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Radiation regime and nitrogen supply in modelled alley cropping systems of *Erythrina poeppigiana* with sequential maize–bean cultivation

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Abstract. A simulation study relating the effect of the spatial arrangement of trees on the photon exposure above an associated crop (PE_i) was carried out for an alley cropping system of the leguminous tree *Erythrina poeppigiana* (Walpers) O. F. Cook with sequential maize–bean cultivation. These results were combined with estimates of the nitrogen supplied by prunings from different tree densities to rank the arrangements. A significant difference was found in the PE_i between the east–west and north–south-oriented alleys. The latter exhibited more areas of moderate shade, while the former has unshaded centres and heavily shaded parts next to the tree row. When the simulated PE_i data was combined with the N supply from tree residues, the wider between-row tree spacings (6 or 8 m, with 1 or 2 m within-row spacing) appeared to be best. In general, to minimize shading of the crop, yet maintain a sufficient supply of organic matter and nitrogen in prunings, alley cropping tree arrangements of high between-row and low within-row spacings seem to be most promising. The east–west orientation seems to be more promising than north–south.

1. Introduction

Alley cropping has been defined as a system, in which arable crops are grown between rows of planted shrub or tree fallows which are periodically pruned during the cropping season to prevent shading and provide green manure for the companion crop [8]. Most of the tree species used in this system are nitrogen fixing legumes [16].

The positive effect of alley cropping on soil fertility, especially on organic matter and nitrogen reserves, has been indicated in several studies [e.g. 7, 8, 9, 18]. It depends mostly on the efficient recycling of nutrients in the mulch and, when nitrogen fixing trees are used, the supply of fixed nitrogen in the prunings. Competition for soil water in dry areas [1, 13] and for solar radiation have been mentioned as the main disadvantages of the system. Most evidence of competition for solar radiation is indirect [4, 8, 16] and quantitative studies are few [5, 7, 17].

The main tools for radiation regime management in alley cropping are the spatial arrangements of the trees and pruning techniques. The latter has to be adapted to the tolerance of the tree species to repeated pruning, which forms the absolute restriction for this practice, and to the phenology of the companion crop. Management of tree spacing attempts to minimize the shading effect and below-ground competition while providing a tree density that gives a reasonable supply of organic matter and nitrogen, which are the main objectives of alley cropping. Simulation studies can be used to solve this optimization problem, since they can be used to rapidly explore the effect of a wide range of different spatial arrangements on the radiation regime above the crop. The most promising arrangements should subsequently be checked in field experiments.

The aim of this paper is to report the results of a simulation study on the effect of the spatial arrangement of the leguminous tree *Erythrina poeppigiana* (Walpers) O. F. Cook on the radiation regime above two companion crops, maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.), cropped sequentially as in traditional Central American agriculture. *E. poeppigiana* is a proven nitrogen fixer [10] and experiments have shown it to be a promising alternative for alley cropping in Tropical America [9, 12, 14]. The results of the simulations and estimations of the nitrogen supply from *E. poeppigiana* in the simulated tree densities are used for initial ranking of tree spacings. Only nitrogen is considered, since part of it is fixed from the atmosphere, constituting a net supply to the system. Other nutrients are likely to be just recycled because of the superficial rooting pattern of the species (A. Campos and P. Nygren, CATIE, unpubl. data).

2. Material and methods

2.1. *Simulation program*

The simulations were carried out using the 'Sibú' simulation program [12] to estimate the potential photon exposure (PE, with subscript 0 for values above the trees and with i for values above the crop) in an agroforestry system over time interval. The simulation is designed for clear sky conditions. The model permits estimation of the PE_i once the location and dimensions of the trees in the field, crop height, geographical latitude and atmospheric transmittance are known. The field is divided into 50 × 50 cm squares and simulation is performed independently for each of them.

The dynamics of tree and crop growth are taken into account by measuring tree dimensions and crop height during the cropping cycle. Weekly mesurements are recommended, but the program accepts any number of weeks between measurements. To take into account the effect of both seasonal and hourly variation of the solar position, several estimations of the instantaneous photon flux density (PFD) are made during each day of the simulation period and these values are integrated over the time period.

The existing model uses the canopy transmittance parameters for *E. poeppigiana*, but if these parameters are modified the model can be applied to any agroforestry tree species managed with periodic prunings [12].

