# Procedures for forest experiments and demonstration plots

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Historically, procedures for forest experiments and demonstration plots were developed mainly with a focus on above-ground parts of the trees and with the main objective to quantify the wood resource and its growth potential. Due to an increasing diversity of the forest policy agenda and of forest management objectives plot procedures are developing to provide data for a broader range of forest and site characteristics and to adjust and refine measurement practices accordingly.

In addition to the classical topics of tree and stand growth, forest health and wood quality, the focus has gradually expanded to include, for example, assessment of forest operations performance, regeneration abundance and quality, carbon stock, biodiversity (fauna, flora and fungi), habitat diversity, range land, water resources, light conditions, crop nutrient balance, soil characteristics, recreation opportunities, cultural heritage and amenity values.

For many of these topics, sampling and measurement procedures have been developed in other branches of science. In the context of forest ecosystem management, the challenge is to combine these procedures cost-effectively with forest measurement practices.

Many of the additional ecosystem attributes correlate well with individual tree properties, stand characteristics or overall forest structure, and traditional forest measurements are often more cost-effective and versatile. So, regardless of management, demonstration or reseach objectives, the trees of the forest must be quantified for informed decision making. Consequently, forest experiments and demonstration plots maintain a strong focus on the above-ground tree components of the forest ecosystem.

The scientific approach to forestry in a modern context began in Central Europe at the introduction of regular and planned forestry in the mid-1700s, coinciding with the advent of modern natural sciences. The establishment of the German Federation of Forest Experiment Stations in 1872 furthered a major breakthrough which resulted in a common norm for forest experiments in Central Europe (Ganghofer 1881).

Following the foundation of the International Union of Forest Research Organizations (IUFRO) in 1892 these recommendations have greatly influenced developments and practices in other parts of the world. Next, the introduction of statistically-designed forest experiments and sampling procedures additionally enhanced the quality of research and demonstration plots.

A large number of recommendations are currently available in the literature for sampling, measurement and modelling practices in the context of forest ecosystems (e.g., Avery & Burkhart 2002, Bitterlich 1984, Husch et al. 2003, Köhl et al. 2006, Loetsch et al. 1973, Philip 1994, Pretzsch 2001, Pretzsch et al. 2002, Prodan 1965, Schreuder et al. 1993, Shiver & Borders 1996, Skovsgaard 2004, van Soest et al. 1965, Vanclay 1994, Vanclay & Skovsgaard 1997, de Vries 1986, West 2004).

Procedures for forest experiments and demonstration plots have received less comprehensive attention, and generally with little concern for practical matters which may influence the interpretation of observations (e.g., Alder & Synnott 1992, Condit 1998, Fabricius et al. 1936, Jeffers 1959, Johann 1993, Pretzsch 2002 – Henriksen 1961, + Res. Inst. Baden-Württemberg).

The following recommendations for plot procedures summarise decades of practical experience in experimental silviculture. More attention is given to pragmatic solutions rather than formal or statistical rigour. However, this should not detract from the fact that all experimentation in forestry should be basically be based on statistically-designed lay-out and sampling procedures.

Considering the relevant research or demostration objectives, the intention throughout is to minimize costs relative to the expected output. To ensure that the initial investment of establishing research and demonstration plots is not lost, things which may go wrong during the investigation is given special attention.

**Research and demonstration objectives**

All experiments and demonstration plots should have a defined objective.

The objective(s) should be associated with one or more testable hypotheses.

Hypotheses should preferably relate to the understanding of cause-effect relationships.

Decide on test criteria (test accuracy) as early as possible. Obviously, this relates to choice of variables, sampling intensity and measurement procedures.

Consider the longeviety of the investigation.

Often research or demonstration objectives may be viewed under different time constraints, for example including short-, medium- and long-term objectives.

Disregarding the type of research objective, all experiments should include demonstration options.

Often, demonstration plots are directly oriented towards forestry practice and with the aim of demonstrating effects of two or more contrasting management practices within a relatively short period of time.

