Carbon accumulation in a high country direct seeded Pinus radiata stand

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Abstract

A stand of radiata pine (*Pinus radiata*) established by direct seeding in unimproved low-productivity grassland in the South Island high country was measured at age 18 to determine growth and carbon accumulation rates. The mean annual volume increment was found to be similar to that of conventionally planted high country stands in a similar rainfall environment if a three-year time-lag allowance was made for seeded stock to reach a similar size to planted stock. Total carbon dioxide equivalents (CO_2-e) in above and below ground live, dead wood and fine litter pools was estimated to be 417 t/ha at age 18 and 804 t/ha at age 30. The mean annual CO_2-e accumulation rate amounted to 26.8 t/ha over a thirty year rotation. Returns from forest carbon accumulation are substantially greater than can be obtained from pastoral farming from similar high country environments.

Introduction

The South Island high country has large areas of low-productivity grassland that would be suitable for forest establishment by direct seeding. Field trials have shown that it is possible to establish pines in the region by direct seeding in undeveloped grassland, though not in improved, fertilised grassland because of competition from resident herbaceous species (Davis 1989, Davis *et al*. 1996). Widespread establishment of conifers as wildings in unimproved high country grasslands (Hunter and Douglas 1984, Ledgard 1988) supports the suitability of these environments for establishment by seeding. The costs of establishment by seeding are potentially lower than for conventional planting.

A field trial was established at Mt Barker (Rakaia catchment, Canterbury) in 1993 to determine if establishment of direct seeded radiata pine (Pinus radiata), Corsican pine (*P. nigra*) and Douglas fir (Pseudotsuga menziesii) could be enhanced by mycorrhizal inoculation (Davis *et al*. 1996). After the trial was completed the seedlings were left to grow on. The faster growing radiata pine suppressed the slower growing species, resulting in a stand entirely dominated by radiata pine. The opportunity was taken to measure the stand in 2011, eighteen years after seeding (Fig. 1), to determine stand growth and carbon accumulation rates.

Methods

The Mt Barker site is at an elevation of 620 m. Annual precipitation at Lake Coleridge Homestead, 2 km west of the trial site and 514 m elevation, is 900 mm. The soil is mapped as Acheron series (Soil Bureau 1968). Vegetation prior to seeding was dominated by hard tussock (*Festuca novae-zelandiae*) the low shrub *Leucopogon fraseri* and moss (*Racomitrium* spp., see vegetation in foreground of Fig. 1). In their unimproved state free draining Acheron soils are of very low productivity.

Fig. 1. Eighteen-year-old radiata pine established by direct seeding at Mt Barker. Note wilding conifer establishment in the vicinity.

The original trial consisted of 20 m long rows spaced at 1 m intervals. Each row consisted of a single species and inoculation treatment. The trial was sown with an experimental drill rig using a coulter which cut and cast to the side a ribbon of turf 100 mm wide by 20 mm deep. Within each row, seed was sown at a rate of 10 seeds per meter. Stocking at the end of the second year was estimated to be over 10,000 stems per hectare. The trial was thinned at age 5-6. In May 2011, a square plot measuring 13 m by 13 m was established in the centre of the trial. The plot contained five unevenly spaced rows (as the treatments had been applied randomly) of radiata pine, and eight rows of suppressed Corsican pine and Douglas fir. All radiata pine trees in the plot were counted and measured for diameter, and the heights of the tallest 50% of trees

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were measured. Stand basal area and volume were calculated, and carbon sequestration was estimated using the Forest Carbon Predictor (Beets *et al.*, in press).

Results and Discussion

The plot at age 18 years contained 48 trees which had a mean top height of 14.9 m and mean diameter of 14 cm (range <1 to 21.8 cm). Seventeen suppressed radiata pine trees (35%) had a diameter of less than 10 cm. The stocking of 2840 stems/ha was assumed to be that generated by the thinning at age 5-6. The live basal area was 63.8 m_2/ha and the volume was 345 m3/ha, giving mean annual basal area and volume increments of 3.0 m_2/ha and 19.2 m^3/ha respectively. The volume increment is lower than the value (24.0 m^3/ha) reported by Ledgard and Belton (1985) for radiata pine stands located in a similar precipitation (800–1000 mm) zone in the Canterbury high country. The lower value may be partly attributed to the young age of the stand compared to Ledgard and Belton's stands (which averaged 43 years and 650 stems/ha), however the difference is more likely to be because the Mt Barker stand was established from seed. Seedlings measured at the end of the first growing season had an average height of 45 mm, indicating that it would take two to three years for seedlings to develop to the height of planted seedlings. If a three year growth lag is assumed for seeded stock, the Mt Barker stand would have had an effective age of 15 years at measurement, giving a current annual volume increment of 23.0 m^3/ha, similar to that of Ledgard and Belton (1985) for stands in a similar rainfall environment.

The Forest Carbon Predictor showed the plot to contain a total of 417 tonnes/ha of CO_2-e at age 18 years, of which 321 tCO_2-e/ha was contained in the above ground live pool, 66 t was in the below ground live pool, 27 t was fine litter and 3 t of dead wood had accumulated (Fig. 2). Predicted total CO_2 accumulation at age 30 amounted to 804 t/ha (Fig. 2), equivalent to an annual accumulation rate of 26.8 tCO_2/ha. The very high stocking (2840 stems /ha) arising from the high seeding rate (38500 seeds per hectare [1.3 kg/ha]) resulted in the high accumulation of carbon in the relatively low productivity site (300Index 8 m^3/ha/year).