The model has been tested on an alley cropping experiment of *E. poeppigiana* and beans. In the experiment, the alley orientations were east—west, northwest—southeast and north—south, each with three replicates. The tree spacing was 4 × 6 m. A set of five line quantum sensors placed over the crop was rotated in randomly selected experimental plots and days during the cropping cycle to measure the comparison values for the simulated PE_i. In 60 comparisons, the simulated daily PE_i presented a mean overestimation of 4.90%, with a standard deviation of ±9.98% (C.V. 204%), to measurements taken with a line quantum sensor. The difference was not statistically significant (t-test for null hypothesis that the difference is equal to 0 at 0.90 level) [12].

2.2. *Simulated alley cropping systems*

Simulations were carried out for an alley cropping system including *E. poeppigiana* as the fallow tree species and sequentially cultivated maize and beans as crop plants. The geographic and climatic parameters of the model system corresponded to Turrialba, Costa Rica (9°53′ N, atmospheric transmittance 0.748). The terrain was assumed to be flat. In the model, maize was sown at the end of May and beans at the beginning of December, which is the normal cultural practise in Costa Rica. *E. poeppigiana* was pruned two weeks before the crops were sown, and no prunings were made during the cropping period, since the best long term management of the species calls for no more than two complete prunings per year (E. Víquez, CATIE, unpubl. data). The simulations were carried out separately for the main phenophases of the crop: vegetative growth, flowering and ripening. Some basic data on the simulation conditions are presented in Table 1.

Table 1. The conditions for the simulations. Pruning refers to the date of pruning of *Erythrina poeppigiana* carried out before the cropping.

Crop	Phenophase	First day	Duration [days]	δ [deg]	ϕ_m [deg]	PE_0 [$mol m^{-2}$]
Maize	Pruning	15/05/90				
	Veg. growth	29/05/90	66	21.6°N—17.7°N	76.5°—82.1°	3411
	Flowering	03/08/90	16	17.5°N—13.0°N	82.4°—86.6°	835
	Ripening	19/08/90	41	12.7°N— 2.1°S	90.0°—78.0°	2102
Bean	Pruning	25/11/90				
	Veg. growth	09/12/90	41	22.8°S—20.5°S	56.8°—59.6°	1622
	Flowering	19/01/91	31	20.3°S—11.6°S	59.8°—68.6°	1345
	Ripening	19/02/91	20	11.2°S— 4.0°S	68.9°—76.1°	951

Abbreviations: δ = solar declination; ϕ_m = maximum daily solar elevation; PE_0 = unshaded photon exposure.

The spatial arrangements studied were 1, 2 and 4 m between trees in the row and 4, 6 and 8 m between the rows, with two row orientations, east—west and north—south. The simulated field areas were 13.5 m (27 simulation squares) long and one alley wide. The area used for the radiation regime analysis was at the centre of the simulated area, being 4.5 m (9 squares) in the orientation of the row multiplied by the alley width, excluding the squares of the tree row. Thus the analyzed area varied according to the alley width, being 63 squares for 4 m alleys, 99 for 6 m and 135 for 8 m alleys. An example of the simulation layout for 2 × 6 m spacing in east—west orientation is presented in Fig. 1.

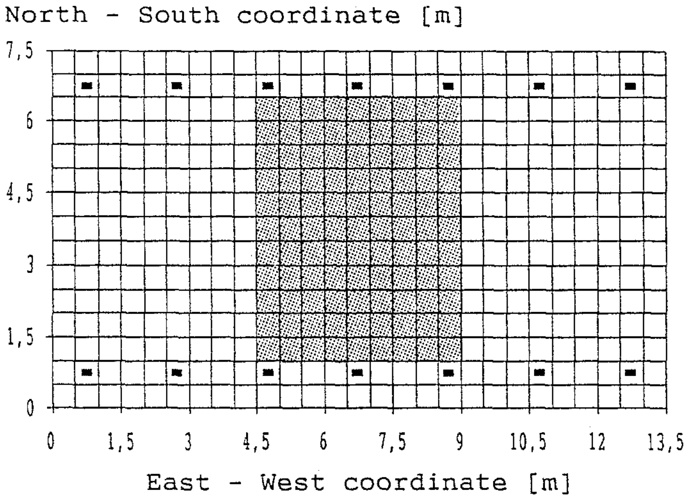

Fig. 1. The grid of simulation squares for 2 × 6 m spacing in east—west orientation. The location of trees is marked with black squares and the area used for radiation regime analysis is shaded.

