**Seed to near market variety; the BEGIN willow breeding pipeline 2003-2010 and beyond**

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***ABSTRACT:*** The Rothamsted-based BEGIN pipeline has begun to produce near market biomass varieties of willow. The breeding and trialling process is described here and the first yield results are showcased. The crossing programme has the capacity of performing up to 200 crosses and rearing over 12,000 seedlings per year. Yields from the most advanced material in the pipeline produced from crosses made in 2004 are compared to current industry standard clone *S. viminalis × schwerinii* ‘Tora’. RR04246, RR04248 and RR04331 out yield Tora (100%) with values of 113.7%, 120.4% and 108.6% respectively when results over two sites and two years are combined.

# Introduction

Interest in dedicated perennial energy crops (short rotation coppice (SRC) willow and miscanthus) has grown enormously in the past 20 years. Most recently there has been a realisation that they offer greater greenhouse gas and energy efficiencies and flexibility to be planted on a wider range of land types than annual arable crops for energy. Rothamsted Research ran the Biomass for Energy Genetic Improvement Network (BEGIN), the UK’s only willow breeding programme. In the seven crossing seasons between 2004 and 2010 609 crosses have been attempted. Breeding efforts are underpinned by one of the largest and most comprehensive willow germplasm collections in the world, the UK National Willow Collection (NWC). The NWC was initiated in the 1920s at Long Ashton Research Station (North Somerset) and moved to Rothamsted Research in 2002. It contains in excess of 1300 accessions and comprises over 100 different *Salix* species [[1](#_ENREF_1)]. BEGIN started in 2003 and furthered the work of the European Willow Breeding Programme (EWBP) detailed in Lindegaard & Barker [[2](#_ENREF_2)].

BEGIN has continued performing crosses to broaden the species range of commercial varieties which had been dominated by *Salix viminalis* and *S. viminalis* × *S. schwerinii* hybrids. Primary aims of BEGIN are to produce high yielding, pest and disease resistant elite genotypes with a growth habit that facilitates mechanical harvesting in all UK environments; arable, grassland and upland.

# Materials and methods

## The BEGIN willow breeding pipeline

Figure 1 is a schematic that represents how the resources, expertise and externally funded collaborative projects at Rothamsted Research unite to make the BEGIN willow breeding pipeline. From making the cross and producing the seed this pipeline takes approximately 10 years to produce a willow ready for release as a SRC biomass variety. As crosses have been made every year since 2004 and are set to be ongoing there is going to be a constant output from the pipeline despite an initial lag in output. Details of the basic steps of the crossing and trialling regime that make up some of the willow breeding pipeline follow.

**Figure 1.** The BEGIN willow breeding pipeline

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### Crossing and seed rearing

Crosses have been made at Rothamsted Research each year since BEGIN commenced in 2003. Winter-dormant branches, 0.6-1.0 m in length containing flower buds, were collected each year in December and early January from either the NWC or other germplasm resources. After collection and labelling these were wrapped in plastic and stored in a -4°C cold room. Breeding material was moved from the cold store into glasshouse compartments in batches from mid-January to late February. Breeding branches were placed in water culture in 5.5 litre buckets and covered with black plastic. Male and female breeding material was arranged in separate glasshouse compartments to avoid out crossing/pollen contamination. All female breeding material was also bagged using clear bags containing microperforations before their catkins became receptive to pollen. The temperature of the glasshouse compartments was maintained at 18°C during the day and 10°C during the evening, temperature differentials were +/-3°C. The bottom 5mm of breeding rods were removed to stop any vascular bundle clogging. These cuts were made twice a week until the branches produced roots.

