Two levels of tree stability

REMIGIJUS OZOLINČIUS
The Lithuanian Forest Research Institute,
4312, Girionys, Kaunas distr., Lithuania

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Tree is a biological system. So studies of changes in it under external impact or under condition of the tree deterioration leads us to the better understanding of the biological systems stability in general.

Tree stability is here defined as the ability of the system to keep its normal functioning despite external disturbances, i.e. conver solar energy into another forms. Foliage is of importance in such conversion system. It is both the product of tree functioning and the reflection of tree energy. Stability has been defined as the stable ratio between the wood increment and the amount of foliage.

With increasing defoliation of the crown, two stabile states have been singled out: first, in the limits 0-35%; second, in the limits 60-85%. The existence of such relatively stable states is based on the results of experiments, which have been carried out by the author or his colleagues. The analogy with the Bohr's atom theory has been applied. Theory does not contradict with-known theories of systems stability and the general theory of stress.

Keywords: tree stability, increment, foliage mass, defoliation.

Introduction

Term "energy" has been used by many authors for the explanation of different aspects of the separate organism or ecosystem functioning (Lindeman 1942, Odum 1975, Hannon 1979). Now it is clear that the stability of every organism and abiotic structures is maintained by a certain level of energy. Due to changes in the state of an organism this energy varies similarly with known physical laws. The well-known postulate of stationary states by N. Bohr (Bohr 1958) asserts that electrons of an atom revolve around the nucleus in stationary orbits. The electron moving to the lower orbit emits a definite quantity of energy. The orbits (the distances from the nucleus) surrounding the nucleus are referred to as energy levels. They are determined by the energy of electrons revolving around the nucleus.

At the beginning we will define the following important concepts: tree "stability", "energy level or energy" of a tree.

The stability of a tree is a relative concept. By stability we mean a property of a system to maintain normal functioning despite external disturbances. It does not, however, mean that a tree remains a stable system in time and space.

The definition of "energy level or energy" is found to be rather intricated. The physical energy is defined as an index of motion of the matter or the ability of a system to perform work. The "work" of a tree is to convert energy from one form to another, for example, solar energy to chemical energy by photosynthesis.

Foliage in the conversion system of solar energy is of extraordinary importance. At the same time, it is the product of the tree "work" and a major link in transforming inorganic into the organic compounds ones including their storage and the process of producing and accumulation of wood. In other words, foliage is created for maintaining vital functions of a tree in the process of growth. Apparently, the ratio of the created wood mass (or the whole phytomass) to the mass of foliage can be assessed as an ability to perform a work. The mass of foliage can be evaluated as an external expression of such ability.

Along with these properties of foliage, the ability to reflect the influence of environmental factors comparatively over a short period is worth to mentioning. Thus, by assessing the total mass of foliage we characterize the current state of a tree energy. On the other hand, data from our experiments and from literature indicate that foliage is the part of a tree, which is most sensitive to changes in ecological conditions or to direct damage of the tree (Lindeman 1942, Udovenko 1979, Kramer 1986, Ozolinčius 1992). Besides, in the protective system of a tree the mass of foliage is of importance. It has been proved that a tree affected by a stress at first "refuses" its old parts (Udovenko 1979, Ozolinčius 1992). Conifers usually lose their old needles. Different significance of various parts of a tree to its functioning is testified by "stringent" succession in the process of dying: needles and shoots are dying from the lower part of a crown and the basal part of branches, and the stem dies finally (Ozolinčius 1993).

The aim was to investigate and sum up regularities of relationship "stem increment-foliage" changes under external impact or under condition of tree deterioration and on that basis to look at tree as a system, which functioning depends on known physical laws.

Material and methods

The experiments carried out in the last decade enable us to summarize the main particularities and regularities of tree growth under different impact. The following items have been covered by the investigations: tree and crown growth changes caused by physical environmental changes (intensity of solar radiation, temperature regime etc.) as these occur during forest ecosystem formation (Scots pine and Norway spruce plantation have been established by different initial density – from 0.75 to 200.0 thousand trees per ha); crown growth under impact of decreased solar radiation; morphological response of tree and its crown to intensive thinning and decapitation of radial roots (Kairiūkštis 1976; Kairiūkštis 1985; Ozolinčius 1992, 1993).

