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Development of Selection Index for Agroforestry Systems

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SUMMARY

Agroforestry systems involving both tree and crop components usually produce multiple outputs which should all be considered in evaluating the productivity of a system. The problem of multiple outputs arising from tree and crop components can be tackled by developing an index that synthesizes these components into a single value. Therefore, this study aimed to develop a new selection index called *Agroforestry System Productivity Index* (ASPI) that can be used for easy assessment and comparison of agroforestry systems. The ASPI may be defined as a sum of the relative proportions of the equivalently scaled yields or products of tree and crop components of an agroforestry system. ASPI scores are calculated by converting the outputs of an agroforestry system to a common scale and then ranking the proportions of the converted values for each year of production. The index is shown to be reliable in ranking agroforestry systems and therefore recommended for use in comparing different agroforestry systems involving tree-crop components.

Keywords: Agroforestry system productivity index; Crop, Kruskal-Wallis, Tree, Weightage parameter.

1. INTRODUCTION

Farmers have practised agroforestry for years in many parts of the world. Nevertheless, queries have been raised on the efficiency of this type of agriculture, especially regarding how the trees and crops components interact and help each other. In an agroforestry system, the different plant components compete with their neighbours to some degree for vital resources, but they can also be helpful to each other if they are well managed to ensure a sustainable agroforestry system. Consequently, the interactions of trees and crops, though latent, reflect in the overall productivity in the form of quantifiable components including crop yield, fodder and wood (firewood and timber) volumes of trees.

Quantification of food-biomass systems is necessary in order to demonstrate their relative effectiveness and to assess their economic potential (Ranasinghe and Mayhead 1990). In fact, the need to develop suitable methodology for food-biomass quantification has been of interest to researchers for several decades now. With the aid of a set of data consisting of sorghum (*Sorghum bicolor L. Moench*)-pigeon pea (*Cajanus cajan*) intercrop returns and sole sorghum returns, it has been demonstrated that the risk associated with intercropping system is only half the risk associated with sole cropping system (Riley, 1989). Using cropped area as weightage variable and total crop yield, Szάsz (1987) developed an index for characterizing the relative level of crop production between countries. While such an index appeared to be suitable for comparing crop yields between countries, Szάsz (1987) noted that the use of area weight was deficient due to variations in data collection approaches on crop yields. Thus, some countries collect data on total sown area while others collect data on only harvested area.

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Some indices like the Competition index, Relative Crowding Coefficient, Relative Yield Totals (de Wit and van den Bergh 1965) and Land Equivalent Ratio (LER) (Willey 1979) have been developed for evaluating intercropping systems. The commonly used index which has been studied extensively is the LER (Oyejola and Mead 1982). Singh (1989) discussed parametric LERs and gave estimates as well as comparison of the ratios over treatments under a randomized complete block setting. Jaggi *et al.* (2004) obtained the LER for assessing yield advantages from agroforestry experiments. Recent application of LER to investigate intercrops can be seen in horticultural (Brintha and Seran 2009; Morales-Rosales and Franco-Mora 2009) and agronomic trials (Dariush *et al.* 2006; Atabo and Umaru 2015; Metwally *et al.* 2015; Amanullah *et al.* 2016; Sebetha 2019). The investigations of Birteeb *et al.* (2020a, 2020b) advocates the importance of studying designs for agroforestry experiments involving multiple trees and multiple crop species.

Koutra *et al.* (2023) proposed a novel model-based approach of optimal design construction for complex blocking structures and network effects for application in agricultural field experiments. It was established that when there is interference between treatments on neighbouring plots, designs incorporating network effects to model this interference are equally or more efficient than randomized row–column designs. Golicz *et al.* (2023) reviewed the current approaches of sampling and data analysis techniques of bio-physico-chemical indicators, including crop yield, in European temperate agroforestry systems to examine the existing statistical methods used in agroforestry experiments.

