Forest Ecology and Management 306 (2013) 275–280

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Do eucalypt plantation management practices create understory reservoirs of scarab beetle pests in the soil?

Adam Frew[a], Uffe N. Nielsen[a,b], Markus Riegler[a], Scott N. Johnson[a,*]

[a] Hawkesbury Institute for the Environment, University of Western Sydney, Locked Bag 1797, Penrith, NSW 2751, Australia
[b] School of Science and Health, University of Western Sydney, Locked Bag 1797, Penrith, NSW 2751, Australia

ARTICLE INFO

Article history:
Received 30 November 2012
Received in revised form 26 June 2013
Accepted 26 June 2013
Available online 27 July 2013

Keywords:
Fertilisation
Grass understory
Irrigation
Nematodes
Root herbivores

ABSTRACT

Eucalypt management practices can affect the population dynamics of defoliating insects. To date, research has focused on how these practices alter eucalypt physiology and chemistry, which in turn affect canopy herbivores. Management practices such as irrigation and fertilisation, however, could also shape the understory plant community and potentially improve habitats for grass root-feeding scarab beetle larvae that later can become defoliators as adults. Using a large scale factorial field experiment comprising 2560 *Eucalyptus saligna*, we investigated the effects of irrigation and fertilisation on the understory ecology of a eucalypt plantation. We specifically focussed on grass communities and populations of scarab beetles and their natural enemies (entomopathogenic nematodes, EPNs). Irrigation and fertilisation increased grass coverage by 40% and 42%, respectively, and affected grass species composition. In particular, fertilisation favoured colonisation with C_3 grasses (e.g. *Microlaena stipoides*) that have higher nitrogen concentrations over lower quality C_4 grasses (e.g. *Setaria incrassata*). Fertilisation increased the nitrogen concentration of grasses by 30% on average. Scarab abundance increased by 52% in fertilised plots, potentially due to higher nutritional quality of host plants and the dominance of nutritionally superior species. Irrigation increased soil water content, but did not promote scarab larvae abundance. The presence of EPNs, however, was 78% higher in irrigated plots, which suggests scarab larvae populations may have been controlled by EPNs. This study illustrates how plantation management practices can affect understory communities of both plants and soil invertebrates with potential for creating 'reservoirs' of scarab beetle pests.

1. Introduction

Timber plantations in Australia have increased in area by 51% over the last 10 years, with eucalypt plantations accounting for the biggest increase, now covering 0.99 million hectares (49% of total plantation area) (Gavran and Parsons, 2010). Moreover, eucalypts are becoming increasingly conspicuous as the most widely planted hardwood species in the world (Turnbull, 1999; Paine et al., 2011). Defoliating insects can cause significant damage to eucalypt plantations (Ohmart and Edwards, 1991; Paine et al., 2011). Even partial defoliation can decrease productivity and growth of eucalypts (Quentin et al., 2011). In addition to reducing transpiration rates of leaves, defoliators often render trees more susceptible to other pests and pathogens (Mackay, 1978) and frequently play a central role in plantation dieback (Jurskis, 2005). Amongst the defoliators, several species of scarab beetles (Coleoptera: Scarabaeidae) are known to sporadically cause severe damage and can even lead to widespread tree mortality (Browne, 1968; Ohmart and Edwards, 1991; Paine et al., 2011).

Many of these scarab beetles feed on grass roots during their soil-dwelling larval development before switching to eucalypts as adults. While eucalypt species vary in their susceptibility to these scarabs (Pryor and Johnson, 1981), several scarab species are considered significant pests of eucalypts. For example, the Christmas beetles (*Anoplognathus* spp.) are common defoliators and are a particular problem in several important plantation eucalypt species (Johns et al., 2004). In addition, the African black beetle (*Heteronychus arator*) is regarded as the most damaging invasive insect pest of Australian eucalypt plantations (Paine et al., 2011).