The data base of the national forest monitoring (grid 4x4 km) has been used (more than 23,000 trees have been analysed). On each permanent observation plot (POP) 24 sample trees are selected to a statistically sound procedure. An example is the 4-point cluster with 4 subplots oriented along the main compass directions at a distance of 25 m from the grid point (POP centre). On each subplot the 6 predominant, dominant and co-dominant trees marest to the subplot centre are selected as sample trees (total 24 trees per POP).

Relative amount of foliage - defoliation - has been estimated in 5% classes relative to a reference tree, i.e. tree with full foliage. The reference tree was either a healthy tree in the vicinity (of the same crown type), a photograph, locally applicable, representing a tree with full foliage, or the sample tree it self with imagined full foliage.

Crown defoliation was assessed by two trained observers (using binoculars) from the distance of one tree lenght. Crown defoliation of trees with full foliage was estimated as 0%, dead trees - as 100% (Manual..., 1994). Tree stem perimeter or diameter was measured at 1.3m above the ground (DBH) using the measuring tape. Stem increment was calculated as a difference between measurements in 1991 and in 1989.

Four Scots pine stands (forest type *vaccinio-myrtillosum*) with stocking level 0.7-0.8 were selected for more detail crown structure and stem increment analysis. In each stand (ayr-from 17 to 100 years) five model trees with the some stem perimeter and crown parameters (various tree indices - height, DBH, crown size, etc - did not differ more than 5%) were cutted down after visual crown defoliation assessment and analysed (table 1). One model branch (average size) per each whole was cutted and following it's indices were determined: lenght, total mass, mass of needles (current year separately), man of shoots, needle lenght (30 needles per branch), etc.

In all above mentioned studies the well known biometrical methods have been applied following (Molchanov 1967, Utkin 1982).

The greatest attention was focused on the relation between stem increment and relative foliage mass.

Results and discusions

During analysis of model trees data it was revealed strong linuar correlation between visually assessed crown defoliation and the real needle mass estimated after tree cuting down in the range of defoliation from 0 to 90% (r = 0.89 - -0.91) (Table 1). So visually assessed defoliation reflects real foliage mass (needle mass) with high probability.

Table 1. Correlation coefficients between Scots pine needle mass and defoliation

Stand age, year	Current year needle mass	Total needle mass
17	-0.93±0.096	-0.83±0.139
40	-0.92±0.099	-0.86±0.116
65	-0.89±0.093	-0.96±0.035
100	-0.99±0.009	-0.95±0.044
All stands	-0.91±0.038	-0.89±0.047

We have calculated changes in stem perimeter of trees grouped in 5% defoliation claseess using national forest monitoring data base (Table 2). It is clear that stem perimeter increment decreases with the defoliation increase (Fig. 1), but it was not found the linear relationship between crown

Table 2. Stem perimeter changes (1989-1991) at different levels of Scots pine crown defoliation (2nd class according to Kraft, more than 60 year-old)

Defoliation, %	Upper part of crown		Whole crown	
	number of trees observed	x±mx, cm	number of trees observed	x±mx, cm
0	2	1.20±0.35		
5	21	2.67±0.59	4	2.00±0.71
10	186	2.80±0.13	53	3.30±0.27
15	274	2.88±0.12	120	3.05±0.16
20	203	2.46±0.13	32	3.06±0.41
25	137	2.33±0.19	196	2.84±0.13
30	73	2.19±0.24	147	2.70±0.16
35	22	2.23±0.45	92	2.85±0.19
40	12	0.91±0.81	64	1.97±0.17
45	1	1.00	20	1.75±0.58
50			11	2.07±0.99
55	1	1.00	3	0.33±0.27
60	5	0.60±0.61	11	1.36±0.65
65-75	6	1.67±0.65	9	1.11±0.79
>75	8	0.38±0.30	3	0.45±0.30

