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PERSPECTIVE

Grassland Research

Forage breeding and cultivar development: A 50-year perspective

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Abstract

This article represents the perspective of one retired, academic forage breeder and cultivar developer after 50 years of working experience. Developing cultivars that help farmers within pastoral agriculture is the main goal, a system where livestock is the consumer. International Grassland Congress proceedings, as well as the general literature, are historical guides for the state of forage breeding. Efficiency was achieved through technologies; better equipment for planting and harvesting; and advances in computer computation and communication. Biotechnology achievements were fitful and continue to evolve. Cultivar performance mean-reversion, cost to the program, and what the farmer seed buyer was willing to pay are important considerations for applying any technology, especially biotechnologies. Biotech promises were too optimistic. This was due, in part, to a lack of understanding that traditional phenotypic/genotypic field selection programs operate in a complex way with multiple species and several traits screened simultaneously at a modest cost. The majority of current forage cultivars are from field-based selection. Industry participation at scientific conferences declined over time, with less sharing of information the result. Cultivar developers will continue using basic field selection methods but should explore applying any technology; just be clever on when, how, and with whom to use them. Practical advice and experiences are also presented and discussed.

KEYWORDS

biotechnologies, breeding, cultivars, farmers, forages, genetics, livestock, pastures

INTRODUCTION

Perspective is defined as "a particular attitude toward, or way of regarding, something; a point of view." For this article, perspective is centered around personal experiences in breeding forage and pasture crops with a goal of developing cultivars for on-farm uses. This paper is therefore informal and written more like a story with few citations and at times in first person. It is a US-centric, personal story by an academic forage breeder who successfully developed and commercialized numerous forage cultivars, some of which are still sold today. However, my main qualification is living through the last 50 years as an active forage breeder and relating what important events happened during that time. The reader is directed to a recent article that provides more details on the individual topics addressed and their literature citations (Caradus et al., 2021).

PASTORAL AGRICULTURE

Pastoral agriculture is where the forage cultivar developer lives and works. Among all the possible production systems, pastoral agriculture's main aim is to produce livestock, rather than crops. There is a diversity of plant and animal species found within pastoral agriculture. The individual farms comprising pastoral agriculture use agronomic inputs including planting desired crop species and improved cultivars. This need for improved cultivars greatly impacts forage breeding.

Species and cultivars are numerous in pastoral agriculture, and planted as monocultures, bicultures, or polycultures. Diverse strategies evolved to manage these species. Persistent perennials are used to minimize environmental risks but sometimes at the expense of animal production. Annuals are used where short-term animal production is needed and more production risk is accepted. Grasses with nitrogen fertilizer supply the persistence base, while any legume component needs enough productivity, but mainly persistence, to fulfill its main roles of replacing nitrogen fertilizer or increasing the nutritive value of the forage supply. The economic system associated with pastoral agriculture is therefore complicated and undervalued. The saleable product is indirect, predominantly an animal product. Most production systems are found on lower-value land containing poorer soils and harsh environmental conditions.

A GOLDEN ERA AND THE QUEST FOR EFFICIENCY IN FORAGE BREEDING

US forage breeders of my generation started undergraduate and graduate school and careers toward the end of what in retrospect was the "Golden Era" of practical crop breeding, genetics, and cultivar development. We were influenced by the writings of those who actively worked during that time. We were trained by them or trained those who were directly trained by them. The Era began with the rediscovery of Mendel's papers, progressed through all the great corn (*Zea mays* L.) breeders and geneticists (Barbara McClintock, Marcus Rhoades, etc.), and ended with Norman Borlaug receiving the Noble Peace Prize in 1970 for the Green Revolution.

Another important event happened right at the end of the Golden Era that impacted breeding and cultivar development in the United States. It was the passage of the Plant Variety Protection Act. Plant Variety Rights were also implemented in other countries. These promised "patent-like" protection for sexually reproduced cultivars. Another milestone occurred when the US Supreme Court decided that it was possible to obtain utility patents on living organisms. This opened the door for what became biotechnology in all its forms. The net result of both events was more overall investment in plant breeding and more positions for graduates. They also greatly advanced biotechnologies, many times at the expense of traditional field breeding.