The majority of crosses were made using fresh pollen. To synchronise male anthesis and female receptivity male and female material were removed from the cold storage in a systematic staggered fashion which ensured a constant supply of fresh pollen and receptive female catkins. Stored pollen was used successfully when the flowering times of the parents for a particular cross are very far apart using Kopp *et al,* [[3](#_ENREF_3)] protocol. Female catkins are fully receptive once the lobes of the stigma are fully reflexed. Crosses were made by gently brushing fresh pollen directly from male catkins onto the female catkin. Each cross received a unique reference number beginning with 1001 the first cross made by the BEGIN programme in 2004 and ending (at the time of writing) at 1609, the last cross made during 2010. The number was allocated irrespective of the success of the cross, so that a record was created of all parental combinations attempted. This information is maintained in a database.

Seeds were collected at capsule dehiscence. Capsule dehiscence was generally sequential with an individual catkin taking up to a week for all capsules to release their seed. This typically happened 4-6 weeks post pollination. At seed dehiscence, seeds were collected and sown in a humid environment within 48 hours of collection as seeds have poor viability. The tufted part of the seed, that in nature facilitates seed dispersal by the wind, was removed by threshing the seed before sowing. Seeds were mixed with sand and sprinkled on the surface of the compost, so they were not to sown too densely, and placed in a mister unit. Seeds germinated within 24-48 hours. After 3-4 weeks the seedlings were moved out of the mister unit to conventional glasshouse compartments and after hardening off they were pricked on into multi cell trays. After a further 4-5 weeks the seedlings were transplanted to 40 cm × 60 cm trays, containing Rothamsted Prescription Mix compost, 24 seedlings per tray. The trays were then moved to the outdoor nursery and each tray was drip irrigated throughout the growing season. Although some crosses did not produce enough seeds, the target number of seedlings per cross was 240-360.

### Nursery Selections

Plants grown on the nursery were subject to two rounds of selection. The first round took place in September, where a selective cull was carried out and proportions of rust infection, tip damage and giant willow aphid infestation were recorded for all families. The second selection was performed in December-January of each year. Typically no more than 10% of the material grown on the nursery was selected. Shortly after the final selection in January/February, when stems were still winter-dormant, the selected plants were made into cuttings, ten 20 cm cuttings per plant. Cuttings were wrapped in plastic and and put into -4°C cold storage after being made. Each genotype selected for advancement to the first stage field trial, the Observation I Trial or Obs I, received a unique identification code beginning with RR04001 (Rothamsted Research, 2004 seedling number, 001). This identification code links with the cross code mentioned above in the willow breeding database.

### Observation 1 Trials

Selected material from the glasshouses/nursery was progressed to the Observation 1 Trial each year. Observation 1 Trials are only present at Rothamsted Research (N 51 48.371, W 0 21.756) and consist of unreplicated plots, containing ten plants of each line. Cuttings are planted in the conventional twin row design with a spacing of 0.8 m within twin rows and 1.6 m between pairs of rows. Cuttings are spaced at 0.5m within the rows. This planting design represents a stocking rate of 16,666 plants per hectare. All trials mentioned in this paper were planted to this twin row design although plot size does vary among trial type. Observation 1 trial plots are planted as a double row five cuttings deep in March/April. Controls of the yield standard Tora were incorporated into the field trial design at a rate of one plot per ten breeding lines. The first season’s growth was cutback/coppiced to *circa* 5 cm above ground level in February at the end of the first year whilst willows were still winter-dormant. After this cut back willows were allowed to grow for two growing seasons. Final selections for progression to the next stage of trialling, the Observation 2 Trial, were made at the end of the trials third year. Obs 1 experiments were assessed twice a year for rust in July and September/October as well as for any vertebrate grazing/browsing and for any invertebrate damage. Form and growth habit were assessed too as SRC willows need to be of a form suitable for mechanical harvesting. Plants were also sexed in the spring of the beginning of their third season, to aid planning of future crossing.

