0156

IMPROVED RANGE PLANTS

SOCIETY FOR RANGE MANAGEMENT
Range Symposium Series
Number 1

The Society for Range Management, *established in 1948, is an international professional organization composed of individuals with a common interest in the study, management, and rational use of rangelands and related ecosystems. The Society's objectives are:*

–to develop an understanding of range ecosystems and of the principles applicable to the management of range resources;

–to assist all who work with range resources to keep abreast of new findings and techniques in the science and art of range management;

–to improve the effectiveness of range management to obtain from range resources the products and values necessary for man's welfare;

–to create a public appreciation of the economic and social benefits to be obtained from the range environment; and

–to promote professional development of its members.

SRM has approximately 5,000 members–representing more than 55 countries in all parts of the world–who are research scientists, ranchers, government agency administrators, technical assistance personnel, educators, students, and people associated with business and industry.

The Society is organized as a nonprofit corporation under the laws of the State of Wyoming. Its headquarters are located at 2120 South Birch Street, Denver, Colorado 80222.

RANGE SYMPOSIUM SERIES
NO. 1 OCTOBER 1975

IMPROVED RANGE PLANTS

A symposium sponsored jointly by Society for Range Management, American Society of Agronomy, and Crop Science Society of America; presented at Annual Meeting, Society for Range Management, Tucson, Arizona, February 5, 1974.

Editors:
Robert S. Campbell
Carlton H. Herbel

SOCIETY FOR RANGE MANAGEMENT
2120 SOUTH BIRCH STREET
DENVER, COLORADO 80222

first edition, first printing

Library of Congress Catalog Card Number: 75-35299

This publication is dedicated to the memory of Francis T. Colbert, June 3, 1923-April 11, 1974. He was Executive Secretary of the Society for Range Management from 1968 to 1974 and helped to arrange for the organization and publication of this symposium.

Printed in the United States of America
Belke Printing Co., Denver, Colorado

Table of Contents

Foreword

Improved Range Plants in Resource Management is the first in a new numbered series of range symposia to be published by the Society for Range Management. One or more symposia have been presented at each of the 28 Annual Meetings of the Society, but publication of the papers has been highly variable. A few complete symposia have been published in the *Journal of Range Management* or in separate bound volumes; many individual symposium papers have been published in the *Journal.* This group of papers on improved range plants is a worthy choice to introduce the new series. We trust that the Society will continue to publish timely and informative symposia in the future.

The **Range Symposium Series** differs from the **Range Science Series, Range Monographs**, and other special publications of the Society. The word "symposium" itself has an interesting and pertinent origin. Webster defines it in part as follows:

> 1. In ancient Greece, a drinking together, usually following the banquet proper, with music, singing, and conversation; hence a banquet or social gathering at which there is free interchange of ideas. 2. A conference at which a particular subject is discussed and opinions gathered; also a collection of opinions on a subject, especially one such published in a periodical.

The Society undertakes the publication of symposia to update the status of information on a particular subject and to make the information available to a far greater audience than is in attendance at a single annual meeting.

The **Range Science Series** was planned to cover at least 18 specific topical aspects of range management and range science. These publications apply to range ecosystems the knowledge of other disciplines, such as soils, plant physiology, meteorology, animal husbandry, etc. They are not intended to be exhaustive studies; rather they are designed to give a summary of current information on a particular aspect of range science, indicating applicable principles and problems. The first three books on the Range Science Series were published as No. 1, *Rangeland Hydrology*, No. 2, *Rangeland Entomology*, and No. 3, *Rangeland Reference Areas.*

The **Range Monograph Series** is still different in purpose and coverage. Each book in this series is a special in-depth treatise of known information, well documented, on a single subject. The first published monograph covers some 60 years of research and experiences on the Jornada Experimental Range in southern New Mexico.

In addition to the numbered series, the Society has many unnumbered special publications, such as workshop proceedings, *Glossary of Terms Used in Range*

Management, Career Opportunities in Range Management, "Benchmarks"—a statement of concepts and positions of SRM, and various organizational handbooks. All of these are in addition to the professional *Journal of Range Management* and the more popularly oriented *Rangeman's Journal,* both published bimonthly.

Lest the reader wonder at the multiplicity of publications issued by the Society, we want to stress that the Society does not suffer from an overabundance of funds—quite the contrary. However, SRM has, as one of its goals, the objective of educating its members and the general public on subjects pertaining to rangelands. In fact, one reason the Society was organized in 1948 was to help meet the need for widespread public understanding of worldwide range resources and problems. Rangeland occupies more than 40% of the earth's land area, as compared to forest land (30%), cropland (10%), urban-industrial (4%), and "non-productive" high mountains, barren deserts, etc. (15%).

Most of the values of rangeland depend upon the maintenance of plant cover under usually scant and highly variable precipitation. In the process of grazing these lands during the centuries, some areas were abused and depleted, especially during severe and prolonged drought. Throughout recorded history, man has searched to find or develop better plants—for crops, fruits, and grasses. As indicated in Dr. Herbel's Introduction to this symposium, range people have participated in this search for better plants. Progress has accelerated in recent decades, as detailed in the several articles. This volume is a much-needed and valuable documentary of that progress.

D. LYNN DRAWE
Chairman, Publications Committee, SRM, 1975
Welder Wildlife Foundation
Sinton, Texas

DAVID A. SMITH
Executive Secretary
Society for Range Management
Denver, Colorado

May, 1975

Preface

This symposium was organized to bring together leading scientists to summarize progress in improving range plants and to suggest some possibilities for future advancement. It was sponsored jointly by Society for Range Management, American Society of Agronomy, and Crop Science Society of America, and presented at the 27th Annual Meeting of the Society for Range Management in Tucson, Arizona, February 5, 1974. The objectives of the main papers were: (1) to update information on selected range plant improvement problems in the western United States and Canada, (2) to document the need for such work under a variety of range conditions and uses, (3) to illustrate methods, procedures, and equipment for selection and breeding, as adapted to stress conditions on the range, and (4) to suggest needed and promising lines of endeavor for future work. Although much of the information pertains to specific locations where work is under way, the ideas and principles should apply throughout the Americas and worldwide.

Each of the participants in the symposium is an expert on his subject, a fact that contributed to an authoritative and well-rounded program. Common and scientific plant names can be a problem. In this book, we have left the matter to the judgment of the several authors, either to follow usage of previous authors quoted or to use generally recognized and approved names. We are deeply grateful to the authors for their cooperation in preparing and presenting the papers at the Annual Meeting and in their energetic collaboration in followup for publication.

We must acknowledge the able assistance of Drs. L. Neal Wright and J. O. Klemmedson in organizing this part of the Annual Meeting program. We must also acknowledge the encouragement and assistance of Publications Committee Chairmen Jeff Powell for 1974 and Lynn Drawe for 1975, and Executive Secretaries Francis T. Colbert and David A. Smith, and SRM Associate Editor Pat Smith in completing this publication.

ROBERT S. CAMPBELL
CARLTON H. HERBEL
Editors

Introduction

Vegetation on some rangelands has been depleted by droughts, past grazing abuses, and replacement of desirable plants by less desirable or unwanted plants. Some of these ranges can be restored by minimizing the causes of depletion and allowing secondary succession to increase range condition to satisfactory levels. On some ranges the desirable plants have been practically eliminated so that secondary succession would be very slow or nonexistent. Seeding is an important improvement practice on these ranges, as well as on those where plants that are more productive or offer better ground cover can be introduced.

Some range revegetation was attempted before 1930, but the program accelerated during the late 1930's in an effort to reclaim lands that were depleted by drought and were in dust-bowl condition. Most of these early seedings used various broadcast techniques or ordinary farm machinery. There were some successes, especially where soil and moisture conditions were favorable. But many of the seedings failed. An important benefit from this early work was recognition of four basic considerations for successful artificial range revegetation: (1) adapted species, (2) suitable site conditions, (3) suitable methods of seeding, and (4) management of seeded stands. In the late 1940's began the development of equipment specifically designed for seeding rangeland. Furthermore, emphasis was given to improving the microenvironment through seedbed preparation to increase chances for successful seeding. Further improvements in seedbed preparation methods have been made in recent years.

Along with the improvement of seeding methods, an improvement has been made in plant material available for range seeding. Good examples of what we can expect from improved plant materials and the problems involved are offered by crested wheatgrass (*Agropyron desertorum*) and some other species. Crested wheatgrass is the most successful introduced grass grown in the Northern Great Plains and much of the western United States. It was first brought into this country from the USSR in 1898, but as far as is known, none of this original introduction was ever increased or distributed. The second lot of seed of crested wheatgrass from the USSR was obtained in 1906 and seed was distributed to 15 experiment stations. Plantings at Newell, South Dakota, and Mandan, North Dakota, during the period 1908–15, were responsible for the early distribution and establishment of crested wheatgrass in the United States. A few early workers were enthusiastic over the great possibilities of this species. They tested, distributed, and promoted it for 25 years before it was really included in many seedings, beginning with the drought years of the 1930's.

The first recorded introduction of smooth bromegrass (*Bromus inermis*) was obtained by the California station from Hungary in 1884. This introduction was widely distributed, and bromegrass was highly recommended in Nebraska as early as 1897–98. About this time, Canadian provinces were growing bromegrass from seed imported from northern Germany. Importation of seed from the USSR in 1898 gave the greatest boost to the use of smooth bromegrass in the Northern Plains.

The first recorded introduction of Russian wildrye (*Elymus junceus*) from the USSR into the United States occurred in 1927. It was first increased at Mandan, North Dakota, in 1935 and eventually was released for general use in 1941. As with crested wheatgrass, it caught on rather slowly, and it has only been since about 1960 that extensive acreages have been seeded.

The first recorded introductions of blue panicgrass (*Panicum antidotale*) into the United States in 1912 came from India. The introduction of A-130, the most widely used strain in the Southwest, was received from Australia in 1932 but it was not formally released until 1950.

Weeping lovegrass (*Eragrostis curvula*) was introduced from Africa in 1927. Boer lovegrass (*E. chloromelas*) and Lehmann lovegrass (*E. lehmanniana*) were introduced from South Africa in 1932. Widespread use of these species has occurred only in the last 10 to 15 years.

These are but examples of introduced plant materials adapted to rangelands and the time it takes for testing and acceptance. During the last 75 years of foreign exploration, how many accessions have been lost that may have been equal to or better than the plants mentioned above?

Prostrate summer cypress (*Kochia prostrata*) was introduced into the United States from the USSR in 1959 and is now undergoing testing at several locations. Do we have the best accessions for some of the varied ecotypes? Will it be poisonous to animals under some of our conditions as are other *Kochia* spp.? In the summer of 1974, I observed a large field of prostrate summer cypress growing in central Asia in an area with 175 mm annual precipitation. It was producing 1,000 kg/ha compared to 250 kg/ha from adjacent unimproved range. We were told of mixtures among *Kochia prostrate, Haloxylon aphyllum, Salsola paletzkiana, Allenia subaphylla, S. orientalis, Artemisia diffusa,* and *Poa bulbosa* var. *vivipara* in the same area producing up to 4.210 kg/ha. Few of these plants are presently being studied in North America.

What are the possibilities of other plant introductions and better range plants from plant breeders? When we examine the progress made in crop plants such as corn and wheat in the last 50 years, is there any reason to expect less from selection and breeding studies with range plants? It is our conviction that the major way to substantially increase livestock and wildlife production from rangelands is through various range improvement practices. One of these practices is revegetation with improved and/or introduced species or varieties. We are all familiar with the benefits derived in some areas from introducing the various wheatgrasses and lovegrasses. In central Asia and Australia there are examples of forbs and shrubs that greatly increase production from rangelands. The possibilities for greatly improving range productivity exist, but we must place increasing emphasis on this phase of range research to capitalize on them.

CARLTON H. HERBEL
Research Leader, Jornada Experimental Range
Agricultural Research Service, USDA
Las Cruces, New Mexico

Improving Range Grasses for Germination and Seedling Establishment under Stress Environments

L. Neal Wright
Research Leader
Western Region, Agricultural Research Service,
US Department of Agriculture
and Professor,
Department of Agronomy and Plant Genetics
University of Arizona,
Tucson, Arizona 85721

The research is a contribution from the Western Region, Agricultural Research Service, US Department of Agriculture, and Department of Agronomy and Plant Genetics, University of Arizona, Tucson, Arizona 85721. Arizona Agricultural Experiment Station Journal Paper No. 2291.

Abstract

Environmental stresses of arid lands limit seedling establishment and restrict the potential growth of plants. These stresses include high temperature, low temperature, low humidity, erratic distribution of rainfall, soil salinity, and the unpredictable extremes and interactions of these and other factors. They interfere with uniform germination, initial growth, stand establishment, and development of plants. Proper cultural techniques and rigorous genotypic selection are necessary to minimize effects of environmental stress so that seedlings can become established. Genetic characteristics that adapt the seedlings to survival in stress environments of arid lands have a major influence on the acceptance and success of seeding in present-day range management.

The primary requirement of grass species used for seeding arid lands is acceptable germination, seedling emergence, and plant establishment under stress environments. The manager of arid lands needs seed that have this performance capability, which is termed seedling drouth tolerance. He can have this kind of seed only with improved cultivars.

This paper reviews the status of the art and science to improve grasses for seedling establishment under stress environments of aridity. Four major topic areas are presented: (a) components of stress environments, (b) seedling vigor, (c) mode of reproduction, and (d) isolation of germplasm. Additionally, this paper presents results of species chosen from the arid land grass-improvement program, Agricultural Research Service, Tucson, Arizona. The breeding goal is to develop improved cultivars of grasses to minimize the effects of environmental stresses and to promote seedling establishment under arid land conditions for increased efficiency of forage production.

Stress Environments

Establishment of plant species from seed and subsequent survival to maturity on arid land can be limited by any one or combination of numerous components of environmental stresses. Stress components discussed in some detail are: moisture, temperature, and salinity.

Moisture Stress

Limited, fluctuating, and unpredictable availability of moisture during the beginning phase of plant life is the primary environmental stress influence that restricts successful seeding of arid grasslands. Grasses vary in response to moisture stress during germination of seed and initial growth of seedlings. This variation is a necessary prerequisite for breeding to improve response to moisture stress.

Effect of moisture stress on plant response is a result of interaction of numerous components of stress environments (Shaw and Laing 1966; Schlatterer and Hironaka 1972). Influence of moisture stress is most pronounced during the early developmental phases of germination, emergence, and initial growth

(Slayter 1969). Water stress can alter the metabolic activity of imbibing and germinating seed to the extent that internal processes delay or terminate germination (Van Overbeek 1966). External water stress and rate of uptake of water can influence plant growth and development after imbibition by germinating seed (Collis-George and Sands 1959, 1961, 1962).

Delay of germination and reduction of rate and total percentage of germination of several range grasses resulted from increased moisture stress (McGinnies 1960). Other research showed that increased soil moisture stress did not delay germination of several range grasses, but total germination percentage and rate of initial seedling growth were reduced (Knipe and Herbel 1960). Emergence of grass seedlings was decreased by soil moisture stress during the first 3 days, with major influence from stress the first day after imbibition and initiation of growth (Herbel and Sosebee 1969). Reduced and fluctuating soil moisture was the major influence in preventing germination of seed of crested wheatgrass, *Agropyron desertorum* (Fisch. ex Link) Schult., (Wilson et al. 1970). Germinating seedlings of some plants can lose a very high percentage of total water content and survive periods of water stress (Milthorpe 1950). Additional evidence has shown the capacity of grass seedlings to withstand water loss without damage (Negbi and Evenari 1962).

Aqueous solutions of mannitol have been used to develop artificial moisture tension during germination of seed. Effectiveness of artificial environment to create limited moisture tension by chemical agents has been established (Knipe and Herbel 1960; McGinnies 1960; Knipe 1968). Differences within and among species of grasses for ability of seed to germinate under artificial moisture stress demonstrate the relationship among species for expected germination and establishment under natural moisture stress. Variability within species for germination under artificial moisture stress suggests the probability of improvement of tolerance to moisture stress through application of plant breeding principles.

Temperature Stress

Knowledge of physiological responses of seed and seedlings to temperature stress, interrelation of temperature with other components of environmental stress, and association of the responses with selection criteria are necessary for progress in developing improved range grasses for germination and seedling establishment.

High temperatures of soil, from 42 to 53° C, reduced germination and delayed emergence of seedlings of perennial grasses, and high temperature exposure during preemergence retarded initial growth (Laude et al. 1952). Response to temperature stress of soil up to 53° C during emergence and initial growth of numerous arid land species varied; however, seedling establishment and ultimate survival of all species decreased as temperature increased (Sosebee and Herbel 1969). Emergence of annual range grasses decreased (90%) as soil temperature was increased from 46 to 49° C (Laude 1957). Perennial rangeland grasses are relatively restricted in temperature ranges that allow germination in an annual-type rangeland community (Young et al. 1973). Interaction of intermediate temperature (20° C) and moisture stress was shown by improved germination while under high moisture stress (McGinnies 1960). Low temperatures inhibited or delayed germination of arid land grasses under various moisture-stress treatments of soil, which suggested that low soil temperatures increase the influence of moisture stress (Tadmor et al. 1969).

Salinity Stress

Two major influences that limit agriculture are salinity and aridity, individually and collectively, because saline soils and saline waters are common in arid environments (Boyko 1966). Soluble salts accumulate in soils of arid grasslands as a result of low rainfall, which is inadequate for leaching of salts. Concentration of salts in plant root zone influences germination of seed and initial seedling growth and limits successful establishment of plants.

Successful seeding on saline soils requires use of seed with capabilities of germination, initial growth, seedling establishment, and growth under moderate intensities of salt accumulations. Characterization of salt tolerance of plants is of major concern, so that we can understand the mechanism of action of salts on seed germination and growth of seedlings and mature plants. Enough variability for tolerance to salt is present within many arid land species for progress in plant improvement programs by plant breeders. Because specific physiological or biochemical characteristics of salt-tolerant plants are not yet definitive enough for selection criteria, the breeder must evaluate plants in artificial environments of salt stress to isolate salt-tolerant genotypes. These germplasm sources will provide plant material for detailed evaluation of components of response of plants with tolerance. An understanding of responses could provide the basis for specific selection criteria for more rapid improvement within plant species.

Comprehensive reviews of plant growth on saline soils include Hayward and Wadleigh (1949), Bernstein and Hayward (1958), Hayward and Bernstein (1958), and Strogonov (1964). An extensive bibliography of publications concerning saline and sodic soils is available (Carter 1962). Discussions of osmotic effects on individual plant species appear on several biological journals (Bernstein 1961, 1963; Greig and Smith 1962; Lagerwerff and Holland 1960).

Salt tolerance is expressed as the degree to which osmotic adjustment is made without significant sacrifice of growth (Bernstein 1961, 1963). Halophytes, the so-called "salt-tolerant plants," are those that accumulate salts in cell sap and can survive on soils with comparatively high concentrations of salt (Walter 1961). Osmotic adjustment is the rise in salt content of cell sap of roots commensurate with an increase in salt concentration of soil solution. Net increase in salts accounts for much of the osmotic adjustment, which primarily occurs during the dark period in roots and during the light period in stems and leaves (Bernstein 1961, 1963).

Salt tolerance of 25 strains of 14 *Agropyron* species varied both among and within species (Dewey 1960). Differences among strains of a species indicate that selection, with appropriate plant breeding procedures, could isolate germplasm with improved salt tolerance. Genetic potential within species is available for plant improvement of tolerance to stress environments, including salt tolerance (Fryxell 1954). Salt-tolerance and cation interaction during germination of alkali sacaton, *Sporobolus airoides* Torr., was inhibited by salts of sodium, magnesium, potassium, and calcium and interactions of these salts (Hyder and Yasmin 1972).

Salinity with excess moisture in soil during part of the season results in environmental stress unlike that of salinity with low moisture. *Paspalum vaginatum* Swartz, seashore paspalum, and *Puccinellia capillaris* (Lilj.) Jansen, alkaligrass, respond to the wet saline environments in Australia (Burvill 1956; Malcolm and Smith 1965). Variability of tall wheatgrass, *Agropyron elongatum* (Host) Beauv., cultivars for tolerance to boron is present, which suggests that boron in soil does not limit use of tall wheatgrass for revegetation of arid lands (Schuman 1969).

Seedling Vigor

Seedling vigor is an accepted asset. The response is expressed during germination and initial plant growth. Plant characteristics with precise influence on seedling vigor are not completely understood which increases the difficulty of the plant breeder.

Various characteristics that may influence seedling vigor and potentials for improvement are reported in research articles and in numerous comprehensive reviews. Inbibition, germination, emergence, and intial growth are phases of growth of major concern. Positive influence of weight of seed on one or more of these characteristics is reported (Wright 1971; Herbel 1972; McKell 1972; Kneebone 1972). Variability among and within grass species for seedling vigor attributes provides evidence that expression of vigor and seedling establishment is heritable.

Mode of Reproduction

Revegetation of extensive areas of arid lands is expected to continue through use of seed. Thus, grass breeders need an understanding of the modes of reproduction that form seed. Both sexual and asexual reproduction of seed are common within and among perennial grass species. Breeding methods, techniques, and expected effectiveness with sexually reproduced species are well known and defined. Sexually reproduced plants are predominantly self-fertilized or cross-fertilized. Differences between the two groups largely determine the choice of appropriate breeding methods for a specific improvement goal.

Apomixis refers to all types of asexual reproduction that replace sexual reproduction. Those forms of apomixis that provide avenues to produce asexual seed are of major concern to grass breeders, and use of the term, apomixis, is restricted to this concept. Two forms of apomictic reproduction through seed, facultative and obligate, are of primary interest and are common in the *Gramineae*. Descriptions and classifications of apomixis in grasses are presented by several authors (Myers 1947; Gustafsson 1946, 1947a, 1947b; Carnahan and Hill 1961).

Obligate apomixis provides the means of continual production of the same genotype from all seed. Assuming variability among apomictic sources, along with methods to distinguish favorable responses, grass breeders can take advantage of superior individual plants and provide true breeding cultivars without lengthy recombination and reselection programs. In essence, obligate apomixis provides progeny plants with maternal characteristics only and prohibits genetic recombination and segregation.

Presence of sexual and apomictic seed within an inflorescence of the same plant, termed facultative apomixis, allows for genetic recombination through activation of sexual embryos. Germplasm is unlocked from a facultative apomict, and the breeder can take advantage of outstanding individual plants that result from segretation. Germplasm resulting from recombination is evaluated for performance capabilities, and the genetic complement of superior individuals may be fixed and seed increased through obligate apomixis.

Obligate apomicts can be used as a source of untouched variability through crosses of obligate apomicts as the paternal parent with sexual plants of closely related biotypes as the maternal parent. Hybrids and plants from subsequent segregating generations provide data for inheritance studies of apomixis and the opportunity to isolate superior types from previously unavailable germplasm. Germplasm of superior individuals may be fixed and seed increased through obligate apomixis.

Isolation of Germplasm

Artifical Arid Land Environment Facility

A plant growth chamber was designed and constructed for precise control of environment to evaluate plant response. Controlled environmental factors are temperature, humidity, illumination intensity, day length, and air movement (Wright 1961). The plant growth chamber, a facility of the arid land grass breeding program, Agricultural Research Service, Tucson, Arizona, can be programmed to simulate the constantly changing environment of arid lands. Programmed environment for evaluation of seedling drouth tolerance represents environmental conditions of the first 10 days of August in the Sonoran Desert of the Southwest (Wright 1964b, 1965). This portion of the growing season is critical for grasses that are established during the warm season. Perhaps the most significant aspect of the artificial environment of the growth chamber for evaluating seedling drouth tolerance is that thousands of individual plants are exposed to controlled environment for precise and repeatable evaluation.

Data were collected to determine the capability of artificial environment to evaluate grass species for seedling drouth tolerance, to compare findings with known performance under natural environments of arid lands, and to determine potential variability under artificial environment for seedling drouth tolerance within species.

Performance under Natural Stress

Seedling trials under natural environments show superiority of three species of *Eragrostis* to three species of *Panicum* for seedling drouth tolerance and

Table 1. Performance ranking for seedling drouth tolerance under natural environments of arid lands of the Southwest among three species from each of two grass genera (Wright 1964b).

Species	Years observed (no.)	Performance ranking	
		Within each genus	Among all species
Eragrostis lehmanniana	25	first	first
E. curvula	20	second	second
E. intermedia	20	third	third
Panicum hallii	20	first	fourth
P. coloratum	15	second	fifth
P. andtidotale	20	third	sixth

provide relative ranking of species within each genus (Table 1). Species were ranked in descending order: *E. lehmanniana* Nees, Lehmann lovegrass; *E. curvula* (Schrad.) Nees, weeping lovegrass; *E. intermedia* Hitchc., plains lovegrass; *P. hallii* Vasey, Hall's panicgrass; *P. coloratum* L., kleingrass; and *P. antidotale* Retz., blue panicgrass. Performance information considers years, sites, varying seeding procedures, and seed of standard strains. Relative rank among species could be expected to be a reliable expression of seedling drouth tolerance and provide information to choose a species for improvement. Major importance of the findings under natural environment was to provide a basis for comparing performances for seedling drouth tolerance under artificial environments with natural environments.

Performance under Artificial Stress

Evaluation of grasses under artificial arid land stresses shows variability among and within species (Fig. 1). Seedling survival among *Panicum* species was critical on the 11th and 12th days of stress. Seedling drouth tolerance of Hall's panicgrass and kleingrass was superior to that of blue panicgrass. Most significant was superiority of *Eragrostis* over *Panicum*. The 18th through 20th days of stress were critical for plains lovegrass and weeping lovegrass. Seedling survival of Lehmann lovegrass was critical on the 20th and 21st days of stress. Seedling drouth tolerance of Lehmann lovegrass was superior to the other five species evaluated.

Seedling survival evaluation in artificial environment showed variability among species and verified that artificial environment confirmed known seedling drouth tolerance capabilities of the grasses. Because artificial environment differentiated grass genera and species for seedling drouth tolerance, differentiation among sources of a species was expected. Testing this was the next phase in the procedure to effectively isolate genotypes within a species for seedling drouth tolerance.

Variability within Species – Available accessions of blue panicgrass, weeping lovegrass, and various lovegrass species were evaluated under artificial environment for seedling survival (Wright 1965). The purose was to differentiate within species rather than to compare species. Accessions of blue panicgrass separated into six groups for survival response (Fig. 1). Weeping lovegrass accessions separated into four groups for survival response. Survival percentages of species of lovegrass separated into four groups. The significant finding is that variability for seedling drouth tolerance was clearly shown among accessions of blue panicgrass, weeping lovegrass, and other species of lovegrass. Survival percentages present a composite of individual plant evaluation, and isolation of genotypes within a species can be expected with confidence.

Species Improvement

Blue Panicgrass

Potential – Desirability of blue panicgrass, *Panicum antidotale* Retz., as an important grass for arid land conditions is recognized, and its limitations and capabilities have been described (Wright 1966). Blue panicgrass has the dual genetic potential of responding with outstanding forage production under

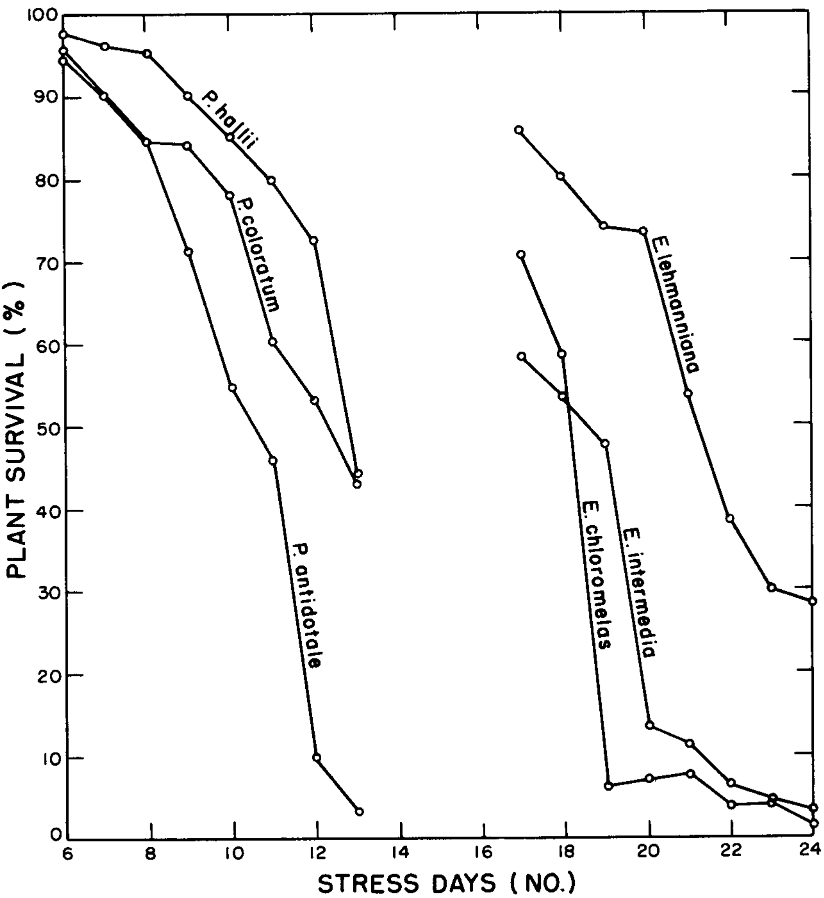

Fig. 1. *Performance for seedling drouth tolerance under artificial environment of arid land among three species of* Eragrostis *and three of* Panicum *(Wright 1964b).*

favorable moisture levels (Wright 1962), and of showing drouth tolerance by established plants (Wright 1966). Capacity of favorable performance under both optimum and stress conditions is expressed by few plant species, and by none that are adapted to arid lands of the southwestern United States. Cytological information on blue panicgrass, which is essential to plan and conduct an effective improvement program, showed that the species is a normally cross-pollinated diploid, 2n=18, with normal behavior for pollen, embryo, and seed development (Wright and Hall 1965).

Breeding for Seedling Drouth Tolerance – Development of the technique of artificial environment to evaluate seedling plants and its success stimulated research on breeding for seedling drouth tolerance of blue panicgrass. Daily environment of dry- and wet-bulb temperatures, day length, light intensities, techniques of seedling establishment, and procedures of collecting and processing data were similar to those previously presented (Wright 1961, 1964b, 1965).

