Selection progress in a commercial forage breeding programme

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Abstract

We analysed historic data from the Agroscope forage crop-breeding programme. A joint analysis of plot trials installed between 1991 and 2015 was performed, revealing the performance of variety candidates produced before or during this period. Linear regression analysis between trait performance and year of production of the variety candidates was then performed. Positive response to selection was found for most traits and species. In red clover (*Trifolium pratense*), average progress in dry matter yield (DMY, sum per year) was more than double in the second compared to the first main season, which may be attributed to strong selection for increased persistence and resistance to detrimental diseases like southern anthracnose (*Colletotrichum trifolii*). In tetraploid ryegrasses (*Lolium* ssp.), progress in DMY was similar for the second and first main season, resulting in a 2.9 to 4.1% increase per decade. In contrast, in diploid ryegrasses, progress in DMY was mostly lower or insignificant. Further results for different species are presented.

Keywords: breeding programme, selection progress, dry matter yield, quality, disease resistance

Introduction

Information on breeding progress in forage crops is available from different studies analysing historical varieties (e.g. Mc Donagh *et al.*, 2016; Sampoux *et al.*, 2011), but is still scarce in terms of progress within a practical breeding programme following a given selection scheme, or for species other than perennial ryegrass (*Lolium perenne*). Here we present data from 25 years of breeding activities at Agroscope, a publicly funded forage crop breeding programme.

Materials and methods

The Agroscope forage crop-breeding programme is mainly based on phenotypic selection among spaced plants in the nursery. After open pollination among selected elite plants (using single plants directly in the nursery for red clover, using cloned plants in the polycross for grasses), half-sib (hs) progeny are grown in trials with seeded rows (SR), which are evaluated for different traits. Before flowering, all rows of hs-families with bad performance within an SR trial are eliminated. Seeds are then harvested in bulk from all positively selected hs-families of a SR trial. These syn-2 seeds harvested in a SR trial are the basis of a new candidate. All candidates produced are tested in plot trials, usually in two series sown one year apart (2 years of installation) at 3 locations, resulting in 6 testing environments. Plot trials last for 3 years (installation year, first and second main season). Different traits related to yield, quality and disease resistance are assessed (Table 1).

A joint analysis of plot trials installed between 1991 and 2015, including candidates produced before or during this period, was performed using the model

$$y_{ijn} = g_i + e_j + ge_{ij} + b_{nj} + \varepsilon_{ijn} \qquad \text{Eq. (1)}$$

where y_{ijn} represents the observed phenotype on a plot basis, g_i the genotypic effect of candidate i, e_j the effect of environment *j* (combination of location and installation year), ge_{ij} the genotype-by-environment interaction, b_{nj} the block effect nested within environment and ε_{ijn} the residual. Comparability of the different trials (=installation years) was enabled via overlapping candidates and standard varieties. Least

Table 1. Results from linear regression of trait performance on year of candidate production. Presented regression parameters are number of candidates (n), regression coefficient (b) and coefficient of determination (R^2).[a]

Trait	*Trifolium pratense*						*Lolium multiflorum*					
	diploid			tetraploid			diploid			tetraploid		
	n	b	R^2	n	b	R^2	n	b	R^2	n	b	R^2
DMY_Y1 [b]	93	0.270	0.17 **	73	0.538	0.41 **	92	0.340	0.24 **	62	0.344	0.40 **
DMY_Y2 [b]	93	0.660	0.48 **	73	1.028	0.64 **	92	0.308	0.19 **	63	0.323	0.24 **
DOM_Y1 [c]	69	-0.010	0.02 ns	58	0.055	0.01 ns	71	0.436	0.13 **	49	0.184	0.03 ns
Vig_Y0 [d]	93	0.006	0.00 ns	73	-0.008	0.05 ns	92	-0.018	0.09 **	63	-0.017	0.13 **
Vig_Y1 [d]	93	-0.036	0.27 **	73	-0.051	0.58 **	92	-0.037	0.21 **	63	-0.034	0.33 **
Vig_Y2 [d]	93	-0.098	0.53 **	73	-0.131	0.71 **	92	-0.070	0.41 **	63	-0.063	0.43 **
Persistence [e]	91	-0.135	0.59 **	73	-0.212	0.77 **	92	-0.073	0.41 **	63	-0.083	0.46 **
Winter [f]	–	–	–	–	–	–	92	-0.039	0.39 **	63	-0.028	0.32 **
Rusts [g]	–	–	–	–	–	–	91	-0.047	0.16 **	63	-0.093	0.66 **
Leaf spots [g]	81	-0.075	0.30 **	59	-0.034	0.10 *	92	-0.015	0.07 *	63	-0.037	0.33 **
Anthracnose [g]	79	-0.154	0.72 **	64	-0.242	0.79 **	–	–	–	–	–	–
Trait	***Lolium perenne* (early maturing)**						***Lolium hybridum***					
	diploid			tetraploid			diploid			tetraploid		
	n	b	R^2	n	b	R^2	n	b	R^2	n	b	R^2
DMY_Y1 [b]	106	-0.063	0.01 ns	75	0.351	0.32 **	38	0.144	0.03 ns	127	0.367	0.24 **
DMY_Y2 [b]	106	-0.037	0.01 ns	75	0.392	0.41 **	38	0.117	0.02 ns	127	0.333	0.21 **
DOM_Y1 [c]	80	0.155	0.02 ns	63	0.374	0.16 **	25	-0.045	0.00 ns	104	0.359	0.05 *
Vig_Y0 [d]	106	-0.007	0.02 ns	75	-0.016	0.09 **	38	-0.032	0.13 *	127	-0.005	0.00 ns
Vig_Y1 [d]	106	-0.018	0.08 **	75	-0.050	0.58 **	38	-0.032	0.12 *	127	-0.028	0.18 **
Vig_Y2 [d]	106	-0.027	0.14 **	75	-0.070	0.65 **	38	-0.026	0.14 *	127	-0.058	0.49 **
Persistence [e]	106	-0.036	0.16 **	75	-0.082	0.65 **	38	-0.010	0.01 ns	127	-0.084	0.43 **
Winter [f]	106	-0.014	0.05 *	75	-0.011	0.04 ns	38	-0.001	0.00 ns	127	-0.013	0.07 **
Rusts [g]	106	-0.100	0.48 **	75	-0.075	0.59 **	36	-0.067	0.32 **	127	-0.030	0.17 **
Leaf spots [g]	106	-0.028	0.17 **	75	-0.038	0.35 **	38	-0.011	0.04 ns	127	-0.048	0.26 **

