Effect of two vs. three year harvest intervals on yields of Short Rotation Coppice (SRC) willow

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Highlights

- Some varieties appear to be more resilient than others when harvested more frequently.

- 10% yield decline when harvesting more regularly over the twelve year assessment period

- Variety has more of an effect on yield that harvesting regime

ABSTRACT

Five genotypes of Short Rotation Coppice (SRC) willow: 'Beagle' ((*S. viminalis* 'L810203' x *viminalis* 'L81102') *x* 'Astrid' *x male parent unknown*), 'Olof' (*S. viminalis* 'Bowles Hybrid') x ((*S. schwerinii* 'L79069') x ((*S. viminalis* 'L78195' x viminalis 'L78101') 'Orm') 'Bjorn'). 'Ashton Stott' (S.viminalis 'Bowles Hybrid') x S.dasyclados 'Korso', 'Tora' (*S. schwerinii* 'L79069') x ((*S. viminalis* 'L78195' x viminalis *'L78101'*) 'Orm'), and 'Torhild' ((*S. schwerinii* '79069') x ((*S. viminalis*) *x S. viminalis* 'L78195' x viminalis 'L78101')) 'Orm') 'Tora') x ((S.viminalis 'L78195' x viminalis 'L78101') ' Orm') were grown in large mono-plots or within plots of intimate mixtures. Over a seven year period half of the plots were harvested on a two-year harvest cycle (three harvests) and the rest on a three-year harvest cycle (two harvests). At the end of this 7 year trial period there were no significant differences between total dry weights or stool survival, irrespective of harvest interval. With the realisation of the importance of this finding for more regular crop management practices, the experiment was continued for a further six years allowing for a further round of two and three year harvests. Results suggest that there ultimately are yield penalties, although these may be minimised by careful and appropriate clonal selection.

Graphical Abstract

Keywords

SRC Willow; *Salix*; Genotype; Harvest interval; Biomass; Yield

1. Introduction

Short Rotation Coppice (SRC) willow (*Salix* spp.) continues to be an important source of woody biomass for the production of renewable energy in Northern Europe. Furthermore, with the

2050 EU Climate neutrality [1] and the UK net zero carbon emissions [2] targets, followed by the Committee on Climate Change urging an increase in perennial energy crops [3], the future seems encouraging for a significant expansion of land area growing such perennial biomass / bioenergy crops.

Following the planting of hardwood cutting in the spring, the developing plants are normally cut back the following winter (i.e. an establishment year) in order to encourage production of multiple stems. The recommendation has been that the crop is then harvested on a three-year cycle [4]. SRC willow can be harvested by a number of different methods which include a single pass harvest and chip process using an adapted forage harvester or a smaller tractor mounted system; as whole rods using a Stemster® type harvester; as billets using a sugar cane derived harvester or as bales using a Biobaler® type harvester. In the case of the one pass harvest and chip method, the wood chips then need to be artificially dried to < 25% moisture to stabilise the wood chip and prevent composting with associated losses of calorific value and excess dust and spore formation increasing the health and safety concerns in managing the wood chip [5]. With whole stem, billet and bale harvesting, the willow can be allowed to dry naturally before chipping, thus alleviating the need for energy intensive artificial drying.

A three-year growth cycle from stools of varying age will give rise to plants which are sufficiently large to give an acceptable yield, in the region of 10 odt ha^{-1} yr^{-1} [6], but are not so large as to cause issues for the harvester. A normal SRC willow plantation will have a life of 20 – 25 years i.e. 6 – 8 harvests every three years [7]. However, in recent years and in some regions, including Northern Ireland, some commercial growers have been interested in harvesting more regularly i.e. every second year. The main reason for this has been that harvesting at a two year interval enables the plantation to be accessed by machinery on a yearly basis for organic fertiliser application (e.g. organic waste/biosolids recycling for non-food crop production) as the crop is lighter and more forgiving for machinery access. As well as this, the plants being smaller, are more easily harvested and this operation may lend itself to lighter and more affordable harvesting machinery while also allowing for faster cash flow and improved site management.

The use of willow plantations for organic waste recycling is not as common place as it had been in the previous decade however other environmental protection opportunities are now being investigated whereby a more frequent, such as two yearly instead of three or four, harvest may also be more practical. Where willows are recommended for biofiltration blocks and riparian protection for mitigation of overland runoff [8], it may be more practical to access the crop more regularly with smaller and lighter machinery due to the more likely wet ground conditions and subsequent more difficult trafficability.

Previous literature has suggested that the plants increased in weight more during the third year of growth than in the second year [9]. Wang & MacFarlane ([10] compared the yield of twelve willow and two poplar clones over three or four year growth periods after coppicing and reported that willow growth was initially slower, but increased over time. High yielding (e.g. 'SX61') and moderate yielding (e.g. '94003') willow genotypes showed an almost constant increase over multiple harvests. The annual yield at the second 3-year cycle after coppicing for ten out of the twelve genotypes was at least 50% higher than at the first harvest cycle [10]. In Swedish growing conditions, (a continental climate of cold winters, which allow for large heavy machinery as trafficking is not an issue on frozen ground, and short warm summers), short rotations (1 – 2 years) were deemed unsuitable and longer 4 – 6 year rotations preformed best [11]. It was therefore assumed that there would be some yield penalty for harvesting at shorter time intervals.

In maritime climates such as that found in Ireland, rust disease caused by *Melampsora epitea* can be a major threat to growing SRC willow [12]. Rust can induce premature leaf fall and in susceptible SRC willow varieties can result in significant yield loss. Furthermore as the crop may be in the ground for 25+ years, previously resistant genotypes grown on mono-culture can become very susceptible [13]. The use of fungicides does not offer a viable, economic or environmentally acceptable option for disease control. However when SRC willow varieties are grown in intimate mixtures, rather than in mono-cultures, the onset of disease is delayed, the progression of the disease is slowed and the final disease effect reduced [14]. The Best Practice Guidelines for growing SRC willow in Ireland [4] strongly recommends the use of *Salix* spp. genotypes mixtures as a cost-effective and environmentally friendly method of disease management. In addition to reducing disease, there were consistent yield increases from mixture plots compared to the sum of the yield of the components grown on mono-plots [15]. SRC willows grown in mixtures have the capacity for more efficient site capture and can compensate for stools or plants that do not establish or die for whatever reason. It was therefore important when comparing the impact of harvest intervals that a mixture treatment was included alongside mono-plots of individual genotypes.

