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Merchantable wood volume response of *P. radiata* D. Don post thinned plots on coated and uncoated urea fertilizers

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Our study was focused on whether the optimization of nutrition at various growth stages of *Pinus radiata* D. Don plantation was an important factor to increase its merchantable wood volume yield in Silviculture. The present study site is located within the 'Green Triangle' bordering the Australian states of South Australia and Victoria. A total of 24 sampling sub-plots, averaged to 12 super plots, were established in both the sites, and all the plots, except one set aside as 'controlled plot' in each site, were treated with 5 types of coated and un-coated urea fertilizers. The data on tree-height and diameter at breast height over bark (DBHOB) of all the standing trees were measured and recorded. A five-year sampling data from the 24 sub-plots consisting of two sites, namely Picks (Site 'A') and Hollands Lane (Site 'B') in post thinned condition were analysed. The specific target was to evaluate a productivity response in terms of merchantable volumes based on fertilizer types. The statistical analysis employing ANOVA, t-test, a neural network model, decision tree and box-plot model based on fertilizer treatment determined that Di-Ammonium Phosphate Entec Urea (DAPEU) fertilizer was found to be more effective in increasing productivity. As such, the merchantable wood volume increments measured after four years of application of DAPEU were found to be 48.61 m^3 ha^{-1} at Site 'A' and 41.97 m^3 ha^{-1} at Site 'B', higher than the 46.71 m^3 ha^{-1} at Site 'A' and 39.79 m^3 ha^{-1} at Site 'B' with 'control' treatment. Hence, the application of DAPEAU was found to be effective as compared to the 'control' treatment in silviculture to increase the merchantable wood volume.

Key words: Fertilizer, Periodic Annual Increment, Silviculture, South Australia, soil

The basal area increment in silviculture is impacted by early growth achieved due to appropriate plantation, thinning and nutrition (Moulinier *et al*., 2015). In this regard, we had considered to conduct our study on radiata pine (*Pinus radiata* D. Don). The *P. radiata* D. Donrotation lasts for up to 40 years, and are thinned 3 to 5 times typically in South Australia (Jeong, 2017). A general policy of Forestry in South Australia has been to apply fertilizer one to two years after thinning so as to improve the productivity of *P. radiata* D. Don (Woollons, 1985, Gavran & Parsons, 2011). The current study Site 'A' at Mount Gambier is a part of the 'Green Triangle' that has *P. radiata* D. Don plantations (O' Hehir & Nambiar, 2010). The overall aim was to test the two types of coated and slow release forms of DAP Urea fertiliser against the standard DAP Urea fertiliser used by Forestry SA for their impact on growth as a post thinning fertilizer application. The measurement of impact of fertilizer was done on the basis of merchantable wood volume produced on each plot treated with a particular fertilizer. Certain coated fertilizers are recently available in the market, but their effectiveness in the local climatic range is yet to be ascertained, and the present analysis is expected to answer it to some extent.

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A sustainable silvicultural practice can be met with a judicious use of fertiliser to meet the steady demand of timber (Boardman, 1988). Therefore, this study is, so far, first of its kind to conduct whether the use of a coated fertilizer makes any significant impact against the uncoated and control treatments. Since there is a need to increase wood supply by implementation of cost-effective methods of plantation (Sedjo & Lyon, 2015), the fertilizer application at different growth stages is important. One of the important interventions in silviculture for improving productivity is to optimize tree nutrition at various growth stages (Pretzsch *et al*., 2015). It has been found that the application of fertilizer impacts on the foliar region that promotes cell division leading to growth in wood volume (Filipescu *et al*., 2016). For instance, three years after application of N (300 kg ha^{-1}) on *P. radiata* D. Don plantation revealed a higher foliar nitrogen concentration compared to control treatment. Here, the effect of Phosphorous (20-40 kg ha^{-1}) level remained insignificant in the foliage health (Alzate *et al*., 2016; Trichet *et al*., 2009; Turner & Lambert, 2017). However after first thinning, the use of superphosphate fertilizer amounting in the range of 50-90 kg ha^{-1} at the rate of NPK 2:3:2 was recommended for all-round tree development and productivity (Donald *et al*., 1987; Turner & Lambert, 2015; Green *et al*., 2016).

An earlier study in Australia reported the application of nitrogen fertilizer at mid rotation showed an increase in growth on *P. radiata* D. Don (Alzate *et al*., 2016). On a study of a relationship between nutrient status in a ten-year-old thinned plantation of *P. radiata* D. Don leaf needles, Sheriff *et al*., (1986) reported that three-year post fertilizer application was dominated by 60%, and 50% N concentration per cm^2 leaf needle. Therefore, the timing of fertilizer application at certain growth stages is important for the plant to achieve a maximum profitability (Nyland, 2016). The temperature and soil properties also play a major factor in controlling growth rates. The drier zone soils are deficient of nitrogen, phosphorous, boron, zinc and other micronutrients (Jackson, B.E., 2008; Mead, 2013. The optimum level of soil pH for growth of *P. Radiata* D. Don is 4.1-5.7, but this species can even tolerate pH ranging from 3.6-7.1 (Romanya *et al*., 2000). As per the study of Alzate *et al*. (2016) on *P. Radiata* D. Don, clay soils did not produce any impacts on productivity; the soil at the present study Site 'A' at Mount Gambier area is, generally, highly leached (https://data.environment.sa.gov.au/Content/Publications/Soils).

Besides the role of nutrients, the role of rainfall is also an important factor on the health of *P. Radiata* D. Don stands (Turner & Lambert, 1985, Simcock *et al*., 2006). The long-lived crop plant such as *P. radiata* D. Don has to undergo several climatic and biological variations throughout its lifetime (Biswas *et al*., 2019). For instance, the variations within and between seasons due to the locations where they are planted in are impacted by hot dry summers, with occasional droughts, and cool wet winters (Nirola & Jha, 2013).The *P. radiata* D. Don have thrived in temperate areas of Southern Australia including the Green Triangle Region of South East Australia and South West Victoria.