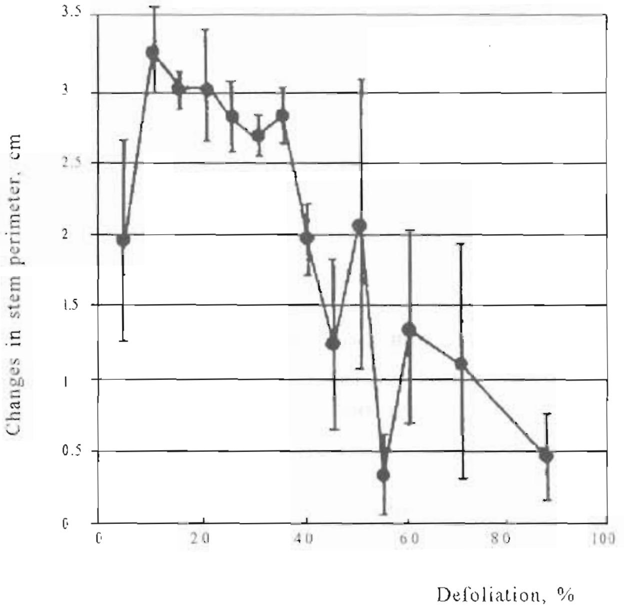

Fig. 1. Stem increment (perimeter) at different levels of crown defoliation (pine, 2nd class according to Kraft, age – 60-80 years, 765 trees analysed).

defoliation and stem increment at the limits of defoliation 0-35%. The analogical regularities of tree increment changes occur in the Norway spruce stands (Soderberg 1991; Petraš 1993). The model tree data show that relative radial increment even decreases with increasing relative needle mass in the limit of defoliation 0-10% (Fig. 2). The second limit, in which is very difficult to reveal linear relationship between crown defoliation and stem increment, is characterised by defoliation 60-85%.

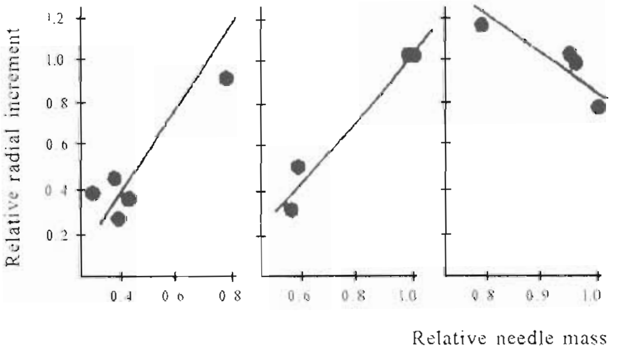

Fig. 2. Relationship between radial increment and needle mass (estimated on felled trees) at different levels of crown defoliation (pine, 2nd class according to Kraft, age 15-100 years).

We have grouped all model trees according to their crown defoliation into 4 groups: defoliation 0-10% (corresponds defoliation class 0; see Manual..., 1994), defoliation 11-25% (defoliation class 1 – slightly defoliated), defoliation 26-60% (defoliation class 2 – moderately defoliated) and 60-80% (defoliation class 3 – severely defoliated). It is well known that various morphological indices of shoots and needles depend on their position in the crown, i.e. there is morphological correlation within the crown. For example, shoot increment decreases from the apical part of the crown to the basal one. Our investigation data show that such kind of correlation is highest in the crowns with defoliation 11-25% (Fig. 3). The lowest correlation was determined in the crowns with defoliation 60-80%. For example, the correlation coefficient between needle length and relative crown height does not exceed 0.08 (Fig. 3). It is interesting to mention that the same correlation in the crowns of healthy looking trees (defoliation 0-10%) is lower that in the crowns of slightly defoliated.