Biomass yield is the main criterion of interest for evaluating clonal performance. There are principally two major factors, genotype and survival rates which combine to determine overall biomass yields of clones [10]. The purpose of this paper is to describe and compare the effect of 2 vs 3 year harvest intervals on the yield and survival of five SRC willow varieties mono plots and mixture plots harvested six times at two-year intervals compared and four times at three-year intervals. These data are unique because of their long-term nature; the trial having been in the ground for 13 years. Hence, in addition to assessing the effect of the length of harvest cycle on yield, conclusions are also drawn about the long-term sustainability of the genotypes included in the plantation.

The aim of this study was to determine whether there are any yield penalties by implementing a more frequent harvest. Yield penalties were assessed on the basis of biological yield and survival.

2. Materials and Methods

2.1. *Planting material*

Five genotypes of Short Rotation Coppice (SRC) willow (breeder, cross & release dates shown in Table 1): 'Beagle' ((*S. viminalis* 'L810203' x *viminalis* 'L81102') *x* 'Astrid' *x male parent unknown*), 'Olof' (*S. viminalis* 'Bowles Hybrid') x ((*S. schwerinii* 'L79069') x ((*S. viminalis* 'L78195' x viminalis 'L78101') 'Orm') 'Bjorn'). 'Ashton Stott' (S.viminalis 'Bowles Hybrid') x S.dasyclados 'Korso', , 'Tora' (*S. schwerinii* 'L79069') x ((*S. viminalis* 'L78195' x viminalis *'L78101'*) 'Orm'), and 'Torhild' ((*S. schwerinii* '79069') x ((*S. viminalis*) *x S. viminalis* 'L78195' x viminalis 'L78101')) 'Orm') 'Tora') x ((S.viminalis 'L78195' x viminalis 'L78101') ' Orm') were selected and fresh 25 cm hard wood cutting of each was prepared. Cuttings were obtained from one year-old rods and as far as was practical were of similar thickness and vigour. Cuttings were planted in spring 2007 at the Northern Ireland Horticulture and Plant Breeding Station, Loughgall. Co. Armagh, N. Ireland (Irish Grid: H 911 519). The soil is well drained Brown Earth with high clay content. The willows were cut back at the end of the establishment year in winter 2007/8.

Loughgall is a relatively low rainfall areas in Northern Ireland (annual average 1971-2000 = 760mm) and higher mean annual temperature areas (annual average 1971-2000 = 9.2-10.0 'C).

The 30 year average weather data for Loughgall is given in Table 2 as provided by Worldweatheronline [16]

Table 1: Breeder and dates of cross & release of SRC Willow Varieties used in this study

Table 2: Average Weather data

2.2. *Plantation design*

Each of the five blocks comprised 12 plots which were 8.6 m x 10.7 m in dimension (92.02 m^2). Each of the five genotypes, plus the mixture plot, containing all five genotypes, was assigned to two plots selected at random within the block. One of the plots was to be harvested every second year and the second plot every third year. It was recognised that there could potentially be side plot effects or shading following the removal of plots at different times. The effect of this was minimised by only harvesting the central plants within the plot, by having a guard row around each block and ensuring that the randomisation would even out any adverse effects. Cuttings were planted in 4 double rows (0.5m between rows and 1.5m between double rows). There was 0.60 m between plants within rows giving a final planting density in the region of 16,600 plants ha^{-1}.

2.3. *Harvesting*

Stools, from the centre of the plots, were harvest by hand using a chain saw and each individual stool was weighed (fresh weight). In total there were potentially 96 stools harvested from every plot. A small number had failed to establish. Five representative stems were taken from each plot, chipped, weighed and oven dried, in order to obtain a representative percentage dry matter, which was, in turn, used to calculate the dry matter yield for each stool. These data were then summed to obtain a total plot yield. In each block six plots, one of each of the genotypes and the mixture were harvest in December/January 2008/09, 2010/11 and 2012/13, i.e. every two years. The other six plots were harvested in December/January 2009/10 and 2012/13, i.e. every three years. The total yields over the six years were calculated i.e. three x two-year harvests and two x three-year harvests.

This was then repeated during the (December/January) of the subsequent six years with harvests occurring in 2014/15, 2016/17 and 2018/19, i.e. in line with the previous plots being harvested every 2 years. The other plots were also continued with 3 year harvests carried out during 2015/16 and 2018/19 as with the previous six years.

2.4. Statistical analysis

All data were subject to an Analysis of Variance (ANOVA) using a Genstat® statistical package. Significant differences are presented at the P=0.05 level, unless otherwise stated.

3. Results

3.1. *Two year and three year rotation harvest stool survival*

With the two year rotation plots there was over 92% survival of stools of all genotypes in mono-plots or mixtures at each of the first three harvests however the following three harvests did reveal a drop off of survival of mainly Ashton Stott (76% survival) and subsequently the stool survival rate of the mixture (86%). All other genotypes remained above a survival of 91% with Beagle and Tora realising the best survival rates of 96% and 94% respectively **(Fig 1).**

With the three year rotation plots, there was over 94% survival of stools of all genotypes in the mono-plots and the mixtures. This pattern largely remained for the third harvest however by the fourth harvest, i.e. 12 years from planting, there was a drop off in survival of the Ashton Stott to 87% and subsequently the stool survival rate of the mixture (89%). All other genotypes remained above 92% with the best surviving genotypes being Tora and Torhild at 98% and 96% respectively **(Fig 2).**

Fig 1. Percentage number (of the cuttings originally planted in 2008) of stools still surviving at each of the six two-year harvests.

Fig 2. Percentage number (of the cuttings originally planted in 2008) of stools still surviving at each of the four three-year harvests.

How the overall survival of the plants behaved within the population is illustrated in **Fig 3**. There were only small differences between stool survival comparing the 2 vs 3 in the first six years. The ranges of stool survival were similar although there was a slight decrease in median survival and an increase in size of the first quartile. This would indicate that there was more stool death in the two-year compared to the three year harvest. This trend was also apparent after the full twelve-year cycle, with the two-year harvest period indicating a wider first quartile, second quartile and a lower median as well as average.

Fig 3. Distribution of plot survival after the first six years, the second six years and over the full 12-year cycle.