Nevertheless, LER is simply an index based on combined crop yields and is mostly suitable for comparing crop yields in mixed cropping situations. Meanwhile agroforestry systems usually produce multiple outputs which should all be considered in evaluating a system. The problem of multiple outputs can be tackled by producing an index that synthesizes them into a single value for comparison. When data is available on crop, fodder and timber yields, it may be standardized to a common scale and aggregated for comparing and evaluating different systems.

However, there is less information on a single index that can be used for adequate assessment of an agroforestry system. Hence, it is necessary to explore the possibility of developing such an index.

2. EXPERIMENTAL SITUATION

Consider several agroforestry systems involving different tree species with either the same or different crop species. The interest of the experimenter would be to compare the productivities of the different agroforestry systems, to choose the best among them, maybe a location specific system. Though several outputs or products are possible from tree-crop components of agroforestry systems, a simple case of using only one predominant component each from crop and tree, say, grain yield from crop and fodder yield from tree, is considered for ease of exposition in this study. However, several outputs could be used simultaneously, provided those outputs can be converted to a common suitable scale for comparison. The converted figures can be used for computing an index based on which comparisons can be made. For instance, in an experiment conducted during 1999-2000 at Jhasi, India, Jaggi *et al.* (2004) studied the productivity of fodder trees-based cropping system comprising four tree species (*Albizia lebbeck*, *Azadirachta indica*, *Dalbergia sissoo* and *Vachellia nilotica*) and two crop species (*Cicer arietinum* and *Hordeum vulgare*). They considered multiple yield components, including grain and straw from each crop species, and foliage and fuelwood from each tree species.

3. THE PROPOSED SELECTION INDEX

A new selection index, herein called *Agroforestry System Productivity Index* (ASPI), which can be used to rank different agroforestry systems, is introduced. The ASPI may be defined as a sum of the relative proportions of the equivalently scaled yields or products of tree and crop components of an agroforestry system. Computation of ASPI involves conversion of outputs of an agroforestry system to a common scale and then ranking proportions of the converted values for each year of production.

We consider only situations where each system comprises of a mixture of one tree species and one crop species. It is expected that in the beginning of the trial, crop yields will not be affected by trees (as interference of trees is almost absent) while no or little yield will be made from trees as they are very young. As the trial advances over years, trees grow and dominate the crops. Therefore more importance should be given to crops in the early years of the trial but this importance reverses systematically over the years as trees grow and dominate over crops. So, considering the relationship between the components, a relative weightage parameter (ω) is incorporated into the computation of the index to reflect the relative importance between trees and crops. There may also be some preference or importance attached to the various tree species based on some perceived usefulness or location specific relevance of the species to farmers. For this, a tree species weightage parameter (η) is introduced to rank one tree species relative to the other species. Similarly in crops, there may be preference of one species over others and this is also taken care of by a crop species weightage parameter (ρ).

Let several agroforestry systems involving t tree species and c crop species be considered as a trial for some number of years, say x. The notation for the ASPI is given below.

$T_{j(k)}$ is the monetary value of total yield of tree species j grown with crop species k, $(j = 1,2,\ldots,t)$; (The yield of a tree may include fruits, fodder, fuelwood, timber, etc., each of which is converted into monetary value before being aggregated as the total yield of a tree.)

$T_j = \sum_{k=1}^{c} T_{j(k)}$, is the sum of all monetary values of tree species j in all the trials;

$\sum_{j=1}^{t} T_j$ is the sum of monetary values of all tree species;

$C_{k(j)}$ is the monetary value of total yield of crop species k grown with tree species j, $(k = 1,2,\ldots,c)$; (The yield of crop may include grain, stover, etc. which are also converted into monetary values before being combined as total crop yield.)

$C_k = \sum_{j=1}^{t} C_{k(j)}$, is the sum of all monetary values of crop species k in all the trials;

$\sum_{k=1}^{c} C_k$ is the sum of monetary values of all crop species.

