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Tree planting pattern effects on forage production in a Douglas-fir agroforest

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Abstract. Resource sharing among agroforestry system components, as expressed by spatial patterns along interfaces between components, is a crucial factor in both understanding present systems and in designing new agroforestry applications. A study of the spatial pattern of forage production surrounding 9–10 year old Douglas-fir trees in a agrosilvopastoral plantation near Corvallis, Oregon, was conducted during 1988 and 1989. Transects of plots were clipped both between trees (tree/tree) and between trees and open pastures (tree/pasture). Best-fit regression models relating forage production to distance from trees (tree/tree $R^2 = 0.87$; and tree/pasture $R^2 = 0.89$) were combined into a single prediction model. Observed forage production increased rapidly with increasing distance from trees during the initial 4 m. Trees had little effect on forage production beyond 4.5 m (approximately 2 canopy diameters) from the nearest tree. Predictions of different combinations of tree density and planting pattern indicated a strong interaction between density and pattern with highly aggregated plantations better able to maintain forage production at high tree densities.

Introduction

Management of agroforests involves the manipulation of system components in both time and space. Horizontal spatial impacts of woody components accrue from density (number of plants per hectare) and distribution pattern. Effects of tree density on tree growth and understory plant production have been reported for many different temperate conifers [Larson and Wolters, 1983]. Little information exists, however, concerning the impact of tree distribution pattern on understory forage production. Most commercial timber plantations in the United States are planted in a uniform grid-like pattern. Uniform patterns minimize intraspecific competition between trees while maximizing interspecific competition between trees and understory vegetation [Avery and Gordon, 1983]. This strategy has proven to be effective in facilitating rapid tree dominance and early suppression of understory vegatation.

Interest in alternative tree planting patterns has increased concurrently with interest in joint production of understory and overstory vegetation (i.e., agroforestry) in recent years. Pattern studies are difficult to do in full scale agroforestry systems because of their complexity (large numbers of possible component configurations), the relatively large area necessary for each replication, and the long time span needed to evaluate the time factor in management. Huxley [1985] suggested that the first two problems might be overcome by using small scale trials designed to elucidate the nature of interactions between components along their interfaces. Knowledge of interfaces could then be used in conceptual models of resource sharing among system components as an aid in agroforestry system design [Buck, 1986].

The objectives of this study were two-fold: First, to determine the pattern of forage production around trees in a sheep/pasture/Douglas-fir agrosilvopastoral system (i.e., study the tree-crop interface); and second, to employ a simple spatial forage production model to screen for the most promising tree planting patterns for agrosilvopastoral systems.

Materials and methods

The study was conducted on the Oregon State University McDonald Research Forest approximately 10 km north of Corvallis, Oregon (Latitude 44°37′N, Longitude 123°20′W). Soils were Jory silty-clay loams (Xeric Haplohumults) which have moderately high productive potential for both commercial timber and crop production [Knezevich, 1975]. Elevation is 70 m above mean sea level. Climate is maritime with warm dry summers and cold moists winters. Approximately 70 percent of the 1100 mm of average yearly precipitation falls as a rain from November through March. Less than 100 mm of precipitation may be expected during June through September. Frost-free period is 165–200 days [Knezevich, 1975].

Two-year old (2–0) bare-root Douglas-fir (*Pseudotsuga menziessi*) seedlings were planted in 1979. Trees were planted in 1.5 m diameter circular clusters of 5 seedlings each. Clusters were arranged in a grid pattern with 7.5 m between clusters. Total tree density was approximately 900 tree/ha. Average tree heights were 7.0 m (n = 20) in 1988 and 8.3 m (n = 30) in 1989. Basal tree diameters averaged 18.2 cm and 20.5 cm and tree canopies extended 1.9 and 2.2 m radically outward from the bole in 1988 and 1989, respectively.