3.2. Two-year harvest period yields of each genotype and mixture after each of six harvests (2006-2018)

The yields of each genotype and mixture at each of six two-year harvests is illustrated in **Fig 4**. When harvested for the first time (2008) the highest yielding plots were Beagle, Tora and the mixture which were significantly greater than Ashton Stott and Torhild. At the second two-year harvest the lowest yielding genotype was Ashton Stott and was significantly lower than all other genotypes and mixture. The highest yielding was Tora which was significantly higher than all other genotypes. At the third harvest the highest yielding genotype was Torhild which was significantly greater than all other genotypes apart from Tora. The lowest yielding genotype was Beagle which was significantly lower than all other genotypes. The fourth harvest was similar to the second harvest with Tora performing significantly better than any other genotype except for Torhild. The lowest yielding genotype was Beagle which was significantly lower than all other genotypes. This pattern remained for the fifth and sixth harvests with Tora and Torhild performing significantly better than the others and with Beagle and Ashton Stott performing significantly worse. The mixture, having all genotypes, also often yielded well although there was no statistically significant difference between it and the higher yielding Torhild (2010, 14, 16, 18). The yield for Ashton Stott was significantly lower than all other genotypes in each of the two-year harvests except for beagle in 2012 and 2014.

Fig 4. Dry Weight Plot yield (kg) from six two-year harvests of five mono-plot SRC willow varieties and a mixture plot between 2008 and 2018. (Bar represents least significant difference (LSD) for genotypes within each harvesting period.

3.3. Three year harvest period clonal yields after each of four harvests (2006-2018)

The yields of each genotype and mixture at each of four three-year harvests is illustrated in **Fig 5.** At the first three-year harvest (2009) the yield of Tora was significantly greater than that from any of the other genotype mono-plots or from the mixtures plot except for Olof. The yield of Ashton Stott was significantly lower than that of the other genotypes except for Beagle. At the second three-year harvest (2012) the yield form the Beagle plot was significantly lower than all of the other mono-genotype plots and the mixture except for Ashton Stott. Again Tora was the highest yielding genotype. At the third harvest (2015), Olof yielded significantly higher than Torhild, Ashton Stott and Beagle while Ashton Stott and Beagle yielded significantly poorer than all other genotypes including the mixture. By the fourth harvest (2018), Torhild and Tora yielded significantly better than all other genotypes including the mixture.

Fig 5. Dry Weight Plot yield (kg) from four three-year harvests of five mono-plot SRC willow varieties and a mixture plot between 2008 and 2018. (Error bar represent the least significant difference P=0.05)

3.4. Cumulative genotype yields after six years (2006-2012)

At the end of the first six years (three two-year and two three-year harvest cycles), significant differences in genotype yields became apparent **(Fig 6).** Tora had the highest dry weight yield which was significantly higher than all the other genotypes, including the mixture. This was true for both the two-year and three-year harvesting period. Inversely, Ashton Stott performed significantly worse than the other genotypes and mixture, except Beagle, again in both the two and three-year harvesting periods.

From the point of view of harvest interval, there were significant differences in yields apparent with the Olof, Ashton Stott, Tora and Mixture, however the overall yields were very similar with the three two-year harvests cumulatively weighing 2,100 kg and the two three year harvests weighing 2,226 kg, a 6.0% increase by using the longer 3 year harvest interval

Fig 6. Total cumulative Dry Weight plot yield (kg) in 2011 of five mono-genotypes and a mixture after three 2-year harvests or two 3-year harvests (Genotype LSD ***. Harvest LSD *)

3.5. Cumulative genotype yields after 12 years (2006-2018)

The pattern for the first six years seemed to remain fairly consistent for the following six years with Tora prevailing as the highest yielding genotype being significantly greater than all the other genotypes including the mixture in both the two and three year harvesting periods. Ashton Stott 10 yielded significantly lower than all other genotypes. From the point of view of harvest interval, there were significant differences in yields apparent with all the genotypes including the Mixture. The yield of the six two year harvests cumulatively weighed 4,278 kg and the four three year harvests weighed 4,724 kg, a 10.5% increase when implementing the longer 3 year harvest interval.

The second six year harvesting period (2012 to 2018) revealed a very similar picture to **Fig 7** and in fact the yield benefit from harvesting at a 3 year interval had increased from 6.0% for the first six years to 14.8% for the second six years. Together this difference was 10.5% over the whole 12 years.

Fig 7. Total cumulative Dry Weight plot yield (kg) in 2018 of five mono-genotypes and a mixture after six 2-year harvests or four 3-year harvests (Genotype LSD ***. Harvest LSD ***)

3.6 Cumulative harvest yields of the first and second 6 year periods and the 12 year period overall

At the end of the first six years, there were very small differences in the total harvested yield between the 3 year and two year harvests. Both harvest regimes (3x2 year and 3 x 2 year) yielded a total in excess of 2 tonnes of biomass and the difference between the two harvesting regimes was less than 6% (125 kg). During the second harvesting phase however, the difference between the two harvesting regimes was almost 15% (322 kg) indicating a strong decline in yield as a result of the more frequent 2 year harvest. Overall, the whole 12 year period, the harvest yield from a three year harvesting interval was over 10% greater with a harvest yield of 4,725 kg compared to 4, 278kg with the 2 year harvest interval (**Fig 8.)**

Fig 8. Cumulative Dry Weight harvest yields during the first and second 6 year period and the full 12 year period

4. Discussion

No fertilisation (including inorganic fertilisers, sewage sludge or waste water) was applied throughout the course of this experiment. In this trial, during the first 6 years, there appeared to be very little effect of harvesting at either a two-year or a three-year interval. However during the second 6-year growth period, certain differences did emerge and this resulted in an almost 15% decline in harvested dry matter mass caused by two-yearly harvesting. This study indicates quite strongly that this is largely as a result of specific variety death in particular Ashton Stott (Fig 1 & Fig 2). This decline was considered to be largely due to its susceptibility to willow rust. The decline in this genotype also affects the survival of the mixture plot and furthermore, these effects start to become much more marked from 2012 onwards and therefore would not really be noticed in the first 6 years of harvest interval comparison.

It is also apparent that the other varieties, apart from Ashton Stott, not only presented better survival rates, but also seemed to yield consistently better when harvested at a three-year interval rather than a two-year interval. This is not as apparent during the first 6 years when only the Olof and Tora genotypes show this increase (Fig 6) however when the following 6 years are observed, it is clear that all 5 genotypes indicate this increase in yield (Fig 7). It is of interest to note the relatedness of Tora and Torhild. Torhild is Tora x Orm, the father of Tora.