Let the number of years for the trial be x, then ω_i is the weightage of trees relative to crops in the i^{th} year, so that weightage of crops in the same year is $(1-\omega_i)$ where $\omega_i + (1-\omega_i) = 1$, $(i = 1,2,\ldots,x)$;

η_j is the weightage of j^{th} tree species relative to the other tree species based on subject experts' suggested ranking among the tree species;

ρ_k is the weightage of k^{th} crop species relative to the other crop species based on subject experts' opinion ranking among the crop species.

The ASPI is computed for each tree-crop mix using annual yield values of tree and crop components. Four situations arise in respect of what importance is attached to either the tree species, or the crop species or both. Let $ASPI_{i(jk)}$ is the index for tree species j and crop species k in year i, and it is given under each of the four situations as follows.

Case I: Equal importance is given to all tree species and equal importance is given to all crop species, but the relative importance between trees and crops differ.

$$ASPI_{i(jk)} = \frac{\omega_i T_{j(k)}}{\sum_{j=1}^{t} T_j} + \frac{(1-\omega_i) C_{k(j)}}{\sum_{k=1}^{c} C_k} \qquad (1)$$

Case II: Equal importance is given to all tree species but weighted importance is allocated to each crop species based on ranking among all crop species.

$$ASPI_{i(jk)} = \frac{\omega_i T_{j(k)}}{\sum_{j=1}^{t} T_j} + \frac{(1-\omega_i) \rho_k C_{k(j)}}{\sum_{k=1}^{c} \rho_k C_k} \qquad (2)$$

Case III: Weighted importance allocated to each tree species based on ranking among all tree species but equal importance is given to all crop species.

$$ASPI_{i(jk)} = \frac{\omega_i \eta_j T_{j(k)}}{\sum_{j=1}^{t} \eta_j T_j} + \frac{(1-\omega_i) C_{k(j)}}{\sum_{k=1}^{c} C_k} \qquad (3)$$

Case IV: Weighted importance allocated to each tree species based on ranking among all tree species and weighted importance allocated to each crop species based on ranking among all crop species.

$$ASPI_{i(jk)} = \frac{\omega_i \eta_j T_{j(k)}}{\sum_{j=1}^{t} \eta_j T_j} + \frac{(1-\omega_i) \rho_k C_{k(j)}}{\sum_{k=1}^{c} \rho_k C_k} \qquad (4)$$

To compare the performances of systems over some number of years, say x, a simple average of the annual ASPI's is taken. We denote this as $ASPI_{\bar{x}(jk)}$ and it is given for each of the four situations as:

$$ASPI_{\bar{x}(jk)} = \frac{1}{x}\sum_{i=1}^{x}\left(\frac{\omega_i T_{j(k)}}{\sum_{j=1}^{t} T_j} + \frac{(1-\omega_i)C_{k(j)}}{\sum_{k=1}^{c} C_k}\right) \quad (5)$$

$$ASPI_{\bar{x}(jk)} = \frac{1}{x}\sum_{i=1}^{x}\left(\frac{\omega_i T_{j(k)}}{\sum_{j=1}^{t} T_j} + \frac{(1-\omega_i)\rho_k C_{k(j)}}{\sum_{k=1}^{c} \rho_k C_k}\right) \quad (6)$$

$$ASPI_{\bar{x}(jk)} = \frac{1}{x}\sum_{i=1}^{x}\left(\frac{\omega_i \eta_j T_{j(k)}}{\sum_{j=1}^{t} \eta_j T_j} + \frac{(1-\omega_i)C_{k(j)}}{\sum_{k=1}^{c} C_k}\right) \quad (7)$$

$$ASPI_{\bar{x}(jk)} = \frac{1}{x}\sum_{i=1}^{x}\left(\frac{\omega_i \eta_j T_{j(k)}}{\sum_{j=1}^{t} \eta_j T_j} + \frac{(1-\omega_i)\rho_k C_{k(j)}}{\sum_{k=1}^{c} \rho_k C_k}\right) \quad (8)$$

The concept of the weightage of trees relative to crops is subjective and dependent on the comparative importance of the trees or the crops in the i^{th} year. For a simplified illustration, let us consider a situation wherein crop output is of importance in the beginning but with the advancement of years tree component becomes important. In this scenario, it is natural to assume that the relative annual importance of trees increases while that of crops decreases over the years. For instance, if the increment is 10% per year, the values of the parameter will change in the following manner within 10 years of the establishment of a system.

