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POTASSIUM AND SODIUM INTERRELATIONS IN ALFALFA PHENOTYPES GROWN ON CALCAREOUS SOIL

by

Suresh S. Dhumal

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Soil Science

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I wish to dedicate this dissertation in memory of my beloved mother Vayani.

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Suresh Dhumal

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ABSTRACT

Potassium and Sodium Interrelations in Alfalfa Phenotypes Grown on Calcareous Soil

by

Suresh S. Dhumal, Doctor of Philosophy

Utah State University, 1991

Major Professor: Dr. David W. James
Department: Plants, Soils, and Biometeorology

Three greenhouse experiments were conducted with three phenotypes of alfalfa (Medicago sativa L.) obtained from a potassium (K)-deficient field and with their diallel crosses grown on low K soil. The first experiment was conducted to study the partitioning and broad-sense heritability of K and sodium (Na) between leaves and stems of the three phenotypes which were deficient in K and exhibited normal (N), marginal chlorotic (M), and white spot chlorotic (W) leaflets. The second experiment was conducted to study the partitioning of K and Na in leaves, stems, and roots as influenced by 32 alfalfa crosses obtained from diallel crossing of the mother plants of the three phenotypes. The objectives of the third experiment were to study the effects and interactions of nine alfalfa crosses and three soil K and Na levels on transpiration, biomass, and elemental composition of alfalfa components.

The three phenotypes showed no variations in their leaf and stem K concentrations but varied in their ability to partition Na between the leaves and stems. Phenotype M accumulated more Na compared to N and W phenotypes. The Na trait was highly heritable in the broad sense.

The K and Na concentrations varied among the diallel crosses. Crosses with M as the maternal parent had high Na concentrations in leaves while stems and roots accumulated lesser amounts. In contrast, the remaining crosses had higher Na concentrations in roots and lower and least amounts in stems and leaves, respectively.

Significant genetic variation among alfalfa crosses from a single cultivar was observed for transpiration, biomass production, plant water-use efficiency, elemental concentrations, and K utilization efficiency. Leaf and stem biomass and K concentrations in alfalfa components increased in response to increasing soil K levels. The Na concentrations in stems and roots fell in response to increasing soil K levels and increased in response to Na application. The K utilization efficiency of alfalfa increased with increase in soil Na levels, indicating partial Na substitution for K.

The differences among alfalfa phenotypes and crosses from a single cultivar in their Na accumulation and translocation were thought to be governed by plant genetics rather than the direct effect of K availability.

(188 pages)

INTRODUCTION

Alfalfa (Medicago sativa L.) is the largest cash crop grown in the state of Utah. About 470,000 acres of the cropland in Utah are under alfalfa cultivation and yield an average of 3.7 tons per acre and a total production of 1,739,000 tons. Alfalfa yield has doubled in the last fifty years (Department of Agriculture, State of Utah, 1990), which may be attributed to higher yielding cultivars, fertilizer use, and efficient soil water management.

Irrigated soils in Utah have been under cultivation for more than a century. Where irrigation water is low in potassium (K) (that is, high quality water), there has been a net loss of K from the soil by crop removal and leaching. Potassium deficiency symptoms in alfalfa have been observed in several areas of the state that are irrigated with low K waters. The classical K deficiency symptom in alfalfa is characterized by white chlorotic spots on older leaves. Another K deficiency symptom, characterized by marginal chlorosis in older leaves that is localized towards the leaf tip and associated with high sodium (Na) concentration in the above-ground plant, has been observed along with the classical K deficiency symptom (Dow and James, 1970; and James, 1988). This occurred on soil that was low in both plant-available K and Na.

Normal growth and development of a plant depends on a certain amount of K. The amount required depends upon plant species, climate, and, in some instances, the amount of Na present in the plant (Bange, 1959; Ulrich and Okhi, 1966). When supplied with both K and Na, a majority of plants show selectivity for K, but there is wide variability between species. The cation selectivity has been attributed more to the differences in uptake and translocation of Na to the shoots than in uptake and transport of K. Collander (1941) has shown that plants behave rather uniformly with respect to K uptake but vary widely in their capability to absorb or exclude Na.

The question of whether Na can replace K in physiological processes in the plant is of practical importance in relation to soil fertility management. Response to Na is maximum when K is limiting, and with increase in potassium levels in the soil, effect of Na is diminished. In many instances, Na applications were found to increase K absorption by plants. This has been explained in terms of cation exchange processes in soil and not as a physiological reaction. The extent to which substitution may occur, however, depends on uptake potential for Na, which has been observed to differ considerably among plant species (Marschner, 1971). Sodium ions tend to accumulate in higher concentrations in the vacuoles than in the cytoplasm. The nutrient uptake rate depends on the concentration of individual cation species. Potassium uptake and retention in plant cells is also competitively affected by Na^+, Mg^{2+}, and Ca^{2+} (Elzam and Hodges, 1967).

Differences among genotypes, cultivars, inbreds, etc., within a plant species have been recognized to exist with respect to uptake, translocation, accumulation, and utilization of mineral nutrients. Most of the differences are under genetic control, which may be altered when plants are grown under different environments. Effects of genetic specificity of mineral nutrition in plants may be evaluated by various means, such as morphological features of leaf, stem, and root; biochemical and physiological processes; cytological and anatomical features of cells and their constituents; uptake, translocation, exudation, and utilization of nutrient ions; concentration of mineral nutrients; shoot root ratios; and biomass. Very few studies have evaluated the genetic specificity of mineral nutrition with respect to concentration and content of individual ions during the ontogenesis of a plant species (Sarić, 1983).

Potassium plays an important role in the water balance of the plant. Uptake of water in plant cells and tissues frequently is a consequence of active K uptake (Läuchli and Pflüger, 1978). Plants well supplied with K, to a large extent, control the opening and closing of stomata, thus lowering the water loss from plants through transpiration. Growth stimulation by sodium under inadequate potassium supply is caused mainly by its effects on cell expansion and on the water balance of plants. It may be concluded that Na may substitute for vacuolar K, thus replacing K in its contribution to solute potential and consequently in the generation of turgor (Flowers and Läuchli, 1983). Plant dry-matter yield and evapotranspiration have been shown to be closely related based on the data obtained from the field (Hanks et al., 1969) and from plants grown in containers (De Wit, 1958).

Alfalfa is well known for its genetically heterogenous and heterozygous nature. However, the genetic specificity of mineral nutrition in alfalfa with regard to K and Na and their interrelationship with other plant nutrient cations and plant processes need further clarification. Therefore, the objectives of this research were to study the

1) Partitioning and broad sense heritability of K and Na in three alfalfa clones,
2) Partitioning of K and Na among alfalfa phenotype crosses, and
3) Effects of soil K and Na levels and alfalfa phenotype crosses on (a) transpiration; (b) biomass production; (c) plant water use efficiency (WUE); (d) genetic dependence on K, Na, Mg, and Ca uptake and partitioning in leaves, stems, and roots and (e) K utilization efficiency (KUE).

REVIEW OF LITERATURE

Potassium Deficiency in Utah Soils

Growth of alfalfa in Utah extends from early spring to late fall. Therefore, there is a continuous demand for nutrients for about five months. The alfalfa demand for K is higher than any other mineral element, with the possible exception of nitrogen. With frequent cuttings, a significant amount of soil K is removed which must be replenished through addition of K fertilizers or in irrigation water, if alfalfa yield is to be maintained.

Utah irrigated soils have been under cultivation for more than a century. Where irrigation water is low in K, that is, high quality irrigation water, there has been a net loss of K from the soil by crop removal and leaching. Potassium deficiency symptoms in Utah alfalfa have been observed in several areas that have been irrigated with low-K waters for a long time. Nielsen et al. (1955) concluded that K deficiencies in Utah would likely develop in areas where irrigation waters were low in K. Research on diagnostic soil test adequacy levels for K in arid and semiarid region soils suggest that less than 100 mg kg^{-1} extractable K is deficient, 100-120 mg kg^{-1} is marginal, and greater than 120 mg kg^{-1} is sufficient K for alfalfa production (Lamborn, 1975). In Utah, K fertilization is recommended for alfalfa grown in soils testing less than 100 mg K kg^{-1} (Topper et al., 1989).

Lindstrom (1983) observed K deficiency symptoms in Weber and Sevier counties in Utah, attributing then to low K in irrigation waters and associated soils. Potassium deficiency in alfalfa was also identified in eastern Utah with yield responses to K fertilization (Hunsaker and James, 1973). Responses to K fertilization were not observed in areas where K content of irrigation water was higher and where soils were medium to heavy in texture (James and Jurinak, 1986).

A complete understanding of the effects of climatic and soil factors, as well as cultural practices, on the growth of alfalfa is necessary in order to maintain high yields and adequate levels of all the essential elements throughout the growing season.

The literature on K and Na as its substitute in plant physiology dates back many years. Whether Na replaces K in its physiological processes is not yet completely understood. It has been observed by many research workers that, where K is deficient in the soil, plants tend to take up Na as a replacement for K. The extent to which Na substitutes for K depends upon the extent of Na absorption and transport within any particular species. When plants tend to accumulate high Na, there is greater potential for substitution.

The following review is categorized on the basis of plant requirements for K and Na, K, Na and plant growth, Na substitution for K, nutrient interactions, and genetic differences in chemical composition of plants.

Plant Requirements for K and Na

Potassium plays a role in many of the biochemical and physiological functions of plants (Mengel and Kirby, 1980). It has an important role in activating many of the enzymes in the cytoplasm of plant cells (Suelter, 1970), and also occurs in high concentration in the vacuoles (Pierce and Higinbotham, 1970), and its salts make a major contribution to osmotic potential and control of turgor pressure (Wyn Jones et al., 1979; Marschner, 1986). According to Marschner (1986), K is the most abundant cation in the cytoplasm and its salts contribute to the osmotic potential of cells and tissues of glycophytic plants. The various functions of K in cell expansion and other turgor-regulated processes are related to the K concentration in vacuoles. Humble and Raschke (1971) concluded that K accumulation in the guard cells of Vicia faba was sufficient to explain the observed changes in guard cell volume and osmotic pressure and associated stomatal opening.

The role of K in CO_2 assimilation in plants has been investigated by a number of authors. Timothy and Koch (1978) worked with hydroponically grown alfalfa under varying K levels to determine the effect of tissue level of K on photosynthesis, dark respiration, photorespiration, and stomatal and mesophyll resistance to CO_2. They observed that photosynthesis and photorespiration were reduced at severe and mild K deficiencies compared to plants grown at high K level; that dark respiration increased under severe and mild deficiencies; and at K deficient levels stomatal resistance to CO_2 was increased. Stomatal conductance decreased only at a severe K deficiency level (1.28% leaf K). Plants grown with sufficient K maintained a vigorous growth rate as compared to deficient K levels.

Smid and Peaslee (1976) grew corn in sand cultures which received solutions containing 15, 45, 135 or 400 mg K L^{-1}, and showed a high correlation of CO_2 assimilation with K tissue levels. Potassium accumulated in large vacuoles moves through plasmodesmatal connections between cells to the vascular tissue for redistribution in the transpiration stream to other parts of the plant (Kochian and Lucas, 1983). During this process, K is moved from living cells to dead xylem cells and hence is physiologically outside the plant.

The role of Na in mineral nutrition of higher plants has been considered from two main viewpoints: whether it is essential and to what extent it can replace Na in plants. Growth stimulation by Na is caused mainly by its effect on cell expansion and on the water balance of plants. Not only can Na replace K in its contribution to solute potential in the vacuoles and consequently in the generation of turgor and cell expansion, it may surpass K in this respect since it accumulates preferentially in the vacuoles (Jeschke, 1977). Milford et al. (1977) demonstrated the increase in leaf area, thickness, and succulence of sugarbeet (Beta vulgaris, L.) leaves when high proportion of K is replaced by Na.

The essentiality of Na has been established for the halopyhte Atriplex vesicaria L. (Brownell, 1965). Growth responses to Na are merely reflections of a high salt requirement for osmotic adjustment (Flowers and Läuchli, 1983), for which, however, Na can be much more suitable than K (Eshel, 1985). Many glycophytes well known in agriculture and horticulture show positive growth responses to Na (Lehr, 1953; Marschner, 1971) but have not been shown to have an absolute requirement for it. Hewitt (1984) indicated that Na is essential for a few plants and the amount needed is in the order of a micronutrient element. Recently it has been suggested that Na may be involved in the regulation of the water economy of C_3 plants (Smith et al., 1980). Harmer et al. (1953) grouped alfalfa in the category where plants showed slight to medium response to Na fertilization.

Stomatal opening and closing in plants is important because stomata are the valves controlling CO_2 and H_2O diffusion and they play a major role in plant water balance. Transpiration influences ion uptake and movement of ions in plants (Kramer, 1959; Weatherly, 1969) and affects K/Na selectivity (Pitman, 1965). It was suggested that increased plant transpiration promotes passive release of ions to the xylem vessels (Bowling, 1968) or increase mass flow of ions across the root (Hylmö 1953). Jeschke (1984) studied the effects of transpiration on uptake and xylem transport of K and Na in root cells of barley seedlings. He showed that transpiration increased the rate of K accumulation at different K concentrations both in the presence and absence of

Na. Though the rates of Na accumulation in leaves were low in the presence of K, it was strongly stimulated by transpiration. De Wit (1958) reported that dry matter production of alfalfa and other crops was linearly related to transpiration and at higher rates of transpiration produced higher yields. Wilson and Ludlow (1983), Jones et al., (1980), and Ford and Wilson (1981) indicated that K played a vital role in the osmotic adjustment of guard cells, which in turn affected transpiration and therefore water use efficiency. Significant differences in water requirement have been found within and among varieties of alfalfa with greater variation within varieties (Cole et al., 1969). The efficiency of water use of 15 alfalfa genotypes studied in a growth chamber at three soil temperatures indicated that water use increased as soil temperature increased and the soil temperature x genotype interaction was significant (Mc Elgunn and Heinrichs, 1975).

Potassium, Sodium and Plant Growth

A considerable amount of K is required by alfalfa to maintain high yields. Fertilization of alfalfa with K increased nodule number, nodule mass, and N-fixation rates (Duke et al., 1980). Relative growth of plants was shown to be correlated with K transport from the root to the shoot, and that K moves towards the meristematic zones of leaves and stems in the plant (Pitman and Cram, 1977). Kimbrough et al. (1971) found that alfalfa yield was highly correlated with K levels in alfalfa leaves or herbage (2.5%-3.5%). Smith (1975) observed highest alfalfa yields at 672 kg K ha^{-1} added to low K acid soils. Most frequently where K is low, K is the key fertilizer element for production of high-yielding, high-quality alfalfa. The data obtained by Drake et al. (1970) from a four year study on K fertilization of alfalfa grown in acid low K soil, indicated that alfalfa should contain at least 3.3% K to maintain high yields and long-lived stands. Alfalfa has been shown to be particularly sensitive to K deficiency and stand maintenance depends on frequent fertilization with K where K is lacking (Burns et al., 1974).

Yield of 'Ranger' alfalfa increased with applied Na when K was low (Wallace et al., 1948). Increased concentration of K and Na was also observed with added Na. Brown (1958) observed that annual application of NaCl did not improve the alfalfa stands or yields where low rates of KCl were applied. The results of Sherrell (1983) also showed no increase in yield of alfalfa when Na was applied indicating that there was no Na substitution for K, but increase in plant Na concentration was observed when plants had very low K concentration. Increase in Na concentration in alfalfa with increase in Na application was also reported by Bear and Wallace (1950), Montasir et al. (1966), and Schultz et al. (1979). The effects of various K:Na fertilizer ratios on yield of alfalfa and white clover were evaluated by Schultz et al. (1979), who showed that significant yield responses to added K were obtained; when K was replaced by Na in the fertilizer (25% K:75% Na) generally producing similar amount of dry matter. Plants that transport minimal amounts of Na to the shoot (maize and beans) do not respond to Na fertilization to nearly the same extent as plants such as beet, in which there is substantial Na transport to the shoot (Marschner, 1971). Sodium fertilization of alfalfa grown on noncalcareous soil, increased shoot yield about 15%, and primary root mass increased 55% (Cope et al., 1953).

Substitution of Sodium for Potassium

Although K is normally preferred over most other monovalent cation species for its biochemical and physiological role, the plant does not need to use it exclusively; other cations, particularly Na, can be substituted when K is in short supply (Marschner, 1971; Harvey et al., 1981). The substitution of K by Na in alfalfa has been reported by Wallace et al., (1948); Cope et al., (1953); Truog et al., (1953); and York et al., (1954) indicating an increase in alfalfa yield with Na substituting for K. In contrast to these results, Brown (1958), Whitehead and Jones (1972), and Sherrell (1983) reported that Na did not substitute for K in alfalfa because there was no increase in yield with applied Na even when plants had very low K concentrations.

Besford (1978) found that the growth of tomato (Lycopersicon esculentum L.) plants was unaffected at a total Na plus K concentration of 6.4 meq L^{-1} but when more than 90% of the K was replaced by Na increase in growth was observed. However, when 95% of the K had been replaced by Na there was a dramatic fall in dry weight production. Figdore et al. (1985) observed differences in dry matter accumulation per unit K, among the five tomato strains grown under low K stress that were unrelated to Na use. However, these differences are relatively small in comparison to the differences in dry matter accumulation per unit K among the strains at either 10 or 160 mg Na pot^{-1}. They concluded that a greater ability to partially substitute Na for K under low K stress was the primary factor in the observed strain differences.

Raising the external Na concentration in Italian ryegrass (Lolium multiflorum Lam.), increased the total plant weight in the middle rather than at the extremes of the K concentrations applied (0.125, 4, and 8 mM K). Sodium was not able to totally substitute K in the plant, but increasing the external Na concentration lowered the critical K level in the leaf at which K deficiency was apparent (Hylton et al., 1967).

Accordingly, it is apparent that Na will substitute for K in some, but not all of its roles in the plant. Further, the degree to which K substitution occurs within any particular species depends upon the extent of Na absorption and transport. When Na is taken up in large amounts and transported within the plant, there is a great potential for substitution (Flowers and Lauchli, 1983).

Smith et al. (1978) drew a distinction between natrophiles and natrophobes, in which the former readily concentrate Na in the aerial tissues and the latter accumulate Na in the roots and lower stems. These authors reported that alfalfa does not transport Na readily from roots to shoots and hence classified it as a natrophobe. Results of Sherrell (1983) are also in agreement with those of Smith et al. (1978), both working on acid soils.

Jacoby (1964) and Wallace et al. (1965) working on Phaseolus vulgaris L. clearly indicate that translocation of Na into leaves of natrophobic plants takes place readily only after accumulation sites in roots and stems have been saturated with this element. Smith et al. (1980) suggest that there is a need to apply considerable higher amounts of Na salts to natrophobes than would be needed for natrophiles in order to increase the concentration of Na in their leaves. However, it should be appreciated that an application of large quantities of Na to plants may depress growth by interfering with the uptake of K and also that high Na gives rise to soil sodicity and sometimes Na toxicity in the plant.

Differences among tomato cultivars for substitution of K has been shown by Makmur et al. (1978). Regulation of Na transport to the shoots have important consequences in pasture plants for animal nutrition and in crop plants in general for salt tolerance (Greenway and Munns, 1980). Brown (1958) reported that Na comprised a very small proportion of the total cations in the above ground portion of the alfalfa plant. The tendency of Na to be retained in roots has been reported by Cope et al. (1953). Alfalfa plants accumulate high levels of Na in their roots with decreasing amounts translocated to stems and leaves respectively (Moshtagi, 1988). He also reported that an increase in soil K led to lower concentrations of Na in roots and a higher translocation of Na from roots to leaves.

Nutrient Interactions

The interactions between cations on nutrient uptake and plant composition have received much attention. The elemental composition of forage plants can have a profound effect on the productivity of the plant. There is a complex relationship between Na, K, Ca, and Mg concentrations in plant nutrition. Many investigations have been concerned with the nutrient content of forages as influenced by species, temperature, management, stage of growth, soils, and fertilization. Soil fertility levels, seasonal growth stage, species, genotype within species, and other factors affect mineral concentrations of forages (Reid et al. 1970). Dow and James (1970) observed reduction in alfalfa yields where K was deficient and showed that the K deficient alfalfa plants contained less K and higher than normal concentrations of Na, Ca, and Mg. Reduction in Ca and Mg occurred in alfalfa plants with increase in K concentrations (Burns et al., 1974; Schultz et al., 1979). According to Sherrell (1983), with Na application, Mg concentration was slightly reduced and Ca concentration was significantly reduced. In contrast, Whitehead and Jones (1972), reported that the replacement of K by Na slightly increased Mg in the shoots but had no effect on Ca concentration. Hylton et al. (1967) observed a decrease in Ca and Mg concentration in all plant parts of Italian ryegrass with increased K and Na in the solutions. Addition of Na to the treatment solutions did not affect the accumulation of Ca in any plant part, whereas the Mg concentrations in all above ground plant parts were significantly increased by Na treatment (Aslam, 1975). Potassium concentration in plant tissue water may be a more reliable indicator of K status in plant tissue than % K in dry matter (Leigh and Johnston, 1983). They showed that, decrease in plant K content resulting from poor K supply were balanced by increase in Na and Ca (but not Mg) contents so that total cation concentration in the plant tissue water were similar in low and high K crops.

Weir (1978) showed that levels of applied K significantly reduced the uptake of Na in maize resulting in 20% increase in dry matter yields over control. A ratio of K:Na less than 10 were associated with poor yield of maize. Smith (1975) and Schultz et al. (1979) also reported that increasing K applications led to higher K and lower Na concentrations in alfalfa plants, and hence lowering Na:K ratio. James (1988) observed K:Na ratios of 0.60 in chlorotic margin plants (K deficiency exhibiting chlorotic leaf margin), 3.81 in chlorotic spot plants (K deficiency exhibiting white chlorotic spots on leaves), and 5.60 in K fertilized plants grown on low K and Na calcareous soil. Chlorotic margin and chlorotic spot plants occurred on separate plants growing in close proximity. James (1988) proposed that under low K condition, chlorotic margin plants actively absorbed larger amounts of Na which was translocated to the extremes of the vascular systems increasing the concentration at the leaf margin because of transpiration. Dow and James (1970) observed K:Na ratios for normal, spotted, and marginal chlorosis plants to be 16.0, 1.0, and 0.63, respectively. Moshtagi (1988) observed that K:Na ratio in leaves, stems, whole plants and roots of alfalfa increased with rising transpiration levels and fell with rising levels of soil K.

Genetic Differences in Chemical Composition of Plants

Interest in the genetics of plant nutrition has centered in two areas: a) more efficient use of mineral nutrients at suboptimal soil levels without sacrificing ability to yield at optimal nutrition (increased nutrient use efficiency); and b) balanced nutrient concentrations in forages where mineral content is important to feed quality (Hill and Guss, 1976).

Numerous variations in the mechanisms of uptake and utilization of various mineral nutrients are under genetic control (Gerloff, 1976). These variations may be expressed at (a) sites exterior to plant roots, (b) at any point along the transportation pathway, or (c) at sites where elements are used in the plants. Variability in nutrient acquisition and its use, within the plant kingdom, reflects differences in root morphology and variations in mechanisms that either aid or prevent ion movement into the root (Gabelman et al. 1986). It is clear from the genotypic differences in nutrient use efficiency that this is a heritable trait, but the underlying mechanisms which determine it are unclear. Differential patterns of K allocation between subcellular compartments (cytoplasm and vacuole) in different barley genotypes were thought to contribute to the observed variations in K utilization (mg of biomass produced per mg of K) by this plant (Memon et al. 1985a). Memon et al. (1985b) working on three varieties of barley selected on their basis of different rates of K utilization, showed distinct differences in the allocation of K between cytoplasm and vacuole. Relatively few studies have investigated the effect of cultivar or genotype within forage species on their elemental composition. Where more than one species of a genus have been studied, intra-specific differences have been reported.

Hill and Jung (1975) observed significant genetic variability among alfalfa genotypes from a single cultivar to accumulate minerals when alfalfa is grown under a good soil fertility regime. Buss et al. (1975) working with six alfalfa clones, showed significant clonal differences for absorption of 11 of the 12 elements studied. The work of Ancalle (1983) showed that 12 alfalfa varieties grown in six counties of Utah, had a high variability in tissue concentration of P, K, Ca, and Na with Mg being essentially constant. Potassium:sodium ratios also differed among the 12 alfalfa varieties. Butler et al. (1962) reported large clonal differences in concentration of 10 out of 12 minerals in ryegrass with no significant relationship between mineral content and growth. Genotypic differences in shoot weight per plant, K efficiency ratio and utilization efficiency ratio of 24 wheat (<u>Triticum</u> <u>aestivum</u> L.) varieties were reported by Woodend et al. (1985). The maximum amount of variation was recorded for utilization efficiency and lowest for efficiency ratio.

Striking genotypic differences were demonstrated by Kylin and Hansson (1971) and Hansson (1975) in experiments on the effects of K and Na on K-Na-ATPases extracted from different inbred lines of sugarbeet. The results of Marschner et al. (1981) demonstrated pronounced genotypic differences in sugarbeet with respect to the response to Na at three levels of K and Na treatments.

Differences among barley (<u>Hordeum</u> <u>distichon</u> L.) genotypes in K use efficiency (dry matter produced/K absorbed) were found by Pettersson (1978), Jensén and Pettersson (1980), and Glass and Perley (1980). Pettersson and Jensén (1983) observed great differences in K use efficiency ratios among 11 cultivars of barley. Their experiments also showed that a high ion uptake efficiency (influx) is not necessarily correlated with high dry matter production. In an experiment with tomato varieties Figdore et al. (1985) reported differences in K efficiency ratio (KER) calculated as the total mg of plant dry weight divided by the total mg K present in a plant. The dry weights and KER values for the tomato strains differed when the plants were grown under low K stress without added Na. The KER values also differed among strains grown under low K stress, with either 10 or 160 mg Na/pot present. Potassium use efficiency was shown to be greater in C_4 grasses than C_3 grasses (Blevins, 1983).

MATERIALS AND METHODS

Plant Material

Five clones from each of the three phenotypes (a total of 15 clones) of alfalfa (cv. WL 309) were selected from a field in Davis County, Utah, that was low in K and where K deficiency symptoms were evident (James, 1988). The three phenotypic classes of alfalfa were plants exhibiting

1) Normal appearing leaflets (N)
2) Classical white spot K-deficiency symptom on leaflets (W), and
3) Marginal chlorotic symptom on leaflets (M).

All the three phenotypes (N, W, and M) were deficient in K exhibiting the above visual symptoms. An incomplete 15 X 15 diallel progeny set was formed by crossing and selfing of the clones from the three phenotypes of alfalfa.

Soil

Millville silt loam (coarse silty carbonatic mesic typic haploxerolls) soil which was low in plant available K was obtained from the Greenville Research Farm in North Logan for all the greenhouse experiments. The soil was air dried, screened, and thoroughly mixed so as to obtain a uniform growth medium. The soil characteristics are presented in Table 1.

Table 1. Some characteristics of experimental Millville silt loam soil.

pH	ECe	P	K	Na	Ca	Mg	$\%CaCO_3$	SAR
	$dS\ m^{-1}$	$mg\ kg^{-1(a)}$		$mg\ L^{-1(b)}$				
7.7	1.6	9.0	77	34	236	46	40	0.52

$^{(a)}NaHCO_3$ extractable, $^{(b)}$Water soluble.

Three successive experiments were conducted with alfalfa clones, and alfalfa diallel crosses at the Utah State University research greenhouse in the years 1988, 1989, and 1990 respectively. The average climatological conditions in the greenhouse were as follows:

Temperature- Day : $24^0C \pm 2$
Night: $18^0C \pm 1$
Photoperiod: 14 hrs day^{-1} (5 a.m. to 7 p.m.)
Light source: High pressure sodium vapor lamps
Photosynthetic irradiance: 230 $\mu mol\ m^{-2}s^{-1}$

Experimental Design

Experiment 1

From the total of 15 mother plants (i.e. five from each of three phenotypes of alfalfa) only 13 mother plants representing three phenotypes were obtained as follows: four representing normal (N), five representing marginal (M), and four representing white spot (W) phenotypes. Two plants, one each from normal and white spot phenotype did not survive after they were transplanted from the field into the greenhouse pots. Clones consisting of 12 plants from each mother plant were propagated vegetatively using stem cuttings on June 9, 1988, in a sand medium. Black polyethylene pots (30 cm in diameter X 30 cm in height) were filled with 14.0 kg of soil per pot. Phosphorus in the form of phosphoric acid was added to each pot at the rate of 45 kg P ha^{-1} (0.4 g P pot^{-1}) followed by soil inoculation with Rhizobium meliloti culture.

The experiment was a completely randomized design, with four plants per pot. Identity of each plant in every pot was maintained.

The moisture availability in each pot was maintained at 75% of the "field" capacity using deionized water. The "field" capacity was calculated by saturating the known quantity of soil in the pot, which was covered to prevent evaporation, and then allowed to drain freely for one day. After the drainage had ceased, the pot was weighed and the "field" capacity was calculated as the ratio of mass of water and mass of soil in the pot (Cassel and Nielsen, 1986). The experimental pots were arranged on the greenhouse table in 4 rows (10 pots per row) in the north-south direction. The cooling pads in the greenhouse were situated on the east side with the exhaust fans on the west side creating variable microclimatic conditions on the east and west side of the table. To reduce this environmental variation the pots were rotated from east to west every other day.

