Aspects of Applied Biology 44, 1996
Vegetation management in forestry, amenity and conservation areas:
Managing for multiple objectives

Dormant season application of broad spectrum herbicides in forestry

By IAN WILLOUGHBY

Forestry Commission Research Division, Forest Research Station, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH, UK

Summary

The control of competitive vegetation is essential for successful tree establishment. Some herbicides control newly germinating weeds, others control established weeds by directed sprays which avoid the crop trees. Broad spectrum herbicides are needed for spraying over the dormant trees, to clear up a site prior to the application of soil acting herbicides in the spring. In an experimental trial, two rates of glyphosate, glufosinate ammonium and amitrole were sprayed over 7 coniferous and 10 broadleaved species, in January and March. Glyphosate at 1.5 litres per hectare of product was a safe overall treatment for conifers. Glufosinate ammonium was safe at 5 litres per hectare in March for broadleaves. Amitrole applied at 20 litres per hectare was only safe when applied over poplar and willow cuttings in March.

Key words: Glufosinate ammonium, glyphosate, amitrole, farm woodlands, short rotation coppice, weeding, herbicides

Introduction

Newly planted trees on fertile lowland ex-agricultural sites can suffer severe moisture and nutrient competition from rapid and profuse weed growth. Previous Forestry Commission trials have used soil acting herbicides to control germinating seedlings (Williamson, MacDonald and Nowakowski, 1992). Current research is investigating selective foliar acting herbicides to spray over trees for control of established weeds that emerge after the herbicidal effect of soil acting herbicides has diminished. Most soil acting herbicides approved for farm forestry will only control germinating seedlings, and hence should only be applied to weed-free sites. Established weeds, need to be controlled later in the growing season using spot applications of broad spectrum herbicides, such as glyphosate. Such treatments must be applied as directed sprays, to avoid damage to crop trees and these methods are generally more expensive than overall applications. Certain selective herbicides do control established grasses but are less active against herbaceous species. It would be advantageous to identify broad spectrum herbicides that could be used to spray over trees in the dormant season through cheaper mechanised applicators. Such products could be used to control established herbaceous weeds in restocking situations, and to facilitate natural regeneration and direct sowing. Garnett and Williamson (1992) reported some success with using glyphosate over dormant trees, but results on broadleaves were too variable to allow broad recommendations for use to be made (Garnett, pers. comm.).Three products which are damaging to plants when they are actively growing, were tested in 1995 as overall applictions to dormant trees.

Materials and Methods

The tolerance of 7 coniferous and 10 broadleaved species (see Table 1-4) to, glufosinate ammonium, glyphosate and amitrole, was tested at the Forestry Commissions Research Nursery at Headley, Surrey. The site has a sandy soil of pH 4.7, and an organic matter content of approximately 2.8%. Each herbicide was applied at the recommended (R1) and three times recommended (R2) rates for effective weed control (see notes to Tables for actual rates). Applications were made in - mid winter (D1, 10.1.95) and late winter (D2, 3.3.95). The effects of each herbicide treatment on growth and survival were compared with untreated controls. The 16 treatment plots were replicated in three blocks arranged in a randomised block design. Ten trees of each species were planted in rows (5 x 25 cm) within each treatment plot. Poplar and willow were planted as unrooted cuttings, the remaining species as one year old seedlings. One block was planted in November 1993, and a further two in November 1994. When treatments were applied one block consisted of 2-year old plants with cut back willow and poplar, and two blocks consisted of 1-year old seedlings and cuttings. Herbicide applications were made at medium volume (200 litres per hectare) through blue polijet nozzles at 0.75 bar (1500 ml per minute) over the tops of the trees. Applications were made in dry frost-free conditions. The weather in the weeks preceding both treatment dates could be regarded as mild and moist. No quantitative measurement of dormancy was made, but all trees appeared to be deeply dormant at both dates - buds were tightly closed, stem elongation had ceased and leader growth had hardened, and deciduous species had dropped all needles or leaves. Assessments were made of initial height, and height and survival at the end of the following growing season (October 1995). Health assessments were also made in May, June and July (data not presented). Trees were kept weed-free throughout the growing season by hand weeding, and irrigated as necessary during the dry summer.

Results

Tables 1a and 2a give survival of conifers and height increment at the end of the growing season and Tables 1b and 2b show the same for broadleaved species.