Year (i)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
ω_i	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$(1-\omega_i)$	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0

However, if there exists a different scenario such as in situations where trees already exit before crops are introduced, it is possible that both tree and crop components could be equally relevant with the advancement of time and so the weights would be assigned accordingly.

The computation and usage of ASPI is summarized in the following steps:

1. Obtain the total yield of each tree species grown with each crop species separately and convert it to its monetary equivalence value.
2. Obtain the total yield of each crop species within each tree species and convert it to its monetary equivalence value.
3. Compute the ASPI scores for each system (tree-crop mix). Since there are a total of tc systems, there will be a total of tc scores, one for each system.
4. Rank the ASPI scores from lowest to highest by assigning rank 1 to the smallest score, 2 to the next smallest, and so on till the highest rank of tc is assigned to the highest score. In case of tie scores, use the average of the scores involved. Systems with higher scores are adjudged better.

The ASPI score is a variable taking values between 0 and 1. It measures relative superiority of one system over another only in absolute values and not in terms of statistical significance. Its distribution is however not deducible straight forward. Since no distribution is assumed for the index, using a nonparametric test for testing the hypothesis of 'no significant difference between systems' would be appropriate. Hence, using 'Kruskal-Wallis one-way analysis of variance' (with further pairwise comparison of groups, if test is significant) test would be undoubtedly the most suitable one for confirming the reliability of ranking of agroforestry systems based on the index. The Kruska-Wallis test (Kruskal and Wallis 1952) statistic (KW) is given as:

$$KW = \left[\frac{12}{N(N+1)}\sum_{j=1}^{q} n_j \bar{R}_j^2\right] - 3(N+1),$$

$j = 1, 2, \ldots, q$

where, q denotes the number of groups

n_j is the number of observations in the j^{th} sample

$N =$ is the total number of observations

$\bar{R}_j$ is the average of the ranks in the j^{th} sample

If there are 3 or more systems being compared and the value of KW is significant, the null hypothesis, H_0 : (no difference among systems) is rejected but it is not known to the research which systems or how many systems are different from the rest. Siegel and Castellan (1988) indicated that the significance of individual pairs of differences can be tested using the inequality,

$$\left|\bar{R}_i - \bar{R}_j\right| \geq z_{\alpha/k(k-1)} \sqrt{\frac{N(N+1)}{12}\left(\frac{1}{n_i}+\frac{1}{n_j}\right)}.$$

Let θ_i and θ_j be the mean ranks of groups i and j respectively. If the inequality is true then the hypothesis $H_0 : \theta_i = \theta_j$ is rejected and we conclude that $\theta_i \neq \theta_j$. Here, $\bar{R}_i$ and $\bar{R}_j$ are the average ranks of i^{th} and j^{th} systems, and the value of $z_{\alpha/k(k-1)}$ is the abscissa value from the unit normal distribution above which lies $a/k(k-1)$ percent of the distribution.

To apply Kruskal-Wallis test, the individual values of trees and crops in each trial (plot) need to be processed by converting to appropriate ratios. Processing the data involves the following:

(i) Convert each value of trees and crops to the respective annual relative importance value. That is, multiply ω_i by tree values and $(1-\omega_i)$ by crop values.
(ii) Obtain the sums of the new values produced in (i) for trees and crops separately.
(iii) Take the ratio of each value to the total for trees, and do same for crops.
(iv) Sum the ratios of tree and crop for each plot.
(v) Apply Kruskal-Wallis test to the data obtained in (iv).

