Veli Pohjonen:

SHORT-ROTATION FORESTRY

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1. Introduction

About fifteen years ago, there was only a handful of biologists and silviculturalists who were interested in short rotation forestry and in using intensive cultural techniques to maximize yields. The basic idea behind their concept was to reduce to rotation time needed in conventional temperate or boreal forestry, even 100 years, to clearly shorter periods, to under 20 years or in the extreme case to even one year - i.e. to annual harvest.

The first reference to the short rotation of forest trees was made by McAlpine et al (1966), but the proper content to the ideas was formulated by Schreiner in 1970. The key to the apparent silvicultural improvement was believed to be on the other hand in the application of advanced agricultural methods on the other in the concept of biomass, i.e. in utilizing the harvest as whole trees instead of mere stems.

Short rotation forestry can to day be defined as hardwood plantations which are established at closer spacings than 2 x 2 meters, managed using intensive cultural techniques to maximize total biomass production, and harvested and regenerated at least every ten years. Originally the aim of short rotation forestry was to produce raw material for pulp industry, but very soon the possibilities for bioenergy production were discovered. This happened especially in Scandinavian countries, but also in Canada, Ireland and USA.

2. Possible species

The goal of short rotation forestry is simple: to maximize biological productivity and at the same time the economic returns per hectare. The possible tree species to carry out this task are not as obvious since they possess many differing factors that contribute to harvestable yields. The ideal tree type, the ideotype, has been considered in that case by tree physiologists and silviculturists (e.g. Siren et al 1979). Although no species or clone can meet all the characteristics, the ideotype can serve in judging species for their initial inclusion of screening programs.

Fege (1981) has collected the following list for an ideotype of tree species in energy forestry:

- Rapid juvenile growth
- Full utilization of growing season
  - -- indeterminate growth habit
  - -- buds set late in the growing season
- High rate of net photosynthesis
- Favourable proportional investment in growth
  - -- High in cambial growth
  - -- Low in reproductive structures
- Narrow compact crown
- Steep branch angles
- Tolerance of competition in dense stands
- Efficient use of water and nutrients
- Ease of reproduction and plantation establishment
- Ease of regeneration after harvest (stump sprouting or suckering)
- High genetic variability
- Suitable wood properties
  - -- high specific gravity
  - -- low moisture content
  - -- thin bark
- Freedom from major pests and diseases
- Adaptation to stress
  - -- frost resistance
  - -- drought tolerance

The first group of characteristics relates to the response of trees to the silvicultural conditions of short rotation forestry: close spacings, management of nutrient availability, and harvest during the early years of the life cycle. The susceptibility of species to biological and climatological stresses are absolute criteria, and are the basis for many initial screening programs.

Four of the more promising genera for short rotation forestry in temperate zone, which meet most of the requiremnts listed above have been listed as Alnus, Platanus, Populus and Salix (Fege 1981). One of them, Platanus, is native to North America, the the three others are indigenous also in Europe. Among those three the most promising species for short rotation energy forestry in Scandinavian conditions can apparently be found. In Finnish conditions, where peatlands dominate in large areas, only one genus, Betula, may be added.

3. Short rotation forestry with willos

In Finland as well as in Sweden much of the research in short rotation forestry has concentrated in willows (Salix). Willows have been found suitable for Nordic weather conditions and also for the soil types available. Following a 1-2 year establishment stage, willow plantations cultivated during a 2-3 year rotation period should yield 15-20 tonnes of dry matter per hectare per year (Siren 1983).

Some more aspects about biomass production with willows is mentioned in separate annex.

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ANNEX: BIOMASS PRODUCTION WITH WILLOWS

by Veli Pohjonen, 1983

(to be printed separately in Sweden)

1. INTRODUCTION

Willow husbandry has old traditions. Since the wood of willows - both of tree willows and bushy willows - is easy to work with, the willows have been under interest through centuries. We do not know for sure when and where the short rotation willow husbandry was established but due to the natural occurence of Salix species it must have happened north of Meriterranean. Indeed, the oldest piece of information (Makkonen 1975) is from Greece, from Theophastros (370-285 B.C.), who mentions that due to their lightness and elasticity (tree) willows are best to make shields for warriors. Bushy willows he recommended as suitable for making baskets. Also the famous speech of Roman Cato (234-149 B.C.) from the same era reveals that utilization of willows and some kind of willow husbandry were known before Christ.

Systematic willow husbandry using selection of species and sites, cultivation of soil, spacing optimization and establishment of the willow plantations with cuttings was developed in Rome during the first century. Experiences and recommendations on willow husbandry have also been documented by two ancient "scientists" Plinius (23-79 A.D.) and Columella (he died around 50 A.D.) (Makkonen 1975). The most important species was S. viminalis. This is illustrated by the name of one of the seven hills in Rome; Collis viminalis (willow hill). Two other species in cultivation, which have been identified later (Makkonen 1975), were S. fragilis and S. purpurea.

The prominent role of willows during the Roman time has its explanation in the trade. Baskets were almost only means to transport many goods, and elastic but hardy willow rods were desired raw material for basket making.

The term biomass, or the concept of dry matter production, was not known to Romans, but the principles developed for basket willow husbandry are basically the same than those used today in biomass production. In fact many of these principles were well established 2000 years ago. This knowledge was, however, to be forgotten for centuries. Practically all of it had to be re-established when basket willow husbandry was reborn in Europe. This happened 100-150 years ago.

The skill of basket making by using willows was maintained through the Middle Ages but the raw material was collected from forests, lake shores and other natural environments. This continued up to the latter half of 1800-century. By that time the demand for baskets, especially for good quality baskets, had risen so high that mere collection of willow rods could no more meet the demand.

