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UNDERSTANDING THE INTERACTIONS BETWEEN VEGETATION CONTROL AND FERTILIZATION IN YOUNG PLANTATIONS: SOUTHERN PINE PLANTATIONS IN THE SOUTHEAST USA

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Introduction

Historically, the practice of silviculture has focussed on controlling the composition, quantity, and structure of forest vegetation and the maintenance of site quality. As forest plantations have become important sources of fiber, fuel, and structural material, this custodial role has given way to active intervention to improve both plant and soil resources. Forest managers are finally recognizing that intensive plantation silviculture is like agronomy; both the plant and the soil need to be actively managed to optimize production. Silvicultural treatments including vegetation control and fertilization can dramatically effect site resource availability and the crop trees' ability to acquire and utilize these resources. The key to optimizing production is to use the best genetic material available and to provide resources in quantities sufficient to allow the trees' genetic potential to be realized. Effective manipulation of the genetic and site resources requires an understanding of what resources limit forest production, how these resources are affected by silvicultural treatment, and how crop trees may differ in their ability to acquire and utilize these resources. Fortunately, our understanding of the physiological and ecological processes regulating forest production has greatly increased during the last decade.

It is now generally accepted that much of the variation in wood production can be accounted for by variation in light interception. (Cannell 1989, Landsberg and Gower 1997, Linder 1987). Light interception is principally a function of the amount of leaf area and the duration of leaf area display. Empirical data from field studies with several conifer and broad-leaved species have shown that leaf area and consequently wood production are below optimum levels (Figure 1, Albaugh et al. 1998, Allen and Albaugh 1999, Benson et al. 1992, Colbert et al. 1990, Pereira et al. 1994, Snowdon and Benson 1992, Vose and Allen 1988). Low nutrient availability is a principal factor causing suboptimal levels of leaf area in many temperate humid areas (Albaugh et al 1998, Colbert et al. 1990). Low soil water availability and high vapor pressure deficits have also been shown to adversely affect leaf area in areas with growing season water deficits (Benson et al. 1992, Hennessey et al. 1992, Pereira et al. 1994).

The variation in production per unit of leaf area (referred to as growth or leaf area efficiency) can also contribute to the variation in production. Growth efficiency can vary due to differences in photosynthetic efficiency, respiration, and partitioning to various biomass components. Improved nutrient and water availability has been shown to increase photosynthetic efficiency (Linder 1987) and aboveground productivity proportionally more than belowground productivity in stand-level studies (Albaugh et al. 1998, Allen and Albaugh 1999, Gower et al. 1994).

Resource Limitations

Low soil water availability has been considered by many to be the principal resource limiting forest productivity (Gholz et al. 1990). This is probably true for seedlings that exploit a limited soil volume (Dougherty and Gresham 1988) however, once roots have fully exploited most soils, low soil water availability and/or high vapor pressure deficits will only limit production in areas with Mediterranean climates or subtropical or tropical savannas. During the rainy season, stands on these same sites may be strongly limited by nutrients. Evidence for the secondary importance of water includes the widespread growth responses found in fertilizer trials (Binkley et al. 1995) and the modest responses to water additions as compared with nutrient additions in trials that have included both (Albaugh et al. 1998, Bergh et al. 1998, Linder 1987). Clearly, in most humid temperate areas, nutrient limitations are more limiting to leaf area and consequently production than water. Fortunately, nutrient limitations are easier and less costly to ameliorate than water limitations.

To effectively ameliorate resource limitations with silvicultural treatments, forest managers must be able to identify what resources (e.g. light, water, nutrients, and oxygen) are limiting production of crop trees. A resource limitation develops when a tree or stand's production potential, given the level of all other resources, cannot be achieved because of a lack of available supply of that resource. Resource use and availability varies spatially, within a tree, a stand, and across sites and also temporally, within a day, a growing season, and over a rotation. These spatial and temporal variations in potential use and supply make the identification and ranking of importance of the resources that limit production a challenge. Since forest production is generally considered on an annual basis and at the stand level, it is very likely that more than one resource (e.g. water or different nutrients) will limit production.

Silvicultural treatments can have either positive, or, if inappropriately applied, negative effects on site resource availability and the allocation of resources to crop trees. The most obvious method for ameliorating a resource limitation is to add more of that resource. For example, nutrients can be added by fertilization. However, very significant impacts can be made on resource availability without additions. Allocating site resources to crop trees by controlling other vegetation and/or increasing the availability of existing resources by changing the soil environment can have as much, or more, impact on production as adding limiting resources (Allen et al. 1990).

