Taproot Organic Reserves and Stress Tolerance of Alfalfa

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ABSTRACT

Accumulation of organic reserves in taproots imparts stress tolerance to alfalfa. Starch, sugars, proteins, and amino acids are important taproot constituents that are mobilized when 1) winter dormancy is broken in spring and shoot growth resumes, and 2) shoot regrowth is initiated after cutting. Harvest mis-management can interfere with accumulation of these organic reserves and results in slow regowth after harvest and poor stand persistence. Understanding taproot function should improve the longevity and productivity of alfalfa stands.

Key Words: alfalfa, persistence, harvesting, winter hardiness, starch, protein

INTRODUCTION

Alfalfa is an incredible plant. Few plant species can tolerate defoliation to the soil surface at monthly intervals. Fewer yet thrive over such a wide range of climatic and geographic extremes. Being perennial, alfalfa is capable of living for decades. However, growers are often pleased if an alfalfa stand persists for as little as 6 years.

Persistence of alfalfa depends on the survival and proper function of plant organs remaining in the field over winter and after harvest. This includes crowns, from which new shoot growth will arise, and a large carrot-like taproot. Our research program focuses on understanding changes in taproots that enable alfalfa plants to survive stresses like defoliation and winter. Our goal is to identify taproot characters essential for stress tolerance. We hope that our research findings will find use in variety development programs. The outcome for the alfalfa grower will be new varieties that are higher yielding and more persistent than those we have today.

This paper summarizes work aimed at understanding changes in alfalfa taproot constituents that occur after defoliation, and as plants harden for winter and subsequently begin growth in spring. We believe these adjustments described below are necessary because both defoliation and the freezing temperatures of winter impair or eliminate two vital processes in alfalfa; photosynthesis and dinitrogen fixation. What we are discovering is that alfalfa taproots contain large amounts of starch and sugar that serve as alternative sources of energy to replace photosynthesis. In addition, taproots contain amino acids and specific proteins that serve as alternative sources of nitrogen (N) to dinitrogen fixation. We believe these taproot constituents are essential for alfalfa stress tolerance.

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Taproot Responses to Defoliation Stress. Alfalfa taproots contain nearly 40 % nonstructural carbohydrate on a dry weight basis. The vast majority of this is in the form of starch. After shoot harvest, taproot starch concentrations decline markedly for two to three weeks as shoots regrow (Fig. 1). When photosynthesis is sufficient to meet the energy needs of regrowing shoots, taproot starch begins to re-accumulate. By the time plants begin to flower (around Day 28 of regrowth) taproot starch levels have returned to pre-defoliation levels. Taproot sugar concentrations also decline after defoliation, but the extent of change is less than that observed for starch. This cyclic pattern of starch and sugar depletion/re-accumulation is one feature that enables alfalfa to tolerate complete defoliation at regular (4 to 5 week) intervals.

Harvesting alfalfa more frequently than every 4 weeks can lead to poor plant persistence. For example, harvesting mid-way through regrowth prevents re-accumulation of taproot carbohydrate reserves; an important process that occurs between Days 21 and 35 of regrowth (Fig. 1). While harvesting early a single time may not eliminate a stand, frequent, early harvesting before starch has re-accumulated in taproots may contribute to poor plant persistence. In addition, plants with low taproot starch and sugar concentrations are generally thought to be more susceptible to other stresses (drought, weed competition, low soil fertility, insects) that, in combination with low taproot starch concentrations, may contribute to stand loss.

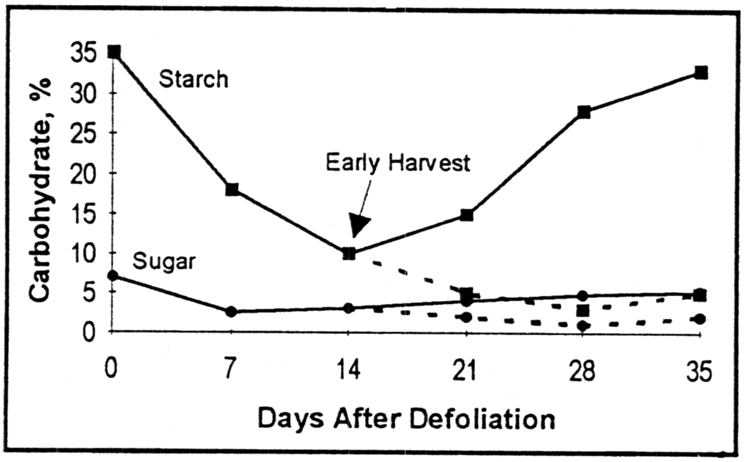

Figure 1. Starch and sugar concentrations (% of dry wt) of alfalfa taproots after defoliation on Day 0 with uninterrupted shoot regrowth (solid lines), or with a second (early) harvest on Day 14 of regrowth (broken line).

