Agricultural and Forest Meteorology 197 (2014) 188–205

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Adverse influences of drought and temperature extremes on survival of potential tree species for commercial environmental forestry in the dryland areas on the western slopes of New South Wales, Australia

Huiquan Bi[a,b,*], Jagrutee Parekh[a], Yun Li[c], Simon Murphy[b], Yuancai Lei[d]

[a] Forest Science and Research, New South Wales Department of Primary Industries, Level 2, 470 Church Street, Parramatta, NSW 2151, Australia
[b] School of Forest and Ecosystem Science, University of Melbourne, Australia
[c] School of Information Science and Technology, Beijing Forestry University, Beijing 100083, China
[d] Institute of Forest Resources Information Techniques, Chinese Academy of Forestry, Beijing 100091, China

ARTICLE INFO

Article history:
Received 10 February 2014
Received in revised form 28 May 2014
Accepted 7 June 2014
Available online 30 July 2014

Keywords:
Establishment risks
Aridity
Drought severity
GEE

ABSTRACT

In order to search for suitable tree species for commercial environmental forestry over the vast semiarid and drought prone areas across the western slopes of New South Wales, Australia, a large species trial involving nine selected potential species was established at 45 sites over three broad regions in 2000. A year later, the "Millennium Drought", the longest uninterrupted series of years with below median rainfall in southeast Australia since 1900, took hold and lasted until 2009. The repeated measurements of tree survival over mostly a 10 year period after planting were analyzed in relation to age, region, site type, species and four continuous climatic variables. Logistic regression models with logit as the link function were specified for the binary and binomial responses of plot survival and the survival rate of individual trees within a plot. At both levels the marginal expectations were modelled through the generalized estimating equations. The results showed that plot survival was the lowest for *Acacia mearnsii*, *Pinus pinaster* and *Corymbia variegata* at 32%, 70% and 94% respectively, while that for all other species was at least 99%. The survival rate of individual trees was the highest for *Eucalyptus camaldulensis*, *E. sideroxylon* and *E. argophloia* at 80%, 73% and 70%, respectively. They were followed by *Corymbia maculata* at 60%, *Eucalyptus* hybrid clones at 58%, *C. variegata* at 54%, and *Eucalyptus cladocalyx* at 42%. *A. mearnsii* and *P. pinaster* had the lowest survival rates of 6% and 33%. Aridity had significant adverse influence on the survival rate of *A. mearnsii*, *P. pinaster* and the *Eucalyptus* hybrid. Except for *C. maculata* and *C. variegata*, all species were significantly influenced by the adverse effects of cumulative drought severity. The mean extreme minimum temperature had significant adverse influences on *C. maculata*, *C. variegata*, *E. cladocalyx* and the *Eucalyptus* hybrid, while the mean extreme maximum temperature had significant adverse effect on *E. cladocalyx* only. The results suggest that *Eucalyptus camuldulensis* and *E. sideroxylon* were the two species most suitable to the semiarid and drought prone areas. For the two *Corymbia* species to maintain an adequate level of survival, areas with mean extreme minimum temperature below −4 °C should be avoided. More careful site selection is needed for *E. argophloia*, *E. cladocalyx* and the *Eucalyptus* hybrid for particular niche plantings because of their sensitivity to drought conditions and temperature extremes. The remaining two species, *A. mearnsii* and *P. pinaster*, are not suitable to the semiarid and drought prone environments because of their poor survival and sensitivity to adverse climatic conditions.

1. Introduction

The western slopes of the Great Dividing Range in the state of New South Wales, Australia cover a vast area extending from close to the Queensland border in the north to the state of Victoria in the south, a distance of more than 900 km. These slopes encompasses a range of biophysical attributes (Sahukar et al., 2003), but largely fall into the low to medium rainfall zone with mean annual

* Corresponding author at: Forest Science and Research, New South Wales Department of Primary Industries, Level 2, 470 Church Street, Parramatta, NSW 2151, Australia. Tel.: +61 2 8843 1172.
E-mail addresses: huiquan.bi@dpi.nsw.gov.au (H. Bi), yclei@caf.ac.cn (Y. Lei).

http://dx.doi.org/10.1016/j.agrformet.2014.06.006
0168-1923/

precipitation between 450 and 700 mm. Much of this area can be categorized as semiarid or dry sub-humid and is drought prone. The main land-use in this area has been dryland agriculture, including both grazing and cropping, and some limited farm forestry (Sahukar et al., 2003; Murphy and Sanson, 2012; Walsh et al., 2008). Like elsewhere in Australia, the conversion of native vegetation to agricultural land since European settlement more than 200 years ago has resulted in extensive clearing of forests, woodlands and other vegetation types, and resulted in significant environmental degradation (Walker et al., 1993; Bradd et al., 1997). The removal of native vegetation at such a scale has led to the increasing spread of dryland salinity and consequently reductions in agricultural productivity and sustainability (Walker et al., 1993; Bradd et al., 1997; Tuteja et al., 2003). The state-wide dryland salinity hazard map derived from spatial modelling showed that approximately 25,000 ha of NSW was already affected by dryland salinity and a further 5 million ha of land had the potential of being affected over time (Bradd et al., 1997). To ameliorate long term environmental degradation, planting trees in the parts of landscape where water tables are most likely to respond to tree planting and developing agro-forestry systems was identified and adopted as part of the integrated strategic framework at both the policy and the practical catchment and land management level (Schofield, 1992; Walker et al., 1993; DLWC, 2000; Pannell, 2001; Crosbie et al., 2007).

