BREEDING FOR IMPROVED SALT TOLERANCE IN ALFALFA

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Salinity now limits crop yields on nearly one-third of the irrigated land on earth, and the amount of salinized land is increasing at a drastic rate worldwide. In the United States, between 25 and 35% of the irrigated cropland is now seriously affected by salinity. Much of this land is in traditional alfalfa growing regions of the West, especially in California, Arizona, and New Mexico. In general, salinity has led only to reductions in yield in these states. However, crop production may become impossible if salinity is extreme, and in some areas, large tracts of once highly productive land have been completely abandoned because of salinity. Without some corrective action yield reductions and abandonment of cropland are likely to increase. Reclamation, drainage, and improved irrigation practices may reduce the severity and spread of salinization in many regions. But the costs of engineering and soil management to reduce salinity are often very high relative to the crops grown. Unfortunately, growers in regions with salinity problems have few management options which do not involve large capital expenditures--something few of them can afford in today's economy. Fortunately, alfalfa breeders may be able to provide a relatively low cost short term solution to the salinity problem for these growers: varieties bred to remain productive in the presence of high levels of salinity, that is, varieties with "salt tolerance".

Salt tolerance as a goal in alfalfa breeding—early efforts

How complicated is salt tolerance?

Many plant, soil, water, and meterological factors interact to influence a plant's response to salinity. Because of this, improving salt tolerance in alfalfa has not proved to be as straightforward as the improvement of traits such as disease and insect resistance, traits which tend to be much less complicated physiologically. For example, early on it was recognized that plants are affected by salinity at all stages of development, but that sensitivity sometimes varies from one stage to another. Recognizing this, workers at the University of Arizona focussed first on the improvement of germination salt tolerance in alfalfa. Starting in 1978 with the cultivar Mesa-Sirsa, nine cycles of selection for the ability to germinate in saline solutions have been conduced. This program has been very successful in producing a population which can germinate at very high levels of salinity; indeed much higher salinities than would probably ever be encountered in agriculture (Fig. 1).

Having developed a germination salt tolerant population, it was now time to turn to salt tolerance during seedling and mature plant growth. Unfortunately, germination salt tolerant materials were no more tolerant of salt as seedlings or mature plants than were unselected populations. Additional breeding would be necessary to develop varieties able to remain productive and tolerate conventional hayfield management following germination under saline conditions. Selection for tolerance during germination and seedling growth was initiated using the Mesa-Sirsa materials with improved germination salt tolerance. This program has been successful, but has not led to the release of agronomically useful populations as salt tolerance after the seedling stage has not been characterized. Preliminary evidence suggests that the materials selected for salt tolerance at germination and during seedling growth may not be any more tolerant of salinity as mature plants than was the original starting population Mesa-Sirsa. The breeding problems continue.

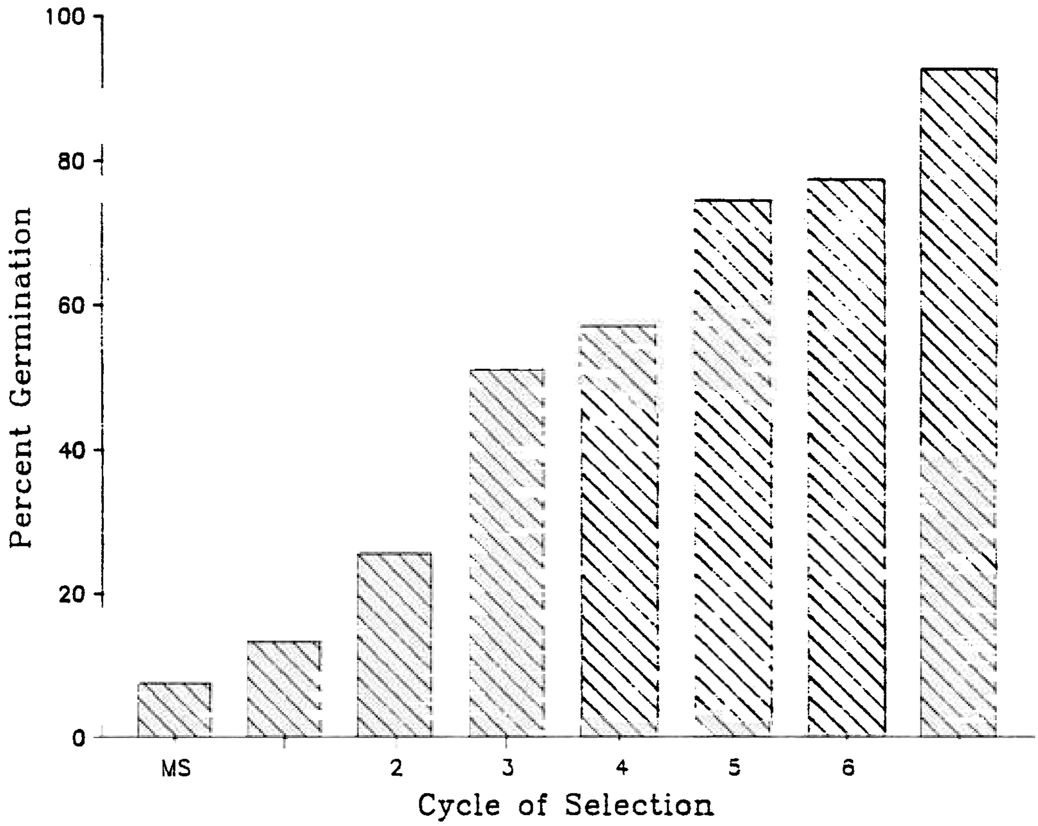

Fig. 1. Germination percentages at -1.1 MPa NaCl for 'Mesa-Sirsa' (MS) and populations resulting from 1 to 7 cycles of selection for germination salt tolerance.

