

Forest Trees, Environment and Genetic Aspects -
a naive but curious view by a bioclimatologist

Gode Gravenhorst

Section of Agriculture and Forestry in the Tropics and Subtropics
and
Institute for Bioclimatology

Georg – August - University, Goettingen, Germany

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In the natural and the social sciences important issues in present public as well as disciplinary and interdisciplinary discussions are concerned with questions like the following: Do humans have a free will? Or: Are human thoughts and actions predetermined? Do genetic constitutions or do socialisation processes determine our personality? I often ask myself: Who am I? Am I merely a pile or a sequence of genes and, therefore, not responsible for my actions or am I a self determining person and responsible for the consequences of my actions? In an analogous way one can also ask: Is a tree determined more by its genome or by its environment it encountered during its lifespan? Or even more radical: is any genome (set of chromosomes) of an organism not the result of environmental conditions during the entire past including all generations altered only by a random sequence of spontaneous or environmentally influenced mutations? In scientific and ethic discussions on manipulations of the genome of organisms questions are raised like this one: Is it justified to transplant single genes and short gene sequences or even entire genomes (set of chromosomes) of one cellular organism into other organisms with the potential to change the entire metabolism? Organisms, which reproduce in a sexual way, show similarities in parent and offspring generations. The question, whether genetic heritage is occurring at all, can be answered in a straight forward way. But how much genetic heritage and ambient environment do contribute to the observed appearance of an organism, for example to the phenotype of an organism at a very concrete time? To what extent is a population of genomes selected by environmental conditions and how far is a population capable of adapting to changing environments? External living conditions for terrestrial organisms are changing all the time. External atmospheric physical and chemical influences, e.g. on growth of

an individual existing organism, and reproduction processes of trees are changing in the course of the day, of the season, from year to year, and in long term variations and during a general trend with time.

Geological soil attributes in the rooting zone of terrestrial ecosystems stay, however, rather constant. The above ground atmospheric living zone is, on the contrary, changing all the time, from day to night time, from winter to summer, from short cold to following short hot periods, from rainy to dry seasons, from stormy to calm days. The chemical climate of the atmosphere is also changing: concentrations of trace gases and particulate concentrations in the air and their deposition rates into ecosystems change: for example, ozone and other photooxidants in the air in the course of intense photochemical episodes, alkaline particles during mineral deposition in dry periods, impaction of cloud and rain droplets with low pH values, high and low concentrations of stack, chimney and car exhaust emissions of air pollutants, as e.g. sulphur dioxide, nitrogen oxides, ammoniaorganic compounds. These short term variations are superimposed by long term concentration and deposition trends of gases with a long atmospheric lifetime as e.g. carbon dioxide, dinitrogen oxide, methane, volatile organic compounds, persistent organic pollutants. The acidic burden of the atmosphere by airborne man made constituents is returning continuously to the earth surface since the onset of industrialisation. These atmospheric variations perpetuate into the surface layer of the soil: soil and ground water quantity and quality, soil temperatures, biological activities in the soil depend on atmospheric influences like e. g. amount and chemistry of rainfall. In addition, the biological environment changes drastically from time to time, e.g. when microbial communities establish themselves at shoot and root systems influencing the plant.

Individual organisms can react and protect themselves, when living conditions shift to hostile and stressful characteristics. They can escape this environment or adapt their metabolic and physiological processes to the new environmental situation by eliminating the stressor or its impact. A plant, which usually can not move and escape menacing environments, should be able to adapt its internal processes and outside structure to a new environment in order to survive as an entity. A survival of individual organisms at least until their regeneration phase is a prerequisite for a population to survive for several generations.

For sexually reproducing higher plants critical processes for generating offsprings are flowering, pollination, formation and dispersal of seeds, seed germination and seedling growth until the reproduction age is reached. During the critical reproductive phases the survival of consecutive generations does not only depend on genetic properties of the plant ensemble, that means on the many genomes of the numerous population members, but also on their immediate environment and its

variation in time and space. Both systems have to fit so that an already existing organism can survive and consecutive generations can establish themselves.

As an atmospheric scientist I have had and still have problems to understand discussions on molecular genetics and their implications for the functioning of ecosystems. Therefore a short and naïve view on aspects of environmental genetics is attempted here.

