ALFALFA'S ROLE IN FEEDING A HUNGRY WORLD

Jon Reich[1]

ABSTRACT

The world population is projected to increase by nearly 30 percent and reach 9.0 billion by 2050. Increasing competition for global protein is anticipated due to this burgeoning population and from the rising demand for food and protein that is a consequence of economic development and higher income in emerging economies, most notably India and China. It has been estimated that the world's farmers will have to produce as much food in the next 40 years as has been consumed since the beginning of humanity. Global livestock production, and the forage needed to support them, has been shifting to marginal lands with more productive agricultural soils being increasingly used to produce higher value crops. Adaptive mechanisms like stress tolerance and salinity tolerance need to be developed in order for forage crops to support this shift. Both non-regulated and regulated technologies will be needed to effectively meet this challenge. With a small carbon footprint, broad adaptation, positive impact on sustainable production systems, and high protein productivity per hectare, alfalfa will be an important contributor.

Key words: Alfalfa, livestock, world population, salinity, stress tolerance

INTRODUCTION

Agriculture faces significant challenges in the 21st century as a result of world population growth, climate change, and bioenergy demands (FAO 2004). Projections show that feeding the world will require increasing crop production in the next 30 years by about 70%, including a 40% rise in cereal production for food and animal feed. Urbanization and per capital income growth, particularly in countries with emerging economies like China and India, will result in a disproportional demand of food and feed crops as human transition to a meat-based diet. The future outlook for agriculture calls for a transformation that increases crop production using sustainable practices that adapt to climate change. Agricultural land use patterns are changing as high commodity prices and increasing demand drive greater planting of row crops in primary production areas and displace livestock and forage production to more marginal areas. These areas are characterized by less moisture and greater stress, particularly exposure to salinity.

Changes in dairy cow numbers from 1990 to 2000 to 2010 as reported by USDA are shown in Figure 1 for important producing states (USDA-NASS). The chart clearly documents a significant loss of cows in traditional producing states in the Midwest (Wisconsin, Minnesota,

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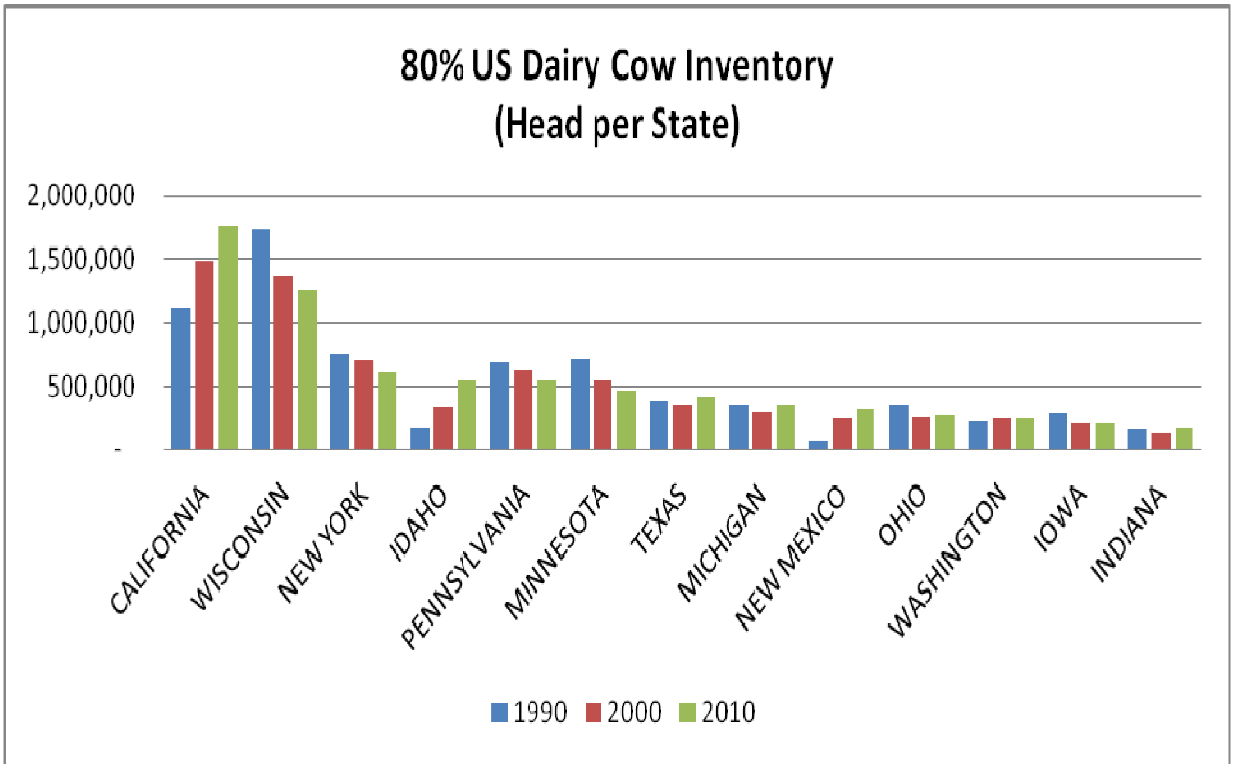
[1] Jonathan M. Reich, PhD, Global R&D Leader, Cal West Seeds LLC, an affiliate of Dow AgroSciences, Woodland, CA 95695. Email: j.reich@calwestseeds.com . **In**: Proceedings, California Alfalfa & Grains Symposium, 10-12 December, 2012, Sacramento, CA, UC Cooperative Extension, Agronomy Research and Extension Center, Plant Sciences Department, University of California, Davis 95616. (See http://alfalfa.ucdavis.edu for this and other proceedings.)