Material and methods

The study area

The study was conducted in the two sites, namely "Picks" (Site 'A') and "Hollands Lane" (Site 'B') within the Green Triangle Region situated at South East Australia (Figure 1). The Site 'A' is located between 37° 55' 19"–37° 55' 20" S latitudes and 140° 56' 25"–140° 56' 43" E longitudes while the Site 'B' is located between 37° 31' 45"–37° 31' 54" S latitudes and 140° 25' 33"–140° 25' 42" E longitudes. This Green Triangle area supplies about 20% of 10.3 million cubic metres of the total log production in Australia (Gavran & Parsons, 2011).

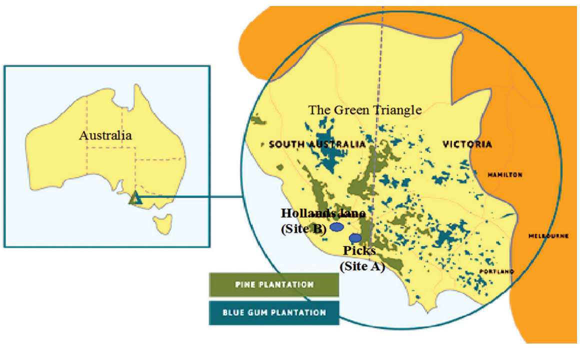

Fig. 1: The Green Triangle (not to scale); Picturesource:http://www.agtg.asn.au/the-gt-region/

Methodology

A total of 24 sampling sub-plots were established within 6 super plots in each site; each super-plot consisting of 4 sub-plots. The sub-plots used under the trial design were, however, not true replicates as the data from two plots were merged to take an average.

All the sub-plots except one plot that was set aside as 'control' in each site were treated with 5 types of coated and un-coated urea fertilizers (Table 1). Altogether, three site-visits were conducted during the course of data collection with the last one during March, 2017 so as to physically assess the status of the plantation stands. The impact of fertilizer application on 22 years old crop, planted in 1992 at Site 'A' (named" Picks") and 17 years old crop, planted in 1997 at Site 'B' (named" Hollands Lane") were analysed. The pine trees at the current treatment-plots were after second thinning stage at Site 'A' and first thinning stage at Site 'B' when the data were analysed. Both the sites receive an average annual rainfall of around 750-800 mm. The fertilizers of minimum of two tonnes were applied by ground-based skidder in bands along each trial compartment. The skidder was calibrated to disperse approximately 150 kg ha^{-1} of nitrogen. The Site 'A' (Picks) soil pH ranged from 4.1 to 5 with the soil condition consisting of Caroline sand to heavy clay. The Site 'B' (Hollands Lane) soil pH ranged from 5.3 to 6.5 with the soil condition of sandy to heavy clays.

Table 1: The ratio of fertilizer applications on the treatment-plots

S.N.	Treatment	Symbol	N:P:K ratio	Nitrogen (kg ha^{-1})	Application rate (tons ha^{-1})
1.	Forest Mix 3	FM3	9:3:6	150	1.63
2.	Forest Mix 4	FM4	14:2:0	150	1.08
3.	Application of DAPU	DAPU	38:6:0	150	0.40
4.	Application of DAPGU	DAPGU	32:10:0	150	0.47
5.	Application of DAPEU	DAPEU	32:10:0	150	0.47
6.	Control	C	nil	nil	Nil

Note: FM3= Fertilizer Mix 3, FM4= Fertilizer Mix 4, DAPU=**Di-ammonium Phosphate Urea; DAPGU=Di-ammonium Phosphate Green Urea; and DAPEU=Di-ammonium Phosphate Entec Urea**.
Source: **Forestry SA, Mount Gambier.**

The data on the diameter at breast height over bark (DBHOB), tree height and total number of trees from the Year 2010 to 2014 from Site 'A' (Picks) and Site 'B' (Hollands Lane) were obtained from the Forestry SA, Mount Gambier. In both the sampling sites, the sampling was conducted during September in 2010, October in 2011, November in 2012, late September to early August in 2013, and October in 2014. The rainfall and solar radiation intensity data were retrieved from the government website (http://www.bom.gov.au/climate/data/?ref=ftr)of the Mount Gambier Station No. 026021 for Picks (Site 'A') and Millicent Station No. 026018 for Hollands Lane (Site 'B').The data in excel sheets were moderated and colour coded. The standard deviation and mean values were calculated initially for each sub-plot within the super-plot (averaged data from sub-plots) for further analysis.

Data analysis

The variation between the plots (which was used to test the fertilizer treatment effects) was found to be more than 230 times as compared to the one between the subplots. Therefore, consideration was given to using multiple measurement technique to see the efficacy of different fertilizer treatments on the growth of *P. radiata* D. Don. Some difficulties in terms of the number of trees in each plot, age difference among the trees, and average tree volume between Site 'A' and 'B' were encountered in course of data analysis. The various statistical models and tools such as ANOVA, 'neural analysis' and 'decision tree models' were used. The' box-plot analysis was also performed primarily on different fertilizers to merchantable volume increment relations. Besides, the't-test' was also done to determine the efficacy of each fertilizer treatment.

The merchantable volumes on different fertilizer treated plots were calculated using the following equations:

Basal area $(BA) = \pi (D/2)^2$, where D stands for DBH OB (Wood *et al.*, 1999).

Wood Volume (WV)=BA×h×F, where, 'h' stands for height of tree, and 'F' for form factor value, for tapering cut-off, of 0.35 (Lu *et al.*, 2018).

Area of each plot (Ap) =l× b, where 'l' and 'b' stand for length and breadth of the plot, respectively.

Total Wood Volume (TV)=NT×WV, where, 'NT' stands for number of trees.