### Observation 2 Trials

Selected material from the Observation 1 Trial was progressed to the Observation 2 Trials. The Obs II field trial was planted on two sites, Rothamsted Research and Fenswood Farm, Long Ashton, Bristol (N 51 25.431, W 2 40.015). The soils at Rothamsted Research are a silty clay loam with flints over clay and Fenswood Farm consist of a silty loam. These trials included two replicates of each genotype in a randomised block design. This gave a much greater insight into the potential of the genotypes created. Cutting material taken from selected Obs 1 plots was planted in the conventional twin row design mentioned above. Observation 2 Trials consisted of two plots of 40 plants per genotype. Each plot consisted of four single rows of ten, with the central double row consisting of the yield area. Typically Observation 2 trials have consisted of 26 selected lines with the remainder consisting of ‘Tora’ yield standards. *S. viminalis × schwerinii* ‘Tora’ is a very popular and consistently high yielding commercial variety. It originates from the Svalöf-Weibull breeding programme in Sweden. Like the Obs 1s, the Obs 2s were subjected to a first year cutback and were then allowed to grow for two seasons before harvesting for yield measurement.

### Yield Trials

After subsequent selection from the Nursery, Observation Trial 1 and Observation Trial 2 seven potential cultivars from the first round crossing in 2004 were progressed to yield trials. These were planted with seven elite biomass varieties, four bred in Sweden and three from the EWBP. These trials, like the Observation Trial 2, consisted of plots of 40 plants; the plant density was also the same. Plots in these trials however were replicated four times and trials were situated in six locations in England and Northern Ireland. These trials are present at Rothamsted Research, Fenswood Farm, Long Ashton, University of Bristol and Loughgall, Agri-Food and Biosciences Institute (AFBI), Northern Ireland and are also hosted by parties involved intimately in the SRC industry, two in Northern England and another one in Northern Ireland. By hosting a trial, the trial hosts have an option to bid to multiply and market the new varieties once registered.

### Yield Harvest

This paper will present results for Observation 2 trials. The yield harvest protocol for this format experiment is as follows. The central pairs of six stools were harvested from each plot. Fresh weights were measured in the field on a cradle attached to an electronic balance. Harvested rods were then chipped and a representative subsample of chip of between 1 kg – 1.5 kg was taken and its fresh weight recorded. Dry weights were taken after drying the chips at 80°C for 48 hours. The mean percentage dry matter was calculated for each variety and yields estimated using the following formulas:

Fresh weight per plot (Kg) × Mean percentage dry matter = Oven dry weight per plot (Kg)

Oven dry weight per plot (Kg) × 10 = Oven dry weight (t) per hectare Sample area m2

Oven dry weight (tonnes) per hectare = Oven dry weight (tonnes) per hectare per year Number of years

#### Scaling up results-a word of warning

Despite the trial design taking care to eliminate factors such as edge effect, it should be noted that the results presented have assumed a whole hectare is in production. In reality some areas are excluded from planting either due to space needed for operations or as they do not qualify for an establishment grant under the Energy Crops Scheme (ESC). For example the ECS specifies that the following need to remain unplanted; 10 m from boundary of neighbouring land/house where views may be compromised, 3m buffer along a watercourse, under power lines/over underground services and operational areas. A small percentage of material may be lost in the harvest operation too. Potential commercial growers should be aware of this.

# Results and Discussion

### Crossing and seed rearing

The crossing output since BEGIN’s inception in 2003 is detailed in Table 1. The crossing success was high in 2004 as mainly intraspecific crosses were performed. Intraspecific crosses tend to be more successful than interspecific crosses. In subsequent seasons the general trend has been that the size and the success of the crossing programme has increased as the breeders have become more experienced. The volume of crosses undertaken steadily increased to a peak in 2009 where 199 crosses were attempted. The combined improvement in crossing success rates and total crosses attempted has led to increasing numbers of seedlings being reared on the willow nursery. Crossing seasons in 2008 and 2009 both produced in excess of 12,000 seedlings which were all transferred and reared successfully on the purpose built and fully irrigated willow nursery.

