ESTIMATING CANOPY CLOSURE AND UNDERSTOREY PASTURE PRODUCTION IN NEW ZEALAND-GROWN POPLAR PLANTATIONS

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ABSTRACT

Digital images of poplar canopies in the Bay of Plenty and East Coast were captured to develop a model to predict canopy closure in poplar stands as a function of basal area. A model to predict basal area as a function of site quality, age, and stocking was also estimated. The effect of canopy closure on relative understorey pasture production in poplar stands was investigated using existing data sources. It was concluded that a simple linear function was unlikely to adequately model this relationship, and a more complex function was consequently estimated. The equations to predict basal area, canopy closure, and understorey pasture production can be used in conjunction with data describing initial livestock-carrying capacity and the seasonal distribution of pasture growth, to predict the effect of site, age, and stocking on understorey livestock-carrying capacity in poplar stands.

Keywords: agroforestry; canopy; *Populus* spp.

INTRODUCTION

Canopy closure, otherwise known as canopy density or crown closure, is defined as the ratio of horizontal area of projected tree canopy to the total ground area covered (Knowles *et al.* 1997). In effect, it is an expression of the percentage of ground area shaded by overhead foliage (Daubenmire 1959). Knowles *et al.* (1997) showed that stand canopy closure for *Pinus radiata* D.Don can be correlated with basal area and mean height ratio. Height ratio is defined as the height above ground to the base of the green crown (crown height), divided by total tree height. Inclusion of height ratio as an explanatory variable helped describe the effect of green crown pruning on canopy closure for *P. radiata*. As pruned height increases, height ratio increases and canopy closure decreases.

Canopy closure has been shown to be directly related to understorey pasture production (Knowles *et al.* 1997), and can therefore be used to predict changes in livestock-carrying capacity of pastoral farmland under forest trees. Canopy closure could also be useful as a surrogate measure for water use (Calder 1996), and an indicator of the contribution of trees to soil stability, as it is correlated with interception losses, and to a lesser extent, transpiration losses. Other than direct physical reinforcement by tree roots, these are the two important mechanisms by which trees contribute to soil stability (Maclaren 1996).

The objective of this study was to develop a model to predict canopy closure in New Zealand-grown poplar plantations. It was also intended to determine the relationship between canopy closure and relative understorey pasture production for poplars, to enable the effect on livestock-carrying capacity to be estimated.

METHOD

Stand Parameter Data

The data set comprised 40 poplar stands, of which 23 were in the Bay of Plenty and 17 on the East Coast. A number of different poplar clones and species were included in the data set (Table 1) although black poplars, particularly Italian hybrids (*P. deltoides* × *P. nigra* clones), made up the bulk of the sample.

TABLE 1–Poplar clones assessed for canopy closure

Poplar section	Clone	No. of stands assessed
Tacomahaca (balsam poplars)	*P. maximowiczii* × *P. trichocarpa* ("Androscoggin")	2
	P. maximowiczii × *P. berolinensi* ("Oxford")	1
	P. yunnanensis	1
	P. nigra × *P. trichocarpa* ("Geneva")	1
Aigeros (black poplars)	*P. deltoides* × *P. nigra* ("I-30")	2
	P. deltoides × *P. nigra* ("I-78")	5
	P. deltoides × *P. nigra* ("I-214")	4
	P. deltoides × *P. nigra* ("Robusta")	6
	P. deltoides × *P. nigra* "Flevo"	1
	P. deltoides × *P. nigra* ("Veronese")	1
	P. deltoides	3
	P. deltoides × *P. nigra* (mixed)	2
	Unidentified Italian hybrids	6
Balsam/black poplar cross	*P. deltoides* × *P. yunnanensis* "Kawa"	3
Other	Mixed clones	2
Total		40

The procedure for determining the degree of canopy closure involved capturing a series of greyscale images (Fig. 1) using a digital camera mounted on a tripod about 0.7 m above ground-level and set to view vertically into the forest canopy. Individual images were downloaded on to computer using Photoimpact® image assessment software and were converted to pure black and white images, then assessed for canopy closure using software developed at the Forest Research Institute (P. Middlemiss pers. comm.). Pixels representing tree canopy showed up as black, and those representing the sky background showed up as white. The numbers of black and white pixels were counted by computer, thus giving a measure of percentage canopy closure.