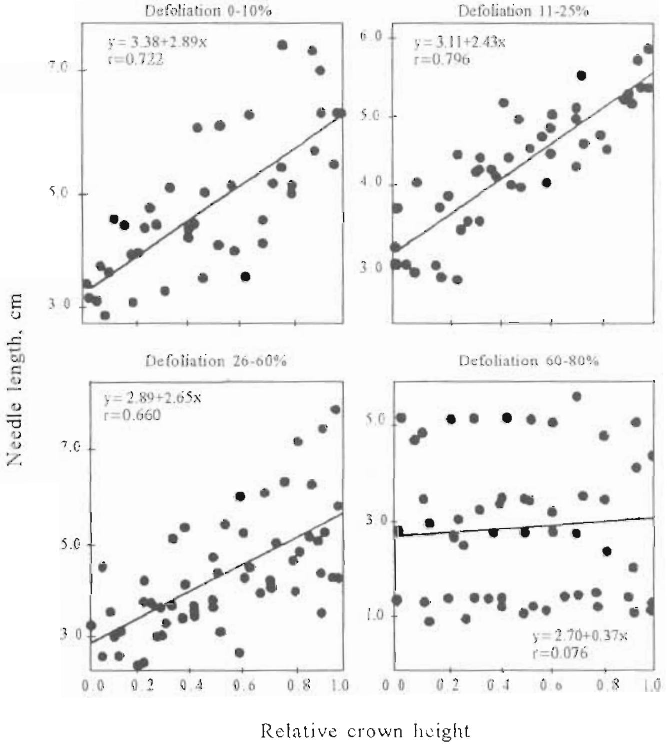

Fig. 3. Relationship between needle lenght and relative crown height (1.0 – top of the crown) at different levels of crown defoliation (pine, 2nd class according to Kraft, age 15-100 years).

For the better explanation and imagination of tree stability levels we have chosen the similarity with the N.Bohr's atom model (Fig. 4).

The nucleus corresponds to a dead tree and the external stationary orbit (we called it the *first relatively stable state*) corresponds to undamaged, healthy tree. The difference in "energy" (relative amount of foliage between the dead tree and tree in the *first stable state* comprises 100%). It is analogical to the energy of electrons, which decreases by approaching the lower orbit with respect to the nucleus.

In the process of tree condition decline (with defoliation increase from 0 to 100%) we have singled out two "stationary orbits", which are called *relatively stable states*.

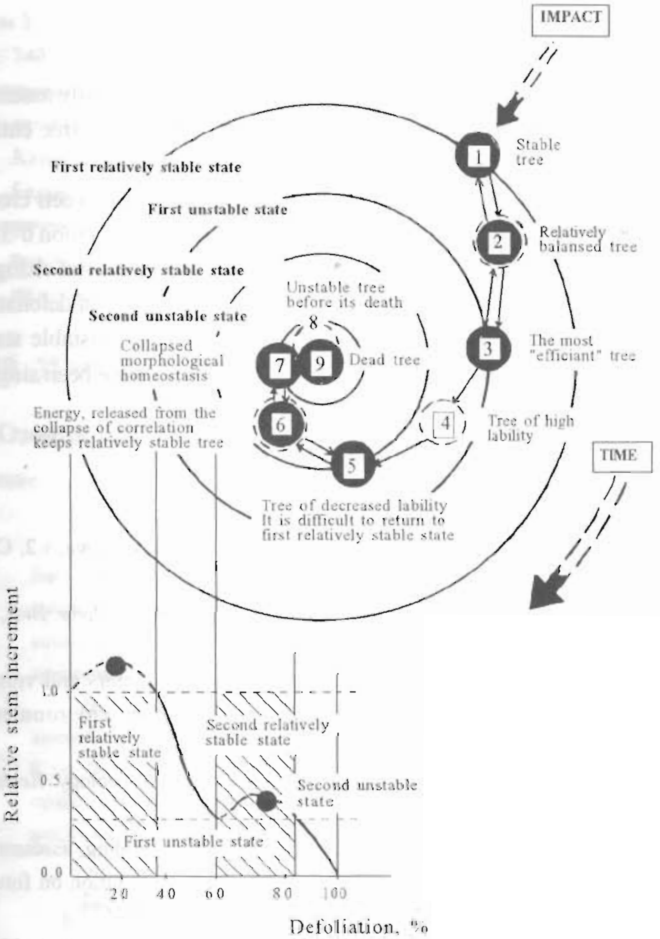

Fig. 4. A schematic figure of tree stability.