Note: Volume occupied by trees per hectare is calculated to determine the productivity of merchantable wood. (Nogueira *et al.*, 2008).

$$\text{Merchantable Vol. (per ha)} = \frac{TV}{Ap}$$

Results

Site 'A' fertilizer growth-plot analysis

The Site 'A' trees planted in 1992 was 22 years old when the last measurements were taken in 2014. The Site 'A' is located towards the east of Mount Gambier city, where the trees were matured and had undergone the second thinning process. The Site 'A 'has Caroline type soil with the pH ranging from 4.1 to 5 which presents an ideal growing condition for *P. radiata* D. Don (Mead, 2013, Romanya *et al.*, 2000). However, in our current study, our interest was mainly focused on the coated fertilizer efficacy that impacted on the tree-growth. Between the period of 2010-2014, the average height of the trees in the sub-plots were found to have increased from 25.3 m to 28.7 m with the fertilizer treatment 'FM 3'; from 26.2 m to 29.4 m with 'FM4'; from 26.5 m to 39.8 m with' DAPU'; from 26.2 m to 29.8 m with 'DAPGU'; and from 26.2 m to 30.1 m with 'DAPEU' while it ranged from 26.0 m to 30.2 m in the case of controlled sub-plots (Table. 2). The height gains were almost consistent (with ³3.5 m) during the period of 2010–2014 in all the sub-plots with all the treatments, which were similar to the findings of Myers *et al*. (1996).

Table 2: The average height and diameter (DBHOB)increment at Site 'A' (n=4, ±std)

Treatments	September, 2010		October, 2011		November, 2012		End of August, 2013		October, 2014	
	Height (m)	DBHOB (cm)	Height (m)	DBHOB (cm)	Height (m)	DBHOB (cm)	Height (m)	DBHOB (cm)	Height (m)	DBHOB (cm)
FM3	25.3±1.0	31.1±0.4	26.7±0.8	33.2±0.5	27.6±0.7	34.3±0.5	27.7±0.7	34.8±0.5	28.7±0.7	35.7±0.6
FM4	26.2±0.6	30.8±0.8	27.3±0.3	32.8±0.9	28.3±0.2	33.9±1.0	28.4±0.1	34.3±0.9	29.4±0.3	35.2±1.0
DAPU	26.5±0.2	31.4±0.7	28±0.4	33.5±0.8	28.7±0.6	34.6±0.8	28.8±0.5	35±0.8	29.8±0.5	36.0±0.8
DAPGU	26.2±0.6	30.3±0.7	28.1±0.3	32.2±0.7	29.2±0.2	33.2±0.8	29.1±0.2	33.6±0.8	30.1±0.2	34.5±0.9
DAPEU	26.2±0.2	30.5±0.4	28.4±0.3	32.4±0.4	29.4±0.3	33.5±0.4	29.4±0.3	33.9±0.4	30.4±0.3	35.1±0.6
Control	26.0±0.3	30.9±0.5	28.3±0.3	33.9±0.6	29.2±0.5	33.9±0.6	29.3±0.5	34.3±0.6	30.2±0.4	35.2±0.7

Similarly, the average DBHOB status after second thinning in Picks (Site 'A') ranged from 31.1 cm to 35.7 cm with the fertilizer treatment 'FM 3'; from 30.8 cm to 35.2 cm with 'FM 4'; from 31.4 cm to 36.0 cm with 'DAPU'; from 30.3 cm to 34.5 cm with' DAPGU'; and from 30.5 cm to 35.1 cm with' DAPEU' while it ranged from 30.9 cm to 35.2 cm in the case of the controlled sub-plots (Table 2).

Site 'B' fertilizer growth-plot analysis

The trees at Site 'B' were 5 years younger than those at Site 'A', and had undergone the first thinning. As the result of fertilizer treatment, the trees at Site 'B' gained height and DBH OB which were almost consistent after the Year 2011 (Table 3). Between the period of 2010-2014, the average height of the trees in the sub-plots were found to have increased from 20.4m to 25.2m with the treatment of fertilizer 'FM3'; from 20.3m to 25.4 m with'FM4'; from 19.9m to 24.1mwith'DAPU'; from 19.8m to 24.5mwith 'DAPGU'; and from 19.8m to 24.9m with 'DAPEU' while it ranged from 20.0m to 24.3m in the case of the controlled sub-plots (Table 3).

Table 3: The average tree height and diameter increment at Site 'B' (n=4, ±std.)

Treatment	Sept. 2010		Oct. 2011		Nov. 2012		Sept. 2013		Oct. 2014	
	Height (m)	DBHOB (cm)	Height (m)	DBHOB (cm)	Height (m)	DBHOB (cm)	Height (m)	DBHOB (cm)	Height (m)	DBHOB (cm)
FM3	20.4±0.3	19.5±0.7	22.5±0.3	21.0±0.8	23.3±0.7	21.8±0.8	24.5±0.9	22.3±0.8	25.2±0.7	23.1±0.8
FM4	20.3±1.3	20.8±0.4	22.8±0.7	22.6±0.5	23.7±0.4	23.5±0.4	24.8±0.5	24.0±0.5	25.4±0.5	24.9±0.5
DAPU	19.9±0.5	19.7±0.2	21.9±0.8	21.7±0.3	22.4±1.0	22.6±0.4	23.1±0.9	23.1±0.3	24.1±0.9	24.2±0.3
DAPGU	19.8±0.4	19.4±0.2	21.9±0.5	21.3±0.3	22.8±0.4	22.2±0.3	24.1±0.4	22.8±0.3	24.5±0.5	23.8±0.3
DAPEU	19.8±0.4	20.1±0.7	22.0±0.3	22.2±0.8	23.2±0.5	23.2±0.9	24.4±0.6	23.7±0.9	24.9±0.4	24.8±1.0
Control	20.0±0.4	20.0±0.3	21.7±0.4	21.6±0.4	22.3±0.5	22.5±0.4	23.6±0.4	23.0±0.4	24.3±0.4	24.0±0.5

Similarly between 2010-2014, the average DBH OB on the sub-plots of Site 'B' were found to have increased from 19.5 cm to 23.1 cm with the treatment of fertilizer 'FM3'; from 20.8 cm to 24.9 cm with 'FM4'; from 19.7 cm to 24.2 cm with 'DAPU'; from 19.4 cm to 23.8 cm with 'DAPGU'; and 20.1 cm 24.8 cm with 'DAPEU' while it ranged from 20.0 cm to 24.0 cm in the case of the controlled sub-plots (Table. 3).