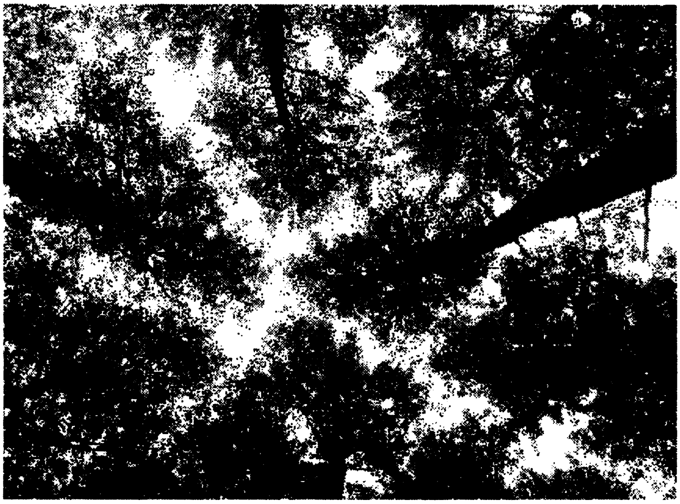

FIG. 1– Greyscale image of poplar canopy.

Usually 17 images were taken in each stand in a star-shaped pattern (Fig. 2) although in some stands as few as 14 or as many as 25 images were taken. The spacing between images was chosen so as to ensure the images did not overlap at 30 m stand height (i.e., to ensure that the images were independent). Where stands were so narrow that a circular sampling pattern would not fit, images were taken at intervals along a transect which was not parallel to the row direction. Estimated canopy closure at each site was simply calculated as the mean of the percentage canopy closure evident in the individual images. It should be noted that this methodology gives only an approximation of true canopy closure to the extent that tree stems as well as canopy are visible in many images. This effect was partly mitigated by ensuring that no images were taken within 1 m of a tree stem.

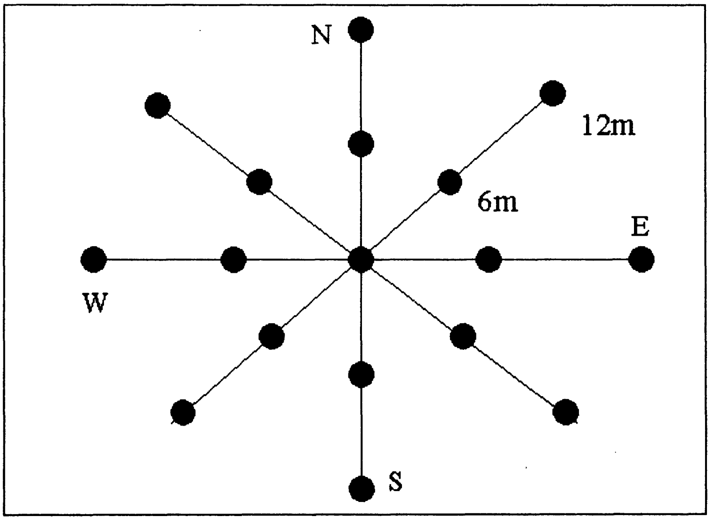

FIG. 2–Sampling design for acquiring images of canopy closure in a sample plot

Poplars are deciduous species, and so it is also necessary to model the seasonal changes in canopy closure that occur when the trees lose their leaves in winter. It is expected that due to reduced shading, relative pasture production beneath poplars will be higher during the winter months than during the summer months. Winter measurements of canopy closure were recorded for 11 of the 40 stands. These included three stands of "Robusta", three of "I-78", two of "I-30", and one each of "Androscoggin", "Geneva", and "Oxford".

In addition to canopy closure, tree height, green crown height, diameter at breast height (dbh), and stocking were measured for a sample of trees in each stand, thus allowing basal area and mean height ratio to be calculated.

Estimation of Canopy Closure, Dbh, and Basal Area Prediction Functions

The stand parameter and canopy closure data were used to estimate an equation to predict canopy closure. The relationship between summer canopy closure and winter canopy closure was also estimated, to allow prediction of seasonal differences in canopy closure and hence understorey pasture suppression.

In order to predict canopy development over time using basal area as an explanatory variable, it is necessary to be able to predict basal area for a stand of given age and stocking. In the absence of growth models for poplar, an equation was therefore developed to relate age, stocking, and site quality to mean dbh, from which mean basal area can easily be estimated. Sites were classified as either "good", "medium", or "poor". Classification of sites was subjective, based on the height of the stands, taking into account stand age.

The dbh prediction model was estimated using a total of 151 data points. These were composed of 38 of the 40 stands used for the canopy closure model (two stands were omitted as their age was unknown), and an additional 113 stands, largely based on data recorded by G.van Melle & C.G.R.Chavasse (unpubl. data) for a variety of poplar clones. The species in the data set were mostly Italian hybrids (114 data points), with the balance comprising balsam poplar clones (23 data points), newer (post 1970s) black poplar clones and black/balsam poplar crosses (10 data points), and white poplar clones* (4 data points).

