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Biomass and Energy Crops IV

Comparative trials of elite Swedish and UK biomass willow varieties 2001–2010

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Summary

Trials of Lantmännen SW Seed (SW) and European Willow Breeding Partnership (EWBP) willow genotypes have been conducted in the UK since 1991. Yield data is presented for all currently available commercial varieties, harvested at multiple UK sites from 2001–2009. Specific details of each trial site are documented. This information will aid growers to make decisions on varieties suitable for their land. The pedigree and genetic background of the varieties are assessed.

Reasons why commercial yields are about 20% lower than trial yields are discussed. Reasons why previous varieties have became outclassed and withdrawn from the market will be provided.

Key words: *Salix*, willow, short rotation coppice, biomass, yield, trials, varieties

Introduction

This paper provides the latest data from yield trials across the UK and builds on a previous paper that summarized trial results from 1991–2001 (Lindegaard *et al*., 2001).

Materials and Methods

Sites

Since 1991, yield trials have been planted at nine sites across the UK. Results from six sites are presented. Details of the soil types and climate conditions are detailed in Table 1. The sites at Long Ashton in Bristol, Loughgall in Northern Ireland and Markington in Yorkshire have been used since 1991. Various sites in West Wales were planted from 2003 as part of the Willow for Wales project (Valentine *et al*., 2008). Other sites have been planted in North Devon and Nottinghamshire. A single trial on Orkney was described by McKenzie *et al*. (2008). Trials conducted at Rothamsted Research are presented elsewhere in this volume (Macalpine, 2011). Data from two yield trials planted at ADAS Gleadthorpe in 2002 was unavailable.

Table 1. *Yield trial site details*

Site	Long Ashton	Markington	South Molton	Loughgall	Retford	Aberystwyth*
County	Somerset	North Yorkshire	Devon	Armagh	Nottingham-shire	Ceredigion
Soil type	Stagnogleyic brown earth	Slightly acid, base rich loamy clay	Clay loam	Brown earth		Lime rich loam
Altitude (Metres asl)	40–50	100–120	190–210	30–50	10–15	32*
Latitude (degrees)	51 N	54 N	51 N	54 N	53 N	52 N
Longitude (degrees)	2 W	1 W	3 W	6 W	1 W	4 W
Mean annual temperature (◦C)	9–10	9–10	8–9	9–10	9–10	8–9
Rainfall amount (mm)	800–1000	600–700	1500–2000	700–800	600–700	1000–1250
Days of rain > 1 mm	120–130	110–120	180–220	140–160	110–120	160–180
Hours of sunshine	1500–1600	1300–1400	1300–1400	1200–1300	1400–1500	1200–1300
Days of ground frost	60–80	100–125	100–125	100–125	100–125	60–80
Avg. wind speed (knots)	6–8	8–10	8–10	6–8	8–10	8–10
Growing season length	290–310	290–310	240–270	290–310	270–290	290–310

*Two other sites were planted near Aberystwyth in 2004 at 228 and 296 masl.

Plot designs

The trials designs conform to standards specified by the Forestry Commission in Research Note 17 with three replicated 52 plant plots of each variety (Lindegaard *et al*., 2001). The spacings and stocking rates for each trial site are detailed in Table 2.

Table 2. *Spacings and stocking rates for different sites*

Site	Stocking rate (plants per ha^{-1})	Distances within plots (m)		
		Between double rows	Between each single row	Between plants within rows
LARS, Ingerthorpe, Holdridge, Retford	20,000	1.3	0.7	0.5
AFBINI	15,000	1.3	0.7	0.65
IBERS	13,333	1.3	0.7	0.75

Planting material and trial management

The pedigrees of the varieties are listed in Table 3. Hardwood cuttings, 20 cm in length were planted in March–June each year. The preparation of the planting sites and establishment of the trials adhered to industry guidelines (Finnan & McCracken, 2010). Following the establishment year, the plantations were coppiced at ground level in order to promote vigorous growth and to encourage multiple stems. At Long Ashton and Loughgall each trial was first harvested at the end of year three having two-year old stems on three-year old roots (S2R3). Following harvesting the

trials were grown for a further 3 years, before a second harvest of three-year old stems (S3R6). The trials were terminated after the second harvest. Variations of this cropping cycle have occurred at the other sites.