2.3. *Field data*

Growth data for *E. poeppigiana* and maize were derived from Jiménez [3] and bean growth data from Nygren [12], both studies carried out in alley cropping experiments at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica (elevation 600 m.a.s.l.; climate humid tropical; soils Typic humitropept). In these soils maize yield has been observed to respond positively to N fertilization up to 100 $kgha^{-1}$ per crop while bean yield increased significantly up to 200 $kgha^{-1}$ per crop N fertilization [11].

The height growth curves of *E. poeppigiana* and the crops are presented in Fig. 2. The crown diameter growth of *E. poeppigiana* was linear from 0 to

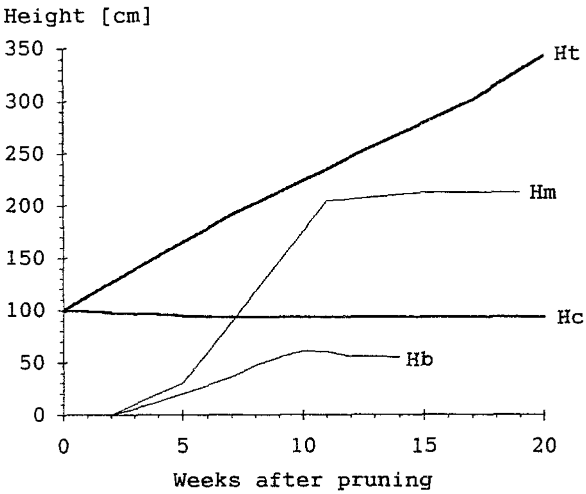

Fig. 2. The development of total height (Ht) and lower crown limit (Hc) of *Erythrina poeppigiana*, mean maize height (Hm) and mean bean height (Hb) used in the simulations.

250 cm during the 20 week period. The *E. poeppigiana* growth curves are means of 90 trees grown in alley cropping with maize, 30 trees in each of the spacings 1 × 6, 2 × 6 and 4 × 6 m [3]. No statistically significant differences were found between the spacings in any of the tree dimensions needed for simulations.

The biomass production data of *E. poeppigiana* per tree (Table 2) was averaged from the same trees. As significant differences were observed in biomass production between the spacings [3], a different biomass production was used in the nitrogen supply estimations according to the within-row spacing. The nitrogen concentrations of the biomass were averaged from the data presented by Nygren [12] and they were assumed independent of the biomass production [cf. 14].

Table 2. The biomass production and nitrogen supplied by pruning the 'mean trees' of *Erythrina poeppigiana* used for simulations.

Within row spacing [m]	Biomass [kg]		Nitrogen % in biomass		N supply/tree [g]	
	Foliar	Woody	Foliar	Woody	Foliar	Woody
1	1.52	1.82	5.20	1.33	79	24
2	2.50	3.16	5.20	1.33	130	42
4	2.70	2.95	5.20	1.33	140	39

2.4. *Data analysis*

To compare the effect of different spatial arrangements and tree row orientations on the PE_i the simulation squares were classified into five classes according to the PE_i on the square: PE_i less than 25% of PE_0, 25.1—50%, 50.1—75%, 75.1—95% and 95.1—100%. The separation of the last two classes was made to detect the frequency of the squares without any shading. A χ^2 test was carried out using the absolute frequencies to test if the PE_i class frequency distributions were equal in the east—west and north—south row orientations by spacing, crop and phenophase.

To rank the different spatial arrangements, two indices were developed. First, a shade index (I_s) was computed comparing the number of slightly (n_s) and heavily shaded (n_h) squares (defined below) for each crop, to the total number of squares (n_t) and multiplying the product with the proportion of field area available for the crop (ca):

$$I_s = ((n_s - n_h) / n_t) \cdot ca \tag{1}$$

The squares receiving a PE_i of 25% or less of PE_0 were classified as heavily shaded. Maize has a C_4 photosynthetic pathway and its photosynthetic response to the increasing PFD does not saturate even in tropical midday conditions; we therefore considered the n_s as the number of squares with no shading. For the bean, C_3 plant, whose photosynthetic rate cannot respond to high PFDs, the n_s used was the number of squares exposed to a PE_i of > 75% of PE_0. The proportion of the area available for the crop was calculated assuming that every tree row occupied a one metre wide strip which could otherwise be used for the crop.