Illustration using hypothetical data: Data on grain yields of crops and fodder yields of trees was simulated for 25 systems comprising 5 tree species namely, (1) siris (*Albizia lebbeck*), (2) neem (*Azadirachta indica*), (3) shisham (*Dalbergia sissoo*), (4) babul (*Vachellia nilotica*) and (5) ghaf (*Prosopis cineraria*), and the five crop species as (a) barley (*Hordeum vulgare*), (b) gram (*Cicer arietinum*), (c) wheat (*Triticum aestivum*), (d) moong (*Vigna radiata*) and (e) maize (*Zea mays*). Hypothetical values are used to demonstrate the computation of ASPI. The sum of monetary values of trees and crops for each plot are given in Table 1. Top values are for crops (i.e., $C_{k(j)}$) and bottom values are for trees (i.e., $T_{j(k)}$). The sums of the cell values are provided in the last column (for crops) and last row (for trees).

Assuming that we are interested in comparing the agroforestry systems in the 4th year of establishment, then we have $i=4$. Let the relative annual importance be $\omega_4 = 0.3$, so that we compute the following values.

$$\sum_{j=1}^{t} T_j = 17.7638 + 14.4954 + 7.4328 + 12.5446 + 19.843 = 72.0796$$

$$\sum_{k=1}^{c} C_k = 692.0128 + 667.5515 + 734.9991 + 735.3868 + 655.262 = 3485.212$$

$$ASPI_{4(1a)} = \frac{(0.3 \times 3.6288)}{72.0796} + \frac{(0.7 \times 123.6808)}{3485.212} = 0.039944$$

Table 1. Monetary value (1000 rupees) equivalence of crop and tree yields

		Tree species					Crop totals
		1	2	3	4	5	
Crop species	*a*	123.6808	142.2850	147.7670	134.3200	143.9600	692.0128
		3.6288	3.0380	1.7590	2.5650	4.0000	
	b	135.3415	125.9625	132.7205	136.0145	137.5125	667.5515
		3.6820	3.0460	1.5840	2.6100	4.0440	
	c	132.4601	153.7150	157.0600	144.2740	147.4900	734.9991
		3.5880	3.1550	1.6500	2.3700	3.8200	
	d	135.5418	152.4150	144.3200	156.9150	146.1950	735.3868
		3.4750	2.3700	1.5448	2.4086	3.9440	
	e	130.2320	139.4200	127.6720	132.9880	124.9500	655.2620
		3.3900	2.8864	0.8950	2.5910	4.0350	
Tree totals		17.7638	14.4954	7.4328	12.5446	19.8430	

Following the same computation process, ASPI scores are calculated for all systems and given in Table 2 along with the respective ranks. From Table 2, the ASPI scores indicated that the best tree crop mix is a ghaf-moong system (5d), followed by ghaf-barley system (5a). The ranking order for all the systems is summarized as:

$$5d \geq 5a \geq 5c \geq 5b \geq 2c \geq 1b \geq 5e \geq ... \geq 4a \geq 4e \geq 3a \geq 3d \geq 3b \geq 3e.$$

Table 2. Agroforestry System Productivity Indices (ASPI) with ranks

		Tree species				
		1	**2**	**3**	**4**	**5**
Crop species	*a*	0.0399	0.0412	0.0370	0.0377	0.0456
		11	15	4	6	24
	b	0.0425	0.0380	0.0332	0.0381	0.0445
		20	7	2	8	22
	c	0.0415	0.0440	0.0384	0.0388	0.0455
		16	21	9	10	23
	d	0.0417	0.0405	0.0354	0.0415	0.0458
		18	14	3	17	25
	e	0.0403	0.0400	0.0294	0.0375	0.0419
		13	12	1	5	19

The top values in each row are the computed ASPI's and the bottom values are the rank scores.

In order to statistically validate the reliability of this ASPI results, the data was also analysed using Kruskal-Wallis test. The test result is statistically significant (Table 3) and a post-hoc test is done to separate the tree-crop combinations into homogeneous groups.

