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Persistency of Grass and Legume Varieties Bred in the Warm Region of Japan

— Achievements of plant breeding revealed in the collaborative research between Japan and France —

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Abstract

Field performance of recently bred varieties and leading varieties of three forage species, *Dactylis glomerata, Festuca arundinaced* and *Medicago sativa* was evaluated in Japan and France, and the results revealed different aspects of plant breeding in the two countries. Japanese varieties bred in the warm region displayed a high yield in both countries and superior persistency under the humid conditions prevailing in Japan. These differences in persistency were evidenced by the larger loss of stands of French varieties in later years, caused mainly by weed invasion during summer and autumn. Japanese varieties displayed a higher competitive ability with weeds. It was concluded that through selection for higher yield and regrowth during shortday seasons under humid conditions, Japanese population acquired a superior competitive ability, and varieties bred in Japan for higher yield became persistent also as a result of adaptation to the climatic conditions of Japan. Varieties from France displayed a high resistance to rust in both countries, and evaluation in Japan confirmed the high palatability of a tall fescue variety of France. The emphasis of breeding work on forage quality in France contrasted with that in Japan and the history of forage use seemed to be an important factor for the differences.

Discipline: Grassland
Additional key words: orchardgrass, tall fescue, alfalfa, regrowth, competitive ability

Introduction

Production of grasses and legumes for forage use in Japan has increased in the past 40 years, and new varieties have been developed through breeding work in research stations under the national forage plant breeding programs. Many varieties have been bred by using ecotypes of Japan, but the introduction of foreign germplasm accessions has played an important role in recent breeding work when they were combined with Japanese ecotypes.

France has a long history of using grasses and legumes and varieties from France have been used as breeding materials in many countries of the world. In Japan also, varieties from France have been utilized as materials for developing new varieties. Evaluation of varieties bred in both countries in relation to the climatic conditions and historical background was considered to have a high significance for the development of breeding work and research in forage plants.

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Table 1. Comparison of dry matter yield of orchardgrass varieties depending on treatments and years (NGRI)

Variety name	Sum of 1-3 yrs[a]		1988/1987 (%)		Range (kg/a)[b]		Stem rust[c]	
	St	Fr	St	Fr	St	Fr	1987	1988
Varieties from NGRI, warm region of Japan								
Nakei-20	363.6	377.6	102	77	10.9	39.0	1.8	2.0
Akimidori	368.9	396.7	108	78	16.1	32.8	2.0	2.0
Aonami	365.5	313.0	108	72	9.2	34.6	3.0	3.0
Makibamidori	375.0	340.0	100	65	3.0	46.1	3.0	2.5
Varieties from INRA, France								
Lude	373.4	322.8	93	56	20.5	62.2	1.0	1.0
Prairial	312.6	336.2	84	64	31.8	47.0	1.0	1.5
Lucyle	332.9	291.6	88	61	28.1	52.1	1.0	1.5
Lutetia	329.2	331.5	77	55	46.4	66.9	1.3	1.0
Varieties from Hokkaido NAES, cool region of Japan								
Kitamidori	353.6	324.2	107	70	8.5	42.9	4.0	3.0
Okamidori	322.5	314.5	101	69	4.0	23.5	4.5	1.0

a): Dry matter yield is expressed in kg/a.
Cutting intervals: St = Standard, 4 cuttings per year; Fr = Frequent, 5 or 6 cuttings per year.
b): Range of yearly variations among 3 years.
c): Degrees of disease occurrence; 1 = no occurrence or very slight - 9 = very severe.

As a part of the joint research project between Japan and France under the title of "Genetic Resources and Plant Breeding", recently bred varieties and leading varieties were exchanged and their performance was investigated in both countries. This paper presents the information derived from the analysis of data obtained for 3 species, orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea Schreb.*) and alfalfa (*Medicago sativa* L.).

Performance of varieties of orchardgrass (*Dactylis glomerata* L.)