Table 3. *Names, breeding numbers and pedigrees of SW and EWBP willow varieties*

Breeding number	Variety name	Breeding programme	Pedigree	
			Female	Male
SW880013	Jorr	SW	*S. viminalis*	*S. viminalis*
SW880205	Jorunn	SW	*S. viminalis*	*S. viminalis*
SW910007	Tora	SW	*S. schwerinii* L79069	*S. viminalis* Orm
SW890129	Loden	SW	*S. dasyclados*	*S. dasyclados*
SW930387	Olof	SW	*S. viminalis* Bowles Hybrid	Bjorn (*S. schwerinii* L79069 × *S. viminalis* Orm)
SW930725	Torhild	SW	Tora	*S. viminalis* Orm
SW930824	Sven	SW	Jorunn	Bjorn
SW930935	Asgerd	SW	*S. viminalis* Astrid	Bjorn
SW960504	Sherwood	SW	Jorunn × *S. eriocephala*	Bjorn
SW950506	Inger	SW	*S. triandra* SW911066	*S. viminalis* Jorr
SW940598	Gudrun	SW	*S. dasyclados* Helga	*S. dasyclados* LV Rod
SW960299	Tordis	SW	Tora	*S. viminalis* Ulv
SW950398	Doris	SW	*S. burjactica* SW 901321	*S. viminalis* SW 881031
SW980537	Karin	SW	Tora × Jorr	Ivar
034/10	Ashton Stott	EWBP	*S. viminalis* Bowles Hybrid	*S. burjactica* Korso
LA960231	Quest	EWBP	*S. viminalis* Pavainen	Bjorn
LA960326	Beagle	EWBP	*S. viminalis* Astrid	*S. viminalis* ?
LA970164	Endeavour	EWBP	*S. schwerinii* Hilliers	Jorr
LA980024	Discovery	EWBP	*S. schwerinii* Hilliers	Bjorn
LA980125	Nimrod	EWBP	Tora	*S. miyabeana* Shrubby Willow
LA980132	Terra Nova	EWBP	*S. viminalis* Bowles Hybrid × *S. triandra* Dark Newkind	*S. miyabeana* Shrubby Willow
LA980414	Resolution	EWBP	SW930812 Jorunn × Bjorn	Quest
LA980442	Endurance*	EWBP	*S. redheriana*	*S. dasyclados* 77056

* LA980442 was named Endurance but has not been released commercially.

Dry weight analysis

Fresh weights were measured in the field with a tractor mounted weighing scale. In older trials representative sample stems from each plot were selected for dry matter analysis. In more recent trials a sample of material from each plot was chipped and bagged before being dried in an oven at 100°C for 48 hours. The fresh weights and dry matters for each plot were used to calculate the yield of each variety (see Lindegaard *et al*., 2001). The results were extrapolated to provide an indication of the yield in dry tonnes (DT) per hectare annually.

Results

Estimated dry weight yields for trials planted from 1996–2006 are presented in Table 4 along with individual trial and variety means.