Because defoliating insects can cause widespread damage in both hardwood and softwood timber plantations, some researchers have examined how management practices might affect their ecology and population dynamics (Ciesla, 2011). In particular, the roles of irrigation and fertilisation have been investigated to determine whether these exacerbate pest problems (Nowak and Berisford, 2000; Coyle, 2002; Coyle et al., 2003; Coyle et al., 2005; Paine and Hanlon, 2010). These studies focussed on how management practices affect defoliating insects via changes in tree physiology

* Corresponding author. Tel.: +61 02 4570 1374.
E-mail address: scott.johnson@uws.edu.au (S.N. Johnson).

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.06.051

and chemistry (e.g. Hopmans et al., 2008; Paine and Hanlon, 2010; Edenius et al., 2012). Irrigation and fertilisation, however, may also affect understory plant communities and alter soil conditions, and through this influence the abundance and diversity of insect pest species. In addition to neighbouring pastures (Landsberg and Wylie, 1988), the grassy understories of eucalypt plantations are prime habitats for scarab beetle larvae, many of which respond to biotic and abiotic changes in their environment (Villani and Wright, 1990; Villani et al., 1999). The effects of management on the understory may therefore create 'reservoirs' of insect pests, particularly the root-feeding scarab beetle larvae, which then emerge as adult defoliators in spring–summer (Paine et al., 2011). Scarab beetles species have overlapping perennial generations with larvae found in the soil all year around.

Fertilisation and irrigation potentially affect root-feeding insects in different ways (Johnson and Murray, 2008). Soil moisture is often the most important property to affect root herbivores (Brown and Gange, 1990). For instance, if the soil is dry then there is risk of larval desiccation (e.g. Johnson et al., 2010), and if there is insufficient rainfall throughout spring and summer adults are often unable to emerge from the pupal stage and die (Goodyer and Nicholas, 2007). Conversely, reduced soil moisture has led to scarab outbreaks in New Zealand through improved survival (King et al., 1981). In addition, the application of fertiliser can increase the weight gain of larvae (Wightman, 1974), presumably because higher quantities of nutrients in the soil improve the nutritional quality of the roots. While valuable for indicating the likely effects of fertilisation and irrigation on root-feeding insects, these laboratory studies did not realistically replicate plantation conditions.

Using a large scale factorial field experiment comprising 2560 *Eucalyptus saligna* over an area of 5 ha, this study investigated the effects of irrigation and fertilisation on the understory ecology of a eucalypt plantation, focussing on grass communities, soil-dwelling populations of scarab beetle larvae and their natural enemies, entomopathogenic nematodes (EPNs). *Eucalyptus saligna* is a close relative of *Eucalyptus grandis*, a species that is highly susceptible to scarab beetle attack (Carnegie et al., 2008). We aimed to characterise how these factors affected grass communities (species and understory coverage), grass nutritional quality (carbon and nitrogen concentrations), canopy coverage, soil water content, together with the abundance of scarab larvae and EPNs. We hypothesised that larval abundance will be promoted by both irrigation and fertilisation through reduced beetle desiccation and increased grass quantity (coverage) and quality (nitrogen concentration), respectively. We further hypothesised that EPN abundance would be positively affected by irrigation and fertilisation as a consequence of greater host abundance.