Disregaring demonstration objective, all demonstration plots should include the option of statistically-based analyses.

**Treatments**

Experiments and demonstration plots should include contrasting treatments.

Treatments should be objectively defined and preferably specified on a numerical basis.

Avoid treatment specifications which are highly subjective or depending specifically on the personal view of one or more scientists, forest managers or land owners.

Simple specifications should be preferred over more complex treatments which, with the passage of time, may be difficult to repeat or interpret.

Treatments should range beyond, but include, the range of contemporary, recommended (or prescribed) forestry practices, and preferably include one or more treatments which, at the time of establishement, are considered extreme compared to contemporary management practices.

There are several objectives of including extreme treatments. One is provide a suitable basis for interpolation (as it is undesirable to do extrapolation for treatments which, now or in the future, may be used in forestry practice). Another is that management practices may change considerably over time, thus changing the perception or relevance of extremes.

**Statistical design**

In a designed experiment, all the variables are supposedly held constant except those varied according to the design. Hence, all variables are accounted for. Data collected without the aid of an experimental design may be suspect for a variety of reasons.

Factorial design:
One-factor experiments
Randomized block design
Latin square design
Factorial design
Split-plot design
Balanced and unbalanced incomplete block design
Combination of experiments carried out on several sites and in different years
Special designs (Nelder, CCT, Scots plaid, clinal) – those might be difficult to evaluate / interprete

Mention advantages and drawbacks of each design. – See Marks Nester's book on design etc.

**Placement of plots**

Ideally, experimental plots should sample the geographic range over which results will be used, and encompass the full range of forest types, site productivity and topography, which is considered to be relevant for the issue in question.

**Number of plots**

The number of plots depends on the research objective and acceptable error of key variables, but is in practice often dictated by available land area for each site and by the resources available. There is little point establishing more plots than can be maintained. It is better to have a few plots providing reliable data, than many plots with inadequate management. The number of plots should also be determined by the variability of the forest and the need to sample the full range of forest conditions. – Design the experiment in a cost-effective way.

A database comprising a few plots each with many remeasurements violates statistical assumptions of independence, and may require special analyses (West et al. 1984, 1986, West 1994). This violation becomes significant when the number of remeasures is large relative to the number of plots. However, plots must be retained for extended periods with many remeasures to allow convincing tests and confidence in possible extrapolations.

Within-site replicates
Between-site replicates
International cooperation
Single-tree plots
The issue of co-variates – promote the use co-variates

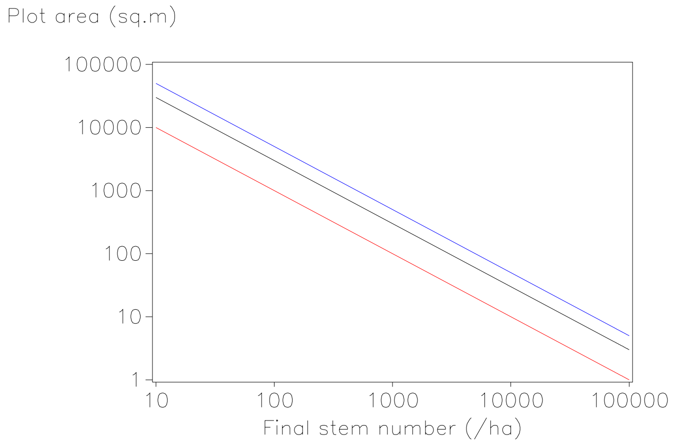
Genuine vs. pseudo-replications. For example, the potential of enlarging plots may be desirable if the experiment should continue longer than originally planned: This can be achieved if some neighbouring plots are treated identically or similarly according to one or more criteria. Again, the use of co-variates is important, - vs. randomization.

For area-based variables: Number of replicates should also depend on production risk. There should always be a minimum of two replicates, at least for the extreme treatments.
The number of treatments should be balanced with the number of replications.

For variables based on individual trees (or parts of trees): Use statistical formulas.