**Table 1.** The total number of crosses made and measures of success by year.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | ♀ Parent | ♂ Parent | Total Parents | Total Crosses | Successful Crosses | % Success | Seedlings on nursery |
| 2004 | 21 | 13 | 34 | 27 | 18 | 66.7 | 4109 |
| 2005 | 26 | 15 | 41 | 53 | 26 | 49.1 | 5282 |
| 2006 | 48 | 22 | 70 | 57 | 18 | 31.6 | 4043 |
| 2007 | 31 | 22 | 53 | 65 | 32 | 49.2 | 11086 |
| 2008 | 33 | 28 | 61 | 111 | 56 | 50.5 | 12111 |
| 2009 | 38 | 25 | 63 | 199 | 102 | 51.3 | 12291 |
| 2010 | 33 | 29 | 62 | 97 | 67 | 69.1 | 9328 |
| Total | (138) | (87) | (225) | 609 | 319 | 52.5 | 58250 |

(#) Numbers of the same genotype were often used repeatedly from year to year. The total is the number of genotypes used as parents over the all breeding seasons.

### Nursery Selections

Table 2 shows how harsh the selection environment is on the nursery, often with much less than 10% of seedlings made being selected for Observation 1 Trials. The humid, high density environment of the nursery makes it an excellent place to select against *Melampsora* spp. rust susceptibility.

Not all crosses in BEGIN were made with the direct aim of producing SRC varieties. A number of crosses were produced to support the science at Rothamsted Research which in turn feed back into the BEGIN pipeline, making it more efficient. Crosses have been made for two main areas and help underpin the science; the development of molecular markers (MAS, marker assisted selection) for key traits and rust inheritance studies. Both these areas of research used crosses specifically made for them and in return the BEGIN pipeline benefits from improved selection tools and a faster pipeline from seed to variety, as well as more focused parental germplasm selection.

**Table 2.** Seedlings produced and their uses per year.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Year | Seedlings on nursery | Observation Trial 1 | Rust inheritance studies | Genetic mapping populations | MAS seedlings |
| 2004 | 4109 | 110 | 1560 | 392 | 726 |
| 2005 | 5282 | 347 | 288 | - | - |
| 2006 | 4043 | 292 | - | - | - |
| 2007 | 11086 | 249 | 2340 | 2000 | - |
| 2008 | 12111 | 401(58\*) | 1128 | 2971 | - |
| 2009 | 12291 | 705 | 984 | 1848 | 2543 |
| 2010 | 9328 | - | 1104 | 432 | 4998 |
| Total | 58250 | 2162 | 7404 | 7643 | 7541 |

\*58 lines of seedlings produced in 2008 are planted in 2010 Obs I.

### Observation 1 Trials

Table 3 shows that the diversity of genetic material was increased within Observation I Trials. This was directly linked to the number of successful crosses made as shown in Table 1. Although the numbers of progeny selected from a particular cross for Observation 1 Trials were normally less, up to 40 progeny have been included in some Observation I Trials. Such large selections from the same parental combinations are only common if the material from that combination looked particularly promising on the nursery.

**Table 3.** Number of selected genotypes planted per Observation 1 Trial and how many unique families/pedigrees they consist of

|  |  |  |
| --- | --- | --- |
| Year | Observation Trial 1 | Families |
| 2004 | - |  |
| 2005 | 110 | 17 |
| 2006 | 347 | 24 |
| 2007 | 292 | 16 |
| 2008 | 249 | 23 |
| 2009 | 401(58\*) | 43 |
| 2010 | 705 | 82 |
| Total |  |  |

\*58 lines of seedlings produced in 2008 are planted in 2010 Obs I.

### Observation 2 Trials Yields

Estimated dry weight yields for 2006 and 2007 Observation 2 Trials are presented in Table 4 for both sites, Rothamsted Research (RRes) and Fenswood Farm, Long Ashton (LA). All yield data represents yield taken from two year old above ground biomass taken from the trials first rotation. Results have been adjusted to represent tonnes of dry matter ha-1 yr-1.