Source materials were 36 sample populations of blue panicgrass, which had shown variability for survival under artificial stress. Presence of adequate variability among sample populations for seedling survival under artificial drouth evaluation suggested that, with appropriate breeding procedures, progress could be expected toward isolating genotypes for seedling drouth tolerance (Wright 1971a).

Recurrent selection, with continued cycles of selection and restricted recombination by random mating, was used to increase the frequency of genotypes for seedling drouth tolerance. Recurrent selection was effected through artificial environment, which provided stress and allowed 5%± survival of seedlings. Restricted recombination by random mating was effected by intermating mature plants, grown from surviving seedlings, to produce seed for the next cycle of recurrent selection of seedlings through artificial stress.

Frequency of desired genotypes was increased with continued cycles of selection and recombination. Survival percentages after six cycles ranged from 3.1 to 15.1 for progeny of sixth cycle plants with a mean of 7.3, while survival percentage of nonselected blue panicgrass was 5.3 (Table 2). Breeder seed of an experimental blue panicgrass was produced in 1973, and first increase of seed for field evaluation is expected in 1974.

Table 2. Performance ranking of blue panicgrass, *Panicum antidotale,* selections for seedling drouth tolerance under artificial environmental stress after six cycles of recurrent selection with restricted recombination (Wright unpublished).

Selection No.	Survival %	Rank
6-131	15.1	1
6-78	13.8	2
6-28	12.1	3
6-60	12.1	4
6-184	3.6	177
6-89	3.3	178
6-162	3.2	179
6-37	3.1	180

Characteristics Associated with Seedling Drouth Tolerance – Sample populations of blue panicgrass were evaluated for percentage of survival after drouth stress, rate of germination, percentage of survival after salinity and mannitol stress, and weight of seed. Results indicated a relationship between survival percentage and slow rate of germination. Salt tolerance and mannitol stress during germination were positively associated, but both were negatively associated with seedling survival. Findings suggested that adequate variability was present to expect success in improving characteristics that were investigated (Wright 1971a).

Seedling drouth tolerant and seedling drouth susceptible clones of blue panicgrass were evaluated for several responses to determine potential relations with seedling drouth tolerance. Data indicated that seedling drouth tolerance and efficient water use were not associated. As soil moisture stress increased, leaf thickness decreased; however, leaf anatomy was not associated with seedling drouth tolerance. Total amino acid content of clones grown under optimum soil moisture conditions was not associated with seedling drouth tolerance (Dobrenz et al. 1969). Stomata density was different among clones of blue panicgrass. A significant correlation coefficient, $r = -0.84$, between seedling drouth tolerance and mean stomata density indicated that clones with the fewest stomata per unit area were most drouth tolerant as seedlings (Dobrenz et al. 1969). Variability was present among and within blue panicgrass clones for various determinations of anatomical characteristics of primary roots of seedlings. Variability was irregular, and data did not indicate any criteria to identify germplasm of seedling drouth tolerant plants. Practicability of root anatomy as an isolation technique is questionable, because evaluation would involve large numbers of plants (Wright et al. 1972).

Results suggested that association of efficiency of water use, leaf anatomy, root anatomy, and total amino acid content were not adequate as criteria to identify seedling drouth tolerant plants, while stomata density could be positively associated. Plant materials of advanced generations with greater expression of seedling drouth tolerance will need detailed investigation to accept or reject these characteristics as criteria in selecting seedling drouth tolerant plants of blue panicgrass.

Germplasm Pools – Eleven germplasm pools, including the previously discussed seedling drouth tolerance germplasm, were developed through six cycles of recurrent selection and random mating by restricted recombination. Each individual set of germplasm originated by evaluation and selection from blue panicgrass sample populations.

Selection pressures included: a) heavy seed weight; b) light seed weight; c) rapid rate of germination; d) slow rate of germination; e) medium artificial moisture stress (7 atm mannitol); f) high artificial moisture stress (14 atm mannitol); g) calcium salinity stress; h) sodium salinity stress; i) magnesium salinity stress; j) trisalt salinity stress; and k) artificial stress environment for seedling drouth tolerance.

Functions of each major characteristic–seed weight, germination rate, artificial moisture stress, and salinity stress–are involved in the primary effects and interactions that influence seedling drouth tolerance. Germplasm pools of extreme types were developed for genetic response, i.e., plants to produce heavy seed, plants to germinate rapidly, plants tolerant to calcium stress, etc.

The isolation phase of the breeding program is relatively complete. Germplasm sources need evaluating for association of specific physiological and biochemical processes and morphological characteristics to determine changes that may have occurred in the species for each selection criterion. This basic information could provide knowledge of the mechanism of plant adjustments to stress environments, provide characteristics that are associated with specific responses, and could serve as criteria to isolate plants rapidly and accurately.

Weeping Lovegrass

Potential – Apomictic reproduction has been reported for weeping lovegrass (Streetman 1963). Thus, isolation of superior genotypes for seedling drouth tolerance depended on the presence of variability among sources. Variability was present which suggested isolation of superior genotypes by artificial stress (Wright 1965).

Performance under Artificial Stress – Artificial environment was used to evaluate 216 progeny plants that were selected from 16 sources of weeping lovegrass (Wright and Jordan 1970). Frequency distribution of selections was

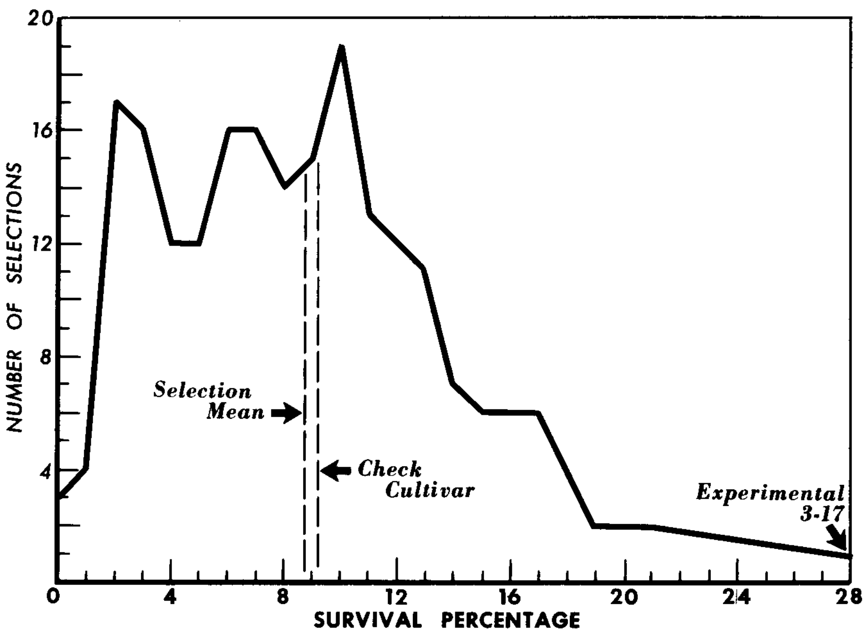

Fig. 2. *Frequency distribution for seedling drouth tolerance of weeping lovegrass,* Eragrostis curvula, *selections that were progeny evaluated by artificial environmental stress (Wright and Jordan 1970).*

skewed toward low survival percentages, which was expected with the 19-day stress period (Fig. 2). Selected plants represented a wide range of variability for arrificial environmental stress. Plant 3-17 showed three times the seedling drouth tolerance of the check cultivar.

Performance under Natural Stress – Final acceptance of plants improved for seedling drouth tolerance rests on performance under natural environments of arid lands. Performance of these lovegrasses showed that experimental weeping lovegrass 3-17 was superior to the check cultivar for seedling drouth tolerance. Performance of the experimental weeping lovegrass 3-17 for seedling drouth tolerance was equal to that of Lehmann lovegrass for all sites in the Southern Desert Shrub of Arizona. Findings confirmed the usefulness of artificial environment for consistent evaluation of large numbers of seedlings and for precise selection for seedling drouth tolerance under natural environments of arid lands.

Cultivar Catalina – Isolation of superior selections under artificial environment, which responded equally as superior genotypes under natural environments, resulted in the release of an improved cultivar (Wright 1971b). Catalina weeping lovegrass represents an extreme of the morphological variation in the species *E. curvula*. It reproduces by obligate apomixis. Catalina, tested as experimental 3-17, is adapted for seeding on arid land sites at elevations generally below 1,400 m with 30 cm minimum rainfall.

Interspecific Crosses – Many of the lovegrass species that have demonstrated promise as arid land grasses reproduce by apomixis. Few plants of the genus with sexual mode of reproduction have been available. Recently, a sexual plant of the Catalina type of weeping lovegrass was found. Interspecific crosses are planned. This research is in the beginning phases and has the potential to contribute to the evaluation of characteristics that were not expressed in apomictic plants and to studies of inheritance of apomixis.

Lehmann Lovegrass

Potential – Mode of reproduction of Lehmann lovegrass is by apomixis (Streetman 1963). Lehmann lovegrass sources showed variability for seedling drouth tolerance, which suggested the potential of isolating superior genotypes by artificial stress (Wright 1965).

Performance under Artificial Stress – Artificial environment was used to evaluate 36 lines and a commercial source of Lehmann lovegrass for seedling drouth tolerance (Wright and Brauen 1971). This species reproduces by obligate apomixis, and success in isolating sueprior levels of seedling drouth tolerance depended on variability among lines. Lines differed significantly in survival percentage (Table 3). Findings suggested that lines of Lehmann lovegrass represent a wide range of variability for response to artificial environmental stress. Research reconfirmed the usefulness of artificial environment for consistent evaluation of large numbers of seedlings and for selection of genotypes that are superior for seedling drouth tolerance. Superior lines have been designated as experimentals L-28, L-38, L-19, and L-11. Evaluation is now

Table 3. Performance ranking of Lehmann lovegrass, *Eragrostis lehmanniana*, lines for seedling drouth tolerance under artificial environmental stress (Wright and Brauen 1971).

Line No.	Survival %	Rank
L-28	32.4	1
L-38	30.2	2
L-19	27.3	3
L-11	25.6	4
L-17	6.6	33
L-29	6.2	34
L-24	6.0	35
L-4	2.5	36

proceeding under natural environments of arid lands.

Characteristics Associated with Seedling Drouth Tolerance – Variability among lines of Lehmann lovegrass was present for several seed and plant characteristics. There was a lack of acceptable association between growth habit, foliage color, anther color, chromosome number, seed weight, seed size, and seed color with seedling drouth tolerance. Thus, none of the characteristics investigated can be used as criteria to isolate for seedling drouth tolerance. Results did show that nondormant seed of heaviest seed weight could be discarded before critical evaluation without seriously influencing isolation for seedling drouth tolerance (Wright and Brauen 1971).

In contrast to the lack of positive association between efficiency of water use and seedling drouth tolerance of blue panicgrass (Dobrenz et al. 1969) and of weeping lovegrass (Wright and Dobrenz 1973), seedling drouth tolerance of Lehmann lovegrass was associated with efficiency of water use (Wright and Dobrenz 1973). Association of these two responses is most significant, because efficiency of water use of an arid land grass is a highly desirable response. Yet, efficiency of water use as a criterion for isolation of seedling drouth tolerant plants of Lehmann lovegrass, which will evaluate a comparatively few plants, is not practical when artificial environmental stress is an accepted technique that will accurately evaluate thousands of seedlings.

Stomata densities varied among lines of Lehmann lovegrass. Density was highest on the upper surface of the leaf blade of Lehmann lovegrass, but the opposite was true for blue panicgrass (Dobrenz et al. 1969). Low stomata density showed a relationship with seedling drouth tolerance of blue panicgrass. However, stomata density of Lehmann lovegrass did not show a consistent relationship with seedling drouth tolerance (Wright and Dobrenz 1973).

Plant Waxes – A comprehensive review of plant waxes (Kolattukudy 1970) concludes that the primary function of waxes covering plants is to protect the plant from excess water loss through transpiration and other hazards of stress environments. Ratios of petroleum ether extract to dry weight of leaves varied among lines of Lehmann lovegrass and were associated with seedling drouth tolerance (Wright 1973). This significant finding suggests a potential for fundamental research and a potential criterion for isolating seedling drouth tolerant genotypes of arid land grasses.

Seed Dormancy – Dormancy of freshly harvested seed of Lehmann lovegrass lines varied from no dormancy to complete dormancy (Wright and Brauen 1971). Seed dormancy may negatively influence stand establishment. However, delayed germination imposed by physiological and biochemical features of seed has potential advantages in relation to germination and seedling emergence (Wright 1971). Favorable response would be germination extended over a broader period of time to increase the probability of stand establishment and plant survival in a more favorable environment.

Dormant seed are metabolically alive, and knowledge of germination requirements was essential to characterize and evaluate seed dormancy of Lehmann lovegrass. Optimum germination environment consisted of alternating temperatures of 20°C in 16 hours of darkness with 30°C in 8 hours of light. Cylinder scarification was a simple and effective treatment to overcome seed dormancy. Definable differences among lines were not detected in the origin of structural parts of the fruit coat. Quantity of the water-soluble part of the gelatinous seed surface varied among lines, yet differences among lines were not related to seed dormancy. To add evidence, removal of the gelatinous seed surface did not overcome dormancy. Variability was found among lines for presence and quantity of chemical compounds of seed extracts. Yet presence or absence of chemical compounds was not related to seed dormancy of Lehmann lovegrass.

Results showed presensce and variability of seed dormancy of Lehmann lovegrass. Perhaps the importance for contributing features and functions of seed dormancy was essentially eliminated with the finding that seed dormancy of this species was not associated with seedling drouth tolerance. An inspection of seed dormancy data showed that a majority of the lines were dormant, and there was greater expression of variability in seedling drouth tolerance than in seed dormancy. Preponderance of germplasm with seed dormancy and with greater variability for seedling drouth tolerance could account for the lack of association between the two characteristics of Lehmann lovegrass.

Black Gramagrass

Potential – Black gramagrass, *Bouteloua eriopoda* Torr., is an important component of arid grasslands in the southwestern United States. It spreads vegetatively by stolons, but widespread use of this grass for seeding was limited by its extremely poor and unreliable seed setting capabilities. Thus, a major research objective was to maintain the many desirable characteristics while improving seed production. Most of the literature has been concerned with facts pertaining directly to or associated with management of black gramagrass rangelands. There has been a minimum of research on the more basic aspects of growth and reproduction (Wright and Streetman 1958).

Seed Germination – Knowledge of seed germination of black gramagrass was essential for conducting seed quality studies, for providing maximum number of progeny plants from selected material, and for providing adequate germination information for cultivar releases. Results of research to determine an effective germination procedure indicated that alternating temperatures of 20°C with 16 hours of darkness with 35° C in 8 hours of light, with 50 ppm of gibberellic acid in the solution, are the optimum laboratory conditions for germination of black gramagrass caryopses (Wright and Baltensperger 1964).

Seedset and Seed Production – Cytological research on black gramagrass indicated that the species is a normally cross-pollinated diploid, 2n=20, with normal behavior for pollen, embryo, and seed development (Streetman and Wright 1960). Thus cytological activities of reproduction and development of seed were normal and the potential for seed setting and seed production was limited by unexplained influences.

Research was conducted on management of black gramagrass for improvement of seedset and seed production under irrigation. Variables included preirrigation moisture levels, irrigation schedules, fertilizers, insecticides, and harvest dates (Wright 1964a). Findings suggested that presence of insects was not the limiting influence of seedset of plants grown with irrigation management at Tucson, Arizona. Results indicated the desirability of combining treatments for highest seedset and subsequent seed production. Treatments include initiation of growth on August 1 with 45 kg/acre of N fertilizer, applied to obtain highest seedset, germination percentage, and seed weight.

Seed production capabilities under cultivation were shown for black gramagrass although seedset had been highly erratic in nature. This response suggested a simple explanation. Black gramagrass is indeterminate for floral initiation and development. The species is largely cross-pollinated. Thus, under natural environments, plants are normally separated, with seed head development and pollination occurring over an extended period of the growing season. Pollination is then inadequate, and seedset does not occur. Under experimental conditions plant growth was stimulated at a given date with seed head initiation and development relatively determinate, which resulted in a mass of pollen to effect fertilization and seed formation.

Compilation of research findings of black gramagrass revealed that reproduction and growth functions were normal in spite of its long-standing characteristic of limited seed development. With these accomplishments and interpretations, the plant breeder could develop and release an improved cultivar, which was not possible until fundamentals of growth and reproduction had been defined.

Cultivar Sonora – Black gramagrass shows many desirable characteristics, including seedling and mature plant drouth tolerance and nutritious and palatable forage. Research revealed that the fundamentals of growth and reproduction of seed formation and seed production were not limiting. Knowledge of these functions provided a basis for developing an improved cultivar of black gramagrass. The cultivar 'Sonora' was released, based on outstanding performance in regard to leafiness, vigor, forage production, vegetative spread, components of seedset, and seed production (Wright 1968).

Sideoats Gramagrass

Potential – Sideoats gramagrass, *Bouteloua curtipendula* (Michx.) Torr., is a recognized component of grasslands in the western United States. Seed of present cultivars tend to germinate rapidly, but seedling plants do not become established under the environmental stresses of limited and sporadic rainfall and high temperatures. One way to exert some genetic influence on rate of germination would be to incorporate seed dormancy into the species. Seed dormancy characteristics could interact with environmental variables and allow germination to continue over a period of time. Successive surges of germination would expose the potential of seedling establishment to a broader array of environments in time and space and increase the probability of seedling establishment.

Presence and influence of germination inhibitors on germination and plant establishment in arid land environments has been discussed and documented (Evenari 1949; Koller and Cohen 1959; Oppenheimer 1960; Negbi and Evenari 1962; Koller and Roth 1963; Koller et al. 1964; Woolhouse 1969; and Wright 1971).

Seed Dormancy – The concept of seed dormancy of sideoats gramagrass was investigated to determine the presence, duration, and pattern of seed dormancy and to locate and identify dormancy conditioning factors of intact seed units (spikes of multiple spikelets). Postharvest dormancy for 4 to 6 months was present in all source materials. Long-term dormancy was present in seed units of dormant sources for 5 years. Mechanism of long-term dormancy involved interactions among several responses: light weight of caryopses, impermeable floral parts of caryopses, and presence of coumarin-like inhibitory compounds. Seed from dormant and nondormant units was increased in 1973, and evaluation can proceed under natural environments to determine the association of seed dormancy with stand establishment (Major and Wright 1974; Cole et al. 1974).

Seed dormancy could provide a positive influence for species establishment under natural environmental stresses of limited and sporadic rainfall. Characteristics of seed that determine the influence of germination inhibitors could interact with variable characteristics of the natural environment and permit seed to germinate and young seedlings to establish during brief and successive cycles of environmental variability. Establishment of plants through successive cycles could allow exposure to a greater array of natural environments in time and space, greatly increasing the probability of successful establishment.

Vine Mesquitegrass

Potential – Vine mesquitegrass, *Panicum obtusum* H.B.K., is best adapted to heavy textured soils at elevations below 1,800 m. It spreads vegetatively by vigorous stolons. Propagation by seed is difficult, and successful seedings are very rare, because germination percentage of seed is low and seedling establishment is limited by slow initial growth. An understanding of the mode of reproduction and the process of seed formation is needed to plan and conduct a program for improved seedling establishment with appropriate plant breeding procedures.

Research showed that diploid, 2n=20, plants of vine mesquitegrass reproduce sexually and polyploid plants reproduce by facultative apomixis. Apomixis creates irregularities in embryo and endosperm development of seed. Seed development is normal for the diploid, sexually reproduced, plants. With appropriate breeding techniques these plants should provide adequate germplasm to improve vine mesquitegrass for germination, seedling vigor, and establishment. Determination of the variability for development of both the embryo and endosperm is the initial step in understanding this limiting characteristic of apomictic plants of vine mesquitegrass (Anderson and Wright 1973).

Conclusion

Competition for use of land by desires, needs, and demands of an increasing world population exerts intensive pressure on all areas of the Earth's surface. Increased productivity of the vast areas of arid lands to share in the responsibility of providing for man's needs provides a continuing challenge.

Considering the magnitude of scientific advancement of plant research and development during recent decades, only meager attention has been directed toward understanding the basic functions of growth and reproduction of plants adapted to stress environments of arid lands. Knowledge of basic reproduction behavior, genetics, cytogenetics, and physiological and biochemical responses of germinating seed and plant growth and development is essential for planning and conducting a plant improvement program. The breeder would be remiss if he were to consume professional and physical resources in an attempt to use breeding methods that are inappropriate for the mode of reproduction of the species. Likewise, choice of breeding goals to strengthen mature plant characteristics of survival and quality would add little to the acceptance and use of a species, if seed and seedling characteristics limited initial establishment and ultimate use.

The tremendous variability among and within components of arid land environments leaves little doubt that stresses of aridity subject germinating seed and initial growth of seedlings to extremely demanding and varying conditions. Limiting influences of environment during early phases of plant establishment can be minimized by improved germplasm with capabilities of response along with improved cultural techniques. Research accomplishments, though not complete, are progressing toward this goal. Advances are expected to accelerate as expansion of research on productivity of arid lands becomes more urgent.

References[1]

Anderson, C. A., and L. N. Wright. 1973. Influence of mode of reproduction of vine mesquitegrass, *Panicum obtusum* H.B.K., on seed formation. Amer. Soc. Agron., Agron. Abstr. p. 2.

Bernstein, L. 1961. Osmotic adjustment of plants to saline media. I. Steady state. Amer. J. Bot. 48:909-918.

Bernstein, L. 1963. Osmotic adjustment of plants in saline media. II. Dynamic phase. Amer. J. Bot. 50:360-370.

Bernstein, L., and H. E. Hayward. 1958. Physiology of salt tolerance. Amer. Rev. Plant Physiol. 9:25-46.

---

[1] Reference list includes some publications not cited in text.

Boyko, H. 1966. Salinity and aridity–new approaches to old problems. Monograph. Biol. Vol. 16. W. Junk Publishers, The Hague. 408 p.

Burvill, G. H. 1956. *Paspalum vaginatum* for salt land. J. Agr. W. Australia, Vol. 5, No. 1, Bull. No. 2324, 2 p.

Carnahan, H. L., and H. D. Hill. 1961. Cytology and genetics of forage grasses. Bot. Rev. 27:1-162.

Carter, D. L. 1962. A bibliography of publications in the field of saline and sodic soils. USDA Agr. Res. Serv. ARS 41-80. 47 p.

Cole, D. F., R. L. Major, and L. N. Wright. 1974. Effects of light and temperature on germination of sideoats grama. J. Range Manage. 27:41-44.

Collis-George, N., and J. E. Sands. 1959. The control of seed germination by moisture as a physical property. Australia J. Agr. Res. 10:628-630.

Collis-George, N., and J. E. Sands. 1961. Moisture conditions for testing germinations. Nature 190:367.

Collis-George, N., and J. E. Sands. 1962. Comparison of the effects of the physical and chemical components of soil water energy on seed germination. Australia J. Agr. Res. 13:575-584.

Dewey, D. R. 1960. Salt tolerance of twenty-five strains of *Agropyron*. Agron. J. 52:631-635.

Debrenz, A. K., L. N. Wright, A. B. Humphrey, M. A. Massengale, and W. R. Kneebone. 1969. Stomate density and its relationship to water-use efficiency of blue panicgrass (*Panicum antidotale* Retz.). Crop Sci. 9:354-357.

Debrenz, A. K., L. N. Wright, M. A. Massengale, and W. R. Kneebone. 1969. Water-use efficiency and its association with several characteristics of blue panicgrass (*Panicum antidotale* Retz.) clones. Crop Sci. 9:213-216.

Dunbier, R. 1968. The Sonoran Desert. Univ. Arizona Press, Tucson, Ariz. 426 p.

Evenari, M. 1949. Germination inhibitors. Bot. Rev. 15:153-194.

Fryxell, P. A. 1954. A procedure of possible value in plant breeding. Agron. J. 46:433-434.

Gardner, J. L., and L. E. Myers. 1967. Water supplies for arid regions. Proc. 10th Symp., Amer. Ass. Advance. Sci. Univ. Arizona Press, Tucson, Ariz. 62 p.

Greig, J. K., and F. W. Smith. 1962. Salinity effects on sweet potato growth. Agron. J. 54:309-313.

Gustafsson, A. 1946. Apomixis in higher plants. I. The mechanisms of apomixis. Lunds Univ. Arsskr. N. F. Avd. 2 Nr. 2. 42:1-66.

Gustafsson, A. 1947a. Apomixis in higher plants. II. The causal aspect of apomixis. Lunds Univ. Arsskr. N. F. Avd. 2 Nr. 2.43:71-178.

Gustafsson, A. 1947b. Apomixis in higher plants. III. Biotype and species formation. Lunds Univ. Arsskr. N. F. Avd. 2 Nr. 2. 43:183-370.

Hayward, H. E., and L. Bernstein. 1958. Plant-growth relationships on salt-affected soils. Bot. Rev. 24:584-635.

Hayward, H. E., and C. H. Wadleigh. 1949. Plant growth on saline and alkali soils. Advances Agron. 1:1-38.

Herbel, C. H. 1972. Environmental modification for seedling establishment, p. 101-114. *In* V. B. Youngner and C. M. McKell (ed.), The biology and utilization of grasses. Academic Press, New York.

Herbel, C. H., and R. E. Sosebee. 1969. Moisture and temperature effects on emergence and initial growth of two range grasses. Agron. J. 61:628-631.

Hyder, S. Z., and S. Yasmin. 1972. Salt tolerance and cation interaction in alkali sacaton germination. J. Range Manage. 25:390-392.

Kneebone, W. R. 1972. Breeding for seedling vigor, p. 90-100. *In* V. B. Youngner and C. M. McKell (ed.), The biology and utilization of grasses. Academic Press, New York.

Knipe, D., and C. H. Herbel. 1960. The effects of limited moisture on germination and initial growth of six grass species. J. Range Manage. 13:297-302.

Knipe, O. D. 1968. Effects of moisture stress on germination of alkali sacaton, galleta, and blue grama. J. Range Manage. 21:3-4.

Kolattukudy, P. E. 1970. Plant waxes. Lipids 5:259-275.

Koller, D., and D. Cohen. 1959. Germination-regulating mechanism in some desert seeds. VI. *Convolvulus lanatus* Vahl., *Convolvulus negevensis* Zoh., and *Convolvulus secundus* Desr. Bull. Res. Council Israel, 7D:175-180.

Koller, D., and M. Negbi. 1957. Hastening the germination of *Panicum antidotale* Retz. Bull. Res. Council Israel, 5D:225-238.

Koller, D., and N. Roth. 1963. Germination-regulating mechanisms in some desert seeds. VII. *Panicum turquidum* (Gramineae). Israel J. Bot. 12:64-73.

Koller, D., M. Sachs, and M. Negbi. 1964. Germination-regulating mechanisms in some desert seeds. VIII. *Artemisia monosperma*. Plant Cell Physiol. 5:85-100.

Lagerwerff, J. V., and H. E. Eagle. 1961. Osmotic and specific effects of excess salts on beans. Plant Physiol. 36:472-477.

Lagerwerff, J. W., and J. P. Holland. 1960. Growth and mineral content of carrots and beans as related to varying osmotic and ionic-composition effects in saline-sodic sand cultures. Agron. J. 52:603-608.

Laude, H. M. 1957. Comparative pre-emergence heat tolerance of some seeded grasses and of weeds. Bot. Gaz. 119:44-46.

Laude, H. M., J. E. Shrum, and W. E. Biechler. 1952. The effect of high soil temperatures on the seedling emergence of perennial grasses. Agron. J. 44:110-112.

Major, R. L., and L. N. Wright. 1974. Seed dormancy characteristics of sideoats gramagrass, *Bouteloua curtipendula* (Michx.) Torr. Crop Sci. 14:37-40.

Malcolm, C. V., and S. T. Smith. 1965. *Puccinellia*—outstanding saltland grass. J. Agr. W. Australia, Vol. 6, No. 3, Bull. No. 3312. 6 p.

McGinnies, W. J. 1960. Effects of moisture stress and temperature on germination of six range grasses. Agron. J. 52:159-162.

McKell, C. M. 1972. Seedling vigor and seedling establishment, p. 74-89. *In* V. B. Youngner and C. M. McKell (ed.), The biology and utilization of grasses. Academic Press, New York.

Milthorpe, F. L. 1950. Changes in the drought resistance of wheat seedlings during germination. Ann. Bot. N. S. 53:79-89.

Myers, W. M. 1947. Cytology and genetics of forage grasses. Bot. Rev. 13:319-421.

Negbi, M., and M. Evenari. 1962. The means of survival of some desert summer annuals, p. 249-259. *In* Plant-water relationships in arid and semiarid conditions. Proc. Madrid Symp., UNESCO, Arid Zone Res. 16, Paris.

Oppenheimer, H. R. 1960. Adaptation to drought: xerophytism, p. 105-138. *In* Plant-water relationships in arid and semi-arid conditions. UNESCO, Arid Zone Res. 15, Paris.

Price, R., and H. W. Springfield. 1952. Research in the management of arid and semi-arid rangelands. Proc. 6th Int. Grassland Congr., 1:499-505.

Schlatterer, E. F., and M. Hironaka. 1972. Some factors influencing tolerance to moisture stress of three range grasses. J. Range Manage. 25:364-367.

Schuman, G. E. 1969. Boron tolerance of tall wheatgrass. Agron. J. 61:445-447.

Shaw, R. H., and D. R. Laing. 1966. Moisture stress and plant response, p. 73-94. *In* Plant environment and efficient water use. Amer. Soc. Agron., Soil Sci. Soc. Amer. Madison, WI.

Shreve, F. 1942. The desert vegetation of North America. Bot. Rev. 8:195-246.

Slayter, R. O. 1969. Physiological significance of internal water relations to crop yield, p. 53-83. *In* J. D. Eastin (Chairman), Physiological aspects of crop yield. Amer. Soc. Agron. and Crop Sci. Soc. Amer. Madison, WI.

Sosebee, R. E., and C. H. Herbel. 1969. Effects of high temperatures on emergence and initial growth of range plants. Agron. J. 61:621-624.

Streetman, L. J. 1963. Reproduction of the lovegrasses, the genus *Eragrostis*. I. *E. chloromelas* Steud., *E. curvula* (Schrad.) Nees, *E. lehmanniana* Nees and *E. superba* Peyr. Wrightia 3:41-51.