Ameliorating Nutrient Limitations

In the Southeastern USA, nutrient limitations are very widespread and nutrient additions are needed on most sites to achieve optimum rates of production. Much attention has been focussed on ameliorating the gross and highly visual deficiencies of phosphorus (P). On P-deficient sites, pines routinely receive fertilizer applications that provide the equivalent 20 to 40 g of P per seedling immediately before or soon after planting (Allen 1987, Jokela et al. 1991). Fertilizers are typically applied by tractor (band or broadcast) or broadcast from the air. The sources of P that are used include diammonium phosphate (DAP), triple superphosphate (TSP), rock phosphate, or NPK blends (e.g. 10-10-10). The benefits of early P fertilization on the wet P deficient soils typical of the southeastern coastal plain have long been recognized with long-term volume gains range from 3 to over 10 m^3/ha/year on severely deficient sites (Pritchett and Comerford 1982, Gent et al. 1986). More recently, we have found that large long-term gains are possible on well-drained sites in the Gulf coastal plain (Allen and Lein 1998, Figure 2). Because the response to applications of 40 to 50 kg/ha P continue to increase for 20 or more years, P fertilization on deficient sites is viewed by many as an improvement in site quality, a Type A (Morris and Lowery 1988) or Type II (Snowdon and Waring 1984) response.

Identification of stands in need of early fertilization has been based on landscape/soil type, soil and foliar tests, and experience. With the advent of effective vegetation control, it is now apparent that early fertilization will improve growth even on sites that have not previously been considered nutrient deficient.

Non-Crop Vegetation Control

The allocation of resources to crop trees can be increased by reducing the use of resources by non-crop vegetation. Prior to planting, both mechanical (e.g. chopping, shearing, piling, and tillage) and/or chemical site preparation treatments are widely used where woody vegetation such as sprouts and seedlings of tree species, or waxy leaved brush species (e.g. ericaceous shrubs), rapidly become competitors with the planted species. Over the last decade, there has been a shift to greater use of chemical treatments as new chemicals and tank mixes have been registered that are more effective at reducing the sprouting of undesirable species, have less risk of erosion and soil damage, allow for the treatment of large areas in a short period of time, and can be less expensive. Mechanical treatments are still used where the use of herbicides is restricted and/or where debris removal or the need for soil tillage dictates the use of mechanical methods. Where competing woody vegetation is a problem and it is effectively controlled, substantial gains in survival, individual tree growth, and stand yield have been realized (Clason 1993, Glover and Zutter 1993, Zutter et al. 1995). Analyses indicate that a negative exponential relationship exists between final crop tree yield and number of hardwood stems at a young age (Glover and Zutter 1993, Figure 3).

Effective reduction of non-crop vegetative regrowth does not end with site preparation. In most areas, effective grass, herbaceous, and brush control during the first year of plantation establishment is essential for rapid early growth of the planted species. This is true for replanting of previously forest sites or reforestation of pastureland. Several very effective pre- and post- emergent herbicides are presently available and their use has resulted in early height growth gains from 1 to 2 m across a broad range of site and climatic conditions (Fortson et al. 1996, Lauer et al. 1993). On most sites, the early growth gains found with weed control do not continue to increase over time; long-term results indicate that early gains have been maintained with treated and non-treated areas showing parallel growth projectories (Lauer et al. 1993). This type of response has been described as Type B (Morris and Lowery 1988) or Type I (Snowdon and Waring 1984). On other sites, the early growth responses have been partially lost (Figure 4, Allen and Lein 1998) with time (Type C or Type III (Richardson 1993) responses). Clearly, an understanding of the resources that limit production and the effectiveness of the vegetation control treatments in ameliorating these limitations over the short and long term are needed to make projections.

Depending on the composition and quantity of the competition vegetation, plantation spacing, and the growth rate of the crop trees, additional release treatments may be needed in subsequent years to optimize growth.

