Breeding of New Alfalfa Cultivars for High Quality Forage Production in Warm Regions of Japan

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Introduction

Alfalfa (*Medicago sativa* L.) was first introduced to Japan about 100 years ago. However, its cultivation by farmers in warm regions of Japan was very limited, because of its very low adaptability to the regions. Alfalfa originated in Central Asia with low total precipitation showed low yielding ability and low persistence in the warm regions having high precipitation. With the rapid development of animal industry in Japan in the 1960s, the cultivation of alfalfa came to be reconsidered, and the breeding of new alfalfa cultivars for the warm regions began in 1964 at the Aichi Prefecture Agricultural Research Center.

Breeding of new cultivars

1) *Breeding of Natsuwakaba*[6]

Breeding for new alfalfa cultivars with high adaptability to the warm regions of Japan started in 1965, and the new cultivar 'Natsuwakaba' was developed and officially released by the Ministry of Agriculture and Forestry in 1973. The origin of Natsuwakaba is as follows: du Puits, Williamsburg and Moapa were chosen as main base cultivars, and Flamande and Common of commercial cultivars were added to them to increase genetic variability. Mass selection was repeated on the basal population for four generations and over six years. They were selected for forage yield, spring- and fall-growth vigor and regrowth after cutting.

Natsuwakaba belongs to the erect plant type with high plant height, and leafy type with dark green leaves. The flowers are mostly purple. As for disease tolerance, it has comparative resistance to spring black stem and also moderate levels of resistance to other diseases. The yield was extremely high (Table 1). Natsuwakaba is widely adapted to the south-western half of Japan.

2) *Breeding of Tachiwakaba*[1]

Following the development of Natsuwakaba, another new alfalfa cultivar 'Tachiwakaba'

Table 1. Green yield of Natsuwakaba and foreign cultivars in three years (Suzuki et al. 1974)

Cultivar	Green yield, kg/a				Ratio (%)	Multiple range
	1st year	2nd year	3rd year	Total		
Natsuwakaba	885	746	724	2, 377	126	a
Moapa	882	650	618	2, 178	116	b
Williamsburg	812	633	600	2, 043	109	c
Cherokee	831	528	552	1, 914	102	d
du Puits	815	546	510	1, 880	100	d

Duncan's multiple range at 5 % level, calculated from the results of tests in five locations.

Table 2. Varietal difference in lodging resistance and dry matter yield under machine harvesting (Fujimoto et al. 1983)

Cultivar	Lodging resistance				3 years total dry matter yield	Ratio
	1 st year		2 nd year	Mean		
	Apr. 17	May 6	Apr. 25		(kg/a)	(%)
Tachiwakaba	1.0	2.3	1.0	1.4	389.5	129
Natsuwakaba	2.8	4.0	3.3	3.4	302.7	100
Moapa	3.5	4.0	3.3	3.6	233.3	77

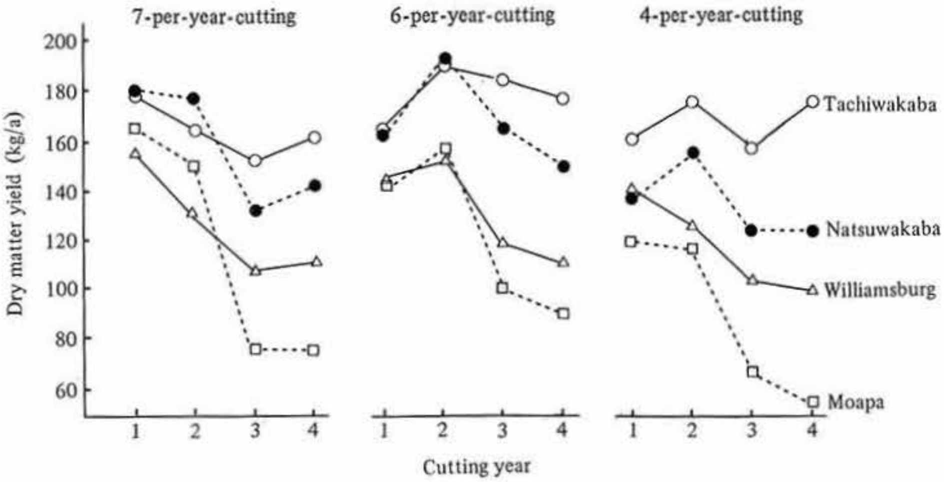

Fig. 1. Varietal difference in dry matter yield for four years when intervals between cuttings were changed

was developed by the Aichi Prefecture Agricultural Research Center in 1982. Base populations of nonhardy type were pollinated with lodging resistant populations in 1969, and selection for high lodging resistance and persistency was continued for four generations. Owing to its high lodging resistance and erect plant type, Tachiwakaba is fit for mechanized cutting (Table 2); yield loss due to mechanized harvesting is slight. Even when intervals between cuttings are longer, yield reduction is small in Tachiwakaba, and high yield level can be maintained for four years or more under the four-per-year-cutting system (Fig. 1).