Rethinking the strategy in breeding for salt tolerance

Where are we headed?

When attempting to improve seedling and mature plant salt tolerance in alfalfa it might seem reasonable at first to concentrate on an improved population which is already salt tolerant at germination. Following this approach, tolerances at each growth stage could be concentrated in a single population in separate sequential breeding programs leading to a single population having true "field tolerance" to salt stress. This was the strategy originally adopted in the mid-1970s at Arizona. The alternative would be to attempt to simultaneously select individual plants in a single breeding program based on their tolerance at each of the critical growth stages.

The first breeding strategy described above might be the most rapid since germination salt tolerant populations already exist and additional selection for this trait would not be necessary; only seedling and mature plant tolerance would need to be considered. However, the second strategy would be preferred if previous selection for salt tolerance at germination had in some way negatively affected the performance of the tolerant population. We have shown that this indeed was the case in our own work. Selection for germination salt tolerance led to significant declines in forage yield under non-saline conditions (Table 1), probably due to the accumulation of inbreeding during the selection process. Given the variability of salinity seen between seasons or even within single salt-affected fields, this yield decline is unacceptable. Salt tolerance can simply not be associated with lower yield under any circumstances. Therefore, we have adopted the second breeding strategy and are now conducting "simultaneous" selection for salt tolerance at germination, and during seedling and mature plant growth in a large-scale greenhouse test. Workers in Australia have recently used this basic approach with success in a small scale experimental breeding program to develop an alfalfa population with good salt tolerance at all growth stages.

Table 1. Mean forage yield of germination salt tolerant populations (ST78 - ST 84) and their progenitor population ('Mesa-Sirsa') on a non-saline site (seven harvests in 1986).

Population	Cycle of selection	Mean yield per cutting	
		Fresh wt./plot (g)	% of Mesa-Sirsa
Mesa-Sirsa	0	1493 D[+]	100
ST78	1	1423 CD	95
ST79	2	1413 BCD	95
ST80	3	1370 ABC	92
ST81	4	1302 A	87
ST82	5	1340 ABC	90
ST83	6	1387 ABC	93
ST84	7	1314 AB	88

[+] Means followed by the same letter are not significantly different (5% LSD).

There has been a tendency among plant breeders in the past to expose plants to unrealistically high levels of salt stress during selection assuming that this would simplify the identification of "survivors"--those plants supposedly most salt tolerant. It may be that these plants are well adapted to survival at high salinities, as are many salt marsh plants in nature, but are not well adapted to active growth under the lower salt stress conditions encountered in agriculture. Simple survivability does not necessarily mean high yields under salt stress. Recognizing this, in our simultaneous selection program we are making every effort to expose plants to conditions which are as realistic as possible. Salinity in the soil and irrigation water used are kept at levels which closely approximate what occurs in fields in the Southwest. In addition, we are conducting selection in a broad-based non-dormant population made up of elite varieties not previously selected for salt tolerance but which carry genes for resistance to most of the important pests found in the Southwest. Hopefully, this will insure that the salt tolerant population which results from our selection will retain much of the disease and insect resistance of its parental varieties.

Will biotechnology provide a "quick fix"?

The tools of biotechnology allow us to understand the details of many relatively simple biological processes in plants and occasionally to attempt to solve a significant problem confronting farmers. Salt tolerance is a complicated trait physiologically and genetically. Because of this complexity, biotechnology does not offer many short-term solutions to this problem. Attempts have been made by many researchers to use biotechnological approaches to speed up the process of selection for salt tolerance in alfalfa. None have been successful. Work also continues in many laboratories on identification of particular natural compounds which may improve salt tolerance when produced in plant cells, but development of salt tolerant varieties using this knowledge does not appear realistic in the near future. For some time to come, plant breeding will represent our only real source for salt tolerant alfalfas.

Just a matter of time?

Much has been learned about the response of alfalfa to salt stress and the genetic controls of this response over the last 30 years, but we are far from totally understanding the effects of salt on plants and salt tolerance. Suprising findings appear regularly. For example, we have recently shown that as alfalfa seed ages it looses its germination salt tolerance. This could certainly have an affect on seed production and marketing of salt tolerant varieties when they are available. We have also shown that germination salt tolerance is not lost during the production of breeders, foundation, and certified seed. However, we do not know whether seedling and mature plant tolerance will be a stable during the seed prodution process. Many, many unanswered questions remain.

Alfalfa varieties specifically bred to tolerate high levels of salinity, should serve only to compliment salinity reduction programs. Salt tolerant alfalfa may allow farming to continue in areas where either the costs of desalinization are prohibitive, or where salinity is not yet severe enough to warrent intensive soil and water management programs. It is important to recognize, however, that very few of our common agricultural plants, including alfalfa, can be bred to tolerate very high levels of salinity, and that salinity problems in arid regions are very rarely self-correcting. Salt tolerant varieties are only a short-term solution to the salinity problem. They provide growers the opportunity to continue farming at a profit during the time which measures are taken to reduce salinity levels in the soil or irrigation water; but salt tolerant varieties don't eliminate the basic problem. Some corrective action must be taken in soil/water management to eliminate long-term salinity problems if profitable intensive agriculture is to continue.