**Table 4.** Yield results for 2006 & 2007 Observation Trial 2

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2006 | | | 2007 | | |
| Line | RRes | LA | Line | RRes | LA |
|  | t DM ha-1 yr-1 | |  | t DM ha-1 yr-1 | |
| Resolution  Endurance  Stott 10  LA2000051  LA2001180  LA2001203  LA2001249  LA2001250  LA2001287  LA2001357  LA2001420  LA2001476  RR04195  RR04236  RR04242  RR04243  RR04246  RR04248  RR04249  RR04250  RR04292  RR04326  RR04327  RR04328  RR04330  RR04331  Tora | 11.80  11.71  13.97  7.98  12.11  12.94  11.39  10.30  9.28  12.89  9.53  13.84  10.91  6.02  5.02  7.07  8.66  15.34  7.56  12.85  9.07  8.44  8.33  10.33  13.31  11.87  13.24 | 14.63  13.42  13.79  8.78  12.91  10.28  12.11  14.44  6.79  9.69  8.69  9.86  9.47  11.29  13.70  14.08  13.99  13.85  9.77  8.49  8.98  2.90  3.72  3.93  4.68  12.66  15.16 | Resolution  Endurance  Stott10  RR04326  RR04327  RR04328  RR04330  RR04331  RR04242  RR04246  RR04248  RR04256  RR04257  RR04260  RR04261  RR04292  RR04295  RR04296  RR05039  RR05054  RR05075  RR05196  RR05222  RR05235  RR05237  RR05242  Tora | 9.31  8.75  9.43  6.74  6.40  6.14  8.61  7.74  2.89  7.68  6.10  7.00  6.34  4.62  8.46  2.37  8.83  3.13  6.74  3.54  4.24  7.49  8.61  8.61  8.16  9.27  6.79 | 9.98  6.90  11.53  6.44  5.59  8.81  9.30  8.93  7.95  12.83  10.39  6.21  9.97  10.87  13.56  4.60  13.10  5.69  -  -  -  -  -  -  -  -  12.24 |
| F pr  sed min rep  sed max-min rep  df | 0.025  5.154  4.464  27 | <0.001  4.191  3.630  27 |  | 0.001  3.253  2.817  28 | <0.001  3.599  3.117  20 |

sed min rep to be used when comparing lines (not Tora) with themselves.

sed max-min rep to be used when comparing lines to Tora.

The LA coded lines presented in Table 4 are material produced in the European Willow Breeding Programme (EWBP). Selections were made in order to exploit promising material and carry on the EWBP selection pipeline. Endurance and Resolution were also produced by the EWBP, Resolution is available as a commercial variety. Stott 10 was produced at Long Ashton Research Station in 1986 before the EWBP was initiated. The 14 lines with codes beginning with RR are the first BEGIN material to be trialled. They were fast tracked from the 2005 Observation 1 Trial. Final selections and cutting material was selected from the material at the end of its establishment year. The eight RR05 codes in the 2007 trial also represent fast tracked material from the 2006 Observation 1 Trial. The 15 RR04 were selected from material one year post cutback in the 2005 Observation 1 Trial.

Unfortunately there was not enough good quality cutting material to propagate duplicate plots of the fast tracked RR05 material in the Long Ashton replicate of the 2007 Observation 2 Trial.

**Table 5.** 2006 Observation Trial 2 yield as a percentage compared to Tora

|  |  |  |  |
| --- | --- | --- | --- |
| Line | RRes | Line | LA |
| RR04248  Stott 10  LA2001476  RR04330  **Tora**  LA2001203  LA2001357  RR04250  LA2001180  RR04331  Resolution  Endurance  LA2001249  RR04195  RR04328  LA2001250  LA2001420  LA2001287  RR04292  RR04246  RR04326  RR04327  LA2000051  RR04249  RR04243  RR04236  RR04242 | 115.87%  105.52%  104.57%  100.53%  **100.00%**  97.73%  97.36%  97.09%  91.50%  89.65%  89.16%  88.44%  86.06%  82.43%  78.05%  77.82%  72.01%  70.08%  68.49%  65.39%  63.77%  62.90%  60.29%  57.12%  53.38%  45.49%  37.93% | Tora  Resolution  LA2001250  RR04243  RR04246  RR04248  Stott 10  RR04242  Endurance  LA2001180  RR04331  LA2001249  RR04236  LA2001203  LA2001476  RR04249  LA2001357  RR04195  RR04292  LA2000051  LA2001420  RR04250  LA2001287  RR04330  RR04328  RR04327  RR04326 | **100.00%**  96.52%  95.24%  92.89%  92.27%  91.37%  90.98%  90.36%  88.56%  85.18%  83.54%  79.90%  74.47%  67.83%  65.06%  64.46%  63.93%  62.45%  59.21%  57.92%  57.30%  56.01%  44.80%  30.87%  25.90%  24.56%  19.16% |
| Tora (t DM ha-1 yr-1) | 13.24 |  | 15.16 |