Other characteristics of Tachiwakaba are strong snow resistance, high dry matter percentage, and high crude fiber content.

Performance tests in locations different in climatic conditions indicated that Tachiwakaba outyielded Natsuwakaba in cooler districts such as inter-mountain and Japan Sea side areas.

The results of these tests were studied from the standpoint of broadening alfalfa adaptation spectrum to humid regions. The relationship between crop growth rate of cultivars and climatic factors was studied and it was determined that the selection in Aichi has realized varietal improvement of alfalfa—selected lines and cultivars having higher dry matter yield under heavier rainfall conditions. Recommended production areas were also examined in relation to climatic conditions of locations and characteristics of cultivars, and Tachiwakaba was estimated to have higher adaptation to cool and wet winter conditions than Natsuwakaba.

Breeding of new germplasm

1) *Breeding of southern blight-resistant strain, CRSY 572*[2]

A strain of alfalfa, CRSY 572, was developed in 1986 in the breeding program for resistance to southern blight, *Corticium rolfsii*, which is an important disease in warm regions of Japan. The breeding program started in 1973. Three cultivars and two strains, Natsuwakaba, Moapa, Sabina, CR 46 and CR 47, were used as the base population. Selection for resistance to the disease was done for up to four generations using the maternal-line selection method on the fields inoculated with the disease. Selection was done also in the last generation of the maternal-line selection using the synthetic variety method.

Strains bred by the synthetic variety method, the CRSY group (composed of three lines), were tested for disease resistance with a check cultivar on the disease-inoculated fields in 1984 and 1985.

The resistance to the disease is summarized as follows: a significantly high positive correlation coefficient was found between the infection percentages of the two years tested, and it was also found between the dead plant percentages of the two years tested. All strains of CRSY group were more resistant to the disease than Natsuwakaba, which is the main component in the base population. CRSY 572, a strain of CRSY group with four component clones which had been selected for four generations, was more resistant than CRSY 521 and CRSY 541, which had been selected for one or two generations (Table 3).

Using a method by Falconer for the relationship between the selection response in percentages of survived plants after inoculation and the cumulative selection differential for disease resistance, the selection response increased in proportion to the cumulative selection differential.

As a result, it was confirmed that selection for disease resistance was clearly effective (Fig. 2).

Research on breeding

1) *Classification of alfalfa cultivars according to their growth habits*[5]

In the beginning, many cultivars of alfalfa collected from nine countries were classified into five groups according to the following

Table 3. Southern blight resistance of selected strains (Inami et al. 1987)

Cultivar or strains	Infection rating[1]		Infected plant percentage		Dead plant percentage		Damaged percentage[2]	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
CR 487-3	2.30	1.19	71.4	43.1	32.5	15.4	42.6	21.5
CR 487-4	2.02	0.59	77.0	28.1	20.0	5.1	35.4	9.8
CR 4871-5	1.66	0.57	72.0	18.0	17.0	9.0	28.5	10.6
CRSY 521-1	2.47	0.98	75.9	44.8	37.4	8.7	46.3	16.7
CRSY 541-1	1.81	0.60	76.0	35.1	17.0	3.0	30.9	9.1
CRSY 572-1	1.28	0.38	49.0	15.8	16.0	3.9	22.7	6.7
Natsuwakaba	4.61	2.96	97.0	74.1	87.0	50.8	91.3	57.4
Moapa	3.59	2.89	86.8	82.6	62.8	43.7	69.9	54.8
Mean	2.47	1.27	75.6	42.7	36.2	17.5	46.0	23.3
Correlation[3]	0.958		0.807		0.963		0.961	

1) : Rating based on 0=no symptom, 3=sympton in about 50% of a whole plant, 5=whole plant dead.
2) : Percentage of (100A+70B+50C+35D+10E+0F)/N
A : No. of plants of infection rating 5—F : No. of plants of infection rating 0, N : No. of all plants.
3) : Between test 1 and test 2.