Table 3. Kruskal-Wallis test result

Independent-Samples Kruskal-Wallis Test Summary	
Total N	50
Test Statistic	46.781[a]
Degree of Freedom	24
Asymptotic Sig. (2-sided test)	0.004
a. The test statistic is adjusted for ties.	

The post-hoc test grouped the 25 tree-crop combinations into 11 homogenous but overlapping subsets (Table 4). Tree-crop combinations within the same subset do not differ significantly but those in different subsets differ significantly at 5% level of significance. The subset which has elements having very high average rank scores, which we may call the superior subset, had the following elements (in decreasing magnitude of average ranks):

$$5d, 5a, 5b, 5c, 5e, 1b, 2c, 1c, 1d, 1a, 1e, 2a.$$

Also, the elements in the most inferior subset included (in decreasing magnitude of average rank scores):

$$2e, 4d, 2b, 4b, 2d, 4c, 4e, 4a, 3c, 3a, 3d, 3b, 3e.$$

In general, the Kruskal-Wallis test results matched with the results of the ASPI scores. Therefore, the ASPI is reliable and is recommended for use in comparing different agroforestry systems.

4. DISCUSSION

A new selection index, *Agroforestry System Productivity Index* (ASPI), which can be used to rank different agroforestry systems, is defined. It is computed as the sum of the relative proportions of the equivalently scaled yields of tree and crop components of an agroforestry system. Calculation of ASPI involves conversion of outputs of an agroforestry system to a common scale and then ranking proportions of the converted values for each year of production. For illustrating the calculation procedure of the index, agroforestry systems comprising of one tree species and one crop species is considered. It is logical to assume that in the beginning of the trial, crop yield will not be affected by the trees and not much yield will be made from trees as they are very young. As the trial advances over years, trees grow and dominate the crops. This aspect is taken care of by incorporating a relative weightage parameter (ω) into the computation of the index to reflect the relative importance between trees and crops. In order to statistically validate the reliability of this ASPI results, the data was also analysed using Kruskal-Wallis test. In general, the Kruskal-Wallis test results matched with the results of the ASPI scores.

Previously developed indices were meant for use in intercropping systems (de Wit and van den Bergh 1965; Willey 1979). Recently, Mukoobwa *et al.* (2023) carried out an assessment of agroforestry practices in Mukura Sector in Southern Rwanda and reported on species diversity and similarity indices. While their work was useful for analysis of species composition, it did not provide any information on quantifiable biomass such as yield. Kermani (1980) presented the findings of extensive research to determine the impact of cultivating *Eucalyptus camaldulensis* and *Acacia nilotica* alongside cotton, wheat, sesamum, and sorghum. It was discovered that agricultural crops cultivated with *E. camaldulensis* produced larger yields. Also, the *E. camaldulensis* and cotton combination was

Table 4. Homogeneous subsets of ASPI scores based on tree-crop (tc) combinations

Sample	**Subset**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
3e	1.50										
3b	3.50	3.50									
3d	5.50	5.50	5.50								
3a	8.50	8.50	8.50	8.50							
3c	9.50	9.50	9.50	9.50	9.50						
4a	14.50	14.50	14.50	14.50	14.50	14.50					
4e	16.00	16.00	16.00	16.00	16.00	16.00					
4c	16.00	16.00	16.00	16.00	16.00	16.00					
2d	16.50	16.50	16.50	16.50	16.50	16.50					
4b	18.00	18.00	18.00	18.00	18.00	18.00	18.00				
2b	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00			
4d	21.50	21.50	21.50	21.50	21.50	21.50	21.50	21.50	21.50		
2e	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	
2a		28.50	28.50	28.50	28.50	28.50	28.50	28.50	28.50	28.50	28.50
1e			29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00
1a				32.50	32.50	32.50	32.50	32.50	32.50	32.50	32.50
1d					34.50	34.50	34.50	34.50	34.50	34.50	34.50
1c						36.50	36.50	36.50	36.50	36.50	36.50
2c							37.00	37.00	37.00	37.00	37.00
1b							38.50	38.50	38.50	38.50	38.50
5e								42.00	42.00	42.00	42.00
5c									44.50	44.50	44.50
5b										46.00	46.00
5a										46.00	46.00
5d											46.50
Test Statistic	20.923	20.803	20.701	20.530	20.581	20.889	17.834	17.953	17.834	19.140	18.540
Sig. (2-sided test)	.052	.053	.055	.058	.057	.052	.058	.056	.058	.059	.070
Adjusted Sig. (2-sided test)	.097	.100	.103	.108	.106	.098	.127	.122	.127	.118	.140
Homogeneous subsets are based on asymptotic significances. The significance level is .05.											
Each cell shows the sample average rank of tc.											

