Temperate/Tropical Transition Zones: A Hotspot for Breeding Forages with Climate Resiliency

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Temperate/Tropical Transition Zones: A Hotspot for Breeding Forages with Climate Resiliency

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Abstract

Species resiliency to climate change is critical for sustainability of grassland agricultural systems. Transition zones between temperate and tropical climates (between 27 and 31° N and S latitude) with variable annual frost/freeze events have proven to be ideal zones for identification of species with variable climate adaptation. This paper will identify these regions around the globe and show how these regions offer distinct advantages in terms of selection for abiotic and biotic stresses, and thus resiliency to changing climate. Programs located in these regions have the advantage of exposure to alternating extreme warm and cold temperatures, drought and flood conditions, and a multitude of biotic stresses. Examples are presented of successes and constraints in moving cool season species into warmer climates, and tropical species into cooler climates. We present rationale for which direction of species movement (tropical to temperate vs. temperate to tropical) may be more likely to encounter success and why. Specific plant attributes that contribute to climate resiliency will be identified and described. The ability to identify small changes in genetic photoperiod responses in these regions, where daily changes are less than 1.5 m, are illustrated as a further advantage when the objective is development of earlier or later maturity. These regions also provide suitable environments for pests, from both tropical and temperate areas, including diseases, nematodes, and insects, providing desirable field environments for screening and genetic improvement through cycles of recurrent selection. A discussion of reproduction method is included to illustrate the need to accomplish seed production of these species in other zones in order to produce higher yields of high-quality seed.

Introduction

Climate change can have major impacts on adaptation of forage species to ecozones around the world. An example would be peninsular Florida where two successive winters with minimum low temperatures characterized as "100-year freeze events" occurred in the mid 1980's. The record low temperature for Gainesville, FL of -12.2° C was recorded in January 1985. However, in the decade since 2010 the lowest temperature has been -4.7° C, and number of freeze events per winter season has dramatically decreased. Both winter minimum and number of freeze events are determining factors for survival of perennial warm season grasses and legumes in transitional climate zones.

Limpograss [*Hemaerthria altissima* Poir (Stap & CE Hubb)] has shown moderate leaf tissue tolerance to light frost and freeze events. This ability to remain photosynthetically active through the winter months in the southern part of peninsular Florida, along with the finding that limpograss has a slower rate of decline in digestibility with age (Quesenberry et al., 2018), has resulted in a dramatic shift away from hay production to use of stockpiled limpograss for winter pastures in South Florida.

Cool season legumes have not been widely utilized in pastures in the southeast USA, primarily because photoperiod dormancy of cultivars developed further north limits late winter – early spring growth. The ability to select for reduced dormancy in red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) has resulted in low dormancy cultivars that are making an impact in beef forage/livestock systems in Florida and the Coastal Plains of the USA (Quesenberry et al., 2012, 2015).

Likewise, development of annual ryegrass (*Lolium multiflorum* Lam.) with variable maturity responses and high levels of foliar leaf disease resistance has increased use of this species in beef and dairy forage systems in the lower southeastern USA (Kenworthy et al., 2016; Prine, 2001; Prine et al., 2002). Furthermore, development of annual cereal crops [oat (*Avena sativa* L.), rye *Secale cereal*e L.), and wheat (*Triticum aestivum* L.)] with reduced winter dormancy and high levels of foliar disease resistance has resulted in increased use as winter annual grazed cereal crops in the SE USA.