Harvesting also severely disrupts alfalfa N metabolism. Within hours of defoliation, dinitrogen fixation, the primary process through which alfalfa obtains its N, declines to zero. This very energy-consuming process, is dependent upon photosynthesis to supply the energy needed to convert atmospheric N into plant-usable forms. Dinitrogen fixation is very low for two to three weeks after harvest until shoot regowth is sufficient to supply photosynthate to the root nodules where dinitrogen fixation occurs. During this period, alfalfa growth depends upon alternative N sources to meet growth demands. Part of this N is supplied by taproot protein and amino acids pools (Fig. 2). After harvest there is an immediate and rapid decline in taproot amino acids. After a brief delay, taproot protein concentrations also decline. With labeling studies we have shown that the N in these taproot constituents is later recovered in the shoots. In fact, as much as 90 % of the N found in shoots on Day 10 of regowth was originally present in taproots when plants were harvested. It appears that alfalfa utilizes taproot amino acids and cannibalizes certain taproot proteins to supply regrowing shoots with the N necessary for growth. As discussed earlier with starch and sugars, frequent defoliation (14 to 21-day intervals) also depletes taproot N reserves and further increases the likelihood of stand deterioration.

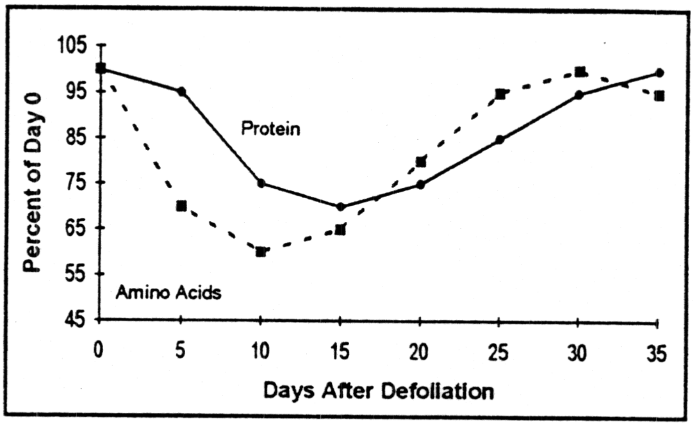

Figure 2. Relative protein and amino acid concentrations of alfalfa taproots harvested on Day 0. Data are adjusted setting concentrations present on Day 0 equal to 100.

Taproot Physiology and Alfalfa Winter Hardiness. Taproot sugars and starch are also key components of alfalfa winter hardiness. In late summer starch accumulates to high concentrations in taproots (Fig. 3).

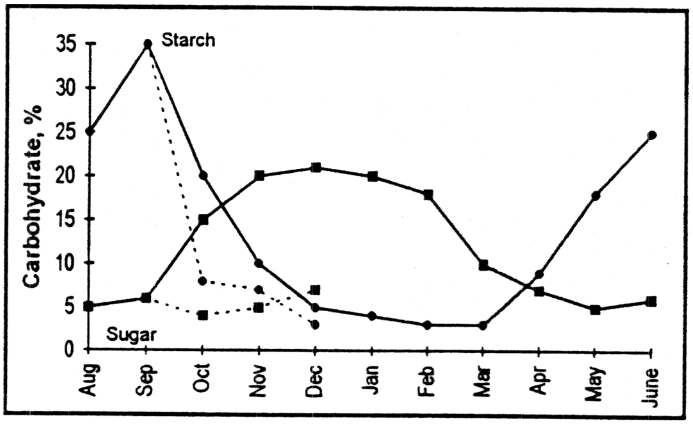

Figure 3. Starch and sugar concentrations (percent of dry wt.) in alfalfa taproots of plants left unharvested in fall (solid lines) and that of plants which have undergone an untimely harvest in late September (broken lines). In this case, harvested plants did not survive beyond December.