Leaf and stem samples were collected during the second harvest, dried, and ground. The primary data collected were the composition of K and Na in leaves and stems. The plant nutrient cation concentrations were expressed on the basis of chemical equivalence as millimole charge per gram ($\text{mmol}_c\ g^{-1}$) of tissue sample.

Plant samples were digested using nitric+perchloric acid and the nutrient cations (K, Na, Mg, and Ca) were determined using Perkin-Elmer Model 2380 atomic absorption spectrophotometer.

The secondary data calculated from the primary data were

1) Na:K ratios in leaves, stems, and shoots,
2) partitioning of K and Na among leaves and stems, and
3) broad sense heritability (H) estimates for K, Na, and Na:K ratio in leaves, stems, and shoots.

The key to analysis of variance and the expected mean squares are presented in Table 2.

Heritability is a measure of the degree to which a phenotype is genetically influenced. Broad sense heritability (H) of a character is defined as the proportion of the total variance (genetic + environmental) that is attributed to genetic variance. The broad sense heritabilities were estimated as follows:

$$H = \frac{\text{All genetic effects among clones}}{\text{Total variance (genetic+environment)}}$$

$$= \frac{\text{genetic variance}}{\text{genetic + environmental variance}} = \frac{\sigma_a^2}{\sigma_a^2 + \sigma^2/n_0}$$

Table 2. Expectations for the analysis of variance for alfalfa clones.

Source	DF	Mean square expectations
Among clones	12	$\sigma^2 + n_0\sigma_a^2$
Within clones	127	σ^2

† where n_0 denotes unequal sample size.

Experiment 2

Black polyethylene pots (30 cm in diameter X 30 cm in height) were filled with 14.0 kg of soil per pot. The soil in each pot was fertilized with 0.4 g P (@ 45 kg P ha^{-1}). Twenty seeds each from 32 crosses obtained from mother plant (Appendix A, Table 41) were inoculated with Rhizobium meliloti culture and germinated in growth chambers. After germination, these seedlings were transferred into conical containers (164 cm^3) containing the experimental soil. The plants were transferred into the pots when they were at 2-3 trifoliate leaf stage. The experiment was a completely randomized design, with five seedlings per pot. Parental identity of each plant was maintained. Soil moisture in the pots was maintained at 75% of its predetermined "field" capacity throughout the experiment. The experimental pots were rotated every other day to minimize the environmental variation among the pots. Every plant was sampled separately for leaves and stems at the third and fifth growth cycles. The plants were sacrificed at the fifth cycle to obtain root samples. The tissue samples were dried, ground, and analyzed. The primary data collected were, K and Na composition ($mmol_c$ g^{-1}) in alfalfa leaves, stems, and roots.

The secondary data obtained were

1) Na:K ratios in leaves, stems, roots, and shoots, and
2) K and Na partitioning in alfalfa components (leaf, stem, root).

Experiment 3

Smaller size black polyethylene pots (21.6 cm in diameter X 21.6 cm in height) were filled with 8.0 kg of the experimental soil. The soil in all the pots was inoculated with Rhizobium meliloti. Each pot received 0.2 g P or about 45 kg P ha^{-1}. Only nine crosses (Appendix A, Table 42) were included in the experiment on the basis that they had the 72 seeds required to conduct the factorial experiment. A complete factorial design (9 crosses x 3 K levels x 3 Na levels) was replicated two times in a completely randomized design with four plants per pot. The 3 levels of K and Na as sulphate salts at equivalent rates (i.e. mol_c pot^{-1}) were 0, 224, and 448 kg K ha^{-1} (0, 0.8, and 1.6 g K pot^{-1}) and 0, 132, and 264 kg Na ha^{-1} (0, 0.5, and 1.0 g Na pot^{-1}). Seeds were germinated in petri dishes and then transplanted to the pots. All the pots were maintained at 75% of predetermined "field" capacity throughout the experiment and the pots were also rotated to reduce the environmental variation among the pots.

Five growth cycles were carried to the early bloom stage. At the end of the second and fifth cycles, leaf and stem samples were collected from each pot, and dried and ground. Root samples were collected after the fifth harvest. Roots were washed with deionized water (for not more than 2 minutes) to remove any adhering soil material and then dried. Leaf, stem, and root samples were chemically analyzed. The primary data obtained were

1) transpiration (cm) (2nd and 4th growth cycles).
2) biomass of leaves, stems, and roots (2nd and 5th cycles), and
3) K, Na, Mg, and Ca composition ($\mathrm{mmol_c\ g^{-1}}$) in alfalfa leaves, stems, and roots (2nd and 5th cycles).

The secondary data derived from the primary data were

1) water use efficiency ($\mathrm{g\ kg^{-1}}$)(WUE),
2) shoot:root ratio,
3) Na:K and Ca:Mg ratios in leaves, stems, roots, and shoots, and
4) potassium utilization efficiency (KUE) ($\mathrm{g^2\ mmol^{-1}}$) (see below for details).

Evapotranspiration (ET) was measured by summing the weighed increments of water added to each pot for every growth cycle. The transpiration data were obtained by subtracting the evaporation (E) data from evapotranspiration. Evaporation was estimated from six unplanted pots distributed at random on the greenhouse tables and measuring the total loss in pot weight due to evaporation. All the non-cropped and cropped pots were covered with polystyrene beads to a depth of 2 cm so as to reduce the evaporation from the soil.

Water use efficiency (WUE) based on evapotranspiration was calculated as grams of dry matter produced per kilogram of ET.

The method of Siddiqi and Glass (1981) was used to calculate K utilization efficiency (KUE) measured as biomass produced per unit of tissue K concentration ($g^2\ mmol^{-1}$). The KUE unit $g^2\ mmol^{-1}$ was derived as follows:

$$\text{KUE} = \frac{\text{Biomass produced (g)}}{\text{K tissue concentration } (\text{mmol}_c\ \text{g}^{-1})} = \frac{\text{g}}{\text{mmol}_c\ \text{g}^{-1}}$$

$$= \text{g}^2\ \text{mmol}^{-1}$$

Statistical analyses (ANOVA) were conducted on the primary and secondary data using Statistical Analysis System (SAS) Version 6.06. Graphical representations were developed to aid in interpretation of the results.

RESULTS AND DISCUSSION

In this section experimental results from three experiments are presented and discussed on the basis of their primary and the secondary data, and their analyses of variance.

Experiment 1

Clones from three alfalfa phenotypes exhibiting normal appearing (N), classical white spot K deficiency symptom (W), and marginal chlorosis symptom (M) on leaflets, were grown in the greenhouse on low K soil. Data were obtained from the second harvest for K and Na composition and Na:K ratio in leaves, stems, and shoots; and broad sense heritability estimates were calculated for the above parameters in leaves, stems, and shoots.

K and Na Composition

The K and Na concentration in leaves and stems in the three phenotypes is shown in Figure 1. No significant differences were observed in K concentration in leaves, stems, and shoots among the three phenotypes (Tables 3 and 4). On the other hand, highly significant differences in Na concentrations in leaves and shoots were observed among M and N and W phenotypes (Tables 5 and 6). Sodium concentrations of 0.047 and 0.037 $mmol_c\ g^{-1}$ were observed in leaves and shoots

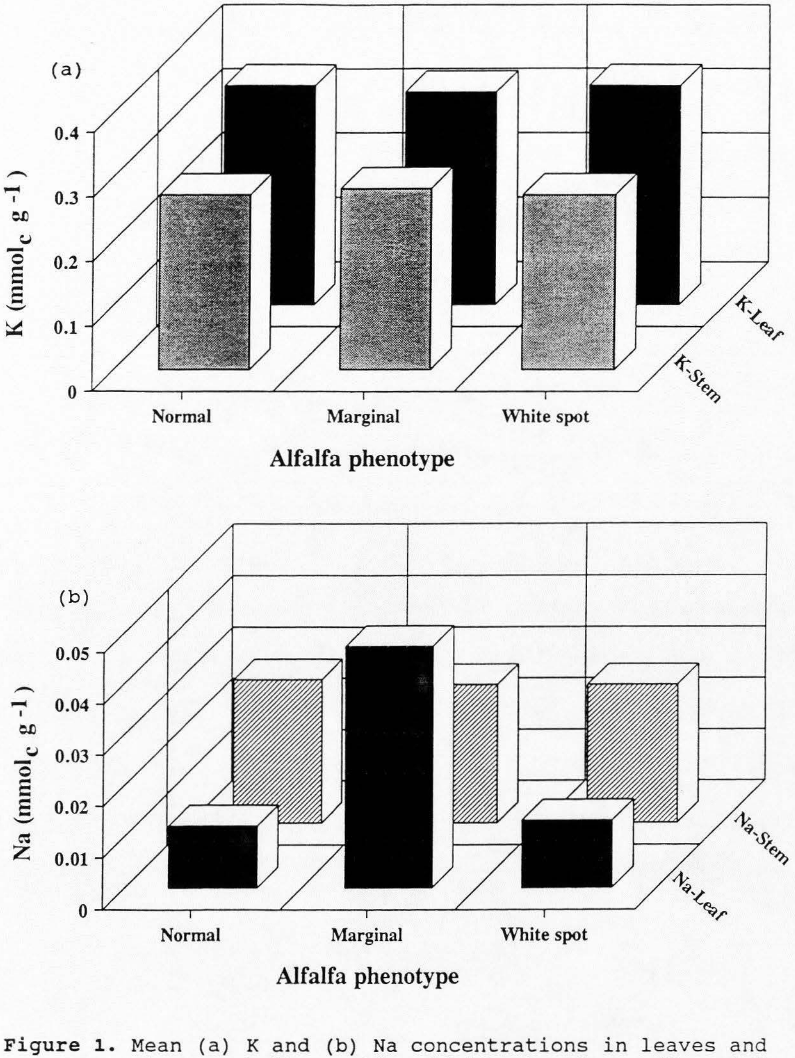

Figure 1. Mean (a) K and (b) Na concentrations in leaves and stems as influenced by alfalfa phenotype. (Normal=K deficient normal leaflets; Marginal=K deficient marginal chlorotic leaflets; white spot=K deficient white spot chlorotic leaflets).

Table 3. Means for K composition in leaves, stems, and shoots (leaves+stems) as influenced by three alfalfa phenotypes grown on low K soil.

Phenotype	K		
	Leaves	Stems	Shoots
	------------- $\text{mmol}_c\ g^{-1}$† ----------		
Marginal (M)	0.33	0.28	0.31
Normal (N)	0.34	0.27	0.31
White spot (W)	0.34	0.27	0.31

†1 mmol_c K g^{-1} = 39102 mg K kg^{-1} = 3.9% K (% K = mg K kg^{-1} /10,000).
‡For more details see Table 43 in Appendix B.

Table 4. Analysis of variance for K composition in alfalfa leaves, stems, and shoots (leaves+stem) as influenced by alfalfa phenotypes grown on low K soil.

Source	DF	MS		
		Leaves	Stems	Shoots
Phenotype†	2	0.173E-2	0.183E-2	0.176E-4
N vs M & W	1	0.103E-2	0.723E-3	0.160E-4
M vs W	1	0.243E-2	0.294E-2	0.190E-4
Plants‡	1	0.164E-1**	0.367E-2*	0.695E-2**
Error	127	0.200E-2	0.169E-2	0.148E-2
Total	139	0.303E-2	0.184E-2	0.185E-2

*, ** significant at 0.05 and 0.01 probability levels, respectively.
†N = normal leaf, M = marginal chlorotic leaf, W = white spotted leaf.
‡Mother plants.

Table 5. Means for Na composition in leaves, stems, and shoots (leaves+stems) as influenced by three alfalfa phenotypes grown on low K soil.

Phenotype†	Na		
	Leaves	Stems	Shoots
	------------mmol$_c$ g$^{-1\dagger}$------------		
Marginal (M)	0.047	0.027	0.037
Normal (N)	0.010	0.028	0.019
White spot (W)	0.011	0.027	0.019

†1 mmol$_c$ Na g^{-1} = 22990 mg Na kg^{-1} = 2.3% Na (%Na = mg Na kg^{-1} /10,000).
‡For more details see Table 43 in Appendix B.

Table 6. Analysis of variance for Na composition in alfalfa leaves, stems, and shoots (leaves+stems) as influenced by alfalfa phenotypes grown on low K soil.

Source	DF	MS		
		Leaves	Stems	Shoots
Phenotype†	2	0.218E-1**	0.287E-4	0.523E-2**
N vs M & W	1	0.119E-1**	0.570E-4	0.257E-2**
M vs W	1	0.317E-1**	0.134E-6	0.789E-2**
Plants‡	10	0.188E-3*	0.596E-3**	0.300E-3**
Error	127	0.937E-4	0.304E-4	0.325E-4
Total	139	0.413E-3	0.710E-4	0.127E-3

*, ** significant at 0.05 and 0.01 probability levels, respectively.
†N = normal leaf, M = marginal chlorotic leaf, W = white spotted leaf.
‡Mother plants.

of the M phenotype, which translated to 327% and 95% more Na in leaves and shoots, respectively than the N and W phenotypes. The data presented in Table 5 also indicate that phenotype M accumulated more Na in leaves with less amounts in the stems. In contrast, leaves of N and W phenotypes retained more Na in stems with smaller amounts translocated to the leaves. High Na:K ratios in leaves (0.145) and shoots (0.123) of M phenotype were also observed, which varied significantly from those of N and W phenotypes (Table 7 and 8). The high Na:K ratios in leaves and shoots of M phenotype were mainly due to their higher Na concentrations.

Accordingly, phenotype M accumulated more Na in its leaf tissue, without any effect on K concentration which was constant in all the components for all the phenotypes. The data in Tables 3 and 5 also show the K and Na partitioning among leaves and stems. Leaves accumulated more K with lower concentrations in stems for all the phenotypes grown on low K soil. Sodium partitioning differed among phenotypes. Phenotype M accumulated more Na in leaves than stems in contrast to lower Na concentrations in leaves as compared stems of phenotypes N and W, respectively.

The phenotypes were classified initially on the basis of their K deficiency symptom expression in the field (James, 1988). The phenotype N showed normal leaflets though it was deficient in K, with the phenotype W showing white spot K deficiency symptom when grown on low K soil. No differences were observed here between the N and W phenotypes in their K

Table 7. Means for Na:K ratio in leaves, stems, and shoots (leaves+stems) as influenced by three alfalfa phenotypes grown on low K soil.

Phenotype†	Na:K		
	Leaves	Stems	Shoots
Marginal (M)	0.145	0.098	0.123
Normal (N)	0.031	0.109	0.065
White spot (W)	0.035	0.106	0.066

‡For more details see Table 43 in Appendix B.

Table 8. Analysis of variance for Na:K ratio in alfalfa leaves, stems, and shoots (leaves+stems) as influenced by alfalfa phenotypes grown on low K soil.

Source	DF	MS		
		Leaves	Stems	Shoots
Phenotype†	2	0.201E+0**	0.138E-2	0.535E-1**
N vs M & W	1	0.114E+0**	0.142E-2	0.290E-1**
M vs W	1	0.288E+0**	0.134E-2	0.780E-1**
Plants‡	10	0.278E-2**	0.122E-1**	0.486E-2**
Error	127	0.104E-2	0.123E-2	0.706E-3
Total	139	0.405E-2	0.202E-2	0.177E-2

*, ** significant at 0.05 and 0.01 probability levels, respectively.

†N = normal leaf, M = marginal chlorotic leaf, W = white spotted leaf.

‡Mother plants.

and Na composition.

For all the traits studied, similar trends were observed by James (1988) among the same three alfalfa phenotypes grown in the field with low K soil.

Broad sense heritability estimates for K, Na and Na:K ratio in leaves, stems and shoots are shown in Table 9. Broad sense heritability estimates were high for K, Na, and Na:K ratio for all the components of alfalfa plant, with higher heritability values of 96, 94, and 96% for Na in leaves, stems, and shoots indicating that plant Na traits were under stronger genetic control.

Alfalfa is well known for its genetically heterogenous and heterozygous nature. It was concluded therefore, that the traits shown by phenotypes M, N, and W to accumulate and translocate Na within the plant, are governed by plant genetics rather than the direct effect of K availability as assumed by Dow and James (1970).

Table 9. Broad sense heritability values (H) for K, Na, and Na:K ratio in leaves, stems, and shoots (leaves+ stems) of alfalfa clones.

Trait	H(%)
K in leaves	86
K in stems	50
K in shoots	75
Na in leaves	96
Na in stems	94
Na in shoots	96
Na:K in leaves	96
Na:K in stems	88
Na:K in shoots	94

Experiment 2

Seeds from 32 alfalfa crosses was obtained from diallel crossing of five mother plants in each of the three alfalfa phenotypes (see Appendix A, Table 42). These seeds were germinated in growth chambers and then transferred into the pots containing Low K soil. Primary data were obtained from the third and fifth harvest for K and Na composition in leaves, stems, shoots (leaves+stems) and roots and secondary data of Na:K ratios were calculated. The results obtained are discussed on the basis of primary and the secondary data, and their analyses of variance.

Potassium

Potassium composition of alfalfa leaves, stems, and roots as influenced by alfalfa cross (C) and harvest time (T) are shown in Table 10. The analysis of variance comparing different combinations of crosses is given in Table 11.

Leaf, stem, and root K concentrations varied significantly among alfalfa crosses. Leaf K concentrations of MxM (1-8) crosses varied significantly from NxN (15-18) crosses. Significant differences were also observed among leaves and stems of NxN (15-18) vs WxW (28-32) crosses in their K concentrations. Crosses MxN (9) vs NxM (11-14) differed in their leaf and stem K concentrations, with no significant differences in crosses MxW (10) vs WxM (25, 26) and NxW (19-24) vs WxN (27) in their K concentrations in stems and leaves, respectively. A high K concentration of 0.24 $\text{mmol}_c\ g^{-1}$ was

Table 10. Group means for K composition of leaves, stems, shoots (leave+stems), and roots as influenced by alfalfa cross and harvest time.

Cross (No.)	Leaves	Stems	Shoots	Roots
	-----------------	mmol$_c$ g^{-1}	-----------------	
MxM (1-8)	0.24	0.20	0.22	0.11
NxN (15-18)	0.26	0.21	0.24	0.11
WxW (28-32)	0.23	0.19	0.21	0.11
MxN (9)	0.22	0.18	0.20	0.10
NxM (11-14)	0.25	0.20	0.22	0.12
MxW (10)	0.23	0.19	0.21	0.12
WxM (25,26)	0.27	0.20	0.23	0.11
NxW (19-24)	0.24	0.21	0.23	0.11
WxN (27)	0.24	0.22	0.23	0.11
LSD (5%)	0.02	0.01	0.01	0.02
Mean	**0.24**	**0.20**	**0.22**	**0.11**
Harvest				
Third	0.25	0.18	0.22	----
Fifth	0.23	0.21	0.22	0.11

† For more details see Table 44 in Appendix B.

Table 11. Analysis of variance for K composition in alfalfa leaves, stems, shoots (leaves+ stems), and roots as influenced by cross and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	31	0.968E-2**	0.903E-2**	0.283E-1**	0.104E-2**
1-8 vs 15-18	1	0.427E-1**	0.107E-1**	0.104E+0**	0.750E-3
1-8 vs 28-32	1	0.123E-3	0.788E-2**	0.170E-1**	0.189E-3
15-18 vs 28-32	1	0.392E-1**	0.288E-1**	0.164E+0**	0.178E-3
9 vs 11-14	1	0.200E-1**	0.980E-2**	0.578E-1**	0.360E-2
10 vs 25 26	1	0.427E-1**	0.667E-3	0.427E-1**	0.133E-2
19-24 vs 27	1	0.952E-4	0.771E-2**	0.771E-2	0.476E-4
Error(a)	608	0.131E-2	0.0.643E-3	0.206E-2	0.135E-3
Harvest time(T)	1	0.125E+0**	0.276E+0**	0.299E-1**	--------
C x T	31	0.456E-2**	0.361E-2**	0.140E-1**	--------
Error(b)	608	0.129E-2	0.895E-3	0.223E-2	--------
Total	1279	0.215E+1	0.160E+1	0.395E+1	--------

†Cross:1. M1xM1 **2.** M1xM2 **3.** M1xM5 **4.** M2xM1 **5.** M2xM2 **6.** M3xM3 **7.** M5xM3 **8.** M5xM5
9. M2xN1 **10.** M1xW1 **11.** N1xM2 **12.** N1xM3 **13.** N2xM3 **14.** N2xM5 **15.** N1xN2 **16.** N2xN2
17. N2xN4 **18.** N4xN4 **19.** N1xW4 **20.** N2xW3 **21.** N2xW4 **22.** N3xW4 **23.** N4xW1 **24.** N4xW3
25. W1xM1 **26.** W2xM3 **27.** W1xN4 **28.** W1xW3 **29.** W2xW2 **30.** W3xW3 **31.** W4xW3 **32.** W4xW4

** Significant at 0.01 probability level.

observed in the shoot component of NxN cross with low K concentrations of 0.20 $\mathrm{mmol_c\ g^{-1}}$ in MxN cross (Table 10). No significant differences were observed in K concentration in roots among the crosses reported above. Harvest time had a significant influence on leaf and stem K content, which showed a significant decrease in leaf and increase in stem concentrations (Table 10).

According to Table 10, K in all the crosses was partitioned alike with leaves having higher concentrations followed by lower concentrations in stems and least in roots. A similar trend was reported for the three phenotypes studied in the first experiment (Table 3). These results indicate that alfalfa grown on low K soils tends to accumulate more K in leaf tissue than in stem and root tissue.

Sodium

As shown in Table 12, the mean Na concentration in leaves, stems, and roots varied significantly among crosses and harvest time. According to ANOVA Table 13, Na concentration in leaves, stems, shoots, and roots was significantly influenced by C, T, and C x T interaction.

The comparisons NxN (15-18) vs WxW (28-32) crosses did not differ in leaf Na concentrations but all the other comparisons that were made did vary significantly in Na concentration (Table 13). The comparison MxW (10) vs WxM (25, 26) did not differ in stem Na concentration but the other groups compared were significantly different in their stem Na concentration.

Table 12. Group means for Na composition of leaves, stems, shoots (leaves+stems), and roots as influenced by alfalfa cross and harvest time.

Cross (No.)	Leaves	Stems	Shoots	Roots
	----------------	mmol$_c$ g^{-1}	----------------	
MxM (1-8)	0.102	0.051	0.076	0.027
NxN (15-18)	0.029	0.058	0.043	0.061
WxW (28-32)	0.032	0.054	0.043	0.052
MxN (9)	0.087	0.049	0.068	0.028
NxM (11-14)	0.047	0.057	0.052	0.042
MxW (10)	0.075	0.045	0.060	0.027
WxM (25,26)	0.040	0.045	0.043	0.041
NxW (19-24)	0.026	0.047	0.037	0.049
WxN (27)	0.012	0.039	0.042	0.043
LSD (5%)	0.011	0.007	0.020	0.009
Mean	**0.050**	**0.049**	**0.052**	**0.041**
Harvest				
Third	0.068	0.070	0.069	-----
Fifth	0.038	0.032	0.035	0.042

† For more details see Table 45 in Appendix B.

Table 13. Analysis of variance for Na composition in alfalfa leaves, stems, shoots (leaves+ stems), and roots as influenced by cross and harvest time.

Source	DF	MS Leaves	 Stems	 Shoots	 Roots
Cross(C)†	31	0.441E-1**	0.335E-2**	0.486E-1**	0.451E-2**
1-8 vs 15-18	1	0.570E+0**	0.523E-2**	0.466E+0**	0.626E-1**
1-8 vs 28-32	1	0.613E+0**	0.134E-2*	0.553E+0**	0.407E-1**
15-18 vs 28-32	1	0.578E-3	0.122E-2*	0.720E-4	0.325E-2**
9 vs 11-14	1	0.512E-1**	0.192E-2**	0.333E-1**	0.260E-2**
10 vs 25 26	1	0.327E-1**	0.667E-5	0.336E-1**	0.243E-2**
19-24 vs 27	1	0.656E-2**	0.238E-2**	0.174E-1**	0.519E-3
Error(a)	608	0.668E-3	0.237E-3	0.105E-2	0.223E-3
Harvest time(T)	1	0.283E+0**	0.463E+0**	0.147E+1**	--------
C x T	31	0.295E-2**	0.177E-2**	0.270E-2**	--------
Error(b)	608	0.502E-3	0.203E-3	0.728E-3	--------
Total	1279	0.245E+1	0.889E+0	0.414E+1	--------

†Cross: **1.** M1xM1 **2.** M1xM2 **3.** M1xM5 **4.** M2xM1 **5.** M2xM2 **6.** M3xM3 **7.** M5xM3 **8.** M5xM5
9. M2xN1 **10.** M1xW1 **11.** N1xM2 **12.** N1xM3 **13.** N2xM3 **14.** N2xM5 **15.** N1xN2 **16.** N2xN2
17. N2xN4 **18.** N4xN4 **19.** N1xW4 **20.** N2xW3 **21.** N2xW4 **22.** N3xW4 **23.** N4xW1 **24.** N4xW3
25. W1xM1 **26.** W2xM3 **27.** W1xN4 **28.** W1xW3 **29.** W2xW2 **30.** W3xW3 **31.** W4xW3 **32.** W4xW4

,* Significant at 0.05 and 0.01 probability levels, respectively.

Sodium concentration in roots also varied in the cross comparisons made, with the exception of the comparison NxW (19-24) vs WxN (27) (Table 13).

The Na concentration in leaves and stems decreased significantly by 44 and 54% from the third to fifth harvest, which translates to 49% decrease in shoot Na concentration between the two harvest (Table 12).

Sodium:potassium ratios in alfalfa leaves, stems, and roots varied significantly among crosses and harvest time (Table 14). The Na:K ratios in all the alfalfa components were significantly influenced by C, T, and the C x T interaction (Table 15). Comparisons of Na:K ratios in leaves and roots between the groups of crosses were significant in all the contrasts. No significant differences were observed in NxN (15-18) vs WxW (28-32), MxN (9) vs NxM (11-14), and MxW (10) vs WxM (25,26). High Na:K ratios in leaves were observed in MxM, MxN, and MxW crosses. The Na:K ratios in leaves and stems dropped significantly by 40 and 60%, respectively between third and fifth harvest (Table 14). This drop in Na:K ratio with time was due to the drop in Na concentration in leaves and stems.

The accumulation and partitioning of Na in alfalfa leaves, stems, and roots varied according to cross. The results in Table 12 demonstrate high concentrations of Na in the shoot component of MxM crosses with highest concentration in leaves, lower in stems and least in roots. Crosses of group MxN and MxW showed a similar trend of high Na concentration in shoots with leaves accumulating more Na and less in stems and roots. In contrast, crosses NxN, NxW, and WxN accumulated more Na in their roots with lower and least amounts in stems and leaves, respectively. Crosses NxM, WxM, and WxW accumulated equal amounts of Na in their roots and stems with lower concentrations in their leaves.

From the above results it was concluded that significant genetic diversity is present among the alfalfa crosses from a single cultivar in their ability to accumulate and translocate Na in the plant. Hill and Jung (1975) observed significant genetic variability among alfalfa genotypes from a single cultivar in plant ability to accumulate minerals, when grown on fertile soil suitable for good plant growth.

Experiment 3

A complete factorial experiment with 9 diallel crosses and 3 levels of K and Na each (9 x 3 x 3 factorial) were replicated two times in a completely randomized design in the greenhouse. In this section, experimental results are presented and discussed on the effects of alfalfa phenotype cross, K, Na, and harvest time on:

1) transpiration;
2) biomass;
3) water use efficiency (WUE);
4) K, Na, Mg, and Ca composition, Na:K and Ca:Mg ratios in leaves, stems, shoots (leaves+stems), and roots;
5) potassium utilization efficiency (KUE).

Table 14. Group means for Na:K ratio of leaves, stems, shoots (leaves+stems), and roots as influenced by cross and harvest time.

Cross (No.)	Leaves	Stems	Shoots	Roots
MxM (1-8)	0.442	0.266	0.357	0.027
NxN (15-18)	0.113	0.285	0.187	0.558
WxW (28-32)	0.138	0.301	0.207	0.478
MxN (9)	0.410	0.280	0.348	0.278
NxM (11-14)	0.203	0.306	0.244	0.360
MxW (10)	0.329	0.252	0.294	0.226
WxM (25,26)	0.152	0.251	0.190	0.371
NxW (19-24)	0.110	0.250	0.169	0.448
WxN (27)	0.050	0.185	0.112	0.381
LSD (5%)	0.051	0.040	0.036	0.084
Mean	**0.216**	**0.264**	**0.234**	**0.347**
Harvest				
Third	0.284	0.390	0.324	-----
Fifth	0.169	0.154	0.161	0.383

† For more details see Table 46 in Appendix B.