While tree plantings are widely recognized to have a range of environmental benefits including salinity amelioration, carbon sequestration, biodiversity, and reductions in soil erosion, there is little prospect of financial return from conventional timber production in these low to medium rainfall areas (Zorzetto and Chudleigh, 1999), except in particular niches or higher (>600 mm) rainfall areas (Schofield, 1992; Pannell, 2001). Consequently, from an afforestation perspective this problematic financial return creates difficulties for developing and implementing longer-term tree planting programs on larger scales unless there is continuing government funding or investment. Although small test sites, demonstration trials, and farm plantings have emerged sporadically in some areas over the past 20 years or more, land owners cannot be expected to bear the cost of continuingly planting trees to produce the common good of environmental benefits without any financial returns over the long run. For economic viability, the fuller range of environmental benefits of plantations on farms needs to be accounted for in addition to those associated with conventional timber production (Schofield, 1992). If markets for these environmental benefits can be found, and they can provide adequate financial contribution, then more sustainable public and private investment in environmental forestry can be expected. Government policy initiatives for integrating trees into landscapes in the low-to-medium rainfall zones (Davey et al., 2006), and initiatives for climate change mitigation which include carbon farming and developing renewable energy options have fostered the development of markets for carbon credits, bioenergy and biofuels (Macintosh and Waugh, 2012; Mitchell et al., 2012; George et al., 2012). Potentially these markets may create new income streams for farmers and landholders, and depending upon future market prices, area previously considered marginal may become economically viable for commercial environmental forestry (George et al., 2012; Mitchell et al., 2012).

In comparison to conventional commercial forestry on sites with higher rainfall and well established silvicultural regimes, commercial environmental forestry in these low to medium rainfall regions, such as the western slopes of NSW, is potentially more complex due to a much wider range of site conditions and a greater degree of climate variability for a much larger number of potential species. Associated with this greater complexity is an increased level of risk, mainly related to a greater level of uncertainty. To reduce this uncertainty, technical barriers such as those outlined by Mitchell et al. (2012) need to be addressed. Foremost among these barriers is the selection of tree species for specific sites based upon their anticipated establishment survival rates, realistic estimates of early growth and projected future yield in terms of both timber products and environmental benefits (Schofield, 1992; Mitchell et al., 2012). In semiarid and drought prone areas, the successful establishment of commercial environmental forestry plantations depends largely on the survival rates of seedlings and young trees as they are vulnerable to adverse climatic conditions during establishment (Huth et al., 2008). To ensure successful plantation establishment under a future climate with increasingly greater variability, a systematic and robust assessment of the risks posed by the adverse influences of drought and temperature extremes on the survival of seedlings and young trees is essential. However, at present there is little such information across the western slopes of NSW because of the lack of large species trials using the same genetic material and establishment techniques over a wide range of site conditions (Walsh et al., 2008). To overcome this deficiency, species demonstration trials were established jointly by the then State Forests of NSW in 2000 on 51 sites across the western slopes and the eastern section of the western plains of NSW, spanning about 750 km in latitude (Barton and Parekh, 2005). The survival and height growth of the nine trial species were assessed and summarized just before age 5 by Johnson et al. (2009). Using data from both previous and the latest field measurements of all the species trials at age 10 and of a small number of plots also at age 12, this study aims to evaluate the risks posed by the adverse influences of drought and temperature extremes on the survival of seedlings and young trees in these semiarid areas by examining the average survival of each species as a function of age, site and climatic variables. The growth and projected future yield of both timber volume and total aboveground biomass will be the subject of a subsequent study.

2. Sites, species, trial design and establishment

The species demonstration trials were initially established in 2000 at 51 sites in three broad experimental regions along the western slopes of New South Wales (Fig. 1). The northern region covers much of the north western slopes, extending from north of Moree and Inverell to south of Quirindi. The 24 sites allocated to this region are distributed across two catchment areas, Gwydir and Namoi. The central region extends from north of Dubbo to south of Orange, encompassing 18 sites in the Macquarie-Bogan catchment area. The southern region is on the southern part of the south west slopes, where 9 sites were allocated across the Murrumgidgee and Murray catchment areas. These sites covered a range of soil types and landscape positions as summarized by Barton and Parekh (2005). Among the 51 sites, nine sites, three from each region, were selected randomly from interested landowners for more intensive research, while the rest were maintained as standard demonstration sites with less intensive field measurements. By 2005, six standard sites that failed much earlier were abandoned, leaving a total of 45 viable sites, 19 in the northern region, 17 in the central region and 9 in the south region (Johnson et al., 2009). The failed sites were commonly heavily browsed by kangaroos and livestock, damaged by cockatoos and other birds, badly trampled by cattle or suffered from other severe damages, generally reflecting poor or lack of site maintenance.

Nine species were included in the trial: *Acacia mearnsii* De Wild., *Corymbia maculata* (Hook.) K.D. Hill & L.A.S. Johnson, *Corymbia citriodora* subsp. *variegata* (F. Muell.) K.D. Hill & L.A.S. Johnson, *Eucalyptus argophloia* Blakely, *E. camaldulensis* Dehn., *E. sideroxylon* Woolls., *Eucalyptus cladocalyx* F. Muell., *Pinus pinaster* Aiton., and the *Eucalyptus* hybrid clones produced from controlled crosses among selected *E. camaldulensis*, *E. globulus* Labill., and *E. grandis*