Within-site replication of treatments should be preferred over additional variations of treatments. If such additional variations are desired, for whatever reason, and the land area available is insufficient, a compromise may be made by replicating a combination of highly relevant treatments and extreme treatments with unreplicated plots of treatment variations.

**Size and shape of plots**
Size of plots
Minimum number of trees = 10 in final sample
log Area = 5 - log N + 'research intensity factor' (red = 1, black = 3, blue = 5)




Can we identify a 'universal' CV for important variables?
What is the propability of (not) detecting a treatment effect if CV = 10% and N = 10?

Shape of plots: Circular (small demo-plots), otherwise close to a square.

Explain the idea of a modular approach. Start with full plot, but sample sub-plots within the full plot, subsequently expand sample size or size of sample units.

**Buffer zone and plot surrounds**
Edge effects. - There must be a minimum size (relative to shape), considering edge effects. This must relate to tree height (equals ½-one tree height) - but a buffer zone of one tree height would demand too large areas. – Find a compromise between replications, nett plot size and available land area. – The more serious the edge effect is expected to be, the wider the buffer zone.
Include something on the single tree approach.

**Plot subdivisions**
Often stem mapping is not possible because of budget constraints.
In this situation, plot subdivisions may provide an indication of spatial within-plot variations.
Plot subdivisions can be established based on permanent plot demarcations.
Plot subdivisions may be marked in the field at regular intervals by short pegs, nails or similar.

Temporary markings (which may last for years) by nylon strands (?).
Planted stands vs. naturally regenerated stands.