Interactions between Fertilization and Vegetation Control

When fertilization and vegetation control treatments are applied, three outcomes are possible. The response to the combination may be greater than the additive effects of the individual treatments (positive interaction), the response may be additive (no interaction), or the response may be less than additive (negative interaction). The outcome of combining fertilization and vegetation control treatments is particularly difficult to predict because vegetation control is known to have positive effects on soil nutrient availability (Li 2000, Vitousek et al. 1992) and the allocation of nutrients to crop trees (Allen and Wentworth 1993, Zutter et al. 1999). To determine the likely outcome, several questions need to be addressed including:

- What resources limit production?
- What is the resource requirement of crop tree species?
- What resource limitations are being ameliorated by fertilization and by vegetation control?
- Do the treatments ameliorate the same or different resource limitations?
- How do the treatments influence competing vegetation?

Where fertilization and vegetation control ameliorate different resource limitations, their combined effects may be additive or better. A typical example occurs on moderately fertile well-drained sites where broad-leaved species can be major competitors to planted loblolly pine. On these sites, the effects of effective hardwood control and fertilization are generally more than additive because with hardwood control, the pines are able to respond to the added nutrients. Without hardwood control, the hardwoods will utilize the added nutrients and respond with increased growth resulting in increased competition for light and water resources with pine crop trees (Figure 5, Allen and Lein 1998). Another example is on grossly P-deficient wet soils where the effects of herbaceous weed control and P fertilization on loblolly pine growth are generally additive (Jokela and Morris 1998). On these sites, fertilization provides much needed P and effective herbaceous weed control increases light and water availability to young seedlings. Although weed control may result in more nutrients to the planted seedlings (Zutter et al. 1999), P additions are needed to meet loblolly pine's P requirements for optimum growth.

Where fertilization and vegetation control ameliorate the same resource limitation (i.e. nutrients), the combined treatment may be less than additive. A typical example occurs on infertile poorly-drained soils where waxy-leaved shrub species can be major competitors to planted pine (Lauer and Glover 1998, 1999, Zutter and Miller 1998). On these sites, the effects of vegetation control and fertilization are generally less than additive for slash pine (Figure 6, Pienaar et al 1998). Slash pines are very responsive to either nutrient addition or vegetation control. With shrub control, slash pines are apparently provided with enough nutrients to meet their modest requirements and the addition of nutrients elicits a good, but less than additive, response.

Based on our understanding of resources and how they are affected by fertilization and vegetation control, we hypothesize that:

- Effective vegetation control, where broad-leaved species are present, and fertilization will be more than additive for species with high nutrient requirements.
- Herbaceous weed control and fertilization will be additive.
- Effective vegetation control and fertilization will be less than additive for species with low nutrient requirements.

It is clear that obtaining optimum plantation production will require the use of integrated systems that couple intensive management of site resources and genetics. Much research is now underway to understand the interactions among silvicultural treatments and genetics. The beneficial effects of improved genetics and intensive culture appear to be at least additive (McKeand et al 1997, Shiver et al. 1998). Clonal forestry also brings new challenges. Procedures for selecting and deploying clones must be optimized with an understanding of how to effectively take advantage of genetic x environment interactions that are often found with clones.

The potential growth rates for forest plantations in the southeastern USA are very high, much higher than commonly thought just a few years ago (Sampson and Allen 1999). In the last five years, our expectations have increased dramatically. Our challenge now is to develop and implement the appropriate silvicultural systems to realize this potential in a cost effective and environmental sustainable way. To be successful will require a basic understanding of how resource availability limits forest production and how crop trees may differ in their ability to acquire and utilize these resources. Key challenges from a resource management perspective include: understanding the relative contributions of water and nutrient limitations to stand productivity across a range of site and stand developmental conditions, assessing resource limitations that are constantly changing, understanding the impacts of intensively managed plantations within a landscape context, developing people capable of making the site specific prescriptions, and securing the capital sufficient to implement those prescriptions.