Global latitudes between 27 and 31° N or S offer unique opportunities for breeding and selection for variable dormancy response. The low daily rate of change in day length in late winter to early spring, and similarly in late fall and early winter, enables breeders to readily select for small differences in dormancy response (Deren, and Quesenberry 1989; Kenworthy, et al 2016; Quesenberry, et al., 2015a, Williams, et al., 2008). These latitudes typically also experience a combination of tropical and temperate plant disease and insect pests, providing ideal locations for pest resistance breeding programs (Quesenberry, et al., 2010, 2015). Likewise, locations in these latitudes often have winter minimum temperatures varying around 0°C that can allow for selection of differences in leaf tissue damage by light to moderate frost/freeze events (Acuna, et al., 2009; Breman, at al., 2008) and winter survival of warm season legume species (Carvalho and Quesenberry, 2009). It has also been demonstrated that in these latitudes expression of apomixis may vary toward the end of the growing season (Rios, et al., 2013). This introductory paper will provide specific examples of why temperate/tropical transition zones are ideal hotspots for identifying and breeding forages with climate resiliency.

Results

Dormancy Responses

Maximum summer day length at near 30° N (e.g. Gainesville, FL) or S are about 14 hr, and the rate of day length change in late winter and early spring is about 1 min and 45 sec (12.25 min per week) at spring equinox. In contrast the longest summer day at near 45° N (e.g. St. Paul, MN) is 15 hr and 37 min and the rate of day length change is 3 min and 10 sec (22.17 min per week) at spring equinox. With the normal variances in plant phenology caused by temperature, rainfall, and other factors, it becomes apparent that the ability to segregate out small differences in dormancy is greater at the lower latitudes.

Since 1997 the annual ryegrass breeding program at the University of Florida has developed and released 25 cultivars that are licensed for production and distribution to the major forage seed production companies in the USA. Seed sales reported on exclusively licensed UF/IFAS annual ryegrass cultivars averaged over the years 2016 to 2019 were just over 12.5 million kg per year. This represents about 15% of the reported seed production of annual ryegrass seed in the USA, and approaches 50% of the proprietary variety seed sales. The success of these cultivars can be attributed to selection for variable spring DM production due to early, mid and late dormancy responses and selection for high level of foliar disease resistance (Prine, 2001).

Red clover has historically been bred and utilized in temperate zones of the world. Beginning in the 1980s, a program of selection for early spring production and pest resistance in red clover was conducted at the University of Florida. This program has resulted in the release of four cultivars and development of a 4*X* germplasm with adaptation to the lower SE USA. Figure 1 illustrates the range of dormancy among these populations, developed at the University of Florida, compared to the mid-dormancy cultivar 'Kenton'. 'Southern Belle', 'Cherokee', and FL4X are low dormancy, whereas 'Barduro' has dormancy between Kenton and Southern Belle. The new FL24D cultivar is the most non-dormant cultivar of red clover we have produced.

The work developing a reduced dormancy red clover for the lower SE USA followed the example of other research at the University of Florida that resulted in the development of 'Osceola' white clover (Baltensperger et al., 1984). The germplasm of white clover has been divided into categories of small, intermediate, and large or Ladino. In Florida the ladino types show little flowering before warm summer temperatures and summer rains in June result in reduced plant vigor and growth. Conversely, intermediate types flower in late winter/early spring and thus have limited yields. Crossing and selection in N. Florida resulted in the development of the cultivar 'Osceola' with traits that fall between intermediate and ladino types. For the decades of the 1990s through 2010, Osceola was utilized throughout the southern and transitional zone states of the USA as a popular and important cultivar.

Alfalfa (*Medicago sativa* L) had historically been considered to be poorly adapted to the lower SE USA. However, a long-term program of recurrent mass selection under field conditions at Gainesville, FL resulted in the release of 'Florida 77' with good production and moderate persistence in N. Florida (Horner and Ruelke, 1981). Additional selection resulted in the release of the cultivar 'Florida 99', and this germplasm pool has been the basis of other breeding efforts that have resulted in the development of several alfalfa cultivars adapted across the Coastal Plains and lower SE USA. New breeding efforts began at the University of Florida by testing germplasm from other subtropical pools and crossing with Florida 99 background (Acharya et al., 2020). A potential new alfalfa cultivar (UF_AP_2015) selected for increased yield and persistence in the SE USA is currently under final stage testing for release.