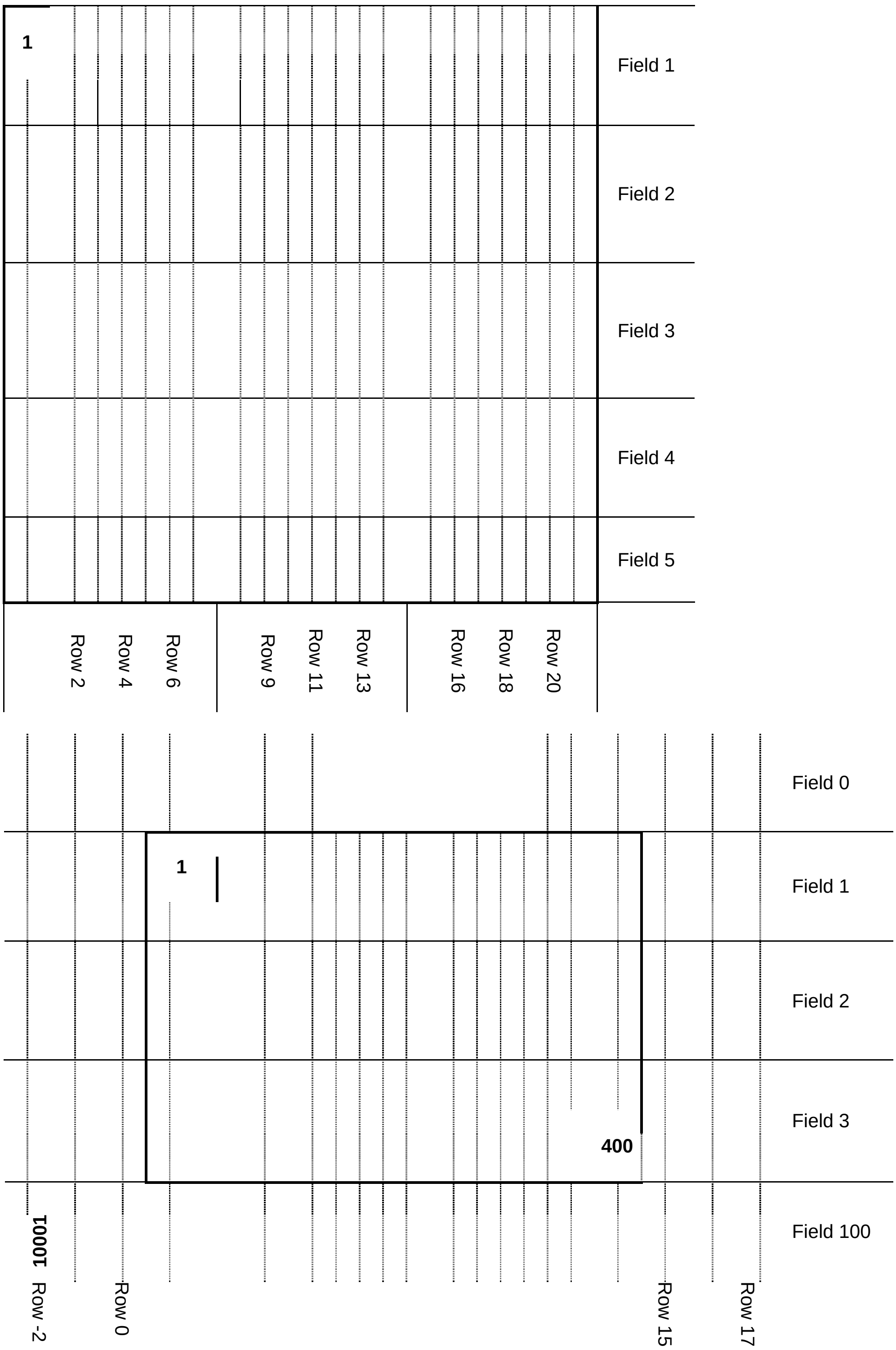



**Figure**
Two examples showing plot subdivisions for a young planted stand.
Above: nett plot. Below: gross plot, including buffer zone.

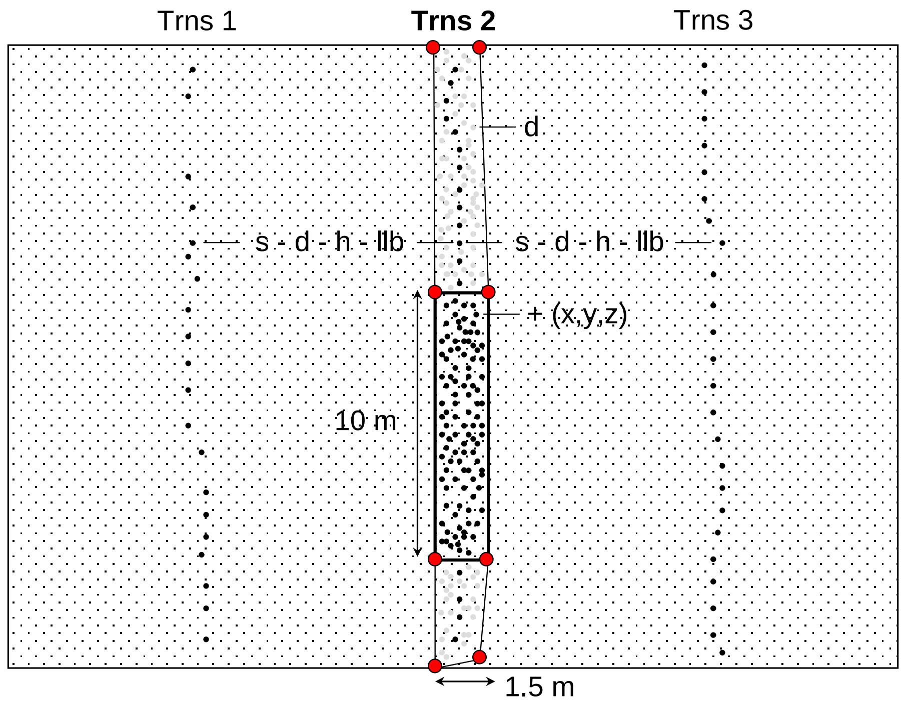



**Figure**
Example showing plot subdivision for a young naturally regenerated stand with four different measurement intensities. Red dots: permanently marked corner posts. Bold black dots: trees which are measured for status (dead/alive), diameter, height to lower live branch and total height. Bold gray dots: trees which are measured for status (dead/alive) and diameter.Thin black dots: trees which are not measured.