Table 4. *Yield trial results*
(& ** indicate IBERS altitude trials at 228 and 296 MASL)*

Year planted	Site	Cropping cycle	Swedish varieties															EWBP varieties									Means
			L78183	Jorr	Jorunn	Loden	Tora	Olof	Torhild	Sven	Asgerd	Gudrun	Tordis	Sherwood	Inger	Doris	Karin	Ashton Stott	Quest	Beagle	Discovery	Endeavour	Nimrod	Terra Nova	Resolution	Endurance	
1996	LARS	*S2R3*	9.2		10.9	11.9	13.2											15.9									12.2
		S3R6	9.0		8.0	12.4	11.9											15.0									11.3
	NI	*S2R3*	4.9		8.6	7.9	8.2																				7.4
		S3R6	9.2		9.7	10.7	11.5																				10.3
	Devon	*S3R4*	4.6		4.5	8.7	11.0																				7.2
1997	LARS	*S2R3*	5.7	9.5			9.5		7.7	10.3																	8.5
		S3R6	7.7	10.4			13.5		10.8	12.9																	11.1
	NI	*S2R3*	7.1	11.7			12.1		12.4	12.6																	11.2
		S3R6	6.2	10.8			14.1		14.3	15.6																	12.2
	Yorks	*S2R4*	2.9	7.1		7.4	10.4		10.2	10.5																	8.1
	Devon	*S3R4*	3.8	5.5			11.3		10.1	12.7																	8.7
1998	LARS	*S2R3*	8.1				11.5	11.7	10.0	11.5	10.8																10.6
		S3R6	9.0				11.6	12.7	10.4	10.1	9.2																10.5
	NI	*S2R3*	7.0				12.7	8.1	8.6	8.8	9.7																9.2
		S3R6	7.5				13.8	8.7	11.5	10.3	10.6																10.4
	Yorks	*S2R4*	5.3				9.2	7.9	6.7	7.7	7.1																7.3
1999	LARS	*S2R3*	8.3				12.8	13.3				8.2						12.6	9.9	11.5							10.9
		S3R6	7.4				10.2	11.0				7.2						8.6	8.7	9.4							8.9
	NI	*S2R3*	3.6				6.5	6.5				6.5						4.7	5.7	6.1							5.7
		S3R6	8.4				12.0	10.2				12.6						7.6	10.0	9.4							10.0
		S3R9	7.9				13.7	7.8				15.9						9.1	9.1	8.7							10.3
2000	LARS	*S2R3*	9.5				9.7						11.8														10.3
		S3R6	10.4				11.9						9.9														10.7
	NI	*S2R3*	7.7				11.5						11.3														10.1
		S3R6	8.4				11.7						9.3														9.8
2001	LARS	*S2R3*	9.4				11.1							11.3							12.2				13.9		11.6
		S3R6	13.6				15.0							13.6							14.4				15.4		14.4
2002	LARS	*S2R3*	7.9				10.3											10.0			9.1	9.4	8.0	6.1	10.5	8.5	8.9
		S3R6	9.2				12.4											12.2			9.2	10.4	9.1	6.2	11.5	13.3	10.4
	NI	*S2R3*	6.9				9.0											7.2			7.8	9.1	4.3	7.9	6.5	12.8	7.9
		S3R6	6.0				10.3											5.7			7.5	11.9	6.5	8.2	8.1	14.6	8.7
	Yorks	*S3 R4*	6.1				9.4											6.1			7.0	9.5	7.0	8.2	8.6	8.5	7.8
	Notts	*S3 R4*	10.0				13.9											13.5			12.2	11.9	11.7	13.4	14.1	16.8	13.0
2003	Aber	*S2R3*	8.7				9.2	11.3	6.6	9.7			12.3	10.6	9.9			9.8		11.9	6.4	10.1		8.2	9.2	11.7	9.7
		S2R5	11.5				13.0	12.8	12.2	13.6			14.1	14.0	12.5			11.9		11.8	10.4	14.2		12.2	13.6	13.2	12.7
2004	Aber	*S3R4*	8.8				10.9					10.0	9.9	10.2	8.8	10.0	3.2	9.9		11.6	14.6	10.9	7.0	6.0	11.6		9.5
		S2R6	13.6				15.9					16.0	16.6	14.0	12.7	16.4	5.9	13.7		16.4	19.0	18.5	17.1	10.4	15.2		14.8
		**S3R4*	6.6				7.0					4.0	4.8	7.1	6.6	4.6	3.1	7.0		6.7	8.2	8.7	6.2	6.2	6.5		6.2
		**S2R6*	6.7				7.7					8.9	5.1	5.8	4.4	7.0	3.1	7.5		5.4	8.8	9.5	10.4	9.0	8.2		7.2
		***S3R4*	4.3				7.8					6.9	4.4	5.8	7.9	6.4	2.0	4.7		6.3	6.6	5.1	7.5	7.1	7.2		6.0
		***S2R6*	3.7				9.0					9.1	7.0	5.8	4.4	9.1	2.9	5.1		7.4	9.8	7.1	11.8	9.7	7.2		7.3
2006	Aber	*S4R5*	/				21.1	18.6		14.6		7.7			12.0	11.9	4.9										13.0
Means			7.6	9.2	8.4	9.8	11.4	10.8	10.1	11.5	9.5	9.4	9.7	9.8	8.8	9.3	3.6	9.4	8.7	9.4	10.2	10.4	8.9	8.5	10.4	12.4	9.5