the most effective due to larger wood production and better financial returns from the agricultural crops. Nevertheless, the volume of wood and monetary value of crops represent different units and should have been standardized to ensure true comparison of the different agroforestry systems.

As seen in Jaggi *et al.* (2004), the extended application of LER to assess yield advantages of agroforestry experiments is commendable. Nevertheless, such an application may be deficient in precision since agroforestry conditions were not considered in developing the LER. Furthermore, the LER represents the total of the ratios of yields of tree-crop components to their corresponding sole-crop yields (Jaggi *et al.*, 2004). Since yield is based on weight, there would be a limitation to the application of LER as an index for comparing agroforestry systems. This is so because tree and crop components may be comparable in weight but not in calorific or monetary value. In the study of Jaggi *et al.* (2004), when the LERs of different tree-crop combinations were compared for two consecutive years of cultivation, there was no significant difference in yields but when the same data was converted to monetary value and compared for the same period of cultivation, there was significant difference. This is a clear indication that data of different components of agroforestry systems need to be standardized on a common unit or scale (such as monetary value) before being combined for the purpose of comparing different systems. In view of this, the ASPI would be an appropriate tool for assessing agroforestry systems, having been developed based on agroforestry conditions and using standardized measurement of tree and crop components.

In conclusion, the proposed ASPI considers the conditions of an agroforestry system in its computations. Also, the inclusion of the different components (products) of an agroforestry system on weightage basis allows the ASPI to yield index scores that represent the symbiotic relationships among tree-crop components and production objectives of farmers in an agroforestry system. Conversion of all products into monetary values removes the limitation of comparing indices with different metric units. Therefore, the ASPI is reliable and is recommended for use in comparing different agroforestry systems involving tree-crop components.

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REFERENCES

Amanullah, Khan, F., Muhammad, H., Jan, A.U. and Ali, G. (2016). Land equivalent ratio, growth, yield and yield components response of mono-cropped vs. inter-cropped common bean and maize with and without compost application. *Agriculture and Biology Journal of North America*, **7**(2), 40-49. doi:10.5251/abjna.2016.7.2.40.49

Atabo, J.A. and Umaru, T.M. (2015). Assessing the land equivalent ratio (LER) and stability of yield of two cultivars of sorghum (Sorghum bicolor L. Moench)-soyabean (Glycine max L. Merr) to row intercropping system. *Journal of Biology, Agriculture and Healthcare*, **5**(18), 144-149.

Birteeb, P.T., Varghese C., Jaggi, S., Harun, M. and Varghese E. (2020a). Tree Network-balanced Designs for Agroforestry Trials. *Journal of the Indian Society of Agricultural Statistics,* **74**(3), 243-254.

Birteeb, P.T., Varghese, C., Jaggi, S., Varghese, E. and Harun, M. (2020b). An efficient class of tree network balanced designs for agroforestry experimentation. *Communications in Statistics-Simulation and Computation,* **51**(12), 7169-7179. doi:10.1080/03610918.2020.1825739

Brintha, I. and Seran, T.H. (2009). Effect of paired row planting of radish (*Raphanus sativus* L.) intercropped with vegetable amaranthus (*Amaranthus tricolor* L.) on yield components of radish in sandy regosol. *The Journal of Agricultural Sciences*, **4**(1),19-28.