The history and evolution of forage breeding are documented for the last 100 years in the proceedings of the International Grassland Congress (IGC). The IGC is held approximately every 4 years across different continents (Allen et al., 2021). The Congress is well attended and includes a diversity of topics within cultivated grasslands and rangelands. There is usually a plant breeding and improvement section at most IGCs. The XIV IGC held in 1981 in Kentucky was my first Congress. The upcoming XXV IGC, also scheduled for Kentucky in 2023, allows me to come full circle some 42 years later.

Forage breeders reporting at the early IGCs adopted the approaches of their Golden Era crop breeder cousins. This was done to increase efficiency. From the titles in "Section 1: Plant Introduction, Evaluation, and Breeding" of the 1981 IGC, one obtains a good idea of the state of forage breeding at that time. Key words like selection, breeding, improvement, disease resistance, hybridization, cytology, performance, genetic variability, and so forth occur many times in paper titles.

The plenary breeding paper at the 1981 IGC was by J. R. (Jack) Harlan (1981), a phylogeneticist from the school of evolutionary biology, plant collection, and stewardship of genetic resources. He makes the point that one becomes efficient when using genetic resources mainly as part of a practical plant breeding program. "Hybridization is the key that unlocks doors and create mysteries. The art and science of plant breeding consists, to a large extent, in finding parents whose offspring perform better than they do." This is why Harlan felt the problem for breeders was to seek the optimum level of divergence and the best combinations. The solution was a great deal of experimental crossing and evaluation.

G. W. (Glenn) Burton was one of the foremost forage grass breeders and cultivar developers of his day. He was also a mentor and colleague for me. His paper at the XIV IGC was entitled "Improving the efficiency of forage-crop breeding" (Burton, 1981). Please note the word efficiency. His advice was to have the best parental germplasm, clear objectives, efficient breeding methods, labor, funding support, and collaboration, especially from other disciplines. He also felt that the cost per unit of breeding advance toward producing a cultivar was critical and could only be improved by efficiency. For him, efficiency was achieved through improvement on basic mass recurrent selection methods, better backcrossing methods for transferring major genes, and management strategies to place F_1 hybrids (even clonal F_{1s}) on farms. Later Burton (1982) expanded on his theme (and as a complement to Borlaug's Green Revolution) by listing "work, motivated by needs of a rapidly expanding world population."

STRIVING FOR EFFICIENCY THROUGH TECHNOLOGY

According to IGC proceedings, but also more generally in the available literature, efficiency therefore became paramount to forage breeders as they advanced toward the millennial year 2000 and beyond. The best ways to achieve efficiency was to be clever, work hard, put in long hours, and also to apply cost- and time-saving technologies. The main technologies were better equipment for planting and harvesting, computers and software to greatly improve plot designs, data collection and analyses, communication capabilities that made interaction with peers on a global basis as easily as previously done within one's own building, and finally, biotechnologies. All these technologies became more cost-effective as they evolved.

For example, hand labor and single push planters seeding hundreds of plots per day were replaced by self-propelled, multirow planters capable of seeding thousands of plots per day. Likewise, harvesting equipment now allows one to cut and sample these plots with less hand labor and easily collect and download data for further analysis. Keeping handwritten records of pedigrees or conducting statistical analyses by hand was replaced by computer technologies that continues to this day to an efficiency of scale that Golden Era breeders would only marvel at. My peers and I initially used typewriters and carbon paper to produce manuscripts and land line phones and snail mail to correspond with colleagues. Word processing now makes writing and editing of papers and letters a breeze. Smart phones and video conferencing allow instant communication and easy participation in meetings and conferences even on a global basis. In fact, the 2021 Kenyan IGC was held via video conference, demonstrating the power of this technology.