Discussion

Increase in yields

It is important to establish whether plant breeding has improved the potential yield of the crop. When the top three or four performing varieties in each trial are assessed a marked improvement in the yield of newer varieties in trials planted from 2001 onwards is evident, as compared to older varieties planted in 1997–1999.

Table 5. *Mean yields of top three varieties in trials (excludes IBERS altitude trials)*

Year range	No. of trials (no. of 2nd & 3rd rotations	Mean yield (odt ha^{-1} yr^{-1}) 1st rotation	2nd and 3rd rotations
1997–1999	9 (7)	10.32	12.07
2001–2004	7 (5)	11.64	14.43
	% yield increase	**13%**	**20%**

Although the rank of particular varieties varies between sites and from first rotation to the second, there is a general consistency amongst the varieties that appear in the top positions. In almost 70% of the instances a variety performing well in the first rotation will retain it's standing at the second harvest. The two breeding programmes to date have managed to produce a number of varieties that are on a par with the industry standard Tora, with genotypes currently under test showing higher yield potential.

Mixtures

In the UK and Ireland it is recommended that SRC is grown in mixed varietal plantations. A flaw of the yield trial methodology is that varieties are tested in monocultures but are then sold to farmers as mixtures. Hence, in most cases there is no indication how a variety will perform when planted in competition with a different variety. McKenzie *et al*. (2001) included a mixed plot of four varieties in a trial on Orkney and found that the yield of the mix reflected the average performance of the individual varieties. However, many studies at Loughgall and Long Ashton have indicated that yields often increase in mixtures (e.g. McCracken & Dawson, 2003). This is especially marked with varieties that show some susceptibility to rust (*Melampsora* spp.) and beetles (*Phratora* spp.). Mixtures are an important tool for reconciling variation in varietal performance in different locations, allowing the best adapted clones to predominate in the particular circumstances.

Table 6 shows the mean yields for first and second rotations for a number of currently available varieties from the EWBP and SW breeding programmes.

Although the data has been acquired from many different sites, seasons and harvesting combinations by averaging the variety yields across all the sites helps iron out extreme results and provides a good indication of varietal performance. From the results above we can assume that these varieties should achieve 10–12 odt ha^{-1} yr^{-1} on good quality farmland. Obviously, the yield of SRC on a particular farm will depend on the soil and climate in that location and most significantly, the management of the crop.

Willow varieties demonstrate different degrees of plasticity. For instance, Olof and Resolution have performed well at Long Ashton and Aberystwyth but have been less productive in Northern Ireland. By contrast Endeavour and Gudrun have produced high yields in Northern Ireland and Aberystwyth, especially in their second rotations.