Streetman, L. J., and N. Wright. 1960. A cytological study of black gramagrass *Bouteloua eriopoda*. Amer. J. Bot. 47:786-793.

Strogonov, B. P. 1964. Physiological basis of salt tolerance of plants. (Transl. from Russian) Israel Program Sci. Transl. Cat. No. 2066. S. Monson, Jerusalem. 279 p.

Tadmor, N. H., Y. Cohen, and Y. Harpaz. 1969. Interactive effects of temperature and osmotic potential on the germination of range plants. Crop Sci. 9:771-774.

Van Overbeek, J. 1966. Plant hormones and regulators. Science 152:721-731.

Walter, H. 1961. The adaptation of plants to saline soils. *In* Salinity problems in the arid zones. UNESCO, p. 129-134.

Wilson, A. M., J. R. Nelson, and C. J. Goebel. 1970. Effects of environment on the metabolism and germination of crested wheatgrass seeds. J. Range Manage. 23:283-288.

Woolhouse, H. W. 1969. Dormancy and survival. Academic Press, Inc. New York. 598 p.

Wright, L. N. 1964b. Drouth tolerance—program-controlled environmental evaluation among range grass genera and species. Crop Sci. 4:472-474.

Wright, L. N. 1965. Drouth tolerance evaluation among range grass genera, species, and accessions of three species using program-controlled environment. Proc. 9th Int. Grassland Congr. 1:165-169.

Wright, L. N. 1966. Blue panicgrass for Arizona and the Southwest. Arizona Exp. Sta. Tech. Bull. 1973. 27 p.

Wright, L. N. 1968. Registration of Sonora black gramagrass. Crop Sci. 8:399.

Wright, L. N. 1971. Drought influence on germination and seedling emergence, p. 19-44. *In* Drought injury and resistance in crops. Crop Sci. Soc. Amer., Spec. Pub. No. 2. 88 p.

Wright, L. N. 1971a. Germplasm potentials among blue panicgrass (*Panicum antidotale* Retz.) sample populations. Crop Sci. 11:751-753.

Wright, L.N. 1971b. Registration of Catalina weeping lovegrass. Crop Sci. 11:939.

Wright, L. N. 1973. Seed dormancy, germination environment, and seed structure of Lehmann lovegrass, *Eragrostis lehmanniana* Nees. Crop Sci. 13:432-435.

Wright, L. N., and S. E. Brauen. 1971. Artificial selection for seedling drouth tolerance and association of plant characteristics of Lehmann lovegrass. Crop Sci. 11:324-326.

Wright, L. N., and A. K. Dobrenz. 1973. Efficiency of water use and associated characteristics of Lehmann lovegrass. J. Range Manage. 26:210-212.

Wright, L. N., and R. L. Hall. 1965. Cytological investigations of blue panicgrass, *Panicum antidotale* Retz. J. Arizona Acad. Sci. 3:136-141.

Wright, L. N., and G. L. Jordan. 1970. Artificial selection for seedling drouth tolerance in Boer lovegrass (*Eragrostis curvula* Nees.). Crop Sci. 10:99-102.

Wright, L. N., G. A. McCoy, and A. K. Dobrenz. 1972. Root anatomy and growth responses of blue panicgrass (*Panicum antidotale* Retz.). Arizona Acad. Sci. 7:82-84.

Wright, N. 1961. A program-controlled environmental plant-growth chamber. Arizona Agr. Exp. Sta. Tech. Bull. 148. 31 p.

Wright, N. 1962. Root weight and distribution of blue panicgrass, *Panicum antidotale* Retz., as affected by fertilizers, cutting height, and soil-moisture stress. Agron. J. 54:200-202.

Wright, N. 1964a. Influence of management practices on seed-set, seed yield, seed weight, germination, and insects of black gramagrass, *Bouteloua eriopoda* (Torr.) Torr. Agron. J. 56:57-60.

Wright, N., and A. A. Baltensperger. 1964. Influence of temperature, light radiation, and chemical treatment on laboratory germination of black gramagrass seed, *Bouteloua eriopoda* Torr. Crop Sci. 4:168-171.

Wright, N., and L. J. Streetman. 1958. Past performance and future potential of black grama for Southwestern ranges. J. Range Manage. 11:207-214.

Wright, N., and L. J. Streetman. 1960. Grass improvement for the Southwest relative to drouth evaluation. Arizona Agr. Exp. Sta. Tech. Bull. 143. 16 p.

Young, J. A., R. A. Evans, and B. L. Kay. 1973. Temperature requirements for seed germination in an annual-type rangeland community. Agron. J. 65:656-659.

Improving Palatability of Range Plants

P. W. Voigt
Research Geneticist
USDA, Agricultural Research Service
Grassland-Forage Research Center
Temple, Texas 76501

The author was formerly stationed at the U.S. Southern Great Plains Field Station, Woodward, Oklahoma.

The research is a result of cooperative investigations of the Agricultural Research Service, U.S. Department of Agriculture, and Oklahoma Agricultural Experiment Station. Published with the approval of the Director, Oklahoma Agricultural Experiment Station as Manuscript No. 2832.

Abstract

"Palatability" is defined as a plant characteristic determined by relative animal preference among two or more forages. It is not synonymous with "voluntary intake," a plant characteristic determined when only one forage is available. Differences in palatability have been reported within many species. Some species that have a reputation for unpalatability have been found to contain anti-quality components, e.g., alkaloids or tannins. Breeding for low levels of anti-quality components can increase digestibility, voluntary intake, animal health, or all three. Breeding for palatability, when anti-quality components are not involved, would appear to be of value only for mixtures of pasture or range plants. However, it has not been shown that most species vary enough to increase palatability sufficiently for significant economic impact. The species most likely to benefit from improved forage quality and palatability are those that are aggressive, productive, and persistent.

Numerous reviews of forage palatability have appeared in the past 50 years. Marten's (1970) is one of the best. Most such reviews emphasize their author's frame of reference, e.g., Heady (1964) stresses range management. This review presents the viewpoint of a forage breeder. It is not a complete review of all aspects of forage palatability.

"Palatability" is here defined as a plant characteristic determined by relative animal preference, as shown by consumption, among two or more forages. In contrast, "voluntary intake" (intake) is determined when only one forage is available per animal or experimental unit.

Palatability is usually not the characteristic most important to the plant breeder. Although it can be of great importance in species mixtures (e.g., Holmgren and Hutchings 1972; Hull and Holmgren 1964), other characteristics such as germination and establishment, productivity of seed and forage, and persistence can be more important. Tall fescue (*Festuca arundinacea* Schreb.) and Lehmann lovegrass (*Eragrostis lehmanniana* Nees) are both widely recognized for their poor palatability, yet both are important forages. However, "No matter how abundant or how nutritious a plant may be, it has no value as fodder unless animals eat it," (Everist, 1972). Bitter lupines (*Lupinus* spp.) are one example (Gladstones 1970).

Aggressive, productive, and persistent species are the ones most likely to show economically significant returns to breeding for forage quality (digestibility and intake). Certain of these species may benefit also from improved palatability. Plummer (1972) has suggested that "we need to give more emphasis to improvement of palatability in ecotypes of this shrub [big sagebrush (*Artemisia tridentata* Nutt.)] rather than perhaps to its widespread elimination."

Inter- and intraspecific palatability differences have been widely reported. Table 1 presents a list of plants for which within-species palatability differences have been reported. The size of the list suggests that such differences might be found in most species.

Table 1. Species for which intraspecific palatability differences have been published.

Species		Reference
Agropyron cristatum and *A. desertorum*	crested wheatgrass	Rogler (1944) Coulman and Knowles (1973)
Agropyron trachycaulum	slender wheatgrass	Gomm (1969)
Artemisia tridentata	big sagebrush	Hanks et al. (1971)
Atriplex sp.		Le Houerou (1972)
Bothriochloa ischaemum	yellow bluestem	See Hanson (1972)[1]
Chloris gayana	Rhodesgrass	Milford and Minson (1968)
Coronilla varia	crownvetch	Reid et al. (1968)[2]
Cynodon dactylon	bermudagrass	Burton (1947)
Dactylis glomerata	orchardgrass	Stapledon and Milton (1932)[2] Bland and Dent (1962) Schwendiman (1963) Saiga et al. (1972)
Elymus canadensis	Canada wildrye	Gomm (1969)
Elymus cinereus	basin wildrye	Chapman (1967)
Eragrostis curvula	weeping lovegrass	Leigh (1961) Voigt et al. (1970)
Festuca arundinacea	tall fescue	Buckner (1955) Peterson et al. (1958) Craigmiles et al. (1964) Gillet and Jadas-Hecart (1965)
Lespedeza cuneata	sericea lespedeza	Wilkins et al. (1953) Donnelly (1954)
Lolium multiflorum	annual ryegrass	Dent and Aldrich (1963)
Lolium perenne	perennial ryegrass	Stapledon and Milton (1932)[2] Dent and Aldrich (1963) Archer (1971)
Lupinus sp.	lupine (yellow, blue, white)	see Gladstones (1970)[1]
Melilotus sp.	sweetclover	see Smith & Gorz (1965)[1]
Oryzopsis hymenoides	indian ricegrass	Bohmont and Lang (1957)
Panicum virgatum	switchgrass	Gomm (1969)
Pennisetum purpureum	elephantgrass	Pacola et al. (1972)
Phalaris arundinacea	reed canarygrass	Brown and Pickett (1960) Roe and Motterhead (1962) Asay et al. (1968) Barnes et al. (1970) Simons and Marten (1971) Marten et al. (1973)
Phalaris tuberosa		Arnold and Hill (1972)
Phleum pratense	timothy	Stapledon and Milton (1932)[2]
Poa pratensis	Kentucky bluegrass	Ahlgren (1941)
Purshia tridentata	bitterbrush	Stutz (1972)

[1] Review article.
[2] Cited by Marten (1970).

Palatability and Other Plant Characteristics

Palatability has been observed to be positively correlated, negatively correlated, and uncorrelated with numerous plant characteristics including chemical composition, morphology, succulence, and disease (Marten 1970). This section of the paper examines one such characteristic, leaf strength.

"Leaf strength" has been defined as leaf tensile strength (Kneebone 1960), strength per unit width (Beaumont et al. 1933), and breaking load per dry weight (Evans 1964). For the purposes of this review, all of these will be considered measures of leaf strength.

Workers generally believed that, as humans prefer tender steak, cattle prefer a tender leaf. Beaumont et al. (1933) found that leaf strength was related to the palatability of several grasses. The correspondence between leaf strength and palatability was excellent for comparisons among timothy (*Phleum pratense* L.), redtop (*Agrostis alba* L.), Kentucky bluegrass (*Poa pratensis* L.), and red fescue (*Festuca rubra* L.). However, reed canarygrass (*Phalaris arundinacea* L.) was an exception. It was the least palatable grass, but was the lowest in leaf strength. Kneebone (1960) reported significant differences in leaf strength among strains of weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees), bermudagrass (*Cynodon dactylon* (L.) Pers.), sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), and sand bluestem (*Andropogon hallii* Hack.). However, later results with weeping lovegrass (Voigt et al. 1970) showed a nonsignificant correlation of $r = 0.56$ between palatability and leaf tensile strength. The two most palatable selections were second and third in leaf strength.

Theron and Booysen (1966) used partial correlation and multiple regression techniques to assess the importance of several characteristics to the palatability of 10 South African grasses. They concluded that the leaf strength "can be relied upon, in most instances, to provide a significant contribution to the estimates of animal preferences but that animal preferences could not be explained in terms of this property alone." They further concluded (Theron and Booysen 1968) that in mature herbage the percentage of strengthening tissue was the most important determinant of leaf strength. In immature herbage, the intensity of lignification was of greatest importance. The cellulose concentration was considered to be of minor importance.

In contrast, Evans (1964) found leaf strength of four ryegrasses to be closely correlated with cellulose content, $r = 0.997$, and percentage of sclerenchyma wall $r = 0.991$. The four grasses were perennial ryegrass (*Lolium perenne* L.), annual ryegrass (*L. multiflorum* Lam.), short-rotation ryegrass (*L. perenne* × *L. multiflorum*), and 'Ariki' ryegrass (*L. perenne* × (*L. perenne* × *L. multiflorum*)). Because of a negative relationship between cellulose content and animal gains from pastures of these ryegrasses (Bailey 1964; Rae et al. 1964), Evans concluded that leaf strength would be useful in screening for nutritive quality in a breeding program.

In a population of annual ryegrass × perennial ryegrass, Wilson (1965) discovered that the mean cellulose contents were 14.4% and 17.5% for the 14 plants with lowest leaf strength and the 14 plants with the highest leaf strength, respectively. The heritability of both leaf strength and cellulose content was high, about 80%, and the genetic correlation between the two characters was very high, $r = 0.93$.

Later, Evans (1967) found that leaf strength and cellulose content were significantly correlated within populations of timothy and orchardgrass (*Dactylis glomerata* L.), but not within the populations of *Holcus lanatus* L., *Poa trivialis*

L., *Bromus unioloides* (Wild) H.B.K., or *Argrostis tenuis* Sibth. Leaf strength was not a good indication of cellulose content among species, but was promising for selection within some species. Thus, the conclusion of Theron and Booysen (1968), that cellulose content is not an important determinant of leaf strength, does not necessarily conflict with Evans' results.

In Oklahoma, within the weeping- or curvula-type of *Eragrostis curvula,* four strains have been studied in detail (Voigt et al. 1970). Palatability of green forage was positively related to its leaf strength, cellulose content, and animal performance. Although the strains with high leaf strength were higher in cellulose content, as observed for ryegrass, one strain with higher cellulose content produced better animal gains than two strains with lower cellulose content. Thus, reduced cellulose content was not an indication of higher forage quality. In weeping lovegrass, the lower cellulose content was associated with a higher lignin content that resulted in lower animal gains. Selection for lower cellulose content alone will not necessarily result in new cultivars with higher animal production potential.

In contrast to the work of Theron and Booysen (1966), leaf strength did not appear to be a good indicator of palatability in the sample of weeping lovegrass studied at Woodward (Voigt et al. 1970). However, results from winter palatability trials of standing cured or partially cured forage had not been consistent. In 1958, the winter results agreed with the summer results. In 1960, the ranking was reversed. In two other years, differences were not significant. Results from two later trials (Table 2) strongly suggest that the palatability of the cured grass is normally the reverse of that observed for green forage. Apparently, either a component is volatilized or leached or some other chemical changes occur and a change in palatability results. The cause of the palatability shift could be as simple as the loss of moisture during curing. During the growing season, the two "more palatable" strains are known to be higher in moisture content than the two "less palatable" strains. In winter, strains with a low leaf strength were higher in palatability than strains with high leaf strength.

Palatability is a complex character caused by the interrelationships of many characters. No single characteristic determines palatability. The narrower the genetic base being examined, the more likely that a single factor will

Table 2. Winter palatability of weeping lovegrass selections, Woodward, Okla.[1]

Selection	Feb. 1970		Dec. 1970	
	Young[2]	Old	Young	Old
Common	86 a[3]	82 a	74 a	88 a
673	86 a	74 a	64 ab	92 a
Morpa	62 ab	32 b	46 bc	62 b
813	58 b	22 b	38 c	64 b

[1] Percentage of available forage grazed by Hereford steers on day 8 and day 13 of the Feb. 1970 and day 2 and day 6 of the Dec. 1970 trials for the young and old forage, respectively.

[2] Young = regrowth since the previous Sept. 1; Old = regrowth since the previous July 15 for the Feb. 1970 and Aug. 1 for the Dec. 1970 trials, respectively.

[3] Values within a column followed by the same letter do not differ significantly (Duncan's new multiple-range test, $P = 0.05$).

predominate in importance. Even then, a change in environment can change the balance of interacting characters. The result can be the complete reversal of palatability rankings.

Interspecific Palatability Differences

The importance of palatability differences can be determined by animal performance. Several studies have compared performance of animals confined to single species known to differ in palatability.

Seath et al. (1956) and Lassiter et al. (1956) compared the performance of cows confined to Kentucky bluegrass, smooth bromegrass (*Bromus inermis* Leyss.), orchardgrass, and tall fescue. The 3-year average for 4-wk persistency in milk production and for body-weight gains were, respectively, 92% and 0.12 kg for bluegrass, 91% and 0.07 kg for bromegrass, 88% and −0.05 kg for orchardgrass, and 73% and −0.70 kg for fescue. Daily dry matter intake per 454 kg of body weight was, respectively, 10.6 kg, 10.2 kg, 11.0 kg, and 9.1 kg. The authors concluded that the differences among bluegrass, bromegrass, and orchardgrass were minor and insignificant. Tall fescue, however, was considered poorer in performance than the other three grasses. Most often the palatability rankings of these four grasses, in decreasing order, are smooth bromegrass, orchardgrass, Kentucky bluegrass, and tall fescue (e.g., Archibald et al. 1943; Richards and Hawks 1945). Animal performance rankings and palatability rankings agree for comparison of tall fescue to the other grasses. Results with the other three grasses show no consistent relationship between animal performance and palatability.

Blakeslee et al. (1956) reported 3-year average lamb gains per day of 0.20 kg for smooth bromegrass and 0.16 kg for reed canarygrass. The difference was considered small enough to be of little importance. However, the direction of the difference agreed with palatability comparisons of these two species.

Marten and Donker (1968) found that, although heifers preferred smooth bromegrass over reed canarygrass, average daily gains did not differ at either light or heavy grazing pressures. During a 4-year period, heifers on both grasses gained 0.74 kg per day. The authors concluded, "The preference of heifers for brome over reed canary was of little or no practical significance when the two grasses were grazed individually without choice."

Blaser et al. (1969) found average daily steer gains of 0.49 kg for orchardgrass and 0.41 for tall fescue during 10 years. When given a choice, cattle preferred orchardgrass, 45% grazed, to tall fescue, 25% grazed. Palatability and animal gain agreed.

Marten and Jordan (1974) grazed sheep on three grasses, here listed in decreasing order of palatability: smooth bromegrass, orchardgrass, and reed canarygrass. Two-year average daily gains of the grazing lambs were positively related to palatability: 0.11 kg, 0.08 kg, and 0.07 kg for brome, orchard, and reed canary, respectively (differences statistically significant). Clipped samples revealed no differences among the grasses in in vitro dry matter digestibility (IVDMD). The reduced gain on orchardgrass was believed caused by lower intake, because lambs grazing this species appeared to consume less than their allotted dry matter. The even lower gain and recurrent diarrhea of the lambs grazing reed canary appeared related to its high alkaloid content.

Hubbard and Nicholson (1968) compared 3-year average daily gains of sheep grazing a mixture of smooth bromegrass, orchardgrass, and ladino clover (*Trifolium repens* L.), 0.14 kg; to reed canarygrass and ladino clover, 0.12 kg; and to reed canarygrass fertilized with 300 kg N/ha, 0.12 kg. Gains did not differ significantly, although they were slightly higher on the more palatable mixture. Gains were not affected by the presence of the palatable clover, compared to those from the fertilized reed canarygrass.

Arnold (1964) compared pastures of perennial ryegrass, orchardgrass, *Phalaris tuberosa* L., subterraneum clover (*Trifolium subterraneum* L.), and alfalfa (*Medicago sativa* L.). Although there were considerable differences in digestible organic matter intakes from pastures producing the same diet digestibility, the ranking for intake did not agree with that for palatability.

Hammes et al. (1962) fed bermudagrass and alfalfa hays. Alfalfa was more palatable, was more digestible, and gave higher intake values than bermudagrass.

Hawkins (1955) and Burns et al. (1972) found the intake of cattle was lower on unpalatable sericea lespedeza (*Lespedeza cuneata* (Dumont) G. Don) than on palatable alfalfa. Digestible dry matter (DDM) of the sericea was lower also than that of alfalfa in both experiments. Burns et al. (1972) found that structural constituents did not explain the digestibility difference. The difference in daily gain of 0.16 kg between alfalfa and sericea was believed to be caused by tannin and phenol differences.

The results above show that, at least in some instances, palatability differences among species are positively associated with digestibility, intake, animal performance, or all three. Most often when such a relationship has been observed, one of the species involved is now known to contain anti-quality components. This is true for tall fescue, reed canarygrass, and sericea lespedeza. When anti-quality components are not present, there is often little relationship between palatability and animal performance, unless the palatability difference is very large (e.g., bermudagrass vs alfalfa). The report of a positive relationship between palatability and animal gain for orchardgrass compared to smooth bromegrass by Marten and Jordan (1974) is an interesting exception. However, all workers have not agreed on the relative palatability of these two species (e.g., Blaser et al. 1969).

Intraspecific Palatability Differences—Anti-quality Components

The most prominent of the forages consistently reported low in palatability include tall fescue, reed canarygrass, sericea lespedeza, sweetclovers (*Melilotus* spp.), and lupine. All these species contain compounds that have the potential to reduce seriously their usefulness as forage plants. These compounds, known as allelochemicals (Barnes and Gustine 1973) or anti-quality components (Marten 1973), are in their broadest sense secondary metabolites "synthesized by one organism that affect another organism, either as a stimulator or an inhibitor" (Barnes and Gustine 1973).

Lupine

Bitter lupines are poisonous to livestock. Normally animals eat very little of this plant, but hungry animals will eat sufficient quantities to cause death (Gladstones 1970). The cause of the bitterness and the poisonous properties is high alkaloid concentration. Also, lupinosis is a disease problem that can occur under some conditions. Gladstones (1970) reports that in Western Australia, the disease is more typically chronic than acute and occurs in animals on sweet as well as on bitter lupines.

One of the earliest conscious attempts to breed for palatability was in lupine. Baur (1931) believed, on purely theoretical grounds, that occasional mutants free of bitter-poisonous alkaloids should arise. However, selection by grazing animals would prevent the persistence and reproduction of such plants. Sengbusch (1938) developed a chemical method that allowed rapid screening for low-alkaloid plants. During 1927–1931, he reported screening "a total of many million single plants." He found very low alkaloid plants in all three agriculturally important lupine species. Other genes reported for low alkaloid content in *Lupinus* sp. include one induced by x ray and one by ethyl methonesulphonate (EMS) (Gladstones 1970). All low-alkaloid genes are apparently recessive. Many low-alkaloid varieties able to produce nutritious forage have been released.

Sweetclover

Low palatability of sweetclover has been associated with coumarin content (Smith and Gorz 1965). Although coumarin itself is not present in the living plant, free coumarin rapidly forms when the normal cell structures are disrupted. Coumarin gives a bitter stinging taste to the sweetcover forage and indirectly causes "sweetclover bleeding disease." Smith and Gorz (1965) have thoroughly discussed the work leading to low-coumarin cultivars of sweetclover. Smith crossed the coumarin-free *Melilotus dentata* (Waldst. and Kit.) Pers. to *M. alba* Desr. and grew three of the albino hybrids as grafts on *M. alba.* A few seeds were obtained by backcrossing with *M. alba* pollen. Later plants were selected for high vigor and low coumarin content. The final result was the cultivar 'Denta' (Smith 1964).The *cu* gene obtained from *M. dentata* results in a low level of coumarin when homozygous and an intermediate level when heterozygous. Other low coumarin cultivars were developed (Smith and Gorz 1965).

Sericea Lespedeza

Tannin content was long suspected as the cause of the poor palatability and also the frequently poor performance of animals grazing sericea lespedeza (Clark et al. 1939). McCullough et al. (1953) found that lespedeza's feeding value often appeared much higher in quality than it actually was. Stitt (1943) reported variation in tannin content in sericea, and Wilkins et al. (1953) showed an inverse relationship between tannin content and palatability. Donnelly (1954) showed that cattle preferred plants with fine, pliable stems and low-tannin content. Stem type appeared the more important factor, because the animals avoided all coarse-stemmed plants, regardless of tannin content.

Smart et al. (1961) reported that extracts, obtained by blending fresh sericea leaves in water, inhibited rumen cellulase activity. Other forages tested, including tall fescue and alfalfa, had no such effect. They also found (Bell et al. 1965) that extracts inhibited pectinase activity under rumen conditions as well as in in vitro trials (Lyford et al. 1967). Although chopping the fresh material or drying the forage reduced the amount of inhibitor to a low level, they did not increase digestibility of the cellulose (Bell et al. 1965). The pectinase inhibitor from sericea has been identified and given the name "sericin" (Cook et al. 1970).

Donnelly and Anthony (1969) found that 10 low-tannin sericea plants were higher in DDM than 10 high-tannin plants. They also observed that tannin and DDM were negatively correlated, but only when data from low- and high-tannin plants were combined (Donnelly and Anthony 1970). These data suggest a critical tannin threshold for sericea in relation to DDM.

Cope and Burns (1971) examined the effect of the inhibitor sericin, a fraction of total tannin, on IVDMD. They found that IVDMD of both low- and high-tannin sericea decreased progressively with added increments of sericin. Although one low-tannin strain was like two high-tannin strains in fiber and lignin, the low-tannin strain was consistently about 25% higher in IVDMD. The results strongly supported the conclusion that tannin, or some fraction of it caused the IVDMD difference. Cope and Burns (1973) also found that leaf IVDMD was sharply depressed as tannin values approached 10% and then declined slowly with higher concentrations. Fiber little affected IVDMD at high tannin levels. High tannin content also reduced crude protein digestibility (Donnelly and Anthony 1973).

Heritability estimates for tannin content in sericea lespedeza range from a relatively high 71% (Cope 1962) and 88% (Cope and Moll 1969) to a relatively low 34 and 43% (Bates and Henson 1955). Much of the difference probably was caused by the different populations sampled. Cope and Moll (1969) suggested that segregation at one locus with a major effect accounted for much of the variation in tannin content in their population. Bates and Henson's (1955) population appeared to contain many genes, all with small effects. The results suggest that, with the proper initial population, selection for low-tannin content should be relatively easy.

In fact, low tannin populations were produced. Donnelly et al. (1971) found that, although the crude protein percentage of low- and high-tannin sericea was the same, the crude protein and dry matter of the low-tannin sericea was more highly digested than that in the high-tannin sericea. However, steers on high-tannin sericea had more forage available and a higher intake. The result was no difference in animal performance. Donnelly et al. (1971) concluded that the experimental low-tannin material had not produced enough forage for selective grazing. At equal grazing pressures, better performance would probably have been obtained from the low- than from the high-tannin strain.

The major need in the breeding of sericea lespedeza appears to be the combining of high vigor with low tannin content.

Reed Canarygrass

Brown and Pickett (1960) reported significant differences in palatability within a population of reed canarygrass. In extremely unpalatable genotypes, a water soluble phenolic compound was present in higher concentrations than in palatable genotypes. Roe and Motterhead (1962) also reported palatability differences among strains of reed canarygrass. When extracts of an unpalatable strain were sprayed onto a palatable strain, the consumption of the palatable strain was reduced. Rabbits, cattle, and sheep all had the same preferences. Intake of one of the unpalatable strains by sheep was 0.44 kg/day of digestible organic matter, compared to 0.68 kg for one of the palatable strains.

O'Donovan et al. (1967) used sheep in an attempt to determine the effect of palatability differences of reed canarygrass clones upon intake and digestibility. They found no significant differences among clones in a continuous-digestion trial. In ad-lib. grazing trials, the two acceptable clones contained more digestible organic matter than did the two unacceptable clones in one of the four harvests. Organic matter intake values favored the two acceptable clones in all four harvests, although they differed significantly in only two of the four.

In trials conducted concurrently with the ad-lib. grazing trials of O'Donovan et al. (1967), Barnes and Mott (1970) used the same source of forage material to determine in vivo digestibility and intake in indoor trials with sheep. DDM of the palatable clones was significantly higher in three of four harvests under ad-lib. feeding. With restricted feeding, the palatable clones were significantly more digestible in the one harvest where the difference had not been significant under ad-lib. feeding, but not in the other three harvests. Intake differences were significant in only one of the four harvests. Although the results were not entirely consistent, the palatable clones usually performed as well as and sometimes better than the unpalatable clones.

Literature about alkaloids in reed canarygrass was reviewed recently (Marten 1973). Briefly, the alkaloids found in reed canarygrass and the closely related *Phalaris tuberosa* could be highly toxic in pure form (Gallagher et al. 1964). These alkaloids were implicated in the peracute syndrome of poisoning and the phalaris staggers, sometimes observed in animals on pastures of *P. tuberosa.* However, the toxicity of phalaris forage could not be predicted from its contents of extractable tryptamines (Oram 1970). A high content of tryptamine alkaloids in reed canarygrass fed to sheep was associated with a rapid onset of diarrhea, high consumption of water, increases in respiration under heat stress, and general irritability (Woods 1973).

At least eight alkaloids exist in reed canarygrass (Marten 1973). Williams et al. (1971) found that the crude alkaloid content of two palatable and two unpalatable clones averaged 0.26 and 0.78%, respectively, on a dry matter basis. In a large population of 411 diverse genotypes, Simons and Marten (1971) reported no apparent relationship between palatability and individual alkaloid type. The correlation between total alkaloid percentage and relative palatability to sheep was $r = -0.83$. Correlations increased to $r = -0.92$ or -0.95, when 18 clones with more precise palatability measurements were evaluated. Alkaloid concentrations in the 18 selected clones ranged from 0.18 to 1.21%.

Factors such as light intensity, plant maturity, and rate of fertilizer nitrogen can affect the concentration of alkaloids (Frelich and Marten 1972). Nevertheless, Marten et al. (1973) found that major alkaloid types and relative total basic alkaloid concentrations were repeatable in 15 clones grown in Alaska, Indiana, Minnesota, and Pennsylvania. Palatability to sheep was closely correlated between Indiana and Minnesota clones, $r = 0.91$ or 0.96, and between harvests within locations, $r = 0.97$ or 0.99. Correlations between alkaloid concentration and palatability ranged from $r = -0.87$ to -0.94.

Marten (1973) reported that in only one of 11 trails, in vitro digestibility was correlated with concentration of alkaloids. In that trial, high concentrations (3% of dry weight) of one alkaloid depressed digestibility. This finding was thought to be of little importance, because genotypes that contained such high levels of alkaloids were rare.

Breeding more-palatable reed canarygrass has been underway for only a few years. Asay et al. (1968) reported significant parent-progeny correlations for palatability. Thus, factors controlling palatability could be transmitted from parents to progenies. Barnes et al. (1970) reported that heritability estimates for one harvest ranged from 89% among selfs to 46% among single-crosses.