Dariush, M., Ahad, M. and Meysam, O. (2006). Assessing the land equivalent ratio (LER) of two corn [Zea mays L.] varieties intercropping at various nitrogen levels in Karaj, Iran. *Journal of Central European Agriculture*, **7**, 359-364.

de Wit, C.T. and Van der Bergh, J.P. (1965). Competition between herbage plants. *Netherlands Journal of Agricultural Science*, **13**, 212-221.

Golicz, K., Piepho, H.P., Minarsch, E.M.L, Niether, W., Große-Stoltenberg, A., Oldeland, J., Breuer, L., Gattinger, A. and Jacobs, S. (2023). Highlighting the potential of multilevel statistical models for analysis of individual agroforestry systems. *Agroforestry Systems,* **97**, 1481-1489. https://doi.org/10.1007/s10457-023-00871-x

Jaggi, S., Handa, D.P., Gill, A.S. and Singh, N.P. (2004). Land equivalent ratio for assessing yield advantages from agroforestry experiments. *The Indian Journal of Agricultural Sciences*, **74**(2), 76-79.

Kermani, W.A. (1980). Developing multiple use silvicultural practices for forestry of arid regions. *Proceedings of lUFRO/MAB Conference, Research on Multiple Use of Forest Resources*, Flag Staff, Arizona.

Koutra, V., Gilmour, S.G., Parker, B.M. and Mead, A. (2023). Design of agricultural field experiments accounting for both complex blocking structures and network effects. *Journal of Agricultural, Biological and Environmental Statistics,* **28**, 526-548. https://doi.org/10.1007/s13253-023-00544-3.

Kruskal, W.H. and Wallis, W. A. (1952). Use of ranks in one-criterion variance analysis. *Journal of the American Statistical Association*, **47**, 583-621.

Metwally, A.A., Safina, S.A. and Noaman, A.H. (2015). Yield and land equivalent ratio of intercropping maize with Egyptian cotton. *Journal of Agri-Food and Applied Sciences,* **3**(4), 85-93.

Morales-Rosales, E.J. and Franco-Mora, O. (2009). Biomass, yield and land equivalent ratio of *Helianthus annus* L. in sole crop and intercropped with *Phaseolus vulgaris* L. in high valleys of Mexico. *Tropical and Subtropical Agroecosystems*, **10**, 431-439.

Mukoobwa, D., Zaninka, B. and Mugunga, C. P. (2023). The Assessment of Agroforestry Practices in Mukura Sector, Huye District, Southern Rwanda. *International Journal of Forestry Research*, 2023, Article ID 2288114, 10 pages. https://doi.org/10.1155/2023/2288114

Oyejola, B.A. and Mead, R. (1982). Statistical assessment of different ways of calculating land equivalent ratios (LER). *Experimental Agriculture*, **18**, 125-138.

Ranasinghe, O.M.S.H.K. and Mayhead, G.J. (1990). The effect of intercropping *Populus* 'RAP' with beans. *Forestry*, **63**(3), 271-277.

Riley (1989). The assessment of the stability of agroforestry systems. World Agroforestry Centre: Meteorology and Agroforestry. https://apps.worldagroforestry.org/Units/Library/Books/Book%2077/meteorology%20and%20agroforestry/html/assessment_stability.htm?n=18

Sebetha, E. (2019). Maize field biomass yield and land equivalent ratio under influence of different management practices and location. *Asian Journal of Crop Science*, **11**, 25-31.

Singh, M. (1989). Estimation of land equivalent ratios. *Journal of Applied Statistics*, **16**(3), 363–371. doi:10.1080/02664768900000044

Szász, K. (1987). An index of relative crop yields. *Journal of Official Statistics*, **3**(2), 183-190.

Willey, R.W. (1979). Intercropping–its importance and research needs–Parts I and II. *Field Crop Abstracts*, **32**, 1-10 and 73-85.