In Japan, orchardgrass has been used as one of the major perennial pasture plants in temperate and cool regions since the Meiji era. Some of the foreign varieties were acclimatized in Japanese environments and became ecotype populations of the areas[2,3]. In the warm region of central Honshu and the cool region of Hokkaido, several varieties have been bred simply using these ecotypes; their combinations with introduced varieties were used in later years. In the present evaluation, 6 varieties from Japan and 4 varieties from France were compared at the National Grassland Research Institute (NGRI), Nishinasuno, Japan. In France, 8 varieties from Japan, 3 from France, 2 from Yugoslavia and 2 from Canada were compared at the Institute National de la Recherche Agronomique (INRA), Lusignan.

Table 2. Duration of sunshine hours in Nishinasuno, Japan

Month	Sunshine hrs		10 years' mean
	1987	1988	
April	253	238	235
May	217	233	256
June	207	135	199
July	168	85	190
August	160	171	209
September	153	86	163
October	172	177	188

1) Evaluation of performance at NGRI, Nishinasuno, Japan

Varieties were evaluated during a period of 3 years under two different cutting intervals, standard and frequent. Significant differences were recognized in dry matter yield throughout the 3 years between varieties under both treatments. However, the most striking difference between variety groups (Japan vs. France) appeared in the yield ratio of 1988/1987 (Table 1). Due to the very small number of sunshine hours from June to September in 1988 as shown in Table 2, varieties from France displayed a severe reduction of yield, nearly half of that of the previous year under frequent cutting, while the Japanese varieties showed smaller decreases and no reduction

under the standard treatment. Range of the yearly yield variations among the 3 years was lower for the Japanese varieties under the standard treatment, revealing their superior stability in yield performance compared with the French varieties.

Varieties from France displayed a distinctly high resistance to stem rust *Puccinia graminis*, as compared with those of Japan. They showed a higher resistance to powdery mildew, too.

From the summer of 1988, invasion of weeds became apparent in the experimental plots and was more severe under the frequent cutting treatments (Table 3). As the growth of orchardgrass is vigorous under longday conditions, all the varieties were able to compete well with weeds in spring, but during summer and autumn, the seasons with shorter daylength, weed invasion caused losses of orchardgrass stands, which showed a high correlation with weed percentages (Fig. 1). Degree of weed invasion was lower in Japanese varieties than in French varieties under both treatments.

Varieties bred at NGRI displayed a higher regrowth vigor during shortday periods compared with those from France and Hokkaido. In the

Table 3. Weed invasion, regrowth vigor and persistency of orchardgrass varieties under two treatments (NGRI)

Variety name	S-EA weed[a]		Regrowth[b]		Stand loss % in last 2 yrs[c]			
	St	Fr	St	Fr	St – 4th yr	– 5th yr	Fr – 4th yr	– 5th yr
Varieties from NGRI, warm region of Japan								
Nakei-20	30.3	63.6	6.3	7.0	2.9	6.3	13.0	20.0
Akimidori	25.9	65.9	6.5	6.5	0.9	1.1	10.1	11.1
Aonami	31.8	68.5	3.8	4.3	5.5	11.8	10.2	10.1
Makibamidori	25.4	49.4	6.0	6.5	1.1	1.9	9.7	9.6
Varieties from INRA, France								
Lude	44.9	83.2	3.3	3.3	16.0	17.4	41.3	47.8
Prairial	43.0	73.8	4.3	4.8	9.7	13.8	34.0	36.3
Lucyle	46.6	87.3	3.5	2.8	20.9	24.1	41.5	47.8
Lutetia	53.3	87.1	2.0	3.0	17.2	29.8	27.0	32.3
Varieties from Hokkaido NAES, cool region of Japan								
Kitamidori	37.8	67.8	4.0	4.5	3.3	4.3	12.1	12.5
Okamidori	39.2	66.4	3.8	4.8	15.3	14.0	20.2	20.3

a): Weed percentages in summer and early autumn (means of 1988 and 1989).
b): Regrowth vigor in summer; 1 = very poor – 9 = very good.
c): Percentages of bare areas due to loss of orchardgrass stands at the end of the 4th and 5th years.