Biotechnologies that promised to make the forage breeding process more efficient were transgenics, genomics, and recently, gene editing. Use of these tools evolved more slowly among the IGC participants than the computer and communication technologies (Figure 1). It was not until the mid-1980s that even a plenary paper included biotechnology (Vasil, 1985). This was followed by plenary papers by Demarly (1989) and Peacock (1993), with barely any of the volunteer papers having a biotech bent. Serving as Chairperson for the Plant Improvement Session at the XVII IGC held in New Zealand and Australia in 1993, my summary stated that most problems associated with forage crops were believed to be governed by multiple genes that are not so easily manipulated by biotechnological techniques (Bouton, 1993). Therefore, my conclusion at that time was that biotechnologies still had great potential, but the lack of interest shown in them raised questions regarding their short-term impact.

By the XIX IGC, the plenary paper by Spangenberg et al. (2001) was accompanied by just over 10% of volunteer papers and posters that included the use of biotechnologies (Figure 1). By the 2008 IGC, however, the Rubicon was crossed and more than 50% of the papers in the breeding section contained biotech approaches. This trend was to continue until the 2021 IGC in Kenya, where the number of biotech papers, and even breeding papers, was reduced, probably owing to the main congress themes being centered on social and climate issues. However, reviews were presented around a few temperate/tropical breeding successes and on implementing modern forage improvement methods, including biotechnologies, but not at the level of recent previous IGC conferences (Klotz & Bouton, 2021). This trend of less emphasis on breeding seems set to continue for the upcoming 2023 IGC program and does not bode well for the future importance

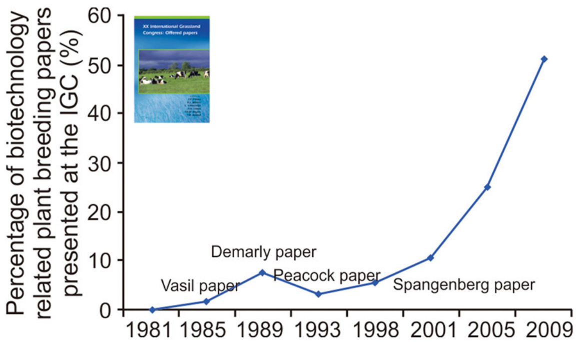

FIGURE 1 Papers with a biotechnology emphasis at the International Grassland Congress (IGC) over the years.

of forage breeding (https://web.cvent.com/event/713616a6-1411-4ad5-a252-152f61ecaa2e/websitePage:645d57e4-75eb-4769-b2c0-f201a0bfc6ce).

HOW DID THESE TECHNOLOGIES WORK OUT?

Equipment, communication, and computers

It is doubtful that there are any forage breeding projects today, public or private, large or small, that are not using modern planting and harvesting equipment, computers, and/or have employees who do not possess a smart phone or laptop with internet access to communicate and analyze data. These technologies and apps continue to improve annually and need to be investigated often for their cost-effectiveness and utility. Therefore, with few reservations, I can say that these particular technologies were the most important and impactful for the vast majority of breeders.

Biotechnologies

> Producing food for 6.2 billion people, adding a population of 80 million more a year, is not simple. We better develop an ever improved science and technology, including the new biotechnology, to produce the food that's needed for the world today. (Norman Borlaug)

If a plant breeding giant like Norman Borlaug says that it is important for breeders to examine the use of biotechnologies, then us mere mortals need to listen and assess those options. As a practical matter, the genotype or genes are what breeders want to directly manipulate but it was always difficult. This was why the initial promises of biotechnologies were so important. They promised direct control of genes and traits with limited interference from the environment and/or any genotype-by-environment effects. In real terms, what we wanted was to increase genetic gain over traditional selection methods.

However, biotechnologies are now being investigated for cultivar development in only a few globally important species such as alfalfa or lucerne (*Medicago sativa* L.), white clover (*Trifolium repens* L.), and perennial ryegrass (*Lolium perenne* L.). They are rarely used (if ever) in a great majority of forage crop species. Even if used, it is a tool whose cost-effectiveness is rarely assessed. Why is that? With all this promise, what applications and problems evolved with using biotechnologies to create and sell new forage cultivars?