Purdue Syn. 1, a synthetic of 25 palatable clones selected by R. F. Barnes and R. C. Pickett, was evaluated for palatability and alkaloid content compared to those of the cultivars "Frontier" and "Rise," the experimental synthetic Ottawa Syn. C, and two sources of common reed canarygrass (Marten 1973). Although significant palatability differences among the six entries were not detected, Purdue Syn. 1 contained significantly lower total alkaloids than did one of the common sources and had the lowest total alkaloids at two harvests.

The most recent breeding work has been concerned more with alkaloids than with palatability per se. Woods and Clark (1971) reported that the presence of tryptamine alkaloids was controlled by a single dominant gene. Tryptamines were also highly heritable in *P. tuberosa* (Oram 1970). Barker and Hovin (1974) studied total indole alkaloid content. They obtained realized heritability estimates from 67 to 72%. Because most of the genetic variance was additive, recurrent selection for low total alkaloids should be very effective.

Low-alkaloid reed canarygrass is being bred in two ways. Canadian workers are concentrating on selecting for low or zero concentrations of single or groups of alkaloids. First, they are selecting for tryptamine-free plants (Bonin 1973; Knowles 1973). In the future, when genetic variability is found, they will probably select also for low contents of the alkaloids gramine and hordenine (Clark and Woods 1973). Variation for hordenine content within low-tryptamine populations of *P. tuberosa* has been reported (Oram 1970).

Woods (1973) compared the performance of sheep on pastures of reed canarygrass free of tryptamines and on those with tryptamines. Although the animals consumed large quantities of water and eventually developed diarrhea on the tryptamine-free pasture, the onset of those symptoms was delayed, as compared to the animals on the tryptamine-containing pasture. He concluded that, while removal of the tryptamine alkaloids from reed canarygrass was an improvement, it did not solve the whole problem of poor animal performance.

Workers at the University of Minnesota selected for low levels of total alkaloids rather than for individual or groups of alkaloids (Hovin 1973). In 1972, they released a broad-based germplasm source, NCRC-1, low in total alkaloids. They are testing a low alkaloid synthetic, MN-72 (Hovin 1973). A grazing test of low- and high-alkaloid clones has been established (Marten 1973). It is hoped that this trial will determine whether alkaloids, and also palatability, will affect intake, toxicity, or animal performance problems in reed canarygrass.

Tall Fescue

The chemical composition of tall fescue has been judged equal to that of other cool-season grasses (Bush and Buckner 1973). However, animals have not performed consistently. Poor animal performance is noticed most often in late summer and parallels the accumulation of alkaloids during the growing season.

The presence of perloline, an alkaloid that produces a mild toxic effect (Cunningham and Clare 1943), was reported in ryegrass more than 30 years ago. Alkaloids were implicated in ryegrass staggers in sheep and cattle (Aasen et al. 1969). Intravenous injection of perloline in sheep produced symptoms like those of ryegrass staggers. Alkaloids other than perloline also might be involved (Aasen et al. 1969). However, perloline is the major alkaloid in tall fescue (Gentry et al. 1969). Perloline was observed also to inhibit cellulose digestion (Bush et al. 1970). Although the growth of two anaerobic cellulolytic bacteria was increased at low concentrations, it was inhibited at higher concentrations (Bush et al. 1972). From the concentrations observed in forage, Bush and Buckner (1973) concluded that the potential existed to accumulate enough perloline to inhibit cellulose digestion.

Alkaloids other than perloline have also the potential to inhibit cellulose digestion and to reduce feed consumption and weight gains of rats (Bush and Buckner 1973). Walls and Jacobson (1970) observed that five of six extracts of tall fescue decreased skin temperature, three of six increased heart rate, two of five reduced blood flow. Poor animal performance was associated with rough hair coat, diarrhea, rapid respiration rates, and high rectal temperatures (Bush and Buckner 1973).

Fescue foot is another problem associated with tall fescue. It has been reported in all seasons of the year, but mostly during cold weather (Bush and Buckner 1973). Its causal agent is not known, but mycotoxins are the most likely cause.

Buckner (1957, 1960) and Craigmiles et al. (1964) showed that palatability in tall fescue was heritable. Inbred lines higher in palatability were developed (Buckner and Fergus 1960), and a synthetic produced from 42 clones representing three inbred lines was released as 'Kenwell' (Buckner and Burrus 1968). Although other forage breeders have included palatability as a selection criterion, e.g., Burton (1947) and Lawrence (1960), few have emphasized it.

Thus, a grazing evaluation of Kenwell is critical to any discussion of improving palatability of forage plants.

Buckner and Burrus (1968) showed that Kenwell was slightly, though not significantly, higher than 'Kentucky 31' in IVDMD. Kenwell was significantly more digestible than Kentucky 31 in one of four comparisons (Buckner et al. 1967). Allinson (1971) also reported that in a growth chamber experiment Kenwell was more digestible than Kentucky 31 in the second of two harvests.

Blaser et al. (1969) compared the performance of milk cows on pastures of Kenwell and Kentucky 31. During 3 years, Kenwell averaged 21% less milk than Kentucky 31. Without grain feeding, Kenwell produced 2.86 kg/day less milk per cow than did Kentucky 31. During the 3 years, cows without grain feeding gained 5.45 kg on Kentucky 31, but lost 38.59 kg on Kenwell. The DDM of the two forages was similar. The 3-year average of spring, summer, and fall digestibility for Kentucky 31 and Kenwell was, respectively, 63.4 and 62.9%. Intake of dry matter per 45.4 kg live weight was, respectively, 1.24 and 1.02 kg. Blaser et al. (1969) also reported severe attacks of fescue foot in cows on two Kenwell pastures. Fescue foot was not observed in cows on Kentucky 31 pastures. The authors concluded that the better animal performance on Kentucky 31 was caused by higher dry-matter intake and better animal health.

Carlson et al. (1973) found, during a 4-year experiment, that average daily gains were significantly higher on Kentucky 31, 0.45 kg, than on Kenwell, 0.31 kg. They observed no symptoms of fescue foot during the experiment.

Gentry et al. (1969) reported that Kenwell contained higher levels of the alkaloid perloline than Kentucky 31. Jacobson et al. (1970) reported a number of within- and among-species comparisons. Poor animal performance almost always was associated with at least some symptoms of fescue toxicity. In one comparison, Kenwell was intermediate in animal gain between orchardgrass and an experimental tall fescue strain. Animals on Kenwell had higher rectal temperatures and respiration rates than did those on orchardgrass.

The evidence suggests that although Kenwell is more palatable than Kentucky 31, it often does not produce as much animal product as Kentucky 31. This poorer performance is associated with a higher content of perloline. Contrary to the results with reed canarygrass, selection for palatability in tall fescue resulted in higher rather than lower alkaloid content. Palatability and alkaloid content are not necessarily positively associated in tall fescue.

Selection for better quality in tall fescue has continued (Buckner et al. 1972). Butler (1962) had found marked differences in perloline levels in various ryegrass genotypes. Broadsense heritability estimates for perloline content of plant material derived from *Lolium-Festuca* hybrids ranged from 57 to 80% (Buckner et al. 1973). Currently, the potential new cultivar Kenhy, selected for low perloline, high IVDMD, and high palatability, is being evaluated (Buckner et al. 1972). It is proving to be agronomically superior to Kentucky 31 or Kenwell. Animal performance is being compared to that on Kentucky 31.

Other characteristics also have been considered important to palatability of tall fescue. Craigmiles et al. (1964) suggested selecting for broad, thick, coarse-leaved plants, because cattle grazed them more often than fine-leaved plants. Gillet and Jadas-Hecart (1965) found that leaf flexibility in tall fescue was heritable and that plants palatable to sheep were more flexible than those that were unpalatable. The significance of these findings to animal performance is not known.

Other Species

Longhurst et al. (1968) proposed that palatability and digestibility were correlated. They suggested that palatability was controlled primarily by aromatic compounds. However, digestibility depended "generally upon two factors: available nutrients which promote bacterial growth such as carbohydrates, proteins, and cellulose, that . . . are balanced against the content of chemicals which inhibit bacterial growth or are actually bactericidal." The latter would be the same compounds controlling palatability. The extent of digestion would depend on the balance between the positive and negative factors.

Smith (1950) observed palatability differences to mule deer in red (*Juniperus scopulorum* Sarg.) and Utah juniper (*Juniperus osteosperma* (Torr.) Little). The palatable red and Utah junipers contained, respectively, 1.84 and 2.13% volatile oils, compared to 2.27 and 2.60% in the unpalatable junipers.

Short (1963) found that white cedar (*Thuja occidentalis* L.) oils inhibited fermentation by steer microorganisms.

Nagy et al. (1964) observed that essential oils of big sagebrush could inhibit bacterial growth and decrease rate of cellulose digestion. They calculated that cellulose digestion of deer could be slowed if a high percentage of the diet consisted of sagebrush.

Oh et al. (1967) found that some of the essential oils of Douglasfir (*Pseudotsuga menziesii* (Mirb.) Franco) needles promoted and some inhibited rumen microbial activity. Oh et al. (1970) later reported that fertilization with N increased not only palatability to deer, but also in vitro fermentability by deer microbes. They also noted that deer browsing was limited to new growth. Although essential oils from new needles inhibited rumen microbes, they were less inhibitory than oils from old needles.

Oh et al. (1968) examined the inhibitory potency of the essential oils of eight plant species unpalatable to sheep and deer. From their results, they divided the species into four groups, from most to least inhibitory. Oils of vinegar weed (*Trichostema lanceolatum* Benth.) and California bay (*Umbellularia californica* (Hook. and Arn.) Nutt.) inhibited most, and oils from Douglasfir and Jerusalem oak (*Chenopodium botrys* L.) inhibited least.

Although the proposal of Longhurst et al. (1968) relating palatability and digestibility does not explain results obtained with all forages, it appears valuable in relation to the results discussed above. Reduction of essential oil content by breeding could increase the usefulness of some plants as forage. Hanover (1966) studied the genetics of monoterpenes in *Pinus monticola* Dougl. Broadsense heritability estimates of five of the six terpenes studied were high, 62.7 to 94.5%. His results suggest that breeding for terpene content should be relatively easy. A recurrent selection program for low essential oils in juniper or big sagebrush using one or more populations with a broad genetic base, might produce very interesting results.

Selection for low levels of anti-quality components could alter resistance to insects and diseases. Sweet lupines are attacked by aphids, but bitter lupines are not (Gladstones 1970). Thrips feed only on the foliage of sweet lupines (Forbes and Wells 1966). Budworms, in contrast, attack both bitter and sweet lupines (Gladstones 1970). The relationships have not been extensively studied between allelochemicals that may be responsible for insect or disease resistance and anti-quality components. More information is needed. Plant breeders selecting for low levels of anti-quality components need to know how lower quantities of those components affect insect or disease resistance.

In breeding plants containing anti-quality components, breeders also must be concerned with the Food and Drug Administration (FDA) regulations on food additives classified as "Generally Recognized as Safe in Food" (GRAS). Under these regulations, the FDA requires review of substances changed by selection that may alter nutritive value or concentration of toxic constituents (Barnes and Gustine 1973). Although forages might not be included under these regulations yet (Spiher 1974), they might be in the future. Forage breeders need to be aware of this possibility and should be prepared for such a change.

Intraspecific Palatability Differences—Other Factors

Numerous characteristics other than anti-quality components, e.g., maturity, morphology, and growth form, may be responsible for palatability differences.

Orchardgrass

Schwendiman (1963) observed that one introduction of orchardgrass was more palatable than the commercial strains with which it was compared. It was later in maturity, lower in lignin, and higher in digestibility than the other less palatable cultivars, and was subsequently released as "Latar" (Schwendiman and Law 1969). In contrast, Bland and Dent (1964) reported that animals preferred early varieties of orchardgrass and that the earlier varieties were higher in digestibility. The relationship of palatability to maturity appears to depend on the plant material being examined, even when only one species is being studied.

Dijk (1959) proposed that selection for smooth leaves might increase the palatability of orchardgrass. He selected plants with smooth leaves but did not examine their importance in determining palatability or animal performance.

*Rhodesgrass (*Chloris gayana *Kunth)*

Rhodesgrass strains differing in digestibility and intake were reported (Milford 1960). However, strains differing very markedly in growth form, maturity, and other characteristics may give very similar animal performance (Christian and Shaw 1952). Milford and Minson (1968) studied the digestibility and intake of six strains of Rhodesgrass that were classified as low, medium, high, or very high in palatability. Differences in digestibility and intake were observed among strains, but there were no significant differences in the intake of digestible dry matter. Palatability was not a reliable guide to the feeding value of

Rhodesgrass strains nor was feeding value related to date of flowering or leafiness.

Weeping Lovegrass

Several cultivars of weeping lovegrass have been either selected for improved palatability or characterized as more palatable. 'Morpa' weeping lovegrass (Voigt 1971) was selected for its greater palatability compared to common, A-67 (Crider 1945), weeping lovegrass. Pasture studies showed that during 3 years, it produced 12% more animal gain than common did (Voigt et al. 1970). This improved animal performance was associated with a lower lignin content and a more favorable lignin:cellulose ratio. Later forage-quality trials showed that Morpa is more digestible than common weeping lovegrass (Table 3).

'Don Juan,' a cultivar selected by Covas in Argentina, was reported to be more palatable to sheep than the "common Tanganyika variety" (Froseth 1970). The Tanganyika variety is probably the same genotype referred to above as "common." Froseth et al. (1970) compared the two strains and found that ingested forage of the Tanganyika variety was higher in crude protein, digestible crude protein, and in vitro organic-matter digestibility. Intakes of digestible organic matter, digestible crude protein, and digestible energy also were higher for Tanganyika than for Don Juan.

Recently, 'Renner' weeping lovegrass was released. It was selected for improved palatability over the Ermelo strain (Streetman, personal communication). Renner has not been thoroughly evaluated, but preliminary results from Woodward (Table 4) suggest that it may be intermediate in digestibility between Ermelo and common, although the differences in this trial were not significant. No information on the intake and performance of animals on Renner is available.

Selection for palatability in *E. curvula* has not produced consistent results. Morpa is superior in digestibility and animal performance. Don Juan is inferior in intake of digestible organic matter. Renner may be inferior in digestibility. The correlations between palatability and digestibility from a forage quality screening trial of 50 entries are presented in Table 5. The plant material represented a relatively wide range of types, some of which might be classified as species of *Eragrostis* other than *E. curvula.* Thus, correlations were calculated over all entries and also for the curvula or weeping types. The significant

Table 3. IVDMD of weeping lovegrass strains, Woodward, Okla., 1973.[1]

Cultivar	Date			Mean
	June 1	July 16	Aug. 22	
Morpa	60.3 a[2]	57.2 a	58.8 a	58.8 a
Ermelo	60.9 a	55.1 a	57.4 a	57.8 ab
Common	58.9 a	52.0 a	52.0 b	54.3 b

[1] IVDMD analyses performed by F. P. Horn, ARS, USDA, Fort Reno Research Station, El Reno, Okla.

[2] Values within a column followed by the same letter do not differ significantly (Duncan's new multiple-range test, $P = 0.05$).

Table 4. IVDMD of five weeping lovegrasses, Woodward, Okla.[1]

Cultivar	Date				Mean
	1971		1972		
	May	Aug.	June	July	
Morpa	34.4	32.4	55.8	61.9	46.1
Ermelo	32.5	33.4	56.1	61.8	46.0
Renner	32.3	31.4	53.4	59.5	44.2
673	32.2	30.1	54.2	58.0	43.6
Common	32.7	31.1	54.5	55.7	43.5

[1] IVDMD analyzed in 1971 and 1972, respectively, by L. I. Croy, Oklahoma State University, and F. P. Horn, ARS, USDA, Fort Reno Research Station.

correlations over all entries for the May harvest resulted from a strong positive relationship between plant maturity, palatability, and digestibility in one of the non-curvula types. This association was not observed in later harvests. Within the curvula types the correlations were all relatively low, and palatability accounted for only a small percentage of the variation in digestibility. Selection for palatability would not appear to be an efficient way to improve digestibility on a summer-long basis.

Ryegrass

Tetraploid ryegrass strains were reported to be more palatable to rabbits than diploid strains (Dent and Aldrich 1963). Alder (1964, 1968) compared diploid and tetraploid cultivars of *Lolium multiflorum* and of *L. perenne* in grazing experiments. He reported no significant difference in consumption in either the early or late part of the growing season. Lamb gains for 2 years were higher on the diploid pastures up to July; thereafter, the gain difference was reversed so that for the whole year, no differences were obtained. In a feeding trial with perennial ryegrasses, no marked differences in overall performance were observed.

Thomson (1971) used two of the same cultivars of annual ryegrass in sheep feeding trials. In studying first-growth herbage he found that the tetraploid tended to be higher in digestibility than the diploid, but that the difference was not significant. However, the intake of the diploid was significantly higher than that of the tetraploid. At a digestibility of 70%, the intake of the diploid was

Table 5. Correlation coefficients between palatability and digestibility in a population of *Eragrostis curvula*, Woodward, Okla.[1]

	1970	1971
All types		
May	.71**[2]	.32*
July	-.18	.24
Sept.	.27	–
Curvula types		
May	.37	.10
July	.59*	.25
Sept.	.54*	–

[1] In vitro dry-matter digestibility determined by L. I. Croy, Oklahoma State University.
[2] *Significant at the 0.05 level; **significant at the 0.01 level.

14% greater than that of the tetraploid. In the regrowth, the tetraploid was six percentage units higher in digestibility but not different in organic matter intake. Although all the results of Alder (1968) and Thomson (1971) do not agree on a grazing season basis, the palatability difference in favor of the tetraploids appears to be of little economic importance.

Palatability Differences–Rangelands

Palatability differences are important when different plant species are grown together in mixtures. Vegetation changes resulting from grazing seem to be correlated more with intensity of range stocking than with palatability (Heady 1964). Nevertheless, the preferred or more palatable species is the most heavily grazed and will eventually disappear from the stand (Cook et al. 1953). However, as with much of the palatability research, "we have too often been content to show palatability differences and assume they have biological or economic significance without testing the validity of the assumption" (Marten 1970).

Holmgren and Hutchings (1972) described successional changes on grazed and ungrazed salt desert shrub ranges. At Snake Valley after decades of heavy use by sheep, the codominant species were *Atriplex confertifolia* (Torr. and Frem.) S. Wats. and *Eurotia lanata* (Pursh) Moq. As the treatment was continued, the more palatable *Eurotia* was replaced by *Atriplex*. When cattle were grazed, the trends changed. *Artemisia nova* A. Nels., the species most palatable to sheep, increased, and *Atriplex* decreased. *Artemisia* was less preferred by cattle than by sheep. However, the same trend was observed on ungrazed range. *Eurotia* continued to decrease, because it continued to be grazed by cows as it had been by sheep. It decreased on the ungrazed area, also, because it could not compete with the increasing *Artemisia*. The palatability of *Artemisia* to sheep appears to be very important in determining species composition and productivity of the Snake Valley area.

Because of differences in palatability and aggressiveness, certain species cannot be grown together in mixtures. Although crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) was highly palatable in early spring, it became relatively unpalatable later in the season (Cook et al. 1956). Intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.) could not be maintained in a mixture with it (Cook 1966) because of intermediate's high palatability throughout the spring and summer (Cook et al. 1956) and probably also because of intermediate's less aggressive nature (Cook et al. 1967). The obvious solution is to plant separate grazing units and to graze each unit to take advantage of the growth characteristics of its species (Plummer et al. 1955).

The advantages and disadvantages of mixtures and pure stands have been widely discussed (e.g., Vallentine 1971). In brief, palatability is involved in determining if any given mixture can be maintained.

Can a plant breeder, by manipulating genes within a species, alter palatability enough so that a new variety will survive and be an economic asset in a mixture where present varieties fail? Little evidence is available on this point. Certainly, if anti-quality components cause very low palatability, breeding for palatability, or preferably for low concentrations of the anti-quality component, might produce economically significant results. But what if anti-quality components are not involved?

Evaluation of several sideoats grama cultivars at Woodward suggests that changes may be possible. Several cultivars of *Bouteloua curtipendula* var. *caespitosa* Gould and Kapadia have been released for the Southern Great Plains. These include 'Tucson' and 'Coronado.' The unreleased strain Hope is also a caespitose type. These strains tend to be high in forage production and early in maturity. In contrast, the rhizomatous cultivars such as 'El Reno' are members of *B. curtipendula* var. *curtipendula* and are later in maturity and often less productive. Despite their high forage production, none of the caespitose strains have had long-term success. One possible reason is their lower palatability. In one study at Woodward, strips of several sideoats grama strains were grazed during the late summer and fall. Essentially 100% of the forage of El Reno was consumed. About 67% of the forage of Hope and only 33% of the forage of Tucson was consumed. Although an estimate for Coronado was not obtained in this trial, results from other trials suggested that it was even less palatable than Tucson. Thus, possibly the caespitose types failed to obtain long-term success partly because their palatability was much lower than that of the rhizomatous cultivars and native harvest materials they were supposed to replace. However, the greater palatability of Hope suggests that selection for palatability within the caespitose type should be possible. Whether a more palatable caespitose-type cultivar could be successful has not been proven.

Species can have different palatabilities at different seasons of the year. Rogler (1944) reported that little bluestem (*Schizachyrium scoparium* (Michx.) Nash.) was palatable only when immature. On the other hand, Indiangrass (*Sorghastrum nutans* (L.) Nash) gradually increased in palatability as the season progressed (Dwyer 1961). Big bluestem (*Andropogon gerardii* Vitman) was preferred throughout the season (Dwyer 1961). Other grasses having good late-season palatability include sand lovegrass (*Eragrostis trichodes* (Nutt.) Wood) and "King Ranch" bluestem (*Bothriochloa ischaemum* (L.) Keng) (Dwyer et al. 1964).

Wide differences in palatability have been reported within the yellow bluestems (*Bothriochloa ischaemum*). El Kan is very winter hardy, but is low in palatability (Hanson 1972). King Ranch is much less winter hardy, but is palatable (Dwyer et al. 1964; Hanson 1972). A yellow bluestem like El Kan has not performed well in mixed grass ranges at Woodward. At best, it has been only lightly grazed. In contrast, animal use and steer gains have been good on rangeland containing King Ranch (E. H. McIlvain, personal communication). The performance of King Ranch bluestem at Woodward is confounded with the periodic fluctuations in stand and vigor caused by occasional severe winter injury and later recovery. Nevertheless, the results do suggest that a strain that is palatable late in the growing season or at maturity has great potential as a range grass if it can be established and is persistent and productive.

As suggested earlier, species that are relatively unpalatable but are otherwise well adapted and aggressive are probably the ones that could benefit most from selection for increased palatability. Lehmann lovegrass is a good example. It is one of the few species aggressive enough to invade established stands of velvet mesquite (*Prosopis juliflora* var. *velutina* (Woot.) Sarg.) (Cable 1971). Unfortunately, Lehmann lovegrass invades also native perennial grass ranges and can almost completely replace these more palatable species. If the palatability and forage quality of Lehmann lovegrass could be increased enough, while its aggressive characteristics were maintained, it could be a much more useful range grass.

Alternatively, one could start with the closely related and more palatable boer type of *E. curvula* (Cable and Bohning 1959) and select for improved establishment characteristics. This approach led to the recent release of "Catalina" (Wright 1971). Information on the palatability and forage quality of Catalina has not been published. However, it is hoped that because Catalina is a boer type, it will be more palatable and thus a more useful range grass than Lehmann lovegrass in areas where both would be adapted.

Conclusions

Breeding for palatability in plants to be used on ranges must be examined species-by-species. Species that are aggressive, productive, and persistent are the ones most likely to benefit from increased forage quality and possibly from increased palatability.

Many range species are adequately utilized and there is no reason to breed for palatability in them. However, new cultivars should probably be evaluated for palatability before their release, if they differ widely from current cultivars in maturity or morphology. This precaution should prevent the release of new cultivars that might not fit into pre-existing mixtures of other species.

Some species may be too palatable for their own survival. Reduced palatability might increase persistence of such species. However, a breeder selecting for lower palatability would have to be careful to retain good forage quality and low levels of anti-quality components. Breeding for increased persistence, such as selecting for a more procumbent growth habit to reduce intensity of defoliation, increased drought tolerance, and improved water-use efficiency, would appear to be a more desirable procedure. A less costly approach would be to grow the highly palatable species in a pure stand where grazing pressure could be controlled. Ideally, this pasture could then be part of a grazing system of complementary pastures and ranges.

Breeding for palatability per se (in the absence of anti-quality components) is not worthwhile, if the goal is increased digestibility and intake. The available evidence does not suppor the validity of this approach. Although Morpa weeping lovegrass and Latar orchardgrass were both selected for their palatability and were later found to be higher in digestibility, other attempts to obtain higher quality grasses by selection for palatability per se have not been successful. Also, digestibility itself can be determined readily by in vitro techniques. In contrast, intake data are much more expensive to obtain. If palatability were closely related to intake, selection for palatability would be justified to obtain greater intake. However, little evidence supports the conclusion that selection for palatability within a species increases intake when anti-quality components are not involved. Although very large differences in palatability, e.g., alfalfa over bermudagrass, can be associated with differences in intake, there is little to suggest that palatability differences of that size could be produced regularly through normal breeding procedures in most species.

Breeding for lower levels of anti-quality components appears a very promising approach to increasing palatability and usefulness of some species, whether the new cultivar is to be used in pastures or ranges. In some species this approach may increase forage digestibility, intake, or both. In other species, the only change may be improved animal health. Low levels of some other allelochemicals eventually may be required by the FDA. Breeding for increased palatability may result in lower levels of some anti-quality components. However, the work with tall fescue shows that the reverse also may occur. When possible, breeding should be for low levels of the anit-quality component rather than for increased palatability per se.

Literature Cited

Aasen, A. J., C. C. J. Culvenor, E. P. Finnie, A. W. Kellock, and L. W. Smith. 1969. Alkaloids as a possible cause of ryegrass staggers in grazing livestock. Aust. J. Agr. Res. 20:71-86.

Ahlgren, H. L. 1941. Cattle like some experimental strains of bluegrass, p. 10-11. *In* What's New in Farm Science. Wisconsin Agr. Exp. Sta. Bull. 451.

Alder, F. E. 1964. Preliminary results of a comparison between tetraploid and diploid ryegrass. Nature 203:546-547.

Alder, F. E. 1968. Comparison of diploid and tetraploid ryegrass in animal-production experiments. J. Brit. Grassl. Soc. 23:310-316.

Allinson, D. W. 1971. Influence of photoperiod and thermoperiod on the IVDMD and cell wall components of tall fescue. Crop Sci. 11:456-458.

Archer, M. 1971. Preliminary studies on the palatability of grasses, legumes and herbs to horses. Vet. Rec. 89:236-240.

Archibald, J. G., E. Bennett, and W. S. Ritchie. 1943. The composition and palatability of some common grasses. J. Agr. Res. 66:341-347.

Arnold, G. W. 1964. Some principles in the investigation of selective grazing. Proc. Aust. Soc. Anim. Prod. 5:258-271.

Arnold, G. W., and J. L. Hill. 1972. Chemical factors affecting selection of food plants by ruminants, p. 71-101. *In* J. B. Harborne [ed.]Phytochemical Ecology. Academic Press, London.

Asay, K. H., I. T. Carlson, and C. P. Wilsie. 1968. Genetic variability in forage yield, crude protein percentage, and palatability in reed canarygrass, *Phalaris arundinacea* L. Crop. Sci. 8:568-571.

Bailey, R. W. 1964. Pasture quality and ruminant nutrition. I. Carbohydrate composition of ryegrass varieties grown as sheep pastures. New Zeal. J. Agr. Res. 7:496-507.

Barker, R. E., and A. W. Hovin. 1974. Inheritance of indole alkaloids in reed canarygrass (*Phalaris arundinacea* L.) 1. Heritability estimates for alkaloid concentration. Crop Sci. 14:50-53.

Barnes, R. F., and D. L. Gustine. 1973. Allelochemistry and forage crops, p. 1-13. *In* A. G. Matches [ed.] Anti-quality components in forages. Crop Sci. Soc. Amer. Special Pub. No. 4, Madison, Wisconsin.

Barnes, R. F., and G. O. Mott. 1970. Evaluation of selected clones of *Phalaris arundinacea* L. I. In vivo digestibility and intake. Agron. J. 62:719-722.

Barnes, R. F., W. E. Nyquist, and R. C. Pickett. 1970. Variation in acceptability and covariation with agronomic characters in *Phalaris arundinacea* L. Proc. XI Int. Grassl. Congr. p. 202-206.

Bates, R. P., and P. R. Henson. 1955. Studies of inheritance in *Lespedeza cuneata* Don. Agron. J. 47:503-507.

Baur, E. 1931. Masters Memorial Lectures. 1931. II: Scope and methods of plant breeding work at the Kaiser Wilhelm Institute for Plant Breeding Research, Muncheberg (Mork). J. Roy. Hort. Soc. 56:183-190.

Beaumont, A. B., R. E. Stitt, and R. S. Snell. 1933. Some factors affecting the palatability of pasture plants. J. Amer. Soc. Agron. 25:123-128.

Bell, T. A., J. L. Etchells, and W. W. G. Smart, Jr. 1965. Pectinase and cellulase enzyme inhibitor from sericea and certain other plants. Bot. Gaz. 126:40-45.

Blakeslee, L. H., C. M. Harrison, and J. F. Davis. 1956. Ewe and lamb gains on brome and reed canarygrass pasture. Michigan Agr. Exp. Sta. Quart. Bull. 39:230-235.

Bland, B. F., and J. W. Dent. 1962. Animal preference in relation to chemical composition and digestibility with varieties of cocksfoot. J. Brit. Grassl. Soc. 17:157-158.

Bland, B. F., and J. W. Dent. 1964. Animal preference in relation to chemical composition and digestibility of varieties of cocksfoot. J. Brit. Grassl. Soc. 19:306-315.

Blaser, R. E., H. T. Bryant, R. C. Hammes, Jr., R. L. Bowman, J. P. Fontenot, and C. E. Polan. 1969. Milk production from tall fescue varieties, p. 30-32. *In* Managing forages for animal production. Virginia Polytech. Inst. Res. Div. Bull. 45.

Bohmont, B. L., and R. Lang. 1957. Some variation in morphological characteristics and palatability among geographic strains of Indian ricegrass. J. Range Manage. 10:127-131.

Bonin, S. G. 1973. Research report. West. Grass Breed. Work Plan. Conf. 22:41.