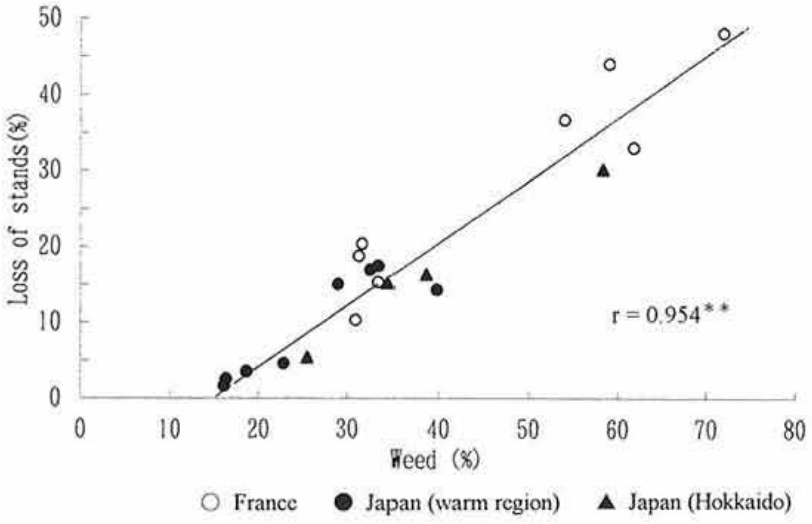

Fig. 1. Relationship between loss of orchardgrass stands at the end of the 3rd year and weed percentage in autumn (NGRI, 1989)

investigation of stand loss of orchardgrass in the 4th and 5th years (Table 3) as an indicator of persistency of varieties, marked differences between variety groups were recognized. Since no severe occurrence of diseases was observed, loss of stands was considered to be mainly due to competition with weeds. Varieties from NGRI which showed a high regrowth vigor, seemed to have a high competitive ability with weeds, indicating their superior persistency in the warm region of Japan.

2) Evaluation at INRA, Lusignan, France

The yield of the varieties from warm regions of both countries was higher in Lusignan, and the 2-year sum of green forage yield for the variety group from France was the largest. Varieties from the warmer region of Japan showed a high yield in the autumn of 1987 and early spring of the next year. In the autumn of 1988, since the occurrence of rust was very severe, green forage yield of susceptible varieties was reduced and a high correlation was obtained between the green forage yield (2-year sum) and the degree of stem rust occurrence (Fig. 2). French varieties were highly resistant whereas the varieties from cooler regions, Hokkaido and Canada, were very susceptible to stem rust.

3) Comparison of climatic conditions between the breeding stations

The three breeding stations where most of the materials of this study were bred differed considerably in climatic conditions (Fig. 3). The temperature in Nishinasuno is more similar to that in Lusignan than Sapporo. The results in the two countries indicated that varieties bred in warm regions of Japan and France have a higher yielding potential even in late autumn compared with those of Hokkaido and Canada. However, precipitation during summer and early autumn differs drastically between Nishinasuno and Lusignan. These differences may result in a difference between the variety groups: French varieties give a low yield under low sunshine and humid conditions and their competitive ability with weeds is weak, while Japanese varieties are susceptible to rust which occurs severely under the summer–autumn conditions of Lusignan.

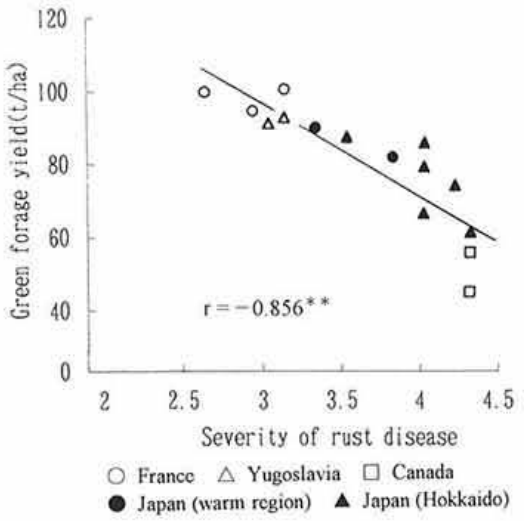

Fig. 2. Regression of green forage yield of orchardgrass on rust occurrence (INRA, 1987–1988)
Severity: 1 = no or slight occurrence – 5 = severe occurrence.