The variety Terra Nova is a three way hybrid involving *S. viminalis*, *S. triandra* and *S. miyabeana* and tends to be lower yielding than other varieties. Despite this, it has several distinct advantages. It is currently free of disease and pests and it's very different genetic origin makes it an ideal

Table 6. *EWBP/SW mix yields (excludes IBERS altitude trials)*

Variety	SW Mix		EWBP/SW mix	
	Mean yields (odt ha^{-1} yr^{-1}			
	1st rotation	2nd rotation	1st rotation	2nd rotation
Tora	10.6	12.7	10.6	12.7
Olof	9.8	10.5	/	/
Tordis	11.3	12.5	/	/
Inger	9.4	12.6	/	/
Gudrun	8.2	12.9	/	/
Beagle	/	/	10.3	11.1
Endeavour	/	/	10.2	13.7
Terra Nova	/	/	8.3	9.3
Resolution	/	/	10.6	12.8
Total of means	**9.9**	**12.2**	**10.0**	**11.9**

variety for mixed plantings. Unlike other varieties, Terra Nova retains leaves all the way down its shoots, even when overshadowed by taller willows. Furthermore, it has shown vigorous growth in hotter climates, (as high as 45°C), performing well in a trial in Greece and a commercial plantation in Portugal.

The unreleased variety Endurance has produced high yields at all sites and been the highest ranking willow on four occasions. It is currently undergoing further tests before a possible release. This variety has many stout stems, a high leaf area index, and holds its leaves late in the season. There is some evidence that this variety performs poorly in drier soils (Bonneau, 2004).

Comparison of commercial and trial yields

The yields from small plot trials have seldom been reflected in commercial plantations. There are many reasons for this. Firstly, many new growers tended to grow the crop on poor quality land. Like any crop SRC will produce superior yields on the best land.

To achieve the highest yields it is imperative to plan early and adhere to best practice guidelines (e.g. Finnan & McCracken, 2010). In this way the farmer will be able to create the correct conditions for optimum growth and reduce any competition from weeds or predation by rabbits or deer. Field trials are planted by hand so that every cutting is placed vertically which optimises establishment. Commercial planting relies on machines managed by contractors and the quality of their work will determine the subsequent productivity and profitability of the crop. It is worth paying more for a job well done and demanding guaranteed performance standards from the contractor. Some contractors are prepared to plant shorter cuttings at a higher stocking rate (16,600 ha^{-1}). Based on a typical 90% survival rate 15,000 plants ha^{-1} will be established.

Even if a farmer produces a high yielding crop there is no guarantee that 100% of the wood chip will be harvested. In small plot trials every stem is cut and measured. During machine harvesting yield could be reduced due to the incorrect height of cut by the harvester, machine operator errors such as poor co-ordination between the driver of the harvester and that of the adjacent tractor and trailer, or spillages from overfilled trailers. In addition, some stems may be missed due to poor habit in individual plants. Following harvest there are further losses. Freshly cut wood chip contains around 50% moisture so any heap may heat up and dry matter will be lost through composting and respiration. Finally, it is inevitable that some material will be misplaced during delivery operations.

Experience suggests that all these factors might contribute to commercial yields being around 20% lower than those produced in small plot trials. Allowing for these losses a grower of SRC on

typical arable land should expect a first harvest of around 8 odt ha^{-1} yr^{-1} and a second harvest of 10 odt ha^{-1} yr^{-1}.

Dry matter

A brief review of raw yield data from sample sites was undertaken to assess the % dry matter of different varieties. Table 7 summarises this information.

Table 7. *Means of the % dry matter from different varieties*

Variety	Mean % dry matter	Number of samples	Number of samples > 50% D.M.
Endurance	50.24	22	12
Endeavour	49.89	22	13
Gudrun	48.27	13	4
Resolution	46.91	25	3
Beagle	46.09	13	1
Terra Nova	45.52	22	2
Olof	45.41	25	0
Tora	45.36	122	6
Tordis	42.20	7	0

The variety with the largest data set is Tora. The mean dry matter from 122 samples is 45.36%. With other varieties the sampling data is more limited, although it is possible to identify interesting trends with the varieties Endurance, Endeavour and Gudrun having consistently elevated dry matters, around 2.9–4.9% higher than Tora.