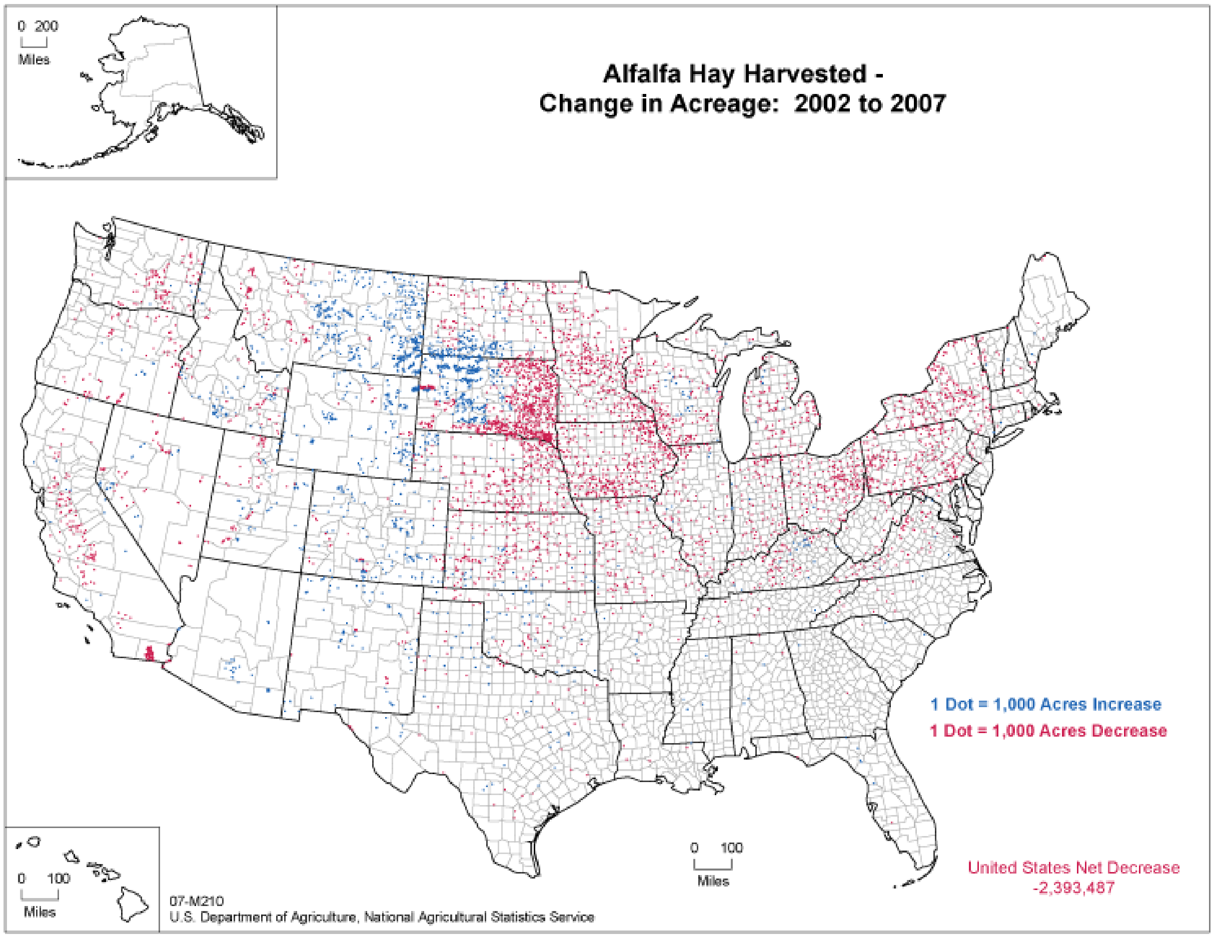
Iowa, Ohio) and Northeast (New York, Pennsylvania) and increases in Western states (California, Idaho, New Mexico).