Plantations, together with contiguous unplanted areas, were rototilled and planted to subterranean clover (*Trifolium subterraneum*) in fall 1982. This seeding, together with resident tall fescue (*Festuca arundinaceae*) plants provided a dense grass/clover pasture which was grazed by sheep during spring-summer 1983–1987. The entire experimental area was fertilized with 40, 96, 48, and 0.5 kg/ha of N, P, S, and Mo applied as a mixture of ammonium sulfate/trebel-superphosphate/sodium molybdate in 1982. Annual applications of 36 kg/ha P and 18 kg/ha S (applied as single superphosphate) were broadcast over the entire experimental area each fall during 1983–1987.

Forage yield along the tree/pasture interface was studied at the end of the growing season in August 1988 and 1989 by harvesting to ground level all forage present in 0.1 m^2 quadrats which were placed at 0, 0.5, 1, 2, 3, 4, 5, 5.5, and 6 m from a randomly chosen initial tree along a line running from cluster to cluster (tree/tree transects). A total of 10 tree/tree transects were sampled in 1988 and 15 transects in 1989. In addition, fifteen 0.1 m^2 quadrats were clipped at 0, 0.5 m then every meter for a distance of 10 meters along line transects extending out from randomly chosen trees within clusters into adjacent open pasture (tree/pasture transects) in 1989. All forage harvested was dried in an oven at 50 °C and its biomass recorded. Pattern of pasture production around trees was examined by fitting least squares regression surfaces to the transect data. All possible combinations of distance (D) from the nearest tree up to D^5 were regressed against kg/ha forage production for 1989 tree/tree (n = 105) and tree/open (n = 135) data sets separately. Regression equations with the highest R^2 and lowest Mallow's Cp were selected as best-fit surfaces [Draper and Smith, 1981]. The resulting 1989 surfaces were combined in a model to predict forage crop production under a variety of different tree patterns and densities. The simulated agroforest was divided into a matrix of 0.5 × 0.5 m cells. Forage production was estimated in each cell using 0 for cells within 0.5 m of a tree, the tree/tree equation for within aggregated cells which were 3 m or less from each of the nearest two trees, and the tree/open equation for between aggregate cells which had only one tree within 4.5 m of the cell. Examination of tree/open transects suggested that tree influences only extended 4.5 m out into open pasture (tree/crop interface was 4.5 m thick). Therefore, cells located > 4.5 m from trees were assigned full open pasture production.

Results and discussion

Forage distribution

Each tree was surrounded by a bare spot which extended approximately 0.9 m outward from the bole (Figs. 1 and 2). Similar zonal distribution of vegetation surrounding individual trees has been reported for several temperate evergreen trees [Arnold, 1964; Everett et al., 1983]. Due to the young age of the timber stand, relatively little needle accumulation had occurred under trees. Therefore, loss of understory vegetation likely accrued from intense competition with trees for soil moisture, soil nutrients, or light rather than the development of a dense layer of decomposing needles near trees. A very narrow (generally less than 20 cm in width) transition zone of sparse understory vegetation separated the bare zone from dense pasture. Pasture production increased quickly with increasing distance from the tree, reaching open pasture levels at approximately 2 canopy diameters (4.5 m) distance.