The results in Tables 1a and 2a reflect that glufosinate ammonium caused severe and rapid chlorosis to the needles of all conifers except larch, with the most damage at the highest dose rate. Damage tended to disappear over the growing season, but was still evident to some extent in October. Survival and height increment were significantly reduced at the high dose rate compared to control, for Sitka spruce, Norway spruce, Douglas fir, Corsican pine, Scots pine and lodgepole pine (Tables 1a and 2a). Damage was worse for all conifers after the January application.

Table 1a. *Survival (%) after 1 growing season of 7 conifers following application of herbicides in dormant season*

Species	Date[1]	Rate	Control	Glufosinate ammonium	Glyphosate	Amitrole	SED[3] (df3)
Sitka spruce	D1	R1	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}[2]	4.15
(*Picea*		R2	100.00^{a}	83.33^{b}	96.67^{ab}	100.00^{a}	
sitchensis)	D2	R1	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}	
		R2	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}	
Norway spruce	D1	R1	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}	7.38
(*Picea abies*)		R2	100.00^{a}	63.33^{b}	100.00^{a}	100.00^{a}	
	D2	R1	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}	
		R2	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}	
Douglas fir	D1	R1	100.00^{a}	96.67^{a}	93.33^{a}	96.67^{a}	6.99
(*Pseudotsuga*		R2	96.67^{a}	13.33^{b}	80.00^{c}	100.00^{a}	
menziessii)	D2	R1	93.33^{a}	100.00^{a}	100.00^{a}	96.67^{a}	
		R2	100.00^{a}	83.33^{b}	100.00^{a}	96.67^{ab}	
Corsican pine	D1	R1	100.00^{a}	96.67^{a}	90.00^{a}	100.00^{a}	13.68
(*Pinus nigra*		R2	100.00^{a}	36.67^{b}	63.33^{bc}	90.00^{ac}	
var. *maritima*)	D2	R1	100.00^{a}	100.00^{a}	100.00^{a}	82.50^{b}	
		R2	100.00^{a}	86.67^{a}	93.33^{a}	96.67^{a}	
Japanese larch	D1	R1	100.00^{a}	100.00^{a}	100.00^{a}	73.33^{b}	11.32
(*Larix*		R2	100.00^{a}	96.67^{a}	100.00^{a}	50.00^{b}	
kaempferi)	D2	R1	93.33^{a}	96.67^{a}	86.67^{a}	96.67^{a}	
		R2	93.33^{a}	96.67^{a}	100.00^{a}	60.00^{b}	
Scots pine	D1	R1	100.00^{a}	86.67^{a}	100.00^{a}	96.67^{a}	9.18
(*Pinus*		R2	100.00^{a}	53.33^{b}	96.67^{a}	100.00^{a}	
sylvestris)	D2	R1	100.00^{a}	100.00^{a}	100.00^{a}	96.67^{a}	
		R2	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}	
Lodgepole pine	D1	R1	100.00^{a}	76.67^{b}	80.00^{b}	96.67^{ab}	10.69
(*Pinus contorta*)		R2	100.00^{a}	23.33^{b}	60.00^{c}	86.67^{ac}	
	D2	R1	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}	
		R2	100.00^{a}	76.67^{b}	96.67^{ab}	100.00^{a}	

Notes (for all tables)

[1] D1 = Applied 10 January
D2 = Applied 3 March
R1 = Normal rate
R2 = 3 x Normal rate

i.e. glufosinate ammonium, 5 l/ha and 15 l/ha (0.75 and 2.25 kg ai /ha)
glyphosate, 1.5 l/ha and 4.5 l/ha (0.54 and 1.62 kg ai /ha)
amitrole, 20 l/ha and 60 l/ha (4.5 and 13.5 kg ai /ha)

[2] Values within rows of means, not sharing the same letter, are significantly different at the $p<0.05$ level.

[3] SED = Standard error of difference.

For survival data, the SED given and the significance letters assigned are for the data transformed to angles. The means presented are untransformed.