Table 15. Analysis of variance for Na:K ratio in alfalfa leaves, stems, shoots (leaves+ stems), and roots as influenced by cross and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	31	0.867E+0**	0.126E+0**	0.292E+0**	0.104E-2**
1-8 vs 15-18	1	0.115E+2**	0.370E-1*	0.310E+1**	0.561E+1**
1-8 vs 28-32	1	0.113E+2**	0.146E+0**	0.278E+1**	0.368E+1**
15-18 vs 28-32	1	0.562E-1*	0.222E-1	0.365E-1*	0.283E+0**
9 vs 11-14	1	0.137E+1**	0.221E-1	0.348E+0**	0.107E+0*
10 vs 25 26	1	0.840E+0**	0.267E-4	0.291E+0**	0.280E+0**
19-24 vs 27	1	0.126E+0**	0.143E+0**	0.113E+0**	0.777E-1*
Error(a)	608	0.135E-1	0.834E-2	0.675E-2	0.35E-3
Harvest time(T)	1	0.425E+1**	0.178E+2**	0.856E+1**	--------
C x T	31	0.535E-1**	0.667E-1**	0.193E-1**	--------
Error(b)	608	0.986E-2	0.724E-2	0.475E-2	--------
Total	1279	0.470E+2	0.332E+2	0.252E+2	--------

†Cross: **1.** M1xM1 **2.** M1xM2 **3.** M1xM5 **4.** M2xM1 **5.** M2xM2 **6.** M3xM3 **7.** M5xM3 **8.** M5xM5
9. M2xN1 **10.** M1xW1 **11.** N1xM2 **12.** N1xM3 **13.** N2xM3 **14.** N2xM5 **15.** N1xN2 **16.** N2xN2
17. N2xN4 **18.** N4xN4 **19.** N1xW4 **20.** N2xW3 **21.** N2xW4 **22.** N3xW4 **23.** N4xW1 **24.** N4xW3
25. W1xM1 **26.** W2xM3 **27.** W1xN4 **28.** W1xW3 **29.** W2xW2 **30.** W3xW3 **31.** W4xW3 **32.** W4xW4

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Transpiration

Soil cover using polystyrene beads and plant shading minimized evaporation (which was about 7%) from soil causing evapotranspiration to consist essentially of transpiration.

The transpiration varied significantly among alfalfa crosses and also between harvest times (Table 16). According to the cross group comparisons (Table 17), significant differences in the transpiration were observed only among cross group NxN (4) vs WxW (7-9) and WxW (7-9) vs WxN (6). According to data in Table 16, cross MxM had the highest transpiration (15.03 cm) and NxN the lowest transpiration (6.47 cm). According to the literature on the influence of K on transpiration, Wilson and Ludlow (1983), Jones et al., (1980), and Ford and Wilson (1981) indicated that K played a vital role in the osmotic adjustment of guard cells, which in turn influenced transpiration and therefore water use efficiency. In the results obtained above (Table 16 and 17) K did not influence transpiration.

Transpiration varied as much as 63% between the two harvests. In response to harvest time, the transpiration increased from 8.47 to 13.80 cm from second to fourth harvest (Table 16).

Transpiration was also related to increased biomass production. The relationship between the transpiration and alfalfa biomass for alfalfa crosses is shown in Figure 2. It is believed that the increase in transpiration from second to

Table 16. Mean transpiration of alfalfa as influenced by cross, K, Na, and harvest time.

Independent variable	Level	ET (cm)
Cross†	MxM (1,2)	15.03
	NxM (3)	11.63
	NxN (4)	6.47
	NxW (5)	10.74
	WxN (6)	11.57
	WxW (7-9)	9.92
K‡ (g pot^{-1})	K1	10.77
	K2	11.69
	K3	10.94
Na§ (g pot^{-1})	Na1	11.34
	Na2	11.03
	Na3	11.03
Harvest	Second	8.47
	Fourth	13.80

† Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.
¶ For more details see Table 47 in Appendix B.

Table 17. Analysis of variance for transpiration as influenced by alfalfa cross, K, Na, and harvest time.

Source	DF	MS
Cross (C)†	8	0.292E+1*
1 vs 2	1	0.062E+0
1 2 vs 4	1	0.488E+1
1 2 vs 7 8 9	1	0.549E+0
3 vs 5	1	0.301E+1
6 vs 5	1	0.196E+0
7 8 9 vs 4	1	0.858E+1*
7 vs 8	1	0.113E+1
7 8 9 vs 6	1	0.891E+1*
Potassium (K)	2	0.194E+1
Sodium (Na)	2	0.103E+0
K x Na	4	0.479E+0
C x K	16	0.868E+0
C x Na	16	0.124E+1
Error (a)	81	0.134E+1
Harvest time (T)	1	0.338E+3**
C x T	8	0.399E+1
K x T	2	0.103E+1
Na x T	2	0.310E+0
Error (b)	81	0.197E+1

†Cross: 1-M1xM1, 2-M1xM2, 3-N1xM2, 4-N2xN2, 5-N4xW3, 6-W1xN4, 7-W1xW3, 8-W3xW3, 9-W4xW4.

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

‡ For more details see Table 79 in Appendix C.

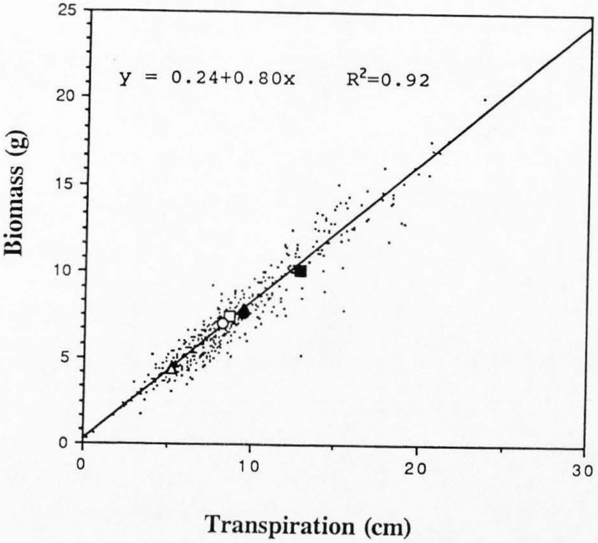

Figure 2. Relation of biomass production to transpiration for six alfalfa crosses based on the individual data of 2nd, 3rd, and 4th growth cycles (N=486). The symbols indicate the mean for respective crosses: ■ MxM, ● NxM, △ NxN, □ NxW, ▲ WxN, ○ WxW.

the fourth harvest (Table 16) was due to greater plant growth and a larger total leaf area.

Our observations are in agreement with those of De Wit (1958) who found that alfalfa biomass production was linearly related to transpiration wherein higher rates of transpiration produced higher biomass.

From the above results it was concluded that genetic variation is present among the alfalfa crosses from a single cultivar in their transpiration rate. The second and the fourth harvest were conducted in March and May, respectively when temperatures outside the greenhouse were cooler and warmer during the respective months. The differences in transpiration with time were believed to be the result of variations in leaf/air vapor pressure deficits and increased radiation and temperature in the greenhouse. During the warmer periods the fans worked longer to maintain the assigned daytime temperature of 24^0C and resulted in more draft and higher vapor deficits thus increasing transpiration.

Biomass

Data on biomass production of alfalfa leaves and stems were collected from the second and fifth growth cycles. Shoot biomass was calculated from the two components. Root biomass data were obtained after harvesting the leaves and stems at the fifth harvest. Results on biomass of leaves, stems, and roots are given in Table 18. According to Table 19, biomass of leaves, stems, and shoots were significantly influenced by

Table 18. Mean biomass of alfalfa leaves, stems, and roots as influenced by cross, K, Na, and harvest time.

Independent variable	Level	Leaves	Stems	Roots
		----------	g pot^{-1}	----------
Cross†	MxM (1,2)	9.50	8.57	17.48
	NxM (3)	8.35	8.35	14.67
	NxN (4)	5.04	6.13	5.29
	NxW (5)	9.29	9.25	11.88
	WxN (6)	9.40	9.13	12.79
	WxW (7-9)	7.39	7.65	9.49
K‡(g pot^{-1})	K1	7.42	7.01	10.31
	K2	8.42	8.44	12.61
	K3	8.56	8.86	13.11
Na§(g pot^{-1})	Na1	7.96	8.01	11.77
	Na2	8.33	8.26	12.06
	Na3	8.12	8.04	12.20
Harvest	Second	3.78	2.50	-----
	Fifth	12.50	13.71	12.01

† Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.

#For more details see Tables 48, 49, 50, and 51 in Appendix B.

Table 19. Analysis of variance for biomass of alfalfa leaves, stems, shoots (leaves+stems), and roots as influenced by cross, K, Na, and harvest time.

Source	DF	MS			
		Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.327E+1**	0.283E+1**	0.432E+2**	0.120E+2**
1 vs 2	1	0.115E+0	0.737E+1**	0.565E+1	0.129E+1
1 2 vs 4	1	0.475E+3**	0.143E+3**	0.114E+4**	0.260E+3**
1 2 vs 7 8 9	1	0.191E+3**	0.366E+2**	0.394E+3**	0.207E+3**
3 vs 5	1	0.159E+2**	0.152E+2**	0.616E+2**	0.064E+0
6 vs 5	1	0.180E+0	0.353E+0	0.162E-1	0.230E+0
7 8 9 vs 4	1	0.149E+3**	0.624E+2**	0.404E+3**	0.328E+2**
7 vs 8	1	0.255E+2**	0.101E+2**	0.678E+2**	0.986E+1
7 8 9 vs 6	1	0.108E+3**	0.583E+2**	0.327E+3**	0.121E+2
Potassium(K)	2	0.725E+1**	0.711E+1**	0.287E+2**	0.782E+1
Sodium(Na)	2	0.100E+1	0.128E+0	0.184E+1	0.197E+0
K x Na	4	0.186E+1	0.158E+1*	0.628E+1	0.853E+1
C x K	16	0.543E+0	0.429E+0	0.175E+1	0.507E+1
C x Na	16	0.500E+0	0.324E+0	0.137E+1	0.492E+1
Error (a)	81	0.866E+0	0.594E+0	0.261E+1	0.454E+1
Harvest time(T)	1	0.715E+3**	0.113E+4**	0.364E+4**	----------
C x T	8	0.960E+1**	0.824E+1**	0.348E+2**	----------
K x T	2	0.171E+2**	0.213E+2**	0.764E+2**	----------
Na x T	2	0.883E+0	0.756E-1	0.143E+1	----------
Error (b)	81	0.196E+1	0.176E+1	0.668E+1	----------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.

, * Significant at 0.05 and 0.01 probability levels, respectively.

‡ For more details see Table 80 in Appendix C.

alfalfa cross (C), K, harvest time (T), and the C x T, and K x T interactions. There was a significant K x Na interaction in stems where K increased and Na decreased the stem biomass. Root biomass was significantly influenced by cross alone.

The mean biomass of leaves, stems, roots, and shoots of crosses MxM, NxN, and WxW varied significantly among each other (Table 19). Crosses MxM, NxW, and WxN produced more leaf and stem biomass as compared with crosses NxN, WxW, and NxM producing less shoot biomass. Cross MxM produced 22% and 47% more leaf biomass than cross WxW and NxN, respectively (Table 18). Stems responded similar to leaves, with MxM producing more biomass (8.57 g pot^{-1}) than WxW (7.65 g pot^{-1}) and NxN (6.13 g pot^{-1}). Root biomass of MxM, WxW, and NxN cross was 17.48, 9.49, and 5.29 g pot^{-1}, respectively, showing similar trends in leaf and stem biomass production. The highest plant biomass was produced by crosses NxW and WxN, with the lowest biomass produced by the NxN cross.

In response to K fertilization, significant increases in biomass production of leaves and stems were observed (Table 18). When K application increased from K1 to K2, biomass production of leaves increased from 7.42 to 8.42 g pot^{-1}, showing a 14% increase in biomass production. With further increase in soil K from K2 to K3, leaf biomass increased by 0.14 g, indicating no significant influence at higher K levels when K was non-limiting. The biomass of stems increased by 20 and 5 percent, when K increased from K1 to K2 and K2 to K3, respectively (Table 18).

The biomass of alfalfa leaves and stems were significantly influenced by harvest time (Table 19). The leaf biomass increased from 3.78 to 12.50 g pot^{-1}, a 231% increase, from harvest two to five, respectively (Table 18). Although the growth cycles were of equal duration (30 days) an increase of 448% was observed in the stem biomass from second to fifth harvest. The stem biomass showed greater variation with harvest time than did leaves.

The mean shoot:root ratios as influenced by cross, K, and Na are given in Table 20. As shown in Table 21, significant differences in shoot:root ratios were observed among alfalfa crosses, with no effect of K or Na. Significant differences were observed in shoot:root ratios among MxM, NxN, and WxW crosses. Shoot:root ratios of 1.65, 3.67, and 2.64 were observed among MxM, NxN, and WxW crosses (Table 20). The low shoot:root ratio in MxM was attributed to high shoot and root biomass, while the high ratio in the NxN cross which was due to low root biomass. A high positive correlation (0.696), significant at 1% level of probability was obtained between shoot and root biomass. This lead to the conclusion that variations exist in shoot:root ratios among alfalfa crosses.

From the above it was concluded that biomass production and shoot:root ratios of alfalfa varied among phenotype crosses from a single cultivar indicating significant differences exist among alfalfa phenotypes in their biomass production ability. With increase in soil K levels, there was an increase in biomass production of alfalfa shoots. The above

Table 20. Mean shoot:root ratio of alfalfa as influenced by cross, K, and Na.

Independent variable	Level	Shoot:root¶
Cross†	MxM (1,2)	1.65
	NxM (3)	1.92
	NxN (4)	3.67
	NxW (5)	2.63
	WxN (6)	2.42
	WxW (7-9)	2.64
K‡(g pot^{-1})	K1	2.44
	K2	2.35
	K3	2.50
Na§(g pot^{-1})	Na1	2.45
	Na2	2.46
	Na3	2.38

---

† Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.

¶Calculated from data of 5th harvest.

#For more details see Table 52 in Appendix B.

Table 21. Analysis of variance for shoot:root ratio as influenced by cross, K, and Na.

Source	DF	MS
Cross(C)†	8	0.965E+0**
1 vs 2	1	0.030E+0
1 2 vs 4	1	0.610E+1**
1 2 vs 7 8 9	1	0.300E+1**
3 vs 5	1	0.657E+0
6 vs 5	1	0.015E+0
7 8 9 vs 4	1	0.157E+1**
7 vs 8	1	0.035E+0
7 8 9 vs 6	1	0.019E+0
Potassium(K)	2	0.435E+0
Sodium(Na)	2	0.053E+0
K x Na	4	0.069E+0
C x K	16	0.194E+0
C x Na	16	0.201E+0
C x K x Na	32	0.132E+0
Error	81	0.197E+0
Total	161	0.225E+1

†Cross: 1-M1xM1, 2-M1xM2, 3-N1xM2, 4-N2xN2, 5-N4xW3, 6-W1xN4, 7-W1xW3, 8-W3xW3, 9-W4xW4.

** Significant at 0.05 and 0.01 probability levels, respectively.

results are in agreement with those of Kimbrough et al., (1971) and Smith (1975) who reported that alfalfa yields were highly correlated with high K levels in alfalfa herbage which increased with K fertilization. The increase in biomass production with time was thought to be due to the well established plant root system with extensive branching providing more root tips which were able to explore and increase water and nutrient uptake. The development of larger plant crowns and more buds producing stems were also thought to be the factors in increasing biomass production with time.

Water Use Efficiency

Data on water use efficiency (WUE) based on grams of biomass produced per kilogram of water lost through transpiration, were obtained to evaluate yield-water relationship.

The means for WUE as related to alfalfa cross, K, Na, and time are given in Table 22. As indicated in Table 23, water use efficiency of alfalfa was significantly influenced by cross, time, and C x T but not by K or Na.

According to Table 22, crosses MxM, NxN, and WxW had WUEs of 1.97, 1.86, and 2.04 g kg^{-1}, respectively, with cross NxN differing significantly from crosses MxM and WxW (Table 23). Cross NxW and NxN were the most and least efficient in their water use, respectively (Figure 3).

As time progressed (i.e. growth cycles), WUE increased significantly from 1.97 to 2.04 g kg^{-1} or an increase of 4%.

Table 22. Mean water use efficiency (WUE) of alfalfa as influenced by cross, K, Na, and harvest time.

Independent variable	Level	WUE ($g\ kg^{-1}$)
Cross†	MxM (1,2)	1.97
	NxM (3)	1.99
	NxN (4)	1.86
	NxW (5)	2.11
	WxN (6)	2.04
	WxW (7-9)	2.04
K‡ ($g\ pot^{-1}$)	K1	1.96
	K2	2.04
	K3	2.01
Na§ ($g\ pot^{-1}$)	Na1	2.03
	Na2	2.03
	Na3	1.96
Harvest	Second	1.96
	Fourth	2.05

†Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.
¶ For more details see Table 53 in Appendix B.

Table 23. Analysis of variance for WUE as influenced by cross, K, Na, and harvest time.

Source	DF	MS
Cross (C)†	8	0.139E+0**
1 vs 2	1	0.038E+0
1 2 vs 4	1	0.814E+0**
1 2 vs 7 8 9	1	0.011E+0
3 vs 5	1	0.001E+0
6 vs 5	1	0.001E+0
7 8 9 vs 4	1	0.761E+0**
7 vs 8	1	0.047E+0
7 8 9 vs 6	1	0.000E+0
Potassium (K)	2	0.057E+0
Sodium (Na)	2	0.019E+0
K x Na	4	0.037E+0
C x K	16	0.011E+0
C x Na	16	0.018E+0
Error (a)	81	0.029E+0
Harvest time (T)	1	0.642E+0**
C x T	8	0.106E+0**
K x T	2	0.073E+0
Na x T	2	0.009E+0
Error (b)	81	0.027E+0

†Cross: 1-M1xM1, 2-M1xM2, 3-N1xM2, 4-N2xN2, 5-N4xW3, 6-W1xN4, 7-W1xW3, 8-W3xW3, 9-W4xW4.

** Significant at 0.05 and 0.01 probability levels, respectively.

‡ For more details see Table 81 in Appendix C.

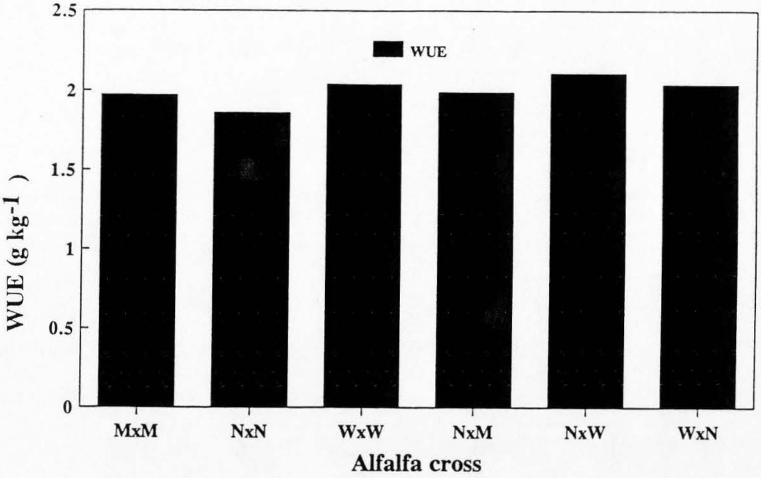

Figure 3. Water use efficiency as influenced by alfalfa cross.

It was concluded that there is genetic variation among the alfalfa crosses in their ability to use water efficiently. The small increase in WUE with time was thought to be caused by an increase in biomass production which increased 317% with time.

Potassium

As shown in Table 24, the concentration of K in alfalfa plants was second highest next to calcium, with stems accumulating more K (0.58 $\text{mmol}_c\ g^{-1}$) followed by leaves (0.46 $\text{mmol}_c\ g^{-1}$) and roots (0.20 $\text{mmol}_c\ g^{-1}$). Rominger et al. (1976) and Wolf et al. (1976) also reported that K was more concentrated in stems than in leaves of alfalfa. Hylton et al. (1967) associated high K in stems with metabolically active stem nodes and leaf buds.

The data in Table 24 also indicate that K taken up by roots was readily translocated to stems and leaves, thus leaving roots with low K concentrations.

The concentrations of K and Na in leaves, stems, and roots as influenced by alfalfa cross is shown in Figure 4.

Table 24. Mean K, Na, Mg, and Ca composition in alfalfa components.

Component	K	Na	Mg	Ca	Total
	------------	------$\text{mmol}_c\ g^{-1}$	------	------------	
Leaves	0.46	0.049	0.38	1.72	2.61
Stems	0.58	0.055	0.21	0.51	1.36
Roots	0.20	0.053	0.14	0.10	0.49

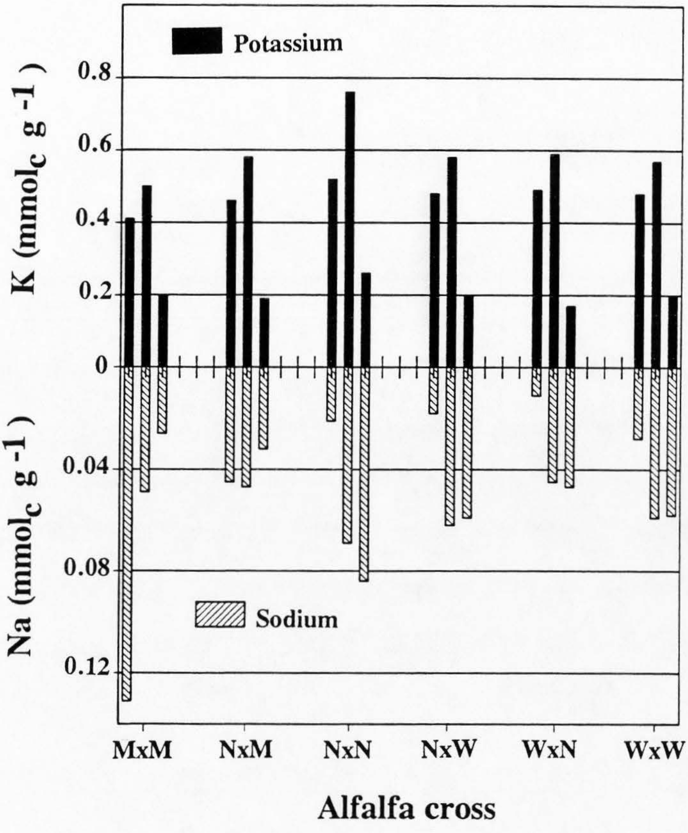

Figure 4. K and Na concentration in leaves, stems, and roots, as influenced by alfalfa cross. (Bars left to right: leaves, stems, and roots). See Tables 26 and 28 for levels of significance for K and Na, respectively.

The K composition of alfalfa leaves, stems, and roots as influenced by independent variables of the experiment are shown in Table 25 with its analysis of variance in Table 26. The K composition of alfalfa leaves, stems, roots, and shoots was significantly influenced by the main effects of cross and K (Table 26). Harvest time also had a significant effect on K composition of leaves, stems, and shoots. Interactive effects of C x T and K x T significantly influenced K composition in stems and shoots, and leaves and shoots, respectively.

Potassium composition in leaves, stems, roots, and shoots of NxN cross differed significantly from MxM and WxW crosses. Cross NxN accumulated higher concentrations of K in leaves, stems, and roots, with the cross MxM accumulating the least amount of K (21% less than NxN) in leaves and stems (Table 25).

Potassium concentration in leaves, stems, roots, and shoots were significantly influenced by K fertilization. Application of 0.8 g K pot^{-1} (K2), mean K concentration in leaves increased by 0.12 $mmol_c\ g^{-1}$ (a 33% increase), and in response to the additional application of 0.8 g K pot^{-1} (from K2 to a total of 1.6 g K pot^{-1} (K3)), leaf K increased by 0.07 $mmol_c\ g^{-1}$ (a 15% increase) (Table 25). These results indicate an increase in K concentration with increase in soil K.

Similar significant effects of K fertilization were observed in K concentration in alfalfa stems. According to the data in Table 25, increasing soil K levels from K1 to K2, led to an increase in mean stem K by 24% and from K2 to K3 an

Table 25. Mean K composition of alfalfa leaves, stems, and roots as influenced by cross, K, Na, and harvest time.

Independent variable	Level	Leaves	Stems	Roots
		---------mmol$_c$ g^{-1}---------		
Cross†	MxM (1,2)	0.41	0.50	0.20
	NxM (3)	0.46	0.58	0.19
	NxN (4)	0.52	0.76	0.26
	NxW (5)	0.48	0.58	0.20
	WxN (6)	0.49	0.59	0.17
	WxW (7-9)	0.48	0.57	0.20
K‡(g pot^{-1})	K1	0.36	0.45	0.15
	K2	0.48	0.56	0.20
	K3	0.55	0.73	0.25
Na§(g pot^{-1})	Na1	0.45	0.56	0.20
	Na2	0.47	0.58	0.20
	Na3	0.48	0.60	0.20
Harvest	Second	0.56	0.78	----
	Fifth	0.36	0.38	0.20

† Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0;

¶For more details see Tables 54, 55, 56, and 57 in Appendix B.

Table 26. Analysis of variance for K composition in alfalfa leaves, stems, shoots (leaves+stems), and roots as influenced by cross, K, Na, and harvest time.

Source	DF	MS			
		Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.933E-2**	0.895E-1**	0.141E+0**	0.184E-2**
1 vs 2	1	0.497E-2	0.128E-2	0.121E-1	0.278E-4
1 2 vs 4	1	0.397E-1**	0.395E+0**	0.689E+0**	0.440E-2**
1 2 vs 7 8 9	1	0.979E-2	0.396E-2	0.273E-1	0.150E-3
3 vs 5	1	0.269E-2	0.193E-1	0.370E-1	0.400E-4
6 vs 5	1	0.527E-2	0.281E-2	0.376E-3	0.640E-3
7 8 9 vs 4	1	0.177E-1**	0.381E+0**	0.561E+0**	0.368E-2**
7 vs 8	1	0.905E-2	0.192E-1	0.523E-1	0.136E-2
7 8 9 vs 6	1	0.743E-3	0.179E+0*	0.201E+0*	0.241E-2*
Potassium(K)	2	0.488E-1**	0.222E+0**	0.437E+0**	0.134E-1**
Sodium(Na)	2	0.999E-3	0.167E-1	0.261E-1	0.120E-3
K x Na	4	0.337E-2	0.168E-1	0.343E-1	0.144E-2*
C x K	16	0.237E-2	0.309E-1	0.375E-1	0.326E-3
C x Na	16	0.271E-2	0.207E-1	0.188E-1	0.337E-3
Error (a)	81	0.250E-2	0.266E-1	0.353E-1	0.517E-3
Harvest time(T)	1	0.393E+0**	0.164E+0**	0.365E+1**	--------
C x T	8	0.422E-2	0.386E-1*	0.594E-1*	--------
K x T	2	0.139E-1**	0.509E-1	0.869E-1*	--------
Na x T	2	0.456E-3	0.981E-2	0.148E-1	--------
Error (b)	81	0.212E-2	0.168E-1	0.232E-1	--------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.

,* Significant at 0.05 and 0.01 probability levels, respectively.

‡ For more details see Table 82 in Appendix C.

increase of 30%, respectively. These data indicate that the accumulation of K in alfalfa stems increased with higher soil K levels.

The K concentrations in roots were also significantly increased by K fertilizers. The data in Table 25, indicate that with increase in soil K concentration from K1 to K2 and K2 to K3, root K increased by 33% and 25% respectively. These observations suggest that the range of K accumulation by roots between the lowest and highest K treatment was relatively higher as compared to leaves and stems.

In response to soil K, concentration of K in shoots behaved very much the same as leaves and stems, with increase of 0.11 $mmol_c$ g^{-1} (28%) from K1 to K2, and an increase of 0.12 $mmol_c$ g^{-1} (23%) from K2 to K3 levels.

Application of Na had no significant effects on K composition of alfalfa leaves, stems, roots, and shoots although there was a trend to increase more K with Na application (Table 25).

Harvest time played a significant role in K composition of alfalfa leaves, stems, and shoots (Table 26). As indicated in Table 25, K concentration in leaves fell significantly from 0.56 $mmol_c$ g^{-1} to 0.36 $mmol_c$ g^{-1}, a 36% decrease, from the second to the fifth harvest, respectively. A significant 51% drop in K concentration in stems was observed between the two growth cycles. In shoots, K dropped significantly by 0.30 $mmol_c$ g^{-1}, a 45% decrease, between the two harvest times.

From the above results of K composition of alfalfa as influenced by cross, K, and harvest time, it was concluded that variations in K accumulation in alfalfa crosses were under genetic control. Hill and Jung (1975) also found significant genetic variation for mineral elements in alfalfa. In response to higher K levels, accumulation of K in alfalfa leaves, stems and roots increased with stems responding more than leaves and roots. Also, the rate of K accumulation by alfalfa plants fell at higher soil K levels where soil K was no longer limiting. In Utah the critical range of K concentration in alfalfa shoots is considered to be between 1.4% and 1.8% (which is equivalent to 0.36 and 0.46 $\mathrm{mmol_c}$ K g^{-1}, respectively) tissue K concentration (Topper et al. 1989). At the time of the fifth harvest alfalfa shoots had about 0.37 $\mathrm{mmol_c}$ K g^{-1} (i.e. 1.4% K) indicating that the plants were approaching K deficiency level. Therefore, the high magnitude of decrease in K concentration in leaves (36%), stems (51%), and shoots (45%) (Table 25) with time was due to the mining effect of K by alfalfa plants (soil K removal through harvested plants), thus decreasing soil K, and hence lowering K concentrations in plant tissue.

Sodium

The Na concentration in alfalfa components is shown in Table 24. Sodium was the least accumulated cation in the alfalfa plants with an average of 0.052 $\mathrm{mmol_c}$ g^{-1}, with leaves having the lowest Na concentration of 0.049 $\mathrm{mmol_c}$ g^{-1}, followed by roots with 0.053 $\mathrm{mmol_c}$ g^{-1} (8% more than leaves), and stems showing the highest concentration of 0.055 $\text{mmol}_c\ g^{-1}$ (12% more than leaves). The Na concentration between roots and stems had a difference of only 0.002 $\text{mmol}_c\ g^{-1}$ (4%) (Table 24). It was concluded that Na accumulated more in roots and stems, with decreasing amounts translocated to the leaves. The results of Sherrell (1983) and Moshtaghi (1988) indicate that most of the Na was retained in the alfalfa root, with minimum translocation to the shoot.

