Relative efficiency of ^{32}P uptake in a banana-based intercropping system

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Abstract — **Introduction**. A study was conducted in India to assess the efficiency of ^{32}P uptake and the feasibility of intercropping using land-use efficiency parameters in a banana-based intercropping system. **Materials and methods**. Absorption of ^{32}P applied to plants in five-crop, two-crop and sole-crop systems involving banana *Musa* AAB ('Mysore'), ginger (*Zingiber officinalis* Rosc.), turmeric (*Curcuma longa* L.), cassava (*Manihot esculenta* Crantz.) and elephant yam (*Amorphophallus campanulatus* Blume.) was studied in field trials. The experiment was conducted for two years. During the first year, the main crop was planted during October, the main planting season for banana in India, and the intercrops were planted in early May of the next year. In the second year, both the main crop and intercrops were planted in May. **Results**. Radiophosphorus applied in the active root zone of one of the component species in the mixed crop system was found to be absorbed not only by the treated plant but also by the neighboring plants. Absorption by banana was prevalent. Differential effects of competition were manifested as observed by the relative uptake of ^{32}P. Lower relative uptake of ^{32}P was observed in the main crop banana when simultaneous planting of intercrops was done. Ginger and turmeric were not affected in relation to planting at different stages of the main crop, whereas cassava and elephant yam showed lesser relative ^{32}P uptake when planted later, confirming that different crops in the mixed crop system react differently. **Conclusions**. The efficiency of different crops in terms of uptake varied with the system of planting. The higher relative efficiency of ^{32}P uptake in a multiple cropping system points to an improved efficiency of uptake and higher dry weight on a per plant basis. It confirms the efficiency and feasibility of the cropping system. Economic analysis emphasizes the concept and proves the viability of the system.

India / *Musa* / *Amorphophallus campanulatus* / *Manihot esculenta* / *Zingiber officinalis* / *Curcuma longa* / phosphorus / radioisotopes / plant competition / intercropping / mixed cropping

Efficacité relative de l'assimilation de ^{32}P en cultures intercalaires à base de bananiers.

Résumé — **Introduction**. Une étude a été entreprise en Inde pour évaluer l'efficacité de l'assimilation de ^{32}P et la praticabilité de cultures intercalaires en utilisant des paramètres aptes à mesurer l'efficacité de l'utilisation de la terre en cultures intercalaires à base de bananiers. **Matériel et méthodes**. L'absorption de ^{32}P apporté à des plants dans des systèmes de culture à cinq, deux et une seule espèce(s) impliquant le bananier *Musa* AAB, ('Mysore'), le gingembre (*Zingiber officinalis* Rosc.), le safran (*Curcuma longa* L.), le manioc (*Manihot esculenta* Crantz.) et le pain d'éléphant (*Amorphophallus campanulatus* Blume.) a été étudiée en champ. L'expérience a porté sur deux années. Lors de la première année, la culture de base a été mise en place en octobre, principale saison de plantation du bananier en Inde, et les cultures intercalaires ont été plantées en début mai de l'année suivante. Lors de la deuxième année, le bananier et les cultures intercalaires ont été plantés en mai. **Résultats**. Le phosphore radioactif appliqué dans la zone active des racines de l'une des espèces composant le système des cultures en mélange a été absorbé non seulement par le plant traité mais également par les plants voisins. L'absorption par le bananier a été prédominante. Différents effets de compétition se sont manifestés comme l'a révélé l'assimilation relative de ^{32}P. Pour la banane, cette assimilation a été inférieure quand les plants ont été plantés simultanément avec les cultures intercalaires. Le gingembre et le safran n'ont pas été affectés par la plantation à différentes étapes de développement du bananier, tandis que le manioc et le pain d'éléphant ont montré peu d'assimilation relative de ^{32}P dans le cas de la plantation tardive, ce qui confirmerait que les différentes cultures du système intercalaire réagissent différemment. **Conclusions**. L'efficacité de l'assimilation de ^{32}P des différentes espèces étudiées a varié avec la date de plantation. Dans un système de plusieurs cultures en mélange, l'assimilation d'intrants a été améliorée et le poids sec plus élevé au niveau du plant. Cela confirme l'efficacité et la praticabilité du système de cultures intercalaires. L'analyse économique effectuée a appuyé le concept et prouvé la viabilité du système.