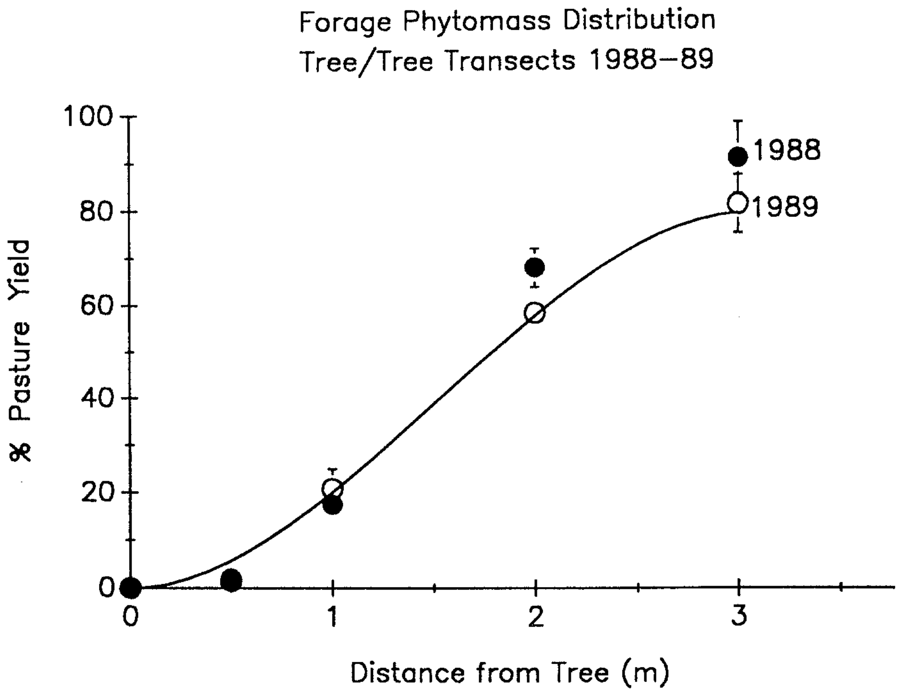

Fig. 1. Forage Production observed in tree-to-tree transects in 1988 and 1989, together with the 1989 production curve predicted by the best fit regression model (kg/ha = 810 D^2 − 177 D^3, R^2 = 0.87). Data points are mean percentage of forage production observed in open pasture ± standard error.

Predictions

Predicting forage production of aggregated tree plantations requires knowledge of spatial understory production patterns both within aggregates and between aggregates. Differences in tree/tree and tree/open pasture regression models (Figs. 1 and 2) suggest that tree/crop competitive relationships within aggregates, where understory is interacting with more than one tree, differ substantially from that between aggregates where crops are interacting with single trees. Therefore, predictions are limited to 1989 when both of these functions are known. Predictions from individual polynomial regression models agreed well with field data collected from agrosilvopastoral plantations in 1989 (Figs. 1 and 2). With the exception of single-tree simulations, patterns examined refer to spatial arrangement of 5-tree clusters. Once canopies coalesce, groups of trees often act as a super-individual. Visually, the clusters produced patterns of understory plant production similar to that expected under single trees of similar total canopy structure and cover. Therefore, general conclusions drawn from this study concerning understory/

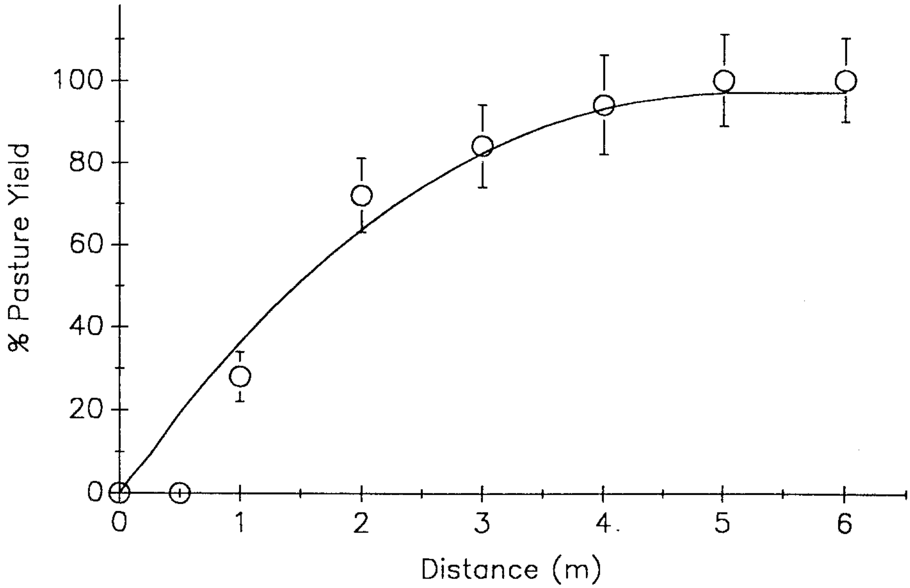

Fig. 2. Forage production observed in 1989 tree-to-pasture transects, together with the production curve predicted by the best fit regression model (kg/ha = $1289D + 0.05\ D^5 - 141\ D^2$, $R^2 = 0.89$). Data points are mean percentage of forage production observed on open pasture ± standard error.

overstory relationships in different spatial configuration of clusters are probably equally valid for single tree configurations.