The treatment means and the analysis of variance for Na composition in alfalfa leaves, stems, roots, and shoots as influenced by the independent variables of the experiment and their interactions are shown in Tables 27 and 28, respectively. Na composition of alfalfa leaves, stems, roots, and shoots varied significantly among crosses. Concentrations of Na in leaves, stems, and roots of MxM cross differed significantly from crosses NxN and WxW. Among the three crosses, cross MxM had 624% and 468% more Na in leaves than the NxN and WxW crosses, respectively, with less Na in stems and least in roots (Table 27). The cross NxM also had high Na concentrations in leaves and stems and low concentrations in roots as compared to crosses without M as one of the parents. Opposite to the high and low leaf and stem Na concentrations of MxM and NxM crosses, Na accumulated more in stems and less in leaves in the remaining crosses.

Distinct variations in root Na concentration among crosses were observed. High Na concentrations in roots were observed in cross NxN with cross MxM having the lowest Na

Table 27. Mean Na composition of alfalfa leaves, stems, and roots as influenced by cross, K, Na, and harvest time.

Independent variable	Level	Leaves	Stems	Roots
		----------mmol$_c$ g^{-1}-----------		
Cross†	MxM (1,2)	0.131	0.049	0.026
	NxM (3)	0.045	0.047	0.032
	NxN (4)	0.021	0.069	0.084
	NxW (5)	0.018	0.062	0.059
	WxN (6)	0.011	0.045	0.047
	WxW (7-9)	0.028	0.059	0.068
K‡(g pot^{-1})	K1	0.071	0.081	0.079
	K2	0.042	0.049	0.049
	K3	0.034	0.037	0.031
Na§(g pot^{-1})	Na1	0.025	0.044	0.032
	Na2	0.049	0.049	0.056
	Na3	0.072	0.073	0.071
Harvest	Second	0.048	0.059	-----
	Fifth	0.049	0.052	0.053

† Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.

¶For more details see Tables 58, 59, 60, and 61 in Appendix B.

Table 28. Analysis of variance for Na composition in alfalfa leaves, stems, shoots (leaves+stems), and roots as influenced by cross, K, Na, and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.106E-2**	0.101E-2**	0.137E-2*	0.111E-2**
1 vs 2	1	0.081E-5	0.414E-5	0.108E-5	0.608E-4
1 2 vs 4	1	0.232E-2**	0.506E-2**	0.527E-3	0.470E-2**
1 2 vs 7 8 9	1	0.564E-2**	0.137E-2*	0.142E-2	0.497E-2**
3 vs 5	1	0.255E-4	0.147E-2*	0.189E-2	0.340E-3
6 vs 5	1	0.472E-5	0.721E-3	0.884E3	0.010E-6
7 8 9 vs 4	1	0.676E-4	0.213E-2**	0.293E-2*	0.287E-3
7 vs 8	1	0.287E-3	0.128E-2*	0.278E-2*	0.324E-4
7 8 9 vs 6	1	0.111E-4	0.201E-3	0.320E-3	0.106E-2*
Potassium(K)	2	0.231E-3	0.306E-2**	0.467E-2**	0.283E-2**
Sodium(Na)	2	0.224E-3	0.146E-2**	0.275E-2**	0.188E-2**
K x Na	4	0.210E-3	0.469E-3	0.131E-2*	0.593E-3*
C x K	16	0.461E-3	0.486E-3*	0.106E-2*	0.255E-3
C x Na	16	0.792E-4	0.686E-3**	0.787E-2	0.185E-3
Error (a)	81	0.179E-3	0.271E-3	0.519E-3	0.170E-3
Harvest time(T)	1	0.215E-4	0.270E-2**	0.230E-2*	--------
C x T	8	0.173E-3	0.725E-3**	0.148E-2**	--------
K x T	2	0.289E-3	0.593E-3	0.792E-3	--------
Na x T	2	0.448E-3	0.448E-3	0.868E-3	--------
Error (b)	81	0.144E-3	0.200E-3	0.405E-3	--------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
*,** Significant at 0.05 and 0.01 probability levels, respectively.
For more details see Table 83 in Appendix C.

concentration.

These results indicate that cross MxM which had low K tissue concentration, accumulated more Na in comparison to all the other crosses. The above observations are in agreement with those of James (1988). As observed in the first experiment (Table 5), phenotype M (Marginal chlorosis) accumulated higher concentrations of Na than the N (Normal) and W (White spot) phenotypes.

In response to K fertilization, Na composition of stems, roots, and shoots was significantly influenced with no significant response on leaf Na composition (Table 28). Increasing soil K application from K1 to K2, Na concentration in stems dropped significantly by 40% (0.032 $mmol_c\ g^{-1}$), and with further increase in soil K from K2 to K3, Na in stems further decreased by 25% (0.012 $mmol_c\ g^{-1}$) (Table 27).

Concentration of Na in roots and shoots showed a similar trend to that of stems, Na concentration decreased with increase in soil K. With increasing soil K levels, Na concentration in roots dropped significantly by 38% (K1 to K2) (0.030 $mmol_c\ g^{-1}$) and 37% (0.018 $mmol_c\ g^{-1}$) (K2 to K3). Sodium concentration in shoots dropped from 0.076 to 0.046 (a 40% decrease) to 0.036 $mmol_c\ g^{-1}$ (a 22% decrease) with increase in K from K1 to K2 to K3, respectively.

The above results, relating decreasing Na accumulation in alfalfa plants with increasing K fertilizer, are in agreement with the findings of Sherrell (1983) and James (1988), who concluded that K fertilization significantly reduced Na concentration in alfalfa plants.

Sodium treatments produced a significant response on Na concentrations in stems, roots, and shoots of alfalfa (Table 28). Soil Na fertilization levels increasing from 0.0 g Na pot^{-1} (Na1) to 0.5 g Na pot^{-1} (Na2), gave an increase in Na concentration in stems by 0.005 mmol$_c$ g^{-1}, or increase of 11 percent. With further increase in soil Na by 0.5 g pot^{-1} (Na3), a total of 1.0 g Na pot^{-1}, stem Na increased by 0.024 mmol$_c$ g^{-1}, a 49% increase (Table 27).

Sodium concentration in roots increased from 0.032 to 0.056 to 0.071 mmol$_c$ g^{-1} with an increase in Na levels from Na1 to Na2 to Na3, respectively. These were equivalent to an increase of 75% and 27% from Na1 to Na2 and from Na2 to Na3, respectively (Table 27). Sodium composition of roots was also significantly influenced by K x Na effect.

Concentration of Na in shoots increased with increase in Na levels. With increasing soil Na levels from Na1 to Na2 to Na3, Na in shoots rose from 0.035 to 0.049 to 0.073 mmol$_c$ g^{-1}, respectively (Table 27).

These results demonstrate that Na concentration of alfalfa is directly related to soil Na. Similar results are shown by Schultz et al. (1979) and Sherrell (1983), who observed a small increase in alfalfa Na concentrations with Na fertilization of the soil.

Harvest time had no significant influence on leaf Na concentrations (Table 28), indicating that Na concentrations remained unchanged. There was more uptake of Na when K concentration in alfalfa shoots fell by 45% with time (Table 25). Harvest time had significant influence on Na content in stems and shoots of alfalfa (Table 28). The Na concentration in stems dropped from 0.059 to 0.052 $mmol_c\ g^{-1}$ (a 12% decrease) from the second to the fifth cut, respectively (Table 27). With increase in time, the Na concentration in shoots fell from 0.054 to 0.051 $mmol_c\ g^{-1}$, a 6% decrease, from the second to the fifth harvest.

The cross MxM accumulated more Na in leaves with less in stems and least in roots, in contrast to high Na concentrations in stems and roots and low in leaves of the other crosses (Figure 3) indicating variations in Na translocation among the alfalfa crosses. It was concluded that the crosses studied varied in their ability to translocate Na from roots to shoots. Cross MxM and NxM translocated more Na from roots to leaves maintaining low concentration in roots in contrast more Na in roots with decreasing amounts translocated to the stems and leaves in other crosses (Table 27). Similar trend was observed with phenotype M (Table 5). It was therefore concluded that Na accumulation is a highly heritable trait in alfalfa. These variations among alfalfa crosses in their ability to accumulate and translocate Na, reflect the genetic diversity present among alfalfa phenotypes in Na accumulation and translocation.

Since the magnitude of decrease in K concentrations in plant tissue with time (Table 25) was much greater than Na (Table 27), and since Na concentration in leaves remained unchanged with time, it was concluded that there was more uptake of Na when K was limiting. Dow and James (1970) and James (1988) reported that K-deficient alfalfa plants contained considerably more Na in their tissue.

Since, cross MxM accumulated less K and more Na with no adverse effect on growth, it was concluded that there was a partial substitution of Na for K (see section on potassium utilization efficiency for more details).

Na:K Ratio

To further explain the relationship between Na and K in components of alfalfa crosses under varying K and Na levels, the Na:K tissue ratios were calculated. Treatment means are given in Table 29, and the analysis of variance for Na:K ratio in alfalfa components as influenced by alfalfa cross, K and Na fertilizers, time, and their interactions are given in Table 30.

Sodium:potassium ratios in alfalfa leaves and roots were significantly influenced by alfalfa cross (Table 30). With the exception of one comparison (1 vs 2), all the crosses differed significantly in their Na:K ratios in leaves and shoots. As shown in Table 29, cross MxM had the highest mean leaf Na:K ratio (0.376), and cross WxN had the lowest ratio (0.025). Similarly the crosses varied significantly in their root Na:K ratios. In contrast to the high Na:K ratio in the leaves of the cross MxM (0.376), the roots had the least Na:K ratio (0.144). The cross WxW had the highest ratio (0.407) (Table

Table 29. Mean Na:K ratio of alfalfa leaves, stems, and roots as influenced by cross, K, Na, and harvest time.

Independent variable	Level	Leaves	Stems	Roots
Cross†	MxM (1,2)	0.376	0.140	0.144
	NxM (3)	0.119	0.111	0.191
	NxN (4)	0.047	0.131	0.395
	NxW (5)	0.043	0.149	0.338
	WxN (6)	0.025	0.104	0.313
	WxW (7-9)	0.068	0.145	0.407
K‡(g pot^{-1})	K1	0.223	0.259	0.541
	K2	0.104	0.094	0.252
	K3	0.068	0.049	0.122
Na§(g pot^{-1})	Na1	0.065	0.074	0.184
	Na2	0.134	0.135	0.330
	Na3	0.196	0.193	0.400
Harvest	Second	0.101	0.086	-----
	Fifth	0.163	0.182	0.305

†Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.

¶For more details see Tables 62, 63, 64, and 65 in Appendix B.

Table 30. Analysis of variance for Na:K ratio in alfalfa leaves, stems, shoots (leaves+ stems), and roots as influenced by cross, K, Na, and harvest time.

Source	DF	MS			
		Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.486E-2**	0.145E-2	0.117E-2	0.396E-1**
1 vs 2	1	0.720E-4	0.115E-2	0.146E-2	0.706E-2
1 2 vs 4	1	0.260E+1**	0.194E-2	0.642E+0**	0.750E+0**
1 2 vs 7 8 9	1	0.411E+1**	0.941E-3	0.970E+0**	0.149E+1**
3 vs 5	1	0.104E+0**	0.260E-1**	0.720E-2**	0.200E+0**
6 vs 5	1	0.583E-2*	0.365E-1**	0.162E-1**	0.656E-2
7 8 9 vs 4	1	0.115E-1**	0.504E-2*	0.504E-2*	0.228E-2
7 vs 8	1	0.583E-2*	0.221E-1**	0.131E-1**	0.335E-1
7 8 9 vs 6	1	0.492E-1**	0.447E-1**	0.425E-1**	0.122E+0**
Potassium(K)	2	0.338E-2	0.468E-2*	0.482E-2**	0.309E+0**
Sodium(Na)	2	0.409E-3	0.194E-2	0.113E-2	0.102E+0**
K x Na	4	0.190E-2	0.181E-2	0.216E-2*	0.688E-1**
C x K	16	0.496E-2**	0.142E-2	0.190E-2**	0.164E-1
C x Na	16	0.522E-3	0.180E-2	0.731E-3	0.764E-2
Error (a)	81	0.115E-2	0.116E-2	0.758E-3	0.105E-1
Harvest time(T)	1	0.301E-1**	0.439E-1**	0.363E-1**	--------
C x T	8	0.567E-2**	0.258E-2	0.417E-2**	--------
K x T	2	0.549E-2*	0.760E-2	0.603E-2*	--------
Na x T	2	0.144E-1**	0.109E-1*	0.130E-1**	--------
Error (b)	81	0.175E-2	0.274E-2	0.151E-2	--------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
*,** Significant at 0.05 and 0.01 probability levels, respectively.
‡ For more details see Table 84 in Appendix C.

29) which occurred in the roots.

Since cross MxM accumulated more Na in leaves and less in roots, it led to higher Na:K ratios in leaves and lower in roots. In contrast, the NxN cross accumulated less Na and more K in leaves and with more Na in roots, thus giving low and high Na:K ratio in leaves and roots, respectively.

Sodium:potassium ratios in stem, root, and shoots of alfalfa significantly decreased with K fertilization (Table 29). With soil K application from K1 to K2 to K3, the Na:K ratio in stems fell from 0.259 to 0.094 to 0.049, which translated to 64% and 49% drop in Na:K ratio from K1 to K2 and K2 to K3, respectively (Table 29). A similar trend was observed in Na:K ratio in roots with K fertilization. The ratio in roots dropped from 0.541 to 0.252 as K increased from K1 to K2, and a further drop of 0.130 (52%) as K increased from K2 to K3.

The Na:K ratio in alfalfa roots was significantly influenced by sodium treatments (Table 30). With increase in soil Na levels from Na1 to Na2, ratio of Na to K in roots increased from 0.184 to 0.330, an increase of 79% (Table 29). With further increase in Na levels from Na2 to Na3, Na:K ratio increased from 0.330 to 0.400, an increase of 21 percent.

These results demonstrate that, with increase in soil Na levels, Na in roots increased, increasing the plant Na:K ratio. Since the alfalfa accumulated more Na and less K in the roots (Table 24), the influence of Na application on Na:K ratio in roots is more pronounced giving higher ratios as compared to leaf and stem ratios.

The K decreased Na:K ratio in roots with greater reduction at the lowest rate of Na giving significant K x Na interaction (Table 30). With increase in K, the reduction in Na:K ratio in leaves varied among crosses giving significant C x K interaction (Table 30).

Growth cycle had a significant influence on Na:K ratio in alfalfa leaves, stems, and shoots (Table 30). The Na:K ratio in leaves increased by 0.062 (61%) from the second to the fifth harvest (Table 29). The stem Na:K ratio in stems increased from 0.086 to 0.182 (a 112% increase) from the second to the fifth harvest, respectively. The interactive effects of C x T, K x T, Na x T, and Na x T, significantly influenced Na:K ratio in leaves, shoots, and stems, respectively (Table 30).

From the above results it can be concluded that the phenotype crosses showed differences in selectivity for K and Na, with MxM showing more selectivity to Na than K, and cross NxN having more selectivity for K than Na. Evidently genetic variability in alfalfa for mineral nutrient accumulation and its translocation within the plant, tend to influence Na:K ratio in alfalfa components. These results are in agreement with those of Hill and Jung (1975); Buss et al. (1975).

With increased soil K, the Na:K ratio decreased in stems and roots which was thought to be the result of increase in K concentration and decrease in Na concentrations. This concurs with the results of Smith (1975), Schultz et al. (1979); and

James (1988) who reported that increasing K applications led to higher K and lower Na concentrations in alfalfa plants, and hence lowering Na:K ratio. It was also concluded that the magnitude with which K decreased in alfalfa over time was much higher (45%) as compared to the decrease in Na concentration which was merely 7%. Therefore, with decreased K concentration and a small change in Na concentration the Na:K ratio in alfalfa increased with time.

Magnesium

Magnesium concentration was highest in alfalfa leaves (0.38 $\text{mmol}_c\ g^{-1}$) with stems (0.21 $\text{mmol}_c\ g^{-1}$) and roots (0.14 $\text{mmol}_c\ g^{-1}$) containing lesser amounts, which concludes that Mg absorbed by roots was translocated to the leaves where it accumulated the most (Table 24 and 31).

The analysis of variance for Mg composition in alfalfa leaves, stems, roots, and shoots as influenced by the independent variables of the experiment and their interactions are shown in Table 32.

Stem was the only alfalfa component with an Mg concentration significantly influenced by cross, harvest time, and C x T (Table 32). According to the cross comparisons, Mg concentration in stems of NxN (4) cross varied significantly with MxM (1,2) and WxW (7-9) crosses. Among the crosses, cross NxN had higher Mg concentrations in all its components (Table 31).

Harvest time had a significant influence on magnesium

Table 31. Mean Mg composition of alfalfa leaves, stems, and roots as influenced by cross, K, Na, and harvest time.

Independent variable	Level	Leaves	Stems	Roots
		----------$\text{mmol}_c\ g^{-1}$----------		
Cross†	MxM (1,2)	0.35	0.21	0.14
	NxM (3)	0.34	0.24	0.13
	NxN (4)	0.44	0.25	0.17
	NxW (5)	0.41	0.18	0.13
	WxN (6)	0.42	0.21	0.13
	WxW (7-9)	0.36	0.20	0.14
K‡(g pot^{-1})	K1	0.42	0.24	0.16
	K2	0.37	0.20	0.14
	K3	0.34	0.19	0.13
Na§(g pot^{-1})	Na1	0.39	0.22	0.15
	Na2	0.37	0.21	0.14
	Na3	0.34	0.20	0.13
Harvest	Second	0.39	0.25	----
	Fifth	0.36	0.18	0.14

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† Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; § Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.

¶For more details see Tables 66, 67, 68, and 69 in Appendix B.

Table 32. Analysis of variance for Mg composition in alfalfa leaves, stems, shoots (leaves+stems), and roots as influenced by cross, K, Na, and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.191E-2	0.127E-1**	0.160E-1**	0.103E-2
1 vs 2	1	0.368E-3	0.556E-2	0.292E-2	0.215E-2*
1 2 vs 4	1	0.430E-2	0.499E-1**	0.825E-1**	0.148E-3
1 2 vs 7 8 9	1	0.709E-2	0.280E-3	0.107E-1	0.474E-5
3 vs 5	1	0.439E-3	0.439E-3	0.203E-4	0.111E-3
6 vs 5	1	0.204E-2	0.135E-2	0.725E-2	0.284E-3
7 8 9 vs 4	1	0.874E-5	0.501E-1**	0.497E-1**	0.214E-3
7 vs 8	1	0.883E-4	0.376E-3	0.580E-3	0.218E-3
7 8 9 vs 6	1	0.195E-2	0.115E-1*	0.239E-1**	0.831E-3
Potassium(K)	2	0.871E-3	0.453E-2	0.968E-2	0.605E-3
Sodium(Na)	2	0.133E-2	0.265E-3	0.292E-2	0.131E-3
K x Na	4	0.525E-4	0.912E-3	0.800E-3	0.437E-3
C x K	16	0.129E-2	0.580E-3	0.206E-2	0.554E-3
C x Na	16	0.116E-2	0.143E-2	0.217E-2	0.444E-3
Error (a)	81	0.128E-2	0.204E-2	0.325E-2	0.542E-3
Harvest time(T)	1	0.119E-1**	0.538E-1**	0.114E+0**	--------
C x T	8	0.257E-2	0.608E-2*	0.794E-2*	--------
K x T	2	0.161E-2	0.167E-2	0.180E-2	--------
Na x T	2	0.904E-3	0.100E-2	0.395E-2	--------
Error (b)	81	0.150E-2	0.167E-2	0.386E-2	--------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
,* Significant at 0.05 and 0.01 probability levels, respectively.
‡ For more details see Table 85 in Appendix C.

concentration in stems. With increase in time, from second to fifth harvest, Mg concentrations fell 0.25 to 0.18 $\text{mmol}_c\ g^{-1}$, a 28% decrease (Table 31).

From the results, it was concluded that differences do exist among alfalfa crosses in their ability to accumulate Mg. Although the K and Na treatments did not influence Mg concentrations significantly in alfalfa crosses, a decreasing trend in Mg concentration was observed with increase in K and Na levels. The magnitude of decrease in Mg concentrations in plant tissue with time was low (28%) (Table 31) as compared to K (45%) (Table 25), indicating that Mg concentrations in plants increased with decrease in plant K.

Calcium

Alfalfa leaves had the highest level of Ca concentration (1.72 $\text{mmol}_c\ g^{-1}$), with a lower concentration in stems (0.51 $\text{mmol}_c\ g^{-1}$) and the least in roots (0.10 $\text{mmol}_c\ g^{-1}$), which demonstrated that Ca was readily translocated from roots to leaves (Table 24).

According to Tables 33 and 34, Ca composition of alfalfa leaves, stems, roots, and shoots was significantly influenced by cross. The Ca in leaves and stems was not influenced by soil K or Na, but was influenced by harvest time and C x T, with Ca in roots being significantly influenced by soil K (Table 34).

The cross MxM (1,2) varied significantly in the leaf Ca concentration with that of NxN (4) and WxW (7-9) crosses. The

Table 33. Mean Ca composition of alfalfa leaves, stems, and roots as influenced by cross, K, Na, and harvest time.

Independent variable	Level	Leaves	Stems	Roots
		----------$mmol_c\ g^{-1}$----------		
Cross†	MxM (1,2)	1.70	0.56	0.11
	NxM (3)	1.69	0.57	0.10
	NxN (4)	1.94	0.55	0.09
	NxW (5)	1.78	0.55	0.09
	WxN (6)	1.73	0.46	0.10
	WxW (7-9)	1.64	0.46	0.09
K‡(g pot^{-1})	K1	1.80	0.55	0.09
	K2	1.71	0.50	0.10
	K3	1.60	0.49	0.10
Na§(g pot^{-1})	Na1	1.80	0.51	0.10
	Na2	1.70	0.51	0.10
	Na3	1.65	0.51	0.10
Harvest	Second	1.60	0.60	----
	Fifth	1.84	0.42	0.10

† Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.

¶For more details see Tables 70, 71, 72, and 73 in Appendix B.

Table 34. Analysis of variance for Ca composition in alfalfa leaves, stems, shoots (leaves+stems), and roots as influenced by cross, K, Na, and harvest time.

Source	DF	MS			
		Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.409E-1*	0.597E-1**	0.128E+0**	0.468E-3**
1 vs 2	1	0.122E-1	0.608E-3	0.705E-2	0.871E-3*
1 2 vs 4	1	0.111E+0*	0.206E+0**	0.595E+0**	0.428E-3
1 2 vs 7 8 9	1	0.940E-1*	0.319E-1	0.163E-1	0.162E-2**
3 vs 5	1	0.140E+0**	0.130E-1	0.233E+0**	0.160E-3
6 vs 5	1	0.881E-1*	0.236E-2	0.117E+0*	0.401E-3
7 8 9 vs 4	1	0.122E-1	0.388E+0**	0.514E+0**	0.980E-4
7 vs 8	1	0.112E-1	0.129E-3	0.894E-2	0.111E-3
7 8 9 vs 6	1	0.560E-2	0.698E-1**	0.114E+0	0.535E-4
Potassium(K)	2	0.104E-2	0.652E-2	0.100E-1	0.627E-3*
Sodium(Na)	2	0.192E-1	0.896E-2	0.514E-1	0.230E-4
K x Na	4	0.889E-2	0.710E-2	0.140E-1	0.245E-3
C x K	16	0.194E-1	0.506E-2	0.304E-1	0.113E-3
C x Na	16	0.185E-1	0.653E-2	0.136E1	0.122E-3
Error (a)	81	0.187E-1	0.962E-2	0.291E-1	0.140E-3
Harvest time(T)	1	0.274E+0**	0.337E+0**	0.256E-2	--------
C x T	8	0.889E-1*	0.368E-1**	0.114E+0*	--------
K x T	2	0.457E-1	0.455E-2	0.532E-1	--------
Na x T	2	0.542E-1	0.814E-2	0.104E+0	--------
Error (b)	81	0.357E-1	0.713E-2	0.482E-1	--------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
,* Significant at 0.05 and 0.01 probability level, respectively.
‡ For more details see Table 86 in Appendix C.

leaf Ca concentration in the MxM, NxN, and WxW crosses was 1.70, 1.94, and 1.64 $mmol_c\ g^{-1}$ (Table 33). The stem Ca concentration of cross NxN (0.55 $mmol_c\ g^{-1}$) varied significantly between MxM (0.56 $mmol_c\ g^{-1}$) and WxW (0.46 $mmol_c\ g^{-1}$) crosses. The MxM cross varied significantly with WxW cross in their root Ca concentration, with MxM having higher concentration (0.11 $mmol_c\ g^{-1}$) than WxW (0.09 $mmol_c\ g^{-1}$) (Table 33).

The shoots of NxN cross accumulated more Ca than the shoots of the WxW cross, indicating variability among the crosses in their Ca composition.

The K and Na showed no significant influence on leaf and stem Ca concentrations, but showed a decreasing trend with increase in soil K.

Calcium concentration in roots was significantly increased by soil K (Table 33). In roots, it rose from 0.09 to 0.10 $mmol_c\ g^{-1}$ when K increased from K1 to K2, with no further increase in Ca concentration when K increased from K2 to K3 (Table 33). The increase in root Ca with K fertilization did not have any significant influence on Ca composition of alfalfa shoots.

With increase in harvest time from second to the fifth harvest, Ca in leaves increased significantly from 1.60 to 1.84 $mmol_c\ g^{-1}$, respectively (Table 32). In contrast, Ca in stems dropped significantly (from 0.60 to 0.42 $mmol_c\ g^{-1}$) from second to the fifth harvest without having any significant influence on the Ca concentration in shoots over time. An increase of 3% was observed in Ca concentration in shoots with time.

The above results indicate that Ca concentration in leaves increased and in stems decreased with increase in time. The 15% increase in Ca concentration in leaves (Table 33) was thought to be correlated to 36% drop in K concentration in leaves with time (Table 25), thus increasing translocation of Ca to the leaves with decreasing concentration in stems. Dow and James (1970) reported that, with decrease in K concentration in alfalfa tissue, there was a marked increase in Ca concentration.

Ca:Mg Ratio

According to Tables 35 and 36, the Ca:Mg ratio in leaves, stems, and shoots was significantly influenced by cross. The Ca:Mg ratio in leaves and shoots and stems varied significantly with harvest time and C x T, respectively.

Significant variations in Ca:Mg ratios in all plant components were observed among MxM (1,2), NxN (4), and WxW (7-9) crosses. According to Table 35, a high Ca:Mg ratio (4.79) was observed in the MxM cross as compared to NxN (4.42) and WxW (4.62) crosses. Similarly, a significant trend was observed in stems, with ratios of 2.73, 2.15, and 2.53 for MxM, NxN, and WxW crosses, respectively. Roots showed the same trend where MxM cross had the highest significant Ca:Mg ratio of 0.83, with cross NxN and WxW having ratios of 0.58 and 0.66, respectively.

Table 35. Mean Ca:Mg ratio of alfalfa leaves, stems, and roots as influenced by cross, K, Na, and harvest time.

Independent variable	Level	Leaves	Stems	Roots
Cross†	MxM (1,2)	4.79	2.73	0.83
	NxM (3)	5.06	2.35	0.75
	NxN (4)	4.42	2.15	0.58
	NxW (5)	4.43	2.61	0.70
	WxN (6)	4.19	2.53	0.79
	WxW (7-9)	4.68	2.53	0.66
K‡ (g pot^{-1})	K1	4.42	2.35	0.61
	K2	4.71	2.55	0.73
	K3	4.78	2.66	0.81
Na§ (g pot^{-1})	Na1	4.65	2.47	0.67
	Na2	4.66	2.52	0.72
	Na3	4.59	2.58	0.75
Harvest	Second	4.15	2.56	----
	Fifth	5.12	2.48	0.72

† Group means of similar parents; ‡K1 = 0.0, K2 = 0.8, K3 = 1.6; §Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.

¶For more details see Tables 74, 75, 76, and 77 in Appendix B.

Table 36. Analysis of variance for Ca:Mg ratio in alfalfa leaves, stems, shoots (leaves+ stems), and roots as influenced by cross, K, Na, and harvest time.

Source	DF	MS			
		Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.221E+0**	0.446E+0**	0.146E+0**	0.137E-1
1 vs 2	1	0.259E+0	0.196E+1**	0.146E+0	0.144E-1
1 2 vs 4	1	0.329E+1**	0.794E+1**	0.94E+1**	0.750E+0**
1 2 vs 7 8 9	1	0.492E+0**	0.159E+1**	0.675E+0**	0.700E+0**
3 vs 5	1	0.714E+1**	0.122E+1**	0.045E+0	0.225E-1
6 vs 5	1	0.104E+1**	0.115E+0	0.113E+1**	0.729E-1*
7 8 9 vs 4	1	0.187E+1**	0.397E+1**	0.212E+1**	0.662E-1*
7 vs 8	1	0.520E+0**	0.259E+0	0.794E+0**	0.324E-1
7 8 9 vs 6	1	0.657E+1**	0.300E-3	0.183E+1**	0.265E+0**
Potassium(K)	2	0.387E-1	0.563E-1	0.710E-1	0.815E-1**
Sodium(Na)	2	0.326E-1	0.384E-1	0.345E-1	0.271E-2
K x Na	4	0.521E-1	0.203E+0	0.603E-1	0.116E-1
C x K	16	0.509E-1	0.113E+0	0.389E-1	0.145E-1
C x Na	16	0.476E-1	0.179E+0	0.557E-1	0.611E-2
Error (a)	81	0.688E-1	0.152E+0	0.528E-1	0.117E-1
Harvest time(T)	1	0.705E+1**	0.145E-1	0.408E+1**	--------
C x T	8	0.112E+0	0.344E+0*	0.102E+0	--------
K x T	2	0.539E-1	0.426E-2	0.520E-2	--------
Na x T	2	0.980E-1	0.979E-2	0.235E-1	--------
Error (b)	81	0.841E-1	0.135E+0	0.551E-1	--------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.