To get a simple index which combines the potential nitrogen supply to the system from the prunings (positive effect of alley cropping) and the shading of the crop by the trees (negative effect), the total N content per hectare in the pruned material (N_t) was multiplied by the shade index:

$$I_{sn} = I_s \cdot N_t \tag{2}$$

The product I_{sn} will be called 'shade-nitrogen benefit index'. This index can be roughly adjusted to the requirements of the crop species by considering only tree densities that can supply nitrogen in amounts that are known to meet or exceed the N consumption of a given crop, and defining the threshold for heavily and slightly shaded squares in the computation of the I_s according to the shade tolerance of the crop.

3. Results

3.1. *Radiation regime below different spatial arrangements of* E. poeppigiana

Classification of simulation squares according to PE_i classes is presented in the appendix. It appears that shading is not a function of tree density alone, but the spatial arrangement of the trees also plays an important role: e.g. 2 × 4 and 1 × 8 m arrangements both have 1250 trees per hectare, but the latter layout has noticeably more unshaded or slightly shaded space in the alleys, both for maize and bean and in both hedgerow orientations.

In the east—west orientation for both maize and bean, with alley widths of 6 or 8 m, more than half the squares were without shading in all phenophases, while in the 4 m alleys, proportions lower than 50% of unshaded squares were observed during flowering and ripening. There were higher proportions of the two lowest PE_i classes (PE_i < 50% of PE_0) than the two classes of moderate shading, except in the 4 m within-row tree spacings. There was a higher proportion of the lowest PE_i class for beans than for maize, and the moderately shaded squares had a relatively low frequency.

As an example, the distribution of the PE_i/PE_0 ratio over an alley of maize in 1 × 8 and 1 × 4 m tree arrangements is shown in Fig. 3 for both orientations and all phenophases. In the north—south oriented alleys the shading is symmetric on both sides of the alley, while in the east—west orientation there is heavier shade to the north or to the south of the tree row, depending on the season. Figure 3 clearly shows the east—west oriented alley divided into a heavily shaded zone next to the tree rows and to the unshaded centre, compared to the larger areas of moderate shade and lack of extremes in the north—south orientation.

According to the χ^2 test the PE_i frequency distributions differed significantly (0.99 level) between east—west and north—south orientation, except during vegetative growth and flowering in 4 × 6 and 4 × 8 m arrangements, both in maize and bean. The frequencies of both the unshaded and heavily shaded squares were smaller in the north—south than in the east—west orientation, and there was a major concentration of the squares in the PE_i classes of 50.1—75% and 75.1—95%, especially in the 4 and 6 m alleys, while in the 8 m alleys the frequency of unshaded squares was high.

3.2. *Nitrogen supply and ranking of systems*

The nitrogen content of *E. poeppigiana* prunings in different spatial arrangements, computed from the data presented in Table 2, is presented in Table 3. Most of the N is supplied in the foliar biomass.

Ranking of spatial arrangements using the shade-nitrogen benefit index is presented in Table 4 for the five best arrangements. The spatial arrangements which resulted in more than 50% of the squares in the PE_i classes of 50% or