A third alternative is, for example, circular plots within a full and fully treated plot.

**Plot demarcation and surveying**
GPS
Mapping of the location.
INKA-TINKA plots, mention those as an example.
Permanent demarcation of plot corners and other permanent research areas (for biodiversity, photograpy, soil condition etc.). – Galvanized iron pipe.
Trenches? - Do we still recommend trenches at plot corners? No, but the practice should be mentioned. – Plast markers agricultural cerials.
Concrete corner beacons? - Can anybody afford this?

Identification and numbering of marker posts
Visibility of markings (including plastic rods).
Mapping of plot and tree locations.

Marking of plots:
Permanent markings cost little more than temporary markings.
Corners or centre?
Visible or invisible?

Invisible: There should be permanent markings in the field anyway, to be located based on mapped information or gps and possibly metal detector.
Visible: Always map the plot boundaries and plot surroundings, in case a machine, a log, a tourist (or otherwise) damages plot markings.

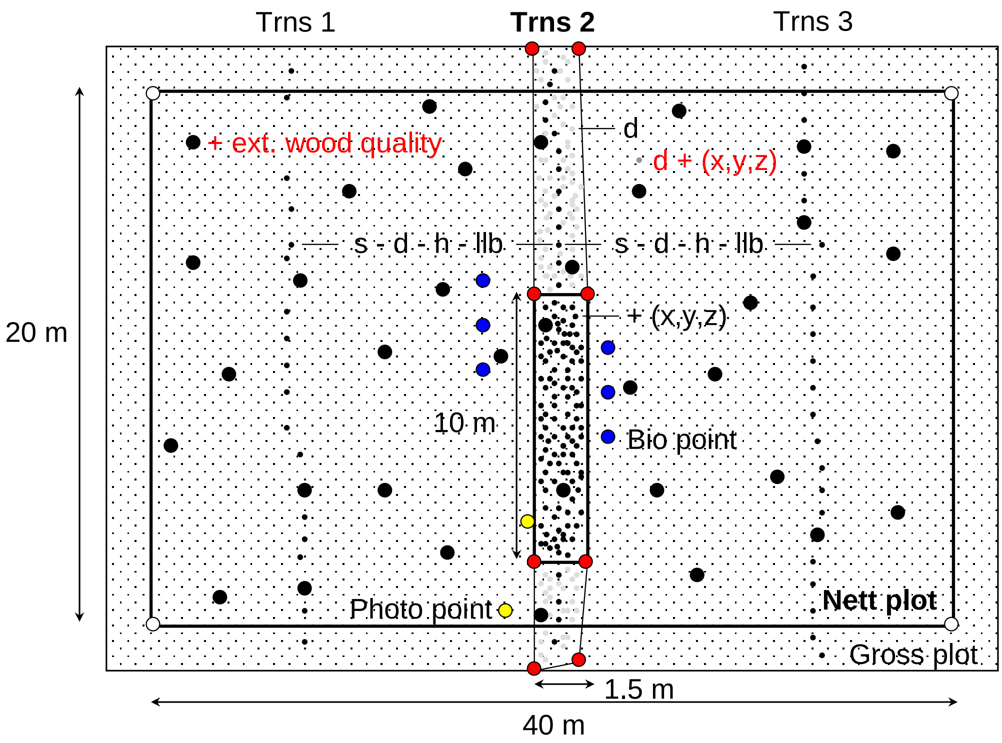



**Figure**
Example of fully marked, but yet extensively monitored young naturally regenerated stand.

**Figure**
Example of an intensively measured section of a stem mapped transsect in a young naturally regenerated stand of beech (cf. above).