,* Significant at 0.05 and 0.01 probability levels, respectively.

‡ For more details see Table 87 in Appendix C.

The above data indicate that cross MxM had the highest Ca:Mg ratio in shoots compared to NxN and WxW crosses. The MxM cross accumulated less Mg (0.56 $\text{mmol}_c\ g^{-1}$ in shoots) and moderate Ca (2.26 $\text{mmol}_c\ g^{-1}$) giving high Ca:Mg ratio, while cross NxN accumulated more Mg (0.69 $\text{mmol}_c\ g^{-1}$) and Ca (2.49 $\text{mmol}_c\ g^{-1}$) giving low ratios. These variations in Ca:Mg ratios among the alfalfa crosses indicate differences in their ability to accumulate Mg and Ca, which was thought to be governed by plant genetics.

Potassium fertilization significantly influenced Ca:Mg ratio in root alone (Table 36). Data in Table 35 indicate that with increase in K from K1 to K2, Ca:Mg ratio in roots increased from 0.61 to 0.73 (a 20% increase). With further increase in K from K2 to K3, the ratio increased significantly by 0.08 (a 11% increase). Increase in soil K, increased Ca concentration in roots (Table 33), hence increasing its Ca:Mg ratio.

Calcium:Magnesium ratio in leaves was significantly influenced by harvest time, with only C x T interaction being significant for stems (Table 36). Increase in time from second to the fifth harvest, Ca:Mg ratio increased from 4.15 to 5.12, respectively (Table 35). This increase in Ca:Mg ratio over time, was thought to be due to the increase in Ca concentration in plant tissue (Table 33).

To further evaluate the mineral interrelationships in alfalfa shoots and roots, partial correlation coefficients were calculated (Table 37).

Table 37. Estimates of partial correlations among mineral concentrations in shoots and roots of alfalfa as influenced by harvest time. ($\underline{n}$ = 162)

Partial correlation	Shoot		Root
	Harvest		
	Second	Fifth	
$r_{Na,K\ .\ Mg,Ca}$	-0.389**	-0.438**	-0.319**
$r_{Na,Mg\ .\ K,Ca}$	0.032	-0.088	0.366**
$r_{Na,Ca\ .\ K,Mg}$	0.057	0.077	-0.283**
$r_{K,Mg\ .\ Na,Ca}$	-0.092	-0.286**	0.156
$r_{K,Ca\ .\ Na,Mg}$	0.062	0.155	0.079
$r_{Mg,Ca\ .\ Na,K}$	0.816**	0.893**	0.137

** Significant at 0.01 probability levels, respectively.

A statistically significant negative correlation was observed between Na and K in shoots during the two harvest times. Potassium was negatively correlated with Mg at the fifth harvest. A high positive correlation existed between Mg and Ca throughout experiment (Table 37).

In roots Na and K, and Na and Ca were negatively correlated, with significant positive correlation between Na and Mg (Table 37).

The results indicate that, with increase in soil K, the Na concentrations decreased in alfalfa tissue during the second harvest. The decrease in plant K content due to the decrease in soil K during the fifth harvest resulted in an increase in Na and Mg uptake. The Ca had a synergistic effect on Mg during both the harvest. In roots, with decrease in K concentration, Na concentration increased and Na having a synergistic effect on Mg and antagonistic effect on Ca.

Based on the above results it was concluded that K affected the concentrations of both monovalent and divalent cations, and higher concentrations of K led to lower concentrations of other cations (Na and Mg).

K Utilization Efficiency

Efficiency of K absorption and the utilization efficiency of absorbed K are the important factors related to plant biomass production in relation to K supply. The K utilization efficiency (KUE) of alfalfa crosses grown on low K soil (i.e. without K treatments) as influenced by Na treatments was calculated. The approach of Siddiqi and Glass (1981) was used to calculate the KUE, expressed as g^2 $mmol^{-1}$, which takes into account tissue concentration and given more weight to the yield component.

The treatment means and analysis of variance for KUE is given in Tables 38 and 39, which show that KUE was significantly influenced by cross, Na, time, and the interactive effects of C x T and N x T.

The mean KUE values in Table 38 are shown with and without Na soil treatments. The crosses NxW and WxN had higher KUE values of 71.85 and 65.13 g^2 $mmol^{-1}$, respectively, with cross NxN having the lowest KUE value of 31.16 g^2 $mmol^{-1}$ (Table 38) when no Na was added to low K soil.

Table 38. Mean shoot Na concentrations, biomass, and KUE of alfalfa crosses grown under low K soil with 0.0, 0.5 1.0 g Na per pot.

Independent Variable	Level	Shoot Na ($mmol_c$ g^{-1})	Shoot Biomass (g pot^{-1})	KUE (g^2mmol^{-1})
			0.0 g Na pot^{-1}	
Cross†	MxM (1,2)	0.059	14.32	52.92
	NxM (3)	0.041	15.00	55.54
	NxN (4)	0.039	9.30	31.16
	NxW (5)	0.050	17.33	71.85
	WxN (6)	0.029	16.47	65.13
	WxW (7-9)	0.045	13.01	59.13
Mean		**0.044**	**14.24**	**55.96**
			0.5 g Na pot^{-1}	
	MxM (1,2)	0.142	16.68	67.92
	NxM (3)	0.093	13.30	45.74
	NxN (4)	0.063	13.48	45.56
	NxW (5)	0.064	16.03	60.41
	WxN (6)	0.048	17.68	67.67
	WxW (7-9)	0.063	14.15	50.12
Mean		**0.079**	**15.22**	**56.24**
			1.0 g Na pot^{-1}	
	MxM (1,2)	0.180	15.09	58.14
	NxM (3)	0.085	14.73	52.95
	NxN (4)	0.117	7.22	29.25
	NxW (5)	0.092	15.47	58.88
	WxN (6)	0.051	17.70	61.45
	WxW (7-9)	0.098	13.47	47.03
Mean		**0.104**	**13.95**	**51.28**

†Group means of similar parents.

Table 39. Analysis of variance for KUE as influenced by alfalfa cross, Na, and harvest time.

Source	DF	MS
Cross (C)†	8	0.522E+3*
1 vs 2	1	0.545E+0
1 2 vs 4	1	0.101E+4*
1 2 vs 7 8 9	1	0.575E+1
3 vs 5	1	0.525E+3
6 vs 5	1	0.470E+1
7 8 9 vs 4	1	0.101E+4*
7 vs 8	1	0.139E+4**
7 8 9 vs 6	1	0.383E+3
Sodium (Na)	2	0.668E+3*
C x Na	16	0.836E+2
Error (a)	27	0.179E+3
Harvest time (T)	1	0.174E+5**
C x T	8	0.474E+3*
Na x T	2	0.695E+3*
C x Na x T	16	0.887E+2
Error (b)	81	0.187E+3
Total	107	0.203E+5

† Cross: 1-M1xM1, 2-M1xM2, 3-N1xM2, 4-N2xN2, 5-N4xW3, 6-W1xN4, 7-W1xW3, 8-W3xW3, 9-W4xW4.

*,** Significant at 0.05 and 0.01 probability levels, respectively.

With the addition of 0.5 g Na pot^{-1} KUE increased in MxM, NxN, and WxN crosses while KUE decreased in the remaining crosses. The highest KUE values were observed for crosses MxM and WxN (Table 38). The magnitude of increase in KUE in the presence of Na for crosses MxM and NxN were 28 and 46%, respectively.

The above results indicate that the crosses NxW and WxN were the most K efficient in the absence of added Na when grown in low K soil. In the presence of added Na, crosses MxM and NxN were the most efficient in utilizing K. Figdore et al. (1989) reported differences in tomato strains in K efficiency with and without added Na. These differences in tomato varieties were thought to be under genetic control.

Potassium utilization efficiency (KUE) of crosses MxM and NxN increased with increase in soil Na from 0.0 to 0.5 g pot^{-1} (Figure 5). With further application of 1.0 g Na pot^{-1}, there was a decrease in biomass production which reduced the KUE values for all the crosses with the exception of cross NxM (Table 38).

Sodium concentration in all the alfalfa crosses increased with increase in Na levels from 0.0 to 0.5 to 1.0 g pot^{-1} (Figure 6). An increase in biomass production was observed for all the crosses, with the exception of NxM and NxW upon the addition of 0.5 g Na pot^{-1} (Table 38). With the Na2 (0.5 g Na pot^{-1}) treatment the highest Na content and biomass increase was observed in the MxM cross (Table 38).

Considering the overall treatment means (Table 40),

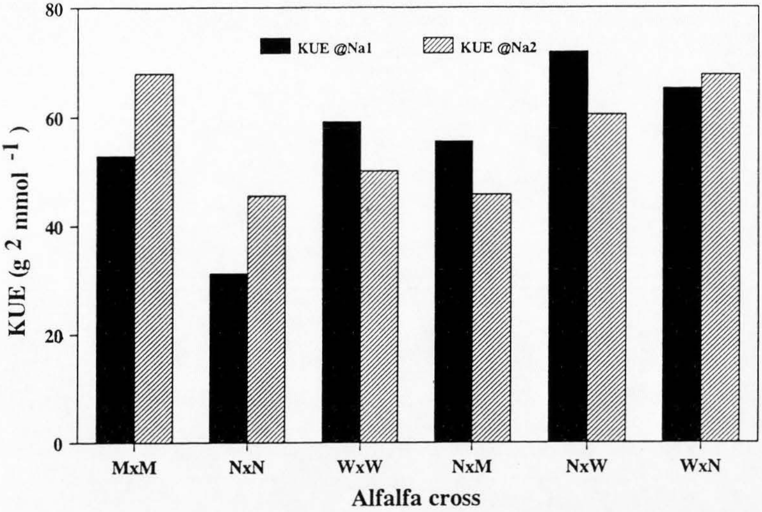

Figure 5. Influence of Na treatments on KUE of alfalfa crosses grown on low K soil. (Na1 = 0.0 Na g pot^{-1}, Na2 = 0.5 g Na pot^{-1}). Mean of 2nd and 5th harvest.

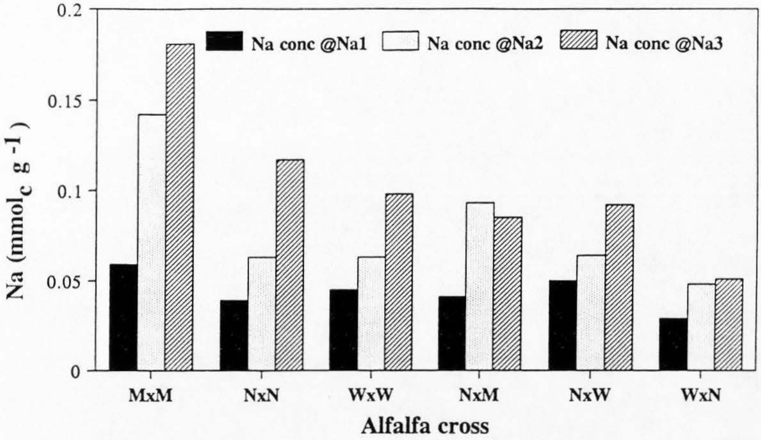

Figure 6. Influence of Na treatments on Na concentration of shoots of alfalfa crosses grown on low K soil. (Na1 = 0.0 Na g pot^{-1}, Na2 = 0.5 g Na pot^{-1}, Na3 = 1.0 g Na pot^{-1}). Mean of 2nd and 5th harvest.

Table 40. Mean shoot K and Na concentrations, biomass, and KUE of alfalfa as influenced by cross, Na, and harvest time.

Independent variable	Level	Shoot			KUE
		K	Na	Biomass	($g^2 mmol^{-1}$)
		-$mmol_c$ g^{-1}-		($g\ pot^{-1}$)	
Cross†	MxM (1,2)	0.35	0.127	15.37	59.66
	NxM (3)	0.40	0.073	14.34	51.41
	NxN (4)	0.45	0.073	10.66	35.32
	NxW (5)	0.40	0.069	16.27	63.71
	WxN (6)	0.39	0.043	17.28	64.75
	WxW (7-9)	0.39	0.069	13.54	49.72
Na‡($g\ pot^{-1}$)	Na1	0.36	0.046	13.97	53.94
	Na2	0.41	0.082	15.44	56.17
	Na3	0.39	0.111	14.19	51.10
Harvest	Second	0.53	0.084	6.03	12.22
	Fifth	0.25	0.075	22.84	95.25

†Group means of similar parents; ‡Na1 = 0.0, Na2 = 0.5, Na3 = 1.0.

§ For more details see Table 78 in Appendix B.

significant differences were observed for KUE between NxN and MxM and WxW crosses. The lowest KUE of 35.32 g^2 $mmol^{-1}$ was observed for the NxN cross, with crosses NxW and WxN showing the highest KUE, 63.71 and 64.75 g^2 $mmol^{-1}$, respectively.

With Na application from 0.0 (Na1) to 0.5 (Na2) g pot^{-1}, KUE values significantly increased from 53.94 to 56.17 g^2 $mmol^{-1}$, which was equivalent to a 4% increase (Table 40). With further increase in Na level of 1.0 g pot^{-1} (Na3), KUE value fell to 51.10 g^2 $mmol^{-1}$ (a decrease of 9%).

From second to fifth harvest, KUE values increased from 12.22 to 95.25 g^2 $mmol^{-1}$, which was equivalent to an increase of 678 percent.

From the above results, it was concluded that variations did exist among the alfalfa crosses in their K utilization efficiency. The initial increase in KUE values with increase in Na levels was thought to be due to partial replacement of K by Na with increased biomass accumulation. The later decrease in KUE value was attributed to the adverse effect of high Na level (Na3) on biomass accumulation. Because of the magnitude of increase in KUE, biomass production and Na accumulation in the MxM and NxN crosses, it was concluded that there was a partial substitution of Na for K in these crosses. Figdore et al. (1985) working with five tomato strains, observed strain differences for the ability to substitute Na for K under K deficiency stress. Woodend et al. (1985) reported genetic variation in the uptake and utilization of K in wheat varieties grown under K stress.

The increase in KUE value with time was attributed to 53% drop in K tissue concentration and 279% increase in biomass production (Table 40). It was concluded that the differences among crosses in K utilization efficiency was more related to the variation in shoot biomass produced. The crosses NxW and WxN having higher K utilization efficiency (Table 40) were also more efficient in their water use (Table 22), indicating that K was utilized efficiently in improving the WUE.

SUMMARY AND CONCLUSIONS

Three greenhouse experiments with alfalfa (Medicago sativa L.) grown on low K soil were conducted at the Utah State University Research Greenhouse Facility from 1988 to 1990.

The first experiment was conducted to study the partitioning and broad sense heritability of K and Na between leaves and stems of three phenotypes of alfalfa obtained from a K-deficient field in Davis county, Utah, were grown on low K soil. The three phenotypes were the plants deficient in K and which exhibited normal appearing leaflets, classical white spot K deficiency symptom on leaflets, and marginal chlorotic K deficiency symptom on leaflets. In the second experiment, the partitioning of K and Na in leaves, stems, and roots as influenced by 32 alfalfa crosses obtained from diallel crossing of the three phenotypes of alfalfa grown on low K soil was studied. The third experiment was conducted with nine crosses grown on low K soil with three K and Na levels (9 x 3 x 3 factorial). The influence of these factors on transpiration; biomass production; water use efficiency (WUE); K, Na, Mg, and Ca composition in leaves, stems, and roots; and potassium utilization efficiency (KUE) were studied.

Results of these experiments are summarized and conclusions derived from them are as follows:

Experiment 1

Three alfalfa phenotypes were selected from the field which exhibited

1) Normal appearing leaflets (N),
2) Classical white spot K deficiency symptoms on leaflets (W), and
3) Marginal chlorotic K deficiency symptoms on leaflets (M).

The three alfalfa phenotypes were reproduced vegetatively on low K soil to evaluate their K and Na composition in leaves and stems. Broad sense heritability (H) estimates were calculated for K and Na traits in leaves and stems.

No differences were observed in leaf and stem K compositions among the three alfalfa phenotypes. Phenotype M accumulated more Na in its leaves as compared to phenotype N and W with no variation between the latter two in their leaf Na composition. The phenotypes M, N, and W showed no variation in their stem Na concentrations. A high Na:K ratio was observed in leaves of phenotype M. All the phenotypes accumulated more K in leaves with lower concentrations in stems. The phenotype M accumulated higher levels of Na in leaves than stems in contrast to phenotypes N and W which had high and low Na in stems and leaves, respectively. High broad sense heritability (H) estimates of 96% and 97% were obtained for the Na trait in leaves and stems, with lower estimates of 86% and 50% for K concentration in leaves and stems, respectively.

The following conclusions were derived from this experiment:

1) The varying traits shown by phenotypes M, N, and W to accumulate and translocate Na within the plant are governed by plant genetics rather than the direct effect of K availability.
2) Significant genetic diversity is present among alfalfa phenotypes from a single cultivar, in their accumulation and partitioning of Na within the plant.
3) The sodium accumulation in leaves and stems of alfalfa is highly heritable trait in the broad sense.

Experiment 2

Thirty two alfalfa crosses obtained from diallel crossing of five mother plants from each of the three alfalfa phenotypes were grown in low K soil. The data obtained from the third and fifth harvest were; K and Na composition and Na:K ratios in leaves, stems, shoots, and roots, respectively.

Potassium and Na concentration in shoots were significantly influenced by cross (C), harvest time (T), and the C x T interactive effect. High and low K concentrations in shoots were observed in crosses NxN and MxN, respectively. No significant differences were observed in K concentrations in roots among the cross comparisons made using contrasts. Potassium concentration in shoots increased significantly from third to fifth harvest. In all the crosses, leaves had higher

K concentrations with lower concentrations in stems and least in roots.

Significant variations in Na concentrations in shoots were observed among crosses. Crosses MxM, MxN, and MxW had high Na concentrations in shoots, with leaves accumulating more Na with decreasing amounts in stems and roots. In contrast, crosses NxN, NxW, and WxN had low Na concentrations in shoots with more Na accumulated in their roots with lower and least amounts in stems and leaves. Sodium concentrations in leaves, stems, and shoots decreased from third to the fifth harvest. The decrease in Na concentrations with time were thought to be due to the increase in K concentrations in the plants. Similar trends were observed for Na:K ratios in all the components.

The following conclusion was derived from this experiment: Significant genetic diversity is present among the alfalfa crosses from a single cultivar, in the ability to accumulate and translocate Na in the plant when grown on low K soil.

Experiment 3

A greenhouse experiment was conducted to study the effects and interactions of alfalfa crosses, and soil K and soil Na amendments on transpiration; biomass; and elemental composition of leaves, stems, and roots. Data were collected also on plant water use efficiency (WUE) and potassium utilization efficiency (KUE).

Transpiration varied significantly among crosses and harvest time with no effect of K and Na treatments. Crosses

MxM and NxN had the highest and lowest transpiration, respectively. The transpiration increased with time which was thought to be caused by increase in radiation and temperature in the greenhouse which were influenced by the change in outside weather and also with the increased leaf surface area.

Biomass of leaves and stems was significantly influenced by cross (C), K, harvest time (T), and the interactive effects of C x T and K x T. Biomass production varied significantly among crosses, with crosses MxM, NxW, and WxN producing more leaf and stem biomass as compared to crosses NxN, WxW, and NxM. High and low root biomass was observed for cross MxM and NxN, respectively. In response to K fertilization and harvest time, biomass production of leaves and stems increased with stems showing greater response than leaves. The increase in biomass production with time was thought to be the result of increased root growth thus increasing water and nutrient uptake and also a larger plant crown with more buds producing stems.

Water use efficiency (WUE) varied significantly among crosses with crosses NxW and NxN being the most and least efficient in their water use, respectively. As time progressed, WUE increased significantly due to larger and more efficient leaf surface area with increase in plant biomass.

Potassium was the second highest element present in the alfalfa plants grown on calcareous soil. Among the alfalfa components, stems accumulated more K followed by leaves and roots. Potassium in leaves, stems, and roots was significantly influenced by cross, soil K, and harvest time. High K concentrations in leaves, stems, and roots were observed in cross NxN with cross MxM accumulating the least K in leaves and stems. The K concentration in leaves, stems, and roots increased in response to increasing soil K levels with roots showing a high magnitude of K accumulation as compared to leaves and stems. The rate of K accumulation by alfalfa plants fell at higher soil K levels. Sodium treatments had no significant effect on K composition of alfalfa components although there was a trend to increase K concentration with Na application. With increase in harvest time, K concentration in leaves and stems fell significantly with stems showing a high magnitude of decrease in their K concentration.

Sodium was the least accumulated cation in the alfalfa plants. Among the alfalfa components, Na had the lowest concentration in leaves and highest in stems and roots. Significant variations were observed among crosses in their Na concentration in leaves, stems, and roots. High Na concentration in leaves was observed for cross MxM, with least concentration in the roots. In contrast, Na was accumulated more in roots and less in leaves of NxN and WxW crosses. The results also indicate that cross MxM accumulated more Na in contrast to its low K concentration.

In response to fertilizer K, Na concentration in stems and roots fell significantly. With Na fertilization, Na concentrations in stems and roots increased significantly. With increase in harvest time, Na concentrations in leaves remained unchanged with a significant decrease in stem Na concentrations.

Sodium:potassium ratios varied among crosses with cross MxM and WxN having the highest and lowest ratios in leaves, respectively. Highest and lowest root Na:K ratios were observed in WxW and MxM crosses, respectively. In response to K fertilization, Na:K ratios in stems and roots decreased significantly, with roots showing a higher magnitude of decrease than stems. Sodium treatments significantly increased Na:K ratio in roots. With increase in harvest time, Na:K ratios in leaves and stems increased, indicating an increase in Na uptake with decrease in K concentrations.

Magnesium concentrations were highest in leaves with lower and least concentrations in stems and roots, respectively. Stem was the only plant component where the Mg concentration was significantly influenced by cross and harvest time. Among the crosses, NxN cross had higher Mg concentrations in all their components. Potassium and Na soil treatments had no significant influence on Mg concentrations in alfalfa components. From second to the fifth harvest, Mg concentrations in all the alfalfa components fell significantly.

Calcium had the highest elemental concentration in alfalfa plants. Calcium concentrations in leaves, stems, and roots varied significantly among crosses. Only calcium concentration in the roots was significantly increased with the first K application level with no further increase with the highest fertilizer K level. Calcium concentration in leaves and stems, increased and decreased, respectively, with no significant influence on shoot Ca concentration. Significant variations were observed in Ca:Mg ratios in all plant components among the crosses, with K significantly increasing Ca:Mg ratio in roots.

A statistically significant negative correlation was found between Na and Mg in shoots. A high positive correlation existed between Mg and Ca throughout the experiment. In roots, significant negative correlations were observed between Na and K and Na and Ca, with significant positive correlation between Na and Mg.

Potassium utilization efficiency varied significantly among crosses both with and without added Na. In the absence of applied Na, the cross NxW and its reciprocal had high KUE values with NxN cross having a lower KUE value. In the presence of applied Na, cross MxM and NxN were the most efficient in utilizing K. With the increase in Na from Na1 to Na2 level, KUE increased significantly, indicating partial Na substitution for K in MxM and NxN crosses. With further increase in Na level to Na3, Na concentrations in shoots increased and shoot biomass and KUE decreased. Potassium utilization efficiency increased with increase in harvest time, which was attributed to increase in biomass production and decrease in K concentration with time.

The conclusions derived from this experiment are as follows:

1) Significant genetic variation is present among the alfalfa crosses from a single cultivar in their transpiration rate, biomass production, shoot:root ratio, and water use efficiency.
2) The increase in transpiration with time was thought to be the result of increased temperature and radiation which was influenced by outside weather.
3) Potassium fertilization increased alfalfa yields and the increase in biomass production with time was attributed to the well established root system and the development of larger crown and more buds producing stems.
4) The increase in water use efficiency of alfalfa crosses with time was thought to be caused by an increase in biomass with time.
5) The K, Na, Mg, and Ca accumulation and Na translocation in alfalfa crosses is governed by plant genetics.
6) The fall in K accumulation rates in alfalfa plants at higher soil K levels indicates that soil K was no longer limiting.
7) With increase in harvest time, K concentrations in alfalfa plants were approaching deficiency level indicating a decrease in soil K.
8) With decrease in soil K with time, there was an increase in Na, Mg, and Ca concentration in alfalfa plants.

9) Potassium affected the concentrations of both monovalent and divalent cations, and higher concentrations of K led to lower concentrations of other cations.

10) Genetic variations do exist among alfalfa crosses from a single cultivar in their ability to utilize K efficiently and partially substitute Na for K when grown on low K soil in presence and absence of added Na.

Implications

Since, alfalfa is well known for its genetically heterogenous and heterozygous nature, it was concluded that significant genetic diversity is present among the alfalfa phenotypes and their crosses from a single cultivar in all the traits studied. The trait shown by phenotype M and crosses MxM, MxN, and MxW to accumulate and translocate high Na levels to the leaves was thought to be governed by plant genetics rather than the direct effect of K availability. The alfalfa phenotypes and crosses behaved rather uniformly with respect to K uptake but varied widely in their capability to exclude Na from the shoot. The alfalfa phenotypes and crosses varied in their selectivity between K and Na, with phenotype M and crosses MxM, MxN, and MxW showing selectivity in favor of Na in the shoots with preferential accumulation of Na in leaves.

Within the roots, different cells such as epidermis, endodermis, xylem parenchyma as well as cortical plasmalemma and tonoplast have been thought to have different selectivity for K and Na. In phenotype M and crosses MxM, MxN, and MxW, a high selectivity for Na was thought to be present in the xylem parenchyma from where there was a preferential release of Na to the xylem vessels. Along with high shoot and root biomass which increased leaf surface area, increased transpiration. The high transpiration was thought to translocate Na to the leaves through the transpiration stream helping to maintain low Na concentration in the roots. Also the high Na:K ratios in leaves indicate a preference for Na over K during xylem release. The low Na:K ratio in roots of crosses MxM, MxN, and MxW indicate that the roots were highly selective in K absorption, indicating that there was no selective absorption of Na at the root surface. Since, the cross MxM accumulated less K and more Na without any adverse effect on growth, it was concluded that Na did substitute partially for K which was also proved by increased KUE when Na was added to low K soil.

The other crosses were thought to have an effective Na exclusion mechanisms whereby Na was reabsorbed from the xylem vessel in exchange of K possibly by a Na/K exchange mechanism operating at the plasmalemma of the xylem parenchyma cells. This mechanism was thought to block Na transport to the shoots maintaining low Na concentrations in the leaves and high concentrations in the stems and roots.

Based on the results of variations among the alfalfa phenotype crosses in their K utilization efficiency when grown on low K soil, the possibility exists that alfalfa cultivars could be developed that are more suitable for low K soils based on higher efficiency in their K utilization (which does not involve Na substitution) as related to higher rates of biomass synthesis. The development of K efficient cultivars would also be more suitable to areas where K fertilizers may be too costly or unavailable.

In the field, the phenotype N (normal) exhibited normal leaflets when it was deficient in K. Since, there was a partial replacement of Na for K in cross NxN, it was concluded that exhibition of the normal leaflet was thought to be the effect of Na substitution on overcoming K deficiency stress. The identification and/or development of alfalfa cultivars which use Na as a partial replacement for K in overcoming K deficiency stress in alfalfa should be feasible.

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APPENDIXES

Appendix A: Alfalfa crosses

Table 41. Alfalfa crosses included in the second greenhouse experiment.

♀	♂	MA					NO					WS				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
MA	1	1	2			3						10				
	2	4	5				9									
	3			6												
	4															
	5			7		8										
NO	1		11	12				15							19	
	2			13		14		16		17				20	21	
	3														22	
	4									18		23		24		
	5															
WS	1	25								27				28		
	2			26									29			
	3													30		
	4													31	32	
	5															

Table 42. Alfalfa crosses included in the third greenhouse experiment.

	♂	MA					NO					WS				
♀		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
MA	1	1	2													
	2															
	3															
	4															
	5															
NO	1		3													
	2							4								
	3															
	4													5		
	5															
WS	1									6				7		
	2															
	3													8		
	4														9	
	5															

Appendix B: Means (C x K x Na)

Table 43. Mean potassium(K) and sodium(Na) composition and Na:K ratio in alfalfa leaves(L), stems(S), and shoots (leaves+stems) (L+S) as influenced by alfalfa clones.