Wood volume analysis

In Site 'A', the Periodic Annual Increment (PAI) of wood volume was found to be slightly less (84.98m^3 ha^{-1}) on the DAPEU-applied sub-plots in comparison with that (86.29m^3ha^{-1}) on the sub-plots with control treatment when the fertilizer application was initiated in 2010 (Table 4).In 2014, the PAI value was found to be just opposite on the controlled sub-plots, producing comparatively less volume (46.71m^3 ha^{-1}) than that (48.61m^3ha^{-1}) on the sub-plots with DAPEU-application at Site 'A'. On the other hand; at Site 'B', the 2010 DAPGU applied plots had somewhat higher PAI in 2011 (71.18 m^3 ha^{-1}) as compared to that (54.47m^3 ha^{-1}) on the controlled sub-plots. While it was found to be just opposite with a slightly less PAI (37.85m^3 ha^{-1}) on the DAPGU than that (39.79 m^3 ha^{-1}) on the control.

Table 4. The PAI on the sub-plots under different fertilizer treatments at Sites 'A' & 'B'

Treatment	PAI (m^3ha^{-1})							
	Site 'A'				Site 'B'			
	2010-11	2011-12	2012-13	2013-14	2010-11	2011-12	2012-13	2013-14
FM3	71.18	42.62	12.99	45.70	65.57	35.94	31.91	35.57
FM4	61.33	44.96	19.92	44.67	66.55	37.79	31.66	40.52
DAPU	55.94	72.76	15.95	51.70	66.75	30.31	20.68	47.79
DAPGU	87.70	48.45	12.99	50.62	71.18	39.56	31.51	37.85
DAPEU	84.98	47.80	15.19	48.61	74.39	42.61	29.48	41.97
Control	86.29	48.80	16.79	46.71	54.47	28.01	28.73	39.79

With regards to the increase in the PAI values of the trees on all the sub-plots both with and without the application of fertilizers, it will be worthwhile to discuss here regarding the annual rainfall during the period of 2011–2014 at both the sites. At the Site 'A', the annual rainfall was 847.4 mm in 2011 and 639.4 mm in 2014, while 750.9 mm in 2011 and 683 mm in 2014 at Site 'B'. The rainfall and solar-radiation data from July to December are presented in Table 5. The period of July to December is the main growing season in this region coinciding with maximum rain fall (Mead, 2013). It is to be noted that the height and diameter data were gathered during spring (September-November), a period when 90% of the growth in wood volume occurs (Squire *et al*., 1985; Colgan *et al*., 2014). When assessing the rainfall data of July to December from 2010 to 2014, the amount of rainfall received by Site 'B' is higher than that received by Site 'A' (Table 5).

Table 5: Rainfall (RF-mm) and solar-radiation (SR-watts/m^2) of Mount Gambier Station No. 026021 for Picks (A) and Millicent Station No. 026018 for Hollands Lane (B)

Year	Factor	Month											
		Jul		Aug		Sep		Oct		Nov		Dec	
		Site A	Site B	Site A	Site B	Site A	Site B	Site A	Site B	Site A	Site B	Site A	Site B
2010	RF	98.2	85.6	163	191	78.2	84.2	59.8	43.6	42.6	30.6	100.8	108
	SR	7.1	7.3	8.9	8.7	12.5	12.6	18.9	19.6	20.1	21.5	25.2	26.2
2011	RF	79.2	67.5	97.2	99.4	62	60.8	44.8	50	72.6	62	29.2	23.2
	SR	6.2	6.8	9.9	10	13.5	14.1	17.2	18	20.6	20.6	27	27.7
2012	RF	78.4	90.4	114.2	117.6	54	44.4	33	33	20	24.6	26.2	25.7
	SR	6.7	6.9	9.4	9.5	14.3	14.8	17.7	17.7	23.5	23.5	25.5	26.6
2013	RF	159	182.2	177.8	190	58.8	50.2	116.8	88.9	47.4	30	30.8	29.2
	SR	7	6.6	9.6	9.6	12.6	12.3	15.2	15.5	19.9	19.9	25.2	26.4
2014	RF	84.2	101.5	43.4	53.8	31.8	42.7	25.2	22	19.4	20.6	29	23.6
	SR	6.7	6.9	10	10.3	13.7	15.3	18.2	18.4	22.1	22.1	24.5	25.2

Source: www.bom.gov.au/climate/data.

As presented in Figure 2 (a, b), the wood volume increment in the Year 2010–11 was an offset of the fertilizer application of 2010.For instance, a sharp decline in rainfall by up to 200 mm in 2012 at Site 'A' (Fig 2a) is reflected by low productivity in 2013 (Ivkovic *et al*., 2015). The merchantable wood volumes of the trees on all the sub-plots in 2011 were found to be comparatively higher with all the treatments including control. This is attributed to the impact of optimum growing condition of the trees in terms of the PAI rather than the application of fertilizers alone.