In a trial conducted in New York, USA triennial and biennial harvesting resulted in significantly higher annual biomass production than annual harvesting [17]. Unfortunately these authors were unable to make direct statistical comparisons of biennial and triennial harvest cycles because trees in the two cycles were not harvested in the same year. However after one triennial and two biennial harvests they found that the triennial harvesting provided higher annual biomass than biennial harvesting. At three spacings (0.3 x 0.3 m; 0.3 x 0.9m and 0.6 x

1.1m) the odt ha^{-1} yr^{-1} were 18.3, 23.8 and 22.4 respectively for triennial harvests compared to 14.9, 17.5 and 15.9 respectively for biennial harvests [17]. A similar relationship was seen in a twelve year study conducted in Poland albeit with different willow genotypes where the effects of planting density as well as annual, biennial and triennial harvest intervals were examined. In this study the yield from the triennial harvest was significantly higher than that from the biennial and annual rotations. It was also seen that this difference increased with planting density [18]. Bullard et al. found that biennial harvesting increased yield compared to triennial harvesting, although this was correlated to planting densities for 10,000 – 111,000 plants ha^{-1} [19].

Mathematical models have also demonstrated that the rotation period for poplar greatly influences yields with the optimum rotation cycle, for yield, being 3 or 4 years [20]. It may be difficult to compare willow to poplar as planting densities tend to be widely different, as are site capture and growth patterns. Nassi *et al*. also found that the choice of harvest interval had a major impact on energy yields [21]. The energy efficiency of poplar SRC improved from annual to biennial to triennial cutting cycles and net energy yield increased from 172 to 299 GJ ha^{-1} yr^{-1}. In a separate study the thermophysical and chemical properties of SRC willow remained practically unchanged irrespective of when it was harvested during an annual harvest cycle [22].

In some situations there may be significant benefits to the grower to be able to harvest every two years. When this work was first initiated the requirement for growers in Northern Ireland was to have the opportunity to apply sewage biosolids more regularly. This more frequent application allowed for improved cash flows in conjunction with compliance with the waste management and environmental regulations. At present in Northern Ireland this method of organic waste recycling no longer occurs due to changes in sewage sludge management policy (incineration is the current solution) and imposed environmental regulations such as the Safe Sludge Matrix at the time. Harvesting the crop every second year is however a way of improving the grower's cash flow as the crop can be sold sooner once established and more frequently. The smaller stems also make the harvesting process quicker and less stressful on the harvester.

While there may be limited biological impacts on the crop by more frequent harvesting other factors will need to be considered in the management of the crop. Three as compared to two harvest events every six years will increase overall harvesting costs, especially in terms of logistics i.e. proximity to harvesting machinery. Similarly it will increase the carbon impacts associated with harvesting machinery, transport and to some extent drying & further processing. On wet sites, which are very common in Ireland, the more frequent passage of heavy machinery may have a greater adverse impact on the soil. Furthermore, research has shown that a higher proportion of bark increases the content of ash-forming elements and nutrients and as such harvesting of larger willow stems is preferable from a fuel quality perspective [23].

5. Conclusions

Harvest interval (two-year vs. three year) has a significant effect on both stool survival and total dry matter yield. Survival and yield were lower after six years, from individual genotype plots, the mixture plot and cumulatively after three two-year harvests compared to two three-year harvests. However these difference were small. The increased survival and yield were more marked and significant after a second six-year cycle. Over the total 12 years of this study the dry matter yield from the four three-year harvest intervals was 10% greater that from the six two-year harvesting regime. These difference were largely due to two genotypes, Stott and Beagle performing less well than the others. Genotype selection at time of planting is therefore critical with the incorporation of more resilient genotypes form new breeding programmes.

The yield penalty for more frequent harvesting may be commercially acceptable depending on the market for biomass. However other economic drivers will also need to be considered such as accessibility to harvesting machinery, and processing infrastructure along with higher associated fuel and carbon costs. The negative impact on survival of some genotypes may also be a factor over the total life of the plantation.

Author contributions

Chris Johnston: Writing, Resources, Formal analysis, Investigation, Writing – Original draft preparation. Alistair McCracken: Resources, Writing, Conceptualization, Review and Editing, Supervision, Project administration. Linda Walsh: Review and Editing, Formal analysis and Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Fig 1. Percentage number (of the cuttings originally planted in 2008) of stools still surviving at each of the six two-year harvests.

Fig 2. Percentage number (of the cuttings originally planted in 2008) of stools still surviving at each of the four three-year harvests.

Fig 3. Distribution of plot survival after the first six years, the second six years and over the full 12-year cycle.

Fig 4. Plot dry weight yield (kg) from six two-year harvests of five mono-plot SRC willow varieties and a mixture plot between 2008 and 2018. (Bar represents least significant difference (LSD) for Varieties within each harvesting period).

Fig 5. Plot dry weight yield (kg) from four three-year harvests of five mono-plot SRC willow varieties and a mixture plot between 2008 and 2018. (Error bar represent the least significant difference P=0.05)

Fig 6. Total cumulative plot dry weight yield (kg) in 2011 of five mono-varieties and a mixture after three 2-year harvests or two 3-year harvests (Variety LSD ***. Harvest LSD *)

Fig 7. Total cumulative plot dry weight yield (kg) in 2018 of five mono-varieties and a mixture after six 2-year harvests or four 3-year harvests (Variety LSD ***. Harvest LSD ***)

Fig 8. Cumulative harvest dry weight yields during the first and second 6 year period and the full 12 year period

Table 1: Breeder and dates of cross & release of SRC Willow Varieties used in this study