Brown, J. W. M., and R. C. Pickett. 1960. Clonal evaluation in *Phalaris arundinacea:* I. Variation in palatability. Agron. Abstr. 52:45.

Buckner, R. C. 1955. Breeding in tall fescue for palatability. PhD Thesis. Univ. of Minnesota. 87 p.

Buckner, R. C. 1957. Evaluations of palatability. West. Grass Breed. Work Plan. Conf. 11:33-34.

Buckner, R. C. 1960. Performance of inbred lines, polycross progenies, and synthetics of tall fescue selected for improved palatability. Agron. J. 52:177-180.

Buckner, R. C., and P. B. Burrus, II. 1968. Registration of Kenwell tall fescue. Crop Sci. 8:389.

Buckner, R. C., L. P. Bush, and P. B. Burrus, II. 1972. Kenhy—potentially a new tall fescue variety, p. 3-5. *In* Agronomy Research - 1972. Kentucky Agr. Exp. Sta. Misc. 402.

Buckner, R. C., L. P. Bush, and P. B. Burrus, II. 1973. Variability and heritability of perloline in *Festuca* sp., *Lolium* sp., and *Lolium-Festuca* hybrids. Crop Sci. 13:666-669.

Buckner, R. C., and E. N. Fergus. 1960. Improvement of tall fescue for palatability by selection within inbred lines. Agron. J. 52:173-176.

Buckner, R. C., J. R. Todd, P. B. Burrus, II, and R. F. Barnes. 1967. Chemical composition, palatability, and digestibility of ryegrass-tall fescue hybrids, 'Kenwell', and 'Kentucky 31' tall fescue varieties. Agron. J. 59:345-349.

Burns, J. C., R. D. Mochrie, and W. A. Cope. 1972. Responses of dairy heifers to crownvetch, sericea lespedeza, and alfalfa forages. Agron. J. 64:193-195.

Burton, G. W. 1947. Breeding bermudagrass for the southeastern United States. J. Amer. Soc. Agron. 39:551-569.

Bush, L. P., J. A. Boling, G. Allen, and R. C. Buckner. 1972. Inhibitory effects of perloline to rumen fermentation in vitro. Crop Sci. 12:277-279.

Bush, L. P., and R. C. Buckner. 1973. Tall fescue toxicity, p. 99-112. *In* A. G. Matches [ed.] Anti-quality components in forages. Crop Sci. Soc. Amer. Special Pub. No. 4, Madison, Wisconsin.

Bush, L. P., C. Streeter, and R. C. Buckner. 1970. Perloline inhibition of in vitro ruminal cellulose digestion. Crop Sci. 10:108-109.

Butler, G. W. 1962. Genetic differences in the perloline content of ryegrass (*Lolium*) herbage. New Zeal. J. Agr. Res. 5:158-162.

Cable, D. R. 1971. Lehmann lovegrass on the Santa Rita Experimental Range, 1937-1968. J. Range Manage. 24:17-21.

Cable, D. R., and J. W. Bohning. 1959. Changes in grazing use and herbage moisture content of three exotic lovegrasses. J. Range Manage. 12:200-203.

Carlson, G. E., J. Bond, and R. H. Hart. 1973. 'Kenwell' vs 'Kentucky 31' tall fescue under grazing. Agron. J. 65:130-132.

Chapman, S. R. 1967. Montana, grass breeding program. West. Grass Breed. Work Plan. Conf. 19:36.

Christian, C. S., and N. H. Shaw. 1952. A study of two strains of Rhodes grass (*Chloris gayana* Kunth) and of lucerne (*Medicago sativa* L.) as components of mixed pastures at Lawes in south-east Queensland. Aust. J. Agr. Res. 3:277-299.

Clark, K. W., and D. Woods. 1973. Research report. West. Grass Breed. Work Plan. Conf. 22:45.

Clarke, I. D., R. W. Frey, and H. L. Hyland. 1939. Seasonal variation in tannin content of *Lespedeza sericea.* J. Agr. Res. 58:131-139.

Cook, C. E., J. A. Buhrman, C. R. Tallent, and M. E. Wall. 1970. The pectinase inhibitor from sericea (*Lespedeza cuneata*). Lloydia 33:255-260.

Cook, C. W. 1966. Development and use of foothill ranges in Utah. Utah Agr. Exp. Sta. Bull. 461. 47 p.

Cook, C. W., L. A. Stoddart, and L. E. Harris. 1953. Effects of grazing intensity upon the nutritive value of range forage. J. Range Manage. 6:51-54.

Cook, C. W., L. A. Stoddart, and L. E. Harris. 1956. Comparative nutritive value and palatability of some introduced and native forage plants for spring and summer grazing. Utah Agr. Exp. Sta. Bull. 385. 39 p.

Cook, C. W., L. S. Stoddart, and P. L. Sims. 1967. Effects of season, spacing, and intensity of seeding on the development of foothill range grass stands. Utah Agr. Exp. Sta. Bull. 467. 73 p.

Cope, W. A. 1962. Heritability estimates and correlations of yield and certain morphological and chemical components of forage quality in sericea lespedeza. Crop. Sci. 2:10-12.

Cope, W. A., and J. C. Burns. 1971. Relationship between tannin levels and nutritive value of sericea. Crop Sci. 11:231-233.

Cope, W. A., and J. C. Burns. 1973. Components of forage quality in sericea lespedeza in relationship to strain, season, and cutting treatments. Agron. J. 66:389-394.

Cope, W. A., and R. H. Moll. 1969. Inheritance of yield, forage quality and seed characteristics in sericea lespedeza. Crop Sci. 9:467-470.

Coulman, B. E., and R. P. Knowles. 1973. In vitro digestibility of crested wheat grass strains. West. Grass Breed. Work Plan. Conf. 22:35-37.

Craigmiles, J. P., L. V. Crowder, and J. P. Newton. 1964. Palatability differences in tall fescue using leaf and plant type. Crop Sci. 4:658-660.

Crider, F. J. 1945. Three introduced lovegrasses for soil conservation. USDA Circ. No. 730. 90 p.

Cunningham, I. J., and E. M. Clare. 1943. A fluorescent alkaloid in ryegrass. V. Toxicity, photodynamic action and metabolism of perloline. New Zeal. J. Sci. and Technol. 24:167B-178B.

Dent, J. W., and D. T. A. Aldrich. 1963. Soluble carbohydrate content of varieties of tetraploid ryegrass. Nature 198:905.

Dijk, G. E. van. 1959. Breeding for quality in cocksfoot (*Dactylis glomerata* L.). Euphytica 8:58-68.

Donnelly, E. D. 1954. Some factors that affect palatability in sericea lespedeza, *L. cuneata.* Agron. J. 46:96-97.

Donnelly, E. D., and W. B. Anthony. 1969. Relationship of tannin, dry matter digestibility and crude protein in *Sericea lespedeza.* Crop Sci. 9:361-362.

Donnelly, E. D., and W. B. Anthony. 1970. Effect of genotype and tannin on dry matter digestibility in sericea lespedeza. Crop Sci. 10:200-202.

Donnelly, E. D., and W. B. Anthony. 1973. Relationship of sericea lespedeza leaf and stem tannin to forage quality. Agron. J. 65:993-994.

Donnelly, E. D., W. B. Anthony, and J. W. Langford. 1971. Nutritive relationships in low- and high-tannin sericea lespedeza under grazing. Agron. J. 63:749-751.

Dwyer, D. 1961. Activities and grazing preferences of cows with calves in northern Osage County, Oklahoma. Okla. Agr. Exp. Sta. Bull. B-588. 61 p.

Dwyer, D. D., P. L. Sims, and L. S. Pope. 1964. Preferences of steers for certain native and introduced forage plants. J. Range Manage. 17:83-85.

Evans, P. S. 1964. A study of leaf strength in four ryegrass varieties. New Zeal. J. Agr. Res. 7:508-513.

Evans, P. S. 1967. Leaf strength studies of pasture grasses. II. Strength, cellulose content and sclerenchyma tissue proportions of eight grasses grown as single plants. J. Agr. Sci. 69:175-181.

Everist, S. L. 1972. Australia, p. 16-25. *In* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [ed.] Sect. I. Continental Aspects of Shrub Distribution, Utilization, and Potentials. Wildland Shrubs–Their Biology and Utilization. USDA Forest Serv., Gen. Tech. Rep. INT-1.

Forbes, I., Jr., and H. D. Wells. 1966. Breeding blue lupine forage varieties for the south-eastern United States. Proc. X Int. Grassl. Congr. p. 708-711.

Frelich, J. R., and G. C. Marten. 1972. Factors influencing indole alkaloids in reed canarygrass, *Phalaris arundinacea* L. Agron. Abstr. 64:68.

Froseth, J. A. 1970. Animal and agronomic evaluation of weeping lovegrass and two cool season grasses grown in semi-arid Argentina. PhD Thesis. Purdue University. 168 p.

Froseth, J. A., C. H. Noller, and J. P. Bishop. 1970. Nutritive value of weeping lovegrass pastures. J. Anim. Sci. 31:177.

Gallagher, C. H., J. H. Koch, R. M. Moore, and J. D. Steel. 1964. Toxicity of *Phalaris tuberosa* for sheep. Nature 204:542-545.

Gentry, C. E., R. A. Chapman, L. Henson, and R. C. Buckner. 1969. Factors affecting the alkaloid content of tall fescue (*Festuca arundinacea* Schreb.) Agron. J. 61:313-316.

Gillet, M., and J. Jadas-Hecart. 1965. Leaf flexibility, a character for selection of tall fescue for palatability. Proc. IX Int. Grassl. Congr. p. 155-157.

Gladstones, J. S. 1970. Lupines as crop plants. Field Crop Abstr. 23:123-148.

Gomm, F. B. 1969. The palatability of range and pasture grasses in Montana. Montana Agr. Exp. Sta. Bull. 619. 29 p.

Hammes, R. C., Jr., R. E. Blaser, H. T. Bryant, and R. W. Engel. 1962. Palatability and digestibility of coastal bermudagrass and alfalfa hays. Virginia Agr. Exp. Sta. Bull. 533. 7 p.

Hanks, D. L., J. R. Brunner, D. R. Christensen, and A. P. Plummer. 1971. Paper chromatography for determining palatability differences in various strains of big sagebrush. USDA Forest Serv. Res. Paper INT-101. 9 p.

Hanover, J. W. 1966. Genetics of terpenes. 1. Gene control of monoterpene levels in *Pinus monticola* Dougl. Heredity 21:73-84.

Hanson, A. A. 1972. Grass varieties in the United States. USDA, Agr. Res. Serv., Agr. Handbook No. 170. 124 p.

Hawkins, G. E., Jr. 1955. Consumption and digestibility of lespedeza sericea hay and alfalfa hay plus gallotannin. J. Dairy Sci. 38:237-243.

Heady, H. F. 1964. Palatability of herbage and animal preference. J. Range Manage. 17:76-82.

Holmgren, R. C., and S. S. Hutchings. 1972. Salt desert shrub response to grazing use, p. 153-164. *In* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [ed.] Sect. IV. Synecology. Wildland Shrubs–Their Biology and Utilization. USDA Forest Serv. Gen. Tech. Rep. INT-1.

Hovin, A. 1973. Research report. West. Grass Breed. Work Plan. Conf. 22:45.

Hubbard, W. A., and H. H. Nicholson. 1968. Reed canarygrass vs grass-legume mixtures under irrigation as pasture for sheep. J. Range Manage. 21:171-174.

Hull, A. C., Jr., and R. C. Holmgren. 1964. Seeding southern Idaho rangelands. USDA Intermount. Forest and Range Exp. Sta. Res. Paper. INT-10.

Jacobson, D. R., S. B. Carr, R. H. Hatton, R. C. Buckner, A. P. Graden, D. R. Dowden, and W. H. Miller. 1970. Growth physiological responses, and evidence of toxicity in yearling dairy cattle grazing different grasses. J. Dairy Sci. 53:575-587.

Kneebone, W. R. 1960. Tensile strength variations in leaves of weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees) and certain other grasses. Agron. J. 52:539-542.

Knowles, R. P. 1973. Research report. West. Grass Breed. Work Plan. Conf. 22:57.

Lassiter, C. A., D. M. Seath, J. W. Woodruff, J. A. Taylor, and J. W. Rust. 1956. Comparative value of Kentucky bluegrass, Kentucky 31 fescue, orchardgrass, and bromegrass as pasture for milk cows. II. Effect of kind of grass on the dry matter and crude protein content and digestibility and intake of dry matter. J. Dairy Sci. 39:581-588.

Lawrence, T. 1960. Grass breeding in western Canada. Intermediate wheatgrass. West. Grass Breed. Work Plan. Conf. 14:8-10.

Le Houerou, H. N. 1972. Africa–the Mediterranean region, p. 26-36. *In* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [ed.] Sect. I. Continental Aspects of Shrub Distribution, Utilization, and Potentials. Wildland Shrubs–Their Biology and Utilization. USDA Forest Serv., Gen. Tech. Rep. INT-1.

Leigh, J. H. 1961. The relative palatability of various varieties of weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees). J. Brit. Grassl. Soc. 16:135-140.

Longhurst, W. M., H. K. Oh, M. B. Jones, and R. E. Kepner. 1968. A basis for the palatability of deer forage plants. N. Amer. Wildl. and Natur. Resources Conf. Trans. 33:181-192.

Lyford, S. J., W. W. G. Smart, Jr., and T. A. Bell. 1967. Inhibition of rumen cellulose digestion by extracts of sericea lespedeza. J. Anim. Sci. 26:632-637.

Marten, G. C. 1970. Measurement and significance of forage palatability, p. D1-D55. *In* Proc. Nat. Conf. Forage Quality Evaluation and Utilization. Nebraska Center for Continuing Education, Lincoln, Nebraska.

Marten, G. C. 1973. Alkaloids in reed canarygrass, p. 15-31. *In* A. G. Matches [ed.] Anti-quality components in forages. Crop Sci. Soc. Amer. Special Pub. No. 4, Madison, Wisconsin.

Marten, G. C., R. F. Barnes, A. B. Simons, and F. J. Wooding. 1973. Alkaloids and palatability of *Phalaris arundinacea* L. grown in diverse environments. Agron. J. 65:199-201.

Marten, G. C., and J. D. Donker. 1968. Determinations of pasture value of *Phalaris arundinacea* L. vs *Bromus inermis* Leyss. Agron. J. 60:703-705.

Marten, G. C., and R. M. Jordan. 1974. Significance of palatability differences among *Phalaris arundinacea* L., *Bromus inermis* Leyss., and *Dactylis glomerata* L. grazed by sheep. Proc. XII Int. Grassl. Congr. (in press).

McCullough, M. E., D. M. Baird, W. E. Neville, Jr., and O. E. Sell. 1953. The intake, digestibility, and nutrient deficiencies of seven southeastern hays. J. Dairy Sci. 36:854-858.

Milford, R. 1960. Nutritional value of sub-tropical pasture species under Australian conditions. Proc. VIII Int. Grassl. Congr. p. 474-479.

Milford, R., and D. J. Minson. 1968. The digestibility and intake of six varieties of Rhodes grass (*Chloris gayana*). Aust. J. Exp. Agr. Anim. Husb. 8:413-418.

Nagy, J. G., H. W. Steinhoff, and G. M. Ward. 1964. Effects of essential oils of sagebrush on deer rumen microbial function. J. Wildl. Manage. 28:785-790.

O'Donovan, P. B., R. F. Barnes, M. P. Plumlee, G. O. Mott, and L. V. Packett. 1967. *Ad libitum* intake and digestibility of selected reed canarygrass (*Phalaris arundinacea* L.) clones as measured by the fecal index method. J. Anim. Sci. 26:1144-1152.

Oh, H. K., M. B. Jones, and W. M. Longhurst. 1968. Comparison of rumen microbial inhibition resulting from various essential oils isolated from relatively unpalatable plant species. Appl. Microbiol. 16:39-44.

Oh, J. H., M. B. Jones, W. M. Longhurst, and G. E. Connolly. 1970. Deer browsing and rumen microbial fermentation of Douglas-fir as affected by fertilization and growth stage. Forest Sci. 16:21-27.

Oh, H. K., T. Sakai, M. B. Jones, and W. M. Longhurst. 1967. The effect of various essential oils isolated from Douglas-fir needles upon sheep and deer rumen microbial activity. Appl. Microbiol. 15:777-784.

Oram, R. N. 1970. Genetic and environmental control of the amount and composition of toxins in *Phalaris tuberosa* L. Proc. XI Int. Grassl. Congr. p. 785-788.

Pacola, L. J., F. P. Lima, O. L. D. Santos, and B. D. E. S. DeCampos. 1972. Palatability of elephant grass, *Pennisetum purpureum* Schum. Bol. Industr. Anim. Sp, n. s. 29:169-173.

Peterson, R. G., P. H. Weswig, and J. R. Cowan. 1958. Measuring palatability differences in tall fescue by grazing sheep. Agron. J. 50:117-119.

Plummer, A. P. 1972. Selection, p. 121-126. *In* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [ed.] Sect. III. Genetic Potential. Wildland Shrubs–Their Biology and Utilization. USDA Forest Serv., Gen. Tech. Rep. INT-1.

Plummer, A. P., A. C. Hull, Jr., G. Stewart, and J. H. Robertson. 1955. Seeding rangelands in Utah, Nevada, southern Idaho, and western Wyoming. USDA Forest Serv. Agr. Handbook 71. 73 p.

Rae, A. L., R. W. Brougham, and R. A. Barton. 1964. A note on liveweight gains of sheep grazing different ryegrass pastures. New Zeal. J. Agr. Res. 7:491-495.

Reid, R. L., G. A. Jung, and R. O. Thomas. 1968. Nutritive evaluation of crownvetch hay using sheep and cattle, p. 86-97. *In* Proc. 2nd Crownvetch Symposium, Agron. Mimeo. 9, Pennsylvania State Univ. (cited by Marten, 1970).

Richards, D. E., and V. B. Hawks. 1945. Palatability for sheep and yield of hay and pasture grasses at Union, Oregon. Oregon Agr. Exp. Sta. Bull. 431. 52 p.

Roe, R., and B. E. Motterhead. 1962. Palatability of *Phalaris arundinacea* L. Nature 193:255-256.

Rogler, G. A. 1944. Relative palatabilities of grasses under cultivation in the Northern Great Plains. J. Amer. Soc. Agron. 36:487-496.

Saiga, S., S. Kawabata, K. Gotoh, and S. Suzuki. 1972. Variation of orchardgrass varieties in palatability in relation to experimental methods and animals. J. Jap. Soc. Grassl. Sci. 18:41-47.

Schwendiman, J. L. 1963. The development of new varieties for use in conservation seedings. West. Grass Breed. Work Plan. Conf. 17:7-10.

Schwendiman, J. L., and A. G. Law. 1969. Latar–a high quality orchardgrass–its history and development. West. Grass Breed. Work Plan. Conf. 20:14-16.

Seath, D. M., C. A. Lassiter, J. W. Rust, M. Cole, and G. M. Bastin. 1956. Comparative value of Kentucky bluegrass, Kentucky 31 fescue, orchardgrass, and bromegrass as pasture for milk cows. I. How kind of grass affected persistence of milk production, TDN yield, and body weight. J. Dairy Sci. 39:574-580.

Sengbusch, R. von. 1938. The breeding of sweet lupines. Herbage Rev. 6:64-71.

Short, H. L. 1963. Rumen fermentations and energy relationships in white-tailed deer. J. Wildl. Manage. 27:184-195.

Simons, A. B., and G. C. Marten. 1971. Relationship of indole alkaloids to palatability of *Phalaris arundinacea* L. Agron. J. 63:915-919.

Smart, W. W. G., Jr., T. A. Bell, N. W. Stanley, and W. A. Cope. 1961. Inhibition of rumen cellulase by an extract from sericea forage. J. Dairy Sci. 44:1945-1946.

Smith, A. D. 1950. Inquiries into differential consumption of juniper by mule deer. Utah Fish Game Bull. 9(5):4.

Smith, W. K. 1964. Denta sweetclover. Crop Sci. 4:666-667.

Smith, W. K., and H. J. Gorz. 1965. Sweetclover improvement, p. 163-231. *In* A. G. Norman [ed.] Advances in Agronomy. Vol. 17. Academic Press Inc., New York.

Spiher, A. T., Jr. 1974. FDA regulations: A new development in agriculture, p. 1-6. *In* The Effect of FDA Regulations (GRAS) on Plant Breeding and Processing. Crop Sci. Soc. Amer. Spec. Pub. 5, Madison, Wisconsin.

Stapledon, R. G., and W. E. J. Milton. 1932. Yield, palatability, and other studies on strains of various grasses. Welsh Plant Breed. Sta. Bull. H13:1-79. (cited by Marten, 1970).

Stitt, R. E. 1943. Variation in tannin content of clonal and open-pollinated lines of perennial lespedeza. J. Amer. Soc. Agron. 35:944-954.

Stutz, H. C. 1972. Genetic improvement in crop species as contrasted with possibilities in shrubs, p. 139-143. *In* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [ed.] Sect. III. Genetic Potential. Wildland Shrubs–Their Biology and Utilization. USDA Forest Serv., Gen. Tech. Rep. INT-1.

Theron, E. P., and P. de V. Booysen. 1966. Palatability in grasses. Proc. Grassl. Soc. South Afr. 1:111-120.

Theron, E. P., and P. de V. Booysen. 1968. A study of the factors influencing the breaking tension of the leaves of various grasses. Proc. Grassl. Soc. South Afr. 3:63-66.

Thomson, D. J. 1971. The voluntary intake of diploid (S22) and tetraploid (Tetila tetrone) Italian ryegrass, and white clover by sheep. J. Brit. Grassl. Soc. 26:149-155.

Vallentine, J. F. 1971. Range development and improvements. Brigham Young Univ. Press, Provo, Utah. 516 p.

Voigt, P. W. 1971. Registration of Morpa weeping lovegrass. Crop Sci. 11:312-313.

Voigt, P. W., W. R. Kneebone, E. H. McIlvain, M. C. Shoop, and J. E. Webster. 1970. Palatability, chemical composition, and animal gains from selections of weeping lovegrass, *Eragrostis curvula* (Schrad.) Nees. Agron. J. 72:673-676.

Walls, J. R., and D. R. Jacobson. 1970. Skin temperatures and blood flow in the tail of dairy heifers administered extracts of toxic tall fescue. J. Anim. Sci. 30:420-423.

Wilkins, H. L., R. P. Bates, and P. R. Henson. 1953. Tannin and palatability in sericea lespedeza, *L. cuneata*. Agron. J. 45:335-336.

Williams, M., R. F. Barnes, and J. M. Cassady. 1971. Characterization of alkaloids in palatable and unpalatable clones of *Phalaris arundinacea* L. Crop Sci. 11:213-217.

Wilson, D. 1965. Nutritive value and the genetic relationships of cellulose content and leaf tensile strength in *Lolium.* J. Agr. Sci. 65:285-292.
Woods, D. 1973. Evaluating reed canarygrass clones for palatability. West. Grass Breed. Work Plan. Conf. 22:34-35.
Woods, D. L., and K. W. Clark. 1971. Genetic control and seasonal variation of some alkaloids in reed canarygrass. Can. J. Plant Sci. 51:323-329.
Wright, L. N. 1971. Registration of Catalina weeping lovegrass. Crop Sci. 11:939.

50

Potentials of Legumes for Rangelands

D. H. Heinrichs
Head, Forage Production
and Utilization Section
Research Station
Research Branch, Agriculture Canada
Swift Current, Saskatchewan S9H 3X2

Abstract

Legumes have become an important constituent of pastures in high rainfall areas where management input is high but they have been used sparingly or not at all on rangelands where precipitation is low and the land is difficult to cultivate. The infrequent use of legumes on rangelands may be attributed largely to their persistence qualities, which are lower than those of grasses, and their bloat hazard to ruminants. The role of legumes in increasing production has received considerable attention in recent years in New Zealand, Australia, the United States, and Canada. The wide climatic adaptability of alfalfa makes it the most promising legume to use on rangelands in the temperate regions of the world. However, breeders will have to evolve a different philosophy about alfalfa which stresses persistence under grazing rather than yield per se. The creeping-rooted character incorporated into many new cultivars in North America improves their persistence in dry climatic regions. Other legumes such as sainfoin, birdsfoot trefoil, milk vetches and vicias may also be used in many areas, but improved cultivars are required. The nitrogen-fixing ability of legumes will help not only to maintain the fertility of the soil, but also greatly increase production of rangelands.

Cultivars and ecotypes of white clover (*Trifolium repens*) are important plants in permanent pastures in many temperate regions of the world where annual precipitation is 625 mm (25 inches) or more. In New Zealand, white clover probably has been exploited more than in any other country as a pasture legume. Such pastures have an excellent productive capacity and a fairly long life with a minimum of nitrogen fertilization. White clover can be used to improve the pasture productivity of the Hill Country (Suckling 1954). When I was there in 1961, it was being aerially seeded and fertilized in the uncultivatable, hilly, rough land. This legume with its dense cover has stabilized soil fertility, reduced erosion, and enhanced production of hill pastures. In oversowing trials with pelleted alfalfa, increasing rates of lime applications increased production and formation of nodules (White 1970).

In Australia the use of legumes in overseeding rangelands is well documented (Donald 1970). Subterranean clover (*Trifolium subterraneum*), an annual legume, is widely used for seeding rangelands in southern regions. Through its capacity to reseed, the plant maintains itself in a stand dominated by perennial grasses. On well-drained soils, alfalfa (*Medicago sativa*) is widely used as a mixture component in permanent pastures in many parts of Australia.

In the North American arid and semiarid grassland regions where precipitation varies from 250 to 500 mm (10 to 20 inches), legumes have been used seldom or not at all in rangeland improvement programs, and even in farm pastures their use has been minimal. The reason for this appears to be poor survival of legumes under heavy grazing and the wariness of ranchers and farmers about using legumes for pasture because of the bloat hazard. Legumes failed to persist in most range seeding programs and were not considered worth the bother; hence pasture improvement programs in the dry areas concentrated on the use of grasses.

Plants as they grow in nature have acclimatized themselves to a natural environment, which has subjected them to competition from many other species and pressures from grazing animals and fluctuating weather conditions over time. Legumes seldom are dominants in plant communities, preferring to grow in combination with other species or in special localities. Many of them, because they are more palatable than grasses or contain nutrients that animals crave, are grazed more intensely than grasses and tend to disappear from the stand.

Legumes for Rangeland Need Special Attributes

When man selects a legume species to cultivate under special conditions, the selection and breeding process begins. This process can be slow, as it has been in the past, largely because man selected the plants that thrived under the new environment; or it can be rapid, if man employs the science of genetics and artificial testing media that exaggerate the facets of the new environment under which the crop is to be grown.

We are now in the rapid stage of breeding, and the emphasis everywhere is to breed for high yield per se and high nutritive value. Legumes are being improved for the most productive farmlands and most often for hay or silage use. Selection programs are concerned with fitting and improved cultivar into monocultural use where the crop produces high yields of forage for relatively few years and has to be reseeded often.

The role of the legume as a pasture plant has largely been overlooked by most agronomists and plant breeders. They tended to have tunnel vision and overemphasized the importance of high yield in legumes for highly productive areas and have failed to select strains for other attributes, such as persistence and sustained yield. Thus, the forage potential of legumes for pasture on the less productive land areas has not been realized. Yet, it is in these areas where their greatest potential lies because intense cultural practices are not feasible or plausible. On rangelands, forage must be used by ruminant animals, which can gather and digest it. Productivity of such areas needs to be increased to sustain a growing livestock population and leguminous plants can be the ones to do it. They will not only add to the productivity of rangelands but should help to maintain their fertility by fixing nitrogen from the air, which will supply this important soil nutrient not only for themselves but also for the grasses that grow in association with them.

We have not come very far in developing legumes for rangelands since Keller (1948), in an article entitled "Wanted: A Paragon for the Range," stated that no legume has yet been found that appears promising for rangelands over extensive areas, and as a result reseeding practices usually include only grasses. However, some progress has been made, at least, in recognizing that the situation is not hopeless if we put our mind to it and improve legumes with the specific characteristics of persistence and low-bloat-causing qualities so essential in a legume for the range. Modifying pasture management to accommodate legumes is important also to retain them in the stand. Legumes should have a chance to reseed themselves occasionally and they should not be overgrazed, especially in the fall.

In western Canada we recognized the need for persistent legumes immediately after the Great Drought of the thirties, when land formerly used for grain production was reseeded to grass. Strong stands of crested wheatgrass (*Agropyron desertorum* and *Agropyron cristatum*) soon depleted soil nitrogen, and production was limited not only by lack of moisture but also because available nitrogen was very low. Wherever legumes persisted in mixture with grasses, production was doubled over the yield of grasses alone (Fig. 1) (Clarke and Heinrichs 1957). It was realized that if such forage yields could be maintained, livestock production could compete with grain production even on the better agricultural lands in the Canadian Prairies. If such production can be developed also on the rougher rangelands, the pasture base which is running low can sustain cattle populations double and triple of what was considered an optimum carrying capacity at the time. In this paper, I am stressing the situation in Canada because I am familiar with it, but the principles involved in using legumes along with grasses for improving rangelands apply equally in many other countries with a temperate climate.