Pest Resistance Responses

Climatic conditions in these temperate/tropical transition zones often are ideal laboratories for plant pest problems. This often allows breeders to make progress in screening for disease resistance using simple field phenotypic responses. An example of this is the annual ryegrass breeding program in the Agronomy Department at the University of Florida. North Central Florida typically experiences the onset of crown rust (*Puccinia coronata* Corda) and grey leafspot (*Pyricularia oryzae* Cavara) on annual ryegrass in late winter to early spring. Table 1 shows that cultivars developed at Florida (Experimental FL4XR16, 'Attain', 'Big Boss', and 'Jumbo') have superior crown rust and grey leafspot resistance compared to cultivars developed in more temperate climates ('Marshall' and 'Lonestar').

Soil borne pests such as plant parasitic nematodes are also more likely to be present in these temperate/tropical transition zones. Little variability exists in temperate legume germplasm for resistance to most of these nematodes (Kouame, et al., 1997). Cultivars of alfalfa, red clover, and white clover developed at Florida have now been released with moderate to high levels of resistance to root-knot nematodes (*Meloidogyne* spp.) (Horner and Ruelke, 1981; Quesenberry, et al., 2012; Quesenberry, et al 2015). We have shown that in red clover recurrent selection for low galling and egg mass production in response to infestation with *Meloidogyne* spp. has identified quantitative genes that result in reduction in all life cycle stages (root penetration, larvae maturation, and fecundity) of the nematode (Call et al., 1997). This research resulted in the development and release of Southern Belle red clover with high levels of resistance to root-knot nematodes. Subsequent research in white clover produced similar findings (Acharya, et al., 2011) and resulted in the development and release of 'Ocoee' root-knot nematode resistant white clover (Quesenberry, et al., 2015). Table 2 shows that in both red clover and white clover significant reductions have been achieved in plant responses to *Meloidigyne* spp. We have also identified variability for response to root-knot nematodes in aeschynomene (Quesenberry et al., 1985) and *Desmodium* spp. (Quesenberry and Dunn, 1987).

Frost/freeze Responses

As mentioned above, a major factor influencing selection for moving tropical species into temperate transitional zones is identification of genetic variability for leaf tissue tolerance to mild frost and freeze events as well overall plant resistance to winter killing from even colder temperature events. Because our winters in Florida frequently have these marginal frost/freeze events we have been able to identify trait diversity in limpograss and bahiagrass (*Paspalum notatum* Flugge) (Breman, et al., 2008). Additionally, these "mild" winter minimum temperatures have allowed us to identify variability for winter survival in rhizoma perennial peanut *Arachis glabrata* Benth (Williams, et al., 2008) and pintoi perennial peanut (*Arachis pintoi*. Krapov. & W.C.Gregory) (Carvalho, at al., 2009). Generally, the tropical perennial species that have been successfully adapted to temperate climates have been those with below ground storage organs (rhizomes) eg. bermudagrass and rhizoma perennial peanut. Major issues encountered with adaptation of temperate species to warm climates have been a lack resistance to new disease, insect and nematode pests, as well as dormancy modifications, described above. Success has been made in both directions of movement, but we suggest that temperate to tropical movement is a likely to be a more challenging breeding objective.

Conclusions

Breeding and selection in a temperate/tropical transition zone environment within 27 and 31°N latitude has been successful at moving cool season species into warmer climates, and of adapting tropical species into cooler climates. Furthermore, we have attempted to identify specific attributes (e.g. growth habits, dormancy responses, pest resistances, methods of reproduction, etc.) of species that contribute to climate resiliency. The papers which follow will amplify examples of temperate and tropical grasses and legumes, and issues related to seed production.

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Table 1. Disease responses of annual ryegrass cultivars and experimental lines at the University of Florida.