Transgenics

As a straightforward strategy, transgenics is the most successful of the biotech approaches for delivering a cultivar product. Witness the Roundup Ready (RR) and reduced lignin alfalfas. However, transgenics does have a cost problem for any but the largest, most well-funded organizations. This is the reason why most cultivar development programs abandoned use unless it could partner with an entity capable of overcoming them.

The first reality impacting cost and eventual use were patents and freedom to operate within those patents. Therefore, overcoming patents proved to be expensive or a legal nightmare. The second reality is that the regulatory (deregulation) process itself is expensive and high risk and one always pays for risk. In the regulatory process, and especially the press, however, a product with a transgene was initially described as a genetically modified organism (GMO). In retrospect, this term gave it a sinister description from the beginning that was ill founded and a red flag to the general public and regulatory agencies.

The technology to produce transgenic crops, especially newer methods using entirely plant-derived genetic elements, does not pose obvious threats to human or animal health or to the environment. However, to allay the concerns raised by the opponents of transgenic crops and many members of the general public, regulatory agencies still proceed with unwieldy and expensive regulatory oversight of the technology itself, rather than of the specific products developed from the technology, a more sensible regulatory target.

Genomics

Genomics, especially marker-assisted selection and genomic selection (GS), promised to overcome the regulatory problems of transgenes. Ironically, genomic approaches also rely on the phenotypic/genotypic selection programs to generate much of their base phenotypic data. All costs in personnel and computational equipment were therefore an add-on to the base selection budget. It is not only an expensive add-on, but as most R&D budgets are "zero-sum," then any funds used for genomics will not be available for improving the base selection programs or buying new field equipment without budget increases (always a hard sell to decision-makers). Therefore, there is an understandable expectation of achieving a significantly higher resultant performance, or even more selection efficiency, when investing in any genomics strategy.

Although the first genetic maps based on molecular markers for several major forage crops have been available for years, the author is not aware of any example where genomic approaches are successfully and directly used to develop new cultivars. The general reasons for this are (1) ever-changing marker types and genotyping platforms (RFLP > RAPD > SSR > SNP > GBS) delayed practical implementation, (2) trait complexity coupled with high environmental interactions made phenotyping still the most complex and costly part of the program, (3) lack of significant positive performance over traditional phenotypic/genotypic selection, and (4) high additional costs.

Actually, no marker type was really robust enough for wide-scale use before SNP, and with SNP, the major issue is the cost of assaying markers. GBS is one of the best low-cost technologies, although it also has limitations. Therefore, developing a platform to analyze SNPs quickly, cheaply, and reliably was a major limitation. The new types of capture-based SNP marker systems (e.g., the new alfalfa DArTag system developed by USDA-ARS) have finally broken through, at least for some crops.

Specifically for GS (the most promising for yield), issues such as (1) number of individuals required in the training populations, (2) rate of prediction model decay, (3) expected GS accuracy for different traits, and (4) bioinformatics requirements must be well researched and overcome before GS can gain an important role in increasing genetic gain. However, the big issue with GS is that it is only an incremental improvement over phenotypic/genotypic selection for yield. This incremental improvement will accrue more cost and is extremely difficult to monetize in the market. A 1% higher yield? Yes, I'll pay more for that, said no farmer ever!

Gene editing

A very promising technology is gene editing (for example CRISPR). It is simply too new in forage cultivar development to have a record of direct impact. The New Zealand government regulatory agencies are taking an initial stand that all products produced by gene editing be considered as GMOs and no different from transgenes in terms of regulatory requirements (Caradus et al., 2021). It is not clear if this is widespread among regulatory agencies, but it needs to be thoroughly considered before investing in this technology.

REALITIES TO CONSIDER

There are critical decisions for anyone on when and how to invest in any technology, but especially biotechnologies. Important fundamental issues are (1) eventual reversion to the mean performance of any new cultivar, (2) high initial costs of any technology, and (3) can any increased R&D budgetary costs be passed onto the seed seller and buyer (what will the market bear and what will the farmer pay)?