The first stable state is observed in the defoliation range of 0-35%, whilst the *second one* takes place when defoliation changes from 60 to 85%. In these stable states, despite the increased in energy losses (decreased of foliage), a tree steadily performs its "work" for some time, i.e. the stem increment conditionally does not decrease. Transition from the first to the second state is, by far, more rapid than "the moving" within a relatively stable state, i.e. decreasing of stem increment suddenly accelerates.

The existence of such relatively stable and unstable states is based on results of our experiments and published papers. We would like to refer to some of them below.

The changes in tree growth and crown structure have been investigated during crown closure in experimental plantations of Norway spruce and Scots pine planted by different initial density (from 0.75 th to 200.0 thousand trees per ha).

Several phases of increment changes were determined during forest ecosystem formation, *i.e.* crown closure. First phase was noted after the closure of the root systems (increment decreases 5-10%), the second one occurs during crown closure or some time following it (increment increases 10-15%) and the third one occurs after crown closure and continues till tree death or till the death of its neighbours. In the beginning of third phase increment decreases 30-50% and remains more or less stable tile the recovering (in case that neighbour dies) or the death of a tree (Kairiūkštis 1976, 1985, Ozolinčius, 1994).

We can single out two relatively stable states namely the first state until crown closure; second state - after crown closure, when the trees are growing in the stand and they are suppressed by each other. When the tree is "going" from the first stable state to the second, it has a significant stem increment loss (30-60%).

Increment changes during the forest ecosystem formation were explained as tree response to stress (stress theory). The second state, for example, was explained as a phase of adaptation.

Each stable state has three relative levels with typical morphological structure of a tree and relationship between amount of foliage and performed "work" (stem, branch increment). For example, the first level *of the first stable state* is characterized by the highest "energy" amount of foliage. It is a so called relatively stable tree which has larger mass of foliage as compared to that necessary for normal functioning, which means that a relatively greater part of the foliage "works" for the branch increment. Ratio between above ground volume (stem and branches) increment and mass of foliage is higher than the ratio between stem volume increment and mass of foliage (Fig.5). Sometimes correlation between the mass of foliage and stem increment is negative (Fig. 2). The morphological correlation between different parts of a tree is weaker than that of the second level of a stable tree.

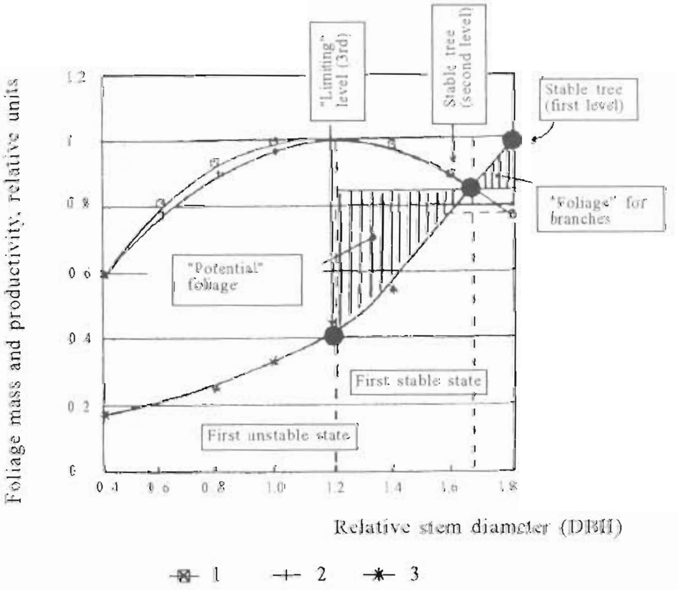

Fig. 5. Relationship between foliage "productivity" and relative diameter (birch stand, 12-year-old): 1 – foliage "productivity" as ratio of stem volume increment and mass of foliage; 2 – foliage "productivity" as ratio of aboveground volume increment and mass of foliage; 3 – mass of foliage (abs. dry). Figure has been prepared using unpublished data with permission.