Willow husbandry had to be developed again. This time it happened in Germany. The willow research, started there around 1850, gave quickly results. By the turn of the century the basic principles of willow husbandry which are still valid, were established. The German researchers Reuter and Krahe were the two founders of modern willow husbandry (Tapio 1965). Especially

Krahe in his text book "Lehrbuch der Rationellen Korbweidenkultur" (Krahe 1886) from 1886 established many facts which are continuously of importance also when planting willows for biomass production.

Maybe the most important innovation introduced by the German pioneers was that willow has to be regarded as any other crop which should also be grown according to the same principles than the field crops. Especially this was discovered in connection with site selection: willows should not be grown in water-logged marginal lands but well-drained, cultivated arable fields, which also are fertile enough.

Around the beginning of the twentieth century basket willow husbandry was strengthened according to the established discipline all over Europe. Areas under willow cultivation were quite remarkable, for instance in France over 100 000 hectares already in 1909 (Tapio 1965). The rise of cheap oil and synthetic basket materials in the 1950s and 1960s meant fall for basket willow growing. Only in the Soviet, in Hungary and in Poland basket willow husbandry kept its role, but it is now diminishing also there.

The problems of willow husbandry actual today in energy forestry, are much the same than previously, in basket willow husbandry. Selection of site and species, soil cultivation, spacing and rotation time with respect to the yield, longevity of stools and coppicing vigour after harvest seem - according to the literature - to be evergreen problems. Many of those problems however gor surprisingly firmly stated answers already 100 years ago. Therefore, for experimenting with biomass willows, it is worth reviewing what we actually knew about willow husbandry before the energy crisis. Special attention must be paid to the Nordic experiences. In this respect it could be especially worthwhile to study the old Finnish experiences in basket willow husbandry, which are quite abundant and the reviewing of which has often been neglected due to the language barrier.

11. Pioneers of willow husbandry in Finland

The success of German basket willow husbandry at the end of 1800-century was noticed also in Finland. Possibilities to produce locally raw material for basket making were started to study into, for fuel wood even earlier (Lithander 1753). The first extension leaflet on the basket willow husbandry was published as early as 1881 by Gustaf Flinta (Flinta 1881).

In the beginning of 1910s J.W. Johnsson had experiments in the vicinity of Kuopio and Lohja using the following species: *S. triandra*, *S. purpurea*, *S. rubra*, *S. acutifolia*, *S. viminalis*, *S. alopecuroides* and *S. polyphylla*. This order of clones was also the first recommendation of clones to southern and central parts of Finland, two last clones with a questionmark (Nordberg 1914).

During the years 1912 and 1913 Lauri Mäkinen imported from the Soviet about 10 promising willow clones to be investigated by their performance in Finland. Mäkinen has also given some general quidelines about the basket willow husbandry in Finland (Mäkinen 1913). Survival and performance of his clones as well as their possible present availability are not known.

Great effort to develop willow husbandry was made by Seth Nordberg during the years 1914-1930. He published the results of his experiments and review of the possibilities of basket willow husbandry in Finland in five different papers (Nordberg 1914, 1919, 1923, 1928 & 1930). Nordberg started his willow research by paying a visit to Baltic countries, Germany and Denmark to familiarize himself with the subject, and he also imported several clones to Finland. Some of those clones may have stayed alive up to present days, but apparently most of them have disappeared.

The experiments in basket willow husbandry was summarized and discussion about suitable clones were presented by A.K. Cajander (1917) in his fundamental text book of silviculture (Cajander 1917).

The last research effort in Finland to promote basket willow husbandry was made by Eeva Tapio (born Relander) in 1949-1954 (Tapio 1965, Relander 1950, 1951, 1952, 1953 & 1953). She had an extensive experimental program in ten different sites in Finland on the performance of a number of promising clones. She imported to Finland many new clones from Central and Eastern Europe. The basket willow husbandry was promoted also in practical scale and a separate company Paju Oy ("Willow Ltd") was founded for the purpose. The practical activities had however a short history; the enterprise became bankrupt in 1954, which meant fall for the Finnish basket willow husbandry. Tapio however summarized her experiences for university thesis in 1965 (Tapio 1965). This thesis has served as a fruitful reference for biomass willow husbandry initiated later for energy purposes. Some of the most important present willow clones in Finland have been imported by Tapio and kept alive in fences (for instance S. dasyclados V761, former 075) and as garden trees in different places in Finland.

At the same time than the rapid development of "Willow Ltd" took place, an extension leaflet was published (in Finland) by German count von der Schulenburg (1951). Although the author had only little experience on the growing conditions in Finland, he could write by the experience of 40 years from German willow husbandry. His leaflet is still one of the best presentations of willow husbandry applicable also in Scandinavia.

2. SELECTION OF SPECIES AND CLONES

Multitude of species and clones has always been the richness of willow husbandry. In germany about 400 different clones were in cultivation already in 1887. The screening program at a silvicultural experiment station near Munchen included 800 clones (nordberg 1928). This large multitude of choices is on the other hand a problem: it is difficult to carry the screening programs out quickly and properly. Apparently the selection of species and clones for basket willow husbandry has happened during the old days more or less at random, and at subjective basis.

A multitude of different species and clones have been imported, tested or at least thought to be suitable in Finland within the past 100 years. These clones have been gathered in Table 1. The table does not include the 23 indegenous species in Finland expect one, S. triandra which was one of the most common in old basket willow husbandry. For every clone the literature does not include documentation whether it has survived in the experiments. The table is an indication of different possibilities in clone selection what we may have for biomass. The table also gives raise to an assumption that we may have lost a number of clones before the investigations of biomass willows were started.