Tables 5 and 6 represent the yield shown in Table 4 as percentages of Tora’s yield. It should be noted that Tora yields from 2007 Observation 2 Trial at Rothamsted are almost half what would be expected. Yields were lower at Rothamsted as although productive, the soils are not as productive as those found at Long Ashton. The less water retentive soils at Rothamsted combine with a lower rainfall to reduce yields. In the three year lives of the Obs 2 trials the Rothamsted 2006 Obs 2 received 305.4 mm less rain than its counterpart at Long Ashton and 189.1 mm less rain during the growing season (from 1st April-30th September). Similarly the Rothamsted Obs 2 2007 received less rainfall, 336.4 mm less in the three years in total and 157.4 mm less in the three growing seasons. Although some months during the growing season were wetter at Rothamsted, often crucial months during the growing season were much dryer at Rothamsted than at Long Ashton. For example in 2006 in May, June and July respectively Rothamsted received 32.9, 70.4 and 22.4 mm less rain in each month than at Long Ashton. In 2007 Rothamsted received 43.4 and 56.7 mm less rain than at Long Ashton, and in 2009 received 22.8 and 60.8 mm less rain, in May and July respectively than at Long Ashton. Although this provides some explanation in differing yields, the severe reduction in yield in Tora at Rothamsted in 2007 is hard to explain. Despite this trial not producing the desired high yields it is positive that so many breeding lines out yielded the industry standard. It also highlights that lines bred at Rothamsted Research like RR04248 could have the potential to perform on more marginal land, the sort of land that it is anticipated energy crops will be cultivated on. The changes in rank among the lines between the two sites can be explained by genotype × environment interactions.

**Table 6.** 2007 Observation Trial 2 yield as a percentage compared to Tora

|  |  |  |  |
| --- | --- | --- | --- |
| Line | RRes | Line | LA |
| Stott10  Resolution  RR05242  RR04295  Endurance  RR04330  RR05222  RR05235  RR04261  RR05237  RR04331  RR04246  RR05196  RR04256  **Tora**  RR04326  RR05039  RR04327  RR04257  RR04328  RR04248  RR04260  RR05075  RR05054  RR04296  RR04242  RR04292 | 138.91%  137.21%  136.62%  130.14%  128.89%  126.90%  126.90%  126.90%  124.61%  120.19%  114.08%  113.12%  110.32%  103.17%  **100.00%**  99.26%  99.26%  94.25%  93.44%  90.49%  89.90%  68.09%  62.42%  52.17%  46.13%  42.59%  34.86% | RR04261  RR04295  RR04246  **Tora**  Stott10  RR04260  RR04248  Resolution  RR04257  RR04330  RR04331  RR04328  RR04242  Endurance  RR04326  RR04256  RR04296  RR04327  RR04292 | 110.79%  107.03%  104.82%  **100.00%**  94.24%  88.84%  84.88%  81.57%  81.45%  76.01%  72.99%  71.97%  64.98%  56.35%  52.60%  50.76%  46.47%  45.69%  37.60% |
| Tora (t DM ha-1 yr-1) | 6.79 |  | 12.24 |

Table 7 takes the nine RR04 lines that are duplicated in both Observation 2 Trials along with the other genotypes that are duplicated across the two years and combines their yields within sites. With an impressive mean yield of 13.70 t DM ha-1 yr-1it is not surprising that Tora is highest yielding variety at Long Ashton. Tora’s yield in 2006 at Long Ashton was exceptional at 15.16 t DM ha-1 yr-1 this yield is well above the 12.8 t DM ha-1 yr-1 reported in 2001[[4](#_ENREF_4)]. [[4](#_ENREF_4)] also reported Stott 10 or ‘Ashton Stott’ was the current highest yield variety (15.4 t DM ha-1 yr-1).