Table 2: Average Weather data

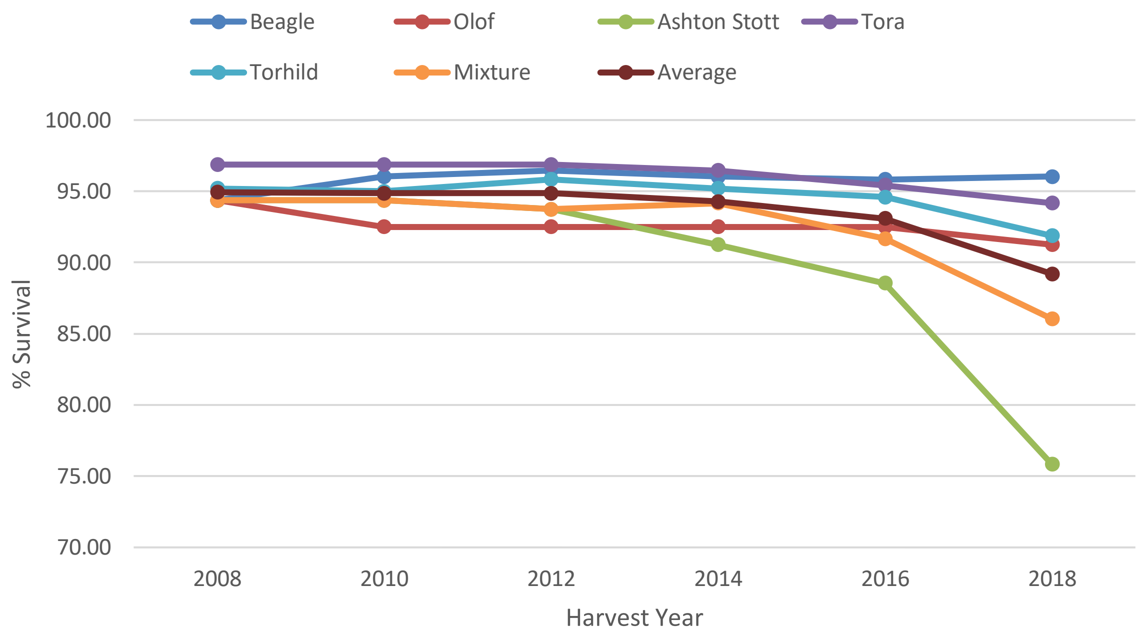


Fig 1. Percentage number (of the cuttings originally planted in 2008) of stools still surviving at each of the six two-year harvests.

(Colour for both web & print)

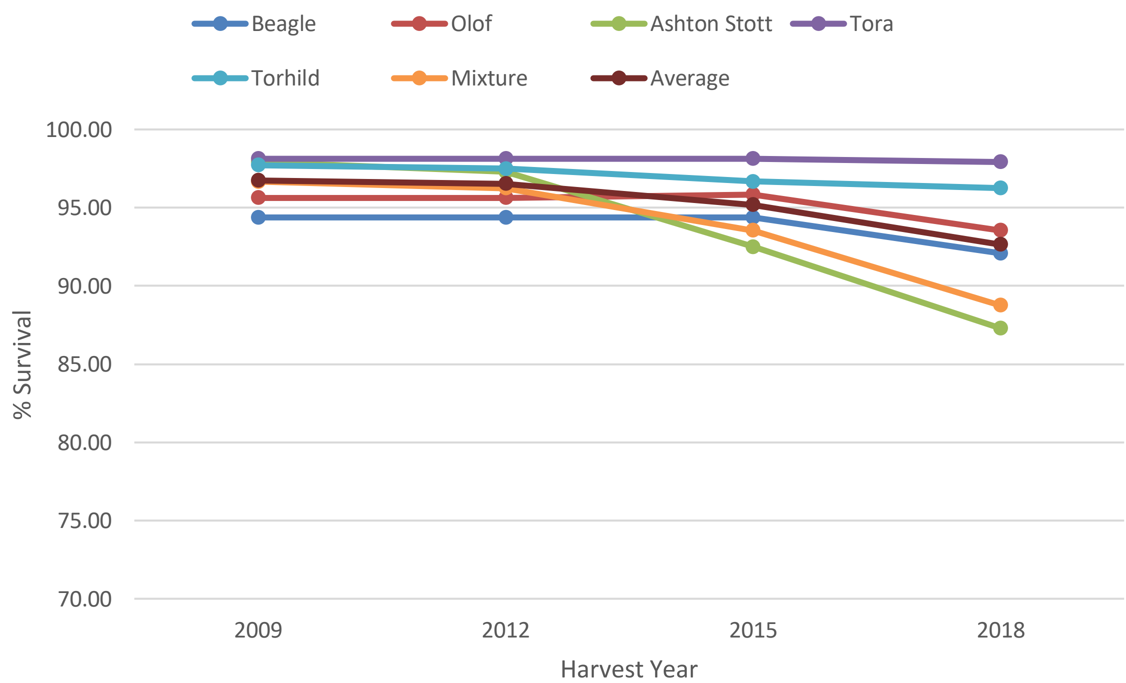


Fig 2. Percentage number (of the cuttings originally planted in 2008) of stools still surviving at each of the four three-year harvests.

(Colour for both web & print)

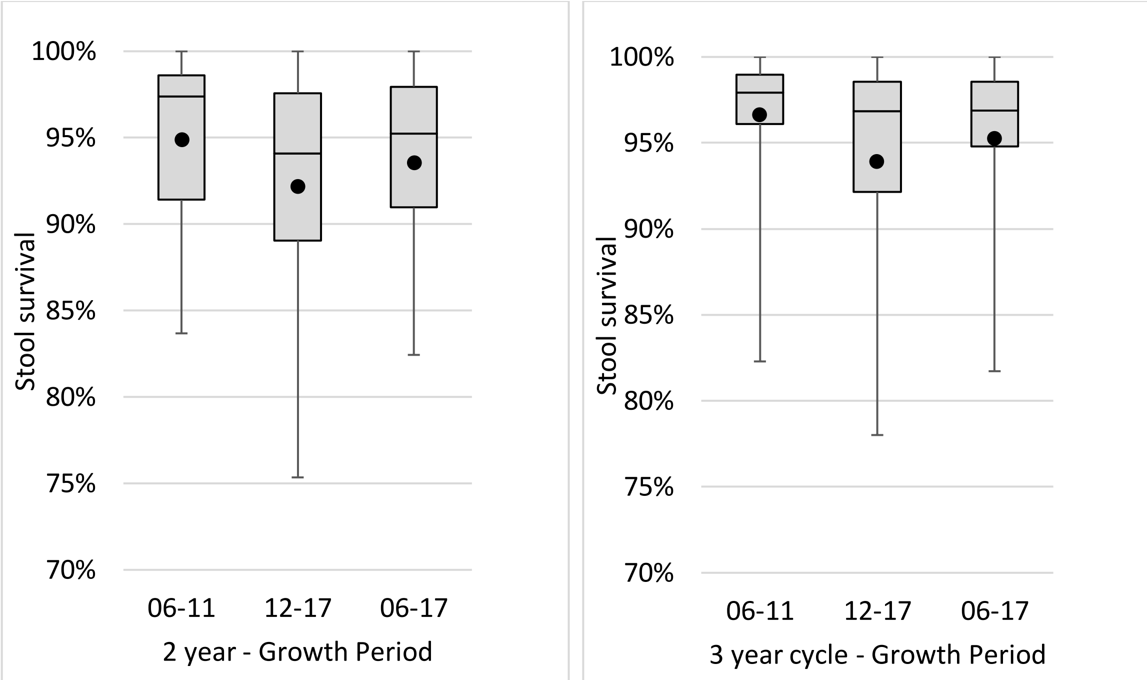


Fig 3. Distribution of plot survival after the first six years, the second six years and over the full 12-year cycle.

