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. Don rotation 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 fertilizer against the standard DAP Urea fertilizer 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.

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 m³ ha⁻¹ at Site 'A' and 41.97 m³ ha⁻¹ at Site 'B', higher than the 46.71 m³ ha⁻¹ at Site 'A' and 39.79 m³ 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. Don rotation 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 fertilizer against the standard DAP Urea fertilizer 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 cm² 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/](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=fr) 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:

\[ \text{Basal area (BA)} = \pi \left( \frac{D}{2} \right)^2, \text{where } D \text{ stands for DBH OB (Wood et al., 1999).} \]

\[ \text{Wood Volume (WV)} = BA \times h \times F, \text{where, } h \text{ stands for height of tree, and } F \text{ for form factor value, for tapering cut-off, of 0.35 (Lu et al., 2018).} \]

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).

| Treatments | September, 2010 | October, 2011 | November, 2012 | End of August, 2013 | October, 2014 |
|------------|-----------------|---------------|-----------------|--------------------|---------------|
|            | Height (m)      | DBHOB (cm)    | Height (m)      | DBHOB (cm)         | Height (m)    |
| FM3        | 25.3±0.1        | 31.1±0.4      | 26.7±0.8        | 33.2±0.5           | 27.6±0.7      |
|            |                 |               |                 |                    | 27.1±0.7      |
| FM4        | 26.2±0.6        | 30.8±0.8      | 27.3±0.3        | 32.8±0.9           | 28.3±0.2      |
|            |                 |               |                 |                    | 28.4±0.1      |
| DAPU       | 26.5±0.2        | 31.4±0.7      | 28±0.4          | 33.5±0.8           | 28.7±0.6      |
|            |                 |               |                 |                    | 28.8±0.5      |
| DAPGU      | 26.2±0.6        | 30.3±0.7      | 28.1±0.3        | 32.2±0.7           | 29.2±0.2      |
|            |                 |               |                 |                    | 29.1±0.2      |
| DAPEU      | 26.2±0.2        | 30.5±0.4      | 28.4±0.3        | 32.4±0.4           | 29.4±0.3      |
|            |                 |               |                 |                    | 29.4±0.3      |
| Control    | 26.0±0.3        | 30.9±0.5      | 28.3±0.3        | 33.9±0.6           | 29.2±0.5      |
|            |                 |               |                 |                    | 29.3±0.5      |

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 25.4m with 'FM4'; from 19.9m to 24.1m with 'DAPU'; from 19.8m to 24.5m with '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 Height (m) | DBHOB (cm) | Oct. 2011 Height (m) | DBHOB (cm) | Nov. 2012 Height (m) | DBHOB (cm) | Sept. 2013 Height (m) | DBHOB (cm) | Oct. 2014 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   | 24.6±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 (84.98m³ ha⁻¹) on the DAPEU-applied sub-plots in comparison with that (86.29m³ ha⁻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 (46.71m³ ha⁻¹) than that (48.61m³ ha⁻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 m³ ha⁻¹) as compared to that (54.47m³ ha⁻¹) on the controlled sub-plots. While it was found to be just opposite with a slightly less PAI (37.85m³ ha⁻¹) on the DAPGU than that (39.79 m³ ha⁻¹) on the control.

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

| Treatment | 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 rainfall (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/m²) of Mount Gambier Station No. 026021 for Picks (A) and Millicent Station No. 026018 for Hollands Lane (B)

| Year | Factor | Jul Site A | Jul Site B | Aug Site A | Aug Site B | Sep Site A | Sep Site B | Oct Site A | Oct Site B | Nov Site A | Nov Site B | Dec Site A | Dec 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.
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 precision of the decision tree model is 15%. This means in the present case; the fertilizers have impacted on the P. radiata D. Don trees.

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).

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 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). At the 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 sloppier 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 the box-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.*

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