**Table 7.** Genotypes combined yield as a percentage compared to Tora results for Obs II 2006 & 2005 for each site

|  |  |  |  |
| --- | --- | --- | --- |
| Line | RRes | Line | LA |
| Stott10  RR04330  RR04248  Resolution  Endurance  **Tora**  RR04331  RR04328  RR04246  RR04326  RR04327  RR04292  RR04242 | 116.83%  109.47%  107.07%  105.44%  102.15%  **100.00%**  97.93%  82.27%  81.57%  75.80%  73.53%  57.09%  39.51% | Tora  RR04246  Stott10  Resolution  RR04248  RR04242  RR04331  Endurance  RR04330  RR04292  RR04328  RR04326  RR04327 | **100.00%**  97.88%  92.44%  89.84%  88.47%  79.02%  78.83%  74.17%  51.03%  49.56%  46.47%  34.09%  34.00% |
| Tora (t DM ha-1 yr-1) | 10.01 |  | 13.70 |

The combined yield for Stott 10 over for the trials planted in 2006 and 2007 at Long Ashton was 12.66 t DM ha-1 yr-1. This reduced yield could be associated with Stott 10s increasing susceptibility to rust and the associated yield penalties. This break down in Stott 10’s rust resistance is the reason for it not being included in new commercial SRC willow plantations.

**Table 8.** Genotypes combined yield as a percentage compared to Tora results for Obs II 2006 & 2005 and combined site

|  |  |
| --- | --- |
| Line | RRes & LA |
| Stott10  Resolution  RR04248  RR04246  RR04331  Endurance  **Tora**  RR04330  RR04242  RR04328  RR04292  RR04326  RR04327 | 128.42%  120.54%  120.40%  113.74%  108.62%  107.48%  **100.00%**  94.63%  77.92%  76.98%  65.92%  64.63%  63.36% |
| Tora (t DM ha-1 yr-1) | 11.85 |

Table 8 demonstrated the potential of three lines from the BEGIN pipeline, RR04331, RR04246 and in particular RR04248. These three along with four other BEGIN lines RR04195, RR04250, RR04256 and RR04261 are currently in yield trials on 6 sites around the UK. First yields from this suite of trials will be taken in the winter of 2010/11 and will allow further insight into the performance of these lines.

# Conclusions

The results demonstrate the potential of the first material fast-tracked through the BEGIN willow breeding pipeline. The data also highlights the vast amount of material in various stages of selection that is still set to come through the pipeline over the next decade.

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# REFERENCES

1. Trybush, S., Š. Jahodová, W. Macalpine, and A. Karp, A Genetic Study of a *Salix* Germplasm Resource Reveals New Insights into Relationships Among *Subgenera*, Sections and Species. Bioenergy Research, 2008. **1**(1): p. 67-79

2. Lindegaard, K.N. and J.H.A. Barker, Breeding willows for biomass. Aspects of Applied Biology, 1997(49): p. 155-162.

3. Kopp, R.F., C.A. Maynard, P.R. de Niella, L.B. Smart, and L.P. Abrahamson, Collection and storage of pollen from *Salix* (*Salicaceae*). American Journal of Botany, 2002. **89**(2): p. 248-252.

4. Lindegaard, K.N., R.I. Parfitt, G. Donaldson, T. Hunter, W.M. Dawson, E.G.A. Forbes, M.M. Carter, C.C. Whinney, J.E. Whinney, and S. Larsson, Comparative trials of elite Swedish and UK biomass willow varieties. Aspects of Applied Biology, 2001(65): p. 183-192.