[a] *, ** indicate significance at the 5% and 1% level, respectively. ns = not significant.

[b] DMY_Y1 and DMY_Y2 = sum of dry matter yield [dt ha^{-1}] of the first and second main season, respectively.

[c] DOM_Y1 = digestible organic matter [g kg^{-1}DM] from all cuts of first main season.

[d] Vig_Y0, Vig_Y1 and Vig_Y2 = vigour rating (1 = good, 9 = bad), average over all cuts in establishment year, first main season and second main season, respectively.

[e] Persistence = persistence rating (1 = high persistence, 9 = low persistence) at end of second main season.

[f] Winter = winter damage rating (1 = no damage, 9 = high damage), also including occurrence of snow mould;

[g] Rusts, Leaf spots and Anthracnose = rating of disease infestation (1 = no infestation, 9 = highly infested) of rusts (mainly caused by *Puccinia coronata*), leaf spots and southern anthracnose (*Colletotrichum trifolii*).

square means were predicted for every candidate. Linear regression analysis was then performed to assess the association between trait performance and production year (i.e. year of installation of SR trial) of the candidates.

Results and discussion

For diploid (2×) and tetraploid (4×) red clover (*Trifolium pratense*), average yearly progress in dry matter yield (regression coefficient b, measured in dt ha^{-1} y^{-1}), was approximately double for the second compared to the first main season (Table 1). The same pattern of increased progress for the second main season was also observed for plant vigour, a trait that was not significantly improved for the installation year. One reason for this observation is that the breeding material has been selected for resistance against detrimental diseases like southern anthracnose (*Colletotrichum trifolii*) that started occurring during this period (Schubiger *et al.*, 2003). This is highlighted by high R^2 values for persistence and southern anthracnose.

For 4× Italian (*Lolium multiflorum*), perennial (*L. perenne*) and hybrid ryegrass (*L. hybridum*), progress in DMY was similar among species and main seasons, ranging from 0.323 to 0.392 dt ha^{-1} y^{-1}. This corresponds to approximately 3% increase per decade (Table 2), which is similar (Sampoux *et al.*, 2011) or somewhat lower (McDonagh *et al.*, 2016) compared to earlier studies. No significant breeding progress was observed in the 2× forms of *L. perenne* and *L. hybridum*. For *L. hybridum* this can partly be explained by the low breeding activities (n=38). In 2× *L. perenne*, breeding activities are higher (n=106), so selection pressure for DMY was apparently too low. Reasons here for might be low correlation between vigour of spaced parental plants, a main selection criterion, and vigour or yield of offspring in swards (Kempf *et al.*, 2019). Progress in DMY of 2× *L. multiflorum*, a relatively short-lived species, was significant. By reducing susceptibility to winter damage (b=–0.039, R^2=0.39) and improving resistance to detrimental diseases like bacterial wilt (*Xanthomonas translucens pv. graminis,* data not shown), persistence of this material was improved (b=–0.073, R^2=0.41). Therefore, progress in DMY is probably an indirect consequence of improved plant survival.

Digestibility of organic matter (DOM) is not being used as a selection criterion in spaced plants in the nursery or in SR trials for the presented species, but selection is only performed among candidates. As consequence, no to very low selection progress could be observed for this trait in all species. In contrast, resistance to diseases like rusts undergoes a high selection pressure in the nursery and in SR trials, and a significant selection progress could therefore be observed for all grass species.

Table 2. Average selection progress in % per decade in dry matter yield for *Trifolium pratense* (Tp), *Lolium multiflorum* (Li), *L. perenne* (Lp) and *L. hybridum* (Lh).

	Species							
Trait	**Tp (2×)**	**Tp (4×)**	**Li (2×)**	**Li (4×)**	**Lp (2×)**	**Lp (4×)**	**Lh (2×)**	**Lh (4×)**
DMY_Y1	1.70%	3.20%	2.90%	2.90%	–	3.10%	–	3.20%
DMY_Y2	5.30%	8.00%	2.90%	3.00%	–	4.10%	–	3.30%

Conclusion

Significant breeding progress has been achieved during the past 25 years. Disease resistance and persistence show a higher response to selection on spaced plants in the nursery. This is why progress for these and related traits like yield in the second main season (DMY_Y2) showed more progress than yield *per se* and early development (e.g. Vig_Y0).

References

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