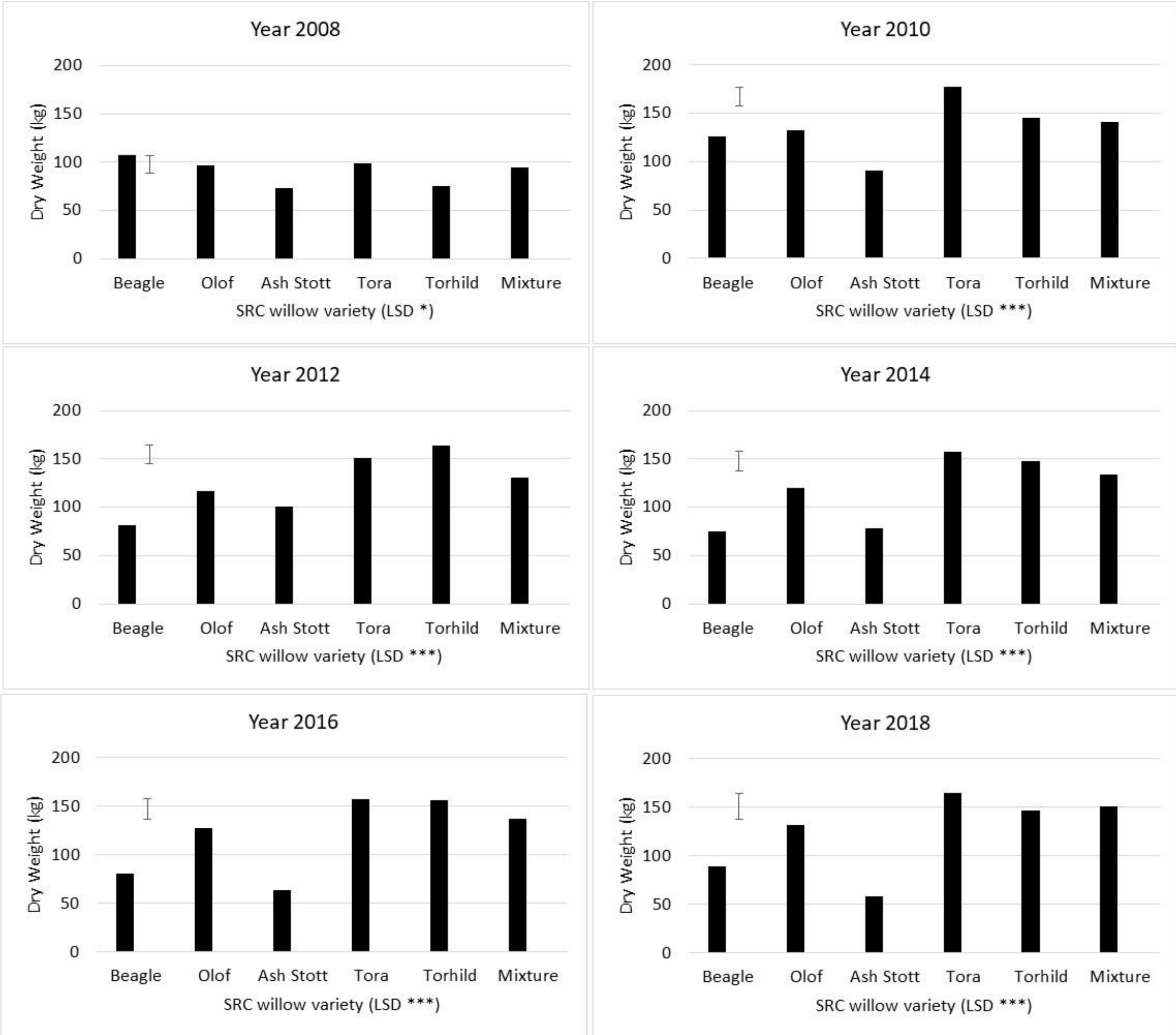


Fig 4. Plot dry weight yield (kg) from six two-year harvests of five mono-plot SRC willow varieties and a mixture plot between 2008 and 2018. (Bar represents least significant difference (LSD) for Varieties within each harvesting period.