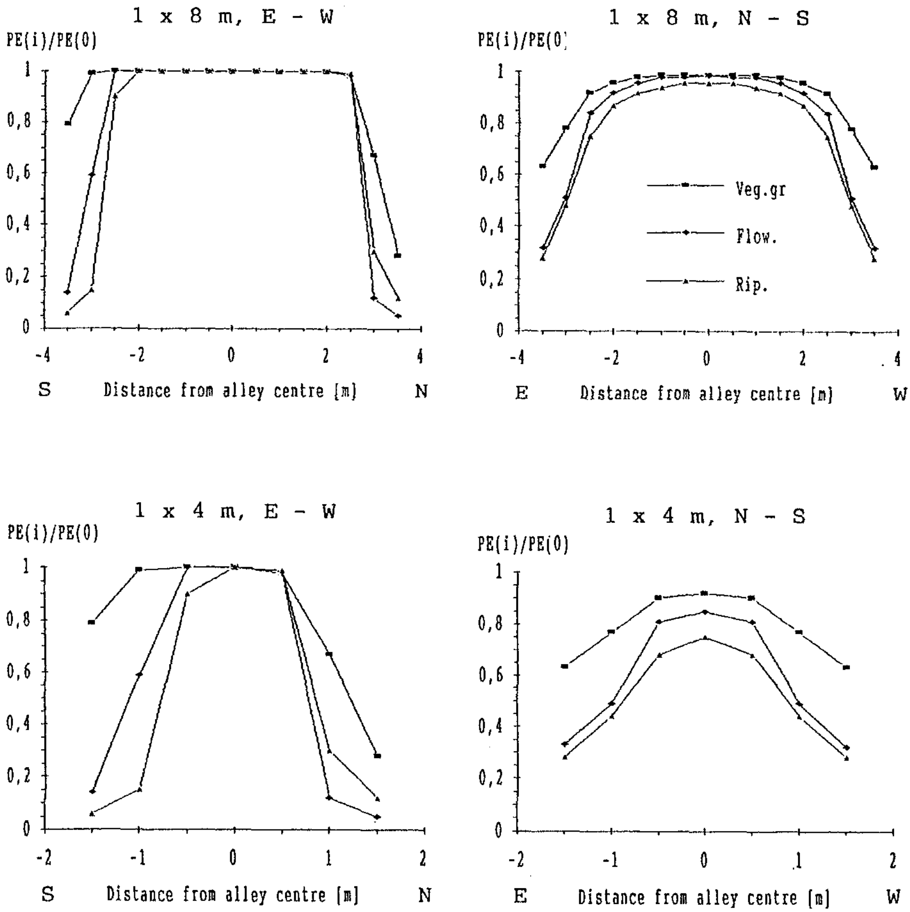

Fig. 3. The PE_i/PE_0 ratio gradient over alleys of 1 × 8 and 1 × 4 m spacings in east—west and north—south orientation.

less in any of the phenophases were excluded from the ranking, since they were considered too shady, although some of them were able to supply large amounts of nitrogen as prunings. The arrangements supplying less than 100 $kgha^{-1}$ of nitrogen per pruning (4 × 6 and 4 × 8 m) were also excluded from the final ranking.

E. poeppigiana spaced east—west at 1 × 6 m was superior to the other spacings for maize during vegetative growth, while the east—west spacings of 2 × 6 , 1 × 8 and 2 × 8 m were the best during flowering and ripening. The only north—south spacing among the five best was the 1 × 8 m during flowering.

For beans the 2 × 4 m and 1 × 6 m, east—west and north—south, arrangements were the best during vegetative growth, while during the

Table 3. Nitrogen supply per pruning of *Erythrina poeppigiana* in different spatial arrangements.

Spacing	Number of trees [ha^{-1}]	Biomass production [$kgha^{-1}$]		Nitrogen supply [$kgha^{-1}$]		
		Foliar	Woody	Foliar	Woody	Total
1 × 4	2500	3800	4550	198	61	258
2 × 4	1250	3125	3950	163	53	215
4 × 4	625	1688	1840	88	25	112
1 × 6	1667	2533	3033	132	40	172
2 × 6	833	2083	2633	108	35	143
4 × 6	417	1125	1229	59	16	75
1 × 8	1250	1900	2275	99	30	129
2 × 8	625	1563	1975	81	26	108
4 × 8	313	844	922	44	12	46

flowering and ripening the east—west spacings of 1 × 6 and 1 × 8 m and the north—south spacing 2 × 8 m were found to be the best ones.

4. Discussion

The 'Sibú' simulation program computes PE_i only for clear sky conditions. Although the diffuse radiation component of a sunny day is taken into account, the simulations reflect the effect of the trees on the radiation regime when direct solar radation dominates. Cloud lowers the PE_0 and, subsequently the PE_i, but the ratio PE_i/PE_0 may be greater in overcast than in clear sky conditions since the trees do not block diffuse sky radiation as completely as the transmission of direct solar beam. Hence, these results are only a first approximation of the optimum spatial arrangements in alley cropping.