Understorey Pasture Production Data

Knowles *et al.* (1997) used a canopy closure model for *P. radiata* in conjunction with data on pasture and stand growth at the Tikitere agroforestry trial to estimate a relationship between pasture production (as a percentage of open pasture), and canopy closure. A linear relationship was found, with 100% pasture production at 0% canopy closure and 0% pasture production at 67% canopy closure (the extinction point). That is,

$$PP = -1.4822CC + 100 \qquad (1)$$

where: PP = pasture production (kg dry matter/ha•yr) as a percentage of open pasture

CC = percentage canopy closure

(Note that the above coefficient is different from that in the published paper by Knowles *et al.* (1997) which contained an error.)

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* White poplars are poplars belonging to the section *Populus*.

If it is assumed that similar linear relationships also exist for other tree species, then only the extinction points need to be found in order to define these relationships. The other end of the straight line will still be at 100% pasture production and 0% canopy closure.

To date, little research has been conducted on the suppression of pasture growth under poplars. However, visual estimates of pasture dry matter relative to that of adjacent open pasture were made in the poplar stands used for the canopy closure model. Only two stands were observed to be clearly past the extinction point (i.e., no pasture production). These were also the two stands with the highest percentage canopy closure (91.6% and 87.7% respectively). All of the 11 stands with canopy closure between 75% and 85% appeared to still have a small amount of pasture production in the understorey. This indicates that the extinction point for poplar stands is likely to be at least 85% canopy closure, which is similar to *P. radiata*.

The visual pasture estimates and data reported by Guevara-Escobar *et al.* (1997) were used to estimate the likely relationship between canopy closure and understorey pasture production in poplar stands. Guevara-Escobar *et al.* (1997) found that pasture growth was suppressed by about 40% under a mature stand of *Populus deltoides* with a stocking of 37 stems/ha and mean dbh of 70.3 cm. Based on stocking and mean dbh, basal area was approximately 14.4 m^2/ha, giving predicted canopy closure of 50%.

RESULTS

Estimation of the Canopy Closure Model

Visual examination of the data suggested a strong correlation between canopy closure and basal area. A function was fitted of the form described by the Chapman Richard's model (Ratkowsky 1989), which predicts canopy closure (CC) from stand basal area (BA):

$$CC = a \times (1 - \exp(-b \times BA))^{1/c} \qquad (2)$$

where: $a = 91.9849$
$b = 0.02544$
$c = 1.9412$

The R^2 is 0.78†. The actual data and fitted function are illustrated in Fig. 3.

An increase in height ratio caused by pruning operations is expected to be reflected by a decrease in canopy closure. Therefore, a model which included height ratio (HR) as an additional explanatory variable was also estimated:

$$CC = a \times (1 - \exp(-b \times BA \times (1 - c \times (HR - 0.4))))^{1/d} \qquad (3)$$

The height ratio variable was not found to be a statistically significant addition to the model at the 5% level of significance using an F-test, regardless of whether height ratio was defined as green crown height divided by mean tree height, or green crown height divided by mean top height. The model was also estimated using green crown length as a second explanatory variable, but the effect of green crown length on canopy closure was less than that of height ratio.

Limitations on the quantity of data available for individual clones or species other than the Italian hybrids prevented the creation of individual functions. There did not appear to be

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† R^2 for the non linear model is defined as 1-SSE/CSS, where SSE is the error sum of squares of the full model and CSS is the corrected total sum of squares.

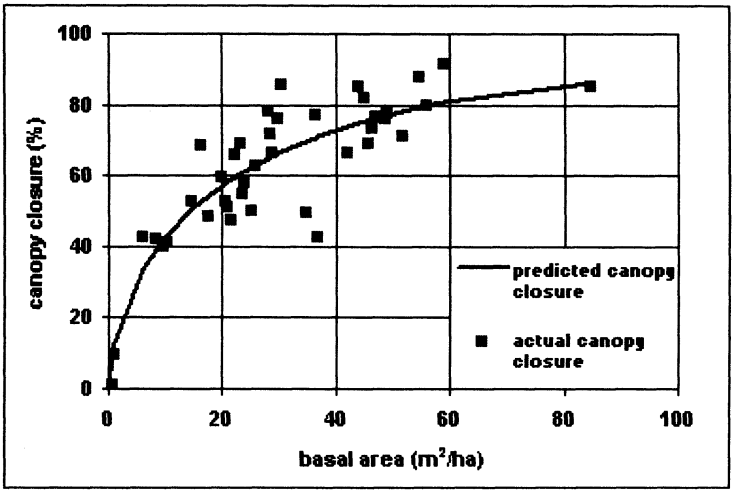

FIG. 3–Actual data and fitted function for predicting summer canopy closure in poplar stands

any obvious differences between the two main groups of poplars planted in New Zealand, black poplars and balsam poplars (Fig. 4), but this may have been due to the limited size of the available data set. There are known to be clear differences in canopy architecture between other poplar hybrids (e.g., Wu & Stettler 1996).