Clone	Entry #	K-L	K-S	K-L+S	Na-L	Na-S	Na-L+S	Na:K-L	Na:K-S	Na:K (L+S)
		------------------mmol$_c$ g^{-1}--------------------								
NO	1	0.38	0.27	0.65	0.012	0.024	0.035	0.037	0.092	0.060
	2	0.32	0.26	0.58	0.017	0.036	0.052	0.055	0.144	0.094
	3	0.29	0.25	0.54	0.010	0.019	0.029	0.035	0.078	0.055
	4	0.36	0.29	0.65	0.008	0.034	0.042	0.020	0.125	0.067
	Av	**0.34**	**0.27**	**0.61**	**0.012**	**0.028**	**0.040**	**0.036**	**0.110**	**0.069**
MA	5	0.33	0.27	0.60	0.045	0.021	0.066	0.139	0.076	0.111
	6	0.31	0.29	0.59	0.048	0.026	0.074	0.156	0.092	0.125
	7	0.35	0.26	0.62	0.050	0.036	0.085	0.142	0.137	0.140
	8	0.35	0.29	0.65	0.047	0.026	0.073	0.139	0.094	0.118
	9	0.32	0.29	0.61	0.046	0.023	0.069	0.146	0.081	0.115
	Av	**0.33**	**0.28**	**0.61**	**0.047**	**0.027**	**0.074**	**0.145**	**0.098**	**0.123**
WS	10	0.36	0.29	0.65	0.008	0.018	0.025	0.022	0.061	0.040
	11	0.41	0.28	0.69	0.008	0.023	0.031	0.018	0.085	0.046
	12	0.30	0.24	0.54	0.017	0.036	0.053	0.060	0.156	0.102
	13	0.30	0.26	0.56	0.019	0.032	0.051	0.065	0.127	0.093
	Av	**0.34**	**0.27**	**0.61**	**0.013**	**0.027**	**0.040**	**0.041**	**0.107**	**0.070**

Table 44. Mean K concentration in alfalfa leaves, stems, shoots (leaves+stems), and roots as influenced by cross.

Cross	Leaves	Stems	Shoots	Roots
	----------------mmol$_c$ g-1---------------------			
M1xM1	0.23	0.19	0.42	0.11
M1xM2	0.22	0.20	0.42	0.11
M1xM5	0.23	0.20	0.43	0.12
M2xM1	0.23	0.19	0.41	0.10
M2xM2	0.22	0.19	0.41	0.11
M3xM3	0.26	0.19	0.45	0.12
M5xM3	0.24	0.20	0.44	0.11
M5xM5	0.25	0.24	0.49	0.13
M2xN1	0.22	0.18	0.40	0.10
M1xW1	0.23	0.19	0.42	0.12
N1xM2	0.23	0.19	0.41	0.10
N1xM3	0.24	0.19	0.44	0.11
N2xM3	0.26	0.20	0.46	0.12
N2xM5	0.25	0.21	0.46	0.13
N1xN2	0.25	0.19	0.44	0.12
N2xN2	0.27	0.20	0.47	0.10
N2xN4	0.25	0.22	0.47	0.11
N4xN4	0.25	0.23	0.48	0.11
N1xW4	0.22	0.19	0.41	0.11
N2xW3	0.25	0.21	0.46	0.12
N2xW4	0.24	0.20	0.44	0.11
N3xW4	0.23	0.20	0.43	0.11
N4xW1	0.26	0.23	0.49	0.11
N4xW3	0.25	0.20	0.44	0.11
W1xM1	0.27	0.20	0.46	0.11
W2xM3	0.27	0.19	0.46	0.11
W1xN4	0.24	0.22	0.46	0.11
W1xW3	0.24	0.20	0.43	0.12
W2xW2	0.26	0.21	0.46	0.12
W3xW3	0.23	0.18	0.41	0.11
W4xW3	0.21	0.17	0.38	0.11
W4xW4	0.23	0.20	0.43	0.10
LSD (5%)	**0.02**	**0.01**	**0.02**	**0.01**

Table 45. Mean Na concentration in alfalfa leaves, stems shoots (leaves+stems), and roots as influenced by cross.

Cross	Leaves	Stems	Shoots	Roots
	------------------mmol$_c$ g^{-1}-------------------			
M1xM1	0.097	0.044	0.141	0.024
M1xM2	0.102	0.046	0.148	0.024
M1xM5	0.099	0.050	0.149	0.025
M2xM1	0.103	0.048	0.150	0.021
M2xM2	0.094	0.044	0.138	0.028
M3xM3	0.109	0.068	0.177	0.037
M5xM3	0.103	0.053	0.155	0.022
M5xM5	0.111	0.052	0.163	0.031
M2xN1	0.087	0.049	0.136	0.028
M1xW1	0.075	0.045	0.120	0.027
N1xM2	0.065	0.045	0.111	0.026
N1xM3	0.055	0.056	0.110	0.029
N2xM3	0.034	0.066	0.100	0.054
N2xM5	0.034	0.060	0.094	0.058
N1xN2	0.031	0.064	0.095	0.053
N2xN2	0.034	0.047	0.081	0.079
N2xN4	0.026	0.060	0.085	0.056
N4xN4	0.026	0.059	0.085	0.055
N1xW4	0.041	0.054	0.096	0.039
N2xW3	0.025	0.050	0.075	0.059
N2xW4	0.027	0.052	0.079	0.058
N3xW4	0.021	0.045	0.067	0.043
N4xW1	0.016	0.033	0.049	0.046
N4xW3	0.025	0.050	0.075	0.046
W1xM1	0.032	0.037	0.069	0.044
W2xM3	0.048	0.052	0.100	0.037
W1xN4	0.012	0.039	0.051	0.043
W1xW3	0.017	0.037	0.054	0.034
W2xW2	0.039	0.050	0.089	0.046
W3xW3	0.022	0.050	0.072	0.056
W4xW3	0.035	0.063	0.098	0.058
W4xW4	0.046	0.069	0.115	0.067
LSD (5%)	**0.011**	**0.007**	**0.020**	**0.009**

Table 46. Mean Na:K ratio of alfalfa leaves, stems, shoots (leaves+stems), and roots as influenced by cross.

Cross	Leaves	Stems	Shoots	Roots
M1xM1	0.436	0.241	0.343	0.214
M1xM2	0.464	0.238	0.354	0.221
M1xM5	0.446	0.256	0.356	0.228
M2xM1	0.457	0.264	0.368	0.203
M2xM2	0.423	0.241	0.340	0.261
M3xM3	0.425	0.392	0.404	0.303
M5xM3	0.435	0.283	0.362	0.197
M5xM5	0.447	0.216	0.331	0.240
M2xN1	0.410	0.280	0.348	0.278
M1xW1	0.329	0.252	0.294	0.226
N1xM2	0.296	0.252	0.274	0.256
N1xM3	0.239	0.316	0.267	0.277
N2xM3	0.138	0.358	0.225	0.448
N2xM5	0.140	0.299	0.209	0.457
N1xN2	0.128	0.356	0.221	0.456
N2xN2	0.121	0.239	0.170	0.795
N2xN4	0.101	0.283	0.180	0.495
N4xN4	0.103	0.262	0.176	0.485
N1xW4	0.189	0.315	0.240	0.367
N2xW3	0.099	0.254	0.167	0.517
N2xW4	0.120	0.277	0.186	0.555
N3xW4	0.094	0.227	0.153	0.400
N4xW1	0.060	0.154	0.099	0.433
N4xW3	0.100	0.271	0.171	0.418
W1xM1	0.120	0.195	0.151	0.407
W2xM3	0.183	0.307	0.228	0.335
W1xN4	0.050	0.185	0.112	0.381
W1xW3	0.072	0.207	0.131	0.288
W2xW2	0.153	0.256	0.196	0.379
W3xW3	0.102	0.311	0.185	0.511
W4xW3	0.167	0.386	0.259	0.539
W4xW4	0.198	0.344	0.264	0.673
LSD (5%)	**0.051**	**0.040**	**0.036**	**0.084**

Table 47. Transpiration of alfalfa as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	13.51	15.15	13.72	**14.13**	15.10	14.03	14.12	**14.42**	11.95	8.01	12.03	**10.66**
K2	14.76	16.31	17.21	**16.09**	14.63	14.79	14.98	**14.80**	13.10	13.37	11.30	**11.78**
K3	16.51	14.44	15.69	**15.55**	15.14	13.19	17.20	**15.18**	12.16	9.08	13.68	**11.64**
Av	**14.93**	**15.30**	**15.54**	**15.26**	**14.93**	**14.00**	**15.43**	**14.80**	**12.40**	**10.15**	**12.34**	**11.36**
	N2xN2				**N4xW3**				**W1xN4**			
K1	5.60	7.45	5.82	**6.29**	11.19	8.75	12.04	**10.66**	11.68	11.24	9.68	**10.87**
K2	6.52	7.18	7.48	**7.06**	12.43	11.93	10.41	**11.59**	13.58	12.59	11.27	**12.48**
K3	7.09	6.15	4.92	**6.05**	10.72	11.09	8.09	**9.97**	11.96	12.02	10.13	**11.37**
Av	**6.40**	**6.93**	**6.07**	**6.47**	**11.45**	**10.59**	**10.18**	**10.74**	**12.41**	**11.95**	**10.36**	**11.57**
	W1xW3				**W3xW3**				**W4xW4**			
K1	11.69	11.07	12.75	**11.84**	9.60	9.93	8.26	**9.26**	7.61	9.50	9.29	**8.80**
K2	10.39	13.07	11.48	**11.65**	9.93	10.20	9.72	**9.95**	8.93	9.26	8.93	**9.04**
K3	11.89	11.28	10.13	**11.10**	10.53	8.13	10.09	**9.58**	8.06	8.68	7.42	**8.05**
Av	**11.32**	**11.81**	**11.45**	**11.53**	**10.02**	**9.42**	**9.36**	**9.60**	**8.20**	**9.15**	**8.55**	**8.63**

Table 48. Biomass of alfalfa leaves as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	7.01	9.21	8.89	**8.37**	7.89	8.53	7.70	**8.04**	7.79	6.89	7.62	**7.43**
K2	8.98	10.33	10.81	**10.04**	9.41	10.91	9.30	**9.87**	8.53	10.03	8.26	**8.94**
K3	11.21	9.38	10.00	**10.20**	9.65	9.87	11.77	**10.43**	8.74	8.30	9.03	**8.69**
Av	**9.07**	**9.64**	**9.90**	**9.54**	**8.98**	**9.77**	**9.59**	**9.45**	**8.35**	**8.41**	**8.30**	**8.35**
	N2xN2				**N4xW3**				**W1xN4**			
K1	4.32	6.25	4.07	**4.88**	8.98	8.47	8.06	**8.50**	8.92	9.29	8.80	**9.00**
K2	4.50	5.58	6.01	**5.36**	10.21	9.60	8.87	**9.56**	9.14	9.56	9.25	**9.32**
K3	4.11	4.76	5.74	**4.87**	10.04	10.39	9.02	**9.82**	10.22	10.01	9.37	**9.87**
Av	**4.31**	**5.53**	**5.27**	**5.04**	**9.74**	**9.49**	**8.65**	**9.29**	**9.43**	**9.62**	**9.14**	**9.40**
	W1xW3				**W3xW3**				**W4xW4**			
K1	8.18	8.96	8.98	**8.71**	7.06	6.69	6.19	**6.65**	4.58	6.19	4.93	**5.23**
K2	8.02	9.45	9.17	**8.88**	7.61	7.50	7.59	**7.57**	6.16	6.66	6.03	**6.28**
K3	8.77	8.46	8.45	**8.56**	8.53	7.13	9.49	**8.38**	6.51	6.43	5.77	**6.24**
Av	**8.32**	**8.96**	**.87**	8.72	**7.73**	**7.11**	**7.76**	**7.53**	**5.75**	**6.43**	**5.58**	**5.92**

Table 49 . Biomass of alfalfa stems as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	6.63	7.96	6.49	**7.03**	7.11	7.66	7.13	**7.30**	7.20	6.41	7.11	**6.91**
K2	8.07	9.07	9.02	**8.72**	8.91	10.00	8.74	**9.22**	8.83	9.96	8.41	**9.07**
K3	9.89	8.43	8.71	**9.01**	8.95	10.21	11.29	**10.15**	9.21	8.55	9.43	**9.06**
Av	**8.20**	**8.49**	**8.07**	**8.25**	**8.32**	**9.29**	**9.05**	**8.89**	**8.41**	**8.31**	**8.32**	**8.35**
	N2xN2				**N4xW3**				**W1xN4**			
K1	4.97	7.23	5.15	**5.78**	8.35	7.55	7.41	**7.77**	7.55	8.38	8.91	**8.28**
K2	5.32	7.03	6.93	**6.43**	10.12	9.38	9.33	**9.61**	9.17	9.38	8.71	**9.09**
K3	4.99	6.63	6.90	**6.17**	11.00	10.86	9.28	**10.38**	10.48	10.53	9.02	**10.01**
Av	**5.09**	**6.96**	**6.33**	**6.13**	**9.82**	**9.26**	**8.67**	**9.25**	**9.07**	**9.43**	**8.88**	**9.13**
	W1xW3				**W3xW3**				**W4xW4**			
K1	8.73	7.69	8.53	**8.32**	6.28	6.51	6.18	**6.32**	4.22	6.41	5.60	**5.41**
K2	8.06	9.00	9.01	**8.69**	8.60	8.25	8.76	**8.54**	6.50	6.91	6.56	**6.66**
K3	9.60	8.71	8.18	**8.83**	9.28	7.12	9.76	**8.72**	8.46	7.19	6.49	**7.38**
Av	**8.80**	**8.47**	**8.57**	**8.61**	**8.05**	**7.29**	**8.23**	**7.86**	**6.39**	**6.84**	**6.22**	**6.48**

Table 50. Biomass of alfalfa shoots (leaves+stems) as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	13.64	17.17	15.36	**15.39**	15.00	16.19	14.82	**15.34**	14.99	13.29	14.73	**14.34**
K2	17.04	19.39	19.83	**18.75**	18.32	20.91	18.04	**19.09**	17.35	19.99	16.67	**18.00**
K3	21.10	17.81	18.71	**19.21**	18.60	20.08	23.06	**20.58**	17.95	16.84	18.46	**17.75**
Av	**17.26**	**18.12**	**17.97**	**17.78**	**17.31**	**19.06**	**18.64**	**18.34**	**16.76**	**16.71**	**16.62**	**16.70**
	N2xN2				**N4xW3**				**W1xN4**			
K1	9.30	13.48	9.22	**10.67**	17.33	16.02	15.45	**16.27**	16.47	17.68	17.70	**17.28**
K2	9.82	12.61	12.94	**11.79**	20.33	18.98	18.20	**19.17**	18.30	18.94	17.96	**18.40**
K3	9.10	11.39	12.64	**11.04**	21.04	21.25	18.30	**20.20**	20.70	20.54	18.38	**19.87**
Av	**9.41**	**12.49**	**11.60**	**11.17**	**19.57**	**18.75**	**17.32**	**18.55**	**18.49**	**19.05**	**18.01**	**18.52**
	W1xW3				**W3xW3**				**W4xW4**			
K1	16.91	16.65	17.51	**17.02**	13.34	13.20	12.37	**12.97**	8.80	12.61	10.53	**10.65**
K2	16.08	18.45	18.19	**17.57**	16.21	15.74	16.36	**16.10**	12.66	13.57	12.59	**12.94**
K3	18.37	17.17	16.63	**17.39**	17.81	14.24	19.25	**17.10**	14.97	13.62	12.26	**13.62**
Av	**17.12**	**17.42**	**17.44**	**17.33**	**15.79**	**14.39**	**15.99**	**15.39**	**12.14**	**13.27**	**11.79**	**12.40**

Table 51. Biomass of alfalfa roots as influenced by cross, K, and Na. Mean of 2 replications (5th cut).

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	10.49	15.06	15.02	**13.52**	16.51	16.40	14.69	**15.87**	14.73	10.77	12.45	**12.65**
K2	17.38	17.11	17.80	**17.43**	16.83	18.13	19.40	**18.12**	15.42	19.72	12.97	**16.04**
K3	21.13	15.84	20.48	**19.15**	19.35	15.96	27.01	**20.77**	16.80	11.74	17.40	**15.31**
Av	**16.33**	**16.00**	**17.77**	**16.70**	**17.56**	**16.83**	**20.37**	**18.25**	**15.65**	**14.08**	**14.27**	**14.67**
	N2xN2				**N4xW3**				**W1xN4**			
K1	3.51	6.58	4.29	**4.79**	10.95	9.33	9.68	**9.99**	10.09	10.93	10.28	**10.43**
K2	4.76	5.95	7.10	**5.94**	13.39	14.35	11.28	**13.01**	14.29	14.63	12.54	**13.82**
K3	4.96	4.09	6.40	**5.15**	12.72	13.55	11.69	**12.65**	13.17	15.37	13.85	**14.13**
Av	**4.41**	**5.54**	**5.93**	**5.29**	**12.35**	**12.41**	**10.88**	**11.88**	**12.52**	**13.64**	**12.22**	**12.79**
	W1xW3				**W3xW3**				**W4xW4**			
K1	10.65	9.39	11.93	**10.66**	8.62	9.20	7.57	**8.46**	4.52	8.42	6.31	**6.42**
K2	11.16	13.99	12.60	**12.58**	8.47	9.71	9.73	**9.30**	5.75	8.68	7.36	**7.26**
K3	13.56	13.36	10.07	**12.33**	12.66	9.75	12.19	**11.53**	5.89	7.65	7.25	**6.93**
Av	**11.79**	**12.25**	**11.53**	**11.86**	**9.92**	**9.55**	**9.83**	**9.76**	**5.39**	**8.25**	**6.97**	**6.87**

Table 52. Shoot:root ratio of alfalfa as influenced by cross, K, and Na. Mean of 2 replications (5th cut).

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	1.92	1.71	1.56	**1.73**	1.35	1.62	1.55	**1.51**	1.56	2.16	1.86	**1.86**
K2	1.53	1.65	1.68	**1.62**	1.71	1.92	1.51	**1.71**	1.73	1.64	2.17	**1.85**
K3	1.57	2.06	1.48	**1.70**	1.55	1.95	1.41	**1.64**	1.80	2.58	1.78	**2.05**
Av	**1.67**	**1.81**	**1.57**	**1.68**	**1.54**	**1.83**	**1.49**	**1.62**	**1.70**	**2.13**	**1.94**	**1.92**
	N2xN2				**N4xW3**				**W1xN4**			
K1	4.39	3.65	3.54	**3.86**	2.67	2.95	2.50	**2.71**	2.44	2.70	2.91	**2.68**
K2	3.54	3.56	3.15	**3.42**	2.45	2.20	2.73	**2.46**	2.09	2.13	2.34	**2.19**
K3	2.75	4.73	3.69	**3.72**	2.83	2.60	2.73	**2.72**	2.68	2.26	2.25	**2.40**
Av	**3.56**	**3.98**	**3.46**	**3.67**	**2.65**	**2.58**	**2.65**	**2.63**	**2.40**	**2.49**	**2.50**	**2.42**
	W1xW3				**W3xW3**				**W4xW4**			
K1	2.52	2.86	2.34	**2.57**	2.48	2.16	2.56	**2.40**	2.84	2.72	2.38	**2.65**
K2	2.31	2.22	2.44	**2.32**	3.10	2.53	2.75	**2.79**	3.37	2.46	2.61	**2.81**
K3	2.14	2.13	2.69	**2.32**	2.34	2.40	2.75	**2.50**	4.50	2.95	2.86	**3.44**
Av	**2.32**	**2.40**	**2.49**	**2.40**	**2.64**	**2.36**	**2.69**	**2.56**	**3.57**	**2.71**	**2.62**	**2.97**

Table 53. Water use efficiency of alfalfa as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	1.90	1.91	1.94	**1.92**	1.96	1.94	1.89	**1.93**	1.97	1.92	1.96	**1.95**
K2	1.88	2.16	2.10	**2.05**	2.00	2.03	1.87	**1.97**	1.94	2.16	1.93	**2.01**
K3	1.99	2.12	1.89	**2.00**	1.90	2.10	1.92	**1.97**	2.02	2.07	1.95	**2.01**
Av	**1.92**	**2.06**	**1.98**	**1.99**	**1.95**	**2.02**	**1.89**	**1.96**	**1.98**	**2.05**	**1.95**	**1.99**
	N2xN2				**N4xW3**				**W1xN4**			
K1	1.92	1.73	1.87	**1.84**	2.06	2.13	2.01	**2.07**	2.20	2.13	1.83	**2.05**
K2	1.94	1.93	1.82	**1.90**	2.18	2.13	2.15	**2.15**	1.99	1.94	2.01	**1.98**
K3	2.00	1.94	1.65	**1.86**	2.15	2.14	2.01	**2.10**	2.16	2.14	1.94	**2.08**
Av	**1.95**	**1.87**	**1.78**	**1.87**	**2.13**	**2.14**	**2.06**	**2.11**	**2.12**	**2.07**	**1.93**	**2.04**
	W1xW3				**W3xW3**				**W4xW4**			
K1	2.21	1.93	1.90	**2.01**	1.96	2.14	2.13	**2.08**	1.79	1.70	1.91	**1.80**
K2	2.05	2.16	2.02	**2.08**	2.23	2.22	2.10	**2.18**	2.20	2.08	2.03	**2.10**
K3	2.11	2.06	2.02	**2.06**	2.17	2.05	2.20	**2.14**	1.85	1.89	1.91	**1.88**
Av	**2.12**	**2.05**	**1.98**	**2.05**	**2.12**	**2.14**	**2.14**	**2.13**	**1.95**	**1.92**	**1.95**	**1.93**

Table 54. K concentration in alfalfa leaves as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	Av	Na1	Na2	Na3	Av	Na1	Na2	Na3	Av
K1	0.35	0.32	0.34	**0.34**	0.30	0.32	0.31	**0.31**	0.34	0.42	0.35	**0.37**
K2	0.43	0.43	0.38	**0.41**	0.41	0.40	0.41	**0.41**	0.44	0.42	0.49	**0.45**
K3	0.50	0.48	0.49	**0.49**	0.49	0.49	0.45	**0.48**	0.52	0.54	0.56	**0.54**
Av	**0.43**	**0.41**	**0.40**	**0.41**	**0.40**	**0.40**	**0.39**	**0.40**	**0.43**	**0.46**	**0.47**	**0.45**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.36	0.40	0.40	**0.39**	0.33	0.39	0.37	**0.36**	0.32	0.39	0.39	**0.37**
K2	0.53	0.54	0.57	**0.55**	0.48	0.50	0.53	**0.50**	0.47	0.49	0.56	**0.51**
K3	0.62	0.63	0.63	**0.63**	0.56	0.55	0.60	**0.57**	0.55	0.59	0.66	**0.60**
Av	**0.50**	**0.52**	**0.53**	**0.52**	**0.46**	**0.48**	**0.50**	**0.48**	**0.45**	**0.49**	**0.54**	**0.49**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.37	0.38	0.39	**0.38**	0.35	0.36	0.39	**0.37**	0.34	0.37	0.37	**0.36**
K2	0.48	0.48	0.53	**0.50**	0.54	0.52	0.56	**0.54**	0.43	0.44	0.44	**0.44**
K3	0.54	0.64	0.59	**0.59**	0.58	0.62	0.59	**0.60**	0.53	0.51	0.52	**0.52**
Av	**0.46**	**0.50**	**0.50**	**0.49**	**0.49**	**0.50**	**0.51**	**0.50**	**0.43**	**0.44**	**0.44**	**0.44**

Table 55. K concentration in alfalfa stems as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	Av	Na1	Na2	Na3	Av	Na1	Na2	Na3	Av
K1	0.46	0.35	0.39	**0.40**	0.41	0.38	0.37	**0.39**	0.40	0.51	0.45	**0.45**
K2	0.49	0.52	0.37	**0.46**	0.51	0.53	0.55	**0.53**	0.49	0.52	0.62	**0.54**
K3	0.56	0.54	0.72	**0.61**	0.57	0.61	0.70	**0.52**	0.81	0.73	0.75	**0.76**
Av	**0.50**	**0.47**	**0.49**	**0.49**	**0.50**	**0.51**	**0.54**	**0.52**	**0.57**	**0.59**	**0.61**	**0.59**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.65	0.53	0.47	**0.55**	0.52	0.44	0.45	**0.47**	0.44	0.46	0.46	**0.45**
K2	0.63	0.75	0.85	**0.74**	0.56	0.54	0.58	**0.56**	0.51	0.56	0.61	**0.56**
K3	0.85	1.03	1.08	**0.99**	0.67	0.62	0.82	**0.70**	0.69	0.83	0.81	**0.78**
Av	**0.71**	**0.77**	**0.80**	**0.76**	**0.58**	**0.53**	**0.62**	**0.58**	**0.55**	**0.62**	**0.63**	**0.60**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.50	0.39	0.43	**0.44**	0.39	0.38	0.40	**0.39**	0.45	0.58	0.43	**0.49**
K2	0.44	0.54	0.52	**0.50**	0.49	0.53	0.58	**0.53**	0.54	0.65	0.57	**0.59**
K3	0.61	0.76	0.67	**0.68**	0.61	0.64	0.64	**0.63**	0.84	0.86	0.84	**0.85**
Av	**0.52**	**0.56**	**0.54**	**0.54**	**0.50**	**0.52**	**0.54**	**0.52**	**0.61**	**0.70**	**0.61**	**0.64**

Table 56. K concentration in alfalfa shoots (leaves+stems) as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.36	0.33	0.37	**0.35**	0.32	0.35	0.34	**0.34**	0.34	0.48	0.39	**0.40**
K2	0.48	0.47	0.37	**0.44**	0.47	0.46	0.48	**0.47**	0.48	0.47	0.56	**0.50**
K3	0.55	0.53	0.59	**0.56**	0.55	0.56	0.56	**0.56**	0.68	0.63	0.67	**0.66**
Av	**0.46**	**0.44**	**0.44**	**0.45**	**0.45**	**0.46**	**0.46**	**0.46**	**0.50**	**0.53**	**0.54**	**0.52**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.46	0.47	0.43	**0.45**	0.36	0.42	0.41	**0.40**	0.32	0.42	0.43	**0.39**
K2	0.61	0.64	0.72	**0.66**	0.54	0.51	0.55	**0.53**	0.50	0.53	0.58	**0.54**
K3	0.76	0.83	0.86	**0.82**	0.63	0.61	0.71	**0.65**	0.63	0.72	0.76	**0.70**
Av	**0.61**	**0.65**	**0.67**	**0.64**	**0.51**	**0.51**	**0.56**	**0.53**	**0.48**	**0.56**	**0.59**	**0.54**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.36	0.40	0.39	**0.38**	0.34	0.37	0.39	**0.37**	0.37	0.47	0.40	**0.41**
K2	0.49	0.49	0.53	**0.50**	0.52	0.52	0.57	**0.54**	0.50	0.55	0.52	**0.52**
K3	0.59	0.72	0.62	**0.64**	0.61	0.63	0.62	**0.62**	0.71	0.66	0.68	**0.68**
Av	**0.48**	**0.54**	**0.51**	**0.51**	**0.49**	**0.51**	**0.53**	**0.51**	**0.53**	**0.56**	**0.53**	**0.54**

Table 57. K concentration in alfalfa roots as influenced by cross, K, and Na. Means of 2 replications. (5th cut).