Figure 1. U.S. Dairy Cow Inventory (Head per State).



USDA census statistics also show that concurrent with this shift in dairy cow numbers has been a shift in the acreage of harvested alfalfa hay. This can be clearly seen in the 2007 census map, the most recent available documenting the changes occurring during the 5-year period from 2002 to 2007 (Figure 2). This map shows significant decreases in harvested alfalfa hay east of the 100th prime meridian which represents the boundary between the moist east and arid west of the United States. Of significance is the increase in harvested alfalfa hay in the Northern Plains, Great Basin, and Intermountain regions, areas known to have serious issues with soil salinity. Continuation of this shift is anticipated in the 2012 census which will document the changes between 2007 and 2012. Shifts in livestock and forage production such as this are also occurring in major producing areas of South America and Asia driven by pressures of population growth, urbanization, climate change, bioenergy, and commodity prices.

Figure 2. Alfalfa Hay Harvested - Change in Acreage: 2002 to 2007.

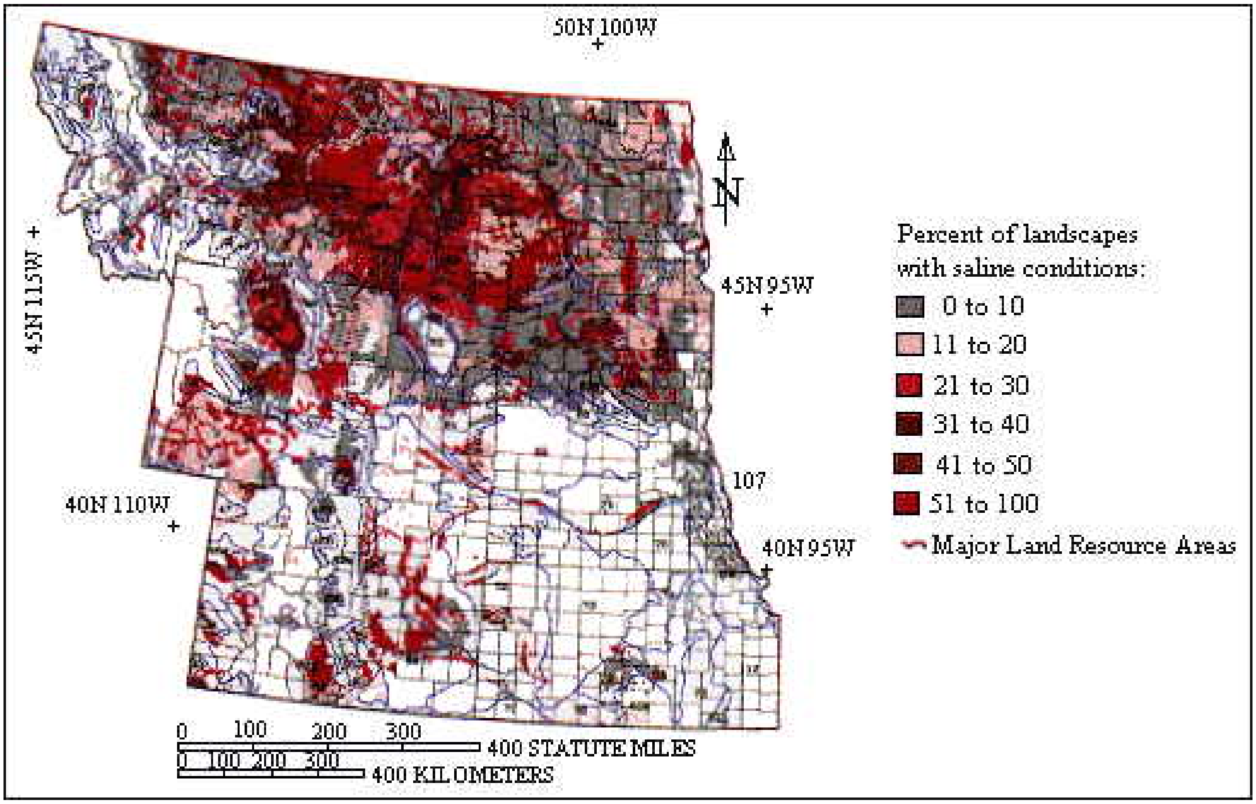


SOIL SALINITY AND DROUGHT TOLERANCE

Soil salinity is an increasing global concern facing agriculture and affects significant areas on virtually every continent. Soil salinity imposes a chronic, yield reducing stress on crop plants while not necessarily revealing itself in the physical or visual appearance of the growing crop. Typical yield loss estimates due to salinity are in the range of 25%, and global crop losses are in the billions of dollars annually. There are two types of salinity in the agricultural landscape, irrigated land salinity and dryland salinity. Irrigated land salinity is more commonly recognized by the general public. Disappearance of the great civilization in ancient Mesopotamia is well documented and linked to failures associated with poor irrigation management and irrigated land salinity. Poorly designed and improperly managed irrigation systems, poor on-farm management practices, and inappropriate management of drainage water is currently responsible for salinization and desertification of millions of hectares worldwide. Dryland salinity, while less commonly recognized, affects more extensive geographic areas around the world and is no less damaging to crops. It typically occurs in areas where soils were formed from salt laden parent material that developed under the ocean (principally shale), is associated with high water tables (<2m), and occurs where natural vegetation has been replaced by agricultural land use systems that do not utilize water to the same extent allowing salt movement to the