Salix acutifolia has been under interest from the very beginning of European willow husbandry. S. acutifolia is adapted to grow in sandy sites, and besides it endures salty water. Therefore it has been used to stabilize loose sand dunes on sea shores. Especially interesting from the biomass point of view is the growth vigour: according to Krahe (1886) S. acutifolia can produce up to 5 meters long rods already during the first summer (apparently from established stool). Frost hardiness of S. acutifolia clones has been quite poor in Finland.

Salix americana, apparently a hybrid between S. triandra and fragilis, was imported at the end of 1800-century from Wisconsin, USA to Germany and distributed thereafter to basket willow growers. S. americana has a dense foliage, an advantage against weeds. According to Tapio (1965) S. americana gives on a good soil better economic return (basket material) than any other species. S. viminalis gives more biomass but S. americana more good quality rods. S. americana is susceptible to autumn frosts and therefore never got wide distribution.

Salix aquatica is apparently a viminalis hybrid, the botanical origin of which could not have been solved. Probably it was originally a single male clone which was selected from mixed stand in Denmark without proper identification (Tapio 1965). Strange enough, also female clone of S. aquatica has been registered (Hagman 1976). S. aquatica belongs probably to the same group than S. dasyclados, or is even dasyclados hybrid.

In his travel report from 1914 Nordberg informs about surprisingly well growing Danish willow plantations which had been established with clones S. dasyclados x purpurea and S. dasyclados x purpurea x viminalis. According to Nordberg's description our present S. aquatica, E4856 (formerly 056) could be either of those hybrids.

Salix dasyclados, also apparently a viminalis hybrid, was popular clone already in the beginning of 1900-century. S. dasyclados was praised by Nordberg (1928) to be very productive when using 2-3 years rotation time. S. dasyclados can give even on peat soils good yields. Tapio had S. dasyclados as well as S. aquatica in her experimental program. She noticed the good growth vigour of them. She ends her summary about the possibilities of willow husbandry in Finland (Tapio 1965) - after the unhappy end of basket business - by the statement: "At the moment, the experiments of willow husbandry seem to have produced nothing else than the awareness of fast-growing clones, suitable for windbreaks, S. aquatica and S. dasyclados 125."

Salix lanceolata belongs to the same group than S. acuminata and S. dasyclados; it may also be the same hybrid than S. smithiana. S. lanceolata was tested in Rovaniemi in the 1920s by Nordberg. The yield potential of S. lanceolata was quite similar to S. viminalis. 3 species features for S. lanceolata was mentioned: i) frost hardiness of stools and stems is good, ii) the leaves fall before the onset of winter and iii) dense foliage. Therefore S. lanceolata would be an interesting clone for biomass production at northern latitudes. Unfortunately the survival or later occurrence of S. lanceolata could not have been identified and the clone has therefore disappeared.

Salix polyphylla is a hybrid between S. triandra and S. viminalis. It was tested by Nordberg in the same experiment than S. lanceolata. S. polyphylla also performed in the experiment in much the same way; it was productive and overwintered even better than S. lanceolata. For instance in 1924-25 S. polyphylla overwintered in Rovaniemi without any frost damage in the shoots. Similarly to S. lanceolata this promising clone could not have been found since Nordberg's experiments.

Salix purpurea is one of the most widely tested basket willow species but apparently all of its clones produce too fine rods to be thought for biomass production. It may, however, be of use in hybridization due to its favourable traits in husbandry. According to Cajander (1917) S. purpurea does best in peatlands; apparently he means fertile, well humified Carex peatlands.

Salix smithiana resemples the other of its parents, S. viminalis, but has broader leaves and coarser stems. It is also more frost hardy than S. viminalis. S. smithiana has, however, not been tested in basket willow experiments in Finland.

Salix undulata is believed to be the same hybrid than S. polyphylla, namely S. triandra x S. viminalis (Rehder 1967). According to another theory S. undulata is S. alba x S. triandra (Chmelar and Meusel 1979). In any case S. undulata is very different from S. polyphylla by its morphological characteristics and by its performance, too. Nordberg had S. undulata in his experiment and it performed like S. viminalis: productive but not frost hardy. Also S. undulata seems to have disappeared in Finland

Salix viminalis, basket willow or common osier, has been the most commonly used species in basket willow husbandry. Many clones of it have been distributed all over the region where basket willows were needed. S. viminalis has indeed kept its dominating role through centuries and the different clones have formed the basic selection for willow husbandry. As early as 1887 at least 29 different S. viminalis clones were known (Nordberg 1928). Some of them have bright green, some brownish green, some yellowish green skin. Therefore plenty of selection from natural S. viminalis stands must have been done in the beginning of basket willow growing. S. viminalis has always been one of the most productive species in willow growing but it has not been the most desired species for basket willow husbandry since it does not produce top quality raw material. The frost hardiness of S. viminalis has been a problem in all old Finnish experiments, but it will, however, have a role of reference species also in biomass production.

3. SITE PREPARATION

31. Selection of site

Before the rise of the proper basket willow husbandry a common opinion was that willows do best in a soil which is wet. Willows were thought to be near aquatic plants because they occur naturally in the vicinity of lakes and rivers. This natural occurence is, however, due to the fact that willows can endure periodical flooding better than other tree species (Malmivaara ym. 1971), and thus they invade in such places as pioneer species.

It was Krahe (1886) who noticed first that willows give higher yields if normal arable fields are selected instead of river shore basins. He stressed the importance of site selection and transferred willows from river banks into arable fields.