No obvious regional differences were evident between the East Coast and Bay of Plenty data sets. Data from all 40 stands were therefore combined for the estimation of the final model.

In the 11 stands used for winter assessments, winter canopy closure appeared to be approximately 31% of full summer canopy closure, as indicated by the straight line relationship in Fig. 5. That is, leaves were responsible for 69% of the shaded area during

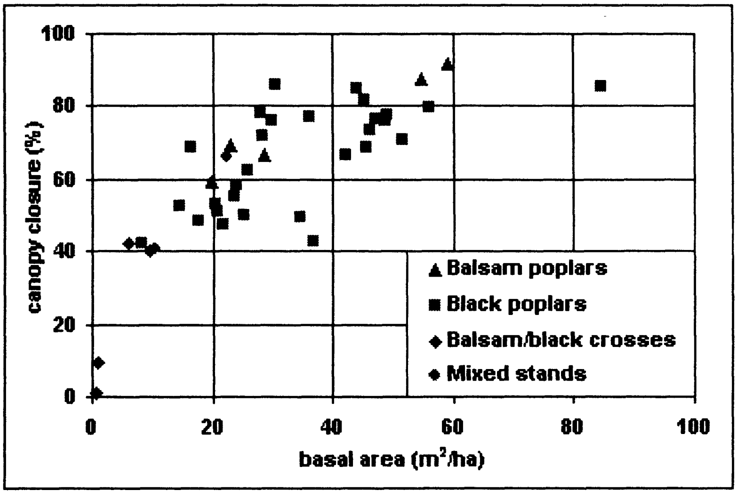

FIG. 4–Summer canopy closure *v*. basal area by poplar group

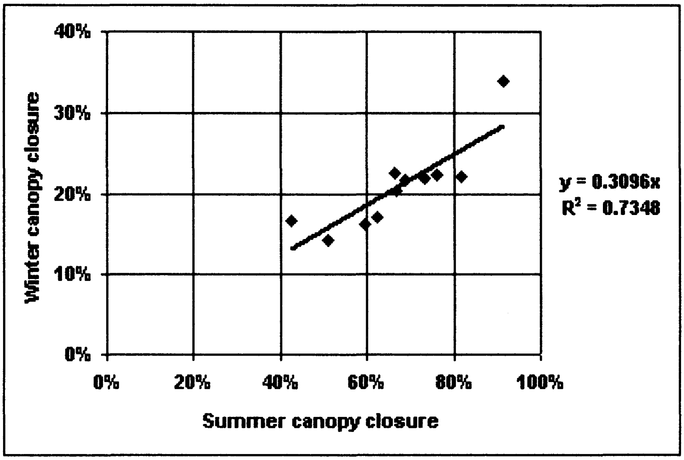

FIG. 5—Winter canopy closure *v.* summer canopy closure in New Zealand-grown poplar stands

summer, with tree stems and branches responsible for the remainder. There were no obvious differences in winter canopy closure between black poplars ("Robusta", "I-78", and "I-30") and balsam poplars ("Androscoggin", "Geneva", and "Oxford"), although once again the sample size was too small to draw any clear conclusions.

The reduction in canopy closure during winter was included in the canopy closure model by multiplying the estimated canopy closure by a factor of 0.31 for the months of May, June, July, August, and September. The exact times of leaf fall in autumn and flushing in spring will vary between years, regions, and clones. Observations made at Palmerston North over a number of years suggest that the time of flushing ranges from early September to late October for different clones, with late September or early October being about average (C.W.S.Van Krayenoord, unpubl. data). Leaf fall usually occurs in about mid April, although this also varies by species and clone. The balsam poplars typically have later leaf fall and bud burst than black poplars. In addition, genotypes that are prone to drought and rust may begin to defoliate during February and March if either of these conditions prevail.