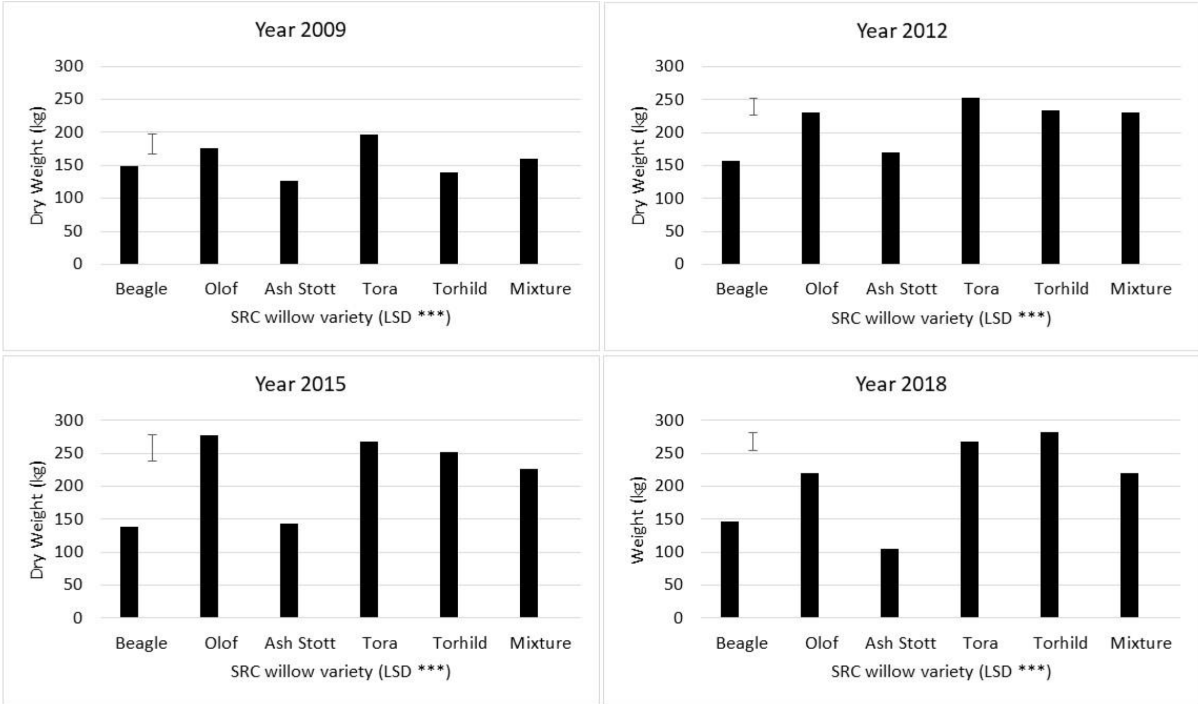


Fig 5. Plot dry weight yield (kg) from four three-year harvests of five mono-plot SRC willow varieties and a mixture plot between 2008 and 2018. (Error bar represent the least significant difference P=0.05)

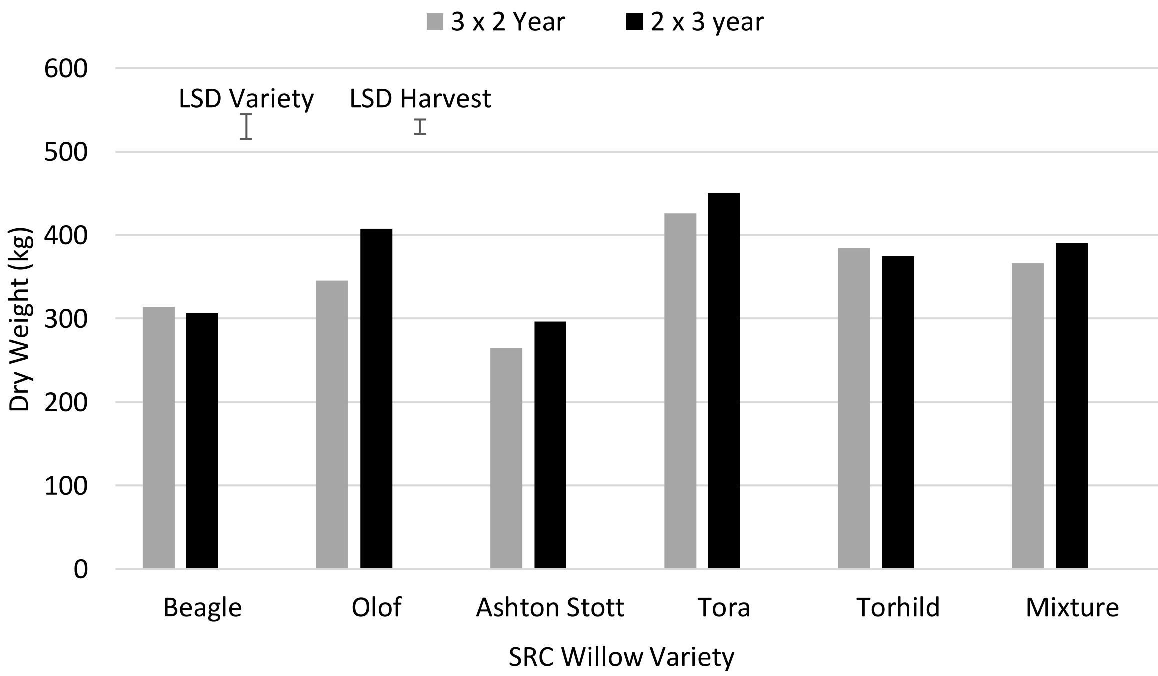


Fig 6. Total cumulative plot dry weight yield (kg) in 2011 of five mono-varieties and a mixture after three 2-year harvests or two 3-year harvests (Variety LSD ***. Harvest LSD *)

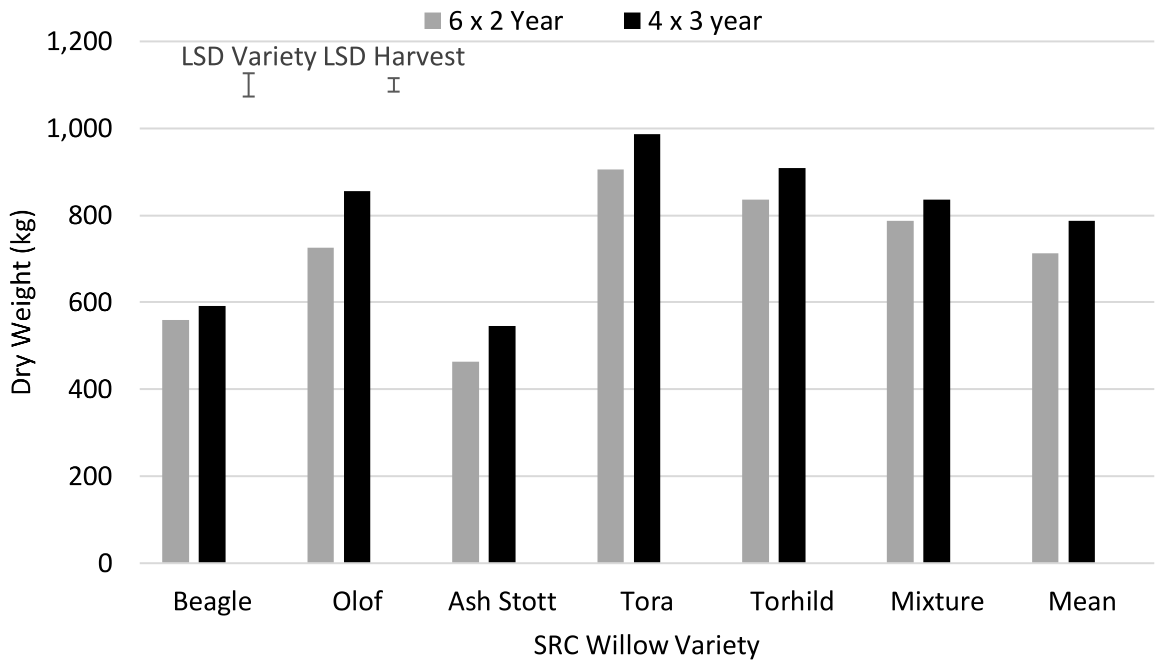


Fig 7. Total cumulative plot dry weight yield (kg) in 2018 of five mono-varieties and a mixture after six 2-year harvests or four 3-year harvests (Variety LSD ***. Harvest LSD ***)