General visibility
Marking of buffer zone

**Site assessment**
Including soil and other indicators (flora, fauna, fungi ?).
Land-use history
Site mapping (elevation, exposure, drainage etc).
Soil pit combined with “stik” – for example 10 x 10 m

**Sampling procedures**
Define the statistical population
Sampling methods:
- Unrestricted random sampling
- Stratified random sampling
- Subjective sampling
- Sequential sampling
- Point sampling
- Sampling for rare objects

Shape and size of sampling unit
Selection of sampling units
Number of sample units required
Uniformity trials and pilot surveys
The sampling scheme should consider the options for statistical analyses

**Measurement procedures**
Measurement intensity (and accuracy) should relate to research objective (for example, growth responses to stand treatment practices vs. variations in relative provenance performance). The expected response surface have implications for sampling and measurement procedures.

Investigations which involve per area estimates vs. individual trees (for example, 'rare' admixed, valuable broadleaved tree species).

Disragarding scale, admixed tree or individual tree management approaches should always be considered an integral part of stand management or the silvicultural system.

What to measure - at initial measurement, on re-measurement occassions, at final measurement
What to measure depending on budget. As annual budgets may vary considerably all measurement procedures for experiments and demonstration plots should include three levels of measurement intensity depending on available funds.

Measurement size thresholds
Tree numbering and marking:
- Paint
- Metal numbers
- Plastic numbers - two different types
- Electronic chips

Numbering and marking of other measurement items
Stem mapping

Marking of potential crop trees

Variables to measure
Number of observations needed on each variable for the cv to stabilize
Consider measurement error relative to rate of change to decide on when to remeasure

Measurement scales:
- Nominal (categorical)
- Ordinal (rank)
- Interval (numerical without zero)
- Relative (numerical with zero)

Stem mapping procedures – do a special discussion

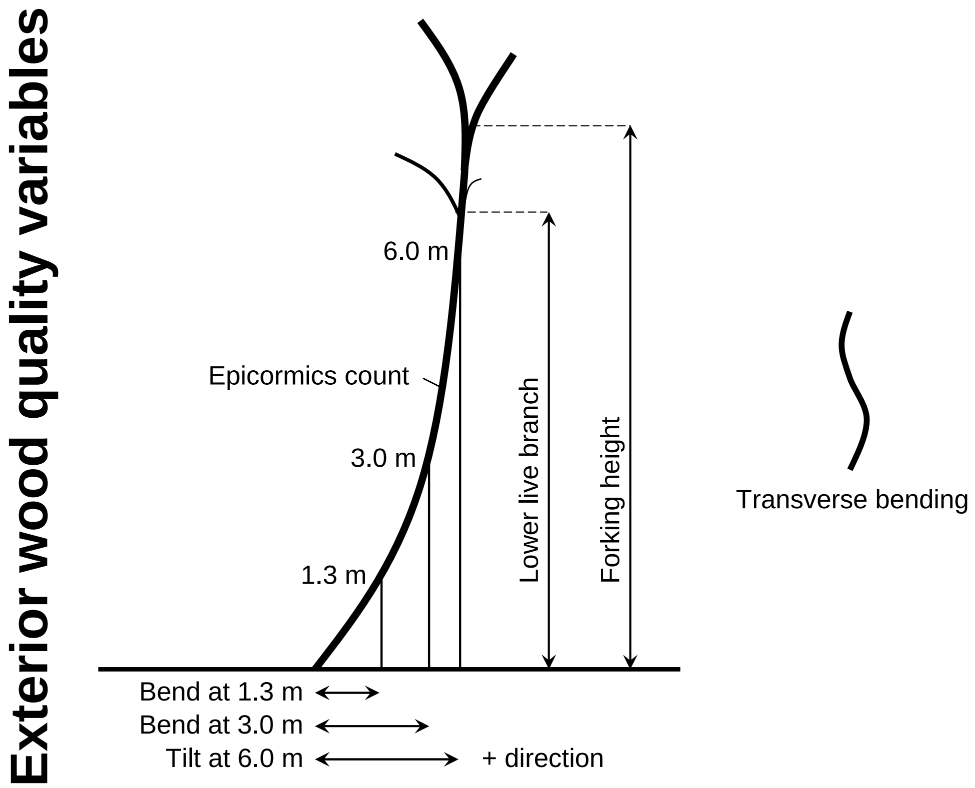
Instruments
Regular checking of instruments

Regular training of staff and quality control

We want consistent measurement standards.