Prediction of Diameter and Basal Area

The fitted diameter equation was a form of the Schumacher function, where the upper asymptote varied with age, stocking, and site quality (Fig. 6 and 7). The fitted function was:

$$D = a/(1+(b(1-\exp(-c \times A)) \times (N-400)) \times (\exp(-d \times A^{-e})) \qquad (4)$$

where: D = dbh outside bark (cm) of tree of mean basal area
A = age (years)
N = stocking (stems/ha)
a = 53.4942 (good sites)
= 42.5215 (medium sites)
= 32.2773 (poor sites)
b = 0.0009853
c = 0.08334
d = 4.8374
e = 0.9222

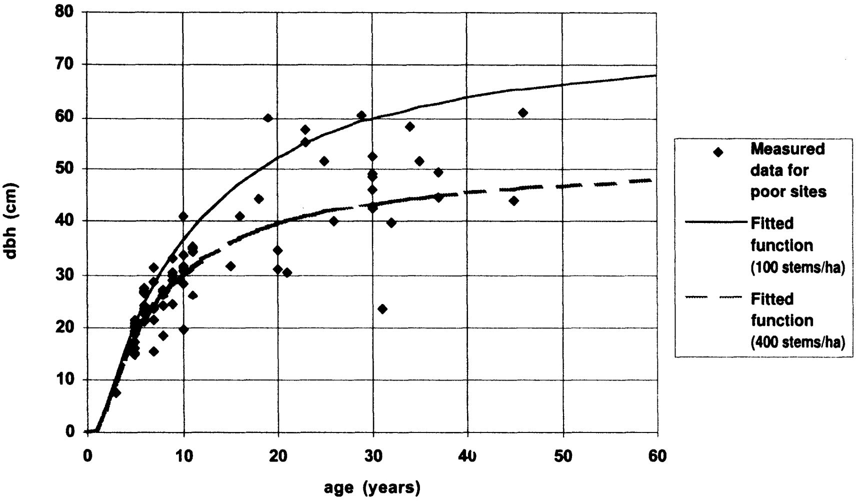

FIG. 6–Estimated diameter function for New Zealand-grown poplar on good sites

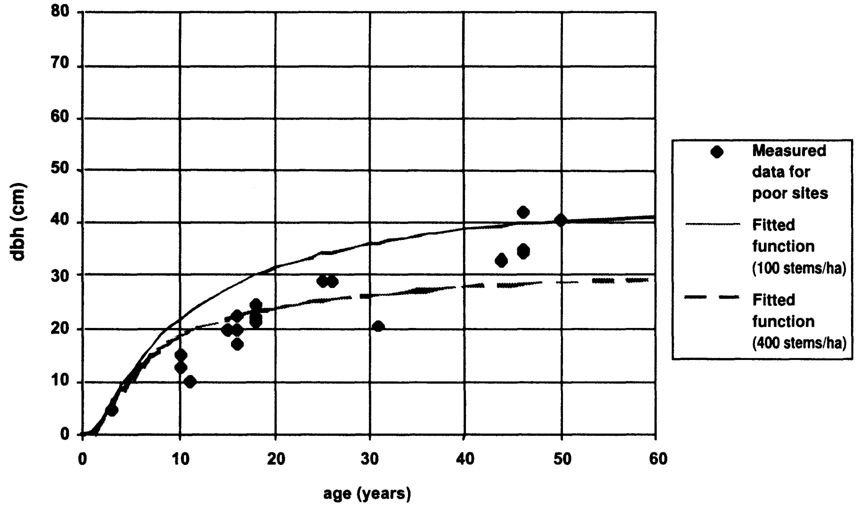

FIG. 7–Estimated diameter function for New Zealand-grown poplar on poor sites

The R^2 for the fitted function was 0.92.

Basal area can be easily estimated using the predicted dbh from the dbh function (Fig. 8 and 9). That is,

$$BA = N\pi(D/2)^2 \quad (5)$$

where: BA = basal area
N = stocking (stems/ha)
D = dbh outside bark (cm) of tree of mean basal area