East—west alleys presented the extremes of no shade in most of the alley, except in 4 m wide alleys, and heavy shade next to the northern or southern side of the tree rows, depending on the season. This shading asymmetry must be taken into account when sampling crop variables: samples should be classified according to their distance from the tree row and orientation from the trees. As expected [6] north—south orientated tree rows provided symmetric PE_is over the alleys under clear sky conditions. The diffuse sky radiation is always symmetric over alleys [6].

Beans were subjected to more shade than maize in the north—south orientation, in spite of a shorter cropping period, because of the season (lower solar elevation) or the relatively greater height difference between beans and trees.

Table 4. Ranking order of five best arrangements of *Erythrina poeppigiana* in alley cropping with maize and bean by phenophase, according to the shade-nitrogen benefit index (see text for explanation of the indices).

Crop	Phenophase	Spacing	Orientation	I_s	I_{sn}
Maize	Vegetative	1 × 6	E—W	0.61	104
		2 × 4	E—W	0.43	92
		1 × 8	E—W	0.70	90
		2 × 6	E—W	0.61	87
		2 × 8	E—W	0.70	76
Maize	Flowering	2 × 6	E—W	0.45	64
		2 × 8	E—W	0.58	62
		1 × 8	E—W	0.47	60
		1 × 6	E—W	0.30	52
		1 × 8	N—S	0.35	45
Maize	Ripening	2 × 8	E—W	0.51	55
		2 × 6	E—W	0.35	51
		1 × 8	E—W	0.38	49
		1 × 6	E—W	0.19	33
		4 × 4	E—W	0.25	28
Bean	Vegetative	2 × 4	E—W	0.56	120
		1 × 6	E—W	0.68	117
		2 × 4	N—S	0.54	115
		2 × 6	E—W	0.70	100
		1 × 8	E—W	0.76	98
Bean	Flowering	1 × 6	E—W	0.45	78
		2 × 8	N—S	0.70	76
		1 × 8	E—W	0.58	75
		2 × 6	E—W	0.47	67
		2 × 8	E—W	0.60	64
Bean	Ripening	1 × 8	E—W	0.53	68
		1 × 6	E—W	0.38	64
		2 × 8	N—S	0.60	64
		2 × 6	N—S	0.43	61
		2 × 8	E—W	0.54	59

Abbreviations: I_s = shade index; I_{sn} = shade-nitrogen benefit index.

Interestingly, the model shows that in the east—west orientation maize was shaded more heavily than beans, indicating that in this orientation the shorter cropping period of the beans masks the effects of season and tree/crop height difference. In this orientation the shadows are always quite short and the shading effect depends on the length of cropping cycle.

According to the ranking of the spatial arrangements combining the simulated radiation regime and potential nitrogen supply, using of the shade-nitrogen benefit index, the east—west orientation seems to be a better alternative than the north—south. On slopes the situation would be different and, in any case, the tree row orientation should be determined according to the contours and not the shading effect.

The alley width seems to determine the radiation regime more than the within-row tree spacing. The 4 m wide alleys were heavily shaded, and their better N supply could not compensate the effect of shading when the spatial arrangements were ranked according to the shade-nitrogen benefit index, except the 2 × 4 m layout during vegetative growth. According to the shade index the 2 m within-row spacing seemed to be best in the 6 and 8 m alleys.

The relative importance of nitrogen supply and shading on crop growth varies according to its phenophase. For maize, a good N supply is important during vegetative growth, but the N requirements are less during flowering and ripening, and reduced shading has a higher relative importance. This suggests that 2 × 6, 1 × 8 and 2 × 8 m spacings, which provide a reasonable amount of nitrogen from pruned material at the beginning of cropping and do not severely shade the crop during flowering and ripening, would be the best arrangements for maize. All of these spacings were also highly ranked according to the shade-nitrogen benefit index. In the case of beans, which respond positively to high N inputs [11], have quite a short cropping cycle and grow relatively well also in shade [15], a good N supply should be a more important criterion than shade prevention, suggesting the use of 1 × 6 and 1 × 8 m spacings.

An earlier study in Turrialba showed the 2 × 6 m *E. poeppigiana* spacing to be the best for two maize crops per year when the long term stability of the maize yield was considered [14]. This conforms with the high ranking of the 2 × 6 m spacing according to our criteria. Thus, we recommend establishing field trials of *E. poeppigiana* alley cropping with 6 and 8 m wide alleys and 1 and 2 m within-row spacings, preferably on different soil conditions, since the final balance between shade prevention and nitrogen supply depends on the importance of the latter for soil improvement.