This result has significant implications. The high moisture content of willow is a disadvantage in cut and chip harvesting systems. Wood chips need to be dried down to 30–35% moisture content before they can be used in most biomass boilers. Piles of wet chip can self heat rapidly as a result of fungal and bacterial activity, leading to loss of dry matter and a fire risk. Having a higher dry matter in the first place will reduce the drying time and rate of decomposition. Varieties with higher DM would also be useful for smallholders who are interested in growing SRC for log production. The lower moisture content means that logs will require less seasoning time. Experiments at IBERS suggest that wood chip from the varieties Endeavour and Endurance have higher calorific values and bulk densities than other varieties (Hinton Jones & Valentine, 2008), possibly burning longer and taking up less space than other willows. These are helpful developments for those wishing to grow their own woodfuel.

Outclassed varieties

Several varieties have now been removed from the marketplace by crop developers. This is due to poor yields, breakdown in resistance to disease and pests, difficulties of producing good quality rods for machine planting (e.g. excessive side branching, wavy stems or terminal bud damage by pests) and other crop management issues.

Commonality amongst released varieties

The attributes of certain clones and released varieties has meant that they have been used extensively in crossing programmes. The high yield and disease resistance of Tora and its male sibling Bjorn have resulted in these varieties being used extensively in crossing programmes. The original cross between *S. schwerinii* L79079 and the variety Orm has therefore resulted in 17 commercial varieties. Similarly, an *S. viminalis* clone from Holland (NL420) was a parent to the varieties Jorr, Jorunn and Astrid, which in turn have been widely used, generating a further 13 varieties. Six varieties (Sven, Asgerd, Sherwood, Resolution, Karin and Klara) have common ancestry involving NL420,

Table 8. *Reasons why certain varieties have become outclassed and removed from cultivation*

Variety	Yield	Susceptibility to disease	Susceptibility to pests	Issues with multiplication	Ease of planting/ harvesting
Orm					*
Jorunn	*	*			*
Bjorn				*	
Sherwood			*		
Karin	*				
Ashton Stott		*			*
Ashton Parfitt		*			*
Quest	*				
Discovery				*	
Nimrod	*			*	

L79069 and Orm. Fig. 1 shows a family tree of currently released varieties sharing a common background.

The only currently available varieties completely outside this parent spectrum are Terra Nova, Gudrun, Doris and Nora. The unreleased variety Endurance is also from an independent genetic background. Bjorn and Tora are still being used extensively in breeding programmes in Sweden but more recent releases have introduced new variability by using exotic species such as *S. eriocephala*, *S. aegyptiaca* and *S. dasyclados*. Nevertheless, it is a concern that so many varieties share a common ancestry. History suggests that breakdown in resistance to disease can be catastrophic (e.g. Irish potato famine in 1846). Similarly, several leading commercial poplar varieties with common ancestry were decimated by a new strain of rust in the 1990s (Lonsdale & Tabbush, 1998).

The varieties so far released from the EWBP were all derived from crosses made during the first three years of the programme (1996–98). However, between 1999–2002 a concerted effort was made to broaden the genetic base of future varieties by largely omitting Tora, Bjorn, Jorr and Jorunn from the crossing programme and refocussing on interspecific crosses between non *S. viminalis* species from Asia, Russia and North America. At the completion of the crossing phase of the programme the best 1700 lines from all crosses were transferred to Ingerthorpe Hall Farm in Yorkshire for further testing in observation, yield and fieldscale trials. Several prospective varieties are already in multiplication and will be registered for EU plant breeders' rights in 2012.