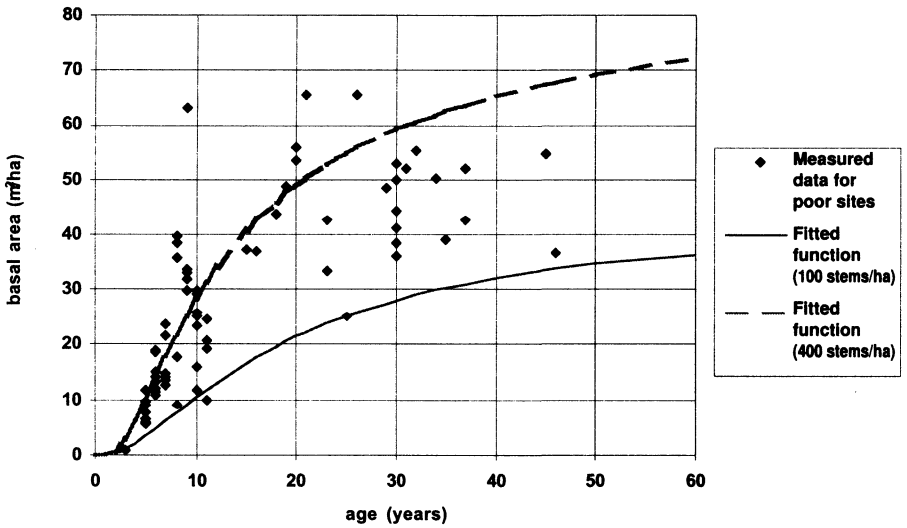

FIG. 8–Estimated basal area function for New Zealand-grown poplar on good sites

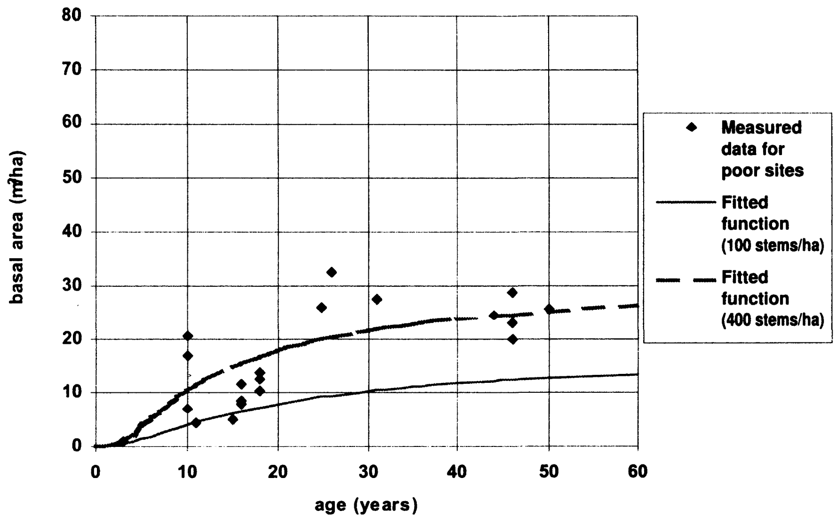

FIG. 9–Estimated basal area function for New Zealand-grown poplar on poor sites

Modelling Understorey Pasture Production

The visual estates of pasture production and data reported by Guevara-Escobar *et al.* (1997) suggest that the relationship between poplar canopy closure and understorey pasture production is unlikely to be linear as was the case for *P. radiata* (Knowles *et al.* 1997). Therefore a non-linear curve was estimated to predict understorey pasture production from canopy closure (Fig. 10). The estimated function achieved 100% relative pasture production at 0% canopy closure, 0% pasture production at least at 85% canopy closure (the estimated

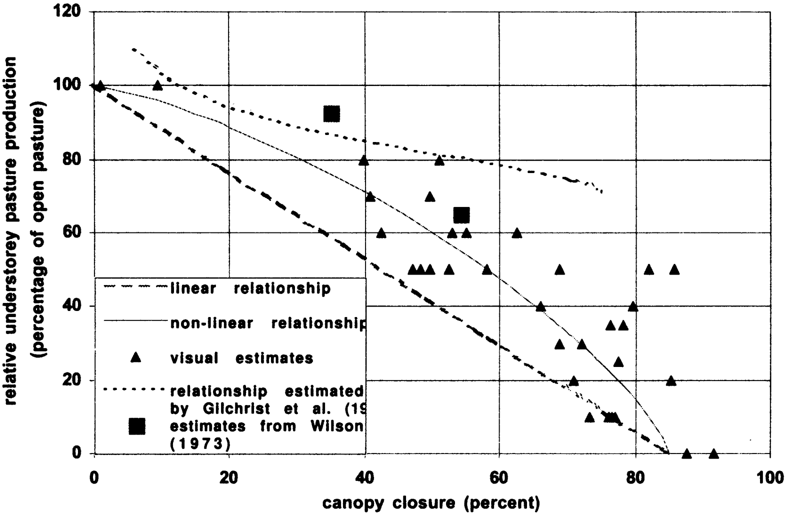

FIG. 10—Models of pasture suppression beneath poplar stands

extinction point from the visual estimates), and 60% pasture production at 50% canopy closure (based on data from Guevara-Escobar *et al.* (1997)). The form of the function is:

$$PP = (100^a - b \times CC^a)^{1/a} \qquad (6)$$

where: PP = relative pasture production (%)
CC = percentage canopy closure
a = 1.3323
b = 1.2418

Other published data also suggest that a linear relationship between canopy closure and relative understorey pasture production may not be appropriate. For example Wilson (1973) stated that a stocking rate of about 100 stems/ha on flat land may reduce pasture production by only about 7% after 7 or 8 years (corresponding to about 35% canopy closure) and 35% towards the end of a 16-year rotation (about 54% canopy closure), although these estimates were not based on numerical data.