The genetic constitution in cells of a higher plant consists of several different chromosome sets. One chromosome set consists of two chromosomes, one of which is derived from the father, one from the mother. These cells are called diploid, because they have two (bi) chromosomes in one set. Only in sperm and egg cells one chromosome set consists of one individual parent chromosome. These cells are called haploid. These haploid cells are preferentially investigated in their molecular genetic structure because - compared to diploid cells - less alteration possibilities in the measured genetic variations are encountered. Each chromosome of a species is made up of a bio-molecule, the DNA (desoxyribonucleic acid). The DNA is made up of sequences of nucleotides (1000 to 1000 000), each nucleotide of one sugar molecule (desoxyribose), one phosphoric acid molecule and one base. Many connecting nucleotides of very different nucleotides combinations form one gene. To generate the structure and function of the evolving plant the genes have to generate proteins. The bio-molecules of the proteins are forming the structure and function of the organisms. Different proteins with different concentrations at different times are, therefore in the cause of development, in the course of development. Genes in higher organisms are mainly confined to the cell nucleus. The proteins, however, are formed from amino acids outside of the nucleus. The information of the genes has, therefore, to be transferred via the membrane confining the nucleus into the cell plasma. The information carrier is the RNA (ribonucleic acid), which is composed similar to the DNA. In other words, to generate a next generation existing organisms should have the capability and the possibility to duplicate their genetic blueprint and to realize the structure and function given in the blueprint. Thus, the generic information on one hand has to be kept constant and to be duplicated and on the other hand to be realized. The bio-molecule DNA has the capability to achieve both goals. Both strands of the DNA helix are not identical but complimentary. To transfer genetic information to the next generation the DNA will be duplicated. For this purpose both strands have to be separated. They serve as a matrix for the organisation of the next complementary strand.

The same genes can be present in different variants on the two strands of the chromosome set. These gene variants are called alleles. A gene

or a group of genes is generating by way of its binding structure - coding for synthesizing from amino acids certain proteins which are responsible sources for certain attributes and capabilities of an organism. The different proteins stir the development of structures and functions in the emerging cells of the future organism. A gene can be active, that means can express itself by forming respective proteins or it can be suppressed and inactive. This depends on the interaction with other genes or conditions in their immediate biophysical and biochemical environment. An allele can be dominant or recessive. A gene or a sequence of genes can be chemically separated from a DNA strand at a primer at certain positions. This tiny part of the genome can be characterised by its mechanical mobility in an electric field by gel electrophoreses. The measured mobility spatial pattern is characteristic for an individual organism. Another way to identify the genetic structure of organisms is offered by a DNA microassay. With a DNA microassay numerous natural genes or artificially made genes are fixed reproducibly in a certain pattern onto a special surface. To analyse which genes are present in a certain cell material this cell material is brought into contact with this particularly structured surface and the same genes are binding to each other. The investigated genes are made fluorescent beforehand. The non-binding genes are washed off and the remaining fluorescent intensity at certain spots of the solid matrix is an indicator for the sequence of genes within certain biological cells.

The genes can produce enzymes as bio-molecules for certain biochemical reactions. Different genes can produce different enzymes. Enzymes can be different in their structure, but are still able to catalyze the same reaction. These enzymes are, therefore, called iso-enzymes. Their mechanical mobility in a gel electrical field is different. These iso-enzymes are separated from the cell solution and concentrated before analysing their mechanical properties in an electrical field. Differences in their structures are differentiated in a quite sensitive way.

A gene or a group of genes characterises a certain trait of an organism, e.g. the colour of the flower. It has a certain fixed position or locus on the DNA. For one offspring the gene herited from the father can be the same as the one herited from the mother (homozygote), or the genes at the same locus but at the two different DNA strands can differ from one another (heterozygote). Therefore, many possibilities exist for a gene transfer from two parents to one offspring. One offspring can have several alleles at one gene locus of its two chromosomes or only one. If several alleles exist at the same locus of different individuals the genotypes of the individuals are different. If different alleles of the same genotype are expressed in individual organisms the phenotypes of these individuals are different. In higher plants the chromosomes are conformed to the cell nucleus. In order to influence structures and

functions of the evolving organisms the many information manifested in the genes of the chromosomes has to be replicated and this copy has to be taken across a membrane into the cell plasma surrounding the cell nucleus. This message carrier is generating the characteristic proteins from amino acids according to the blueprint of the gene structures and positions.