Sales and marketing of new cultivars are momentum-driven, but performance of a new cultivar is mean-reverting over time. This is not a good model for the long-term "rate of return" success for investing in any costly technology. One must therefore recover a cultivar's R&D and technology costs and make a profit before it mean-reverts and loses its market power. There are some very old US forage cultivars that escaped the mean reversion phenomenon, but this was probably due to market stratification and their low cost, which will be discussed in a later section. These cultivars are also few in comparison to those that did not escape mean-reversion.

Biotech-based programs dramatically increase costs and risks over traditional phenotypic/genotypic selection. Costs and issues for deploying transgenes into a new cultivar are very problematic as described earlier. If traditional phenotypic/genotypic selection increased yields at an estimated

0.5% per annum over time, then applying genomics must achieve higher genetic gain and consistently beat this phenotypic/genotypic baseline index to justify its increased cost. As mentioned above, GS has been, at best, only an incremental improvement over phenotypic/genotypic selection for yield and its accrued cost is difficult to monetize in the market.

Finally, any additional R&D and technology costs are eventually passed along to the farmer seed buyer. From my own experience at the point of sale, it is easy to see that many forage farmers are cost-sensitive and risk-averse. They push back and purchase a lower-cost product unless convinced of the more costly product's added value (this is where the marketing and sales staff become important). It is hard now to see what future traits will be of such importance to justify potentially higher purchase prices.

Effects on the seed industry and their interaction with forage–livestock producers

All commercial cultivars strive to assume market share by performance. Performance is correlated with the traits that it possesses. The sum of all the traits is sold as better performance, especially better yield. Yield is still the ultimate performance indicator of a cultivar in the seed market and on the farm. The result of prior investments for many forage crops was a steady, but low increase in yield over time using a collection of unique parents, hybridization of these parents, and phenotypic/genotypic selection methods to develop and test new experimentals. From a breeding perspective, these systematic yield increases, when they did occur as not all did, were due to genetic gain, although development and use of management variables such as pesticides, fertilizers, irrigation, and so forth were also impactful.

What was the effect of striving for efficiency and using technologies on products to be sold by the forage seed industry? Well, it has stratified the industry. Seed and sprigging companies and sellers want more per unit margin returns with less inventory. They attain this with high-margin products containing either unique traits and/or better performance. However, many forage–livestock farmers and ranchers live in a high-risk economic world and normally want lower cost per bag unit when buying. This is why the 80-year-old forage grass cultivar Kentucky 31 tall fescue (*Lolium arundinaceum* [Schreb.] Darbush.) is still sold today. It is this low cost and stability of performance that allowed Kentucky 31 and a few other cultivars to escape the reversion to the mean problem mentioned earlier. A similar case can be made for "Vernal" alfalfa. It is hard to overcome any of these situations with new cultivars that have costlier seed unless their performance is truly exceptional or they contain important value-added traits that farmers are willing to pay for.

To participate in this low-margin market, the seed seller must carry high inventory of these older, low-cost cultivars to supply the market and make some profit. This cost stratification then creates a tension between the sellers and buyers but also dictates how much research can be funded in the future. This is especially true with investing in high-priced technologies and directly impacts how much advertising and marketing can be done to promote a new product. Corn farmers normally justify high seed costs, but except for a very limited number of species, many forage crops cannot.

What can be done?

There is little doubt that the science behind biotechnologies, and their academic theory, is sound. One problem is to understand how they will fit into existing commercial forage breeding operations, given their high cost structure and inflexibility. The efficiency with which most current commercial forage breeding companies operates is often taken for granted by many decision-makers, multiple species with many traits being screened simultaneously, all done at a modest cost. Even with this complexity, it is reassuring that conventional phenotypic/genotypic selection remains hard to beat in forages, and it is flexible! Understanding and finding ways to implement any technology into this type of selection program in clever, cost-effective ways deserves more attention.

Future academic research can help greatly by concentrating on making any technology, but especially biotechnologies, (1) low-cost tools, (2) high-cost tools worth the cost, or (3) hopefully, both. As a low-cost tool, a technology must be able to lower its overall deployment and application costs (human, monetary, and capital assets) before it becomes useful, especially for companies with modest R&D budgets. It must also become more flexible for any company (forage or otherwise) developing cultivars of more than one species, across distinct populations within a species, and across multiple geographies.