Table 1b. *Survival (%) after 1 growing season of 10 broadleaves following application of herbicides in dormant season*

Species	Date[1]	Rate	Control	Glufosinate ammonium	Glyphosate	Amitrole	SED[3] (df3)
Oak	D1	R1	100.00[a]	100.00[a][2]	100.00[a]	96.67[a]	5.85
(*Quercus robur*)		R2	100.00[a]	100.00[a]	96.67[ab]	93.33[b]	
	D2	R1	100.00[a]	100.00[a]	100.00[a]	96.67[a]	
		R2	100.00[a]	100.00[a]	100.00[a]	82.22[b]	
Ash	D1	R1	96.67[a]	100.00[a]	93.33[a]	83.33[a]	11.54
(*Fraxinus*		R2	100.00[a]	80.00[a]	96.67[a]	53.33[b]	
excelsior)	D2	R1	100.00[a]	100.00[a]	90.00[a]	90.00[a]	
		R2	100.00[a]	93.33[ab]	100.00[a]	69.63[b]	
Sycamore	D1	R1	100.00[a]	100.00[a]	100.00[a]	93.33[a]	6.85
(*Acer pseudo-*		R2	100.00[a]	100.00[a]	100.00[a]	79.17[b]	
platanus)	D2	R1	100.00[a]	96.67[a]	96.67[a]	86.67[b]	
		R2	100.00[a]	100.00[a]	100.00[a]	76.67[b]	
Beech	D1	R1	100.00[a]	100.00[a]	100.00[a]	93.33[a]	9.16
(*Fagus*		R2	100.00[a]	96.67[a]	100.00[a]	56.67[b]	
sylvatica)	D2	R1	100.00[a]	96.67[a]	96.67[a]	89.63[a]	
		R2	100.00[a]	100.00[a]	100.00[a]	36.67[b]	
Cherry	D1	R1	100.00[a]	100.00[a]	100.00[a]	96.67[a]	4.59
(*Prunus avium*)		R2	100.00[a]	100.00[a]	100.00[a]	46.67[b]	
	D2	R1	100.00[a]	100.00[a]	100.00[a]	80.00[b]	
		R2	100.00[a]	100.00[a]	100.00[a]	13.33[b]	
Birch	D1	R1	100.00[a]	100.00[a]	100.00[a]	73.33[b]	5.16
(*Betula*		R2	96.67[a]	96.67[a]	100.00[a]	10.00[b]	
pendula)	D2	R1	100.00[a]	100.00[a]	100.00[a]	96.67[a]	
		R2	100.00[a]	100.00[a]	100.00[a]	70.00[b]	
Alder	D1	R1	100.00[a]	100.00[a]	100.00[a]	70.00[b]	7.62
(*Alnus*		R2	96.67[ab]	89.63[a]	100.00[a]	46.67[b]	
glutinosa)	D2	R1	96.67[a]	100.00[a]	100.00[a]	0.00[c]	
		R2	100.00[a]	100.00[a]	100.00[a]	73.33[b]	
Sweet chestnut	D1	R1	96.67[a]	96.67[a]	100.00[a]	63.33[b]	13.25
(*Castanea*		R2	96.30[a]	93.33[a]	100.00[a]	6.67[b]	
sativa)	D2	R1	96.67[a]	96.67[a]	83.33[a]	56.67[b]	
		R2	86.67[a]	96.67[a]	96.67[a]	20.00[b]	
Poplar	D1	R1	93.33[a]	96.67[a]	96.67[a]	93.33[a]	8.35
(*Populus* spp.)		R2	96.67[a]	90.00[a]	83.33[a]	90.00[a]	
	D2	R1	90.00[a]	100.00[a]	100.00[a]	93.33[a]	
		R2	100.00[a]	100.00[a]	100.00[a]	76.67[b]	
Willow	D1	R1	100.00[a]	100.00[a]	96.67[a]	90.00[a]	10.94
(*Salix* spp.)		R2	100.00[a]	76.67[b]	73.33[b]	60.00[b]	
	D2	R1	100.00[a]	100.00[a]	100.00[a]	90.00[a]	
		R2	100.00[a]	80.00[b]	100.00[a]	60.00[b]	

Table 2a. *Height increment (cm) after 1 growing season of 7 conifers following application of herbicides in dormant season*