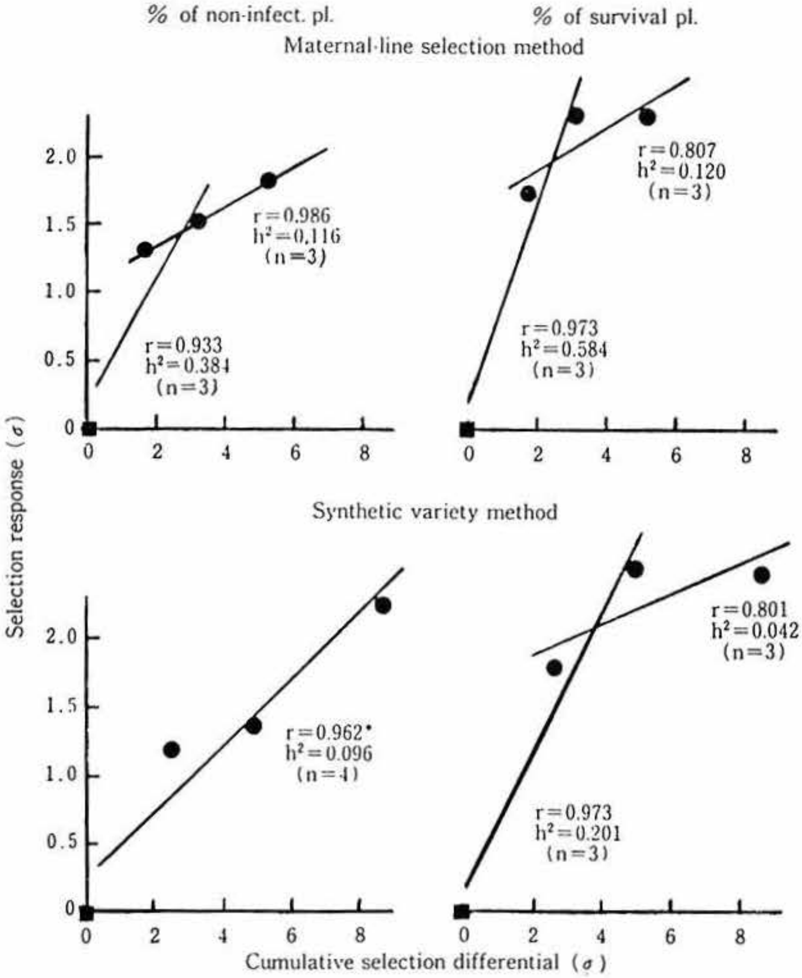

Fig. 2. Relation between the cumulative selection differential and the selection response about percentages of non-infection and survival plants under inoculation of *Corticium rolfsii*
(Inami et al. 1987)

growth habits; plant height in spring and fall, regrowth after cutting and yielding ability in fall (Table 4). The cultivars which belonged to the 1st group were erect in plant type and early growers in spring. They grew well even in the fall and were early in regrowth after cutting. These growth habits indicated that this group did not readily respond to the environment and could be adapted to warm regions. The cultivars of the 2nd group were somewhat slow in the growth in spring and in the regrowth after cutting. They stopped their growth earlier in the fall than that of the 1st group. The 3rd group was the intermediate type between the 2nd group and the 4th group in these characteristics. Cultivars of the 4th group were still slower in these characteristics than that of the 3rd group. Cultivars of the 5th group were prostrate type. Their growth was slowest and the growing period was shortest, indicating that this group responded sensitively to the environment and was thought to be adapted to cool climate conditions.

Table 4. Classification of alfalfa cultivars according to their growth habits (Suzuki et al. 1969)

Group	Country of origin					
	U.S.A. Canada	Australia New Zealand	Germany	France	Italy	Spain
I	Sonora, Moapa Indian Hairy Peruvian Arizona common					
						Tierra de Campos Urgel Mediterranea
II	New Mexico common			Provence	Polesana Leonicena	Ampurdan
	Caliverde	Broad-leaf giant			L. 21, L. 202	
	Common (unknown)	Dry Land Hunter River			Cremonese Romagnola Florida	Mielga
	Zia California common				Marchigiana Friulana di Pre.	Spain YT-1
III	du Puits (produced in USA) Williamsburg Lahontan			du Puits, Emeraude Europe Flamande Orchesienne		
	Kansas common Buffalo			Luciole Hybride Milfeuil		
IV	Cherokee			Marais Challans		
	Montana common Nebraska common Dakota common Utah common Cayuga, Culver	Marlborough	Kurmark-Ostsaat Schlesische Wehrdaer-Hildebrand			
	Atlantic Narragansett		Altdeutche-Bastard			
V	Ladak Rhizoma	Rhizoma type				

From this classification of alfalfa cultivars, it becomes easy to understand the growth habit of each cultivar systematically and one could select the best cultivars adapted to warm regions.