	2016-17	
Entry	Crown Rust	Grey leaf spot
FL4X R16	1.7	1.0
Attain	2.7	1.7
Big Boss	3.0	2.0
Jumbo	2.3	2.3
Lonestar	6.0	3.0
Marshall	8.3	.
Average	4.0	2.4
LSD (P=0.05)	2.1	1.5

Table 2. Response of red and white clover cultivars to three root knot nematode species

	M. arenaria		M. incognita		M. javanica	
Entry	Galls†	Eggs	Galls	Eggs	Galls	Eggs
Kenstar	5.0 a‡	5.0 a	3.9 a	3.9 a	4.7 a	4.6 a
Southern Belle	3.3 b	3.3 b	2.3 b	2.2 b	0.7 c	0.3 c
FL 4X	3.0 b	2.8 b	2.4 b	2.3 b	1.8 bc	1.4 bc
Barduro	2.3 b	1.9 b	2.3 b	1.9 b	2.2 b	2.1 b
Osceola	3.9 x	3.1 x	3.9 x	3.3 x	4.2 x	4.0 x
Ocoee	2.6 y	2.4 y	1.6 y	1.4 y	3.0 y	2.6 y

†0 = no galls or egg masses per plant; 1 = 1 or 2; 2 = 3–10; 3 = 11-30; 4 = 31–100; 5 = more than 100.
‡Means within a column followed by the same letter are not significantly different, Duncan's Multiple Range Test, P = 0.05.
Note that the white clover cultivars Osceola and Ocoee were evaluated in a different experiment from the red clover cultivars, thus a different set of letters are used to denote statistical differences.

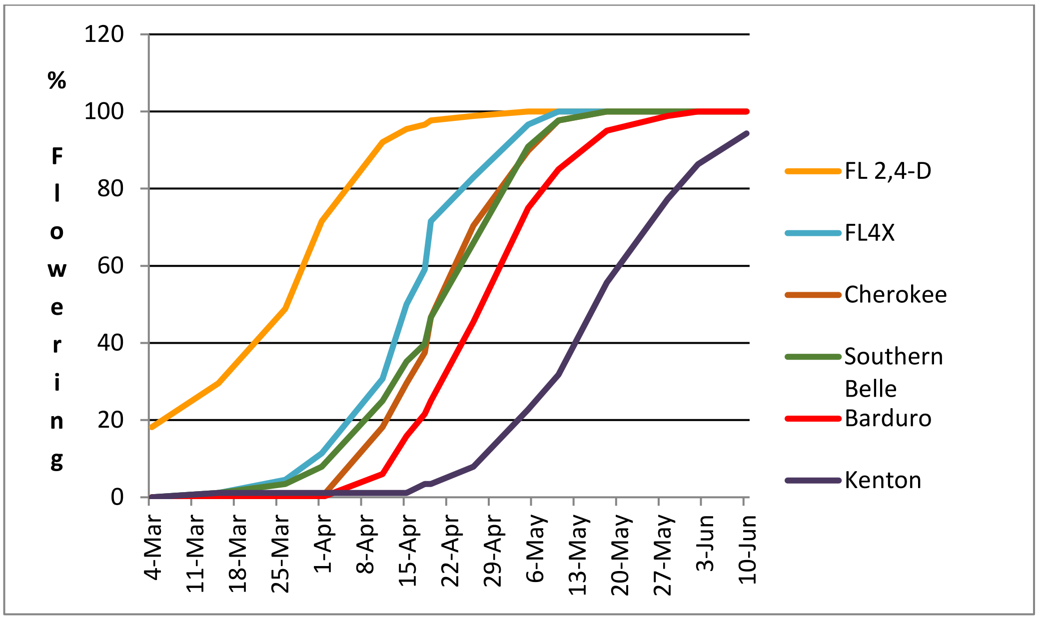

Figure 1. Percentage flowering of red clover cultivars over time in the spring in Gainesville, FL