Species	Date[1]	Rate	Control	Glufosinate ammonium	Glyphosate	Amitrole	SED[3] (df30)
Sitka spruce	D1	R1	14.79^{a}	14.81^{a}	21.98^{a}	14.11^{a2}	3.99
(*Picea*		R2	14.87^{a}	-1.79^{b}	11.85^{a}	10.20^{a}	
sitchensis)	D2	R1	13.57^{a}	15.26^{a}	13.73^{a}	15.60^{a}	
		R2	16.46^{ab}	9.20^{a}	20.40^{b}	15.52^{ab}	
Norway spruce	D1	R1	14.60^{a}	13.74^{a}	11.75^{a}	9.83^{a}	2.50
(*Picea abies)*		R2	13.80^{a}	6.68^{b}	8.20^{b}	5.27^{b}	
	D2	R1	12.05^{a}	13.36^{a}	11.48^{a}	12.87^{a}	
		R2	14.53^{ab}	13.33^{ab}	19.19^{a}	9.73^{b}	
Douglas fir	D1	R1	21.27^{a}	8.21^{b}	12.50^{b}	10.38^{b}	4.01
(*Pseudotsuga*		R2	26.13^{a}	2.33^{b}	6.59^{b}	1.07^{b}	
menziesii)	D2	R1	16.57^{a}	18.33^{a}	16.60^{a}	17.24^{a}	
		R2	20.20^{a}	6.76^{b}	17.29^{a}	16.06^{a}	
Corsican pine	D1	R1	15.93^{a}	12.67^{a}	9.93^{a}	11.06^{a}	3.29
(*Pinus nigra* var.		R2	14.27^{a}	12.47^{ab}	7.71^{ab}	6.80^{b}	
maritima)	D2	R1	13.80^{a}	14.95^{a}	15.07^{a}	13.16^{a}	
		R2	17.80^{a}	8.92^{b}	15.93^{a}	15.07^{ab}	
Japanese Larch	D1	R1	46.60^{a}	45.47^{a}	47.67^{a}	29.04^{b}	8.06
(*Larix*		R2	45.93^{a}	23.85^{b}	45.07^{a}	9.56^{b}	
kaempferi)	D2	R1	37.84^{a}	40.33^{a}	33.33^{a}	35.82^{a}	
		R2	39.46^{a}	20.89^{b}	44.53^{a}	22.04^{b}	
Scots Pine	D1	R1	21.53^{a}	19.29^{a}	20.67^{a}	19.44^{a}	3.34
(*Pinus sylvestris*)		R2	22.40^{a}	8.60^{b}	13.61^{b}	10.93^{b}	
	D2	R1	20.73^{a}	23.27^{a}	21.93^{a}	22.99^{a}	
		R2	24.47^{a}	17.13^{b}	24.00^{a}	19.67^{ab}	
Lodgepole Pine	D1	R1	14.87^{a}	9.96^{ab}	10.67^{ab}	9.29^{b}	2.75
(*Pinus contorta*)		R2	15.00^{a}	-3.97^{b}	5.66^{c}	9.73^{ac}	
	D2	R1	13.40^{a}	13.67^{a}	14.07^{a}	12.64^{a}	
		R2	14.47^{a}	8.71^{b}	11.75^{ab}	11.87^{ab}	

Table 2b. *Height increment (cm) after 1 growing season of 10 broadleaves following application of herbicides in dormant season*