Gilchrist *et al.* (1993) examined pasture growth under single poplar trees at age 16 years, concluding that pasture suppression (grass, clover, and lotus) during summer is likely to vary from 12.5% at 25 stems/ha to 23% at 156 stems/ha. No suppression of pasture growth was found under deciduous trees during winter. The estimated relationship between stocking and relative pasture production was:

$$PP = 110 \times N^{-0.07154} \qquad (7)$$

where: PP = pasture production (kg dry matter/ha•yr) as a percentage of open pasture
N = stocking (stems/ha)

This relationship does not explicitly model the effect of stand age and can be assumed to apply only to trees of the same age as used for the creation of the model (16 years).

The pasture estimates made by Wilson (1973) and the relationship estimated by Gilchrist *et al.* (1993) are also shown in Fig. 10. Canopy closure is estimated for these sources using the canopy closure and basal area prediction equations.

DISCUSSION

It was found that canopy closure could be predicted from stand basal area, but a height ratio variable was not a statistically significant addition to the model. This implies that green crown pruning does not significantly affect canopy closure. It is possible that this is because, for the genotypes examined, the widest point of the crown is higher up the tree rather than near the base of the green crown. It is also possible that the data represented an insufficient range of silvicultural treatments to reflect this effect.

Although differences between genotypes are likely to affect diameter growth, a lack of data on individual species and clones precluded the integration of a species variable into the diameter prediction model. In particular, the clones commonly planted at present tend to be different from the clones planted prior to the early 1970s. The older clones have been largely replaced by new cultivars that are resistant to poplar leaf rust and unpalatable to possums, but as yet there are insufficient data to estimate the model using these cultivars alone.

Visual estimates of pasture production under poplars appear to indicate that the relationship between canopy closure and relative understorey pasture production is non-linear, whereas the relationship for *P. radiata* is linear (Knowles *et al.* 1997). The reason for this may be that poplars tend to allow more light through the canopy than *P. radiata* for a given level of canopy closure, or that non-light-related competition (for example, competition for water or nutrients) is greater beneath *P. radiata* than poplar. A further possible explanation is that the rate of litter decomposition is slower for *P. radiata* needles than poplar leaves, hence the pasture is smothered. It should be noted, however, that the small size of many of the poplar stands measured means that in many of them the understorey was receiving light from the side of the stand. In such stands the observed pasture growth is likely to be greater than could be expected in a larger stand of the same percentage canopy closure. Furthermore, the observation of a stand at a single point of time does not necessarily give a good indication of the production of pasture over time. Comparison with areas of pasture adjacent to the stand may also be misleading if the two areas have received different levels of fertiliser, or different grazing management.

The estimated relationship between canopy closure and understorey pasture production indicates that the model estimated by Gilchrist *et al.* (1993) may tend to over-estimate pasture production. This is plausible, as the model was based on measurements around single trees only, and therefore includes the effects of incoming side-light, as well as that coming through the tree canopy.

The models to predict basal area and canopy closure for poplars may be used in conjunction with the non-linear pasture production function in Fig. 10 to predict relative understorey pasture production as a function of stand age (Fig. 11). Furthermore, data describing the seasonal distribution of pasture growth may be used to convert the monthly relative pasture production estimates to monthly absolute pasture production estimates (kg DM/ha·month) and thus predict the change in annual pasture production through time. The livestock-carrying capacity of land planted in poplars (Fig. 12) may then be estimated by assuming that the ratio of the carrying capacity in any given year to the initial carrying capacity is equal to the ratio of annual pasture production in that year to annual pasture production with no trees. That is:

$$SR_t / SR_0 = PP_t / PP_0 \qquad (8)$$

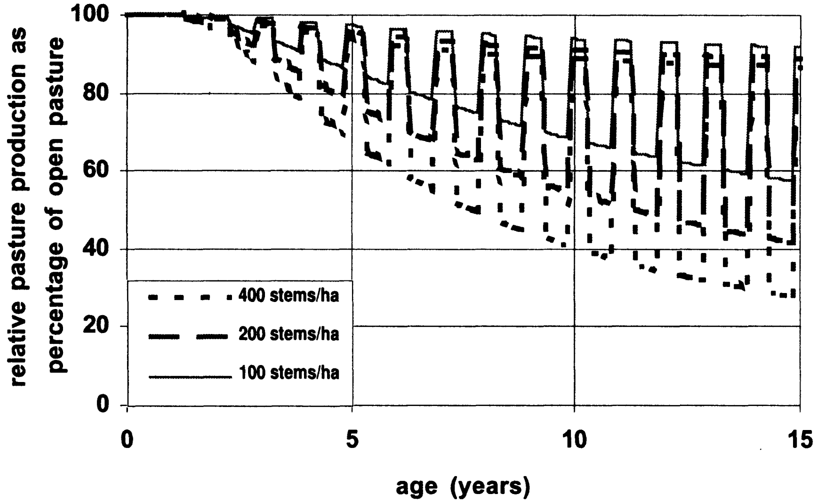

FIG. 11–Predicted relative understorey pasture production for poplars on good sites, showing the effects of stocking, age, and seasonal variation