As to the selection of soil, different willow clones are adapted to grow in different soils. Some, like S. acutifolia or S. viminalis do well only in mineral soils, some, like those in the dasyclados group or S. purpurea, also in peat soils. On average willows do not require as fertile soil as the other field crops. For reasonable growth, however, mineral soils with good structure - not too sandy, not too heavy - and abundant humus are needed. In other words, willows do best in garden soils. Heavy clay is not suitable because even the planting with cuttings is difficult, and the cuttings do not develop strong root system in heavy clay (Tapio 1965).

On the suitability of peatlands for willow husbandry there has been variable opinions. Schulenburg (1951) has presented maybe the strongest opinion. According to him peatlands are not recommended for basket willows at all due to their acidity. Nordberg (1919) on the other hand recommended utilization of peatlands, too, especially if the peat layer is so thin that mineral soil can be mixed with peat by plowing. In general peat soil has been regarded as moderate growing media for willows, but adequate liming and proper drainage are needed (Tapio 1965).

32. Soil water regulation

Although willows occur naturally in sites which are abundant in soil water, the water must, however, not be standing but moving. Standing subsoil water is in fact harmful for the growth of willows. The water table should be lowered by drainage down to at least 50 cm, preferably to 70-100 cm, but to not more than 125 cm. If the water table cannot be lowered below 40 cm, a furrow cultivation and planting has been recommended like for potato (Tapio 1965). Such cultivation method has also a favourable effect on the soil temperature.

The soil moisture availability in willow husbandry is of dual nature. Plenty of water is needed, but on the other hand an efficient drainage is as important. In this respect willows should benefit irrigation. This was, however, not investigated in old basket willow experiments, maybe due to technical limitations only. Another way to meet the dual nature could be to explore better the favourable water holding capacity of peat soils.

33. Modification of soil structure

At the same time as willows were transferred from river banks to arable fields, the favourable effect of proper soil cultivation was also noticed. As compared to other field crops willow plantations differ in their longevity. Therefore careful soil cultivation, much more careful than for other crops, should be carried out in order to secure even stands without empty plots over 10-20 years.

Deep plowing for willows before the planting has been widely recommended. The aim is to turn the top soil under the raw bottom soil. This is because of the position of the developing roots in the cuttings. The main roots develop relatively deep to the lower part of the cutting to the soil depth of 20-25 cm. If the soil is not properly plowed the roots are not capable to penetrate through the subsoil. Conventional plowing depth in agriculture 20-25 cm is therefore not enough. Deep plowing of at least 25 cm (Tapio 1965), preferably 50 cm (Krahe 1886, Mäkinen 1913) or even 60 cm (Schulenburg 1951) has been recommended to willows.

On the modification of soil structure in peat soil the willow literature has only few remarks. Nordberg (1928) regards the ground frost as one of the most difficult problems in peatland plantations since the frost may lift the stools from the soil during the first winter after planting. This harmful effect can be avoided if sand can be mixed with peat by deep plowing or by applying a sand layer of 5 cm on the peat. Massive ash fertilization may have the same effect.

34. Preplanting weed control

"The weeds are the main enemies for willow husbandry. If they take the power, the whole willow plantation is doomed to be destroyed"(Nordberg 1928). Weed control during the establishment phase has been, and seems continuously to be one of the most critical phases in willow husbandry. Therefore all the possibilities already in site preparation must be taken into account to enlighten the later weeding work. In this respect deep plowing is favourable, since it turn the weed seeds with the top soil under the bottom soil. In basket willow husbandry this seems to have been the only preplanting weed control method. Chemical weed control was not born yet.

4. STAND ESTABLISHMENT

41. Planting material

Use of cuttings has been a traditional way of stand establishment in willow plantations; in fact the method was known already to Columella. He even knew the two ways of planting: horisontal and vertical methods. The most suitable time for preparing the cuttings is to cut them in spring just before the planting. Since this is not always possible in practice, the cuttings must often be prepared earlier during the winter or in the autumn. Too early autumn harvest must be avoided. The cuttings have been advised to be prepared not until the first proper autumn frosts (Schulenburg 1951).

If prepared during autumn or winter the cuttings must be carefully stored until planting season. The cuttings have been advised to be collected in a bundle of 100-1000 cuttings and be stored in a cool storage in a mixture of sand and peat (Schulenburg 1951). A common rule has also been to store them in their natural position, upright (Tapio 1965). This determined position has something to do with the auxin content at the bottom of the cuttings, but the favourable effect of this manovere on the rooting ability or later growth has not been confirmed.

During the last century the cuttings were usually taken from 2-3 years old rods (Nordberg 1919), but already Krahe noticed that 1-year old rods do as well. To ensure high rooting ability he recommended, however, only 2-3 thickest cuttings to be taken, and the rest used for basket making (Krahe 1886).

Size of cuttings

The opinions about suitable lenght of cuttings have varied to some extent, in general so that the recommended cutting has become shorter in the course of time and experiences. Krahe (1886) regarded shorter cuttings than 30 cm unreliable for good stand establishment. In Great Britain and in the Netherlands a common cutting lenght has been 25-30 cm. But according to Schulenburg (1951) the most common lenght is 15-20 cm. "Since there is no advantage of using longer cuttings, it is mere waste of planting material to make them lengor than 20 cm." The most commonly mentioned lenght for the cutting in the later basket willow literature is 20 cm. In fact, in 1935 it was determined by law in Germany that shortest allowable lenght for willow cuttings is 20 cm (Tapio 1965).

The thickness of cuttings is determined by the soil: how easily the cutting can be planted into (mineral) soil. A rule of thump has been presented that the minimum thickness for cuttings is the average thickness of the 1-year old rods (Nordberg 1919).