Species	Date[1]	Rate	Control	Glufosinate ammonium	Glyphosate	Ametrole	SED[3] (df30)
Oak (*Quercus robur*)	D1	R1	13.20[ab]	12.00[ab][2]	21.60[a]	8.34[b]	5.32
		R2	14.47[a]	14.13[a]	11.43[a]	-9.70[b]	
	D2	R1	11.20[a]	16.13[a]	17.83[a]	9.07[a]	
		R2	17.07[a]	17.47[a]	10.23[ab]	-0.31[b]	
Ash (*Fraxinus excelsior*)	D1	R1	10.90[a]	5.67[ab]	4.63[b]	-5.03[c]	2.97
		R2	7.67[a]	3.25[a]	5.99[a]	-5.83[b]	
	D2	R1	10.13[a]	7.80[a]	4.59[a]	-0.40[b]	
		R2	8.47[a]	5.72[a]	6.60[a]	-3.73[b]	
Sycamore (*Acer pseudo-platanus*)	D1	R1	23.87[ab]	26.07[ab]	29.47[a]	14.13[b]	7.38
		R2	25.73[ab]	11.00[a]	31.00[b]	-3.89[c]	
	D2	R1	20.33[a]	20.63[a]	11.63[a]	11.93[a]	
		R2	23.73[a]	23.47[a]	26.33[a]	24.41[a]	
Beech (*Fagus sylvatica*)	D1	R1	9.33[a]	9.80[a]	13.07[a]	9.76[a]	2.95
		R2	13.33[a]	1.39[b]	8.20[ac]	2.33[bc]	
	D2	R1	11.80[a]	11.26[a]	8.12[ab]	4.80[b]	
		R2	13.33[a]	6.80[bc]	11.73[ab]	3.80[c]	
Cherry (*Prunus avium*)	D1	R1	30.13[a]	40.33[a]	35.53[a]	16.21[a]	12.91
		R2	43.53[a]	15.67[bc]	28.20[ab]	-1.50[c]	
	D2	R1	37.53[a]	28.40[a]	14.13[a]	11.44[a]	
		R2	22.53[a]	24.20[a]	29.13[a]	7.67[a]	
Birch (*Betula pendula*)	D1	R1	35.07[a]	34.60[a]	39.47[a]	35.21[a]	7.44
		R2	43.65[a]	23.21[b]	41.53[a]	29.30[ab]	
	D2	R1	34.93[a]	33.20[a]	28.53[a]	24.76[a]	
		R2	32.27[a]	36.90[a]	41.80[a]	33.18[a]	
Alder (*Alnus glutinosa*)	D1	R1	20.13[a]	18.16[a]	22.86[a]	7.77[b]	4.32
		R2	23.54[a]	9.65[b]	14.27[b]	8.54[b]	
	D2	R1	26.47[a]	19.07[a]	19.53[a]	8.70[b]	
		R2	22.73[a]	21.13[ab]	22.07[a]	13.03[b]	
Sweet Chestnut (*Castanea sativa*)	D1	R1	7.07[a]	5.76[ab]	11.60[a]	-1.16[b]	4.15
		R2	8.82[a]	8.45[a]	10.67[a]	-23.23[b]	
	D2	R1	5.49[ab]	13.20[a]	7.66[ab]	3.73[b]	
		R2	1.04[a]	6.37[a]	7.47[a]	-12.26[b]	
Poplar (*Populus* spp.)	D1	R1	102.00[a]	105.30[a]	98.77[a]	115.92[a]	16.20
		R2	101.60[ab]	103.07[ab]	71.37[b]	124.23[a]	
	D2	R1	90.66[a]	90.67[a]	85.07[a]	107.96[a]	
		R2	100.07[a]	113.67[a]	100.27[a]	125.94[a]	
Willow (*Salix* spp.)	D1	R1	157.73[ab]	190.13[a]	132.67[b]	108.57[b]	26.32
		R2	176.67[a]	136.15[ab]	119.93[b]	65.01[c]	
	D2	R1	154.13[a]	171.67[a]	128.67[a]	129.22[a]	
		R2	166.87[a]	169.53[a]	144.20[ab]	104.00[b]	

Chlorosis occurred at the higher dose rate on oak, ash, beech, cherry, birch and alder when they started to regrow, but damage was less apparent by July. Survival was not significantly affected by any application date or rate, except for a January application at the higher rate on willow. Height increments of birch, cherry, beech and alder were significantly reduced by R2 in January, and also in March for beech (Table 1b).

The recommended application rate of Glyphosate (R1) did not reduce either survival or height increment of most conifers, except for Douglas fir and lodgepole pine after the January application. There was no effect on growth from the high rate dose rate applied in March, but the same rate applied in January significantly reduced growth or survival of Douglas fir, Corsican pine, lodgepole pine, Norway spruce and Scots pine.

Characteristic glyphosate strapping was seen on ash, sycamore and willow leaves. Survival of willow was significantly reduced at the highest application rate in January. Height increments of ash and willow were significantly less after applications of glyphosate in January at the recommended rate, and also for sycamore, alder, poplar and willow at the higher dose rate.