If biotech remains a high-cost tool for specific crops, or even populations within those crops, such that only well-funded R&D units can afford to use it, then, standards for success will remain very high. For cultivar developers relying on high-cost biotech tools, this means achieving a rate of genetic gain that cannot be achieved by flexible and low-cost phenotypic/genotypic selection. Outcome performance must therefore be high (must be an alpha generator and consistently beat the mean performance base index), consistent, and at lower costs.

Finally, all seed companies must help by offering political support for continued government funding for public and academic research to address these problems. Their breeders need to participate in meetings, symposia, and seminars on any evolving scientific outcomes. It is from this outcome knowledge that companies will know when, how, with whom, and how much to invest. However, industry participation at many scientific conferences declined over time, with attendant loss of connection between industry and academia. Another related point is that the seed industry has become stronger relative to academia. Trade secrets about breeding methods, germplasm use, and so forth have become more prevalent. Previously, commercial companies registered cultivars, explaining a little about their origins, and so forth. They no longer do so. Therefore, important information is becoming less and less available to the breeding community at large. This will have a long-term negative consequence on cultivar improvement (not just forages), and yet, this is probably not on anyone's radar.

CLOSING WITH SOME PRACTICAL ADVICE

The reader is now provided with some practical things learned over 50 years. When applied, they allowed me, and others, to become better at our craft, maybe not great, but definitely better.

Collaboration

Good students, postdoctorals, technical staff, and collaborators (especially from other disciplines) will make you better and smarter. The team approach is best when developing commercial cultivars! I have been blessed with many great students, postdoctorals, and colleagues over the years and any success is due to us working as a team.

Know the market—Especially seed sales and production

Will your variety produce enough seed to reward the seed producer on a per unit of production basis? Do you understand that you are dealing with a perishable product that only has limited storage, planting, and sales windows? Do you understand that at the point of sale, everyone (seed production manager, seed shipping and sales staff, distributors and dealers, and the farmer buyer) is manic because decisions are driven by things beyond their control like the weather? Do you understand that a company can accumulate high costs, debt, and risk before the first bag of seed of any new cultivar is sold? One needs to ask these questions before expending too many resources on some new trait or species that may not meet the expectations of the seed industry. Experience in these areas would be extremely helpful, maybe closer personal relationships and internships for students?

Understand basic forage production and management principles (grazing persistence is as important as yield)

Forage breeders are heavily trained in breeding, genetics, statistics, and molecular biology, and rightfully so. However, the production systems and species diversity will impact developing and using cultivars within those species. A breeder needs to know how a forage–livestock system is managed for profitability. The following also needs to be assessed: What is the effect of the animal on the forage and what is the effect of the forage on the animal? These plant–animal assessments are best done by understanding proper forage management and underlying forage crop production principles. The reader needs to note that the following paragraphs are focused on grazing and not hay production. However, both are important to forage producers, and one must understand the basic production principles underlying both systems.

On reflection, I see in my own career a milestone event that speaks to the value of understanding and using basic forage management principles in setting breeding goals and strategies. This included being a student in Dr. G. O. Mott's tropical forages management class at the University of Florida, Gainesville, FL, USA. I am not sure I am going to heaven, but I know I walked with the angels during that course!

Dr. Mott was a giant in forage management and production and emphasized to us budding forage breeders in his class that yield (hay or grazed forage) is critical and grazing tolerance and persistence are as important as yield for pasture species. After all, no persistence, no yield. If the primary trait for any forage species, especially perennials, is grazing tolerance, then early generation testing for survival under animal grazing was necessary. In other words, why advance genotypes in the breeding program if they were not persistent under overgrazing pressure? First of all, although grazers strive for the optimal grazing pressure, a likely outcome in the real world is overgrazing due to weather conditions. Second, this type of selection is based on tried and true selection for pest resistance (e.g., overgrazing is analogous to heavy pest inoculation to prevent escapes or cattle just become large insects or pathogens). It is a simple breeding approach to avoid escapes and make sure that every plant is exposed to the stress. We used this approach to develop “Alfagraze” and other persistent, grazing-tolerant alfalfa cultivars. At the time, alfalfa was not used as a pasture species due to its lack of grazing persistence. The commercial success of grazing tolerance as a trait, and particularly Alfagraze as a leading product, also allowed Alfagraze to be used as a platform for inserting the RR biotech trait and produce the cultivar Alfagraze 600RR that is still sold today. This is also an example of name recognition and economy of scale since original R&D costs for both RR and Alfagraze were already borne and their names were positive terms to the farmer-buyers.