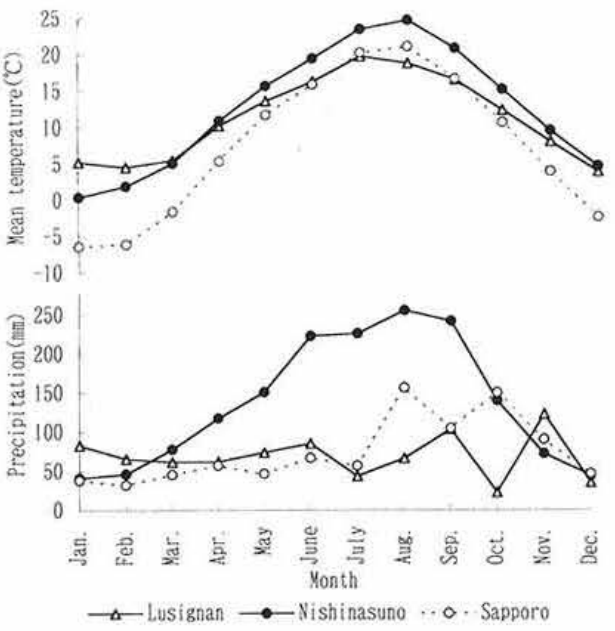

Fig. 3. Monthly mean temperature and precipitation in breeding stations of Japan and France

Concerning the breeding materials, ecotypes adapted to domestic conditions were mainly used in both countries. Although the time from introduction of orchardgrass is shorter in Japan than in France, differentiation of ecotypes with high regrowth vigor and persistency was reported[2,3]. The high persistency of the Japanese varieties bred at NGRI may be due to selection during acclimatization of these ecotypes, as well as breeding work at NGRI.

Performance of tall fescue varieties (*Festuca arundinacea*)

Tall fescue as forage in Japan is now grown on pastures in warmer regions and also used as cover-

Table 4. Dry matter yield and other characteristics of tall fescue varieties (NGRI)

Variety name	DM yield (kg/a)			Regrowth[a]		Weed % [b]	Loss % [b]	Flexibility[c]		Crown rust
	1-3 yrs	4-5 yrs	Range	1988.7.	1990.8.	1990.10.	1991.12.	1988	1989	
Varieties from Kyushu NAES, warm region of Japan										
Nanryo	386.3	224.7	24.8	6.3	7.0	14.6	0.0	4.7	4.5	1.3
Varieties from France										
Manade	390.2	207.4	37.9	5.7	5.3	20.1	4.6	3.2	2.7	1.3
Lubrette	313.7	169.7	34.7	3.0	2.3	47.0	13.4	1.0	1.0	1.1
Clarine	331.9	170.5	42.5	4.3	4.0	40.0	12.7	3.7	3.2	1.5
Varieties from Hokkaido NAES, cool region of Japan										
Yamanami	328.4	173.6	36.9	4.0	4.3	59.3	3.7	3.7	3.5	4.1
Hokuryo	350.3	169.9	46.5	3.0	3.3	58.7	12.6	3.3	2.8	1.2

a): Regrowth in summer; 1 = very poor - 9 = very good.
b): Weed percentages and stand loss percentages due to weed invasion, etc.
c): Scores of leaf flexibility (soft to hard) judged by hand; 1 = flexible - 5 = hard.

plants on the roadsides of newly cleared lands to prevent soil erosion. In the present study, 6 varieties were used commonly in both countries: 3 bred in Japan, and 3 bred in France. Manade, an old variety registered in 1957, was included in the materials as a variety now widely used in France.

1) Evaluation at NGRI, Nishinasuno, Japan

Significant differences between the varieties were recognized throughout the 5-year period. Manade selected from ecotypes of southwestern France was the best in the first 3 years, but in the last 2 years, Nanryo which was bred at Kyushu National Agricultural Experiment Station showed the highest yield. Nanryo exhibited the smallest range of variations among years, indicating a high stability in yield performance (Table 4). Nanryo differed from other varieties by its superior regrowth vigor in summer, and the invasion of weeds in summer and autumn was negligible. Varieties from Hokkaido suffered from invasion of weeds and their persistency was nearly the same as that of the varieties from France. Greenness in early spring and the last cutting (autumn) percentage were higher in Nanryo and Manade, suggesting that these varieties have a higher potential of growth under short daylength than other varieties.