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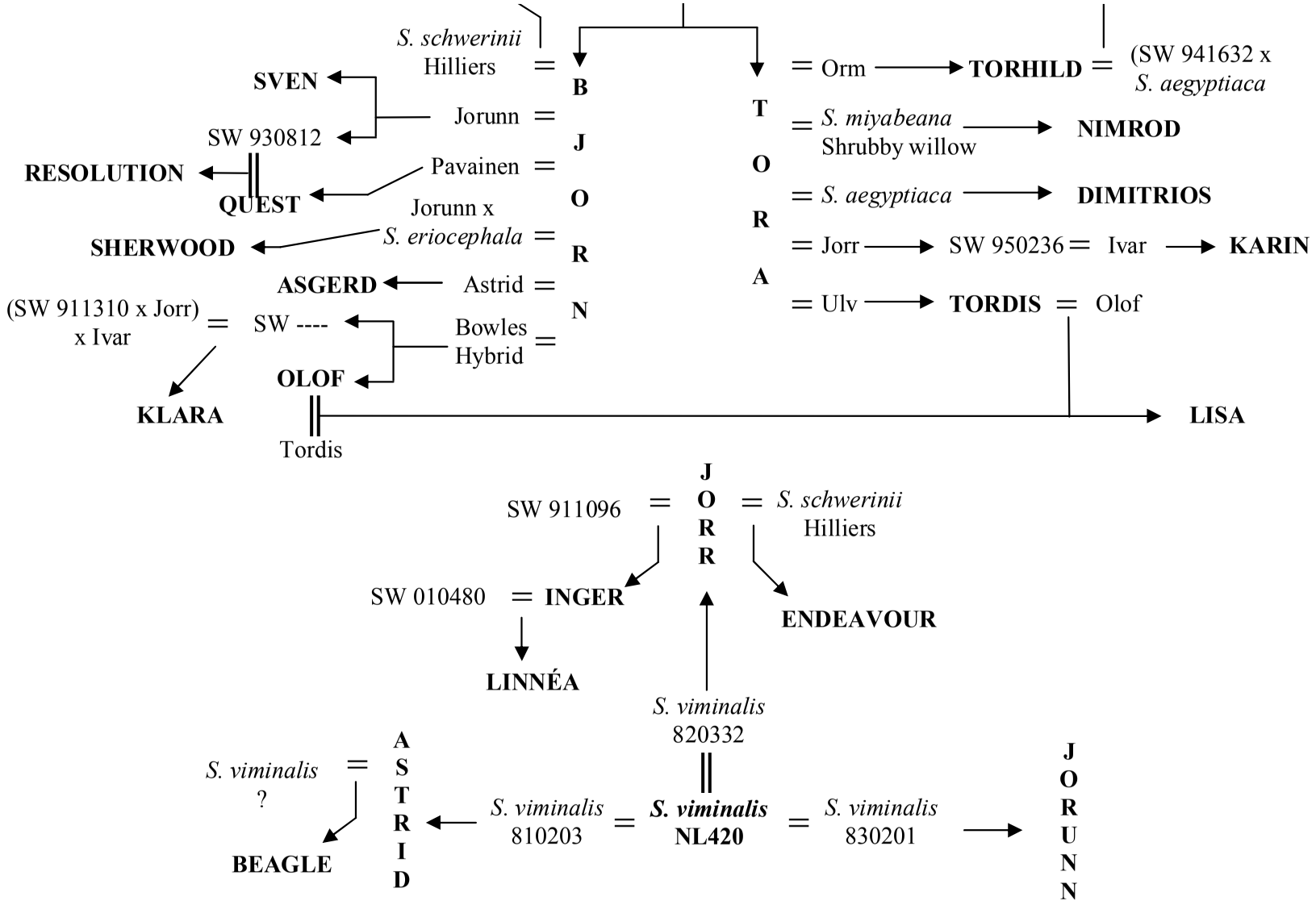

Fig. 1. Family tree of SRC willow varieties resulting from *S. viminalis* NL420, *S. schwerinii* L79069 and Orm.

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