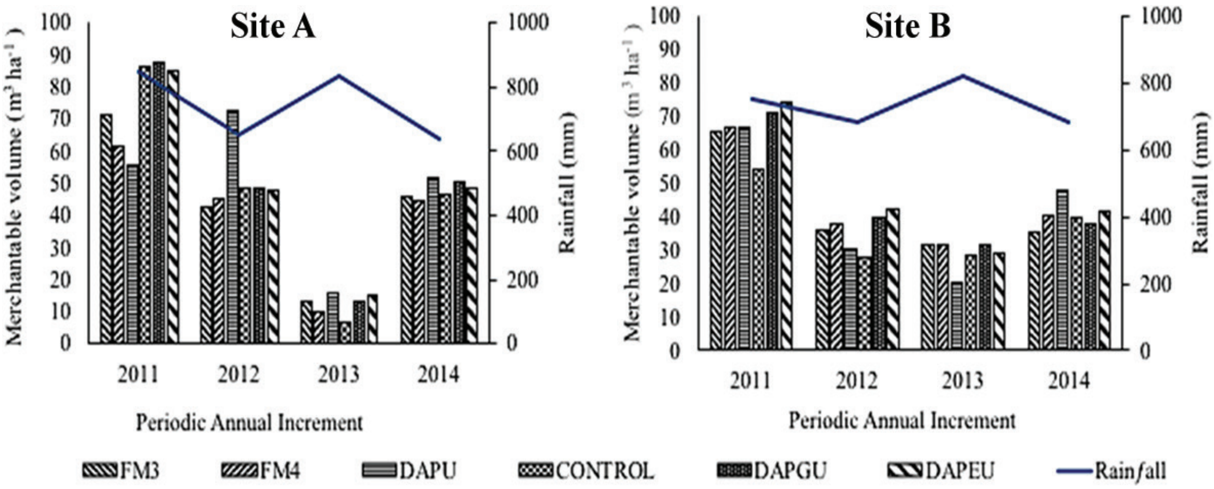

Fig. 2: The PAI based on rainfall and fertilizer application at Site 'A' and Site 'B'

ANOVA and decision tree model

The analysis of variance of growth trends of the merchantable volume against fertilizer treatments of both the Sites 'A' and B are presented in Table 6. The results of analysis could have been relied only on super-plots, but there were only 12 super-plots, so the data input was not sufficient to get a reliable result. The actual analysis performed was 24 sub-plots for the data of Site 'A' and 'B' merchantable wood volume. However, the sub-plot analysis gave very similar *p* values (0.097) to the super-plot approach.

Table 6. The analysis of variance (ANOVA) of periodic increment of wood volume

Source of variation	SS	df	MS	F	P-value	F critical
Between Groups	10,322	5	2064.4	0.15	0.97	2.4
Within Groups	752,356	54	13932.5	0	0	0
Total	**762,678**	**59**	**15996.9**	**0.15**	**0.97**	**2.4**

A classification analysis was also conducted to see whether the fertilizers were effective as a whole and individually. We used annual growth of trees in centimetre to predict the fertilizer types (including the control type). The idea is that if the predictions are accurate, then the correlation (non-linear) between the growth and the fertilizer types are strong. The two classification models were built (Hedl *et al*., 2009; Safavian & Landgrebe, 1991). One is a decision tree model while the other is a neural network mode. The performance of the models compared to the baseline is described in the Receiver Operating Characteristic (ROC) Curve (Figure 3). If the area between the decision tree model and the baseline is larger, the decision model is precise. The mis-classification rate of the decision tree model is 15%. This means in the present case; the fertilizers have impacted on the *P. radiata* D. Don trees.

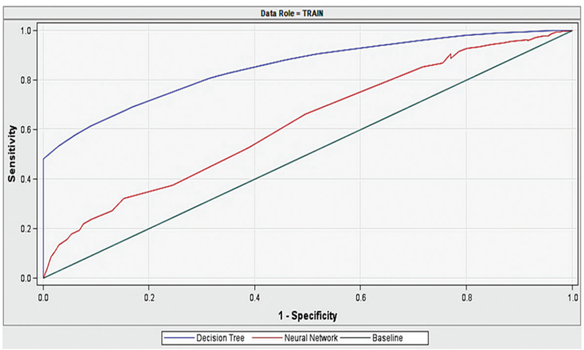

Fig. 3: The ROC-curve for decision tree and neural network model based on fertilizer treatment

An analysis on the False Positive (FP) vs. False Negative (FN) plot was performed to see whether there were any effects of fertilizers on wood volume growth. Figure 4 indicates that the FP errors are more than the FN errors. The X-axis shows the annual growth at the 4th year (the strongest predictor), and the Y-axis shows the number of wrong predictions (Tyre *et al*., 2003). A False Positive prediction (Type I error) indicated that the trees on the controlled sub-plots were growing as fast as some trees in the fertilized plots. A False Negative prediction (Type II error) showed that some trees in the fertilized plots were growing slowly like some trees in the control plots (Ellis, 2010).

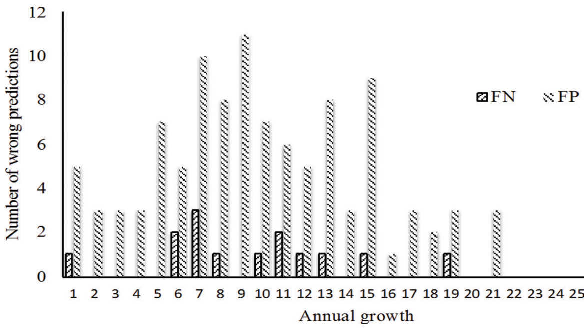

Fig. 4: The False Positive (FP) and False Negative (FN) plots with respect to fertilizer application

Discussion

The Australian silviculture for *P. radiata* D. Don managed on a rotation of 32 years has the mean annual wood volume increment of 17-20 $m^3 ha^{-1} yr^{-1}$ (Gavran & Parsons, 2011). The total area of Australia's plantation estate is about 2 million hectares, with approximately half each of softwood and hardwood (Gavran, 2015). Wood quality is influenced by well managed silviculture (Woollons & Will, 1975) and mostly by the use of micronutrients such as calcium, boron and copper (Turner & Kelly, 1981). In the present study, we focused on quantitative analysis. Overall, the treatment with DAPU at the rate of 0.04 Tha^{-1} impacted on the highest DBHOB increase from 2010 to 2014 (Table 3). The possible reason for this increased diameter could be the result of thinning and sufficient water availability (Woollons & Will, 1975; Draper, 1980; Mead *et al*., 1984; Turner & Lambert, 2015; Zhang *et al*., 2016). The nitrogen-based fertilizer plays a significant role in the foliar chlorophyll concentration with an overall 45% basal area increase in the fertilized plots over control (Fife & Nambiar, 1997).