	M1 x M1				**M1 x M2**				**N1 x M2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.16	0.15	0.17	**0.16**	0.14	0.15	0.16	**0.15**	0.15	0.17	0.15	**0.16**
K2	0.21	0.20	0.20	**0.20**	0.19	0.18	0.21	**0.19**	0.18	0.16	0.18	**0.17**
K3	0.23	0.26	0.25	**0.25**	0.21	0.24	0.21	**0.22**	0.21	0.25	0.21	**0.22**
Av	**0.20**	**0.20**	**0.21**	**0.20**	**0.18**	**0.19**	**0.19**	**0.19**	**0.18**	**0.19**	**0.18**	**0.18**
	N2 x N2				**N4 x W3**				**W1 x N4**			
K1	0.18	0.16	0.19	**0.18**	0.13	0.15	0.19	**0.16**	0.13	0.13	0.13	**0.13**
K2	0.29	0.25	0.24	**0.26**	0.18	0.19	0.19	**0.19**	0.17	0.18	0.17	**0.17**
K3	0.37	0.33	0.30	**0.33**	0.26	0.25	0.27	**0.26**	0.21	0.22	0.24	**0.22**
Av	**0.28**	**0.25**	**0.24**	**0.26**	**0.19**	**0.20**	**0.21**	**0.20**	**0.17**	**0.18**	**0.18**	**0.17**
	W1 x W3				**W3 x W3**				**W4 x W4**			
K1	0.13	0.13	0.14	**0.13**	0.15	0.13	0.15	**0.14**	0.18	0.15	0.14	**0.16**
K2	0.22	0.16	0.21	**0.20**	0.20	0.19	0.18	**0.19**	0.25	0.23	0.23	**0.24**
K3	0.21	0.24	0.27	**0.24**	0.22	0.29	0.24	**0.25**	0.31	0.29	0.29	0.30
Av	**0.19**	**0.18**	**0.21**	**0.19**	**0.19**	**0.20**	**0.19**	**0.19**	**0.25**	**0.22**	**0.22**	**0.23**

Table 58. Na concentration in alfalfa leaves as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	Av	Na1	Na2	Na3	Av	Na1	Na2	Na3	Av
K1	0.081	0.202	0.207	**0.185**	0.087	0.198	0.259	**0.181**	0.041	0.096	0.087	**0.075**
K2	0.046	0.138	0.206	**0.130**	0.046	0.113	0.174	**0.111**	0.017	0.027	0.062	**0.035**
K3	0.035	0.083	0.150	**0.099**	0.033	0.086	0.144	**0.088**	0.016	0.034	0.028	**0.026**
Av	**0.054**	**0.141**	**0.209**	**0.135**	**0.055**	**0.133**	**0.192**	**0.126**	**0.024**	**0.052**	**0.059**	**0.045**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.015	0.035	0.056	**0.035**	0.022	0.017	0.037	**0.025**	0.016	0.011	0.012	**0.013**
K2	0.008	0.019	0.021	**0.016**	0.008	0.016	0.019	**0.014**	0.007	0.010	0.009	**0.009**
K3	0.007	0.014	0.017	**0.013**	0.008	0.012	0.021	**0.014**	0.006	0.007	0.029	**0.014**
Av	**0.010**	**0.023**	**0.031**	**0.021**	**0.012**	**0.015**	**0.025**	**0.018**	**0.009**	**0.009**	**0.016**	**0.011**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.050	0.011	0.038	**0.033**	0.018	0.032	0.061	**0.037**	0.032	0.050	0.089	**0.057**
K2	0.007	0.008	0.008	**0.008**	0.009	0.021	0.021	**0.017**	0.019	0.036	0.049	**0.035**
K3	0.015	0.006	0.006	**0.009**	0.014	0.014	0.022	**0.017**	0.027	0.022	0.054	**0.042**
Av	**0.024**	**0.008**	**0.017**	**0.017**	**0.014**	**0.022**	**0.035**	**0.024**	**0.026**	**0.036**	**0.064**	**0.042**

Table 59. Na concentration in alfalfa stems as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.043	0.060	0.096	**0.666**	0.043	0.065	0.095	**0.068**	0.041	0.080	0.080	**0.067**
K2	0.043	0.042	0.060	**0.048**	0.039	0.042	0.063	**0.048**	0.036	0.036	0.054	**0.042**
K3	0.028	0.028	0.036	**0.031**	0.028	0.021	0.041	**0.030**	0.027	0.034	0.039	**0.033**
Av	**0.038**	**0.043**	**0.064**	**0.048**	**0.037**	**0.043**	**0.066**	**0.049**	**0.067**	**0.050**	**0.058**	**0.047**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.065	0.067	0.166	**0.099**	0.079	0.098	0.131	**0.103**	0.047	0.076	0.084	**0.069**
K2	0.060	0.043	0.087	**0.063**	0.050	0.041	0.046	**0.046**	0.040	0.025	0.038	**0.034**
K3	0.026	0.034	0.078	**0.046**	0.026	0.037	0.051	**0.038**	0.026	0.023	0.049	**0.045**
Av	**0.050**	**0.048**	**0.110**	**0.069**	**0.052**	**0.059**	**0.076**	**0.062**	**0.038**	**0.041**	**0.057**	**0.045**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.043	0.084	0.078	**0.068**	0.060	0.088	0.141	**0.096**	0.066	0.082	0.125	**0.091**
K2	0.057	0.033	0.041	**0.044**	0.053	0.047	0.071	**0.057**	0.066	0.037	0.064	**0.056**
K3	0.027	0.029	0.037	**0.031**	0.042	0.036	0.060	**0.046**	0.041	0.030	0.059	0.043
Av	**0.042**	**0.049**	**0.052**	**0.048**	**0.052**	**0.057**	**0.091**	**0.066**	**0.058**	**0.050**	**0.083**	**0.063**

Table 60. Na concentration in alfalfa shoots (leaves+stems) as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.057	0.139	0.185	**0.127**	0.061	0.143	0.176	**0.127**	0.041	0.093	0.086	**0.073**
K2	0.035	0.092	0.137	**0.088**	0.035	0.082	0.120	**0.079**	0.020	0.034	0.059	**0.038**
K3	0.027	0.055	0.096	**0.059**	0.022	0.055	0.095	**0.057**	0.018	0.034	0.036	**0.029**
Av	**0.040**	**0.095**	**0.139**	**0.091**	**0.039**	**0.093**	**0.130**	**0.088**	**0.026**	**0.054**	**0.060**	**0.047**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.039	0.063	0.117	**0.073**	0.101	0.128	0.184	**0.138**	0.059	0.097	0.103	**0.086**
K2	0.014	0.034	0.057	**0.035**	0.029	0.057	0.072	**0.053**	0.026	0.037	0.057	**0.040**
K3	0.012	0.026	0.047	**0.028**	0.025	0.052	0.074	**0.050**	0.016	0.031	0.085	**0.044**
Av	**0.022**	**0.041**	**0.074**	**0.045**	**0.052**	**0.079**	**0.110**	**0.080**	**0.034**	**0.055**	**0.082**	**0.057**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.047	0.049	0.072	**0.056**	0.039	0.067	0.104	**0.070**	0.048	0.074	0.118	**0.080**
K2	0.015	0.023	0.025	**0.021**	0.017	0.039	0.050	**0.035**	0.020	0.042	0.058	**0.040**
K3	0.018	0.018	0.023	**0.020**	0.021	0.023	0.045	**0.030**	0.031	0.022	0.064	**0.039**
Av	**0.027**	**0.030**	**0.040**	**0.032**	**0.026**	**0.043**	**0.066**	**0.045**	**0.033**	**0.046**	**0.080**	**0.053**

Table 61. Na concentration in alfalfa roots as influenced by cross, K, and Na. Mean of 2 replications. (5th cut).

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.020	0.049	0.054	**0.041**	0.013	0.037	0.047	**0.032**	0.030	0.059	0.070	**0.053**
K2	0.016	0.033	0.046	**0.032**	0.014	0.022	0.029	**0.022**	0.020	0.033	0.026	**0.026**
K3	0.007	0.017	0.021	**0.015**	0.006	0.017	0.020	**0.014**	0.007	0.021	0.020	**0.016**
Av	**0.014**	**0.033**	**0.040**	**0.029**	**0.011**	**0.025**	**0.032**	**0.023**	**0.019**	**0.038**	**0.039**	**0.032**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.096	0.119	0.143	**0.084**	0.048	0.102	0.135	**0.095**	0.047	0.070	0.092	**0.070**
K2	0.036	0.075	0.124	**0.078**	0.035	0.053	0.071	**0.053**	0.027	0.045	0.067	**0.046**
K3	0.021	0.067	0.080	**0.056**	0.011	0.035	0.042	**0.029**	0.011	0.030	0.033	**0.025**
Av	**0.051**	**0.087**	**0.116**	**0.084**	**0.031**	**0.063**	**0.083**	**0.059**	**0.028**	**0.048**	**0.064**	**0.047**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.048	0.103	0.112	**0.088**	0.058	0.120	0.136	**0.105**	0.090	0.096	0.147	**0.111**
K2	0.027	0.059	0.043	**0.043**	0.050	0.082	0.095	**0.076**	0.036	0.073	0.097	**0.069**
K3	0.040	0.040	0.053	**0.044**	0.018	0.033	0.054	**0.035**	0.035	0.027	0.072	0.045
Av	**0.038**	**0.067**	**0.069**	**0.058**	**0.042**	**0.078**	**0.095**	**0.072**	**0.054**	**0.065**	**0.105**	**0.072**

Table 62. Na:K ratio in alfalfa leaves as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.223	0.686	0.867	**0.592**	0.283	0.682	0.904	**0.623**	0.122	0.263	0.307	**0.231**
K2	0.120	0.358	0.564	**0.347**	0.126	0.337	0.457	**0.307**	0.040	0.068	0.134	**0.081**
K3	0.077	0.185	0.317	**0.193**	0.068	0.178	0.336	**0.194**	0.030	0.063	0.045	**0.046**
Av	**0.140**	**0.410**	**0.583**	**0.377**	**0.159**	**0.399**	**0.566**	**0.375**	**0.064**	**0.131**	**0.162**	**0.119**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.039	0.091	0.144	**0.091**	0.068	0.045	0.110	**0.074**	0.050	0.029	0.034	**0.038**
K2	0.016	0.034	0.035	**0.028**	0.017	0.035	0.036	**0.029**	0.013	0.020	0.016	**0.016**
K3	0.012	0.022	0.028	**0.021**	0.014	0.026	0.035	**0.025**	0.010	0.012	0.042	**0.021**
Av	**0.022**	**0.049**	**0.069**	**0.047**	**0.033**	**0.035**	**0.060**	**0.043**	**0.024**	**0.020**	**0.031**	**0.025**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.110	0.028	0.114	**0.084**	0.050	0.092	0.181	**0.108**	0.090	0.148	0.271	**0.170**
K2	0.013	0.015	0.016	**0.015**	0.018	0.046	0.042	**0.035**	0.044	0.087	0.113	**0.081**
K3	0.030	0.010	0.010	**0.017**	0.025	0.021	0.038	**0.028**	0.053	0.046	0.111	**0.070**
Av	**0.051**	**0.018**	**0.074**	**0.039**	**0.031**	**0.053**	**0.087**	**0.057**	**0.062**	**0.094**	**0.165**	**0.107**

Table 63. Na:K ratio in alfalfa stems as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.102	0.286	0.344	**0.244**	0.104	0.318	0.317	**0.246**	0.132	0.223	0.259	**0.205**
K2	0.068	0.133	0.206	**0.136**	0.063	0.137	0.157	**0.119**	0.055	0.095	0.094	**0.081**
K3	0.036	0.049	0.068	**0.051**	0.017	0.040	0.072	**0.043**	0.031	0.046	0.061	**0.046**
Av	**0.069**	**0.156**	**0.206**	**0.144**	**0.061**	**0.165**	**0.182**	**0.136**	**0.073**	**0.121**	**0.138**	**0.111**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.124	0.257	0.446	**0.276**	0.199	0.273	0.472	**0.315**	0.143	0.228	0.262	**0.211**
K2	0.029	0.079	0.113	**0.074**	0.049	0.083	0.108	**0.080**	0.046	0.051	0.091	**0.063**
K3	0.020	0.039	0.066	**0.042**	0.027	0.063	0.068	**0.053**	0.014	0.030	0.068	**0.037**
Av	**0.058**	**0.125**	**0.208**	**0.131**	**0.092**	**0.140**	**0.216**	**0.149**	**0.068**	**0.103**	**0.140**	**0.104**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.140	0.236	0.395	**0.257**	0.165	0.291	0.472	**0.309**	0.162	0.245	0.404	**0.270**
K2	0.061	0.108	0.098	**0.089**	0.056	0.142	0.170	**0.123**	0.042	0.085	0.121	**0.083**
K3	0.038	0.042	0.064	**0.048**	0.047	0.047	0.105	**0.066**	0.040	0.025	0.106	**0.057**
Av	**0.00**	**0.129**	**0.186**	**0.131**	**0.089**	**0.160**	**0.249**	**0.166**	**0.081**	**0.118**	**0.210**	**0.137**

Table 64. Na:K ratio in alfalfa shoots (leaves+stems) as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.159	0.485	0.611	**0.418**	0.186	0.502	0.609	**0.432**	0.126	0.239	0.287	**0.217**
K2	0.093	0.244	0.391	**0.243**	0.091	0.231	0.294	**0.205**	0.047	0.082	0.112	**0.080**
K3	0.055	0.111	0.172	**0.113**	0.040	0.101	0.184	**0.108**	0.030	0.053	0.053	**0.045**
Av	**0.102**	**0.280**	**0.391**	**0.258**	**0.106**	**0.278**	**0.362**	**0.249**	**0.068**	**0.125**	**0.151**	**0.114**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.086	0.168	0.294	**0.183**	0.135	0.159	0.277	**0.190**	0.094	0.127	0.144	**0.122**
K2	0.023	0.058	0.080	**0.054**	0.032	0.059	0.069	**0.053**	0.030	0.036	0.053	**0.040**
K3	0.016	0.032	0.052	**0.033**	0.021	0.047	0.053	**0.040**	0.012	0.022	0.056	**0.030**
Av	**0.042**	**0.086**	**0.142**	**0.090**	**0.063**	**0.088**	**0.133**	**0.094**	**0.045**	**0.062**	**0.084**	**0.064**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.126	0.131	0.234	**0.164**	0.105	0.190	0.316	**0.204**	0.127	0.196	0.338	**0.220**
K2	0.036	0.057	0.054	**0.049**	0.036	0.090	0.103	**0.076**	0.042	0.085	0.117	**0.081**
K3	0.034	0.026	0.038	**0.033**	0.036	0.035	0.073	**0.048**	0.044	0.033	0.103	**0.060**
Av	**0.065**	**0.071**	**0.109**	**0.082**	**0.059**	**0.105**	**0.164**	**0.109**	**0.071**	**0.105**	**0.186**	**0.120**

Table 65. Na:K ratio in alfalfa roots as influenced by cross, K, and Na. Mean of 2 replication. (5th cut).

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.124	0.323	0.320	**0.256**	0.093	0.250	0.293	**0.212**	0.206	0.347	0.487	**0.347**
K2	0.076	0.170	0.228	**0.158**	0.074	0.122	0.139	**0.112**	0.110	0.205	0.146	**0.154**
K3	0.030	0.066	0.083	**0.060**	0.028	0.072	0.096	**0.065**	0.030	0.085	0.098	**0.071**
Av	**0.077**	**0.186**	**0.210**	**0.158**	**0.065**	**0.148**	**0.176**	**0.130**	**0.115**	**0.212**	**0.244**	**0.191**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.557	0.780	0.742	**0.693**	0.373	0.699	0.751	**0.608**	0.354	0.547	0.754	**0.552**
K2	0.123	0.301	0.523	**0.316**	0.198	0.293	0.384	**0.292**	0.165	0.273	0.394	**0.277**
K3	0.059	0.203	0.263	**0.175**	0.044	0.143	0.160	**0.116**	0.052	0.135	0.139	**0.109**
Av	**0.246**	**0.428**	**0.509**	**0.395**	**0.205**	**0.378**	**0.432**	**0.338**	**0.190**	**0.318**	**0.429**	**0.313**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.370	0.796	0.889	**0.685**	0.410	0.938	0.968	**0.772**	0.507	0.649	1.081	**0.746**
K2	0.128	0.385	0.222	**0.245**	0.255	0.440	0.538	**0.411**	0.146	0.328	0.431	**0.302**
K3	0.257	0.167	0.205	**0.210**	0.081	0.115	0.222	**0.139**	0.117	0.093	0.247	**0.152**
Av	**0.252**	**0.449**	**0.439**	**0.380**	**0.249**	**0.498**	**0.576**	**0.441**	**0.257**	**0.357**	**0.586**	**.400**

Table 66. Mg concentration in alfalfa leaves as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	Av	Na1	Na2	Na3	Av	Na1	Na2	Na3	Av
K1	0.44	0.38	0.27	**0.36**	0.39	0.38	0.36	**0.38**	0.45	0.37	0.37	**0.40**
K2	0.37	0.34	0.33	**0.35**	0.38	0.32	0.35	**0.35**	0.33	0.31	0.32	**0.32**
K3	0.38	0.31	0.37	**0.35**	0.34	0.33	0.31	**0.33**	0.31	0.29	0.33	**0.31**
Av	**0.40**	**0.34**	**0.32**	**0.35**	**0.37**	**0.34**	**0.34**	**0.35**	**0.36**	**0.32**	**0.34**	**0.34**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.53	0.46	0.46	**0.48**	0.47	0.44	0.46	**0.46**	0.47	0.45	0.48	**0.47**
K2	0.44	0.42	0.45	**0.44**	0.41	0.42	0.36	**0.40**	0.42	0.43	0.40	**0.42**
K3	0.41	0.41	0.41	**0.41**	0.36	0.38	0.36	**0.37**	0.35	0.39	0.37	**0.37**
Av	**0.46**	**0.43**	**0.44**	**0.44**	**0.41**	**0.41**	**0.39**	**0.41**	**0.41**	**0.42**	**0.42**	**0.42**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.42	0.45	0.41	**0.43**	0.46	0.40	0.35	**0.40**	0.42	0.41	0.34	**0.39**
K2	0.40	0.34	0.37	**0.37**	0.35	0.31	0.32	**0.33**	0.37	0.37	0.33	**0.36**
K3	0.32	0.33	0.29	**0.31**	0.35	0.31	0.31	**0.32**	0.32	0.29	0.29	**0.30**
Av	**0.38**	**0.37**	**0.36**	**0.37**	**0.39**	**0.34**	**0.33**	**0.35**	**0.37**	**0.36**	**0.32**	**0.35**

Table 67. Mg concentration in alfalfa stems as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.21	0.23	0.24	**0.23**	0.25	0.25	0.20	**0.23**	0.28	0.32	0.26	**0.29**
K2	0.22	0.18	0.18	**0.19**	0.22	0.20	0.24	**0.22**	0.25	0.24	0.21	**0.23**
K3	0.21	0.17	0.19	**0.19**	0.22	0.18	0.21	**0.20**	0.25	0.18	0.21	**0.21**
Av	**0.21**	**0.19**	**0.20**	**0.20**	**0.23**	**0.21**	**0.22**	**0.22**	**0.26**	**0.25**	**0.23**	**0.24**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.27	0.32	0.26	**0.28**	0.24	0.18	0.22	**0.21**	0.25	0.24	0.21	**0.23**
K2	0.22	0.25	0.24	**0.24**	0.17	0.20	0.16	**0.18**	0.23	0.22	0.22	**0.22**
K3	0.27	0.24	0.23	**0.25**	0.16	0.14	0.16	**0.15**	0.19	0.18	0.20	**0.19**
Av	**0.25**	**0.27**	**0.24**	**0.25**	**0.19**	**0.17**	**0.18**	**0.18**	**0.22**	**0.21**	**0.21**	**0.21**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.23	0.19	0.22	**0.21**	0.18	0.17	0.16	**0.17**	0.30	0.35	0.27	**0.31**
K2	0.18	0.19	0.16	**0.18**	0.13	0.12	0.14	**0.13**	0.25	0.27	0.24	**0.25**
K3	0.16	0.16	0.16	**0.16**	0.14	0.12	0.11	**0.12**	0.23	0.24	0.26	**0.24**
Av	**0.19**	**0.18**	**0.18**	**0.18**	**0.15**	**0.14**	**0.14**	**0.14**	**0.26**	**0.29**	**0.26**	**0.27**

Table 68. Mg concentration in alfalfa shoots (leaves+stems) as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.33	0.32	0.32	0.32	0.32	0.32	0.28	0.31	0.38	0.34	0.32	0.35
K2	0.28	0.26	0.26	0.27	0.29	0.27	0.30	0.29	0.28	0.29	0.26	**0.28**
K3	0.30	0.24	0.28	0.27	0.27	0.25	0.25	0.26	0.27	0.24	0.27	**0.26**
Av	**0.30**	**0.27**	**0.29**	**0.29**	**0.29**	**0.28**	**0.28**	**0.29**	**0.31**	**0.29**	**0.28**	**0.30**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.42	0.39	0.35	0.39	0.35	0.31	0.35	0.34	0.36	0.35	0.35	**0.35**
K2	0.34	0.33	0.36	0.34	0.29	0.31	0.25	0.28	0.32	0.33	0.30	**0.32**
K3	0.33	0.32	0.32	0.32	0.26	0.26	0.26	0.26	0.26	0.29	0.29	**0.28**
Av	**0.36**	**0.35**	**0.34**	**0.35**	**0.30**	**0.29**	**0.29**	**0.29**	**0.31**	**0.32**	**0.31**	**0.32**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.31	0.34	0.31	0.32	0.33	0.27	0.25	0.28	0.38	0.38	0.30	**0.35**
K2	0.29	0.25	0.26	0.27	0.25	0.21	0.23	0.23	0.31	0.32	0.28	**0.30**
K3	0.24	0.24	0.22	0.23	0.24	0.21	0.21	0.22	0.28	0.26	0.27	**0.27**
Av	**0.28**	**0.28**	**0.26**	**0.27**	**0.27**	**0.23**	**0.23**	**0.24**	**0.32**	**0.32**	**0.28**	**0.31**

Table 69. Mg concentration in alfalfa roots as influenced by cross, K, and Na. Mean of 2 replications. (5th cut).

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.21	0.15	0.16	**0.17**	0.14	0.14	0.13	**0.14**	0.19	0.15	0.15	**0.16**
K2	0.15	0.14	0.12	**0.14**	0.14	0.14	0.13	**0.14**	0.13	0.13	0.12	**0.13**
K3	0.12	0.12	0.13	**0.12**	0.10	0.13	0.12	**0.12**	0.11	0.13	0.10	**0.11**
Av	**0.16**	**0.14**	**0.14**	**0.15**	0.13	0.14	0.13	0.13	0.14	0.14	0.12	0.13
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.24	0.16	0.15	**0.18**	0.14	0.13	0.18	**0.15**	0.14	0.13	0.14	**0.14**
K2	0.21	0.15	0.19	**0.18**	0.14	0.12	0.13	**0.13**	0.13	0.13	0.13	**0.13**
K3	0.20	0.14	0.12	**0.15**	0.13	0.12	0.10	**0.12**	0.12	0.12	0.11	**0.12**
Av	**0.22**	**0.15**	**0.15**	**0.17**	**0.14**	**0.12**	**0.14**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.14	0.13	0.13	**0.13**	0.16	0.13	0.14	**0.14**	0.26	0.21	0.20	**0.22**
K2	0.13	0.10	0.12	**0.12**	0.14	0.16	0.12	**0.14**	0.21	0.17	0.16	**0.18**
K3	0.13	0.13	0.11	**0.12**	0.13	0.13	0.12	**0.13**	0.14	0.16	0.16	**0.15**
Av	**0.13**	**0.12**	**0.12**	**0.12**	**0.14**	**0.14**	**0.13**	**0.14**	**0.20**	**0.18**	**0.17**	**0.20**

Table 70. Ca concentration in alfalfa leaves as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	2.00	1.69	1.88	**1.86**	1.89	1.91	1.65	**1.82**	2.11	1.71	1.71	**1.84**
K2	1.64	1.70	1.62	**1.65**	1.71	1.55	1.63	**1.63**	1.58	1.80	1.54	**1.64**
K3	1.83	1.40	1.71	**1.65**	1.74	1.64	1.41	**1.60**	1.67	1.51	1.58	**1.59**
Av	**1.82**	**1.60**	**1.74**	**1.72**	**1.78**	**1.70**	**1.56**	**1.68**	**1.79**	**1.67**	**1.61**	**1.69**
	N2xN2				**N4xW3**				**W1xN4**			
K1	2.08	1.93	1.85	**1.95**	1.99	1.68	1.89	**1.85**	1.94	1.84	1.78	**1.85**
K2	1.99	1.93	2.02	**1.98**	1.88	1.88	1.75	**1.84**	1.79	1.84	1.64	**1.76**
K3	1.85	1.87	1.95	**1.89**	1.72	1.61	1.59	**1.64**	1.48	1.74	1.55	**1.59**
Av	**1.97**	**1.9.94**	**1.94**	**1.86**	**1.72**	**1.74**	**1.78**	**1.74**	**1.81**	**1.66**	**1.73**	
	W1xW3				**W3xW3**				**W4xW4**			
K1	1.71	2.00	1.68	**1.80**	2.03	1.57	1.52	**1.71**	1.95	2.01	1.78	**1.91**
K2	1.77	1.42	1.58	**1.59**	1.57	1.38	1.44	**1.46**	1.81	1.95	1.76	**1.84**
K3	1.53	1.39	1.18	**1.37**	1.55	1.47	1.34	**1.45**	1.71	1.61	1.62	**1.65**
Av	**1.67**	**1.60**	**1.48**	**1.59**	**1.72**	**1.47**	**1.43**	**1.54**	**1.82**	**1.86**	**1.72**	**1.80**

Table 71. Ca concentration in alfalfa stems as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.56	0.57	0.69	**0.59**	0.54	0.60	0.59	**0.58**	0.54	0.65	0.57	**0.59**
K2	0.56	0.50	0.54	**0.53**	0.56	0.54	0.57	**0.56**	0.50	0.62	0.57	**0.56**
K3	0.60	0.54	0.59	**0.58**	0.56	0.50	0.47	**0.51**	0.62	0.47	0.56	**0.55**
Av	**0.57**	**0.54**	**0.61**	**0.57**	**0.55**	**0.55**	**0.54**	**0.55**	**0.55**	**0.58**	**0.57**	**0.57**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.59	0.64	0.52	**0.58**	0.53	0.46	0.48	**0.49**	0.52	0.57	0.55	**0.55**
K2	0.51	0.53	0.53	**0.52**	0.47	0.48	0.41	**0.45**	0.58	0.55	0.54	**0.56**
K3	0.53	0.50	0.56	**0.53**	0.43	0.39	0.47	**0.43**	0.51	0.49	0.52	**0.51**
Av	**0.54**	**0.56**	**0.54**	**0.55**	**0.48**	**0.44**	**0.45**	**0.46**	**0.54**	**0.54**	**0.54**	**0.54**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.52	0.56	0.53	**0.54**	0.46	0.43	0.42	**0.44**	0.54	0.64	0.49	**0.56**
K2	0.50	0.47	0.46	**0.48**	0.34	0.36	0.45	**0.38**	0.48	0.47	0.45	**0.47**
K3	0.48	0.46	0.44	**0.46**	0.38	0.37	0.34	**0.36**	0.52	0.49	0.49	**0.50**
Av	**0.50**	**0.50**	**0.48**	**0.49**	**0.39**	**0.39**	**0.40**	**0.39**	**0.51**	**0.53**	**0.48**	**0.51**

Table 72. Ca concentration in alfalfa shoots (leaves+stems) influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	1.30	1.15	1.28	**1.24**	1.21	1.27	1.11	**1.20**	1.34	1.18	1.14	**1.22**
K2	1.07	1.11	1.08	**1.09**	1.13	1.04	1.11	**1.09**	1.02	1.23	1.06	**1.10**
K3	1.22	0.95	1.14	**1.10**	1.14	1.07	0.93	**1.05**	1.13	0.99	1.06	**1.06**
Av	**1.20**	**1.07**	**1.17**	**1.14**	**1.16**	**1.13**	**1.05**	**1.11**	**1.16**	**1.13**	**1.09**	**1.13**
	N2xN2				**N4xW3**				**W1xN4**			
K1	1.36	1.28	1.17	**1.27**	1.27	1.06	1.19	**1.17**	1.24	1.21	1.17	**1.21**
K2	1.26	1.22	1.30	**1.26**	1.18	1.18	1.07	**1.14**	1.16	1.21	1.07	**1.15**
K3	1.19	1.17	1.25	**1.20**	1.06	1.00	1.02	**1.03**	0.99	1.11	1.04	**1.05**
Av	**1.27**	**1.22**	**1.24**	**1.24**	**1.17**	**1.08**	**1.09**	**1.11**	**1.13**	**1.18**	**1.09**	**1.14**
	W1xW3				**W3xW3**				**W4xW4**			
K1	1.10	1.31	1.07	**0.79**	1.25	0.99	0.95	**1.06**	1.25	1.31	1.12	**1.23**
K2	1.14	0.92	1.03	**1.03**	0.97	0.85	0.94	**0.92**	1.14	1.21	1.10	**1.15**
K3	1.01	0.92	0.80	**0.91**	0.96	0.91	0.85	**0.91**	1.11	1.04	1.04	**1.06**
Av	**1.08**	**1.05**	**0.97**	**0.91**	**1.06**	**0.92**	**0.91**	**0.96**	**1.17**	**1.19**	**1.09**	**1.15**

Table 73. Ca concentration in alfalfa roots as influenced by cross, K, and Na. Mean of 2 replications. (5th cut).