2) Influence of daylength and temperature on plant growth in the classified groups of alfalfa cultivars[7]

A comparative study of five groups on the multiple correlations among daylength, temperature and plant height throughout various growing periods between cutting dates in the natural environment was conducted for three years starting from 1965.

The simple correlation between plant height increase per day and daylength was 0.820, while that between plant height and temperature was 0.590. This result confirmed that alfalfa is influenced quite sensitively by daylength, and that temperature is a secondary factor. Of the simple correlations between daylength and plant height for each of the five groups, 0.714 (the lowest) was obtained from the group I and about 0.84 from the groups IV and V. The correlation for the

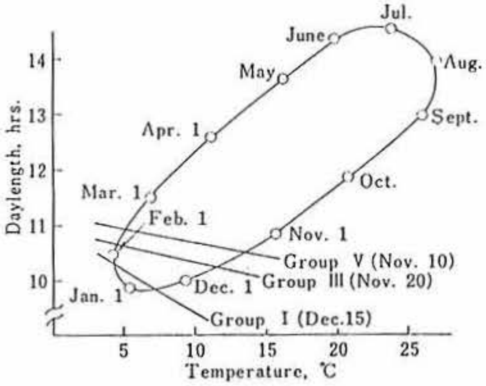

Fig. 3. Dormant period calculated by each multiple regression formula when plant height was 0 cm/day and photothermograph (Aichi)
(Suzuki et al. 1975)

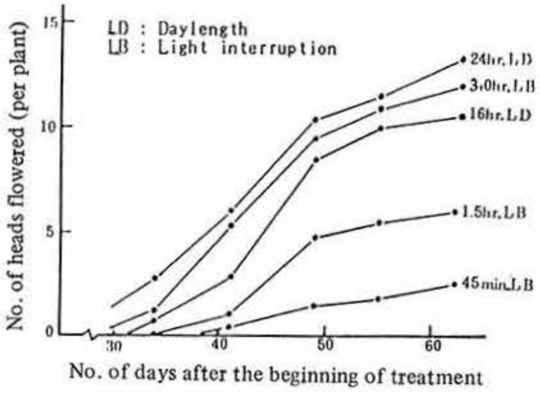

Fig. 4. Increase in the number of heads flowered by long photoperiod and the light interruption treatments (Kanbe et al. 1979)

group V tended generally to exceed that for the group I. Cultivars of the group I which originated from low-latitude regions were insensitive to daylength. On the other hand, cultivars of the groups IV and V originated from high-latitude regions were very sensitive.

The dormant period and the critical time for fall harvest were estimated through the photothermograph at the experiment station. As cultivars of the group V had three months of dormant period, this group might not be utilized after about Oct. 20 for fall harvest. In cultivars of the group I, the dormant period was very short and fall utilization might be possible up to about Nov. 20 (Fig. 3). The utilization period of this group could be longer by one month than that of the group V.

From the above results, it is concluded that great emphasis should be placed on the photoperiodic factor rather than the temperature factor in alfalfa cultivation. Moreover, it is also concluded that cultivars of the groups I and II with high ecological adaptability to warm regions should be used for cultivation in the south-western warm region in Japan.

3) Studies on seed production[3]

The influence of daylength and light interruption on the flowering of alfalfa plants, and the photoperiodic sensitivity of the alfalfa seedling were studied to establish better seed production in alfalfa breeding.

Alfalfa plants flowered earlier under an 18- to 24-hr photoperiod and produced more abundant inflorecences and florets than plants grown under a 15-hr photoperiod, suggesting that the longer the daylength, the more dominant was the reproductive growth over the vegetative growth.

The differences in flowering between alfalfa cultivars were recognized under long-day conditions; flowering of Natsuwakaba was earlier than that of Chubut grown under 15- to 24-hr daylength. The differences of variation between and within cultivars tended to be smaller with an increasing light period. From these results, the effective range of daylength for better seed production in alfalfa breeding was considered to lie between 18 to 24 hr.

A light interruption of 3 hr in the middle of the dark period had the same effect as a long photoperiod on flower formation, and with light interruption, alfalfa plants flowered earlier and more profusely with increasing duration of illumination (Fig. 4). This suggested that light interruption in the dark period could be used as a practical method to make alfalfa flowering earlier and more complete under field conditions.