The fertilizer application after first thinning yields a better volume for younger plantation in terms of economic returns (Woollons & Whyte, 1988). In a study of Moulinier *et al.* (2015), the thinned and fertilized plots of *P. banksia* performed better than control plots in terms of basal area growth. Here, the application of nitrogen-based fertilizer enhanced diameter growth increasing the total merchantable volume. In the present analysis, Hollands Lane (Site 'B') as compared to the Picks (Site 'A') indicated a steady growth in the height with a steady DBHOB increase on the fertilized plots than on the controlled ones. The increase in the DBHOB as a result of the first thinning is generally faster in young plantations like that of Site 'B' plots in the present study (Hebert *et al*., 2016).In the post thinning stands, the trees put on girth as the sunlight passes down through branches to aid in higher lateral surface area photosynthesis due to aeration (McMurtrie *et al*., 1990; Bloomfield *et al*., 2014). Atthe Site 'B', the first thinning had brought a considerable overall increase in girth or DBHOB. The merchantable wood volume at Site 'B' was comparatively less than at Site 'A', a condition related to the age of plantation, site productivity and thinning period (Castedo-Dorado *et al*., 2007). The terrain of Site 'B' is slightly sloppy as compared to that of Site 'A'. The surface runoff from the elevated landscape at Site 'B' cannot be ruled out limiting soil moisture retention.

The Site 'B' of the study area has a pH range of 5.5 to 6.5 with calcareous sandy to heavy clayey soil. This is a possible reason for slightly lower merchantable volume at Site 'B' compared to Site 'A' whose soil condition was better suited for the growth of *P. radiata* D. Don species (Mead, 2013; Romanya *et al*., 2000). However, the solar radiation values did not differ much at both the sites like the rainfall pattern to bring a significant difference on the PAI data. Therefore, more than the solar radiation, it is a rainfall intensity that is impacting on wood PAI (Ivkovic *et al*., 2015).

Most likely, the soils at Picks (Site 'A') is inherently more fertile and may retain moisture better than those at Hollands Lane (Site 'B'), giving more productivity (Kirschbaum, 2004; Pinkard *et al*., 2014). The solar radiation intensity also impacts on forest productivity (Caldwell *et al*., 1998). However, there was no significant radiation variation recorded in 2012 for Site 'A' compared to Site 'B' (Table 5) to impact on the PAI in 2013.The PAI of wood volume is the net increment on that particular year.A sufficient tree spacing together with fertilizer application yields good productivity along with the integration of biological and socio economical aspects of management (Mead, 2013; Fernandez *et al*., 2017).

The analysis for wood volume done using box-plot method opens scopes for discussion on whether some fertilizers performed better than the others. According to Williamson *et al.* (1989), the box-plot analysis involves "identifying patterns by using the median, the approximate quartiles and the lowest and highest data points to convey the level, spread, and symmetry of a distribution of data values". The ranking of fertilizers was conducted where the volume to fertilizer data of both the sites were put together so that each fertilizer had eight observations of the growth between 2010 and 2014 (Figure 5).

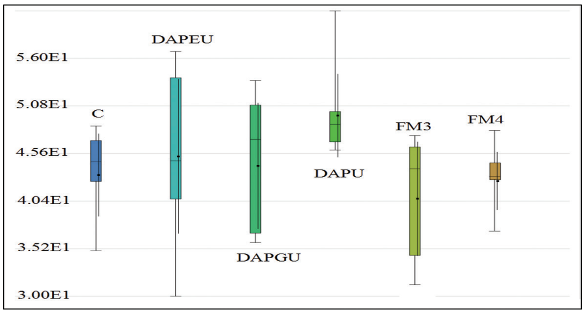

Fig. 5: The fertilizer ranking using thebox-plot method (Y-axis ranking advantage while X-axis ranking fertilizer)

There is a clear growth difference of *P. radiata* D. Don on the DAPEU, DAPGU and DAPU fertilizers against the rest (Figure 5). We further conducted a t-test to see if the mean of the wood volume of the concerned fertilizers was really different. The t-score values were negative for all fertilizers except FM4. However, the negative highest value was scored by DAPEU (-2.59) with the t-critical two tails (5%) value being 2.2.The DAPEU fertilizer is designed to release nitrogen as per the plant requirement, and is said to be more stable and adaptive to the climatic conditions of Mount Gambier in South Australia (Raymond, 2016). The DAPEU consists of active ingredients of dimethyl pyrazole phosphate (DMPP) that helps in the nitrification inhibition process, and stabilizes ammonium nitrogen in soil (Zhang *et al*., 2016). The coated DMPP Entec fertilizer

DAPEU is, therefore, found to be helpful to promote growth indicating a better yield of *P. radiata* D. Don.

Conclusion

In the present findings, DAPEU consisting of coated Di Methyl Pyrazole Phosphate (DMPP) was overall the most effective fertilizer that helped relatively increase the merchantable wood volume of *P. radiata* D. Don. However, the thinned and mature plantation coupled with rainfall advantage also increased the productivity irrespective of fertilizer treatment.

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Note: The first author Ramkrishna from Damak-9, Jhapa, Nepal dedicates his work to motherland.

References

Alzate, M. R., Rubilar, R. A., Montes, C., Allen, H. L., Fox, T. R. & Sanfuentes, E. (2016). Mid-rotation response to fertilizer by *Pinus radiata* D. Don at three contrasting sites. Journal of Forestry Science, 62 (4), pp. 153–162.

Biswas B., Nirola R., Biswas J. K., Pereg L., Willett I. R. & Naidu R. (2019). Environmental Microbial Health Under Changing Climates: State, Implication and Initiatives for High-Performance Soils. *In:*R. Lal & R. Francaviglia, (Eds.). *Sustainable Agriculture Reviews*Vol. 29. Springer, Cham.

Bloomfield, K. J., Farquhar, G. D. & Lloyd, J. (2014). Photosynthesis–nitrogen relationships in tropical forest tree species as affected by soil phosphorus availability: a controlled environment study. *Functional Plant Biology* 41 (8) : 820–832.