land surface with the movement of groundwater. In these situations, salt accumulation occurs whenever the quantity of water leaving the soil surface through evaporation or transpiration exceeds the quantity of water entering the soil through precipitation. These are typified in their most extreme manifestation by saline seeps that develop near the shoulders, backslopes, and footslopes in individual landscapes (Daniels, 1987). In the U.S. salinity is a significant and increasing problem largely west of the 100th meridian.

To illustrate the regional importance of salinity, Figure 3 shows the percent of landscapes with saline conditions in the northern Great Plains (Waltman and Stephens, 1995).

Figure 3. Salinity-affected landscapes of the Northern Plains region.



While plants have different genetic and physiological mechanisms associated with drought and salinity tolerance, there is a strong association in the physical landscape in the occurrence of salinity and low rainfall (arid or semi-arid environments). While farmers in the eastern two-thirds of the U.S. were faced with catastrophic drought in 2012, western producers are routinely challenged by water scarcity. Large portions of the western U.S. are regularly plagued by drought and diminishing water resources for irrigation. In most of the Southern Great Plains and western U.S., inadequate surface water supplies, declining water tables, and high water pumping costs limit crop production (Ray et al., 1999). While improvements in irrigation management such as drip irrigation have had a positive impact on water use efficiency where they've been implemented, genetic improvements in crop drought tolerance and water use efficiency are needed to support future agricultural production in the face of climate change and competition from urban areas and environmental requirements.

CONVENTIONAL SELECTION

Alfalfa is generally considered to be a moderately salt-sensitive species (Maas and Hoffman, 1977). Considerable work has been done using recurrent phenotypic selection to improve alfalfa salinity tolerance. Different genetic mechanisms in alfalfa are responsible for salt tolerance at the germination and establishment stage and at the mature plant stage. Multiple cycles of selection at both stages is required to improve adaptation of alfalfa to saline field conditions. When properly applied, recurrent cycles of selection in aqueous or soil based media for germination and seedling growth followed by yield selection over multiple cuttings results in significant improvements that have been validated in field environments as shown in Figure 4.

Figure 4. Differential stand establishment in salt selected and unselected alfalfa populations.