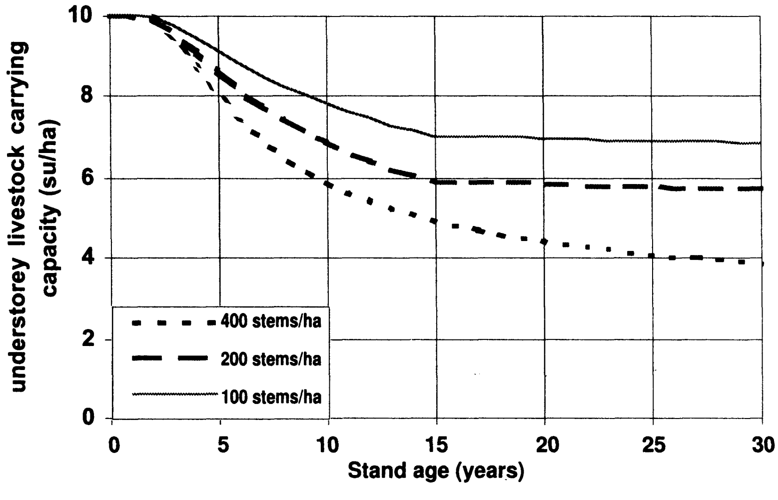

FIG. 12–Predicted annual understorey livestock-carrying capacity for poplars on good sites, showing the effects of stocking and age

where: SR_t = livestock-carrying capacity in year t (lsu/ha)
SR_0 = initial livestock-carrying capacity (lsu/ha)
PP_t = annual pasture production in year t (kg DM/ha·yr)
PP_0 = initial annual pasture production (kg DM/ha·yr)

Seasonal pasture production data for the Gisborne plains was used in this example (Radcliffe & Sinclair 1975) and the initial livestock-carrying capacity was assumed to be 10 lsu/ha. Site quality for growing poplars was assumed to be "good". If site quality were "medium" or "poor", canopy development would be slower, and the percentage reduction in livestock-carrying capacity would be smaller. The benefits associated with the trees—such as shelter, erosion control, and wood production—would also be less.

Note that average annual understorey livestock-carrying capacity shown in Fig. 12 is quite high even after 15 years (for example, nearly 60% of initial livestock-carrying capacity at a stocking of 200 stems/ha). This is largely because of reduced pasture suppression during the winter months when the trees lose their leaves.

Strictly speaking, understorey livestock-carrying capacity may not be directly proportional to understorey pasture production, due to changes in pasture quality and species composition that occur as a stand develops. Changes in pasture quality were ignored in this model, although in reality the quality as well as the quantity of pasture will be changing over time (Guevara-Escobar *et al.* 1997).

In addition to canopy closure, the percentage of ground area covered by slash from thinning and pruning is also likely to affect pasture production. This was ignored, however, as poplar foliage is very palatable to stock, and will be readily eaten (New Zealand Poplar Commission 1995). The feed value of the slash itself is assumed to compensate for lost pasture production on the ground that it covers. Pasture growth is also likely to be suppressed when poplars lose their leaves. This effect was also ignored, as the leaves may be eaten by stock. In practice, grazing management will influence the validity of these assumptions. If the forested paddocks are not grazed immediately after pruning or leaf fall in autumn, then pasture suppression may be increased. Management of the seasonal distribution of understorey grazing is likely to be important in ensuring that understorey pasture suppression is minimised.

CONCLUSIONS

Canopy closure in poplar stands may be estimated as a function of basal area using a sigmoid function. Basal area in turn may be estimated as a function of site quality, age, and stocking.

It is unlikely that the effect of canopy closure on relative understorey pasture production in poplar stands can be modelled as a simple linear relationship as can be done for *P. radiata*. Equations to predict basal area, canopy closure, and understorey pasture production can be used in conjunction with data describing initial livestock-carrying capacity and the seasonal distribution of pasture growth, to predict the effect of site, age, and stocking on understorey livestock-carrying capacity in poplar stands.

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