42. Plant methods and equipment

Willow species suitable for basket making have always been easy to root. Problems have occurred only when there has been a possibility of the soil to dry up. This drying has been avoided partly by preparing to cuttings long enough, partly by planting them deep enough. Since the prerequisite for successful willow plantation has been deep plowing and through cultivation, it is not difficult to use deep planting. In fact it is a recommendation by for instance Tapio (1965) that the cuttings should be planted so deep that the top of the cutting is at the level of soil surface.

In 1800-century it was a common way to leave 3-5 cm of the cutting visible. Although the result of planting can be controlled more accurately when the top of cutting is visible, several disadvantages have been mentioned. For basket material the most harmful disadvantage has been that the shoots growing from visible top of cutting are not straight enough. High cutting leaves also a stubble which makes the harvesting later more and more difficult. Such high stubble should therefore removed after harvest by "shaving". It has also been believed that high cutting is susceptible to attacks by pests and diseases (Nordberg 1919).

Common planting method in basket willow husbandry was to do it manually. Since labour costs were lower than nowadays there was no need to mechanize the planting. Some manual device to help the planting work, like sticks to make a hole into the soil, were however in use very early.

Planting time

Common time to plant the cuttings has been early spring. A prerequisite for successful planting is that soil cultivation, at least deep plowing has been successfully carried out late in the previous autumn.

The planting should be carried out as early as melting of ground frost and outrunning of excess soil water allow. In Finnish conditions this means May. If planting is delayed from this, two harmful effects follows (Schulenburg 1951): i) the (mineral) soil hardens so that the skin of cutting may be wounded in planting act which results in poor growth due to rottening of cuttings, and ii) the top layer of the soil dries up and prevents the root growth.

Also autumn planting has been used in basket willow husbandry Although it has several advantage - no need for storing of cuttings, no delay in the spring growth - it has not been common i Finland. The problem has been the ground frost which lifts the cuttings from the soil during the winter.

5. SPACING, ROTATION TIME AND YIELD

The opinions about optimal spacing for willow plantations vary remarkably. The willow species and the use of the yield seem to determine what spacing should be used. Basket willow cultivation using one year rotation only, requires closer spacing than willows for hoop production using 2-3 years rotation. Recommendations for suitable spacings have, however, clearly different from the present practice: spacings have been denser. For instance Schulenburg (1951) classifies (Table 2) spacing possibilities quite differently from those common in present day energy forestry.

The row width of 60 cm is an indication of using narrow oldfashioned tractors; today the corresponding row width is 70 cm or even 75 cm. In the Finnish energy experiments a normal spacing has been 70 cm x 30 cm even in the production cuttings of (1-year rotation).

The old recommendations for close spacing especially when using 1-year rotation time, have based on field data. Closer spacings in general have given higher yields than wider spacings. This was discovered already by Krahe (1886) 100 years ago (Table 3).

In willow plantations aiming at production of hoops with 2-3 years rotation, wider spacings than for basket willow have been in use. However, Tapio used not wider spacing than 60 cm x 20 cm in her experiments which also was common in Denmark (Tapio 1965).

The older willow literature does not contain information about such wider spacings (less than 50 000 cuttings per ha) which are common in present day biomass production. These wider spacings may therefore not be based on biological facts but on pure technical or economical arguments.

About suitable rotation time Nordberg (1930) has a clear opinion: the greatest yields will be produced using one year rotation only. But again, this is a question of spacing. However, there is plenty of evidence from basket willow husbandry that spacing close enough can give yields so big with one year rotation, that they are not attainable with 2-3 year rotation using whatever spacing. Longer rotation time than 3 years has not even been mentioned in the willow husbandry literature.

6. GROWTH OPTIMIZATION USING CULTURAL TECHNIQUES

61. Nutrient requirements and supply

Willows are fast growing plants which require notable amounts of nutrients. The nutrient requirements of willow has been generally satisfied with selection of site which is fertile enough Also cultivation of root crops before planting of willows has been recommended (Nordberg 1919).

The nutrients must, however, be returned to the plantation in one form or another. Despite of this known fact fertilization of willows with chemical fertilizers has not been very common in basket willow husbandry, apparently because of the era commercial fertilizers is quite young, only quarter of a century. Some early observations about nitrogen fertilization inform that it cannot be recommended because of the quality of basket rods is lowered. Instead Nordberg (1919) suggests fertilization with lime and ash.

Tapio (1965) has already (from 1950s) some propositions for willow fertilization, but in the light of present day biomass production, they are quite elementary. The older willow literature is indeed rather poor if growth optimization with fertilizers is concerned. This has to be established according to the modern discipline, i.e. by studying the removals of nutrients in intensive willow husbandry.

62. Weed control

The growth of weeds has caused maybe the biggest problems in present day energy experiments. And the same problem has existed in the willow plantations from the very beginning. The control of weeds during the establishment phase of the plantations has been so laborous that it has been compared with weed control difficulties in sugar beet cultivation (Tapio 1965).

Especially important is the weed control after planting. In this respect deep planting of cuttings to the soil surface level or even below is favourable since the first emerging weeds can be eliminated by light surface harrowing between the planting and sprouting from the cuttings (Nordberg 1919).

After the sprouting during the first summer the weeds must be removed several times, at least twice (Schulenburg 1951). After the harvest, in the next spring, the weeds must be controlled at least once; later in the summer the growth of willows will keep the weeds low providing that no empty plots have been left in the stand.

Weed control was carried out in basket willow husbandry almost solely manually. Mechanical control by horse or later tractor drawn machines was also in use. The use of chemical weed control which today is essential in modern crop husbandry, was not used at all. Some first observations about herbicides have only revealed that willows are very sensitive themselves to the common weed killers. But because the chemical weed control of potato and even sugar beet has now been solved, there is no doubt about finding selective herbicides for willow plantations too.