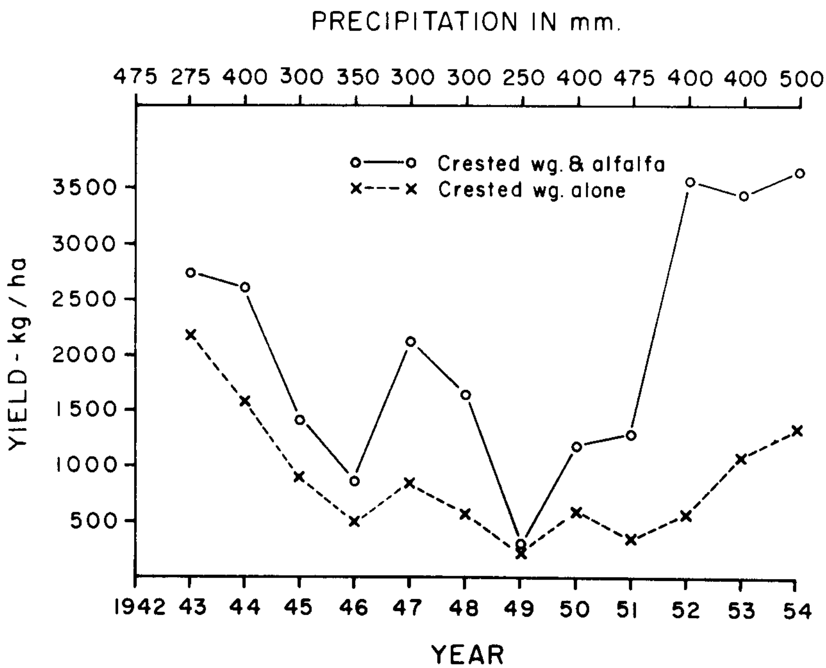

Fig. 1. *Production of crested wheatgrass with alfalfa and alone.*

Drought-Tolerant Alfalfas

Isolated stands of Siberian alfalfa (*Medicago falcata*) were found to persist for 20 years or more in North and South Dakota, Montana, Alberta, and Saskatchewan. These stands originated from seed distributed in the early years in this century by N. E. Hanson of South Dakota after plant exploration trips to Russia and Siberia (Hanson 1909). We had such a stand at the Research Station, Swift Current, Saskatchewan. The alfalfa had been seeded with crested wheatgrass in the early twenties and had persisted under heavy grazing until the

late thirties when we began using this alfalfa as a base in our breeding program. The aim was to develop hardier, more persistent alfalfas than the very winter-hardy cultivars Grimm and Ladak which were still not persistent enough in the dry regions of western Canada.

At Swift Current, we have concentrated on developing cultivars that are creeping-rooted and recover slowly after cutting or grazing (Heinrichs 1963). These two characteristics were found to be positively related to survival and persistence in the cold, dry climatic region of western Canada. Horizontal roots of true creeping-rooted alfalfas are structured anatomically different than those of rhizomatous alfalfas and the difference has been clearly outlined by Murray (1957). Creeping-rooted alfalfas are especially well suited for grazing. The crowns are below ground level, protected from trampling by animals, and the horizontal rootstocks, usually 10 to 15 cm below the ground surface, make it possible for the plants to spread and renovate the stand if it has been reduced by adverse climatic conditions or overuse (Fig. 2, Table 1). Southworth (1921) stated: "When alfalfa has the habit of spreading by means of root proliferation, we have a form of spreading and multiplying in a vegetative manner which promises to give to the plant greater powers of resistance to cold and also greater powers of recuperation from injury than is possessed by even true rhizomes, and we venture to hope that these properties will render it possible to grow good crops in adverse climatic conditions under which it would be quite impossible to raise common alfalfa." Many others have recognized the significance of the root system of alfalfa in broadening its use and I have written a comprehensive review on creeping alfalfas (Heinrichs 1963).

It is a well-established fact that cultivated grasses, such as crested wheatgrass and Russian wild ryegrass (*Elymus junceus*) produce twice as much as the indigenous native vegetation, and this yield advantage has persisted for 25 to 35

Table 1. Dry matter yield (kg/ha) from 15-year-old creeping-rooted alfalfa plants growing in a 20-year-old stand of crested wheatgrass. These alfalfa plants had attained a horizontal spread of 4 m^2 or more.

Plant material	D.M. yield kg/ha
Within the peripheral border of creeping-rooted alfalfa plants:	
alfalfa portion	1085
grass portion	1472
Crested wheatgrass in adjacent pure stand:	515
Increase of alfalfa-grass mixture over grass alone:	2042

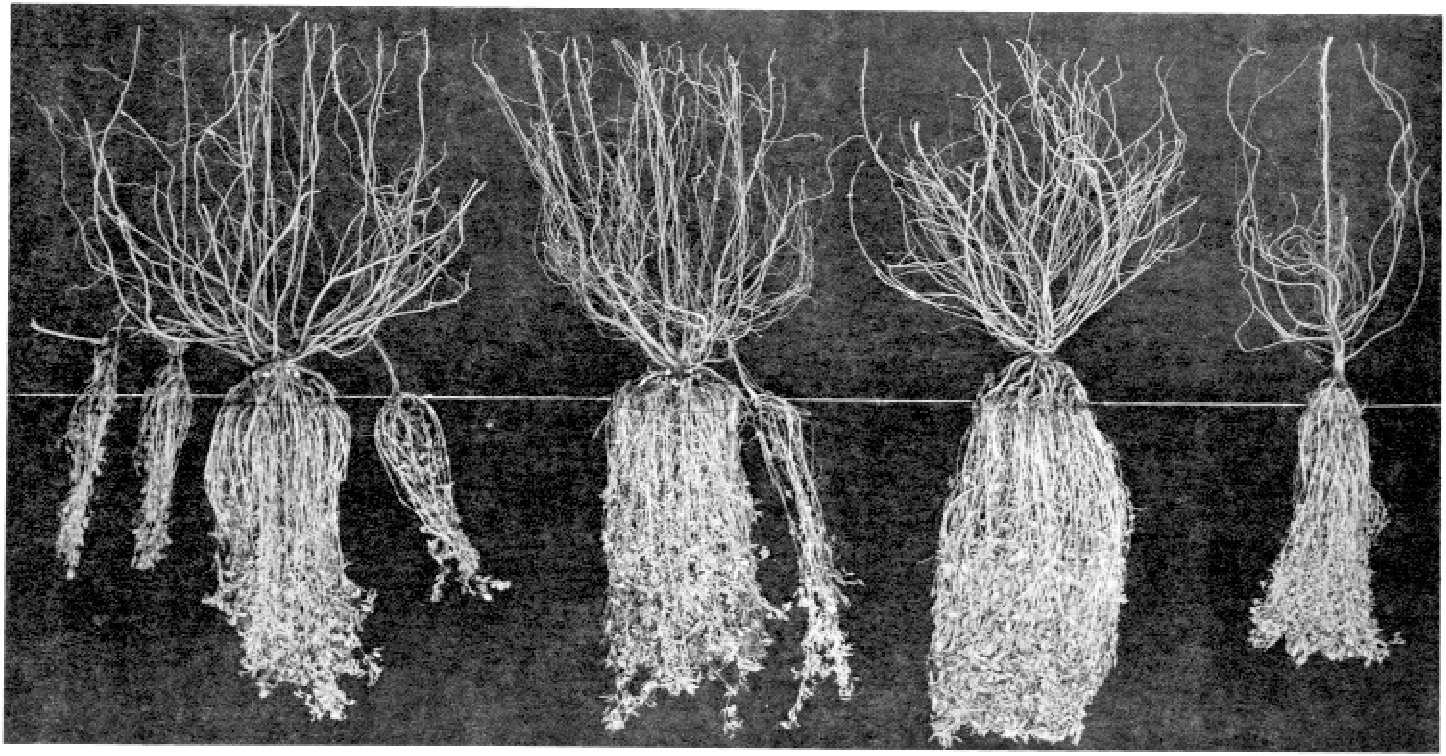

Fig. 2. *Alfalfa root systems left to right: tap, branch, rhizomatous, creeping.*

Table 2. Productivity of grass-alfalfa pastures in contrast to that of grass alone pastures grazed by ewes in a repeated seasonal pattern, grazing season May 1 to October 1, 1956

Crop	Grazing season	Production kg/ha	Consumption kg/ha	Carrying capacity ewe day/ha	Gain/ewe kg/season	Consumption of herbage/kg of ewe gain
Crested wheatgrass + alfalfa	spring					
Intermediate wheatgrass + alfalfa	summer	1580	1116	943	6.6	11.1
Russian wild ryegrass + alfalfa	autumn					
Mixture of the 3 grasses + alfalfa	spring					
	summer	1122	880	833	6.1	10.3
	autumn					
Mixture of the 3 grasses	spring					
	summer	824	742	634	2.7	27.9
	autumn					
Mean		1176	913	803	5.1	16.4
S.E. Mean %		11.6	13.0	5.6	9.3	8.7

Note: Annual precipitation during the period was 305 mm, considerably below the average of 365 mm.

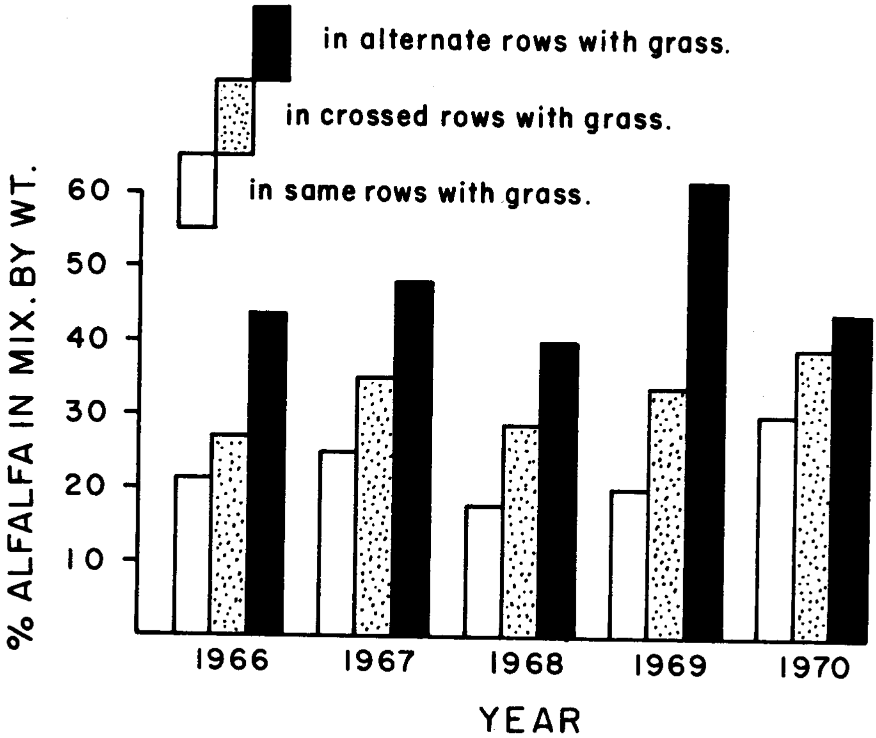

Fig. 3. *The amount of alfalfa in the harvested mixture as affected by stand pattern.*

years (Looman and Heinrichs 1973). Alfalfa growing with grasses such as these was shown by Campbell (1963) to increase pasture production by another 50% (Table 2). Not only was the production and carrying capacity of the grass-alfalfa mixtures greater but the sheep also gained more through the season and utilized the forage more efficiently.

Our research, related to patterns of seeding, has clearly illustrated that the alfalfa component remains at a higher level in the stand when growing in alternate or crossed rows with the grass component (Fig. 3 and 4) (Kilcher and Heinrichs 1971). The total production was 25% greater in alternate rows and 12% greater in crossed rows than in mixed rows. Water runoff was also reduced in crossed row stands and we recommend the cross-row method of seeding for dryland pastures.

We have developed three creeping-rooted alfalfa cultivars at Swift Current, namely Rambler, Roamer, and Drylander. Of the three, Drylander is best suited for pasture because it is the most strongly creeping-rooted and has the slowest regrowth capability. It has an excellent ability to remain dormant through long dry and cold periods, an essential characteristic in a dry climate. However, I feel we have only just made contact with the possibilities and need to go much farther and stress persistence in our selection program rather than yield.

Fig. 4. *Alfalfa and crested wheatgrass in cross-seeded rows 61 cm (2 feet) apart.*

It is important to get long-term economic yields from pasture legumes, not high short-term yields followed by nothing. To achieve real progress in breeding legumes for rangelands, breeders will have to stop looking for lush leafy plants and turn their eye to the more xerophytic, pubescent, lack-lustre fibrous plants that hold their leaves. The success will depend on how well the breeder can develop tunnel vision in the direction of sustained yield rather than short-term yield and maintenance of high soil nitrogen with legumes rather than with chemical fertilizers.

I mentioned the fear of bloat as one reason why legumes are not used more extensively on rangelands where cattle receive minimal attention. In Canada, we are attempting to overcome death loss from alfalfa bloat by breeding low-bloat cultivars. Fraction I protein (18-S) was found to be a major contributor to cattle bloat (McArthur et al. 1964). Recently, however, Howarth et al. (1973) reinvestigated the foaming qualities of alfalfa leaf proteins and found that the larger Fraction II proteins were also contributing to the problem and concluded that the majority of soluble proteins are probably responsible for bloat in cattle which graze alfalfa. A comprehensive breeding program is underway at the Research Station in Saskatoon, Saskatchewan to develop a low-soluble protein alfalfa. Howarth et al. (1973) report a broad distribution of plants, in an alfalfa population of diverse genetic origin, for soluble protein (Fig. 5). The prospects for developing alfalfa cultivars with low-soluble protein are good, and if this is

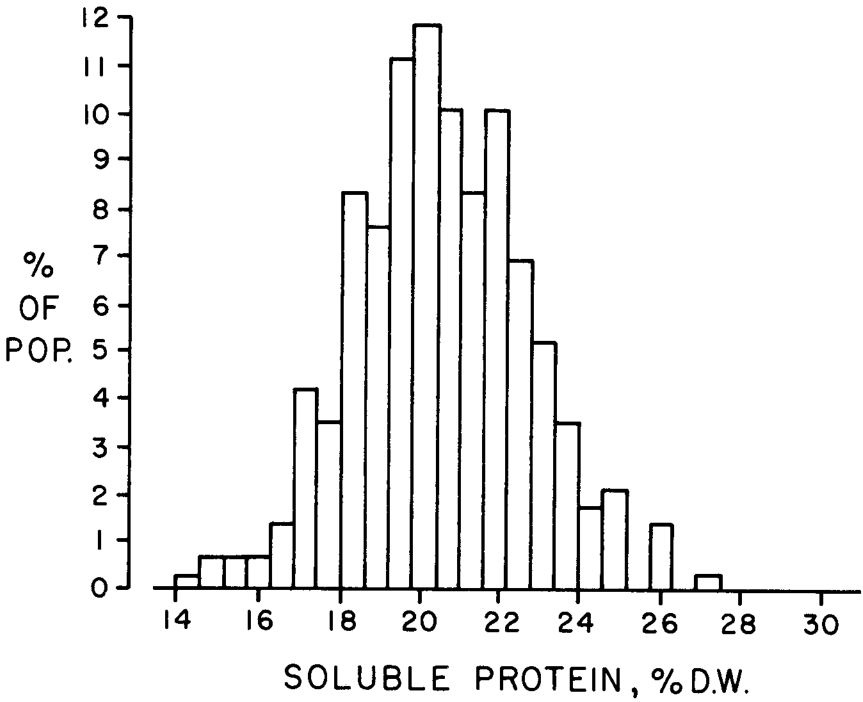

Fig. 5. *Frequency distribution of 286 alfalfa plants of diverse genetic origin for soluble protein (g/100 g dry weight).*

combined with persistence and longevity qualities, a suitable pasture alfalfa for northern rangelands may soon be developed.

Other Legumes

Sainfoin (*Onobrychis viciaefolia*), cicer milkvetch (*Astragalus cicer*), and birdsfoot trefoil (*Lotus corniculatus*), all three no-bloat legumes, appear to have considerable promise for seeding rangelands in many regions of Canada and the United States.

A sainfoin symposium held at Montana State University (1968) illustrates the potential this legume may have in the foothill regions of Montana and Alberta. Greater winter hardiness, ease of establishment, and better nitrogen-fixing ability were some of the stated improvement aims for this legume.

Cicer milkvetch, a native legume of Europe has been in Canada and the United States since 1931 and sporadic evaluations of its possible pasture potential have been made, but to date it has not experienced general acceptance, probably because it is slow to establish and generally yields less than alfalfa (Smoliak et al. 1972). New cultivars of cicer milkvetch have been released in Montana and Alberta, and it is likely that the use of this legume will expand in the future, as it persists well under grazing.

Birdsfoot trefoil is considered to have promise in eastern Canada as a constituent of roughland pastures (Watkin et al. 1971). Paraquat was required to reduce grass growth so that the legume could become established. An increased production of pastures was maintained for at least 5 years. ***Astragalus danicus, Astragalus striate, Astragalus crassicarpus, Vicia americana*** and ***Vicia cracca*** may have some value on rangelands, but the plant breeder will have to play a major role in fitting them into the right niche or they will not go far.

Legume Inoculation

Legumes differ from other plants in that they are able to convert nitrogen from the air into a form that is available to them. In some instances they release nitrogen from decaying roots and nodules and benefit grasses growing in close proximity by supplying nitrogen to them. Legumes play a major role in conserving soil nitrogen and are, therefore, very important to agriculture.

To make use of nitrogen from the air, legumes require bacteria of the *Rhizobium* genus with which they go into symbiosis to fix nitrogen in nodules on their roots. Although bacteria associated with various kinds of legumes are closely related, different types have become so adapted to certain legume species that they are unable to produce nodules on other species. Thus, different species of legumes often require different species of *Rhizobium* to produce nodules and fix nitrogen.

The nitrogen-fixing efficiency of different legumes varies as does also that of different *Rhizobium* species and strains. It is therefore important that legumes and *Rhizobium* strains are properly matched to fix nitrogen efficiently and maintain an adequate nitrogen status in the soil. The need for inoculation varies with climate, soil conditions, and the species of legume being used, but generally it is advisable to inoculate the seed at the time of seeding with a specific *Rhizobium* culture to insure maximum nodulation and nitrogen fixation. Australian scientists are leaders in this field of research, and I refer the reader to an article by Norris (1970) on inoculent specificity and efficient nitrogen fixation.

Conclusions

Legumes can play an important role in increasing production of rangelands in North America; but considerable research and work remains to be done in breeding, selection, and management to make it all come about. Sustained missionary zeal is needed by scientists, conservationists, and ranchers, to get legumes into rangelands, because it will be a long-term proposition and little genuine progress is made by impetuous starts and stops. I can say without hesitation that there are 10 million ha of rangelands in western Canada that can benefit from the use of legumes in seeding programs. Production can be doubled over and above the use of grasses alone; at the same time, the fertility of the soil and ecological balance can be maintained. Assuming that the situation in the US is similar, the potential of legumes for the improvement of rangelands is great indeed.

Literature Cited

Campbell, J. B. 1963. Grass-alfalfa versus grass-alone pastures grazed in a repeated-seasonal pattern. J. Range Manage. 16:78-81.

Clarke, K. W., and D. H. Heinrichs. 1957. Grass-legume mixture trials. Can. Dep. Agr. Mimeo. Bull. p. 1-29, Ottawa.

Cooper, C. S., and E. A. Carlton (editors). 1968. Sainfoin Symposium, Montana State University, Bozeman, Mont. p. 1-107.

Donald, C. M. 1970. Temperate pasture species. Ch. 20:301-320. *In* Australian Grasslands ed. Milton Moore, Australian National University Press, Canberra.

Hanson, N. E. 1909. The wild alfalfas and clovers of Siberia with a perspective view of the alfalfas of the world. USDA Bull. 150.

Heinrichs, D. H. 1954. Developing creeping-rooted alfalfa for pasture. Can. J. Agr. Sci. 34:269-280.

Heinrichs, D. H. 1963. Creeping alfalfas, p. 317-337. *In* Advan. Agron. A. G. Norman (ed.) Academic Press, Inc., New York.

Howarth, R. E., J. M. McArthur, and B. P. Goplen. 1973. Bloat investigations: The determination of soluble protein concentration in alfalfa (*Medicago sativa* L.). Crop Sci. 13:677-681.

Howarth, R. E., J. M. McArthur, M. Hikichi, and S. K. Sarkar. 1973. Bloat investigations: Denaturation of alfalfa fraction II proteins by foaming. Can. J. Anim. Sci. 53:439-443.

Keller, W. 1948. Wanted: A paragon for the range. *In* Grass, the Yearbook of Agriculture, p. 347-351. USDA. Washington, D.C.

Kilcher, M. R., and D. H. Heinrichs. 1971. Stand patterns for alfalfa-grass hay production in a dry climate. Can. J. Plant Sci. 51:317-322.

Looman, J., and D. H. Heinrichs. 1973. Stability of crested wheatgrass pastures under long-term use. Can. J. Plant Sci. 53:501-506.

McArthur, J. M., J. E. Miltimore, and M. J. Pratt. 1964. Bloat investigations: The foam stabilizing protein in alfalfa. Can. J. Anim. Sci. 44:200-207.

Murray, Beatrice E. 1957. The ontogeny of adventitious stems on roots of creeping-rooted alfalfa. Can. J. Botany 35:463-475.

Norris, D. O. 1970. Nodulation of pasture legumes. Ch. 22:339-360. Australian Grasslands ed. R. Milton Moore, Australian National University Press, Canberra.

Smoliak, S., A. Johnston, and M. R. Hanna. 1972. Germination and seedling growth of alfalfa, sainfoin and cicer milkvetch. Can. J. Plant Sci. 52:757-762.

Southworth, W. 1921. A study of the influence of the root system in promoting hardiness in alfalfa. Sci. Agr. 1:5-9.

Suckling, F. E. T. 1954. Pasture management trials on unploughable hill country at Te Awa. N.Z. J. Sci. and Tech. 36:237-273.

Tiver, N. S. 1958. Scrub to pasture in the South-East. J. Agr. South Australia Leaflet 34:1-18.

Watkin, E. M., J. E. Winch, and G. W. Anderson. 1971. Establishment of birdsfoot trefoil in paraquat-treated roughland pastures. Can. J. Plant Sci. 51:163-166.

White, J. G. H. 1970. Establishment of lucerne (*Medicago sativa* L.) in uncultivated country by sod-seeding and oversowing. Proc. Int. XI Grassland Congress, Surfers Paradise, Queensland, Australia: 134-138.

62

Shrubs and Forbs for Improvement of Rangelands

Cyrus M. McKell
Professor of Range Science and
Director, Environment & Man Program,
Utah State University,
Logan, Utah 84322

Abstract

The potentials of shrubs and forbs for improving rangeland productivity have not been adequately considered. Range improvement programs should include selected shrubs and forbs because of their adaptation to harsh environments, high productivity, contributions as wildlife habitat, protection of rangeland watersheds, and general contribution to the proper functioning of rangeland ecosystems.

We need to improve methods for establishing and managing highly productive forbs and shrubs, and to develop more information on their biology. Managers of the world's rangelands and arid ecosystems would do well to carefully consider ways to capitalize upon the desirable characteristics of shrubs and forbs.

Range revegetation with shrubs and forbs in past years has met with formidable difficulties related to seed collection and production, establishment problems, complexity of managing grazing on multiple-species seedings, and simply a lack of information. Recent emphasis on native species, grazing management as a range improvement tool and total ecosystem management has given new prominence to the use of shrubs and forbs for improving range productivity. Managing rangelands for their multiple use potential demands consideration of species other than grasses. As described in the proceedings of an international symposium on *Useful Wildland Shrubs* (McKell et al. 1972), shrubs have many virtues that justify their use in improvement programs either as species to be seeded or as species to be given equal attention in management plans. Monsen (1975) reports that requests for outplantings of shrubs and forbs have stimulated studies and pilot plantings.

Shrubs and Forbs Adapting to Harsh Environments

The harsh environmental conditions of rangelands limit the productivity of many plants. Adaptation to drought, salinity, wide temperature fluctuations, and other environmental extremes characterizes range shrubs. In fact, many shrub genera such as *Atriplex, Artemisia, Purshia, Chrysothamnus, Sarcobatus, Prosopis, Larrea, Acacia, Ceanothus, Quercus* and *Adenostema* include species that can produce considerable biomass in spite of harsh conditions. Not all species may be regarded as yielding products useful to livestock, but they may be important for other purposes. In many cases not enough is known about a given species to accurately determine its virtues or disadvantages.

Forbs also exemplify unrealized opportunities for obtaining increased range productivity. Both perennial and annual forbs have gradually evolved adaptations to harsh environments. Annual forbs (some of which may be termed "weeds" by agronomists) respond rapidly during short periods of favorable temperature and moisture to produce large quantities of biomass. This biomass may be a good source of protein and carbohydrate and a vital means of recycling minerals. A few genera such as *Erodium, Brassica, Cucurbita, Medicago, Vicia* are examples.

Range Productivity

Shrubs and forbs have not been fully credited for their contributions to the production of commercial animal products from rangelands. The grazing returns cited for the various shrub-dominated ranges by the Forest-Range Task Force (1972) reflect the grazing use obtained from all palatable plant species. Carrying capacities range from .77 AUM/ha for the Texas Savanna range ecosystem to a low of .07 AUM/ha for the Desert Shrub ecosystem.

The productivity of a given shrub species under field conditions varies with the site but can be substantial as Chew and Chew (1965) reported for *Larrea tridentata*. They found the primary productivity to be 1000 kg/ha for a relatively young stand.

Mason (1971) assessed Utah's range sites on the basis of current above-ground production of shrubs, forbs, and grasses (regardless of height and accessibility) according to site condition. As an example, semidesert stony loam sites in good condition with 200 to 300 mm of precipitation produce a mean air-dry annual yield in favorable years of 766 kg/ha. The species composition on such sites averages 30% shrubs, 5% forbs, and 56% grasses. Nonforage species, however, constitute 30% of this vegetation. In contrast, sites in fair condition produce 706 kg/ha from a species composition of 53% shrubs, 15% forbs and 32% grasses. Nonforage species on such sites still make up 30%, but the variety of forbs and shrubs is more extensive than on the good condition sites.

Yield reports under experimental conditons greatly exceed those from the open range. Gasto and Contreras (1972) reported that an 18-month-old stand of *Atriplex repanda* in an area of Chile that has a Mediterranean climate produced about 14,000 kg/ha in a grazing trial. The high productive capacity of saltbush species was also demonstrated in a field experiment at Riverside, California (Goodin and McKell 1971), where *Atriplex polycarpa*, *A. lentiformis*, and *A. canescens* produced yields ranging from 7,500 to 10,000 kg/ha (Table 1). These results suggest that the potential yield of marginal agricultural lands and favorable range sites could be increased many fold by planting adapted shrubs.

In comparison with grasses, fewer species of forbs have been studied for their productivity as components of range revegetation. Legumes and poisonous forbs have been the most popular subjects for study. The notes of Dayton (1960) are replete with botanical information about forbs and suggestions for their management. Some range forbs such as *Erodium* have a remarkable ability to produce herbage during short periods of favorable weather. Indeed, under the protective canopy of shrubs, many forb species are as aggressive as annual grasses and just as palatable.

Table 1. Dry weight yields (kg/ha per season) of three *Atriplex* species at Riverside, Calif. Data are for the second and third seasons of growth.

Species	1968 (irrigated)	1969 (not irrigated
A. polycarpa	3,805	7,599
A. lentiformis	6,185	10,169
A. canescens	–	9,189

Shrubs and forbs offer other advantages beyond productivity. Nutritional value is probably the most important according to Dietz (1972), with the current year's growth often being the higher in protein and carbohydrate content than older tissues. Data from the most arid region of the great central valley of California indicate that the crude protein content of *Atriplex polycarpa* leaves, new stems, and old stems is highest in January and lowest in early summer (Goodin and McKell 1971). The protein content of leaves may be as high as 20%, new stems 12%, and old stems less than 10%. Measurements of total digestible nutrients follow essentially the same pattern as crude protein through the season, with the TDN of leaves reaching a high of 45% in February.

On some ranges, shrubs may be almost the only source of nutrition during some periods of the year. For example, two small sub-shrubs on the floodplain of the Desaguadero River of the Bolivian Altiplano furnish much of the feed for sheep from nearby villages (Table 2). The plants furnish a level of crude protein and energy in excess of the minimum maintenance requirements of grazing animals for up to 7 months of the dry season. In Western Australia, extensive saline areas provide valuable grazing from halophytic shrubs and forbs (Malcolm 1969). Without these species, the carrying capacity of lands in that region would be considerably less.

A review of forage nutritional value tables further indicates the favorable levels of protein and carbohydrate in young plant parts (Committee on Feed Composition 1958). Crude protein contents range from 20 to 35% in buds, shoots, and leaves. Genera such as *Purshia, Kochia, Atriplex, Ceanothus, Acacia, Ceratoides, Artemisia, Cowania, Suaeda* and even *Prosopis* have particularly favorable nutritional characteristics. On a comparative basis, shrubs are highest in protein, phosphorus, lignin, and calcium; grasses are high in available carbohydrate, crude fiber, and cellulose, while forbs are intermediate between grasses and shrubs in most nutritional components (Cook 1972).

Because of their crude protein content during winter months, shrubs are the mainstay of winter range. Cook (1972) maintains that when combined with grass residues high in energy, a mix of shrubs, forbs, and grasses provide a balanced nutritional diet on winter range. However, Holmgren and Hutchings (1972)

Table 2. Chemical constituents of stems of two forage species of the Desaquadero River floodplain in the Bolivian Altiplano.[1] Figures are on the basis of oven-dry weight.

	% Crude Protein		% Carbohydrate		% Crude Fiber	
Date	Leaves	Stems	Leaves	Stems	Leaves	Stems
Atriplex						
Aug. 6, 1972	13.3	10.1	45.0	46.9	11.2	25.3
Sept. 5, 1972	13.0	9.3	27.8	48.6	–	27.4
Dec. 7, 1972	13.1	9.9	36.4	53.4	12.2	18.9
Sueada						
Aug. 6, 1972	14.8	10.1	37.4	54.2	9.0	24.2
Sept. 5, 1972	16.0	11.1	30.1	40.8	–	28.0
Dec. 7, 1972	14.7	12.2	34.7	42.0	9.8	28.9

[1] Unpublished data from files of Gover Barja, Director of Research, Ministry of Agriculture, La Paz, Bolivia.

caution that grazing of the salt desert shrub should be only moderate to avoid the loss of *Ceratoides lanata* and an excessive increase in the less adapted (for given areas) *Atriplex canescens* and unpalatable forbs.

An interesting opportunity occurred for forb utilization in 1967 in the southern end of the San Joaquin Valley of California (Temblor Range Research 1969). Abundant winter precipitation encouraged a luxuriant growth of annual forbs, which were mowed and windrowed as they approached maturity. The result was a harvest of about 800 kg/ha of highly palatable herbage with a crude protein content of 17%.

One of the less-publicized virtues of shrubs is the capacity to regrow vigorously when their tops are removed by grazing or by other actions. Such regrowth offers several advantages to the range manager for increasing productivity.

First is the assurance that dense shrub areas opened up by fire or other disasters will quickly regrow to provide a protective cover for watersheds.

Second is the possibility of manipulating shrub regrowth for use as wildlife and livestock feed. Willard and McKell (1973) found that defoliation of little rabbitbrush (*Chrysothamnus viscidiflorus*) and snowberry (*Symphoricarpos vaccinoides*) generally increased sprouting, but the best survival of new shoots occurred under a simulated rest-rotation system.