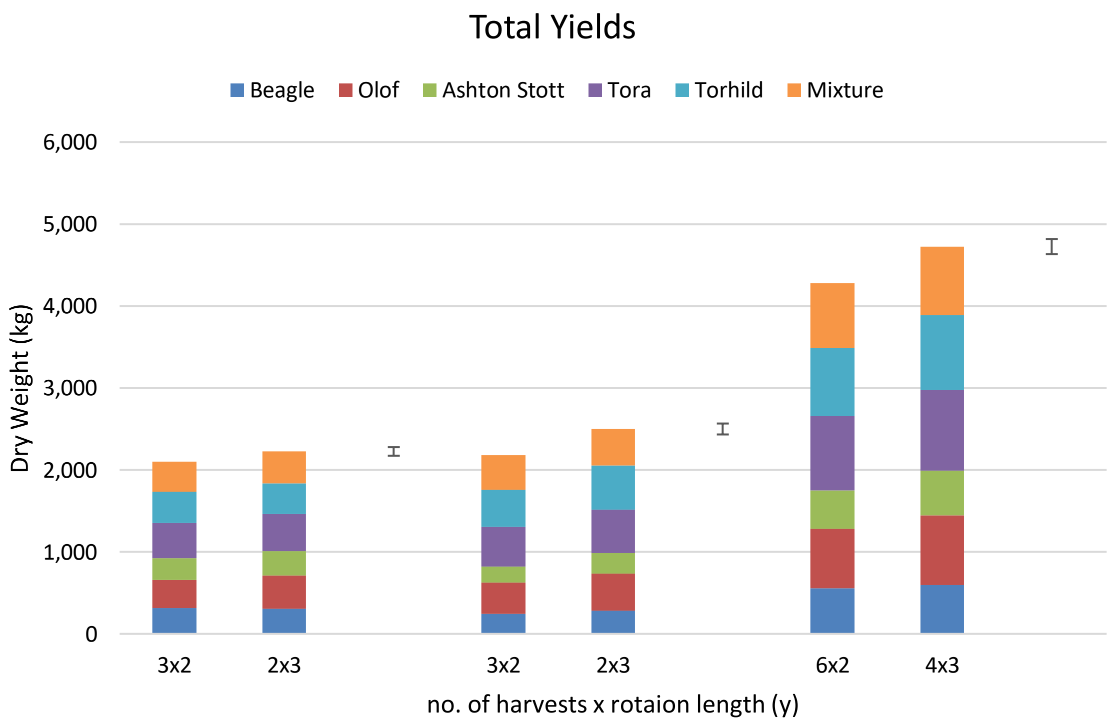


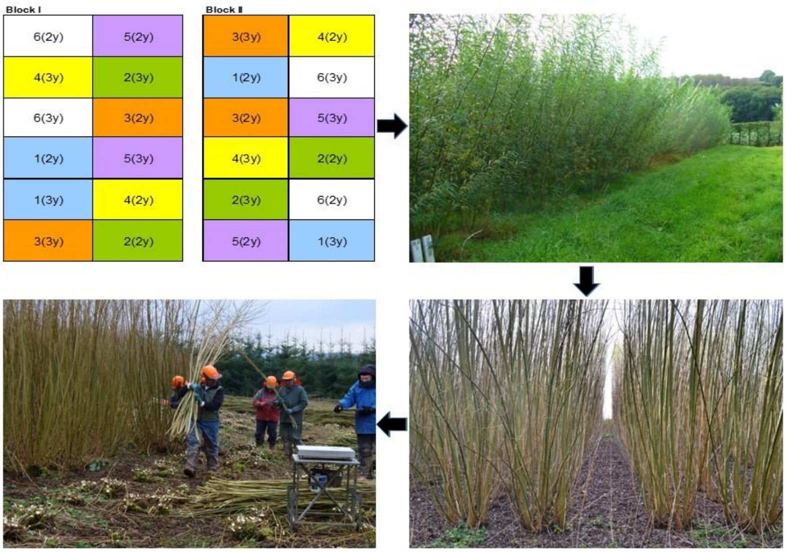
Fig 8. Cumulative harvest dry weight yields during the first and second 6 year period and the full 12 year period

Table 1: Breeder and dates of cross & release of SRC Willow Varieties used in this study

Variety	Breeder	Date of Cross	Date of Release
Beagle	European Willow Breeding Partnership	1996	2001
Olof	Svalöf-Weibull AB	1993	1998
Aston Stott	Long Ashton	1984	2001
Tora	Svalöf-Weibull AB	1991	1994
Torhild	Svalöf-Weibull AB	1993	2004

Table 2: Average Weather data

Month	Day	Night	Rain Days	Rainfall (mm)
January	6°c	2°c	18	57.8
February	7°c	2°c	19	54.5
March	9°c	3°c	19	49
April	11°c	4°c	18	43
May	13°c	7°c	22	51.7
June	16°c	9°c	22	68.2
July	17°c	11°c	25	68.6
August	17°c	11°c	26	75
September	15°c	9°c	19	54.3
October	12°c	8°c	20	69.6
November	9°c	5°c	19	69.8
December	7°c	3°c	17	55.4


Block I
6(2y)
5(2y)
4(3y)
2(3y)
6(3y)
3(2y)
1(2y)
5(3y)
1(3y)
4(2y)
3(3y)
2(2y)
Block II
3(3y)
4(2y)
1(2y)
6(3y)
3(2y)
5(3y)
4(3y)
2(2y)
2(3y)
6(2y)
5(2y)
1(3y)

Highlights

- Some varieties appear to be more resilient than others when harvested more frequently.
- 10% yield decline when harvesting more regularly over the twelve year assessment period
- Variety has more of an effect on yield that harvesting regime