As one might expect from a 10-year-old conifer plantation, forage production was consistently lower than that possible on open pasture regardless of tree density or planting pattern examined (Fig. 3). Reduction of understory plant production in conifer grid plantations generally becomes evident by the time total tree canopy cover reaches 20–30 percent of plantation area [Krueger, 1981]. Predicted total tree canopy cover of cluster plantings was approximately 6, 11, 22, and 44 percent for 110, 225, 450 and 900 tree/ha stocking rates, respectively. Predicted forage production decreased as total tree density increased beyond 450 trees/ha in all patterns. However, a strong interaction was apparent between tree density and planting pattern. For example, reducing tree density from 900 to 450 trees/ha increased forage production of single-tree grids by approximately 500 kg/ha and cluster-grids by 780 kg/ha, while single rows of clusters increased by only 190 kg/ha (Table 1). More forage could be produced by agroforests stocked with 900 trees/ha in clusters than those with only 450 trees/ha in conventional single tree grids. A simulation model of ash (*Fraxinus excelsior*)/grass plantations in Britain [Doyle et al. 1986] produced similar results with grass yields declining as ash density increased and/or tree aggregation decreased. Predicted

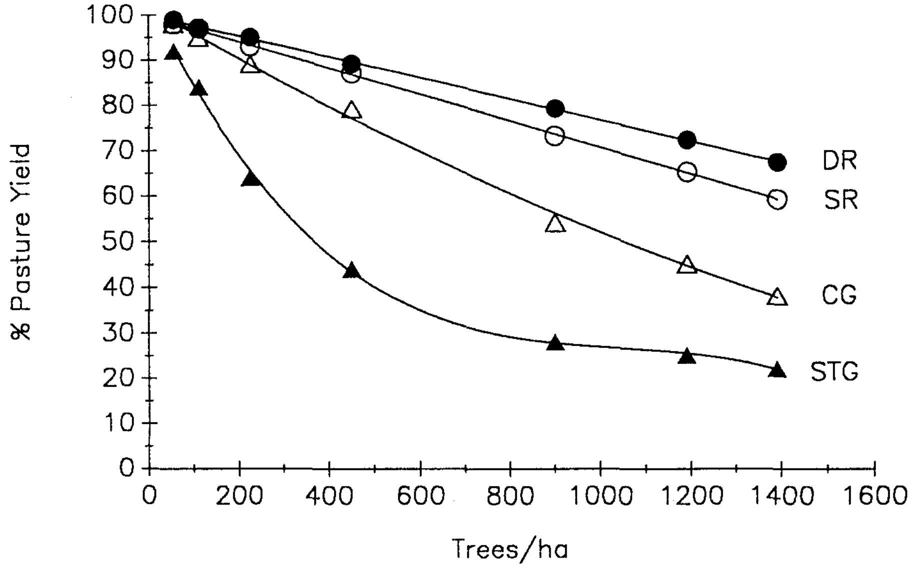

Fig. 3. Predicted forage production for 7 tree densities planted in single-tree grids (ST), 5-tree clusters in grids (CG), 5-tree clusters in single rows (CDR). Data are percentage of forage production observed in open pasture.

forage yield under 100 20-year-old ash stems ha^{-1} in rows was 50 percent of that expected from open pasture, while the same ash density planted in a grid was estimated to produce only 20 percent as much forage as open pasture. These observations suggest two interesting points; (1) understory crop production is as responsive to changes in tree planting pattern as it is to total tree density, and (2) tree density/forage production relationships derived from one planting pattern may not be useful for other patterns.

Forage production tended to increase with increasing degree of tree aggregation from single-tree grids, to cluster-grids, to cluster-rows (Table 1). Greatest forage increase was realized by the initial aggregation of trees into clusters. Further aggregation of clusters into single or multiple row configurations provided progressively more modest increases in forage yields. Theoretically, aggregation should increase the severity of competition between trees and understory crops within aggregates while concomitantly reducing competition in the interspaces between aggregates. These properties were observed in predictions as increased loss of potential forage production in the bare areas beneath trees together with reduced loss of forage production in the open interspaces between trees as aggregation of trees into clumps and/or rows increased (Table 1). Increased levels of predicted forage production in aggregated conifer plantations accrued from the simple geometric property of within aggregate areas (i.e., bare spots) increasing more slowly than tree-crop interface competition area decreased with increasing tree aggregation. This provided a relatively large proportion of the total plantation area outside of the competitive influence of trees in highly aggregated stands (Table 2).