Intake of harvested fresh matter by sheep which reflects the palatability of varieties was investigated in 2 years and Lubrette bred in Lusignan was the highest in this character (Fig. 4). The high palatability of the variety Lubrette was developed by selection for leaf flexibility in Lusignan[4]. The flexibility of leaves of this variety which contributed to preference by animals was also confirmed through soft-

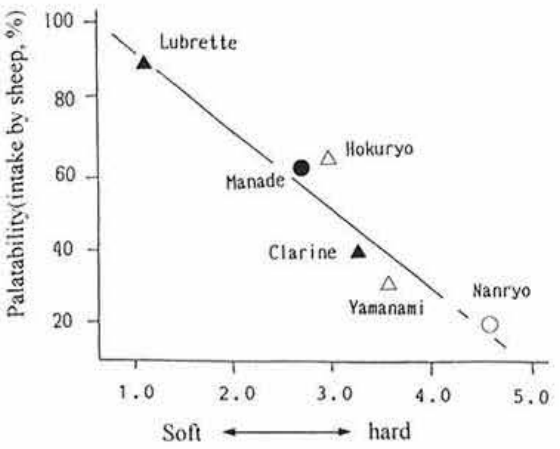

Fig. 4. Palatability and leaf flexibility of tall fescue varieties (NGRI, 1989)

ness estimated by hand. Resistance of Lubrette to crown rust *Puccinia coronata*, which affects animal preference, was also high. Yamanami, one of the Japanese varieties, was severely damaged by this disease.

2) Evaluation at INRA, Lusignan, France

Dry matter yield was investigated for 3 years including the seeding year, 1986. Marked differences in yield between the varieties were recognized in February and March when seasonal changes were compared (Fig. 5), indicating the outstanding growth of Nanryo and Manade, which were bred in the warmer regions. Nanryo gave the highest total dry matter yield of 3 years and Hokuryo the lowest, and the varieties of France were intermediate between the two.

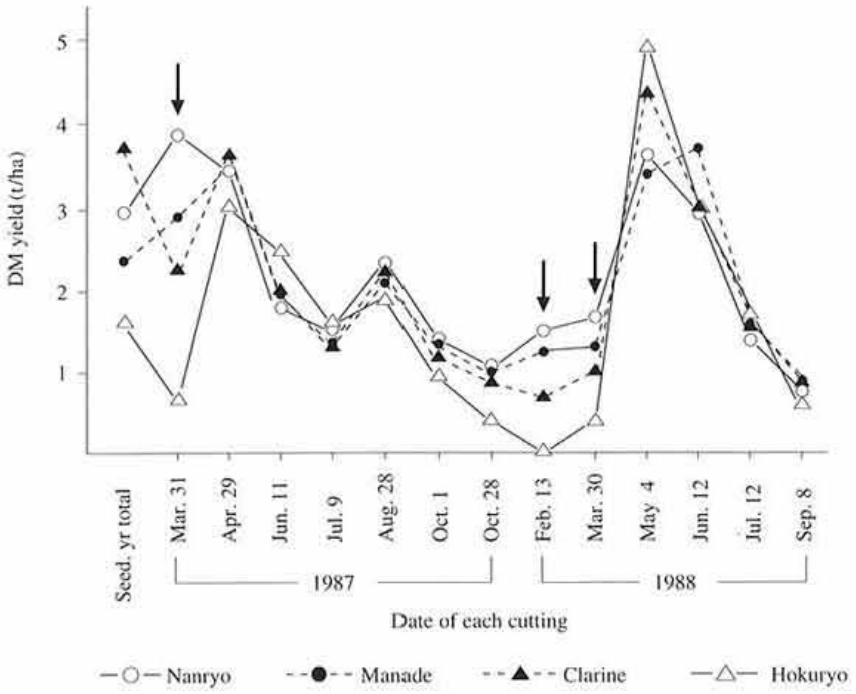

Fig. 5. Seasonal change of dry matter yield of tall fescue varieties in Lusignan (INRA, 1986–1988)

