The highest mean total nitrogen deposition of the cembra pine TF (27.79 kg $N.ha^{-1}.year^{-1}$) at the **PP site** plot was 3.5 times greater than in the open field. Considerable was also mean total nitrogen deposition at the spruce TF plot (25.62 kg $N.ha^{-1}.year^{-1}$).

The mean depositions at the **VSD site** are lower than at VH and PP sites. The highest mean deposition was at the spruce TF plot and amounted to 11.58 kg $N.ha^{-1}.year^{-1}$ which was about 1.6 times the OF value. At the plots of broadleaved species TF, the mean depositions were lower than those of the spruce TF. Particularly, birch TF total

nitrogen mean deposition was 1.4 and rowan TF total nitrogen mean deposition was 1.2 times the value of the OF.

At the **ST site** the maximum of total nitrogen mean deposition (LTF – 12.71 kg $N.ha^{-1}.year^{-1}$, 1.9 times the OF value) was higher than at the VSD site (STF – 11.58 kg $N.ha^{-1}.year^{-1}$), but lower than at the other plots.

4. Discussion

Lower depositions were measured at the PP and VH site in 1997 and 1998 (*Sitková et al. 2003*). According to the results of this study, the highest nitrogen deposition (nitrate + ammonium deposition) at the PP site in 1998 amounted to around 16 kg $N.ha^{-1}.year^{-1}$ in spruce throughfall and was about double the bulk deposition. At the VH site the highest N deposition occurred in larch throughfall and was also about double the bulk deposition. These values are much lower comparing to our results from the same research sites. *Škvarenina et al. (2000)* compares nitrogen loads between the bulk and throughfall plots at the research site in the West Tatra Mts according to canopy closure. Spruce throughfall N load amounted to about 23.96 kg $N.ha^{-1}.year^{-1}$ in the stand with ideal canopy closure, whereat the bulk deposition was 22.17 kg $N.ha^{-1}.year^{-1}$. Interesting are the findings, that $N\text{-}NO_3^-$ deposition of throughfall was about 2 kg $N.ha^{-1}.year^{-1}$ lower than the bulk deposition, but deposition of NH_4^+ ions was higher than the bulk. The sum of nitrate and ammonia throughfall deposition was also lower than bulk deposition in the case of throughfall in stand with canopy opening and disconnected canopy closure. In central part of Slovakia in a beech stand, the sum of nitrate and ammonia of throughfall was higher than bulk deposition *(Kunca 2006)*. The lower deposition of NO_3^- and NH_4^+ in throughfall in some cases compared to bulk depositions might be explained by the retention of nitrate and ammonia in the canopy. *Malek and Astel (2008)* report retention of nitrate and ammonia by the canopy in young spruce stands in Silesian Beskid Mts. (Poland), especially in the growing season. Also in the study of *Stachurski and Zimka (2002)*, the pool of NO_3^- and NH_4^+ was reduced after rainwater had passed the forest canopy of European beech stand in western part of Karkonosze Mts. Net throughfall data for NO_3^- and NH_4^+ indicated retention of these ions, whereat retention of ammonium was much greater than that of nitrate in ratio 59% to 36%.

5. Conlusions

The nitrogen deposition did not correspond with the precipitation amount, while the precipitation amount increased with the altitude. However, depositions of nitrogen did not follow this trend, whereby the highest nitrogen depositions occurred at the VH site and PP site. Throughfall depositions were higher than bulk depositions in most of the cases. In some cases, when throughfall deposition was lower than bulk deposition, retention of nitrogen in the canopy might be the reason. However we have no proof for this suggestion, yet. Further investigation will be needed to support this hypothesis. Not much about birch and rowan trees throughfall and canopy interactions with rain is written in the literature, therefore more investigation on how the canopy of these broadleaved trees interact with precipitation is needed. Nitrogen loads in this study are higher than in 1997 and 1998, therefore nitrogen saturation of ecosystems with other stress factors on forest health are gaining in importance concerning decline of the forest health in Tatra National Park.

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