Little additional forage production is expected from aggregating clusters of trees into multiple row patterns compared to single rows (Table 1). The few reports of tree growth available for different row patterns suggest that tree growth is generally not reduced by aggregation into rows provided that trees have at least one side bordering the open tree/crop interface [data contained in Tombleson and Inglis, 1986] and are not too closely spaced, (< 1 m apart) within rows [Lewis et al., 1985]. Young conifers in single and double row configurations typically grow as fast as grid plantations of similar total tree density [Lewis et al., 1985; Reid and Wilson, 1985]. The inside trees in 3-row or 4-row configurations may have growth reduced by intense intraspecific competition. Single or double-row patterns appear to offer the most promising combination of tree and understory production in agroforestry systems which emphasize achieving high levels of forage production while maintaining tree production levels near maximum. Ease of managing livestock, constructing fencing, access with mechanical equipment, and concentration of thinning wastes are also enhanced by row patterns compared to grids.

Density alone determines plant placement in grids. In row configurations, however, density and distribution are to some extent independent in that

Table 1. Effects of tree density and planting pattern on forage yield.

Density/Pattern	Forage yield (kg/ha)	Loss due to bare spots (kg/ha)	Loss due to competition (kg/ha)
Open pasture	3170	0	0
180 Clusters = 900 Trees per Hectare			
Single tree, grid	889	56	2225
Cluster, grid	1713	179	1278
3 × 18.5 m single row	2327	343	500
3 × 3 × 34 m double row	2490	476	204
3 × 3 × 3 × 50 m 3-row	2539	482	149
3 × 3 × 3 × 3 × 66 m 4-row	2577	485	108
90 Clusters = 450 Trees per Hectare			
Single tree, grid	1398	28	1744
Cluster, grid	2494	89	587
5.1 × 19 m, single row	2518	162	490
3 × 37 m, single row	2748	171	251
3 × 6 × 34 m, double row	2816	108	246
3 × 3 × 71 m, double row	2830	214	126

Table 2. Percentage of plantation area in which trees and forage do not compete (non-competitive), in which trees and forage compete for site resources (competitive), and which contain no understory vegetation (bare).

Density/Pattern	Non-competitive (%)	Competitive (%)	Bare (%)
180 Clusters = 900 Trees per Hectare			
Single tree, grid	0	98	2
Cluster, grid	0	94	9
3 × 18.5 m single row	46	43	11
3 × 3 × 34 m double row	65	21	14
3 × 3 × 3 × 50 m 3-row	70	15	15
3 × 3 × 3 × 3 × 66 m 4-row	74	10	16
90 Clusters = 450 Trees per Hectare			
Single tree, grid	0	99	1
Cluster, grid	29	68	3
5.1 × 19 m, single row	61	34	5
3 × 37 m, single room	73	22	5
3 × 6 × 34 m, double row	80	16	4
3 × 3 × 71 m, double row	82	11	7

density may be reduced by either increasing the distance between rows or by increasing the distance between trees within rows. Forage production response to density reduction in row plantations follows the principles discussed previously regarding the effects of aggregation on understory forage production. Single rows spaced 19 m apart with trees 5.1 m apart within rows are effectively less aggregated than are single rows spaced 37 m apart with trees more densely planted at 3 m apart. Forage production of the former is slightly lower than the latter (Table 1). Double rows are highly aggregated by nature and, therefore, are not very responsive to further changes in configuration. Thinning single or double row plantations by removing alternate rows gives similar forage production as thinning by removing every other tree within rows. Therefore, decisions to reduce tree density of young plantations by removal of entire rows vs. by removing trees within rows can concentrate on silvicultural or other operational considerations.

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