The impact of a gene, that means its expression or influence on the formation of proteins, can be switched on and off depending on the influence of other genes as well as of biochemical and biophysical circumstances.

One scientific hypothesis is put forward concerning the impact of alleles on the fitness of an individual organism to cope with a changing environment. This hypothesis states, that a large number of alleles at one gene locus and/or a large number of gene loci with different alleles support the capability of this single individual to adapt to a changing environment and to different realisations of the environment.

A population of organisms adapted to a constant environment do not have to sexually reproduce, because there is no need for genetic variation to be able to adjust to new environmental conditions, because the environment is constant. But in reality the physical, chemical and biological "climates" for terrestrial plants like trees are not constant. An individual tree with its long life span and especially several tree generations are exposed to quite different influences with time.

Therefore, the gene constitution of a single tree and the gene pool of a tree population should have an adequate genetic variation in order to withstand future environmental changes within a life of a tree and during environmental trends along several generations. How can a genetic variation within a species generation be estimated and quantified? The genetic variation within a representative tree species population can be expressed by a quantitative indicator, which takes into account the total number of gene loci within the population, which, in turn, are characterized by two or more alleles. Since a tree species can have more than 30 000 gene loci, and a representative tree population may comprise hundreds of trees it will hardly be possible in the near future to quantify such an indicator.

Several examples given in the scientific literature are indicating that such an advantageous heterozygote principal is acting in nature, when environmental conditions change or vary over short time scales. These examples will be shortly described here. They empirically demonstrate, that the environment of tree species influences the genetic structures of the species that short term environmental stress conditions can be better withstand by heterozygote individual trees at certain gene loci than homozygote at the same gen loci. Several case studies have been reported by Mueller- Starck et al. (2005), Ziehe et al. (2000), and

Mueller-Starck (1989), which support this assumption. These investigations can be classified into different groups: For one tree group the geographical distribution of a tree species is correlated with its present genetic constitution in these regions. In the second tree group the effect of atmospheric SO₂ concentration on the genotypes of trees reacting in a different manner is discussed. For a third tree group the relation between soil properties and genetic markers is analysed.

1. Based on two different DNA markers, that means genes at different gene loci, 22 genetically different types of sycamore tree populations were detected. Clusters of gene markers could be observed, which were typical for certain geographical regions in Europe (Bittkau 2002). Major refugial regions during the last glaciation of Northern Europe and of the Alps about 15 - 20 thousand years ago could be identified. In southern Italy, in south-western Europe and in regions close to the Alps different sycamore genotypes have been concentrated. From there they began their migrant way to reconquer their growth regions. The different environmental conditions at that time and during the time afterwards can still be observed at genetic markers, e.g., in germ cells. Differentiation in geographically distributed subpopulations of a tree species reveals that environmental conditions which prevailed several ten thousand years ago are still traceable by means of the recolonisation pathway after glaciations.

Tree provenances, therefore, have genetic structures mirroring past environmental conditions for their growth regions.

2. New environmental conditions can stress a tree population. Different genotypes within the population can have a different viability with respect to the new stress factors. Such a different reaction can be tested. The genetic constitution of two phenotype population subsets growing under the same environmental stress but with different selections can be compared. In one empirical field and laboratory study tree pairs were chosen of which one tree looked healthy whereas the other one looked unhealthy. Both the healthy subset of trees and the unhealthy subset were aggregated and the genetic constitutions compared. The resulting comparison of tree pairs of the same age and exposed to quite similar environmental conditions could suggest that genetic differences might cause the two different observable attributes. One factor indicating stress which showed a different reaction within paired trees was a high salinity concentration in soil solution caused by NaCl salt used to prevent icing of a nearby road.

Another stress factor was the high acidity of the soil, in which seedlings grew in the field compared to seedlings which grew in normal garden soils. The acidity may only be an indicator for other accompanying stress factors or of a general stress milieu (Mueller-Starck 1993).