Boardman, R. (1988). Living on the edge-the development of silviculture in South Australian pine plantations. *Australian Forestry* 51 (3) : 135-156.

Caldwell, M. M., Björn, L. O., Bornman, J. F., Flint, S. D., Kulandaivelu, G., Teramura, A. H. & Tevini, M., 1998. Effects of increased solar ultraviolet radiation on terrestrial ecosystems. *Journal of Photochemistry and Photobiology B: Biology* 46 (1-3): 40-52.

Castedo-Dorado, F., Dieguez-Aranda, U. & Alvarez-Gonzalez, J. G. (2007). A growth model for Pinus radiata D. Don stands in north-western Spain. *Annals of Forest Science* 64 (4) : 453–465.

Colgan, M. S., Swemmer, T. & Asner, G. P. (2014). Structural relationships between form factor, wood density, and biomass in African savanna woodlands. *Trees* 28 (1): 91–102.

Donald, D. G. M., Lange, P. W., Schutz, C. J. & Morris, A. R. (1987). The application of fertilisers to pines in Southern Africa. *South African Forestry Journal* 141 (1): 53–62.

Draper, D. A. (1980). Crown biomass response of 7-year-old*Pinus radiata* D. Don to fertilisation and thinning. University of Canterbury, Christchurch, NZ.

Ellis, P. D. (2010). The essential guide to effect sizes: Statistical power, meta-analysis, and the interpretation of research results. Cambridge University Press.

Fernandez, M. P., Basauri, J., Madariaga, C., Menéndez-Miguélez, M., Olea, R. & Zubizarreta-Gerendiain, A. (2017). Effects of thinning and pruning on stem and crown characteristics of radiata pine (*Pinus radiata* D. Don). *iForest-Biogeosciences and Forestry* 10 (2) : 383.

Filipescu, C. N., Trofymow, J. A. & Koppenaal, R. S. (2016). Late-rotation nitrogen fertilization of Douglas-fir: growth response and fibre properties. *Canadian Journal of Forest Research* 47 (1) : 134–138.

Gavran, M. (2015). Australian plantation statistics 2015 update. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. http://data.da.gov.au/data/warehouse/aplnsd9ablf002/aplnsd9ablf201505/AustPlantationStats_2015_v.1.0.0.pdf (pdf 1.7mb).

Gavran, M. & Parsons, M. (2011). Australian plantation statistics 2011. Canberra: Bureau of Agricultural and Resources Economics and Sciences.

Green, P., Turner, J. & Knott, J. (2016). Effects of fertiliser applications after thinning of *Pinus radiata* on a high-elevation site in south-eastern Australia. *Australian Forestry*79 (3) : 196–202.

Hebert, F., Krause, C., Plourde, P. Y., Achim, A., Prégent, G. & Ménétrier, J. (2016). Effect of tree Spacing on tree-level volume growth, morphology, and wood properties in a 25-year-old *Pinus banksiana* plantation in the boreal forest of Quebec. *Forests* 7 (11) : 276.

Hedl, R., Svatek, M., Dancak, M., Rodzay, A. W., Salleh, A. B. & Kamariah, A. S. (2009). A new technique for inventory of permanent plots in tropical forests: a case study from lowland dipterocarp forest in Kuala Belalong, Brunei Darussalam. *Blumea-Biodiversity, Evolution and Biogeography of Plants* 54 (1-3):124–130.

Ivkovic, M., Gapare, W., Yang, H., Dutkowski, G., Buxton, P. & Wu, H. (2015). Pattern of genotype by environment interaction for radiata pine in southern Australia. *Annals of Forest Science* 72 (3) : 391–401.

Jackson, B. E. (2008). ackson, B. E. 2008. Chemical, physical, and biological factors influencing nutrient availability and plant growth in a pine tree substrate. PhD Diss. Virginia Polytechnic Institute and State Univ., Blacksburg, VA.

(19) (PDF) Container Medium pH in a Pine Tree Substrate Amended with Peatmoss and Dolomitic Limestone Affects Plant Growth. https://www. researchgate. net/publication/255696642_Container_Medium_pH_in_a_Pine_Tree_Substrate_Amended_with_Peatmoss_and_Dolomitic_Limestone_Affects_Plant_Growth#fullTextFileContent[accessed Nov 29 2020].

Jeong, J., Bolan, N. S., Harper, R. J. & Kim, C. (2017). Distribution of carbon and nitrogen in forest floor components in *Pinus radiata* plantations of different ages in South Australia. *Australian Forestry* pp.1–6.

Kirschbaum M. U. F. (2004). Direct and indirect climate change effects on photosynthesis and transpiration. *Plant Biology* 6: 242–253.

Lu, K., Bi, H., Watt, D., Strandgard, M. & Li, Y. (2018). Reconstructing the size of individual trees using log data from cut-to-length harvesters in *Pinus radiata* plantations: a case study in NSW, Australia. *Journal of Forestry Research* 29 (1) : 13–33.

McMurtrie, R. E., Rook, D. A. and Kelliher, F. M. (1990). Modelling the yield of *Pinus radiata* on a site limited by water and nitrogen. Forest Ecology and Management, 30 (1-4) : 381–413.

Mead, D. J. (2013). Sustainable Management of *Pinus Radiata* Plantations. FAO Forestry Paper No. 170. Food and Agriculture Organization, Rome.

Mead, D. J., Draper, D. & Madgwick, H. A. I. (1984). Dry matter production of a young stand of *Pinus radiata*: some effects of nitrogen fertiliser and thinning. *New Zealand Journal of Forestry Science* 14 (1) : 97–108.

Moulinier, J., Brais, S., Harvey, B. D. & Koubaa, A. (2015). Response of boreal jack pine (*Pinus banksiana* Lamb.) stands to a gradient of commercial thinning intensities, with and without N fertilization. *Forests* 6 (8) : 2678–2702.