Wide alleys (6 and 8 m) gave the best maize and bean yields in alley cropping with *Sesbania sesban* (L.) Merill in Rwanda [19]. In a semiarid zone in India, where competition for water is more important than shading, *Leucaena leucocephala* (Lam.) de Wit alley cropped with a sorghum—pigeon pea intercrop gave the best land equivalent ratio in 4.95 m wide alleys when *L. leucocephala* prunings were removed from the field [13], but the difference to sole intercrop was small and trials with wider alleys were suggested. Within-row spacing (0.5 m for *S. sesban* and 0.2 m for *L. leucocephala*) was not varied in these studies. A contrasting observation was made in Kenya, where 2 and 4 m wide alleys between *L. leucocephala* rows gave better maize yields than in 8 m wide alleys [2]. The authors attributed the benefit of narrow alleys to better weed control during the fallow period and to better nitrogen supply.

Spatial arrangements with wide alleys and dense within-row tree spacing seem to be best, at least on relatively fertile soils, to combine a good N supply with the least possible shading. However, if the soil is very poor, narrow alleys may give better results, because of the very high relative importance of the nitrogen supply and/or nutrient recycling [cf. 2]. If the alley orientation can be determined considering the shading only, the east–west orientation seems to be the best alternative of plain terrains.

Acknowledgements

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Appendix

Table A1. Photon exposure above crop (PE_i) in alley cropping of *Erythrina poeppigiana* with maize by alley orientation, tree spacing and phenophase.

Orientation	Spacing	Phenophase	PE_i class (% of PE_0)				
			0–25	25,1–50	50,1–75	75,1–95	95,1–100
E–W	1 × 4	Vegetative	–	14%	21%	8%	57%
		Flowering	43%	6%	–	8%	43%
		Ripening	49%	8%	–	24%	29%
E–W	2 × 4	Vegetative	–	11%	8%	24%	57%
		Flowering	16%	24%	10%	8%	43%
		Ripening	22%	25%	10%	11%	32%
E–W	4 × 4	Vegetative	–	3%	6%	29%	62%
		Flowering	6%	13%	10%	21%	51%
		Ripening	6%	22%	16%	16%	40%
E–W	1 × 6	Vegetative	–	9%	13%	5%	73%
		Flowering	27%	4%	–	5%	64%
		Ripening	31%	5%	–	9%	55%
E–W	2 × 6	Vegetative	–	7%	5%	15%	73%
		Flowering	10%	15%	6%	5%	64%
		Ripening	14%	16%	6%	7%	57%
E–W	4 × 6	Vegetative	–	2%	4%	18%	76%
		Flowering	4%	8%	6%	13%	69%
		Ripening	4%	14%	10%	10%	62%
E–W	1 × 8	Vegetative	–	7%	10%	4%	80%
		Flowering	20%	3%	–	4%	73%
		Ripening	23%	4%	–	7%	67%
E–W	2 × 8	Vegetative	–	5%	4%	11%	80%
		Flowering	7%	11%	4%	4%	73%
		Ripening	10%	12%	4%	5%	68%

Table A1 (continued).

Orien-tation	Spacing	Phenophase	PE_i class (% of PE_0)				
			0–25	25,1–50	50,1–75	75,1–95	95,1–100
E–W	4 × 8	Vegetative	—	1%	3%	33%	82%
		Flowering	3%	6%	4%	10%	77%
		Ripening	3%	10%	7%	7%	72%
N–S	1 × 4	Vegetative	6%	37%	57%	—	—
		Flowering	14%	43%	—	43%	—
		Ripening	14%	43%	37%	6%	—
N–S	2 × 4	Vegetative	3%	16%	67%	14%	—
		Flowering	11%	30%	10%	49%	—
		Ripening	11%	40%	33%	16%	—
N–S	1 × 6	Vegetative	—	—	18%	36%	45%
		Flowering	9%	18%	40%	23%	9%
		Ripening	—	36%	10%	54%	—
N–S	2 × 6	Vegetative	—	2%	10%	42%	45%
		Flowering	7%	21%	4%	40%	27%
		Ripening	9%	19%	11%	61%	—
N–S	4 × 6	Vegetative	—	1%	6%	21%	72%
		Flowering	4%	5%	10%	23%	58%
		Ripening	4%	13%	11%	33%	38%
N–S	1 × 8	Vegetative	3%	10%	13%	74%	—
		Flowering	7%	7%	13%	27%	47%
		Ripening	7%	20%	7%	39%	27%
N–S	2 × 8	Vegetative	—	1%	7%	24%	67%
		Flowering	5%	7%	12%	27%	49%
		Ripening	7%	14%	13%	36%	30%
N–S	4 × 8	Vegetative	—	1%	4%	14%	81%
		Flowering	3%	4%	7%	15%	71%
		Ripening	3%	10%	7%	24%	56%