As the stand was seeded in 1993, it is a "Kyoto" forest for which the total carbon stocks accumulated during the 2008–2012 commitment period are eligible for carbon trading under the New Zealand Emissions Trading Scheme (MAF 2011). Total CO_2 stocks increased from 307 t/ha in January 2008 to 418 in May 2011, giving an accumulation of 110 tCO_2/ha over this period. For the whole first commitment period (5 calendar years) an estimated total of 160 t CO_2/ha

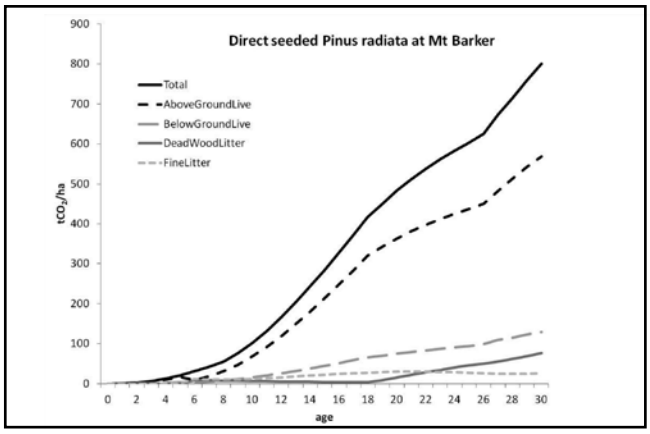

Fig. 2. Total carbon accumulation in above and below ground live wood, dead wood and fine litter components in direct seeded radiata pine at Mt Barker.

would be sequestered, or 32 t CO_2/ha/yr. Assuming that 1 t of CO_2–e is worth $25 (MAF 2011), the value of CO_2 accumulated over the first commitment period amounts to $800/ha/yr. However, the current value of CO_2 is declining so returns are likely to be lower. Returns over the commitment period for a range of CO_2 prices are:

These returns are substantially greater than can be obtained from pastoral farming on Acheron soils with a likely stocking rate of less than 0.2 sheep/ha in an unimproved state, and 1 sheep/ha if improved (Soil Bureau 1968). The gross and marginal (after subtraction of working costs) returns from South Island high country sheep and beef farms averaged $76 and $32 per stock unit respectively for the 2010/11 year, these values being somewhat greater than previous years ($46-$62 gross and $13-$26 per stock unit respectively between 2002/03 and 2009/10) (Beef + Lamb New Zealand 2011).

Introduced trees, especially exotic conifers, have the ability to spread from parent stands in the high country, where some species have become serious weeds (Hunter and Douglas 1984, Ledgard 1988), however radiata pine has a low spread risk in the region (Ledgard and Langer 1999). Relative to other species it performs well in the high country, at least up to 750 m elevation (Ledgard 1999), and because of it's low spread risk as well as the ready availability of seed, it seems to be the best species to consider for direct seeding.

The direct seeding of radiata pine can be a low cost option for establishing a carbon forest if seeding is successful and impacts like rabbit browsing are controlled. The sowing rate used in the present trial (10 seeds/m) produced 4.8 seedlings/m at the end of the first season, which declined to 2.8 seedlings/m at the end of the second season, largely because of rabbit browsing. Seedlings averaged 12 cm in height

at the end of the second season and mortality from this stage on was likely to be limited, but assuming a further decline to 2 seedlings/m, then the sowing rate used would have resulted in 10 000 seedlings/ha if sown at a row spacing of 2m, which would result in a highly stocked carbon forest sequestering carbon quickly from an early age. From the present trial currently stocked at 2840 stems/ ha, the seed rate required to achieve a similar stocking of 3000 stems/ha is 0.50 kg/ha. The high initial seeding rate of the trial might not be necessary if browsing was controlled. At current prices for unimproved seed ($500/kg) the cost of seed for seeding one ha is $250, and the cost of contract drilling is estimated to be $100/ha, giving a total establishment cost of $350/ha, a little over half the cost of planting ($640/ha) at a density of 1000 trees/ha. Additional later costs for thinning would be incurred if the seeded stand was grown for timber production, and thinning might also be necessary to maintain stand stability. However, the high stocking allowed very early and rapid carbon sequestration which would not be achieved at such a rate with planting at approximately a third of the current stocking rate. A stand established at a stocking of 1000 stems per hectare would have only accumulated approximately half the total carbon of the current stand on this site. If the stand was thinned there would be a short-term reduction in the carbon sequestration rate which would be countered by increased growth of the remaining trees.

Questions of how long carbon accumulation in high country radiata pine stands might continue for, and what might happen once carbon stocks reach their peak, are difficult to answer. The stands in Ledgard and Belton's high country survey (Ledgard and Belton 1985) had an average age of 44 years and standing volumes up to 1300 m^3/ha, indicating the potential for substantial carbon accumulation over time. The Forest Carbon Predictor indicated that carbon accumulation would reach a peak at around age 75 when there was a balance between very slow growth and decay. Because of lack of data for old radiata pine stands, this peak age is clearly highly uncertain, especially for the high country. Given the vagaries of high county climates (high wind speeds and heavy snowfalls) there is a possibility of stand collapse creating a potential carbon liability for future generations. The introduction of more persistent native or exotic 'climax' species at some stage during stand development might be considered to mitigate such a decline.

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