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.09	0.10	0.14	**0.11**	0.11	0.09	0.10	**0.10**	0.10	0.09	0.09	**0.09**
K2	0.13	0.12	0.11	**0.12**	0.11	0.10	0.09	**0.10**	0.09	0.12	0.10	**0.10**
K3	0.12	0.12	0.14	**0.13**	0.10	0.11	0.12	**0.11**	0.10	0.10	0.09	**0.10**
Av	**0.11**	**0.11**	**0.13**	**0.12**	**0.11**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.09**	**0.10**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.09	0.08	0.10	**0.09**	0.08	0.08	0.10	**0.09**	0.08	0.09	0.10	**0.09**
K2	0.10	0.09	0.11	**0.10**	0.09	0.09	0.09	**0.09**	0.10	0.11	0.10	**0.10**
K3	0.10	0.11	0.09	**0.10**	0.10	0.10	0.09	**0.10**	0.10	0.12	0.10	**0.11**
Av	**0.10**	**0.09**	**0.10**	**0.10**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.11**	**0.10**	**0.10**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.09	0.08	0.09	**0.09**	0.08	0.09	0.09	**0.09**	0.10	0.10	0.09	**0.10**
K2	0.10	0.08	0.09	**0.09**	0.09	0.13	0.09	**0.10**	0.10	0.10	0.09	**0.10**
K3	0.09	0.10	0.09	**0.09**	0.09	0.08	0.08	**0.08**	0.10	0.10	0.10	**0.10**
Av	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.10**	**0.09**	**0.09**	**0.10**	**0.10**	**0.09**	**0.10**

Table 74. Ca:Mg ratio in alfalfa leaves as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	4.75	4.48	4.76	**4.66**	4.88	5.04	4.57	**4.83**	4.75	4.75	4.61	**4.70**
K2	4.52	5.11	4.89	**4.84**	4.57	4.97	4.64	**4.73**	4.92	5.78	5.02	**5.24**
K3	4.87	4.51	4.68	**4.69**	5.11	5.06	4.76	**4.98**	5.57	5.33	4.79	**5.23**
Av	**4.71**	**4.70**	**4.78**	**4.73**	**4.85**	**5.02**	**4.66**	**4.85**	**5.08**	**5.29**	**4.81**	**5.06**
	N2xN2				**N4xW3**				**W1xN4**			
K1	3.96	4.16	4.04	**4.05**	4.21	3.87	4.16	**4.08**	4.22	4.10	3.74	**4.02**
K2	4.62	4.57	4.57	**4.59**	4.62	4.44	4.90	**4.65**	4.32	4.27	4.05	**4.21**
K3	4.56	4.58	4.70	**4.61**	4.82	4.31	4.52	**4.55**	4.28	4.48	4.28	**4.35**
Av	**4.38**	**4.44**	**4.44**	**4.42**	**4.55**	**4.21**	**4.53**	**4.43**	**4.27**	**4.28**	**4.02**	**4.19**
	W1xW3				**W3xW3**				**W4xW4**			
K1	4.13	4.40	4.07	**4.20**	4.41	3.98	4.30	**4.23**	4.67	4.99	5.35	**5.00**
K2	4.45	4.12	4.34	**4.30**	4.58	4.52	4.60	**4.57**	5.04	5.32	5.37	**5.24**
K3	4.89	4.28	4.04	**4.40**	4.56	4.80	4.51	**4.62**	5.41	5.66	5.69	**5.59**
Av	**4.49**	**4.27**	**4.15**	**4.30**	**4.52**	**4.43**	**4.47**	**4.47**	**5.04**	**5.32**	**5.47**	**5.28**

Table 75. Ca:Mg ratio in alfalfa stems as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	2.78	2.32	3.09	**2.73**	2.18	2.42	2.94	**2.51**	1.79	2.05	2.20	**2.01**
K2	2.75	2.91	2.93	**2.86**	2.80	2.49	2.39	**2.56**	2.13	2.52	2.81	**2.49**
K3	2.88	3.21	3.18	**3.09**	2.66	2.78	2.39	**2.61**	2.39	2.67	2.59	**2.55**
Av	**2.80**	**2.81**	**3.07**	**2.89**	**2.55**	**2.56**	**2.57**	**2.56**	**2.10**	**2.41**	**2.53**	**2.35**
	N2xN2				**N4xW3**				**W1xN4**			
K1	2.14	2.06	2.11	**2.10**	2.41	2.49	2.22	**2.37**	2.17	2.52	2.52	**2.40**
K2	2.21	2.20	2.10	**2.17**	2.71	2.53	2.83	**2.69**	2.57	2.43	2.49	**2.50**
K3	2.11	2.13	2.29	**2.18**	2.65	2.67	3.03	**2.78**	2.85	2.64	2.62	**2.70**
Av	**2.15**	**2.13**	**2.17**	**2.15**	**2.59**	**2.56**	**2.69**	**2.61**	**2.53**	**2.53**	**2.54**	**2.53**
	W1xW3				**W3xW3**				**W4xW4**			
K1	2.46	2.83	2.39	**2.56**	2.61	2.73	2.65	**2.66**	1.75	1.79	1.94	**1.83**
K2	2.91	2.59	3.02	**2.84**	2.63	3.22	3.11	**2.99**	1.97	1.73	1.90	**1.87**
K3	3.10	2.78	2.83	**2.90**	2.90	3.04	3.14	**3.03**	2.17	2.24	1.95	**2.12**
Av	**2.82**	**2.73**	**2.75**	**2.77**	**2.71**	**3.00**	**2.97**	**2.89**	**1.96**	**1.92**	**1.93**	**1.94**

Table 76. Ca:Mg ratio in alfalfa shoots (leaves+stems) as influenced by cross, K, and Na. Mean of 2 replications and 2 cuts.

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	4.11	3.59	4.10	**3.93**	3.87	4.00	3.99	**3.95**	3.54	3.53	3.65	**3.57**
K2	3.92	4.31	4.20	**4.14**	3.96	3.97	3.71	**3.88**	3.81	4.33	4.15	**4.10**
K3	4.16	4.06	4.20	**4.14**	4.20	4.24	3.89	**4.11**	4.22	4.28	3.97	**4.16**
Av	**4.06**	**3.99**	**4.17**	**4.07**	**4.01**	**4.07**	**3.86**	**3.98**	**3.86**	**4.05**	**3.92**	**3.94**
	N2xN2				**N4xW3**				**W1xN4**			
K1	3.30	3.35	3.42	**3.36**	3.65	3.48	3.53	**3.55**	3.51	3.57	3.37	**3.48**
K2	3.74	3.77	3.68	**3.73**	4.06	3.86	4.33	**4.08**	3.72	3.64	3.53	**3.63**
K3	3.65	3.74	3.91	**3.77**	4.16	3.84	4.09	**4.03**	3.80	3.90	3.68	**3.79**
Av	**3.56**	**3.62**	**3.67**	**3.62**	**3.96**	**3.73**	**3.98**	**3.89**	**3.68**	**3.70**	**3.53**	**3.64**
	W1xW3				**W3xW3**				**W4xW4**			
K1	3.54	3.87	3.52	**3.64**	3.82	3.60	3.80	**3.74**	3.44	3.60	3.98	**3.67**
K2	3.96	3.62	3.94	**3.84**	4.01	4.18	4.16	**4.12**	3.84	3.80	3.96	**3.87**
K3	4.30	3.79	3.64	**3.91**	4.08	4.29	4.12	**4.16**	4.08	4.27	4.02	**4.12**
Av	**3.93**	**3.76**	**3.70**	**3.80**	**3.97**	**4.02**	**4.03**	**4.01**	**3.79**	**3.89**	**3.99**	**3.89**

Table 77. Ca:Mg ratio in alfalfa roots as influenced by cross, K, and Na. Mean of 2 replications.(5th cut).

	M1xM1				**M1xM2**				**N1xM2**			
	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**	Na1	Na2	Na3	**Av**
K1	0.44	0.71	0.89	**0.68**	0.79	0.65	0.79	**0.74**	0.54	0.64	0.58	**0.59**
K2	0.88	0.82	0.94	**0.88**	0.84	0.72	0.71	**0.76**	0.69	0.88	0.91	**0.83**
K3	0.97	0.96	1.08	**1.00**	0.99	0.83	1.00	**0.94**	0.90	0.74	0.87	**0.84**
Av	**0.76**	**0.83**	**0.97**	**0.85**	**0.87**	**0.73**	**0.83**	**0.81**	**0.71**	**0.75**	**0.79**	**0.75**
	N2xN2				**N4xW3**				**W1xN4**			
K1	0.41	0.47	0.70	**0.53**	0.58	0.63	0.54	**0.58**	0.59	0.70	0.70	**0.66**
K2	0.46	0.60	0.60	**0.55**	0.68	0.75	0.73	**0.72**	0.79	0.87	0.77	**0.81**
K3	0.52	0.75	0.72	**0.66**	0.75	0.76	0.90	**0.80**	0.84	0.97	0.92	**0.91**
Av	**0.46**	**0.61**	**0.67**	**0.58**	**0.67**	**0.71**	**0.72**	**0.70**	**0.74**	**0.85**	**0.80**	**0.79**
	W1xW3				**W3xW3**				**W4xW4**			
K1	0.66	0.65	0.72	**0.68**	0.53	0.73	0.63	**0.63**	0.39	0.46	0.43	**0.43**
K2	0.76	0.82	0.76	**0.78**	0.63	0.75	0.77	**0.72**	0.48	0.57	0.55	**0.53**
K3	0.75	0.74	0.84	**0.78**	0.70	0.70	0.71	**0.70**	0.66	0.66	0.64	**0.65**
Av	**0.72**	**0.74**	**0.77**	**0.75**	**0.62**	**0.73**	**0.70**	**0.68**	**0.51**	**0.56**	**0.54**	**0.54**

Table 78. K utilization efficiency of alfalfa as influenced by cross and Na. Mean of 2 replications and 2 cuts.

Cross	Na level	KUE (g^2mmol^{-1})
M1xM1	Na1	47.29
	Na2	70.81
	Na3	59.26
M1xM2	Na1	58.54
	Na2	65.03
	Na3	57.03
N1xM2	Na1	55.54
	Na2	45.74
	Na3	52.95
N2xN2	Na1	31.16
	Na2	45.56
	Na3	29.25
N4xW3	Na1	71.85
	Na2	60.41
	Na3	58.88
W1xN4	Na1	65.13
	Na2	67.67
	Na3	61.45
W1xW3	Na1	70.87
	Na2	60.17
	Na3	63.93
W3xW3	Na1	57.36
	Na2	46.17
	Na3	44.16
W4xW4	Na1	27.77
	Na2	44.01
	Na3	33.00

Appendix C: Analysis of variance tables

Table 79. Analysis of variance for transpiration as influenced by alfalfa cross, K, Na, and harvest time.

Source	DF	MS
Cross (C)†	8	0.292E+1*
1 vs 2	1	0.062E+0
1 2 vs 4	1	0.488E+1
1 2 vs 7 8 9	1	0.549E+0
3 vs 5	1	0.301E+1
6 vs 5	1	0.196E+0
7 8 9 vs 4	1	0.858E+1*
7 vs 8	1	0.113E+1
7 8 9 vs 6	1	0.891E+1*
Potassium (K)	2	0.194E+1
Sodium (Na)	2	0.103E+0
K x Na	4	0.479E+0
C x K	16	0.868E+0
C x Na	16	0.124E+1
C x K x Na	32	0.129E+1
Error (a)	81	0.134E+1
Time (T)	1	0.338E+3**
C x T	8	0.399E+1
K x T	2	0.103E+1
Na x T	2	0.310E+0
K x Na x T	4	0.778E+0
C x K x T	16	0.148E+1
C x Na x T	16	0.173E+1
C x K x Na x T	32	0.215E+1
Error (b)	81	0.197E+1
Total	323	0.362E+3

†Cross: 1-M1xM1, 2-M1xM2, 3-N1xM2, 4-N2xN2, 5-N4xW3, 6-W1xN4, 7-W1xW3, 8-W3xW3, 9-W4xW4.

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Table 80. Analysis of variance for biomass of alfalfa leaves, stems, shoots (leaves+stems), and roots as influenced by cross, K, Na, and harvest time.

Source	DF	MS Leaves	 Stems	 Shoots	 Roots
Cross(C)†	8	0.327E+1**	0.283E+1**	0.432E+2**	0.120E+2**
1 vs 2	1	0.115E+0NS	0.737E+1**	0.565E+1	0.129E+1
1 2 vs 4	1	0.475E+3**	0.143E+3**	0.114E+4**	0.260E+3**
1 2 vs 7 8 9	1	0.191E+3**	0.366E+2**	0.394E+3**	0.207E+3**
3 vs 5	1	0.159E+2**	0.152E+2**	0.616E+2**	0.064E+0
6 vs 5	1	0.180E+0	0.353E+0	0.162E-1	0.230E+0
7 8 9 vs 4	1	0.149E+3**	0.624E+2**	0.404E+3**	0.328E+2**
7 vs 8	1	0.255E+2**	0.101E+2**	0.678E+2**	0.986E+1
7 8 9 vs 6	1	0.108E+3**	0.583E+2**	0.327E+3**	0.121E+2
Potassium(K)	2	0.725E+1**	0.711E+1**	0.287E+2**	0.782E+1
Sodium(Na)	2	0.100E+1	0.128E+0	0.184E+1	0.197E+0
K x Na	4	0.186E+1	0.158E+1*	0.628E+1	0.853E+1
C x K	16	0.543E+0	0.429E+0	0.175E+1	0.507E+1
C x Na	16	0.500E+0	0.324E+0	0.137E+1	0.492E+1
C x K x Na	32	0.572E+0	0.425E+0	0.165E+1	0.421E+1
Error (a)	81	0.866E+0	0.594E+0	0.261E+1	0.454E+1
Total	161				0.740E+2
Time(T)	1	0.715E+3**	0.113E+4**	0.364E+4**	----------
C x T	8	0.960E+1**	0.824E+1**	0.348E+2**	----------
K x T	2	0.171E+2**	0.213E+2**	0.764E+2**	----------
Na x T	2	0.883E+0	0.756E-1	0.143E+1	----------
K x Na x T	4	0.614E+1*	0.514E+1*	0.206E+2*	----------
C x K x T	16	0.141E+1	0.117E+1	0.448E+1	----------
C x Na x T	16	0.122E+1	0.105E+1	0.367E+1	----------
C x K x Na x T	32	0.127E+1	0.136E+1	0.451E+1	----------
Error (b)	81	0.196E+1	0.176E+1	0.668E+1	----------
Total	323	0.770E+3	0.118E+4	0.385E+4	----------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.

,* Significant at 0.05 and 0.01 probability levels, respectively.

Table 81. Analysis of variance for WUE as influenced by alfalfa cross, K, Na, and harvest time.

Source	DF	MS
Cross (C)†	8	0.139E+0**
1 vs 2	1	0.038E+0
1 2 vs 4	1	0.814E+0**
1 2 vs 7 8 9	1	0.011E+0
3 vs 5	1	0.001E+0
6 vs 5	1	0.001E+0
7 8 9 vs 4	1	0.761E+0**
7 vs 8	1	0.047E+0
7 8 9 vs 6	1	0.000E+0
Potassium (K)	2	0.057E+0
Sodium (Na)	2	0.019E+0
K x Na	4	0.037E+0
C x K	16	0.011E+0
C x Na	16	0.018E+0
C x K x Na	32	0.016E+0
Error (a)	81	0.029E+0
Time (T)	1	0.642E+0**
C x T	8	0.106E+0**
K x T	2	0.073E+0
Na x T	2	0.009E+0
K x Na x T	4	0.026E+0
C x K x T	16	0.009E+0
C x Na x T	16	0.022E+0
C x K x Na x T	32	0.017E+0
Error (b)	81	0.027E+0
Total	323	0.126E+1

†Cross: 1-M1xM1, 2-M1xM2, 3-N1xM2, 4-N2xN2, 5-N4xW3, 6-W1xN4, 7-W1xW3, 8-W3xW3, 9-W4xW4.

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Table 82. Analysis of variance for K composition in alfafla leaves, stems, shoots (leaves+ stems), and roots as influenced by cross, K, Na, and harvest time.

Source	DF	MS			
		Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.933E-2**	0.895E-1**	0.141E+0**	0.184E-2**
1 vs 2	1	0.497E-2	0.128E-2	0.121E-1	0.278E-4
1 2 vs 4	1	0.397E-1**	0.395E+0**	0.689E+0**	0.440E-2**
1 2 vs 7 8 9	1	0.979E-2	0.396E-2	0.273E-1	0.150E-3
3 vs 5	1	0.269E-2	0.193E-1	0.370E-1	0.400E-4
6 vs 5	1	0.527E-2	0.281E-2	0.376E-3	0.640E-3
7 8 9 vs 4	1	0.177E-1**	0.381E+0**	0.561E+1**	0.368E-2**
7 vs 8	1	0.905E-2	0.192E-1	0.523E-1	0.136E-2
7 8 9 vs 6	1	0.743E-3	0.179E+0*	0.201E+0*	0.241E-2*
Potassium(K)	2	0.488E-1**	0.222E+0**	0.437E+0**	0.134E-1**
Sodium(Na)	2	0.999E-3	0.167E-1	0.261E-1	0.120E-3
K x Na	4	0.337E-2	0.168E-1	0.343E-1	0.144E-2*
C x K	16	0.237E-2	0.309E-1	0.375E-1	0.326E-3
C x Na	16	0.271E-2	0.207E-1	0.188E-1	0.337E-3
C x K x Na	32	0.208E-2	0.215E-1	0.301E-1	0.536E-3
Error (a)	81	0.250E-2	0.266E-1	0.353E-1	0.517E-3
Total	161	--------	--------	--------	0.488E+0
Time(T)	1	0.393E+0**	0.164E+0**	0.365E+1**	--------
C x T	8	0.422E-2	0.386E-1*	0.594E-1*	--------
K x T	2	0.139E-1**	0.509E-1	0.869E-1*	--------
Na x T	2	0.456E-3	0.981E-2	0.148E-1	--------
K x Na x T	4	0.279E-2	0.947E-2	0.218E-1	--------
C x K x T	16	0.238E-2	0.169E-1	0.217E-1	--------
C x Na x T	16	0.228E-2	0.128E-1	0.115E-1	--------
C x K x Na x T	32	0.165E-2	0.142E-1	0.203E-1	--------
Error (b)	81	0.212E-2	0.168E-1	0.232E-1	--------
Total	323	0.678E+1	0.259E+2	0.555E+2	--------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
,* Significant at 0.05 and 0.01 probability levels, respectively.

Table 83. Analysis of variance for Na composition in alfalfa leaves, stems, shoots (leaves+ stems), and roots as influenced by cross, K, Na, and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.106E-2**	0.101E-2**	0.137E-2*	0.111E-2**
1 vs 2	1	0.081E-5	0.414E-5	0.108E-5	0.608E-4
1 2 vs 4	1	0.232E-2**	0.506E-2**	0.527E-3	0.470E-2**
1 2 vs 7 8 9	1	0.564E-2**	0.137E-2*	0.142E-2	0.497E-2**
3 vs 5	1	0.255E-4	0.147E-2*	0.189E-2	0.340E-3
6 vs 5	1	0.472E-5	0.721E-3	0.884E-3	0.010E-6
7 8 9 vs 4	1	0.676E-4	0.213E-2**	0.293E-2*	0.287E-3
7 vs 8	1	0.287E-3	0.128E-2*	0.278E-2*	0.324-4
7 8 9 vs 6	1	0.111E-4	0.201E-3	0.320E-3	0.106E-2*
Potassium(K)	2	0.231E-3	0.306E-2**	0.467E-2**	0.283E-2**
Sodium(Na)	2	0.224E-3	0.146E-2**	0.275E-2**	0.188E-2**
K x Na	4	0.210E-3	0.469E-3	0.131E-2*	0.593E-3*
C x K	16	0.461E-3	0.486E-3*	0.106E-2*	0.255E-3
C x Na	16	0.792E-4	0.686E-3**	0.787E-3	0.185E-3
C x K x Na	32	0.171E-3	0.206E-3	0.380E-3	0.225E-3
Error (a)	81	0.179E-3	0.271E-3	0.519E-3	0.170E-3
Total	161	--------	--------	--------	0.219E+0
Time(T)	1	0.215E-4	0.270E-2**	0.230E-2*	--------
C x T	8	0.173E-3	0.725E-3**	0.148E-2**	--------
K x T	2	0.289E-3	0.593E-3	0.792E-3	--------
Na x T	2	0.448E-3	0.448E-3	0.868E-3	--------
K x Na x T	4	0.528E-3**	0.402E-3	0.185E-2**	--------
C x K x T	16	0.299E-3*	0.331E-3	0.806E-3*	--------
C x Na x T	16	0.186E-3	0.457E-3**	0.701E-3	--------
C x K x Na x T	32	0.223E-3	0.144E-3	0.336E-3	--------
Error (b)	81	0.144E-3	0.200E-3	0.405E-3	--------
Total	323	0.122E+1	0.501E+0	0.218E+1	--------

†**Cross: 1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
,* Significant at 0.05 and 0.01 probability levels, respectively.

Table 84. Analysis of variance for Na:K ratio in alfalfa leaves, stems, shoots (leaves+stems) and roots as influenced by cross, K, Na, and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.486E-2**	0.145E-2	0.117E-2	0.396E-1**
1 vs 2	1	0.720E-4	0.115E-2	0.146E-2	0.706E-2
1 2 vs 4	1	0.260E+1**	0.194E-2	0.642E+0**	0.750E+0**
1 2 vs 7 8 9	1	0.411E+1**	0.941E-3	0.970E+0**	0.149E+1**
3 vs 5	1	0.104E+0**	0.260E-1**	0.720E-2**	0.200E+0**
6 vs 5	1	0.583E-2*	0.365E-1**	0.162E-1**	0.656E-2
7 8 9 vs 4	1	0.115E-1**	0.504E-2*	0.504E-2*	0.228E-2
7 vs 8	1	0.583E-2*	0.221E-1**	0.131E-1**	0.335E-1
7 8 9 vs 6	1	0.492E-1**	0.447E-1**	0.425E-1**	0.122E+0**
Potassium(K)	2	0.338E-2	0.468E-2*	0.482E-2**	0.309E+0**
Sodium(Na)	2	0.409E-3	0.194E-2	0.113E-2	0.102E+0**
K x Na	4	0.190E-2	0.181E-2	0.216E-2*	0.688E-1**
C x K	16	0.496E-2**	0.142E-2	0.190E-2**	0.164E-1
C x Na	16	0.522E-3	0.180E-2	0.731E-3	0.764E-2
C x K x Na	32	0.996E-3	0.878E-3	0.651E-3	0.151E-1
Error (a)	81	0.115E-2	0.116E-2	0.758E-3	0.105E-1
Total	161	--------	--------	--------	0.109E+2
Time(T)	1	0.301E-1**	0.439E-1**	0.363E-1**	--------
C x T	8	0.567E-2**	0.258E-2	0.417E-2**	--------
K x T	2	0.549E-2*	0.760E-2	0.603E-2*	--------
Na x T	2	0.144E-1**	0.109E-1*	0.130E-1**	--------
K x Na x T	4	0.839E-2**	0.512E-2	0.680E-2**	--------
C x K x T	16	0.344E-2*	0.272E-2	0.241E-2	--------
C x Na x T	16	0.341E-2*	0.260E-2	0.208E-2	--------
C x K x Na x T	32	0.305E-2*	0.239E-2	0.184E-2	--------
Error (b)	81	0.175E-2	0.274E-2	0.151E-2	--------
Total	323	0.136E+2	0.665E+1	0.751E+1	--------

†Cross: 1-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.

,* Significant at 0.05 and 0.01 probability levels, respectively.

Table 85. Analysis of variance for Mg composition in alfalfa leaves, stems, shoots (leaves+ stems), and roots as influenced by cross, K, Na, and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.191E-2	0.127E-1**	0.160E-1**	0.103E-2
1 vs 2	1	0.368E-3	0.556E-2	0.292E-2	0.215E-2*
1 2 vs 4	1	0.430E-2	0.499E-1**	0.825E-1**	0.148E-3
1 2 vs 7 8 9	1	0.709E-2	0.280E-3	0.107E-1	0.474E-5
3 vs 5	1	0.439E-3	0.439E-3	0.203E-4	0.111E-3
6 vs 5	1	0.204E-2	0.135E-2	0.725E-2	0.284E-3
7 8 9 vs 4	1	0.874E-5	0.501E-1**	0.497E-1**	0.214E-3
7 vs 8	1	0.883E-4	0.376E-3	0.580E-3	0.218E-3
7 8 9 vs 6	1	0.195E-2	0.115E-1*	0.239E-1**	0.831E-3
Potassium(K)	2	0.871E-3	0.453E-2	0.968E-2	0.605E-3
Sodium(Na)	2	0.133E-2	0.265E-3	0.292E-2	0.131E-3
K x Na	4	0.525E-4	0.912E-3	0.800E-3	0.437E-3
C x K	16	0.129E-2	0.580E-3	0.206E-2	0.554E-3
C x Na	16	0.116E-2	0.143E-2	0.217E-2	0.444E-3
C x K x Na	32	0.105E-2	0.207E-2	0.347E-2	0.466E-3
Error (a)	81	0.128E-2	0.204E-2	0.325E-2	0.542E-3
Total	161	--------	--------	--------	0.197E+0
Time(T)	1	0.119E-1**	0.538E-1**	0.114E+0**	--------
C x T	8	0.257E-2	0.608E-2*	0.794E-2*	--------
K x T	2	0.161E-2	0.167E-2	0.180E-2	--------
Na x T	2	0.904E-3	0.100E-2	0.395E-2	--------
K x Na x T	4	0.440E-3	0.287E-3	0.357E-3	--------
C x K x T	16	0.159E-2	0.493E-3	0.283E-2	--------
C x Na x T	16	0.161E-2	0.128E-2	0.293E-2	--------
C x K x Na x T	32	0.135E-2	0.167E-2	0.424E-2	--------
Error (b)	81	0.150E-2	0.167E-2	0.386E-2	--------
Total	323	0.154E+1	0.181E+1	0.476E+1	--------

†Cross: 1-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
,* Significant at 0.05 and 0.01 probability levels, respectively.

Table 86. Analysis of variance for Ca composition in alfalfa leaves, stems, shoots (leaves+ stems). and roots as influenced by cross, K, Na, and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.409E-1*	0.597E-1**	0.128E+0**	0.468E-3**
1 vs 2	1	0.122E-1	0.608E-3	0.705E-2	0.871E-1*
1 2 vs 4	1	0.111E+0*	0.206E+0**	0.595E+0**	0.428E-3
1 2 vs 7 8 9	1	0.940E-1*	0.319E-1	0.163E-1	0.162E-2**
3 vs 5	1	0.140E+0**	0.130E-1	0.233E+0**	0.160E-3
6 vs 5	1	0.881E-1*	0.236E-2	0.117E+0*	0.401E-3
7 8 9 vs 4	1	0.122E-1	0.388E+0**	0.514E+0**	0.980E-4
7 vs 8	1	0.112E-1	0.129E-3	0.894E-2	0.111E-3
7 8 9 vs 6	1	0.560E-2	0.698E-1**	0.114E+0	0.535E-4
Potassium(K)	2	0.104E-2	0.652E-2	0.100E-1	0.627E-3*
Sodium(Na)	2	0.192E-1	0.896E-2	0.514E-1	0.230E-4
K x Na	4	0.889E-2	0.710E-2	0.140E-1	0.245E-3
C x K	16	0.194E-1	0.506E-2	0.304E-1	0.113E-3
C x Na	16	0.185E-1	0.653E-2	0.136E-1	0.122E-3
C x K x Na	32	0.164E-1	0.582E-2	0.203E-1	0.237E-3
Error (a)	81	0.187E-1	0.962E-2	0.291E-1	0.140E-3
Total	161	--------	--------	--------	0.380E-1
Time(T)	1	0.274E+0**	0.337E+0**	0.256E-2	--------
C x T	8	0.889E-1*	0.368E-1**	0.114E+0*	--------
K x T	2	0.457E-1	0.455E-2	0.532E-1	--------
Na x T	2	0.542E-1	0.814E-2	0.104E+0	--------
K x Na x T	4	0.289E-1	0.259E-2	0.380E-1	--------
C x K x T	16	0.436E-1	0.460E-2	0.604E-1	--------
C x Na x T	16	0.314E-1	0.519E-2	0.303E-1	--------
C x K x Na x T	32	0.276E-1	0.465E-2	0.352E-1	--------
Error (b)	81	0.357E-1	0.713E-2	0.482E-1	--------
Total	323	0.283E+2	0.650E+1	0.352E+2	--------

†**Cross: 1**-M1xM1, **2**-M1xM2, 3-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
,* Significant at 0.05 and 0.01 probability levels, respectively.

Table 87. Analysis of variance for Ca:Mg ratio in alfalfa leaves, stems, shoots (leaves+ stems), and roots as influenced by cross, K, Na, and harvest time.

		MS			
Source	DF	Leaves	Stems	Shoots	Roots
Cross(C)†	8	0.221E+0**	0.446E+0**	0.146E+0**	0.137E-1
1 vs 2	1	0.259E+0	0.196E+1**	0.146E+0	0.144E-1
1 2 vs 4	1	0.329E+1**	0.794E+1**	0.394E+1**	0.750E+0**
1 2 vs 7 8 9	1	0.492E+0**	0.159E+1**	0.675E+0**	0.700E+0**
3 vs 5	1	0.714E+1**	0.122E+1**	0.045E+0	0.225E-1
6 vs 5	1	0.104E+1**	0.115E+0	0.113E+1**	0.729E-1*
7 8 9 vs 4	1	0.187E+1**	0.397E+1**	0.212E+1**	0.662E-1*
7 vs 8	1	0.520E+0**	0.259E+0	0.794E+0**	0.324E-1
7 8 9 vs 6	1	0.657E+1**	0.300E-3	0.183E+1**	0.265E+0**
Potassium(K)	2	0.387E-1	0.563E-1	0.710E-1	0.815E-1**
Sodium(Na)	2	0.326E-1	0.384E-1	0.345E-1	0.271E-2
K x Na	4	0.521E-1	0.203E+0	0.603E-1	0.116E-1
C x K	16	0.509E-1	0.113E+0	0.389E-1	0.145E-1
C x Na	16	0.476E-1	0.179E+0	0.557E-1	0.611E-2
C x K x Na	32	0.788E-1	0.112E+0	0.671E-1	0.175E-1
Error (a)	81	0.688E-1	0.152E+0	0.528E-1	0.117E-1
Total	161	--------	--------	--------	0.464E+1
Time(T)	1	0.705E+1**	0.145E-1	0.408E+1**	--------
C x T	8	0.112E+0	0.344E+0*	0.102E+0	--------
K x T	2	0.539E-1	0.426E-2	0.520E-2	--------
Na x T	2	0.980E-1	0.979E-2	0.235E-1	--------
K x Na x T	4	0.400E-1	0.130E+0	0.448E-1	--------
C x K x T	16	0.744E-1	0.134E+0	0.462E-1	--------
C x Na x T	16	0.884E-1	0.137E+0	0.588E-1	--------
C x K x Na x T	32	0.894E-1	0.950E-1	0.749E-1	--------
Error (b)	81	0.841E-1	0.135E+0	0.551E-1	--------
Total	323	0.171E+3	0.815E+2	0.893E+2	--------

†Cross: **1**-M1xM1, **2**-M1xM2, **3**-N1xM2, **4**-N2xN2, **5**-N4xW3, **6**-W1xN4, **7**-W1xW3, **8**-W3xW3, **9**-W4xW4.
,* Significant at 0.05 and 0.01 probability levels, respectively.

VITA

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Doctor of Philosophy

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