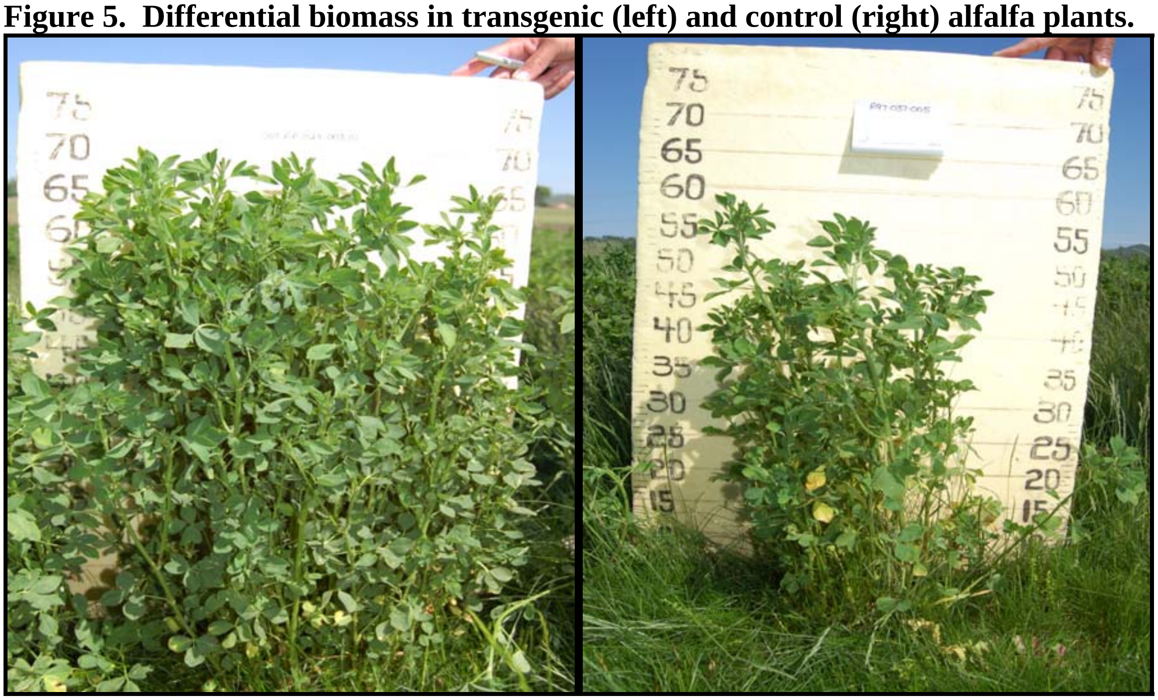
MARKER ASSISTED SELECTION

The enormous potential of DNA markers to improve plant breeding efficiency is well recognized, and many agricultural research centers and plant breeding institutes have adopted the capacity for marker development and marker-assisted selection (MAS) (Collard et al., 2005). We are collaborating with New Mexico State University on a project to utilize molecular markers associated with improved forage productivity under deficit irrigated field conditions. The markers, identified in a mapping population, are being used to move putative drought tolerance genes into elite alfalfa cultivars and potentially eliminate negative genes.

TRANSGENIC SOLUTIONS

Different transgenic strategies are being studied to produce alfalfa with significant improvement in stress tolerance including salinity tolerance. One strategy involves the use of transcription factors, powerful regulatory elements that control the flow, or transmission, of genetic information and thereby regulate cellular biochemical activities in response to a range of biotic and abiotic stresses (Singh et al., 2002). The transcription factors being used in our program provide tolerance to multiple kinds of stress. One such gene has been extensively studied and produces improved tolerance to stress induced by salinity, nutrient availability, and drought. In addition, this particular gene has demonstrated pleiotropic effects and has also been shown to improve productivity in the absence of stress. In replicated growth room bioassays and field studies, transgenic events have produced 30-60% higher yield than controls when salinity, nutrient availability, and drought stresses have been imposed. In the absence of stress these events also produced more than 50% greater forage yield than the controls as shown in Figure 5.

Figure 5. Differential biomass in transgenic (left) and control (right) alfalfa plants.



Another strategy involves the use of a specific membrane antiporter protein that pumps sodium ions against a concentration gradient and sequesters them in the cellular vacuole. Sodium ions in saline soils are toxic to plants because of their adverse effects on K^+ nutrition, cytosolic enzyme activities, photosynthesis, and metabolism (Jacoby, 1999). This mechanism has been demonstrated in cotton, rice, and tomato to provide protection at up to one-third strength seawater, an electrical conductivity (EC) of 18 mmhos/cm. Transgenic events recently generated using this strategy will be evaluated for salinity tolerance in bioassays beginning in early 2013.

An additional transgenic strategy being deployed to improve alfalfa adaptation to marginal environments utilizes a gene which confers improved water use efficiency. This physiological mechanism manifests itself in two ways. First, transgenic plants are able to recover from prolonged severe drought whereas control plants remain desiccated and are unable to recover with the addition of water. Second, the biomass of transgenic plants was not changed under a two-thirds reduction in applied irrigation whereas control plants experienced a reduction in biomass of greater than 50%. Transgenic events recently generated using this strategy will be evaluated for drought tolerance and water use efficiency in bioassays beginning in early 2013.

SUMMARY

Agriculture faces a daunting challenge to feed a growing world population expected to reach 9.0 billion by 2050. Livestock and forage production systems are expected to continue shifting to more marginal production areas being displaced by row crops as a result of climate change, bioenergy, protein demand, and commodity prices. Alfalfa will continue to play a significant role in feeding a hungry world owing to its inherent characteristics of having a small carbon footprint, broad adaptation, positive impact on sustainable production systems, and high protein productivity per hectare. However, adaptive mechanisms like stress tolerance and salinity tolerance need to be developed in order for alfalfa to support this shift.

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