Inde / *Musa* / *Amorphophallus campanulatus* / *Manihot esculenta* / *Zingiber officinalis* / *Curcuma longa* / phosphore / isotope radioactif / compétition végétale / culture intercalaire / culture en mélange

1. Introduction

Crop producers aspire to the greatest possible yield commensurate with reasonable cost. Normally, the balance struck varies with location and occasion. In the developed countries where population pressure is not yet excessive, the cost and availability of labor is the prime consideration, and at times even more important than total production or even yields. On the contrary, in the underdeveloped and overcrowded parts of the world, labor is far less important than its total production and so can accommodate a system where every inch of land will be farmed, at the expense of hours of tedious hand labor. Different systems of farming exercise this effort but at varying intensities.

Mixed cropping provides a system in which maximum realization of yield is aimed per unit of land area and it merits serious thought in the tropical belts where population explosion can be observed in conjunction with undue pressure on arable land. Mixed cropping involves a system where crops are so adjusted that the efficiency of the land is exploited to the fullest extent. It involves both advantages and disadvantages.

Component crops in a mixed cropping pattern have to be in a definite geometry to avoid competition between and within the crops. This calls for accommodating the root spread of a crop within its active root zone area and canopy within limited aerial spread. Practically, overlapping of roots cannot be undone, though theoretical claims can be made. The competitive or complementary interactions in the mixed crop stand are not yet fully understood and one of the probable reasons for the yield advantage or disadvantage is the root level interaction among component species during absorption of water and nutrients. The geometry of planting also decides the proportion of space exploited by the component species in intercropping systems. Different methods are used for studying the root system of crops [1–3]. Physical excavations give a holistic picture and include the live, dead and the dormant roots. On the other hand, root studies involving the use of isotopes give an idea of only the live and active roots [1, 4]. Absorption of ^{32}P by component species in grass-legume and cereal-legume mixtures has already been reported [5–8]. A number of reviews have appeared concerning interactions in crop communities [9–13].

Competition for resources occurs between species in crop mixtures. The total biomass per unit of land area when more than one species is present will frequently be greater than that produced by one of the species grown alone at the same density. In general, the greater the difference in the habits of the component species, the greater the yield advantage of the mixture or the complementarities between the crops and conversely, the degree of the competitive pressure between the component species will be less [14]. On the other hand, when there is strong similarity in the crop habits of component crops, it will lead to yield disadvantage or fewer yields, meaning a higher degree of competition between component crops. Investigations into complementary or competitive interactions among horticultural crops in mixed culture are relatively few. One report on these lines is in a cassava-based intercropping system [15]. Though different studies have been undertaken at the center by varying the crop geometry [15, 16], no studies on a banana-based intercropping system exist by adjustment of the planting time of intercrops along with the two main seasons of planting of banana in the state. Hence, a study was undertaken to understand the relative level of complementarities or competitiveness in a banana-based cropping system, as it is one of the major crops of the state of Kerala (India) and the nation, besides being a major component of the mixed cropping pattern and the home garden system of Kerala. This study reports the relative absorption of ^{32}P by component species and the land-use efficiency of such a system.

2. Materials and methods

The soil at the experimental site (12° 32' N, 74° 2' E, altitude of 22.52 m above mean sea level) belongs to the group Eutrorthox, order Oxisol, Vellanikkara (India) series with a pH of 5.3 (soil-water 1:2.5), sandy clay loam with 1.3% organic matter, 54 $\mu g \cdot g^{-1}$ Bray IP and 226 $\mu g \cdot g^{-1}$ neutral one normal ammonium oxalo acetate (N NH_40 AC) exchangeable K, CEC of 10.4 cmol $(P^+) \cdot kg^{-1}$ and pore space of 42.83%.

Absorption of ^{32}P by the main crop and intercrops in all possible five-crop combinations of banana *Musa* AAB ('Mysore'), turmeric (*Curcuma longa* L.), cassava (*Manihot esculenta* Crantz.), ginger (*Zingiber officinalis* Rosc.) and elephant yam (*Amorphophallus campanulatus* Blume.) and two-crop combinations with banana as one crop, as well as by the sole crops were studied. Nine plants of banana spaced at 2 m × 2 m formed a plot with the central plant being the experimental plant receiving the ^{32}P. Four raised beds were made on the opposite sides of the main experimental banana plant, measuring 1 m in length and 0.50 m in width (*figure 1*). Ginger and turmeric are planted worldwide on raised soil beds.

The elephant yam and cassava were planted diagonally 1 m away from the experimental main crop such that two plants in opposite directions were occupied by one species. The ginger and turmeric were planted in the beds at 25 cm × 25 cm spacing such that the opposite beds were occupied by one species. The ginger and turmeric intercrop plants on the raised beds 1 m away from the experimental banana crop formed the experimental plant. Thus, 14 treatment combinations of banana-based intercropping systems were studied (*table I*).

Each treatment was replicated twice and the experiment was in a randomized design. All the plants received cultural and manurial doses separately as per the package of practices recommendations [17].