The weed control in basket willow husbandry does not seem to be as big problem as nowadays. Maybe it was just question of allocating enough manpower to do the nuisant work. But today such manpower is not available from economic reasons. It is task of willow husbandry research to find a compromise between mechanical and chemical weed control without which large scale biomass plantations may be impossible to be established.

63. Control of pests and diseases

Pest and diseases have not caused as much problems or work in the willow plantations as weeds. Number of especially insect species occurring in willow stands is known to be high - such list is presented for instance Tapio (1965) - but according to old willow literature no complete failure in willow husbandry caused by insects, has been documented.

Diseases of willow have been bigger problem. Nordberg writes for instance about S. acutifolia that it is susceptible to rust fungi Melampsora salicina, which can even destroy a whole 1-year old stand (Nordberg 1928). Another fungi harmful to cultivated willows has been Fusicladium saliciperdum, which causes brown spots in the tops (in both leaves and stones) and gradually blackening and drying of the tops in the stems (Tapio 1965).

Control of pests and diseases were usually not needed; the means for this were also poor. Flooding of the whole plantation under water in case of insect attack has been recommended (Mäkinen 1913).

For control of diseases burning of the stubble and residues after harvest has been advised. Some copperbased fungicides were also known in the 1950s (Tapio 1965). As a whole the disease problem (rust) had only elementary solution in basket willow husbandry, and more modern approach based for instance biological control, would be needed in biomass production.

7. HARVEST AND REGENERATION

The opinions about the proper timing of the harvest in the basket willow husbandry have been quite parallel. The harvest should be carried out after the leaves have fallen down but before the next growing season starts. In Denmark and Central Europe the most suitable harvesting time has been November to December; for Polish basket willow husbandry the harvest has been recommended to be done between November 15 and April 1.

It was early noticed that harvesting the rods after the start of the season lowers the growth rate of the shoots, and even the lifetime of the stand (Nordberg 1919). Harvesting late in the spring was, however, quite common in the basket willow growing because the outskinning of the rods is easier when the phloem sap has started to flow. In biomass production there is, however, no need to leave the harvest too late.

The harvest should be done into as short stubble as possible. Too high stumps must be removed later by shaving because otherwise rot may start to spread through them (Nordberg 1919). The shaving must be done "absolutely with sharp saw, never with hitting weapon" (Schulenburg 1951).

Longevity of the stand

Willows have been regenerated traditionally through coppice. According to Tapio (1965) willows should always be cut in the first autumn following the planting. This is necessary for obtaining vigorous coppice and good quality rods for basket making as soon as possible. The longevity of the willow plantations was an important economic question in the basket willow era as it is also in biomass production. Quite common is the opinion that the willow stools do not endure frequent harvest as is the case with poplars. To solve the problem of the longevity of the annually cut basket willow stand a through study was carried out already in 1800-century by Krahe (1886). The results of his long experiment are presented in Figure 1.

According to this old experiment the longevity of willow plantation reaches well over 10 years, and recultivation and replanting should be done somewhere between 12 and 15 years. More or less similar have been the later recommendations: 10-20 years (Nordberg 1919), 12-15 years (Schulenburg 1951), 15-20 years (Tapio 1965).

Since basket willow production happened most often with 1-year rotation, experiences on the longevity of the plantations in 2-3 years rotation are fewer and not documented as well. It is known, however, that the coppicing vigour is stressed most with annual harvest. Therefore it may be concluded on the basis of basket willow husbandry, that in biomass production aiming at 3-years rotation the willow stands will remain productive at least for 30 years, probably for 50-100 years.

8. YIELD AND ECONOMIC RETURNS

For basket making the main purpose was to produce good quality rods. Quite often the yields in the production studies have been announced with respect to that, as skinned rods or already as sorted out rods. There is, however, plenty of experimental data even from Finland about basket willow yields. The total stem biomass can be estimated from basket rod figures. In all cases the yield figures have been measured as per fresh weight basis. To make them comparable with present biomass studies assumption for moisture content of 55 per cent can be made.

Common yield figures in basket willow husbandry have been 4.5-6.8 tons/ha/a for finer rods and 9.0-11.3 tons/ha/a for coarser rods. In intensive cultivation willow plantation can produce up to 18 tons/ha/a and top yield obtained in Danish basket willow husbandry was 26 tons/ha/a (Tapio 1965).

More detailed yield data from Finnish willow experiments have been presented in Tables 4-8.

This Nordberg's experiment gave surprising yield figures. The stands were cut annually, and in 1925 the second or the third yield was in question. All the species overwintered in Rovaniemi at least as stools.

The problem in interpreting these early results as well as in many present results is that the experiment was small by area, in this case 10 m x 10 m as a whole. Border effect apparently has favoured the growth, but on the other, according to Stott's latest investigations (Stott ym.) the border effect in Salix plantations does not go deeper than the first row. One explanation to Nordberg's high yield figures must be close spacing, high number of coppice and despite this density, remarkable height growht.

In her large experimental program (ten different sites, years 1950-1954) Tapio had both successes and failures. As has been the case in biomass willow experiments, also she had difficulties to establish plantations with hundred per cent rooting success. Usually her rooting success was under 50 per cent. This must have had influence on her yield figures too. The fertilization in Tapio's experiments was quite modest, and this reflects in the height growth figures which also are modest according to the standards of biomass willow experiments.

To make Tapio's old experiments more comprable with the succeeded experiments of present day biomass willow trials, yield data from the best three clones from the best three sites, and the best years in each case have beem collected in Table 6.

The yield differences between different parts of Finland were quite remarkable. Anjala is in Southern Finland, in an area where early summer drought is common. Maaninka on the other hand is in Eastern Finland, in an area with abundant moisture and somewhat continental climate.