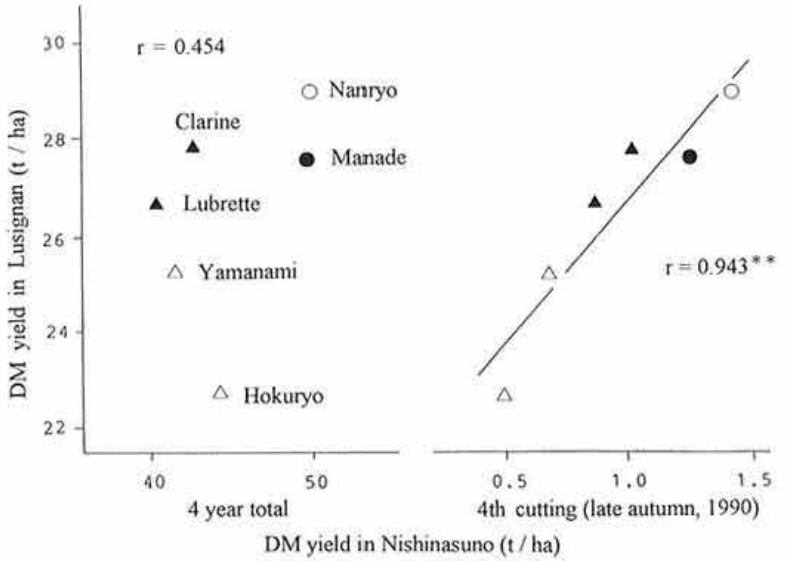

Fig. 6. Correlation of dry matter yield between Lusignan (3 years total, INRA) and Nishinasuno (4 years total and late autumn, 1990, NGRI)

As for diseases, varieties were evaluated under spaced planting conditions and all the Japanese varieties showed a lower resistance to rust, *Puccinia graminis*, than the French varieties.

Although the correlation of total dry matter yield between the two locations was not high, total yield at INRA, Lusignan, was highly correlated with the 4th cutting yield of 1990 at NGRI, Nishinasuno, as shown in Fig. 6. The temperature during the late autumn of 1990 in Nishinasuno was high and the potential difference of growth under short daylength was revealed under this unusually warm climate; high performance of Nanryo in France may be due to the regrowth ability acquired by selection during the humid and warm autumn season in Kyushu, southern Japan.

Performance of alfalfa varieties (*Medicago sativa*)

Use of alfalfa is increasing in Japan in response to the demand for quality forages. Alfalfa production in the warm region of Japan had been unsuccessful previously because of the humid climatic conditions. Recently, however, advanced dairy-farmers have started to grow alfalfa using varieties newly bred in Japan. Two varieties bred at Aichi-ken Agricultural Research Center (AARC) are mostly used in the warm regions. The performance of these 2 varieties and one bred at Hokkaido NAES was evaluated and compared with that of varieties from France and other countries.

1) Evaluation at NGRI, Nishinasuno, Japan

Two varieties bred at AARC, Natsuwakaba and Tachiwakaba, showed a higher dry matter yield throughout the 5-year period. Reduction in the 2nd year, the year with low sunshine, was remarkable in foreign varieties, while Tachiwakaba from AARC maintained nearly the same yield in 1988 (Table 5). The yield of this variety and Natsuwakaba remained higher than 70% of that of the first year even in

Table 5. Dry matter yield and persistency of alfalfa varieties (NGRI)