Table A2. Photon exposure above crop (PE_i) in alley cropping of *Erythrina poeppigiana* with bean by alley orientation, tree spacing and phenophase.

Orien-tation	Spacing	Phenophase	PE_i class (% of PE_0)				
			0–25	25,1–50	50,1–75	75,1–95	95,1–100
E–W	1 × 4	Vegetative	—	14%	14%	14%	57%
		Flowering	29%	14%	—	14%	43%
		Ripening	29%	22%	6%	—	43%
E–W	2 × 4	Vegetative	—	—	25%	17%	57%
		Flowering	25%	3%	14%	3%	54%
		Ripening	29%	8%	16%	5%	43%

Table A2 (continued).

Orientation	Spacing	Phenophase	PE_i class (% of PE_0)				
			0–25	25,1–50	50,1–75	75,1–95	95,1–100
E–W	4 × 4	Vegetative	—	—	6%	29%	65%
		Flowering	—	13%	13%	17%	57%
		Ripening	—	16%	25%	13%	46%
E–W	1 × 6	Vegetative	—	9%	9%	9%	73%
		Flowering	18%	9%	—	9%	64%
		Ripening	18%	14%	4%	—	64%
E–W	2 × 6	Vegetative	—	—	16%	11%	73%
		Flowering	16%	2%	9%	2%	71%
		Ripening	18%	5%	10%	3%	64%
E–W	4 × 6	Vegetative	—	—	4%	18%	78%
		Flowering	—	8%	8%	11%	73%
		Ripening	—	10%	16%	8%	66%
E–W	1 × 8	Vegetative	—	7%	7%	7%	80%
		Flowering	13%	7%	—	7%	73%
		Ripening	13%	10%	3%	—	73%
E–W	2 × 8	Vegetative	—	—	12%	8%	80%
		Flowering	12%	1%	7%	1%	79%
		Ripening	13%	4%	7%	2%	73%
E–W	4 × 8	Vegetative	—	—	3%	13%	84%
		Flowering	—	6%	6%	8%	80%
		Ripening	—	7%	12%	6%	75%
N–S	1 × 4	Vegetative	—	16%	84%	—	—
		Flowering	29%	57%	14%	—	—
		Ripening	41%	59%	—	—	—
N–S	2 × 4	Vegetative	—	6%	22%	71%	—
		Flowering	13%	24%	59%	5%	—
		Ripening	—	19%	67%	14%	—
N–S	1 × 6	Vegetative	—	14%	45%	40%	—
		Flowering	—	18%	18%	64%	—
		Ripening	27%	27%	45%	—	—
N–S	2 × 6	Vegetative	—	6%	22%	72%	—
		Flowering	8%	17%	63%	12%	—
		Ripening	—	12%	36%	52%	—
N–S	4 × 6	Vegetative	—	—	2%	12%	86%
		Flowering	—	4%	10%	32%	54%
		Ripening	—	6%	20%	36%	37%
N–S	1 × 8	Vegetative	—	13%	20%	67%	—
		Flowering	13%	13%	40%	33%	—
		Ripening	23%	17%	60%	—	—
N–S	2 × 8	Vegetative	—	—	3%	20%	77%
		Flowering	—	6%	13%	39%	41%
		Ripening	—	9%	23%	60%	8%
N–S	4 × 8	Vegetative	—	—	1%	9%	90%
		Flowering	—	3%	8%	19%	70%
		Ripening	—	4%	13%	39%	43%

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