From the view of biomass production the most interesting of Tapio's experiments are those for hoop production with 2-years rotation. Such experiments were also carried out in ten different sites. The interpretation of these experiments is unfortunately rather difficult since no established routine was used when to harvest at one year's age or at two years's age. Tapio summarized, however, these as in the Table 7.

Salix viminalis was the best of the species also in 2-years production. About S. dasyclados Tapio had a comment that the clone in question, number 63 was poorer than later clone number 125 which she regarded as one of the most promising.

The most thorough willow experiment was carried out in Pälkäne experiment station where the yield level was measured twice, at two years' age from cutting and two years' age from coppice (Table 8.).

The results of this hoop willow experiment are quite similar to those obtained from succeeded present day experiments in biomass production. The low figure of S. dasyclados is explained by low rooting success, only 7 per cent.

Old remarks on economy in willow husbandry

The opinions on the economics in basket willow husbandry were quite optimistic. Very early it was taught in the Finnish forest college of EVO that growing of willows is most profitable of all tree growing (Makkonen 1975). The basket willow husbandry was very often compared to agriculture and it was regarded to be as profitable as wheat cultivation (Mäkinen 1913, Nordberg 1928) or even better (Relander 1952).

The great variation in the expenditure and in the yield level was, however, very common. It seems that basket willow husbandry had in the old days only two options: very productive or failure. Since the risks of failure are big in unfavourable sites Tapio concluded that willow husbandry is not worth starting at all but on good arable fields only.

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Table 1. Willow species, hybrids and clones thought to be suitable for Finnish willow husbandry according to Flinta (1881), Mäkinen (1913), Cajander (1917), Nordberg (1919) and Tapio (1965).

Salix species, hybrid or clone	Notes
S. acuminata Sm.	= S. dasyclados (Rehder 1967)
S. acutifolia Willd.	
S. alba L.	
S. alopecuroides Tausch.	= S. triandra x fragilis (Chmelar and Meusel 1979)
S. americana Hort.	= S. triandra x purpurea (Nordberg 1930)
S. amygdalia L.	= S. triandra
S. aquatica cult.	Viminalishybrid
S. britzensis Spaeth.	= S. alba var. vitellina f. britzensis Spaeth. (Rehder 1967)
S. caspica Pall.	Not same than S. acutifolia (Chmelar and Meusel 1979)
S. daphnoides Vill.	
S. dasyclados Wimm.	= S. viminalis x cinerea (Chmelar and Meusel 1979) or S. viminalis x cinerea x caprea
S. fragilis L.	
S. lanceolata Fr.	= S. smithiana (Nordberg 1928) or S. undulata (Rehder 1967)
S. longifolia Muhlenb.	
S. nigricans Enand.	
S. polyphylla cult.	= S. triandra x viminalis
S. pruinosa Bess.	= S. acutifolia
S. purpurea L.	
S. rosmarinifolia L.	For very fine baskets
S. rossica Gmel.	Near to S. viminalis
S. rubra Huds.	= S. purpurea x viminalis
S. Schwurbitziana cult.	= S. triandra x viminalis
S. serotica Pall.	= S. rossica (Chmelar and Meusel 1979)
S. smithiana Willd.	= S. caprea x viminalis (Chmelar and Meusel 1979)
S. triandra L.	
S. undulata Ehrh.	= S. triandra x viminalis (Rehder 1967) or S. alba x triandra (Chmelar and Meusel 1979)
S. viminalis L.	At least 29 different clones
S. vitellina (L.) AST.	= S. alba var. vitellina

Table 2. Spacing recommendations (Schulenburg 1951) for basket willow husbandry using 1-year rotation time.

Dense spacing	Normal spacing	Wide spacing
60 cm x 15 cm	60 cm x 20 cm	60 cm x 30 cm
30 cm x 20 cm	50 cm x 25 cm	50 cm x 40 cm

Table 3. Effect of spacing on the coppice yield of basket willow in 1-year rotation (years 2,3,4,5 on average). Yield data from Krahe (1886), moisture content of 55 per cent assumed.

Spacing cm x cm	Dry matter yield tons/ha/a
40 x 10	15.2
45 x 15	10.1
50 x 20	7.3
55 x 25	6.1
60 x 30	5.1

Table 4. Yield figures (Nordberg 1928) from basket willow husbandry experiment in Rovaniemi forest school in 1925. Spacing 50 cm x 15 cm, no fertilization, moisture content of 55 per cent assumed.

Salix species	Coppicing, sprouts over 50 cm	Average lenght of sprouts, cm	Longest sprout, cm	Estimated yield tons/ ha/a (DM)
S. undulata	14.5	139	190	29.2
S. viminalis	9.5	173	230	27.7
S. polyphylla	13.6	152	225	25.1
S. lanceolata	14.0	130	235	23.7
S. triandra	6.3	164	220	15.3

Table 5. Summary of Tapio's basket willow experiments during the years 1950-1954 (Tapio 1965). Spacing 50 cm x 10 cm, varying fertilization (modest by present standards), 55 per cent moisture content assumed.

Salix species	Success in planting, per cent	Average lenght of coppices, cm	Longest sprout, cm	Average dry matter yield for years 2-4, tons/ha/a
S. viminalis	54.5	135	267	8.3
S. americana	36.6	102	181	3.3
S. britzensis	51.0	107	202	2.6
S. longifolia	17.3	119	208	2.5
S. purpurea	21.3	97	203	2.2

Table 6. Yield figures from best species in Tapio's experimental program (Tapio 1965). 3 sites, highest annual coppice yield in each clone during the years 1950-1954, moisture content of 55 per cent assumed.