Thereafter, taproot starch concentrations decline rapidly until mid-December. During this time taproot sugar concentrations increase four-fold. It is generally believed that taproot starch is not lost from roots in fall, but instead, is converted to sugars which act as cellular antifreeze. The high sugar concentrations are maintained in taproots until early March, when shoot growth resumes. It is at this time that alfalfa is at great risk of winter injury if severe cold weather returns. Less fall-dormant germplasms resume growth earlier, and grow more quickly in early spring, making them particularly susceptible to winter killing at this time. Starch accumulates in May, so that by the time first harvest arrives in late May, taproot starch reserves are again at high levels.

Untimely harvesting in fall can cause serious problems for alfalfa persistence. Defoliation stimulates shoot regrowth and in doing so, depletes starch reserves (Fig. 3). If a killing freeze occurs before alfalfa restores its root starch reserves, plants may not survive winter or have sufficient energy to grow in spring. Fall harvesting can also interrupt the accumulation of sugars in taproots and crowns and increase the likelihood that water in these tissues will freeze during winter. Death (as indicated by the termination of data collection in Fig. 3 in Dec.) is almost certain if ice forms within cells of these tissues. The ongoing controversy surrounding fall harvest management exists because, as the severity of winters vary, so does the amount of sugar and starch necessary for survival.

Protein concentrations of taproots increase 50 % in fall as alfalfa hardens for winter (Fig. 4). Some of these proteins are "storage proteins" that will be later used as a source of N. Other proteins are likely to play an important role in winter survival, but as of yet are not fully characterized.

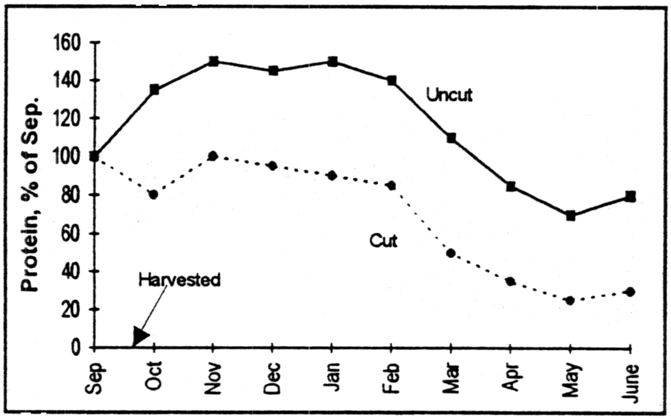

Figure 4. Protein concentrations of alfalfa taproots from September through June for unharvested plants (solid line) and plants that have undergone a late September harvest (broken line). Data are expressed as percent of taproot protein present in September.

High protein levels are maintained in taproots throughout winter, but taproot protein declines as shoot growth resumes in March. This occurs because photosynthate production is low in early spring and cannot meet the energy demands of root nodules where N is fixed. Therefore, taproot N pools are used as a source of N in spring for initial shoot growth. Thereafter, taproot protein concentrations fluctuate in response to defoliation as shown previously (Fig. 2). Defoliation in fall interrupts dinitrogen fixation and can prevent taproot protein accumulation (Fig. 4, broken line). Plants entering winter with low levels of taproot protein can survive, but they are slow to initiate growth in spring, and are at a competitive disadvantage with weeds and neighboring alfalfa plants.

CONCLUSIONS

Proper taproot function is essential for alfalfa productivity and persistence. Producers can do several things that have a direct impact on taproot function and health that can improve persistence and performance of their alfalfa .

1. Select varieties that have resistance to diseases that impair taproot function. These include bacterial wilt and *Phytophthora* root rot.

2. Inoculate seed with the proper strain of *Rhizobium* at planting. This ensures plants have the capacity to fix nitrogen, and may lessen plant dependency on taproot nitrogen reserves.

3. Maintain soil fertility and pH levels. Proper taproot function depends on both of these factors.

4. Control insect infestations. Potato leafhoppers and aphids remove sugars directly from plant, while alfalfa weevil removes leaf area thereby reducing sugar production by the plant. These insects can result in decreased protein and starch concentrations in taproots that could slow regrowth after harvest and decrease plant persistence.

5. Select a variety adapted to winters in your area. Unadapted varieties grown in temperate regions often are unable to harden properly and may not persist.