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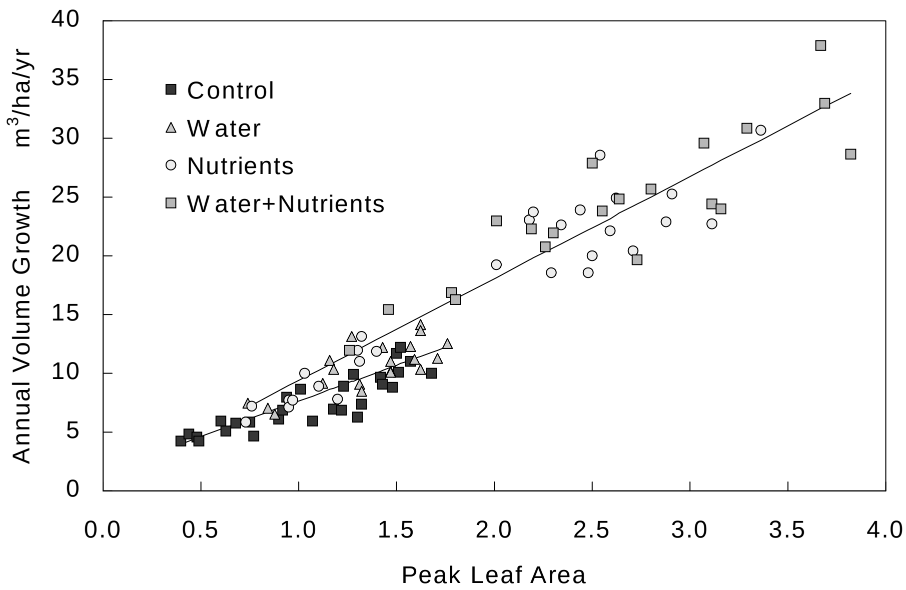
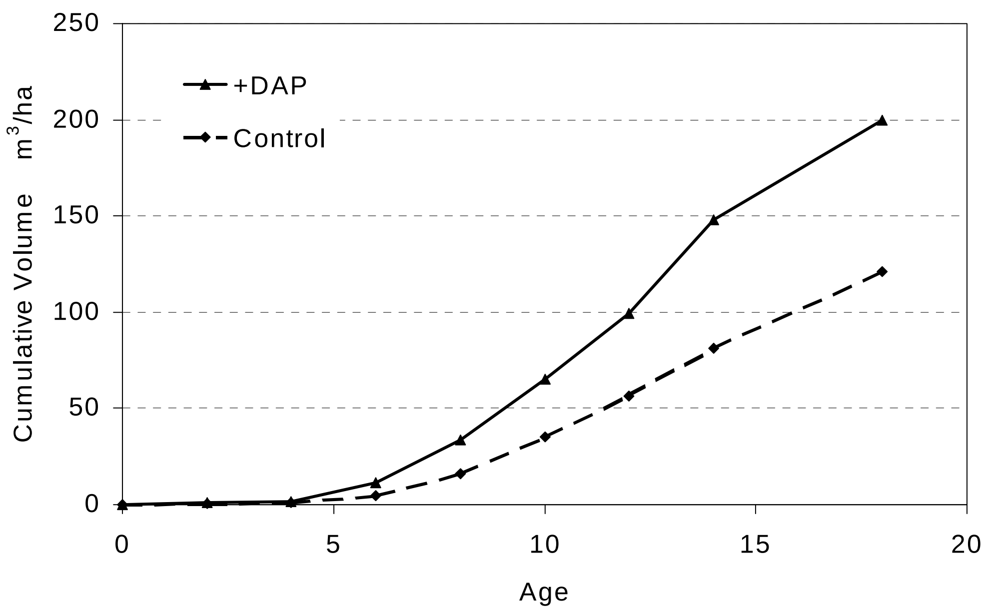
Figure Titles