3. A third group of tree populations exposed to another stress factor was investigated in the Ore Mountains in Saxony, Germany, where high ambient SO₂ - concentrations prevailed (Wolf 2001). Both a sensitive, damaged looking subsample and a tolerant, healthy looking subsample showed distinct, statistically significant different markers at the same gene loci. This genetic difference reveals that environmental conditions assigned here as the two stress factors salt concentration in soil solution and atmospheric SO₂ concentration select genetic constitutions of the trees which favour good or bad adaptation of the trees to the stressor. From the many genes a tree species can have (with an upper range of about 30 000 genes) only very few genes were analysed in these investigations. It is a surprise that a correlation between the heterogeneity of these few genes at certain gene loci and the reaction of these trees to certain environmental stresses could be found. Constitutions and positions of the many genes of a genome have been identified. Their functions for the character of the organism, however, are mostly unknown. A relevant property of plants, e.g. of trees, may depend on one gene (monogenetic), or on few genes (oligogenetic), but also on many genes (polygenetic). The individual contribution of the many genes on one single attribute can hardly be recognised in the trait expression of the phenotype. It is even much more difficult to identify the contribution of genes and of the environment to the observed phenotype variation. One of the parameters mainly influenced by the atmosphere is the temperature of plant reproductive organs and entities. The temperature determines the speed of reactions and, therefore, the concentrations of macro-, meso-, and micro - elements and compounds of reactants in physiological processes in plants. Therefore, the genetic processes are in a large extent stirred by the temperature of the system. Concentrations of e.g. aminoacids, proteins, enzymes, lipids, ions, they all depend on temperature of their environment. They determine the expression or suppression of genetic functions. For example, the temperature of the cytoplasm and not the chromosomes determines whether a crocodile becomes a female or a male (Nüsslein-Volhard 2006). Adaptation to present and future prevailing temperature conditions will, therefore, be an advantage for long living individual organisms to generate offsprings and for populations to survive for many generations in their cooperating and competitive struggle for living resources and reproductive capabilities and possibilities. The average or mean temperature of plant organs, seeds, or seedlings are not as important as extreme values. Rare but extreme values of temperatures or other atmospheric influenced properties can cause great and permanent changes in genetic effects. The function of some genes in plants has been identified. With molecular genetic techniques individual genes, gene groups or even entire

genomes can be introduced into other organisms. Genetically fixed properties can thus be transferred from one plant to another and be heritaged for the purpose of increasing resistance against biotic and abiotic threats and damages and to support better crop yield and crop quality.

In forestry caution should, however, be demonstrated in an even more sensitive way than in agriculture to apply molecular genetic techniques to alter the genome structure of widespread plant populations because forest trees are special in their properties (Finkeldey 2008): 1. they have a very long lifetime, during which the environment may change unforeseeable, 2. they are immobile and grow in low input land use systems, 3. forest trees are still rather natural and not “domesticated” in their genetic structure although forests are often managed by introducing selected seed and seedlings .

Therefore forests should in the first place not be adapted exactly to the present environment but should keep the capability to adapt to future at present unknown environmental conditions, if forests should be managed in a sustainable way. It is, therefore, necessary to understand and project future physical, chemical and biotic conditions, genetic bases of the properties of forest tree populations and the dynamic evolution of the interaction of forests and the climatic environment.

In pinpointing one can come to the conclusion that the genetic structures of an individual organism and of an entire population are the result of the everlasting and everchanging physical, chemical and biological environments. The atmosphere and competing other organisms contribute most to shape these environments and, therefore, are of prime importance for the short and long term evolving genetic constitution of the living organisms at the interface of atmosphere, hydrosphere, and pedosphere.

Plants and humans may be viewed in a quite similar way in their relation to environmental genetics. The genetic structure of humans forms the basis for the biological existence of their carriers. The frame work of the inside and outside appearance of an individual person is prescribed by its parent generations. The function and intensity of some traits can, however, be changed by training in adapting to eustress and distress situations like e. g. in sports and thinking, so that individuals can have a wide spectrum of attributes and fulfil a large range of activities. But human generations are also shaped by the mating choices and their success of women and men. A population can maintain itself and propagate in a sustainable way, if different heritaged capabilities and learned skills are present and evolve in a dynamical way.

However, human beings represent more than pure biological plant organisms, they have a moral compass, with which their actions can be directed. Humans as well as plants can not escape their basic nature,

defined by the genome and they both can adapt to a changing environment as individuals and as populations. But in addition humans can have the choice to neglect the environment for their own assumed sake. If humans have a choice, they are free.

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