Myers, B. J., Theiveyanathan, S., O'brien, N. D. & Bond, W. J. (1996). Growth and water use of *Eucalyptus grandis* and *Pinus radiata* plantations irrigated with effluent. *Tree Physiology* 16 (1-2) : 211–219.

Nirola, R. & Jha, P. (2013). Phytodiversity and soil study of Shiwalik hills of Ilam, Nepal: an ecological perspective. *Ecoprint: An International Journal of Ecology* 18: 77–83. doi: 10. 3126/eco. v18i0. 9414.

Nogueira, E. M., Fearnside, P. M., Nelson, B. W., Barbosa, R. I. & Keizer, E. W. H. (2008). Estimates of forest biomass in the Brazilian Amazon: New allometric equations and adjustments to biomass from wood-volume inventories. *Forest Ecology and Management* 256: (11): 1853–1867.

Nyland, R. D. (2016). Silviculture: concepts and applications. Waveland Press.

O'Hehir, J. F. & Nambiar, E. K. S. (2010). Productivity of three successive rotations of P. *radiata* plantations in South Australia over a century. *Forest Ecology and Management* 259 (10): 1857–1869.

Pinkard, E., Battaglia, M., Bruce, J., Matthews, S., Callister, A. N., Hetherington, S., Last, I., Mathieson, S., Mitchell, C., Mohammed, C. & Musk, R. (2014). A history of forestry management responses to climatic variability and their current relevance for developing climate change adaptation strategies. *Forestry: An International Journal of Forest Research* 88 (2) : 155–171.

Pretzsch, H., Del Río, M., Ammer, C., Avdagic, A., Barbeito, I., Bielak, K., Brazaitis, G., Coll, L., Dirnberger, G., Drössler, L. & Fabrika, M. (2015). Growth and yield of mixed versus pure stands of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) analysed along a productivity gradient through Europe. *European Journal of Forest Research* 134 (5): 927–947.

Raymond, J. E. (2016). Use of Stable Isotopes to Trace the Fate of Applied Nitrogen in Forest Plantations to Evaluate Fertilizer Efficiency and Ecosystem Impacts. *Forests* (2016) 7: 270

Romanya, J., Cortina, J., Falloon, P., Coleman, K. & Smith, P. (2000). Modelling changes in soilorganic matter after planting fast-growing *Pinus radiata* on Mediterranean agricultural soils. *European Journal of Soil Science* 51: 627–641.

Safavian, S. R. & Landgrebe, D. (1991). A survey of decision tree classifier methodology. IEEE transactions on systems, man, and cybernetics, 21 (3) : 660–674.

Sedjo, R. A. & Lyon, K. S. (2015). The long-term adequacy of world timber supply. Routledge. ISBN: 9781317387626.

Sheriff, D. W., Nambiar, E. K. S. and Fife, D. N. (1986). Relationships between nutrient status, carbon assimilation and water use efficiency in *Pinus radiata* (D. Don) needles. *Tree Physiology* 2 (1–3) : 73–88.

Simcock, R. C., Parfitt, R. L., Skinner, M. F., Dando, J. & Graham, J. D. (2006). The effects of soil compaction and fertilizer application on the establishment and growth of *Pinus radiata*. *Canadian Journal of Forest Research* 36 (5) : 1077–1086.

Squire, R. O., Farrell, P. W., Flinn, D. W. & Aeberli, B. C. (1985). Productivity of first and second rotation stands of radiata pine on sandy soils II. Height and volume growth at five years. *Australian Forestry 48* (2): 127–137.

Trichet, P., Bakker, M. R., Augusto, L., Alazard, P., Merzeau, D. & Saur, E. (2009). Fifty years of fertilization experiments on *Pinus pinaster* in Southwest France: the importance of phosphorus as a fertilizer. *Forest Science* 55 (5) : 390–402.

Turner, J. & Kelly, J. (1981). Relationships between soil nutrients and vegetation in a north coast forest, New South Wales. *Australia Forest Resources* 11:201–208

Turner J. & Lambert M. J. (1985). Soil phosphorus forms and related tree growth in a long-term *Pinus radiata* phosphate fertilizer trial. *Communications in Soil Science and Plant Analysis* 16 : 275–288.

Turner, J. & Lambert, M. J. (2015). Long-term growth responses to phosphatic fertilisers in a *Pinus radiata* plantation. *Australian*

Forestry 78 (4) : 207–218.

Turner, J. & Lambert, M. (2017). Analysis of foliage phosphorus requirements of radiata pine plantations. *Communications in Soil Science and Plant Analysis* 48 (18) : 2218–2229.

Tyre, A. J., Tenhumberg, B., Field, S. A., Niejalke, D., Parris, K. & Possingham, H. P. (2003). Improving precision and reducing bias in biological surveys: Estimating false□negative error rates. *Ecological Applications* 13 (6): 1790–1801.

Williamson, D. F., Parker, R. A. & Kendrick, J. S. (1989). The box plot: a simple visual method to interpret data. *Annals of Internal Medicine* 110 (11) : 916–921.

Wood, G. B., Turner, B. J. and Brack, C. L. (1999). Code of Forest Mensuration Practice: A guide to good tree measurement practice in Australia and New Zealand. Department of Forestry, Australian National University.

Woollons, R. C. (1985). Problems associated with analyses of long-term Pinus fertilizer and thinning experiments. *Australian Forest Research* 15 (4) : 495–507.

Woollons, R. C. & Will, G. M. (1975). Increasing growth in high production radiata pine stands by nitrogen fertilisers. *New Zealand Journal of Forestry*. 20 : 243–53.

Woollons, R. C. & Whyte, A. G. D. (1988). Analysis of forest fertilizer experiments: obtaining better precision and extracting more information. *Forest Science* 34 (3): 769–780.

Zhang, J., Webster, J., Young, D. H. & Fiddler, G. O. (2016). Effect of thinning and soil treatments on *Pinus ponderosa* plantations: 15-year results. *Forest Ecology and Management* 368: 123–132.