Refer to standard texts regarding classical forest mensuration, - but should we do something special for 'other' variables? - wood quality? - recreation? - where is the limit, and how do we strike a balance.

**Measuring exterior wood quality - an example**



**Exterior wood quality: the positives**

- No forking < 6 metres
- High natural pruning
- Vertical (no tilting)
- Straight (no bending)
- No epicormics
- No or little transverse bending (sinousity)
- No or little spiral grain
- Regular spatial distribution

**Eight exterior wood quality variables**

| | |
|---|---|
| • Vertical (no tilt) | Tilt at 6.0 m + direction |
| • Straight (no bend) | Bend: 1.3 + 3.0 m + *(0,1,2)* |
| • No forking < 6 metres | Height to lowest fork |
| • High natural pruning | Height to lower live branch |
| • No epicormics | No of epicormics < 6 m |
| • No or little transverse bending (sinousity) | Present = 1, Absent = 0 |
| • No or little spiral grain | |
| | + OS tree: dist + dir |

### Data recording and processing

Notebook
Loose paper sheets – minimum requirements, provide examples
Electronic data recording by entering data manually to field pc
Direct electronic data recording to field pc
Keeping track of individual instruments in case of errors relating to these
Data quality control, in the field and subsequently
Note the name of measuring crew

### When to measure and remeasure

-

### Establishment report

Always make an establishment report including relevant information on research or demonstration objectives, location of experiment, statistical design, plot lay-out, plot demarcations, site conditions (climate, topography, soil), initial stand conditions, treatment specifications, measurement programme (three levels, depending on funding), status of experiment depending on funding, agreement on conditions for conduct of experiment signed by all partners involved (research institution, land owner, forest authority and other relevant partners). – Including photographs.

### Administration

Databases of forestry experiments (example: NOLTFOX, http://noltfox.metla.fi/).
Priorities of experiments (institutional or otherwise)
Searchable database of experiments and demo-plots at regional, national or super-national level, for example in the context of a forest owners' association, a regional forest authority, a national forest service or a group of countries.

### Costs

Generally, initial costs for planning and establishing an experiment are considerably higher than costs of remeasurement and maintenance.

Overview of costs on a relative scale (rule-of-thumb, excluding travelling cost):

| | | |
|---|---|---|
| Plot installment costs | 100 | Once |
| Initial meauserement | 100 | Once |

| | | |
|---|---|---|
| Re-measurement | 50 | At regular, short intervals |
| Plot maintenance | 50 | At regular, long intervals |
| Final measurement | 75 | Once |

**Plot maintenance**
Here we need lots of paint and students

**Regular reappraisal of experiments and demonstration plots**
Research priorities
Experiment priorities
Measurement programmes depending on funding

**Special considerations depending on research or demonstration objective**
What do we do about valuable broadleaves?
Can we define a standardized procedure for sparsely admixed trees, for example based on circular plots with a size depending on the size of the target tree? – Single-tree plots.
Chronosequences and growth series (Wuchsreihe – Assmann; single-tree gowth series - Spiecker).

**Information to the public**
?

**Intellectual property rights**

**Continuity –** in funding (diferent funding scenarios), in objectives, in working methods, experimental infrastucture (who is doing what) ----- etc.
Replicability – persuading, but all forestry acitivities will be (more or less) situational
The notion of covariates vs. replicability

**Catalogue of irregularities**

**Other items**
Can we make a simple check-list for general use? This would be very valuable.
We should make a brief guideline, including site assessment and spread-sheet for measurements, for use by forestry practice, simple research plots and inexperienced scientists.

Publish interesting results

**Literature:**

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Bannwaldaufnahme