A third advantage is the capacity of some shrubs to survive and even flourish under intense utilization by animals. Root crowns of *Suaeda* and *Atriplex* in Bolivia appear to withstand intense grazing by sheep each year for several years (Fig. 1) thus making them a dependable forage source. Gasto and Contreras (1972) reported a phenomenal recovery of up to 250 mm of new shoot growth of *Atriplex repanda* after intense sheep grazing.

A fourth advantage is the high palatability of new shrub shoots to many domestic and wild animals. Shrubs that are normally not browsed when mature may be intensively utilized if many new shoots are present. Any generalizations regarding palatability should take regrowth into account.

The increased nutritive value of new growth as compared with old growth constitutes the fifth advantage. High protein and carbohydrate contents with little fiber make new shoots from shrubs a good source of additional animal feed.

Palatability varies greatly among shrub species and even within a species. Such differences make it possible for the range manager to develop productive management and improvement systems. Less palatable species should receive more attention in grazing management to insure a degree of utilization sufficient to stimulate their regrowth and bring about a better balance in competition. After observing site variations in palatability of *Artemisia tridentata* ecotypes, Plummer et al. (1968) advocated emphasis on selecting for palatability so that depleted areas could be seeded with improved types. They were opposed to the widespread, indiscriminate elimination of sagebrush.

Methods of seed collection have been developed for many shrub species (Plummer et al. 1968), and this does not presently constitute a significant

Fig. 1. *Root crown of* Atriplex sp. *(a) and (b)* Suaeda sp. *grazed intensely by sheep in the Bolivian Altiplano, 1972.*

deterrent to the inclusion of such species in range improvement plans. The big problem that remains is obtaining good field establishment, especially where saline soil conditions occur. Malcolm (1972) reviewed some of the hazards that shrub seedlings must endure in saline soil and concluded that by following a set of guidelines the level of success can be improved. Shallow planting depths and the use of locally adapted ecotypes are advocated by Nord et al. (1971) for seeding saltbush (*Atriplex spp.*) in California. Springfield (1971), after reviewing many past studies, concluded that winterfat (*Ceratoides lanata*) seedlings would also establish best from shallow seeding depth and a moderately dry soil. Cable's (1972) reports of fourwing saltbush (*Atriplex canescens*) seeding and transplanting trials in southern Arizona indicate a need for improved moisture conservation. Poorest survival was on a mesquite-burroweed site. The practice of transplanting *Atriplex halimus* rooted cuttings in Israel has resulted in a 90 to 93% success, according to reports by Ellern (1972). Fertilization may improve success in stand establishment (Williams and O'Connor 1973) but must be carefully studied in relation to species and environmental conditions to avoid the effects of competition for soil moisture as reported by Smith (1971) in his studies of mountainmahogany (*Cercocarpus ledifolius*). Although many studies of shrub seeding have been reported, we still lack enough information to adequately plan for range management by seeding shrubs along with other range species.

Wildlife Habitat Improvement

Shrubs are particularly important to wildlife because of the cover and feed they provide. According to Yeager (1961), nearly half of the 369 mammal species and 58% of the birds of North America occur in conjunction with woody cover. Associated forbs undoubtedly provide an important food supply. Any person proposing a range improvement program should take in account the impact of the program on habitat requirements of and feed supplies for game and nongame animals. Because of the close dependency of animals on their surrounding vegetation, any manipulation or conversion practice done in the name of range improvement will bring corresponding changes in wildlife numbers. Robinette (1972), in his *International Shrub Symposium* review of the important relationships of shrubs for wildlife, declared that nearly every shrub provides feed for one or more species of wildlife.

As cover, forbs and shrubs are vital for the existence of many species of wildlife. Species diversity in the vegetative cover assures both open spaces and dense areas. Well-planned range improvement projects can provide this needed diversity by proper planning to leave untreated islands and include a variety of species if seeding is to take place. Plummer et al. (1968) outlined some important steps to follow in restoring big game range.

Wildlife species need cover for concealment from predators, or conversely as a place to hide while stalking prey. All of the functions of reproduction from mating to hiding offspring require various kinds of cover. Sage grouse populations appear to thrive at an optimum when sagebrush (*Artemisia* *tridentata*) cover is about 10%, or a density of about 3,300 plants/ha (Phillips 1972). Less dense stands apparently do not provide sufficient protection while a more dense stand does not allow space for strutting grounds and limits the diversity of associated species that are needed for food and cover. Reynolds (1964a) found that deer and elk numbers increased with shrub density and diversity in the pinyon-juniper woodland type. A pinyon-juniper forest that has deteriorated to the point that little remains besides pinyon and juniper is not only poor range for game animals but may also be unproductive for other range uses.

In the semiarid western United States, .3 km is about as far as deer will move from cover (Leopold et al. 1951; Reynolds 1964b). Range improvement projects should be designed so that cleared or open areas are less than 1.4 km in width. "Edge effects" can be enhanced by careful planning of cleared and uncleared areas, which at the same time may serve to improve the aesthetic quality of a project (Williamson 1971).

During cold periods, dense shrub communities such as mountainmahogany, sagebrush, snowberry, and serviceberry (*Amelanchier alnifolia*) are sought by deer for both cover and feed. Loveless (1967) reported that deer seek cover for its moderating effects on cold temperatures and wind velocity.

Because of their shorter season of availability, forbs are most beneficial to wildlife primarily in the spring and summer. At that time the flowers, fruits, and seeds form an important component of the diet of wildlife, while other plant parts may be used either for nesting materials or forage.

Seeding or management practices should adequately consider the value of forbs in the composition of range ecosystems to obtain optimum productivity. Seventy-eight species of shrubs and 74 forbs that are among the most attractive for game range improvement in Utah were rated by Plummer et al. (1968). Many of these species would be equally suitable for general range improvement. Considerable interest has recently been expressed in increased requests for outplanting stock from native plant nurseries (Monsen 1975).

Rangeland Watersheds

Range watershed improvement typically involves efforts to increase sustained water yield by enhancing percolation and subsequent groundwater flow. Reducing surface runoff is also a perpetual objective of range watershed management because of the danger of soil erosion and its undesirable effects on water pollution and sedimentation. Maintaining a good cover of range plants is the prime method used to achieve good infiltration and minimize surface runoff.

Native shrubs and forbs may or may not be the desired range watershed plants, depending on factors such as depth of rooting, leaf characteristics, height and breadth of the canopy, and susceptibility to grazing. Shrubs and forbs with deep rooting habits have been reported to extract soil moisture from the full extent of the soil profile (Branson et al. 1972). However, soil moisture withdrawal has been reduced by removing top growth by burning (Veihmeyer 1953; McKell et al. 1968), cutting (Tew 1969), or by spraying with a herbicide

(Cook and Lewis 1963). Any advantage in such moisture conservation disappears, however, as soon as the top portions regrow or in a season of below average precipitation.

Leaf characteristics and plant height and spread are important from the standpoint of interception losses. So many variables such as leaf surface characteristics, wettability, orientation, and height above ground are operative that generalizations are of limited value. Shrubs and forbs with various favorable characteristics cannot be arbitrarily cast aside and should be considered for watershed development. Indeed low-growing or mat-forming plants such as snowbrush (*Ceanothus velutinus*), snowberry, engelman aster (*Aster engelmannii*), Lewis flax (*Linum lewisii*), mountain lupine (*Lupinus alpestris*), and bearberry (*Arctostaphylos uvaursi*) would be as suitable as some grass species that are commonly used in seeding watershed areas.

Palatability of watershed species can be an important factor in modifying the effects of grazing on runoff. Low to moderately palatable species can be expected to sustain less defoliation than highly palatable ones, and they would thus offer more canopy cover for watershed protection. Two of the four watershed grazing studies reviewed by Branson et al. (1972) involved grass cover. The Badger wash area in western Colorado is a salt-desert shrub range and the watershed in the Sierra Ancha Experimental Forest in Arizona is a chaparral range. Results from these studies indicate that moderate grazing appears to be feasible, although some runoff may be expected under long-duration storms. Shrubs of moderate to low palatability have a place in maintaining a persistent ground cover for watersheds.

Although conversions of vegetation type have almost universally involved substituting a grass cover for a shrub cover, there is no reason why low-growing shrubs or forbs supporting a spreading canopy, a relatively shallow root system, and a moderate degree of palatability would not also be suitable for seeding range watersheds.

According to Gifford (1972), vegetation conversion in pinyon-juniper areas by chaining, leaving the debris in place, and seeding into the rough gives best results from a watershed standpoint. The resulting vegetation usually has a good proportion of native shrubs and forbs in addition to the seeded species.

Ecosystem Functioning

The basic need to maintain a proper functioning of the ecosystem is often overlooked in planning for range improvement and productivity increases. Soil nitrogen levels, nitrogen fixation, nutrient cycling, soil organic matter balance, soil permeability, cryptogam soil cover, and soil micro-fauna numbers are just a few of the important activities or characteristics of an ecosystem that are influenced by the kind of range plants present and the way they are managed. However, the mechanisms are not well understood and the bulk of the literature ignores arid ecosystems (Charley 1972).

Soil nitrogen levels are probably more critical to range productivity than any other single factor except water. One reason is that the total amount of nitrogen in rangeland soils is relatively low. Charley and Cowling (1968) contrasted data from 77 Australian arid soil samples and 38 soil samples from other arid locations in the world to obtain a mean of .06% nitrogen for the Australian soils and .11% for those overseas. Most of the nitrogen in range soils is located near the surface in association with fine soil particles and organic matter. Garcia-Moya and McKell (1970) reported a tenfold decrease in nitrogen content between the surface 2.5 cm and a depth of 45 cm. Their results, like those reviewed by Charley (1972), reflect the strong influence of shrub root systems in the distribution pattern of nitrogen. A recent discussion with Skujins and West (personal communication, 1974) indicated not only a great heterogeneity in the vertical distribution of nitrogen but also in the contribution of organic matter from understory forbs and grasses, the litter fall from the canopy, and canopy temperature effects. All of these factors tend to foster a higher nitrogen content in the close vicinity of shrubs than in interspace areas (Kline 1973) and thus create "islands of fertility" (Garcia-Moya and McKell 1970).

Nitrogen fixation by shrubs and forbs may be limited to some degree in arid regions; but it is still more substantial than are inputs from nitrogen dissolved in rainwater, absorption of ammonia from the air, and from blue-green algae. Herbaceous legumes may be fixing significant amounts of atmospheric nitrogen in such range types as the annual range of California, where up to 60 kg/ha of nitrogen have been attributed to dense stands of annual clovers (*Trifolium spp.*) (Holland et al. 1969). Adapted strains of alfalfa with low palatability have been sought in the past as a means of increasing arid land nitrogen. Likewise, some attention has been given to finding productive woody legumes that could contribute to soil nitrogen. One such introduction was *Medicago arborea* for warm range climates, but apparently little has come from this effort. Unfortunately, a number of rangeland legume species are poisonous and require special management practices.

How much nitrogen is symbiotically fixed in the roots of nonlegume plants is not known. Garcia-Moya and McKell (1970) did not find any anatomical evidence of nodulation nor did they identify any gross fertility differences among the soils under two desert shrub legumes, *Cassia armata* and *Acacia gregii,* and the soil under *Larrea tridentata.* Nitrogen fixation or nodulation has been reported in *Ceanothus* by Wagel and Vlamis (1961), in *Artemisia ludoviciana* by Farnsworth and Clawson (1972), and in *A. tridentata* by Wallace and Romney (1972). However, Skujins and West (1974) have not found any evidence of nitrogen fixation in *A. tridentata* roots and say that nitrogen inputs and losses in arid ecosystems represent a big knowledge gap.

Blue-green algae also contribute to the nitrogen pool of most ecosystems. Beadle (1964) reports that up to 3 kg/ha of nitrogen is the annual increment fixed in many locations in New South Wales.

Nutrient Cycling

In addition to their values as forage, wildlife habitat, and soil cover, forbs and shrubs play a role in nutrient cycling vital to the functioning of any range ecosystem. Shrubs act as a reservoir of nutrients that are released back to the system as decomposition occurs. Decomposition of the leaf and bark components may be relatively fast as compared with that of stems and roots. Charley and Cowling (1968) gave the relative amounts of nitrogen and phosphorus in above-ground parts, below-ground components, and in annual litter fall in an *Atriplex vesicaria* plant community. They estimated that about one-third of the organic matter, nitrogen, and phosphorus of the plant community turns over in the standing crop each year (Table 3), thus indicating the importance of a nitrogen "sink" in the system. Dahlman et al. (1969) suggested that an appreciable fraction of nitrogen is returned in available form by the shoot and root turnover and that mineralized nitrogen from these sources is nearly adequate to satisfy the minimum requirements of higher plants.

Bjierregard (1971) cited figures to show that a substantial portion of the nitrogen in a sagebrush grass community is in a microbial form. The partly decomposed litter residue is the most available form of nitrogen for the plant community. Here again shrubs act as a buffer or pool for the nutrient capital of the system.

Large quantities of minerals may be cycled by selective uptake from the soil. McKell et al. (1962) showed that some legumes have a greater ability to accumulate phosphorus than others. In their study, introduced legumes exceeded natives in the amount of phosphorus accumulated in above-ground parts. The high accumulation of salts by salt desert shrubs may not be clearly beneficial to the ecosystem, but it represents an adaptation for productivity in an unfavorable environment. Mozafar and Goodin (1970) showed that the vesiculated hairs of *Atriplex* species are an effective mechanism for eliminating

Table 3. Distribution (g/m^2) of organic matter, nitrogen, and phosphorus in soil and plant material of an *Atriplex vesicaria* community.[1]

Compartment	Organic matter	Total nitrogen	Total phosphorus
Above-ground:			
Leaf	82.5	1.6	0.07
Wood	140.0	0.8	.03
Litter	14.8	.06	–
Total	237.3	2.46	0.10
Below-ground:			
Roots[2]	91	.6	.03
Soil (0–45 cm)	3,704	265.0	–
Total	3,795	265.6	.03
Litter fall (1 yr.):			
Leaf	68.4	.43	.03
Fruit	36.1	.45	.04
Wood	4.9	.01	–
Total	109.4	.89	.07
Above/below (%):	6	1	.1
Turnover litter fall/ above-ground (%):	46	36	

[1] Reported by Charley (1972) and adapted from an earlier report.
[2] Estimates.

salts from the tissues of the plants. Subsequent deposition of salt on the soil surface is not a deterrent to establishment of seedlings of *Atriplex.* For, as Chatterton and McKell (1969) have shown, *A. polycarpa* seedlings were able to grow in culture solutions of 39,000 ppm of sodium chloride, a salinity value roughly equal to ocean water.

Conclusion

The many favorable characteristics of shrubs in terms of productivity, nutritive value, vigor of regorwth, and palatability obviously warrant consideration in range improvement plans. Multiple-use management objectives and an increased understanding of the advantages to be gained by incorporating favorable plant species argue for inclusion of shrubs and forbs in seeding operations and management plans. Any conversion of a rangeland from shrubs to grass should be undertaken only after careful consideration of all shrub species and their uses.

Literature Cited

Beadle, N. C. W. 1964. Nitrogen economy in arid and semi-arid plant communities. III. The symbiotic nitrogen-fixing organisms. Linn. Soc. NSW Proc. 89:273-286.

Bjierregard, R. S. 1971. The nitrogen budget of two salt desert shrub communities of western Utah, PhD diss. Utah State Univ., Logan.

Branson, Farrel A., Gerald F. Gifford, and J. Robert Owen. 1972. Rangeland hydrology. Range Sci. Series No. 1. Soc. Range Manage. Denver, Colo. 84 p.

Cable, Dwight. 1972. Fourwing saltbush revegetation trials in southern Arizona. J. Range Manage. 25:150-153.

Chatterton, N. J., and C. M. McKell. 1969. *Atriplex polycarpa* I. Germination and growth as affected by sodium chloride in water cultures. Agron. J. 61:448-450.

Charley, J. L. 1972. The role of shrubs in nutrient cycling. p. 181-203. *In:* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [eds], Wildland shrubs–their biology and utilization. Proc. Intern. Shrub Symposium. USDA Forest Serv. Gen. Tech. Rep. INT-1.

Charley, J. L., and S. W. Cowling. 1968. Changes in sôil nutrient status resulting from overgrazing and their consequences in plant communities of semiarid areas. Ecol. Soc. Aust. Proc. 3:28-38.

Chew, R. M., and Alice Chew. 1965. The primary productivity of a desert shrub (*Larrea tridentata*) community. Ecol. Monogr. 35:355-375.

Committee on Feed Composition, Agricultural Board. 1958. Composition of cereal grains and forages. Nat. Acad. Sci. Nat. Res. Counc., Pub. 585. 663 p.

Cook, C. W. 1972. Comparative nutritive values of forbs, grasses and shrubs. p 303-310. *In:* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [eds], Wildland shrubs–their biology and utilization. Proc. Intern. Shrub Symposium. USDA Forest Serv. Gen. Tech. Rep. INT-1.

Cook, C. W., and C. W. Lewis. 1963. Competition between big sagebrush and seeded grasses on foothill ranges in Utah. J. Range Manage. 16:245-250.

Dahlman, Roger, Jerry Olsen, and Kenneth Doxtader. 1969. The nitrogen economy of grassland and dune soils. Proc. Conf. Biology and Ecology of Nitrogen. IBP. Nat. Acad. Sci.

Dayton, William A. 1960. Notes on Western Range Forbs. USDA Forest Serv. Agr. Handbook No. 161. 254 p.

Dietz, Donald R. 1972. Nutritive value of shrubs. p 289-302. *In:* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [eds], Wildland shrubs–their biology and utilization. Proc. Intern. Shrub Symposium. USDA Forest Serv. Gen. Tech. Rep. INT-1.

Ellern, S. J. 1972. Rooting cuttings of saltbush (*Atriplex halimus L.*) J. Range Manage. 25:154-155.

Farnsworth, R. B., and M. A. Clawson. 1972. Nitrogen fixation by *Artemisia ludoviciana* by acetylene-ethylene gas assay. Agron. Abst. 96 p.

Forest-Range Task Force. 1972. The nation's range resources–A forest-range environmental study. Forest Resource Rep., No. 19, USDA Forest Service, Washington, D.C. 147 p.

Garcia-Moya, Edmundo, and C. M. McKell. 1970. Contribution of shrubs to the nitrogen economy of a desert-wash plant community. Ecology 51:81-88.

Gasto, Juan, and David Contreras. 1972. Analysis del potential pratense de fanerofitas en regiones Mediterraneas de pluviometria limitada. Congresso Internacional de Zonas Aridas Y Z[a] Jornadas Nacionales Interdisciplimarias de Estudio de las zonas Aridas Del Norte de Chile, Arica, Chile.

Gifford, G. F. 1972. Influence of chaining pinyon-juniper on watershed values in Utah. Utah Agric. Exp. Sta. unnumbered proj. report. 96 p.

Goodin, J. R., and C. M. McKell. 1971. Shrub productivity–a reappraisal of arid lands. p. 235-246. *In:* W. G. McGinnies, B. J. Goldman and P. Paylore [eds.], Food, fiber and the arid lands. Univ. of Arizona Press. Tucson.

Holland, A. A., J. E. Street, and W. A. Williams. 1969. Range legume inoculation and nitrogen fixation by root-nodule bacteria. Calif. Agr. Exp. Sta. Bull. 842. 19 p.

Holmgren, Ralph C., and Selar S. Hutchings. 1972. Salt desert shrub response to grazing use. p. 153-164. *In:* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [eds], Wildland Shrubs–their biology and utilization. Proc. Intern. Shrub Symposium. USDA Forest Serv. Gen. Tech. Rep. INT-1.

Kline, L. G. 1973. Bromegrass productivity in relation to precipitation shrub canopy cover and soil nitrogen content. MS thesis. Utah State Univ., Logan.

Leopold, A. S., T. Rirey, R. McCain, and L. Tevis, Jr. 1951. The jawbone deer herd. Calif. Div. Fish and Game. Bull. 4. 139 p.

Loveless, C. M. 1967. Ecological characteristics of a mule deer winter range. Colo. Dep. Game, Fish, and Parks Tech. Pub. 20. 125 p.

Malcolm, C. V. 1969. Use of halophytes for forage production on saline wastelands. J. Australian Inst. of Agric. Sci. 35:38-49.

Malcolm, C. V. 1972. Establishing shrubs in saline environments. p. 392-404. *In:* C. M. McKell, J. P. Blaisdell, and J. R. Goodin [eds], Wildland shrubs--their biology and utilization. Proc. Intern. Shrub Symposium. USDA Forest Serv. Gen. Tech. Rep. INT-1.

Mason, Lamar. 1971. Yield and composition of Utah's range sites. Soil Conserv. Serv. Mimeo. Rep.

McKell, C. M., Alma Wilson, and W. A. Williams. 1962. Effect of temperature on P. utilization by native and introduced annual legumes. Agron. J. 54:109-113.

McKell, C. M., J. R. Goodin, and C. C. Duncan. 1968. Chaparral fires change soil moisture depletion patterns. Calif. Agric. 22:(11)15-16.

McKell, Cyrus M., J. P. Blaisdell, and Joe R. Goodin [eds]. 1972. 494 p. Wildland shrubs–their biology and utilization. Proc. Intern. Shrub Symposium. USDA Forest Serv. Gen. Tech. Rep. INT-1.

Monsen, Steven. 1975. Selecting plants to rehabilitate disturbed areas. p. - . *In:* R. S. Campbell and Carlton H. Herbel [eds], Improved range plants in resource management. Range Sympos. No. 1, Soc. for Range Manage. Denver, Colo.

Mozafar, A., and J. R. Goodin. 1970. Vesiculated hairs: a mechanism for salt tolerance in *Atriplex halimus L.* Plant Physiol. 45:62-65.

Naveh, Z. 1967. Mediterranean ecosystems and vegetation types in California and Israel. Ecology 48:445-459.

Nord, E. C., Patric Hartless, and W. D. Nettleton. 1971. Effects of several factors on saltbush establishment in California. J. Range Manage. 24:216-223.

Phillips, T. A. 1972. Information concerning sagebrush stand density and its effect on sage grouse habitat. US Forest Service Intermountain Region. Range Improvement Notes 17:(1)3-9.

Plummer, A. Perry, Donald R. Christensen, and Steven B. Monsen. 1968. Restoring big game range in Utah. Utah Div. of Fish and Game Pub. 68-3. 183 p.

Reynolds, H. G. 1964a. Elk and deer habitat use of a pinyon-juniper woodland in southern New Mexico. N. Amer. Wildlife and Natural Resource Conf. Trans. 29:384-444.

Reynolds, H. G. 1964b. Some livestock-wildlife habitat relations in Arizona and New Mexico. Amer. Soc. Range Manage. Proc. N. Mex. Sect. Meeting. 13 p.

Robinette, W. Leslie. 1972. Browse and cover for wildlife. p. 69-76. *In:* C. M. McKell, J. P. Blaisdell and J. R. Goodin [eds], Wildland shrubs–their biology and utilization. Proc. Intern. Shrub Symposium. USDA Forest Serv. Gen. Tech. Rep. INT-1.

Skujins, John, and Neil West. 1974. Personal communication.

Smith, Dwight R. 1971. Growth responses of true mountain mahogany on four soil types within the front range of Colorado PhD diss. Utah State Univ., Logan. 197 p.

Springfield, H. W. 1971. Winterfat seedlings emerge best from shallow seeding, moderately dry soil. J. Range Manage. 24:395-397.

Tew, R. K. 1969. Converting gambel oak sites to grass reduces soil moisture depletion. US Forest Serv. Res. Note INT-104, 4 p.

Temblor Range Research. 1969. Temblor range research annual report, 1968-69. Univ. of California, Davis.

Veihmeyer, F. J. 1953. Use of water by native vegetation versus grass and forbs on watersheds. Am. Geophys. Union Trans. 34:201-212.

Wagel, R. F., and V. Vlamis. 1961. Nutrient deficiencies in two bitterbrush soils. Ecology 42:745-752.

Wallace, A., and E. M. Romney, 1972. Radioecology and ecophysiology of desert plants at the Nevada test site. USAEC, Office of Information Service TID 25954; p. 350-357.

Willard, E. E., and C. M. McKell. 1973. Simulated grazing management systems in relation to shrub growth responses. J. Range Manage. 26:171-174.

Williams, Stephen E., and George A. O'Connor. 1973. Chemical fertilization of fourwing saltbush. J. Range Manage. 26:379-380.

Williamson, Robert. 1971. Planning range improvement projects to achieve natural appearance. J. Range Manage. 24:2-6.

Yeager, L. E. 1961. Classification of North American mammals and birds according to forest habitat preference. J. Forest 59:671-674.

Selecting Plants to Rehabilitate Disturbed Areas

Stephen B. Monsen
Botanist/Biologist
USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah 84401
Stationed in Boise, Idaho

Abstract

A wide array of plants is needed to revegetate disturbed areas in the western United States. Recent developments in selection and propagation have provided useful plants for improving wildlands and rangelands characterized by adverse climatic or edaphic conditions. Disturbances due to logging, grazing, fire, road construction, powerlines, water developments, and recreation activities can be improved if specific plants and treatment practices are utilized. Through the development of nursery stock and seed orchards, many native shrubs and herbs are being produced for wildland plantings. The selection and breeding of specific ecotypes provide improved strains for revegetation. Similar improvements can be expected as present research programs are expanded.

Although substantial progress has been made during the past two decades in revegetating disturbed wildlands within the western United States (Holmgren and Basile 1959; Plummer et al. 1968; Hodder et al. 1970), many areas still require corrective treatment. Plummer (1972) notes that although mining, road construction, logging, and fires have created dramatic impacts, these activities have not been as continuous nor as widespread as grazing. Grazing by game animals (Klemmedson 1967) and livestock (Hutchings 1954) has contributed to the reduction of forage and the destruction of native plants over large areas.

Of all nonforested range ecosystems in the United States, 29% are estimated to be in good condition, 48% in fair, and 23% in poor condition (Forest-Range Task Force 1972). Although circumstances vary among states, approximately 72% of all federal lands in the Four Corners region of Arizona, Colorado, Utah, and New Mexico need treatment in addition to improved range management (McArthur et al. 1973).

The success of vegetative rehabilitation depends upon a number of climatic and biologic factors, as well as upon the type of disturbance. This paper will outline the status of revegetation on various problem areas and the advances that have been made in selecting and propagating plant materials for use on these areas.

Blaisdell (1972) noted that stabilizing and improving road disturbances and mine dumps, and beautifying various landscapes are problems of prime importance. Rights-of-way, water developments, and natural calamities such as fires and debris avalanches (Swanston 1970) create problems of equal concern. Revegetation has not been as successful on these areas as on most rangelands, because conditions are usually more adverse. Revegetation is also more dependent upon artificial restoration measures, as severely disturbed areas recover very slowly through natural succession. Nonetheless, encouraging progress has been achieved in various problem areas through restoration measures (New Mexico Interagency Range Committee 1971; Chan et al. 1971; Highway Environment Conference 1973).

In contrast, Medin and Ferguson (1972) report that large acreages of depleted game and livestock ranges in the intermountain region have been successfully restored. The improvement of these range and forest ecosystems is often due to natural processes encouraged by proper management (Holmgren and Hutchings 1972). Although artificial revegetation measures have been utilized to improve disturbed game and livestock ranges, the sites usually are less severe and do not require the intensive treatments prescribed for roadways, mine spoils, etc. Also, practices to improve rangelands have developed over a number of years. Fewer plants and less planting equipment have been developed for mine spoils, roadways, and related disturbances than for rangelands and forage pastures.

Disturbed Areas

Livestock and Wildlife Ranges

Many depleted game and livestock ranges cannot be returned to full productivity with present techniques and procedures. Bleak et al. (1965) found that desert sites with high salinity, fluctuating water tables, low annual rainfall, and poor fertility are difficult to improve once existing species have been destroyed.

The recovery of remnant plants in arid ranges is often delayed until the cyclic recurrence of years with above-average precipitation. Conditions are then favorable for plant growth and seedling establishment (Holmgren and Hutchings 1972).

A diversity of forage and cover plants is required to improve disturbances within the various western plant communities. Maintaining specific habitats with different plants is necessary to perpetuate wildlife animals (Yeager 1961). Forage productivity is dependent upon varied plant composition that supplies preferred species (Smith and Hubbard 1954), extends the grazing season (Robinette 1972), and improves forage digestibility (Longhurst et al. 1968). Seasonal changes in herbage consumption must also be considered in game range revegetation (Kofeld et al. 1973).

Plummer et al. (1968) listed approximately 20 characteristics that determine the suitability of plants for revegetation; many of these facilitate artificial plantings—seed processing and handling, ease of planting, initial establishment, range of adaptation, persistence, and natural spread. Vallentine (1971) described various management traits that should also be considered in the selection of plants for range seeding.

Research has revealed that most shrub species possess ecotypic variability and has demonated the potential to improve herbage yields, palatability (Hanks et al. 1973), and seed production (Plummer et al. 1966) through artificial selection. Some projects have been initiated, and additional attention will undoubtedly be given to this phase of range revegetation.

The control of weedy or poisonous plants and less productive species is also dependent upon the introduction or improvement of desirable vegetation.

Watersheds

Watershed problems have usually resulted from soil and vegetative disturbance caused by logging, road construction (Rice et al. 1972), mining, and grazing (Vallentine 1971). Of particular concern are watersheds with highly erosive soils, for example, the Idaho and Southern California Batholiths, the coastal range in California, and portions of the North Cascades. Corrective measures related to road construction require: (1) the immediate establishment of plants for ground cover on roadcut and fill slopes to minimize surface erosion occurring immediately after construction and (2) the establishment of deep-rooted plants to reduce the potential of mass failures from unstable roads. Road construction usually obliterates existing soils and vegetation, thereby creating entirely different site conditions for planting (Fig. 1).

Disturbed roadways are usually less productive and initially incapable of sustaining all the original species or herbage production. Plants capable of existing on infertile substrata and unstable surfaces are thus required.

Vegetation along stream channels is necessary to protect the aquatic habitat. Water quality and streambank habitat can also be improved by changes in stream and air temperatures through the reestablishment of overstory vegetation. Vegetation must also be maintained along the edges of drainage channels to intercept eroded materials, which could otherwise be deposited in the streams as sediment.

