

From the Gene to the Field: A Retrospective Summary of Alfalfa Research by the USDA-ARS-Plant Science Research Unit

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The USDA Agricultural Research Service (ARS) Plant Science Research Unit (PSRU), located in St. Paul, Minnesota, has conducted extensive research on alfalfa to improve its productivity, quality, and usefulness in modern agricultural systems. The major focus of PSRU alfalfa research is genetic improvement and breeding. The unit was founded in 1955 with a plant pathologist to work on alfalfa diseases, primarily bacterial wilt and several foliar diseases. A research geneticist joined the team and together they developed the first *Phytophthora* root rot variety Agate, winter-hardy disease resistant cultivars, and other germplasms that became the basis for commercial varieties. The screening and evaluation techniques developed at St. Paul (bacterial wilt, *Fusarium* wilt, *Phytophthora* root rot, fall dormancy) became national standards. Studies on the inheritance of disease resistance, flower color, leaf traits, seed coat color, and root traits and development and characterization of core collections, were the basis of training a large cohort of alfalfa geneticists who found positions in industry, academia, and ARS. The addition of two plant physiologists resulted in ground-breaking research to measure nitrogen fixation in lab and field situations and research into the plant enzymes involved in nitrogen and carbon assimilation in nodules. Mutant ineffective alfalfas lacking the ability for nitrogen fixation were identified, characterized, and released. These mutants are used worldwide in nitrogen fixation research and for remediation of nitrate from soil and water. In addition, 'Nitro' alfalfa, the first legume variety selected for enhanced nitrogen fixation and nitrogen assimilation was released. Research capacity was enhanced by the addition of a soil scientist and dairy scientist. In the 1990s to early 2000s research focused on developing alfalfa with novel root architecture for reducing nitrogen losses to the environment and a biomass type as a bioenergy feedstock. The team evaluated alfalfa leaf and stem fractions of alfalfa as animal feeds and measured the environmental, agronomic, and economic benefits of alfalfa rotation with corn. Alfalfa was shown to prevent nitrate runoff and to remove nitrate from tile drains. Terminating a three-year-old alfalfa stand releases sufficient nitrogen for the subsequent corn crop. A long-term project, now coming to fruition, was launched to identify the traits relating to nutritional quality and to select for alfalfa stems with improved fiber digestibility. Expertise added in molecular genetics resulted in the development of a rapid and efficient alfalfa transformation system to examine expression of genes and develop alfalfa with novel traits. Current work focuses on development and use of genomic tools including gene editing and DNA markers to accelerate breeding for disease resistance, stress tolerance, and improved fiber digestibility. Current research includes characterization of microbial communities for enhancing yields, stress tolerance, and disease resistance. The unit explores new uses for alfalfa, including human food products, which can increase the acreage of alfalfa and improve agricultural sustainability. By coordinating research across multiple laboratories and engaging stakeholders, the PSRU ensures that alfalfa research addresses real-world agricultural challenges and contributes to improved soil health, environmental sustainability, and farm profitability.