2. Materials and methods

2.1. Site description – Hawkesbury forest experiment

The field site (5 ha) was converted from a native pasture to a paddock in 1997. The site is situated on an alluvial floodplain near the Hawkesbury River in western Sydney (Australia) at 25 m elevation (33°36′40″S, 150°44′26.5″E). The soil – described fully in Barton et al. (2010) – is of the Clarendon Formation type (Isbell, 2002), an alluvial formation of low-fertility sandy loam soils (top 70 cm) with low organic matter content (0.7%), moderate to low-fertility (available P, 8 mg kg^{-1}; exchangeable cations: K 0.19; Ca 1.0; Mg 0.28 mEq, 100 g^{-1}) and low water holding capacity. In March 2007 the site was cleared of vegetation with glyphosate herbicide (Roundup™, Scotts Australia Pty Ltd., Baulkham Hills, NSW, Australia) treatment before planting 2560 *E. saligna* (details below) in April 2007 at a density of 1000 trees ha^{-1} (2.6 × 3.85 m tree spacing). At planting, trees were supplied with insecticidal imidacloprid tablets (Initiator™, Bayer Crop Science, East Hawthorn, VIC, Australia). These tablets also contained nutrients (N, P. K, Mg) to promote initial plant growth. At this point, the site was free of understory plants. From November 2008, no pesticides or herbicides were applied and natural grass colonisation between trees was allowed. By December 2011 the grasses at the site were dominated by African Love-grass (*Eragrostis curvula*), weeping meadow grass (*Microlaena stipoides*) and couch grass (*Elymus repens*). Other grass species were present in smaller quantities, including summer grass (*Digitaria sanguinalis*), pigeon grass (*Setaria incrassata*), windmill grass (*Chloris truncata*) and cocksfoot grass (*Dactylis glomerata*).

2.2. Treatments

Sixteen plots, each containing 160 trees in 10 rows of 16 *E. saligna* (provenance Styx River, NSW; seedlot 20752 CMA from the Australian Tree Seed Centre, Clayton South, VIC, Australia) were designated for irrigation and fertilisation treatments using a 2 × 2 factorial design, such that four plots received both irrigation and fertilisation, four received just irrigation, four were fertilised only and the remaining four were left untreated. Irrigation treatments were applied every four days throughout the year using an *in situ* irrigation system that delivered water evenly throughout the plot via 65 spray heads, equivalent to 15 ml of rainfall (24,000 L per plot $year^{-1}$). Fertilisation treatments were also applied every four days between September and April at a rate of 150 kg N ha^{-1} (Nutrifeed19 and Liquid N, Amgrow Fertilisers, Lidcome, NSW, Australia). At the time of this study (January 2012) trees typically ranged in height, being 12.9 ± 0.27 m, 12.8 ± 0.29 m, 16.9 ± 0.35 m and 17.4 ± 0.32 m for control, fertilised, irrigated and both irrigated and fertilised trees, respectively. The diameter of trees at 65 cm from the ground was 15.3 ± 0.32 cm, 15.2 ± 0.63 cm, 18.1 ± 0.64 cm and 19.5 ± 0.59 cm for these same trees (B. Amiji, personal communication).

2.3. Soil and grass sampling

The sampling was performed over two weeks during January 2012 when the plantation understory had become properly established (c. three years years after the last applications of insecticides and herbicides). Larval densities had been observed to be greatest during January (G. Lopatiki, personal communication), and the new generations of larvae laid from eggs in the previous spring were sufficiently large to distinguish and recover from the soil. Four 1 m^2 sample locations from each plot were selected at random. Soil moisture was measured in each sample location using a moisture probe – three readings were taken and averaged. Grass coverage of the 1 m^2 sample areas was estimated using a 1 m^2 quadrat split into a grid of 100 sections (10 × 10 cm each). Grass and soil were taken from a 20 cm × 20 cm area in the centre of the 1 m^2 sample area, to a depth of 10 cm (c. 4 L). Grass and soil were separated and examined by hand for presence of beetle larvae, which were counted and identified to species level for scarabs and to family level for other beetles (Lawrence et al., 2000). A 1 kg sub-sample of soil was taken for nematode extraction (see below). The grasses were snap frozen and stored at −20 °C, freeze dried and ground before analysing shoots for carbon and nitrogen concentrations using a LECO TruSpec® CHN analyser. Our previous work indicated that shoot and root C and N concentrations are highly correlated in these grass species (Johnson, personal communication). Shoot concentrations were therefore used as an approximation of how treatments were affecting the plant.