Amitrole caused severe chlorosis to most species, across all treatment rates and dates. Only poplar and willow cuttings appeared fully healthy by July. Survival of most species except Sitka spruce, Norway spruce and Douglas fir, was significantly reduced at higher dose rates compared to the control. Survival of poplar and willow at recommended dose rates was not significantly different from the control. Some applications at recommended rates did not significantly reduce survival of Sitka spruce, Norway spruce, Corsican pine, Japanese larch, Scots pine, lodgepole pine, oak, ash, sycamore, beech, cherry, birch, but this varied between dates. Most applications gave some significant reduction in height increment compared to the control, notable exceptions being Sitka spruce and poplar at all rates and dates, and lower rate applications to Norway spruce, Douglas fir, Corsican pine, Japanese larch, Scots pine, oak, sycamore, cherry and birch but this varied between application dates. Growth increment of willow was significantly reduced at all rates and dates, except the lower rate application in March.

Discussion

Applications of glufosinate ammonium to dormant conifers (excluding larch) caused significant damage and this is an unacceptable treatment when safer alternatives are available. Glyphosate caused less damage, and the current recommendation that it can be safely applied to dormant conifers at 1.5 l/ha (Willoughby and Dewar, 1995) was confirmed.

Broadleaved species were more sensitive than conifers to glyphosate. Damage at higher dose rates occurred on sycamore, alder, poplar and willow, and also at recommended rates for ash and willow. These results confirm findings of Garnett and Williamson (1992), and suggest that there may be opportunities to use glyphosate safely, at recommended rates (1.5-2.0 l/ha) on most dormant broadleaves (excluding willow).

Glufosinate ammonium caused no damage or growth reductions to broadleaves when applied at 5 l/ha. However, height increments were reduced after applications at 15 l/ha to oak, ash, beech, cherry, birch, alder and willow. These results suggest that both glyphosate and glufosinate ammonium are safe to apply over dormant broadleaves at the recommended dose rates.

The level of damage induced by amitrole makes it an unacceptable treatment for most species, and glyphosate or glufosinate ammonium will be safer. However, amitrole proved to be the least damaging treatment for poplar cuttings. Willow was more sensitive in January but was unaffected by the 20 l/ha application in March. These results confirm the current recommendation that it is a safe treatment to apply amitrole at 20 l/ha or lower after cutback in March, although applications of 5 l/ha of glufosinate ammonium in March may be safer for willows.

January applications were more damaging than those made in March, suggesting that the trees were more susceptible in January despite expectations that trees were more dormant. All the herbicides will control weeds in March, as long as they are actively growing, and although glyphosate and amitrole work more slowly than glufosinate ammonium, they are more efficient at controlling deeply rooted perennial species. Previous studies have found variable levels of damage when glyphosate has been applied over dormant trees. (Garnett and Williamson, 1992; Garnett pers. comm.). Recommendations should take account of these findings as follows:

When overall dormant season applications are required, glufosinate ammonium at 5 l/ha can be used in March over all the broadleaved species tested in this trial, when trees are deeply dormant. For the conifers, glyphosate at 1.5-2 l/ha should be used. If applications are made to willow and poplar cuttings in March, amitrole at 2 l/ha may be a safer and more effective alternative to glufosinate ammonium.

Glyphosate and glufosinate ammonium both have full label approval for forestry use, but glufosinate ammonium can only be used between 1 March and 30 September. Amitrole is approved only for farm forestry and short rotation coppice weed control under the long-term off-label arrangements.

The implication of these results for weed control in farm woodlands and short rotation coppice will be dealt with in Willoughby and Clay (in press). Future publications will deal with weed control in natural regeneration and direct seeding systems.

Acknowledgements

Thanks are due especially to John Budd and the team at Headley Nursery who established and assessed the experiment, to Tracy Houston and Alpa Enver who provided the statistical analysis, to Chris Bailey who helped with data manipulation, and to Richard Jinks and John Morgan who made helpful comments on the text.

References

Garnett R P, Williamson D. 1992. The susceptibility of trees to over-the-top applications of glyphosate during the winter dormant season. *Aspects of Applied Biology 29, Vegetation management in forestry, amenity and conservation areas*, pp. 131-138.

Williamson D R, MacDonald H G, Nowakowski M R. 1992. Vegetation management during the establishment of farm woodlands. *Aspects of Applied Biology 29, Vegetation management in forestry, amenity and conservation areas*, pp. 203-210.

Willoughby I, Clay D. In Press. Herbicides for Farm Woodlands and Short Rotation Coppice.

Willoughby I, Dewar A. 1995. The Use of Herbicides in the Forest. Forestry Commission Fieldbook 8, HMSO.