Naturally occurring ecotypes have great value

Forage species were planted by farmers over the years in a specific geography, but many of these farmers concluded that stands were failures. This does not mean that individual plants did not perpetuate and either they or their offspring still survive in these paddocks. These survivors were subjected to the natural pasture stresses and weather conditions and are called naturalized ecotypes. For example, parents of three major cultivars still planted today and found on millions of acres, “Coastal” bermudagrass (*Cynodon dactylon* L.), “Pensacola” bahiagrass (*Paspalum notatum* Flugge), and “Kentucky 31” tall fescue, were from ecotypes. Recently, white clover (*T. repens* L.) ecotype collections that we made throughout Georgia pastures resulted in the development and release of "Durana," now a commercially successful cultivar noted for its persistence, especially in mixed pastures. These ecotypes were intermediate and not ladino types and so it also provided research information of the importance of intermediates as base germplasm, probably due to their stolon density and reseeding ability. Naturalized ecotypes can therefore become very important base germplasm for your breeding program.

The eye of the breeder

Harlan (1981) mentioned the term "art and science" during his IGC presentation. Art invokes creativity and imagination. For cultivar developers, it is the "eye of the breeder." There is something to this, I believe. The best advice is to live with your plants where they live and get to know them as individuals, how they look and change, and be creative and use intuition. One cannot do this in front of a computer screen.

It is unclear if on-farm experience helps develop the eye of the breeder, as many with no direct experience are good. However, for me, it was important and critical. Even as a child, living with crops in all weathers and the economic risks created were a hard education. Those without on-farm experience need to be doubly careful, and do not be the last ones to know what the practicing farmer knows, and most importantly, believes. At the very least, forage breeders need undergraduate training in agronomy and forage management.

Is there an easier or better way?

If some breeding strategies are too costly and problematic, then make sure that you need to use them; this is particularly true of biotechnologies. Figure 2 demonstrates that progress is made, and cultivars developed, by choosing the correct base germplasm or using simple selection methods. In the picture comparing the two tall fescue paddocks, the lesson learned was that the breeding program targeting low-rainfall areas needed to begin with the summer-dormant base population and not the traditional summer-active germplasm. The tall fescue summer-dormant germplasm was then used to develop the cultivar "Chisholm." The original crabgrass cultivar, Red River, headed too early and lost nutritive quality and yield in late summer. Phenotypic mass selection for later heading date became a simple and cheap way to change this highly heritable trait. The late heading crabgrass was commercialized as "Impact."

Local versus global issues

We are now living in an era of peace (no world wars) and prosperity (amazing reductions in global poverty rates) that would marvel our recent ancestors. The result is a notable shift from a singular focus on maximizing pasture productivity early in my career to now a breeder who must account for sustainability, social, and climate issues (Klotz & Bouton, 2021). Currently, integration of any agritech developments into current pastoral systems will require assessments of their negative impacts. This will challenge breeders, farmers, and society as a whole.

One must also remember that all issues are local, and forage breeding is done within a specific population of genotypes and a specific population of environments. Your target environment is certainly local. It is the weather trends within your specific environment that are important to understand. In the day-to-day livestock farmer's world of pastoral agriculture, and by extrapolation the forage breeder world, weather changes, as they affect their crops and animals, are the concern. In other words, one year (or month or week), it could be extremely wet and cool, and the next, it could be extremely hot and dry such that weather records may be set in the same locale during a 12-month period. Although farmers normally talk about weather (short term) and not climate (long term), their weather concerns make them extremely risk-averse due to immediate economic needs.