Variety name	DM yield (kg/a)		1988 /1987	5-Y /1-Y[a]	Regr. coef.[b]	Regrowth		Weed % in Aug.		Stand loss %[c]	
	1-3 yr	4-5 yr				1988	1989	1990	1991	1990	1991
Varieties from AARC, warm region of Japan											
Natsuwakaba	339.7	206.6	83	78	−4.86	7.7	8.0	30.4	29.8	16.4	33.8
Tachiwakaba	369.3	203.0	98	74	−7.54	7.0	8.0	27.9	35.3	7.7	21.4
Varieties from France											
Magali	238.2	110.4	78	51	−9.85	5.0	5.0	60.5	63.3	55.2	82.8
Lutece	285.7	89.2	68	32	−19.52	1.3	3.7	55.4	74.6	64.6	87.4
Orca	326.1	84.2	87	27	−22.14	3.0	4.0	62.6	80.5	63.2	90.3
Varieties from Sweden and cool region of USA											
Vertus	304.9	102.9	77	33	−18.49	2.7	4.3	58.2	77.1	61.6	83.8
Thor	302.0	71.1	74	20	−24.47	1.7	2.0	62.7	81.3	72.3	89.4
Varieties of Hokkaido NAES, cool region Japan											
Kitawakaba	300.4	113.8	87	41	−15.86	4.0	4.0	56.5	71.2	43.4	79.6

a): Percentage: 5th year yield/1st year yield.
b): Regression coefficient of the dry matter yield on the harvested year.
c): Percentages of bare areas due to loss of alfalfa stands at the end of each year.

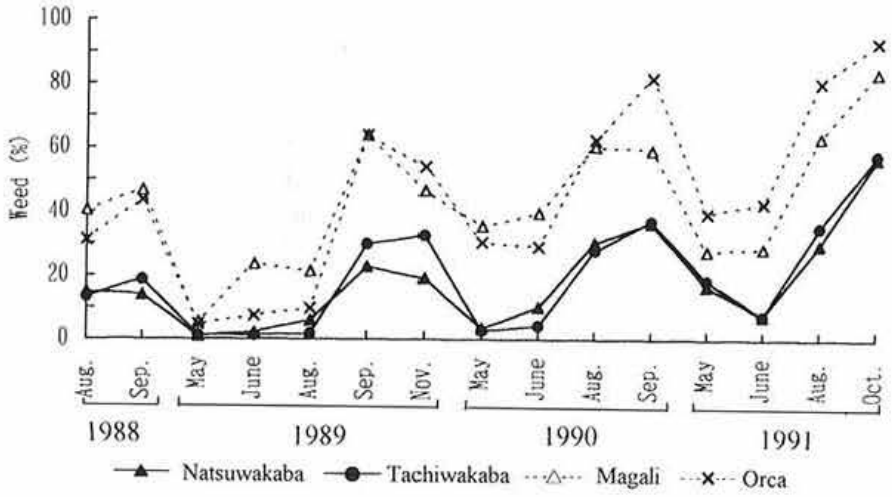

Fig. 7. Differences in weed percentage among alfalfa varieties depending on years and cutting seasons (NGRI, 1988-1991)

the 5th year. Regression coefficients of dry matter yield on years, an indicator of persistency, revealed clear differences between the varieties, and these varieties from AARC demonstrated a superior persistency under the highly humid conditions of Japan. On the contrary, yield reduction in the foreign varieties was very large in the 4th and the 5th years.

These changes in yield with the lapse of time seemed to be caused by the loss of alfalfa stands. Under the highly humid summer conditions of Japan, weed invasion is one of the most serious problems for alfalfa. In our field evaluation, significant differences in weed percentages were recognized between varieties from the 2nd year until the 5th year (Fig. 7). The differences were more pronounced in the later years, especially during summer and autumn. Two varieties from AARC, Aichi, Japan, showed a distinctly higher regrowth vigor (Table 5), and exhibited lower weed percentages consistently. As the loss of stands was strongly correlated with weed invasion (coefficients of determination r^2 ranged between 0.72 and 0.88), the superior persistency of the varieties from AARC seemed to be due to their superior competitive ability with weeds. Appropriate cutting intervals, however, should be applied to attain a high persistency, as reported previously based on the studies of cutting frequency carried out at AARC[1].

2) Evaluation at INRA, Lusignan, France

Green forage yield was evaluated during a period of 3 years under sward rows and spaced planting conditions. Tachiwakaba and Natsuwakaba 139R1 (seed increase of Natsuwakaba using 139 roots) were compared with Europe, a leading variety which has been widely used in France. Natsuwakaba gave a higher yield than Europe in the 3rd and 4th cuttings (Fig. 8) in 2 years, although the total yield was slightly lower. Under spaced planting conditions also, Natsuwakaba showed better growth in shortday periods in France. However, the Japanese varieties were susceptible to nematodes, which are one of the important pests in France but are not observed under the humid conditions of Japan.