Mining Sites

Mining operations pose a substantial challenge to revegetation (Copeland and Packer 1972). Changes in the landscape and deposits of overburden and mine

Fig. 1. *On extremely adverse sites, roadways must be stabilized by planting.*

tailings create planting sites that are difficult to revegetate. Soil erosion and discharge of contaminants from mine wastes into streams and waterways must be substantially reduced through the establishment of a protective plant cover. Few plants originate on soils that are similar to the sterile and toxic substrates of many mine spoils. Consequently, plants must be selected that are adapted to these conditions. Problems vary among mining locations and revegetation cannot be based on a simple group of plants.

Strip mining causes perhaps the most traumatic impact of all land uses, both esthetically and biologically. Esthetic damage occurs to both the spoil area and surrounding sites. Attempts to restore vegetation are often difficult, and the problem is compounded when native plants are desired to retain compatibility with undisturbed areas. Abandoned mine spoils must often be treated to restore grazing resources and animal habits—a task which cannot be achieved without a diversified array of plants.

Highways, Rights-of-way, and Recreation Areas

Roads and other rights-of-way have infringed on almost all ecosystems in the West and have utilized 10% of the western land area exclusive of Alaska and Hawaii (Willard 1973). In addition to removing vegetation and soils, road construction intercepts the flow of streams and subsurface discharges, draining them into new channels. Unless corrective steps are taken, this causes severe erosion, sedimentation, and stream pollution.

Noxious weeds may spread along rights-of-way if routes remain free of other types of vegetation. Treatment costs can be reduced if competitive plants are utilized to control weeds.

Maintaining natural landscape features and integrating roadways, installations, and other facilities with adjacent lands requires the use of different plant forms and species. Roadway plantings have been used to screen special-use areas and minimize vehicle disturbances. However, restoring esthetic values on or along the narrow corridor of most rights-of-way remains a formidable problem, particularly where plants are difficult to establish.

Plantings of native species to enhance buildings, boat docks, and other facilities in recreation areas are now being stressed. This may reduce maintenance costs where watering and fertilization have been necessary to support exotic plants.

Flammable Brushfields

Abatement of destructive fires, particularly in the chaparral brush types in California, has instigated programs to select less flammable plants. Nord and Countryman (1972) listed the requirements for such species: (1) low growth habit, (2) low fuel volume, (3) low heat output when burned, (4) readily established, and (5) adaptation to brushland conditions.

Recent Advances in Species Selection

The selection and development of plants for revegetating game and livestock ranges is more advanced than similar programs for other disturbed lands. Useful forage and pasture plants have been selected for most range plant communities. The Agricultural Research Service Plant Introduction Stations have provided continuity to the selection and distribution of numerous forage species, and have assisted the Soil Conservation Service with the release of useful named varieties. Although fewer native plants have been selected, a significant base of materials is available for most range sites.

Seed propagation centers have been established for some native species. Seed of antelope bitterbrush (*Purshia tridentata*), fourwing saltbush (*Atriplex canescens*), and Vasey big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) is now harvested from selected populations having desirable growth habits, palatability, and seed characteristics (Plummer 1972).

Species Mixtures

Single-species plantings have not provided the ultimate return of desirable attributes to disturbed areas. Variation within a disturbed area should be recognized and dealt with by planting species mixtures best adapted to each site within the area.

Declining vigor quickly becomes apparent when single species such as orchardgrass (*Dactylis glomerata*) and other grasses are seeded alone on infertile soils. Stand degeneration is much less noticeable if other plants are present. Intermixing herbs and shrubs or trees in direct seedings often results in loss of the slower developing seedlings of the latter due to competition. However, transplanting shrubs and trees onto roadways seeded with grasses to provide a storied ground cover has been successful. Deep-rooted species not only help to reduce surface erosion, but mass erosion as well. Transplanting ponderosa pine (*Pinus ponderosa*) on bare, unstable road fills has aided the establishment of seeded grasses and the invasion of native plants. Logging roads in portions of the Gold Fork drainage of the Boise National Forest, although repeatedly seeded, remained bare of herbaceous plants until transplanted with small trees.

Native Species

Research to date supports the use of native plants. Replanting sites with species that occur within the narrow boundaries of certain habitat types is often recommended. Seeding ranges and, to a lesser extent, forested communities has been successful when they are replanted with climax species. Ponderosa pine and lodgepole pine (*Pinus contorta*) establish quickly by natural seeding on disturbed areas within their natural range. In contrast, Douglasfir (*Pseudotsuga menziesii*) and ninebark (*Physocarpus malvaceus*) do not immediately return to disturbed areas and have proven to be poor plants for revegetation.

Successful treatment of game and livestock ranges is dependent upon the use of the principal native plants. Consequently, ecotypes should be closely surveyed to insure that seed of the most adapted sources is used. To the extent possible, seed should be obtained from the problem area or from an area with similar climate and soil.

A general awareness has also developed for the potential use of herbs and "half shrubs" to provide more diversity in animal diets and to assist soil stabilization. This group of plants has also increased the possibility of successfully treating the more adverse sites. Evaluations of old planting trials and range improvement projects on deer winter ranges in Idaho have revealed the persistence of sulfur eriogonum (*Eriogonum umbellatum umbellatum*) and western yarrow (*Achillea millefolium lanulosa*). Both plants, although heavily grazed by game, have survived and spread on sites where other important forage plants have succumbed.

Other successful forbs and herbaceous plants, selected through prior research projects, have been entered into seed production programs. Although plantings are still limited, seeds of Lewis flax (*Linum lewisii*) and Utah sweetvetch (*Hedysarum boreale utahensis*) are being produced under field conditions for use in game range revegetation projects by the Utah Division of Wildlife Resources.

Tests in forested areas have shown that habitat type is the most suitable indicator for selecting plants to revegetate disturbed sites. In highly disturbed areas, a general guideline has been to utilize the species from adjacent vegetative types that persist under more xeric conditions. For example, antelope bitterbrush is frequently confined to dry slopes as an understory shrub with ponderosa pine. In more mesic situations, common snowberry (*Symphoricarpos albus*) and ninebark dominate. But once these or other plants are destroyed, the more sparsely occurring bitterbrush becomes the principal species.

Introduced Species

The selection of plant materials, particularly for mine spoils or other highly disrupted areas, is difficult because comparable native communities do not always exist. However, selections from distant but somewhat comparable sites have assisted rehabilitation in a number of cases. For example, Hodder et al. (1970) report the encouraging success of black greasewood (*Sarcobatus vermiculatus vermiculatus*), fourwing saltbush, and tall wheatgrass (*Agropyron elongatum*) planted on alkaline mine spoils in Montana. These species are native or adapted to the northern desert shrub communities, but are finding a place on the former shortgrass prairie. The selection of other plants adapted to similar circumstances could be extrapolated from the success contained with these findings.

A Mediterranean source of rush leaf wheatgrass *Agropyron junceum* has outperformed most other grasses in seedling vigor and growth rate when planted on slightly acid soils in Idaho. The species is reported to exist in the coastal regions of France, where shifting sand along the beach often buries the foliage. Perhaps the ability of the plant to survive in this environment has promoted its survival on unstable road-fill soils in the Idaho Batholith.

The introduction of exotics onto sites similar to their natural environment has assisted in propagating a number of useful plants (Plummer et al. 1968). A most recent accomplishment has been the introduction of *Kochia prostrata,* a low shrub from the steppes of the Soviet Union, to arid and semiarid ranges in

Utah. This semiwoody shrub increases the possibility of successfully planting large acreages on desert shrub ranges, which are most difficult to treat through artificial measures. It also provides additional species diversity and exhibits high palatability.

Somewhat in contradiction to the premise of native plant superiority, several introduced shrubs are showing promise on Idaho ranges. Plantings, some approaching 20 years of age, of a California source, of wedgeleaf ceanothus (*Ceanothus cuneatus*) and Utah sources of Martin ceanothus (*Ceanothus martinii*), Apache-plume (*Fallugia paradoxa*), Stansbury cliffrose (*Cowania mexicana stansburiana*), desert bitterbrush (*Purshia glandulosa*), and green ephedra (*Ephedra viridis*) have survived well despite heavy winter grazing by deer. Recent plantings of Arizona cypress (*Cupressus arizonica*) indicate this southwestern tree has potential as a forage and cover plant for big game in Utah and Idaho.

Road construction, like grazing and flooding, may not permanently reduce the capability of a site to again support the original plant complex, but the hydrologic properties may necessitate a transitory cover of different species. Exotics like smooth brome (*Bromus inermis*) and intermediate wheatgrass (*Agropyron intermedium*) greatly improve the groundcover and reduce erosion when planted on disturbed ponderosa pine-bunchgrass habitat types. Although native grasses—bluebunch wheatgrass (*Agropyron spicatum spicatum*), Idaho fescue (*Festuca idahoensis*), and the grasslike elk sedge (*Carex geyeri*)—are capable of reestablishing, they do not provide the desired soil protection that exotics supply. Perhaps as studies continue, a better selection of native plants will provide replacements for the grasses now being used.

Although these species originate from regions and plant communities quite different from those on which they are planted, the temperature, precipitation, and soil variables are sufficiently similar for them to do well. Attempts have been made to delineate plant-growth regions within which the exchange of plant materials can be accomplished with reasonable success. Although the range of adaptation of a plant is difficult to predict, particularly for sites that have been dramatically disturbed, exotics can significantly aid revegetation.

Lithic Species

In Idaho a most interesting array of plants has been selected from the lithic soils of ridge crests and steep canyon walls for planting on the exposed substrata of roadcuts. Bush penstemon (*Penstemon fruticosus*) (Fig. 2), sulfur eriogonum, golden aster (*Chrysopsis* spp.), and western virginsbower (*Clematis ligusticifolia ligusticifolia*) are plants which have been helpful in revegetating rocky or shallow soils.

A collection of orange honeysuckle (*Lonicera ciliosa*) obtained from a rocky slope near Kellogg in northern Idaho exhibits a number of promising qualities. The plant has persisted, apparently unaffected, although exposed to toxic air pollutants discharged from a nearby smelter. Many other native plants have succumbed to the daily deluge of pollutants. Low and trailing, the plant is usually less than 0.5 meter in height, but occupies a 15 × 15-meter site. Numerous stems are produced each year, and rootlets are initiated at the junction of each node when the stem contacts a moist soil surface. Considerable expense has been directed to the rehabilitation of barrow sites and the road surfaces exposed by the construction of Interstate I-90 in this area. This plant appears adapted to such exposed substrata.

Squawcarpet ceanothus (*Ceanothus prostratus*), a low shrub of sandy soils in the Sierra Nevada mountains (Brown et al. 1971), has performed well on unstable road fills in areas outside of its natural range. Although somewhat slow to develop, the plants persist and spread if buried by sloughing soil. Shrubs such as this could be utilized to stabilize psammitic soils.

Pioneer Species

Plants considered to be pioneer species have also been successful in treating bare surfaces. The group includes not only the more rapidly appearing herbs and grasses, but also a variety of shrubs and trees that achieve dominance 10 or 15 years after the initial disturbance. Successful herbs include various species of aster (*Aster* spp.), Canada goldenrod (*Solidago canadensis*), and penstemons (*Penstemon* spp.). Transplanting sod of Louisiana sagebrush (*Artemisia ludoviciana ludoviciana*) has rapidly provided cover on many erosive sites. This plant, although unimportant on undisturbed sites, has the capability of spreading rapidly by vegetative rooting and persists on infertile soils. The considerable

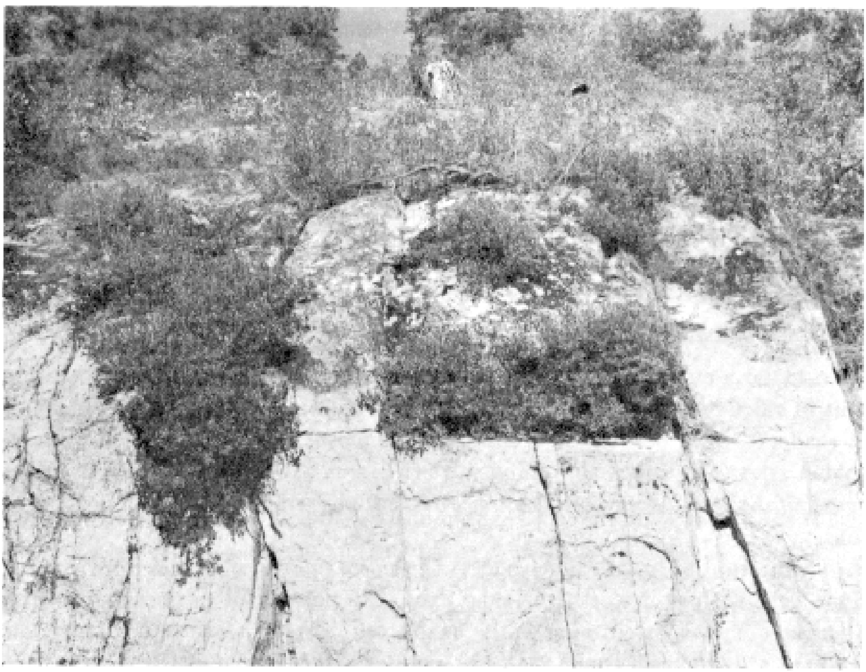

Fig. 2. *Bush penstemon collected from rocky outcrops is well adapted to roadcuts.*

variation among subspecies and ecotypes is being investigated to produce even more aggressive collections. Farnsworth and Hammond (1968) have discovered root nodules on some sources, indicating the presence of nitrogen-fixing organisms similar to the rhizobia on legumes.

Merely sticking stem cuttings of oldman wormwood (*Artemisia abrotanum*), an exotic, into raw soils of road cuts and fills in the early spring has quickly produced a shrub overstory; this provides a good microenvironment in which herbs naturally become established and gradually replace the introduced shrub (Plummer 1970). Scouler willow (*Salix scouleriana*) can also be similarly planted or rooted in a nursery or greenhouse and then transferred into the field. Scouler willow is well adapted to dry mountain slopes. Like oldman wormwood, it provides an environment in which other species can become established. Along with many other willows, it is also useful for streambank stabilization.

It is important to recognize characteristics that contribute to a plant's usefulness in revegetation. Testing should not be limited to species that occur only on disturbed sites. Many shrubs are now recognized for their ability to utilize nitrogen through symbiotic association with soil organisms. Species of alder (*Alnus*) have this capability (Li et al. 1972), as well as those of *Purshia* (Webster et al. 1967), *Ceanothus* (Russell and Evans 1966; Zavitkovski and Newton 1968), and *Cercocarpus* (Youngberg and Hu 1972) on infertile soils.

Seral Species

Seral species that invade forest burns may be useful for other disturbances. Snowbrush ceanothus (*Ceanothus velutinus*), an aggressive understory shrub that flourishes following fires or logging and is often suppressed to promote reforestation, has the particular qualities necessary to immediately stabilize exposed soils. Although numerous ecotypes need evaluation, this is one of the most rapidly developing shrubs occurring in forested communities. Because it develops rapidly, it is able to withstand competition from grasses that normally eliminate seedlings of many other shrubs.

Some plants are slow to invade disturbed areas, because the lack of native seed crops or damage to young seedlings from unstable soil conditions results in poor establishment. Yet, the same plants are quick to respond if artificially established; for example, rooted cuttings or nursery stock of bittercherry (*Prunus emarginata*), mountain snowberry (*Symphoricarpos oreophilus oreophilus*), Wood's rose (*Rosa woodsii ultramontana*), and blueberry elder (*Sambucus caerulea*).

Artificial Selection

Plant materials should be selected and propagated to meet specific site and management requirements. Revegetation can be aided if genetic variability of existing sources is taken into account. A chromatographic technique to identify various subspecies of the *Tridentatae* complex of *Artemisia* (Hanks et al. 1973) has led to better selection of palatable ecotypes of big sagebrush and black sagebrush (*Artemisia arbuscula nova*). This will improve restoration programs by assuring the planting of the right ecotype or subspecies. Rabbitbrush (*Chrysothamnus* spp.) and fourwing saltbush are being given specific attention because of their ability to develop rapidly.

Improvements in groundcover qualities of some native shrubs have also been achieved through selection programs. Low-growing, compact forms of snowbrush ceanothus, snowberry, bitterbrush, and rose have been propagated for this purpose, and further improvements can be made through continued selection and breeding.

Nord and Countryman (1972) have been successful in selecting low-profile species, particularly creeping sage (*Salvia sonomensis*) to reduce brush fires. Sources with low-flammable foliage have been selected for this purpose and other plants.

The necessity to immediately stabilize road fills and reduce surface erosion has led to the selection of some aggressive sod formers having strong and rapidly developing seedlings. Intermediate wheatgrass (P.I. 273732, 273733), pubescent wheatgrass (*Agropyron trichophorum*), and smooth brome (P.I. 315374, 315378) are important collections for this purpose.

Propagation of Plant Materials

As the more promising species are selected for improvement on disturbed sites, the supply of seeds and transplants must be provided. The use of selected plants is often delayed because of difficulty in obtaining seed from native stands. Seed production from agricultural land must be encouraged to supplement native sources. Problems associated with seed orchards, collections, and processing are being investigated for species of *Atriplex, Chrysothamnus, Purshia, Artemisia,* and *Eurotia* by the Utah State Agricultural Experiment Station in collaboration with the Utah Division of Wildlife Resources and the Intermountain Forest and Range Experiment Station.

Recent demands for outplanting stock have stimulated studies and pilot plantings of various native and exotic species at the Lucky Peak and Coeur d'Alene Forest Service Nurseries. Excellent results have been achieved by using nursery stock in field plantings, and demands have prompted the expansion of the program. Annual production of seed-grown transplants, wildlings, and rooted segments of various sod formers has fluctuated, but both nurseries have steadily increased their supply. A list of the principal plants produced at both locations during 1972 illustrates the variety of species and uses being considered (Table 1). Although the plants grown serve many purposes, listings are arranged according to the primary uses proposed by requesting agencies.

Seed purchases by State and Federal agencies reflect the acceptance and use of various plants for revegetation. Although acquisition has depended upon availability and funding, native plants–grasses, forbs, and shrubs–have comprised a substantial part of the seed purchases made by State agencies, the Bureau of Land Management, and the USDA Forest Service.

Summary

Many range types, disturbed areas, and recreation sites can be improved with

Table 1. Transplants produced for wildland planting by the Coeur d'Alene and Lucky Peak Peak Forest Nurseries, 1972.

Species	Number transplants	
	Coeur d'Alene	Lucky Peak
Wildlife Plantings		
Apache-plume (*Fallugia paradoxa*)		500
Bitterbrush, desert (*Purshia glandulosa*)		2,600
Bitterbrush, antelope (*Purshia tridentata*)	7,700	260,000
Ceanothus, deerbrush (*Ceanothus integerrimus*)		1,400
Ceanothus, redstem (*Ceanothus sanguineus*)	13,000	300
Ceanothus, wedgeleaf (*Ceanothus cuneatus*)		10,000
Cliffrose, Stansbury (*Cowania mexicana stansburiana*)		4,000
Cypress, Arizona (*Cupressus arizonica*)		150
Elder, blue (*Sambucus caerulea*)	2,600	
Ephedra, green (*Ephedra viridis*)		13,000
Ephedra, Nevada (*Ephedra nevadensis*)		1,000
Mahogany, curlleaf (*Cercocarpus ledifolius ledifolius*)		1,300
Mahogany, true (*Cercocarpus montanus montanus*)	1,500	1,700
Rabbitbrush, rubber (*Chrysothamnus nauseosus*)		100
Saltbush, fourwing (*Atriplex canescens*)		1,000
Serviceberry, Saskatoon (*Amelanchier alnifolia alnifolia*)	6,300	
Squawapple (*Peraphyllum ramosissimum*)		500
Sumac, skunkbush (*Rhus trilobata trilobata*)	8,000	
Watershed Plantings		
Alder, thinleaf (*Alnus tenuifolia*)	8,200	
Bitterbrush, antelope (*Purshia tridentata*)		11,000
Cascara, buckthorn (*Rhamnus purshiana*)	4,200	
Ceanothus, snowbrush (*Ceanothus velutinus*)		2,400
Ceanothus, squawcarpet (*Ceanothus prostratus*)	1,100	
Ceanothus, wedgeleaf (*Ceanothus cuneatus*)		2,000
Cherry, Anderson (*Prunus andersonii*)		100
Cherry, Bessey (*Prunus besseyi*)	60	2,000
Chokecherry, black (*Prunus virginiana melanocarpa*)	1,000	8,000
Dogwood, red osier (*Cornus stolonifera stolonifera*)	18,000	3,000
Honeysuckle, tatarian (*Lonicera tatarica*)		3,500
Ninebark, mallow (*Physocarpus malvaceus*)	225	
Penstemon, bush (*Penstemon fruticosus*)		2,000
Rose, woods (*Rosa woodsii ultramontana*)	8,850	
Sagebrush, Louisiana (*Artemisia ludoviciana ludoviciana*)		5,000
Salt-tree, Siberian (*Halimodendron halodendron*)		700
Snowberry, common (*Symphoricarpos albus*)	1,000	2,000
Spirea, shinyleaf (*Spiraea lucida*)	70	
Willow, Scouler (*Salix scouleriana*)		5,000
Wormwood, oldman (*Artemisia abrotanum*)		2,500
Yarrow, western (*Achillea millefolium lanulosa*)		2,000
Esthetic and Recreation Plantings		
Ash, mountain (*Sorbus scopulina*)	1,600	
Barberry, creeping (*Berberis repens*)	1,200	
Birch, western paper (*Betula papyrifera commutata*)		500
Buffaloberry, roundleaf (*Shepherdia rotundifolia*)		100
Maple, big tooth (*Acer grandidentatum*)	800	
Peashrub, pygmy (*Caragana arborescens pygmaea*)		300

the use of plants and planting stock now available. A mixture of grasses, forbs, and shrubs improves the herbage production and forage values of range sites. However, planting native shrubs and herbs is often discouraged because of the lack of planting stock and knowledge of proper planting techniques. Recent selections of palatable ecotypes and aggressive strains of some native shrubs have increased the forage quality on seeded game and livestock ranges. The inclusion of forbs has also greatly improved range plantings.

Many western ranges can be improved as seeds of the more promising species become more available. Seed propagation centers are currently being established to provide an adequate supply of planting stock. Research of seed production and processing practices has demonstrated the practicality of growing native seeds under cultivation.

Native plant communities provide a guide to the selection of plants for revegetation. Native plants furnish a suitable group of species for replanting, but exotics have also greatly assisted in treating wildlands.

Research has provided a better understanding of the planting conditions encountered in roadway and mining disturbances; consequently, plants can be better selected for restoration. Planting stock obtained from areas with adverse conditions has furnished a number of useful species for treating harsh disturbances. Species which persist on lithic or psammitic sites have provided an encouraging group of plants for sites which are difficult to revegetate. Pioneer species can be established on adverse sites and utilized as a nurse crop to aid in the natural succession of other species.

The use of nursery stock, wildlings, and containerized materials has also assisted the revegetation of disturbed areas. The production of transplants of species which usually are in short supply and the propagation of superior strains have recently resulted from improved culture practices. The selection and breeding of particularly useful ecotypes, hybrids, or special collections have been promoted through nursery practices. Additional improvements can be expected through the expansion of present programs.

Recent developments in plant selection programs have made substantial progress in improving revegetation practices. Areas often left untreated can now be planted, and the plant composition can be improved as additional species become available for planting.

Many range types, disturbed sites, and recreation areas can now be improved with the use of plant materials becoming available. The further selection of adapted species or ecotypes with particular capabilities could enhance present programs. Artificial selection and breeding can also contribute greatly to the improvement of many species for revegetation purposes.

Literature Cited

Blaisdell, James P. 1972. Needs and opportunities for shrub research in the western United States. USDA Forest Serv. Gen. Tech. Rep. INT-1, p. 409-413.

Bleak, A. T., Neil C. Frischknecht, A. Perry Plummer, and R. E. Eckert, Jr. 1965. Problems in artificial and natural revegetation of the shadscale vegetation zone of Utah and Nevada. J. Range Manage. 18:59-65.

Brown, Ray W., Robert H. Ruf, Jr., and Eugene E. Farmer. 1971. Suitability of *Ceanothus prostratus* Benth. for the revegetation of harsh sites. USDA Forest Serv. Res. Note INT-144, 12 p.

Chan, F. J., R. W. Harris, A. T. Leiser, J. L. Paul, and R. E. Fissell. 1971. Establishment of woody plants by direct seeding in California. Highway Res. Rep. HPR-PR-1(6) F0502, RTA 13945-13069 U.C.D. Calif. Div. of Highways, 81 p.

Copeland, Otis L., and Paul E. Packer. 1972. Land use aspects of the energy crisis and western mining. J. Forest 70:671-675.

Farnsworth, Raymond B., and Max W. Hammond. 1968. Root nodules and isolation of endophyte on *Artemisia ludoviciana*. Utah Acad. Sci. Arts and Letters Proc. 45(1):182-188.

Forest-Range Task Force. 1972. The nation's range resources–a forest-range environmental study. USDA Forest Serv. Forest Resour. Rep. 19, 147 p.

Hanks, David L., E. Durant McArthur, Richard Stevens, and A. Perry Plummer. 1973. Chromatographic characteristics and phylogenetic relationships of *Artemisia* section *Tridentatae*. USDA Forest Serv. Res. Pap. INT-141, 24 p.

Highway Environment Conference, 10. 1973. Proceedings. Univ. B.C., 109 p.

Hodder, Richard L., D. E. Ryerson, Ron Mogen, and James Bucholz. 1970. Coal Mine Spoils Reclamation Research Project - Progress Report. Mont. Agr. Exp. Sta. Res. Rep. 8, 56 p.

Holmgren, Ralph C., and Joseph V. Basile. 1959. Improving southern Idaho deer winter ranges by artificial revegetation. Idaho Dep. Fish and Game Wildl. Bull. 3, 61 p.

Holmgren, Ralph C., and Selar S. Hutchings. 1972. Salt desert shrub response to grazing use. USDA Forest Serv. Gen. Tech. Rep. INT-1, p. 153-164.

Hutchings, Selar S. 1954. Managing winter sheep range for greater profit. USDA Farmers' Bull. 2067, 46 p.

Klemmedson, J. O. 1967. Big game winter range–a diminishing resource. N. Am. Wildl. and Nat. Resour. Conf. Trans. 32:259-269.

Kufeld, Roland C., O. C. Wallmo, and Charles Feddema. 1973. Foods of the Rocky Mountain mule deer. USDA Forest Serv. Res. Pap. RM-111, 31 p.

Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen. 1972. Nitrate-reducing capacity of roots and nodules on *Alnus rubra* and roots of *Pseudotsuga menziesii*. Plant and Soil 37(2):409-414.

Longhurst, W. M., H. K. Oh, M. B. Jones, and R. E. Kepner. 1968. A basis for the palatability of deer forage plants. N. Am. Wildl. and Nat. Resour. Conf. Trans. 33:181-192.

McArthur, J'wayne, Darwin B. Nielson, and Jay C. Anderson. 1973. Feasibility of range improvement of the rangelands of the Four Corners Economic Development Region. N. Mexico State Univ. Agric. Exp. Sta. Spec. Rep. 23, 57 p.

Medin, Dean E., and Robert B. Ferguson. 1972. Shrub establishment on game ranges in the northwestern United States. USDA Forest Serv. Gen. Tech. Rep. INT-1, p. 359-368.

New Mexico Interagency Range Committee. 1971. Critical Area Stabilization Workshop. Proc. USDA Agr. Res. Serv., 197 p.

Nord, Eamor C., and Clive M. Countryman. 1972. Fire relations. USDA Forest Serv. Gen. Tech. Rep. INT-1, p. 88-97.

Plummer, A. Perry. 1970. Plants for revegetation of roadcuts and other disturbed and eroded areas. Range Improv. Notes 15(1):1-8.

Plummer, A. Perry. 1972. Selection. USDA Forest Serv. Gen. Tech. Rep. INT-1, p. 121-126.

Plummer, A. Perry, Donald R. Christensen, and Stephen B. Monsen. 1968. Restoring big game ranges in Utah. Utah Div. Fish and Game Pub. 68-3, 183 p.

Plummer, A. Perry, Stephen B. Monsen, and Donald R. Christensen. 1966. Fourwing saltbush–a shrub for future game ranges. Utah State Dep. Fish and Game Pub. 66-4, 12 p.

Rice, R. M., J. S. Rothacher, and W. F. Megahan. 1972. Erosional consequences of timber harvesting: an appraisal. Natl. Symp. on Watersheds in Transition, p. 321-329.

Robinette, Leslie W. 1972. Browse and cover for wildlife. USDA Forest Serv. Gen. Tech. Rep. INT-1, p. 69-76.

Russell, Sterling A., and Harold J. Evans. 1966. The nitrogen-fixing capacity of *Ceanothus velutinus*. Forest Sci. 12(2):164-169.

Smith, A. D., and R. L. Hubbard. 1954. Preference ratings for winter deer forages from northern Utah ranges based on browsing and forage consumed. J. Range Manage. 7:262-265.

Swanston, Douglas N. 1970. Mechanics of debris avalanching in shallow till soils of southeast Alaska. USDA Forest Serv. Res. Pap. PNW-103, 17 p.

Vallentine, John F. 1971. Range developments and improvements. Brigham Young Univ. Press, Provo, Utah, 516 p.

Webster, S. R., C. T. Youngberg, A. G. Wollum. 1967. Fixation of nitrogen by bitterbrush (*Purshia tridentata* (Pursh) D.C. Nature 216:392-393.

Willard, Beatrice E. 1973. Ecological and environmental considerations in rights of way. Right of Way, Aug. 1973, p. 7-13.

Yeager, L. E. 1961. Classification of North American mammals and birds according to forest habitat preference. J. Forest. 59:671-674.

Youngberg, C. T., and L. Hu. 1972. Root nodules on mountain mahogany. Forest Sci. 18(3):211-212.

Zavitkovski, J., and M. Newton. 1968. Ecological importance of snowbrush *Ceanothus velutinus* in the Oregon Cascades. Ecology 49:1134-1145.

Other books available from SRM

A Glossary of Terms Used in Range Management

Arid Shrublands: Proceedings of the 3rd Workshop of the US/ Australian Rangelands Panel

RANGE MONOGRAPH SERIES:

The Jornada Experimental Range

RANGE SCIENCE SERIES:

Rangeland Hydrology

Rangeland Entomology

Rangeland Reference Areas