At the second level the ratio of wood increment to mass of foliage is relatively balanced: foliage "productivity" and ratio of stem volume increment and mass of foliage is less than at the "limiting" level (third level), but remains still high; foliage "productivity" as a ratio of stem volume increment and mass of foliage is less than at the "limiting" level (third level), but remains still high; foliage "productivity" as a ratio of aboveground volume increment and mass of foliage is high and there is some foliage reserve for producing wood of branches (Fig. 5). The morphological structure of tree is more simple than at the first level. The morphological correlation is characterized as strong.

The third level is found to be a "limiting" one, the "work" of a tree is the most efficient, especially in respect to stem volume increment (Fig. 5).

The first unstable state is characterized by one morphological level. Over a very short period of time by "losing" additionally 30-35% of the foliage, the effective "work" suddenly decreases - the radial increment diminishes by 60-70%. A tree is characterized by augmented "lability". Although its increment diminishes, the *relative* values of "response" exceed these of trees being in a stable state. In unfavorable conditions, for example, of meteorological origin the increment of a tree decreases in particular.

The second relatively stable state is essentially similar to the first one but differs by the lower energy. "The lability" of a tree diminishes at the first level of these state. Environmental conditions must be considerably changed in an effort to return a tree to the first relatively stable state. For example, in forestry such cases are known when suppressed trees do not recover after intensive thinning.

At the second level of the second stable state tree remains stable in terms of the increment. Apparently, due to such releasing of energy the increment does not diminish. The third level is a level of completely destroyed morphological homeostasis (correlation between various morphological structury). More detailed investigations are needed to prove foliage - wood increment relations in *these two levels*.

The existence of the *second unstable state* is based on the fact that with increasing defoliation approximately from 85 to 100% the increment of a tree does not decrease gradually up to the infinitesimal. From a certain limit it suddenly falls to the zero value and tree dies. As it is evident from the experimental results, presented in our paper and published earlier (Ozolinčius 1992, 1993), the described theory of tree stability is applicable not only for tree as an organism, but for a separate its parts – branches – as well (for example, experiments with shading of branches etc.).

Described two levels of tree "stability" do not contradict the concepts of the biological system stability and homeostasis and the general theory of stress (Selye 1952; Odum 1975; Udovenko 1979). They just show the same nature of phenomenon in micro and macro systems.

CONCLUSIONS

1. There is strong linear relation between visually assessed crown defoliation and "real" foliage estimated after tree cuting down (r = -0.89 – -0.91).

2. There was not found linear relationship between crown defoliation and stem increment. At the limits of defoliation 0-35% and 60-85% radial increment remains without significant changes.

3. Two relatively stable states (first, in the limits of defoliation 0-35%; second - in the limits 60-85%) and two unstable states (first, in the limits 35-60%; second - 85-100%) have been singled out and characterised by 1-3 morphological levels.

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Два уровня стабильности дерева

Р. Озолинчюс

Резюме

Стабильность определена как свойство системы нормально функционировать не смотря на внешнее воздействие. У дерева, как биологической системы, такое нормальное функционирование – его "перевод" солнечной энергии в другие ее формы. Листва в такой системе занимает особое место. Это не только продукт функционирования дерева, но и внешнее отражение его "энергии", т.е. способности осуществить определенную работу. Стабильность дерева определена как стабильность соотношения между приростом древесины и массой листвы.

На основе базы данных лесного мониторинга, а также на данных модельных деревьев и экспериментов, осуществленных автором и его коллегами, выделены два уровня стабильности дерева: первый, при снижении массы листвы - дефолиации кроны - от 0 до 35%; второй, при дефолиации – 60-85%. В вышеотмеченных пределах дефолиации радиальный прирост дерева остается без существенных изменений. Прирост резко падает, когда дефолиация увеличивается от 35 до 60% и от 85 до 100%. Приводится аналогия между описанными изменениями в строении дерева и теорией строения атома, разработанной Н.Бором.

Ключевые слова: стабильность деревьев, прирост, масса листвы, дефолиация.