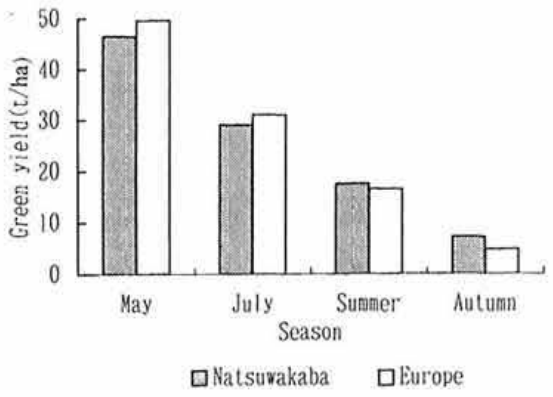

Fig. 8. Seasonal distribution of green forage yield of alfalfa varieties in Lusignan (INRA, 1989-1990)

Conclusion

1) Effects of climatic conditions of the breeding stations on persistency of varieties

Higher regrowth vigor and competitive ability under short daylength were displayed by varieties bred in the warmer regions of Japan as compared with those bred in France for the 3 species. In the warmer region of Japan, temperature and precipitation are high enough to allow for luxuriant growth of grasses and legumes during the shorter daylength seasons of summer and autumn, and selection for better regrowth was effective. In France, on the contrary, precipitation is too low during these seasons to allow for good growth, making selection ineffective. In Hokkaido, early decrease of temperature in autumn is the limiting factor for growth under short daylength. It is concluded, therefore, that the selection of plants and modification of populations to improve regrowth had actual effects under the humid environment of Japan which is conducive to weed growth even during the shorter daylength seasons.

These results indicate another important implication about selection. In contrast to grain crops, selection in forage grasses and legumes is directed toward higher vegetative growth; selected plants give higher allocation of resources to vegetative growth than to reproductive growth. Reproduction and survival of a plant usually involve a trade-off relationship. If this relationship is controlled genetically, higher persistency can be achieved by changing the direction of resource allocation to survival rather than to reproduction. Persistency may be achieved even if the evaluation for selection covered a short period of 1 or 2 years, when selection was repeated for a number of generations as was the case in the breeding of the Japanese varieties. In grassland agriculture, persistency is an important characteristic, especially in the future due to the increasing importance of sustainability in agriculture. However, selection criteria have not been yet developed. Our results suggest that selection for persistency in forage plants can be effective by selecting for higher resource

allocation to vegetative growth in the field. It must be emphasized that the selection under field conditions in Japan resulted in high competitive ability which is associated with persistency under the humid climate.

2) Importance of breeding objectives

Varieties of the two grass species bred in France displayed a high resistance to rusts in both countries. The occurrence of the diseases was observed in both countries, but most of the varieties from Japan were more susceptible than those from France. The difference may be ascribed to the severity of occurrence and virulence of the fungi. In France, however, rust is considered to be important as it affects the palatability of grasses, and strong selection for resistance has been carried out. Moreover, for grasses with a low palatability such as tall fescue, the animal preference or palatability has been an important breeding objective and methods for testing palatability were studied[5]. Evaluation of quality of forage plants, efficiency of nutrient use such as digestibility, intake ability and milk production have been of great concern in the breeding work of grasses in France[6]. In Japan, on the contrary, selection was directed primarily toward higher yield, followed by disease resistance, and palatability was not evaluated at all in the selection procedures. These differences in the breeding objectives and processes, which reflect the history of forage use in the two countries, are considered to be one of the important factors in the analysis of the results of our collaborative research and in the understanding of the achievements of the breeding work in the two countries.

Through the evaluation of varieties of 3 forage species in Japan and France, we were able to obtain valuable information for plant breeding. These varieties were bred mainly by population improvement under the environments of each country, and rapid change of populations by adaptation to new environments or breeding objectives was demonstrated, underscoring the importance of the germplasm from ecotype populations and history of selection in the breeding of these forage species.

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