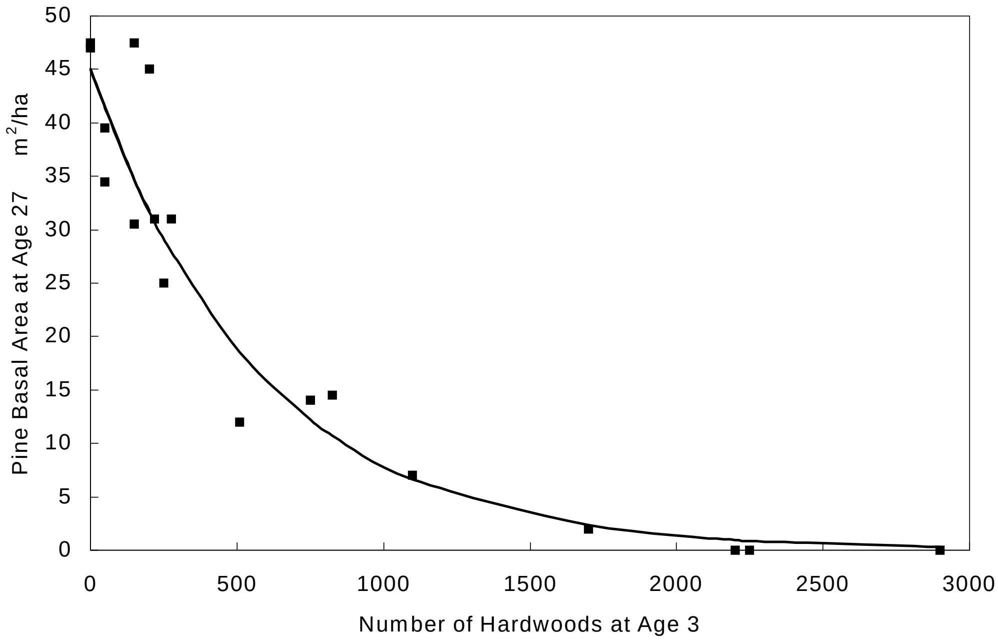
1. Relationship between annual stemwood volume growth and peak leaf area in an 8 to 16 year old loblolly pine plantation on an infertile sandy soil in North Carolina subjected optimum nutrition and/or irrigation treatments.
2. Cumulative volume growth during the first 18 years following planting for a loblolly pine plantation with and without 280 kg/ha of diammonium phosphate applied at time of planting.
3. Relationship between 27-year basal area yield and number of hardwood stem at age 3 for a loblolly pine plantation in the southeastern U.S. (From Glover and Zutter, 1993).
4. Cumulative height of 18-year old loblolly pine in the southeastern USA following vegetation control (2-years banded application of Velpar™) or no vegetation control applied at time of planting.
5. Cumulative height of six-year old loblolly pine in the southeastern USA following vegetation control (2-years banded application of Velpar™ or none) and/or fertilization (280 kg/ha of diammonium phosphate or none) applied at time of planting.
6. Cumulative volume of 17-year old slash pine in the southeastern USA following vegetation control (complete or none) and/or fertilization (280 kg/ha of diammonium phosphate or none) applied at time of planting.



Annual Volume Growth m^3/ha/yr
Peak Leaf Area
Control
Water
Nutrients
Water+Nutrients
0
5
10
15
20
25
30
35
40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0



Cumulative Volume m^3/ha
Age
+DAP
Control
0
50
100
150
200
250
0
5
10
15
20


Pine Basal Area at Age 27 m2/ha
Number of Hardwoods at Age 3
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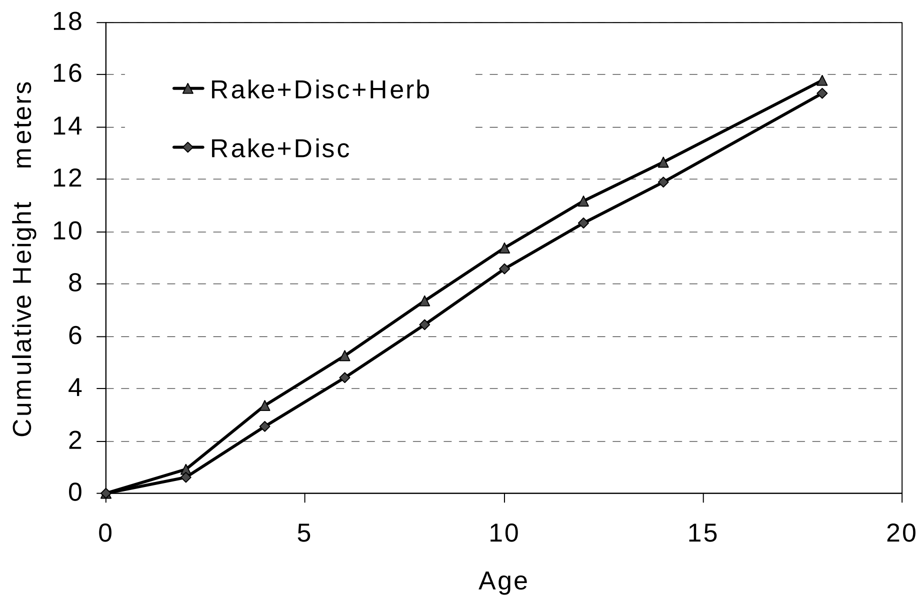
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
3000