Though photoperiodic sensitivity of alfalfa was acquired at the cotyledon stage, flowering response increased after the 3-leaf stage and

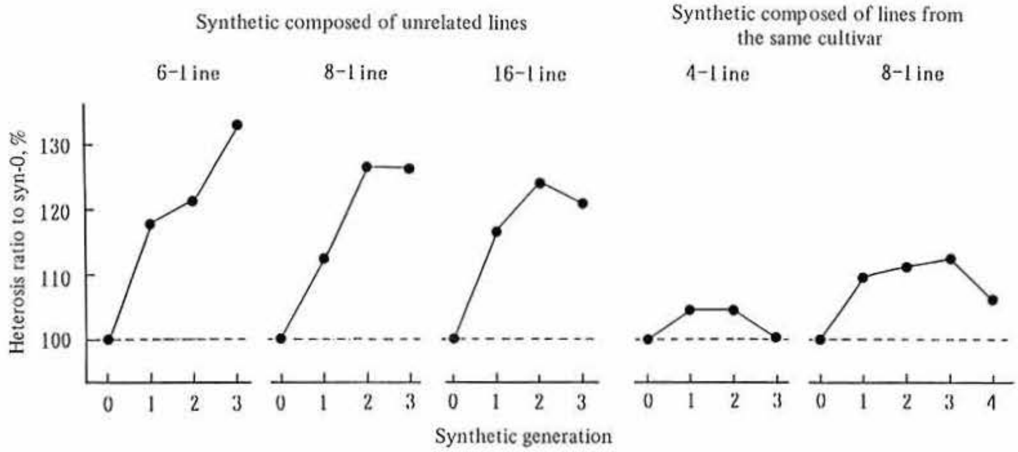

Fig. 5. Heterosis ratio of dry matter yield in advanced generations of synthetics composed of unrelated lines selected from different cultivars and that composed of lines from the same cultivar

the plants produced more florets. In order to shorten the life cycle of alfalfa in the breeding program, we had better expose the plants to continuous light from the 3-leaf stage. By this method, alfalfa seed could be harvested in 120–130 days from seeding.

4) Heterosis effect in advanced generations of synthetic cultivars[4]

The heterosis effect in advanced generations of synthetic cultivars, using component lines bred for one breeding objective and those using unrelated component lines for different objectives was investigated.

The heterosis effect in yield in advanced generations of synthetic cultivars composed of unrelated lines selected from different cultivars was higher than that of synthetics composed of lines from the same cultivar (Fig. 5). In synthetics composed of selfed lines, component lines greater than 6 seem to be necessary to avoid inbreeding depression. Futhermore, even with parents from maternally selected lines, inbreeding would be unavoidable when lines are closely related.

Considering the heterosis effect on yield and inbreeding, the alfalfa breeder should determine the combination and the number of component lines to be used to produce a synthetic cultivar.

Main breeding objectives

The present main objectives of alfalfa breeding at the Aichi Prefecture Agricultural Research Center are wet tolerance, disease resistance to sclerotinia crown and stem rot, *Sclerotinia trifoliorum* Eriks. and spring black stem, *Phoma medicaginis* Malbr. & Roum. var. medicaginis Boerema and insect resistance to blue alfalfa aphid, *Acyrthosiphon kondoi* Shinji. Furthermore, the breeding for the combined resistance to wet injury, sclerotinia crown and stem rot and southern blight just started in 1987.

References

1) Fujimoto, F. et al.: A new variety of alfalfa 'Tachiwakaba', *Res. Bull. Aichi Agr. Res. Ctr.*, 15, 110–121 (1983) [In Japanese with English summary].
2) Inami, S. et al.: A southern blight-resistance line of alfalfa 'CRSY 572', *Res. Bull. Aichi Agr. Res. Ctr.*, 19, 111–119 (1987) [In Japanese with English summary].
3) Kanbe, M. et al.: Studies on the seed production of alfalfa. I. Influence of daylength on flowering of alfalfa plants, *Res. Bull. Aichi Agr. Res. Ctr.*, 11, 49–55 (1979) [In Japanese with English summary].
4) Seki, M. et al.: Heterosis effect in advanced

generations of synthetic varieties of alfalfa. *In* Proc. 15th Int'l. Grassl. Congr., 234–236 (1985).
5) Suzuki, S., Inami, S. & Sakurai, Y.: Classification of alfalfa varieties according to their growth habits. *J. Jpn. Grassl. Sci.*, **15**, 33–41 (1969) [In Japanese with English summary].
6) Suzuki, S. & Inami, S.: The new variety of alfalfa 'Natsuwakaba', *Res. Bull. Aichi Agr. Res. Ctr.*, **A6**, 21–31 (1974) [In Japanese with English summary].
7) Suzuki, S., Inami, S. & Sakurai, Y.: Influence of daylength and temperature on plant growth in the classified groups of alfalfa varieties. *J. Jpn. Grassl. Sci.*, **21**, 245–251 (1975) [In Japanese with English summary].

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