Changing real-time weather events, and predictions of climate change, then represent a call for an "adjustment philosophy" for both farmers and forage breeders. From a breeding standpoint, programs developing new forage crop cultivars may need to concentrate on traits

FIGURE 2 The photo on the left shows summer-dormant tall fescue (paddock on left) versus summer-active tall fescue (paddock on right) fall recovery growth after a severe summer drought in Oklahoma. The photo on the right shows the results of two cycles of selection for later heading date in crabgrass (*Digitaria ciliaris* [Retz.] Koeler) (the parent population "Red River" is plotted on the left, while the late heading material on the right became the cultivar "Impact").

that allow performance under weather extremes. If you are convinced that it is getting hotter and drier, then plan breeding goals for hotter and drier weather. Breeding programs concentrating on stress tolerances will therefore continue to grow in importance. For the future, breeding strategies may be for even wider extremes, especially when weather is combined with the movement of forages onto more marginal lands. However, it is still most important to know what is going on in your target geography and not so much what is happening half-way around the globe.

Do not forget the germplasm

This should be unquestioned, but with all the emphasis on traits and technologies, even in this paper, it is important to remember that one needs an extensive collection of base germplasm. Storage, curation, and real-time inventory of this collection are critical; technology helps with this too. Remember that if you are trying to add an important trait, it is best to do that onto a platform that includes many other desired traits that are the end results of years of plant collection and selection and cultivar development.

CONCLUSIONS

Forage breeding and cultivar development, and its seed sales industry, are still critically important to forage–livestock farmer livelihoods and our overall food supply. Developing and applying new technologies remain critical for efficiency and advancement, but costs and farmer acceptance always need to be assessed. Forage breeding enjoyed a long history of success and made direct contributions to improving pastoral agriculture. The complexity and success with which most breeding projects operated are undervalued, with many species and traits screened at reasonable costs. Conventional phenotypic/genotypic selection remains a flexible strategy that is hard to beat in forages.

However, earlier in this paper, it was pointed out that in the more recent IGCs, forage breeding, genetics, and biotechnologies lost some importance. For example, during the IGC that I first attended in 1981, there was a specific plenary speaker and a breeding session that included over 50 papers. At the upcoming 2023 IGC, there is no specific plenary speaker or session listed in the posted program containing the key words forage breeding or related terms. One only finds a few papers scattered throughout the rest of the program within general grassland production and utilization sessions. Maybe other conferences are filling the need. It may also be that the IGC itself has rightfully changed emphasis due to the attendees seeking more presentations around biodiversity, climate, sustainability, and social issues. Nonetheless, it is a worrying trend for the future of forage breeding and cultivar development when the main international conference with the longest history is reducing emphasis. This changing emphasis will not only challenge breeders but also farmers and society as a whole. One only has optimism due to the current success and importance of the global commercial forage seed industry.

Since our world's population is now estimated at over 8 billion souls, with each person still needing adequate food and nutrition on a daily basis, nonproduction goals can only be met if we continue to feed people. Therefore, a quote from Vaclav Smil's book, *How the World Really Works*, in the chapter devoted to agriculture production, certainly states an obvious conclusion for everyone to consider:

> Modern agriculture's higher yields are not produced with a fraction of the labor that was required just a lifetime ago because we have improved the efficiency of photosynthesis, but because we have provided better varieties with better conditions for their growth by supplying them with adequate nutrients and water, by reducing weeds that compete for the same inputs, and by protecting them against pests. Concurrently, our much increased capture of wild aquatic species has depended on expanding the extent and intensity of fishing, and the rise of aquaculture could not happen without providing requisite enclosures and high quality feed.
>
> All these critical interventions have demanded substantial—and rising—inputs of fossil fuels; and even if we try to change the global food system as fast as is realistically conceivable, we will be eating transformed fossil fuels, be it as loaves of bread or as fishes, for decades to come.

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Joseph Henry Bouton: Conceptualization; writing—original draft; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable—no new data were generated; the article describes entirely theoretical research.

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