Cumulative Height meters
Age
Rake+Disc+Herb
Rake+Disc
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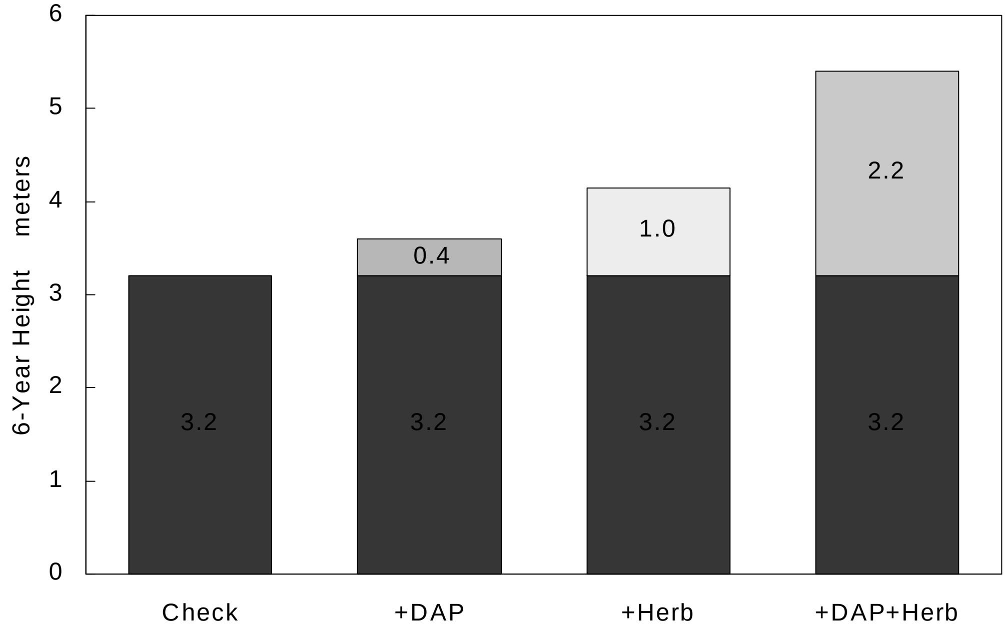
2
4
6
8
10
12
14
16
18
0
5
10
15
20


6-Year Height meters
0
1
2
3
4
5
6
3.2
3.2
0.4
3.2
1.0
3.2
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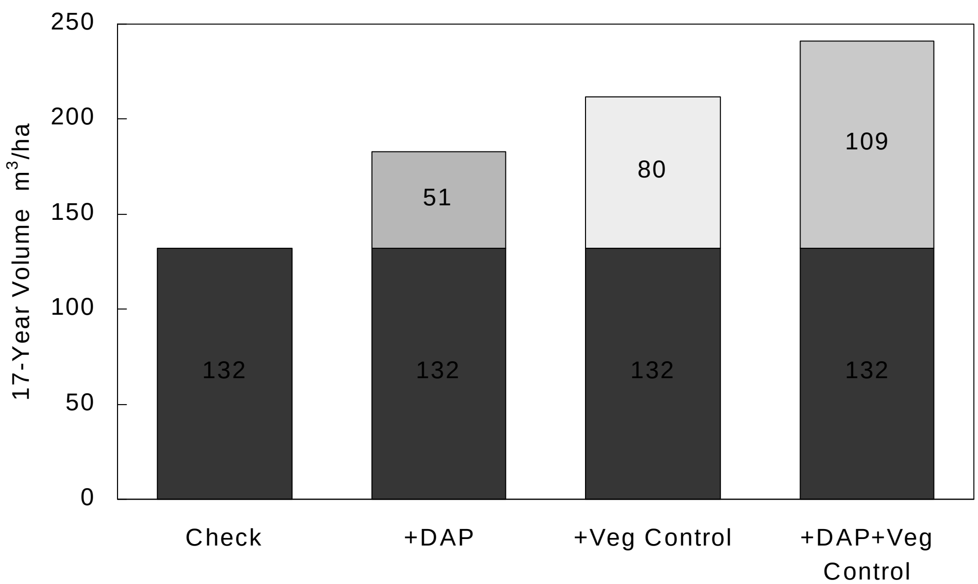
+DAP
+Herb
+DAP+Herb


17-Year Volume m3/ha
0
50
100
150
200
250
132
132
51
132
80
132
109
Check
+DAP
+Veg Control
+DAP+Veg Control