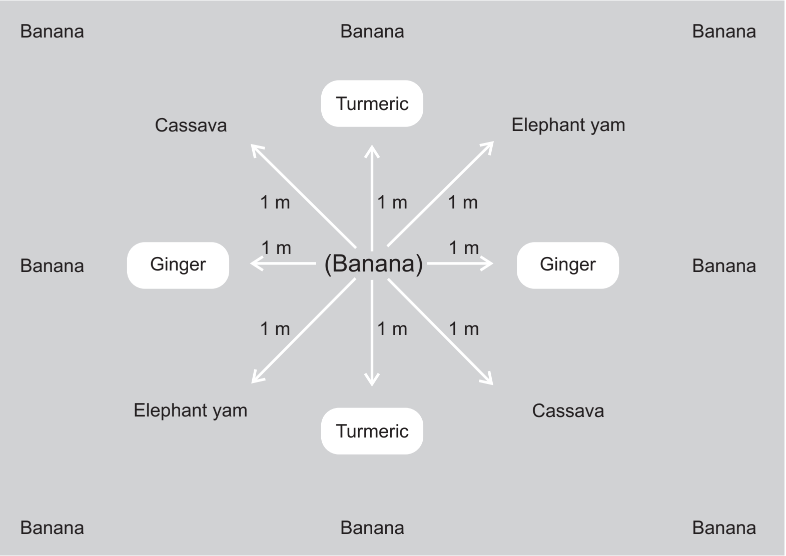

Figure 1.
Layout of experimental plot used to study the efficiency of ^{32}P uptake in a banana-based intercropping system (India) [(Banana): experimental plant for tracer application].

Table I.
Treatment combinations used to study the efficiency of ^{32}P uptake in a banana-based intercropping system (India).

Combination number	Plant receiving ^{32}P	Other plants of the cropping sytem
1	Banana	Cassava + turmeric + ginger + elephant yam
2	Cassava	Banana + turmeric + ginger + elephant yam
3	Turmeric	Banana + cassava + ginger + elephant yam
4	Ginger	Banana + cassava + turmeric + elephant yam
5	Elephant yam	Banana + cassava + turmeric + ginger
6	Banana	Ginger
7	Banana	Tumeric
8	Banana	Cassava
9	Banana	Elephant yam
10	Banana	–
11	Cassava	–
12	Elephant yam	–
13	Ginger	–
14	Turmeric	–

Two separate field experiments were conducted to study the relative absorption of applied ^{32}P by component species in an intercropping system with planting of intercrops planned at two stages of the main crop. The experiment was studied in a banana-based intercrop system, the planting of which was timed in two years, in 1997 and 1998. Mysore, syn. Palayankodan, the cultivar of banana formed the main crop. The two stages of planting of the intercrop in relation to the main crop formed the two experiments.

2.1. Experiment I: intercrops planted 5 months after banana

The main crop was planted in October 1997, the main season of planting, and the intercrops were planted only in mid-May 1998. By this time, the main crop had established itself, covering the entire block, and was in the very active stage of growth.

2.2. Experiment II: intercrops planted at the same time as banana

The banana planting was done in May 1998 and, after the crops showed the initial stage of establishment, the intercrops were planted immediately within a fortnight in May 1998, coinciding with the time of planting of intercrops in the state.

2.3. Application of ^{32}P

The ^{32}P radiotracer was applied in the active root zone of the plant concerned using a field dispenser which dispenses the correct and only required volume of ^{32}P [18]. In all crops the activity was applied through prebored PVC tubes (2 cm diameter). In the case of banana, ten pipes were pre-laid in equally spaced holes around the plant whereas, in the case of cassava, elephant yam, ginger and turmeric, only five pipes were used. The pipes were laid at the correct depth and in the zone of maximum root activity of each crop. To each hole, 3 mL of ^{32}P in a carrier level of 1000 P $\mu g \cdot L^{-1}$ was applied to give a total activity of 1 $mCi \cdot plant^{-1}$ in the case of banana and of 0.5 $mCi \cdot plant^{-1}$ for two plants, each of 0.5 mCi, in the opposite direction to the main plant, 1 m away from the main crop, in the case of intercrops. The carrier was added to minimize the fixation of ^{32}P [19]. To minimize the incidence of the activity from sticking onto the sides of the access tube, a jet of distilled water was used to wash down the same. After this, the access tubes were removed and the holes were plugged with soil. The radial distances and depths of ^{32}P application for the crops were selected based on the previous studies conducted at the same center: for banana, 30 cm [20]; for cassava and elephant yam, 20 cm [15], and for ginger and turmeric, 10 cm [21].