Salix species	Year in question	Coppice yield tons/ha/a (DM)	Site
S. viminalis	4	5.4	Anjala
S. purpurea	4	4.1	Anjala
S. americana	4	3.2	Anjala
S. viminalis	3	10.2	Fiskars
S. purpurea	3	6.3	Fiskars
S. americana	3	5.9	Fiskars
S. viminalis	2	15.4	Maaninka
S. americana	2	5.7	Maaninka
S. aquatica	4	14.0	Maaninka

Table 7. Summary of willow experiments for hoop production in 1950-1955 in Tapio's program (Tapio 1965). Spacing 60 cm x 20 cm, modest fertilization, moisture content of 55 per cent assumed.

Salix species	Yield for first two years from cuttings, cut annually tons/ha/a (DM)	First coppice yield, 2-years rotation tons/ha/a (DM)
S. viminalis	4.9	10.3
S. smithiana	2.8	8.3
S. aquatica	4.7	8.0
S. dasyclados	-	3.2

Table 8. Results of hoop willow experiment at Pälkäne experiment station (Tapio 1965). Planting in May 1950, 1st harvest in 1952, 2nd harvest in 1954. Spacing 60 cm x 20 cm, moisture content of 55 per cent assumed.

Salix species	Yield from cuttings, 2-years rotation tons/ha/a (DM)	First yield from coppice, 2-years rotation tons/ ha/a (DM)
S. viminalis	6.9	13.3
S. smithiana	8.6	14.8
S. aquatica	6.6	12.8
S. dasyclados	1.6	4.7
S. viminalis II	11.2	18.6

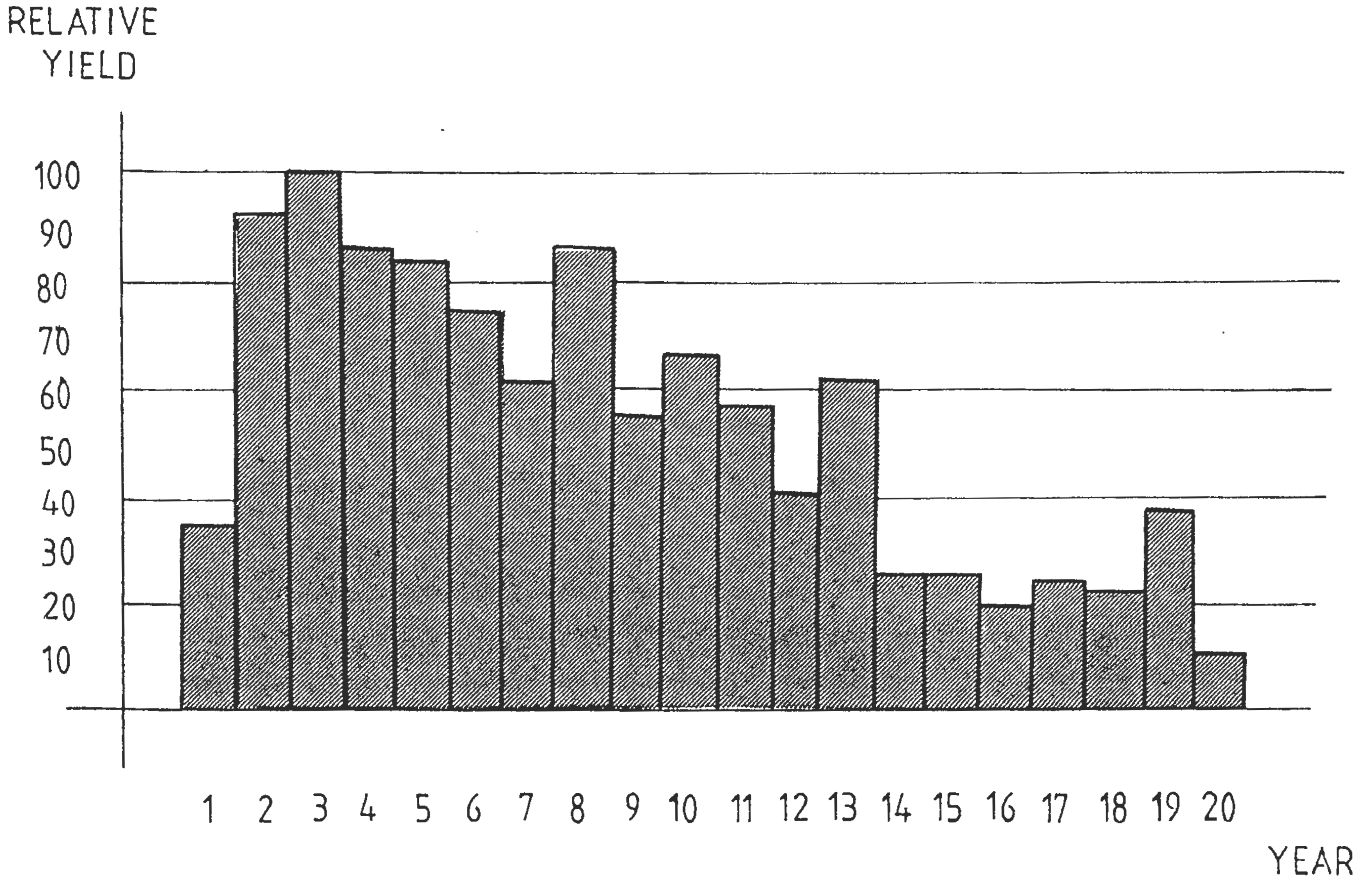

Figure 1. Pattern of yield level in annually harvested basket willow stand. First year: yield from cuttings, the others: yield from coppice. Data from Krahe (1886).