2.4. Plant sampling and radio assay

The leaves which have been reported to give minimum variation are the third leaf from the top in banana [22], the fifth leaf from the top of the new unfurled leaf in cassava and in elephant yam [15] and the second fully unfurled leaves in ginger and turmeric [23–25]; hence, these leaves were used as the sampling material.

The leaves of the treated plants and intercrops were separately sampled (5, 15, 25 and 35) days after ^{32}P application and the recovery of radioactivity was determined by the Cerenkov counting technique using a liquid scintillation counter (Rack Beta of LKB Wallac OY, Finland) [26]. The activity was corrected for background and decay and finally expressed as counts per min per g of dry leaf sample. Relative absorption of ^{32}P by each treated plant was computed as the ratio [plant count in the intercropping system / count in the sole-crop situation].

2.5. Land-use efficiency system

The economic analysis of the system was made from three angles. The land equivalent ratio (LER) was calculated as per the standard formula [27] and the area-time equivalency ratio (ATER) was computed based on the work of Hiebsch and McCollum [28]. The third approach was by calculating the mean of LER and ATER, as this method is reported to counterbalance the overestimation or underestimation of probabilities of each value [29].

2.6. Statistical analysis

To avoid any error due to variation, the count rates (cpm) were subjected to log transformation and then analyzed using the analysis of variance technique [24].

3. Results

3.1. Banana-based intercropping system and recovery of activity

The leaf assay of the recovery of radioactivity in the five-crop and two-crop intercropping systems and those of the sole crops revealed that the ^{32}P was absorbed not only by the treated plants but also by the surrounding intercrops and plants (*table II*).

In the five-crop combinations, in the study where the intercrops had been planted after 5 months of planting banana, the treated plants showed the highest recovery when banana, ginger and turmeric were the experimental treated plants, but when cassava and elephant yam were the treated plants, banana and turmeric, and banana and cassava intercrops could show higher recovery of the radioactivity than the treated plants. In the study where the intercrops were planted just after the establishment of the banana main crop, the treated main plants in all cases showed higher recovery than the surrounding plants. During both the experiments, a similar trend was observed at all sampling intervals. One important aspect observed during both the studies was that banana plants showed good recovery even when other intercrops were the treated crops. This superiority was explicitly significant in the second experiment, whereas it was on a par with cassava and turmeric when turmeric, elephant yam and cassava were the treated plants in the first year.

Analysis of data on recovery revealed that, in the case of elephant yam, the recovery of activity was very low or zero in the first and last samplings, but the second and third samplings showed high values. On the other hand, in the case of ginger and turmeric, recovery of activity increased up to the third sampling and thereafter decreased. Cassava was conspicuous by its differential nature of recovery. In the first study, absorption was found to be evenly spread but, in the second study, the second sampling mostly completed its absorption. The main crop banana showed good recovery in all four samplings.

In the two-crop combinations, involving all the intercrops and where the treated plant was only banana, a similar trend was observed in both the experiments. More than half of the recovery was observed in all the intercrops and at all intervals of sampling.

In the sole crops, the uptake of activity in both the experiments was again similar at all stages of sampling. Ginger and turmeric showed the highest recoveries, which were on a par and significantly superior in both experiments; cassava and elephant yam obtained the next levels of recovery: cassava more than elephant yam in the first experiment, and elephant yam more than cassava in the second experiment. The sole banana crop showed the least recovery.

The most important observation was that the recovery of activity in the three systems of cropping involving banana as the treated plant revealed that recovery in the five-crop pattern was highest and significantly superior in the first study, whereas it was on a par with two crops and the sole crops in the second study.

3.2. Relative ^{32}P and dry matter yield

When banana was the treated plant, there was an increase in relative ^{32}P absorption in leaves during the samplings in the five-crop combination, whereas, in the two-crop combination with ginger in the first experiment, the relative ^{32}P absorption was lesser. Nevertheless, in the second experiment, the relative ^{32}P absorption of banana was better in the two-crop combination with ginger than in the five-crop combination (*tables III, IV*). During both the studies,

Table II.
Absorption of ^{32}P (log of cpm·g^{-1} of dry leaf) by the component species in five-crop, two-crop and monocrop systems.

Cropping system	Plant sampled (in parenthesis: crop receiving the isotope)	Intercrops planted 5 months after planting of banana								Intercrops planted just after planting of banana							
		Treated plants				Surrounding plants				Treated plants				Surrounding plants			
		Days after application				Days after application				Days after application				Days after application			
		5	15	25	35	5	15	25	35	5	15	25	35	5	15	25	35
Banana	(Banana)	3.18	4.33	3.80	3.69	–	–	–	–	2.45	2.83	2.56	2.08	–	–	–	–
+ Ginger	Ginger	–	–	–	–	2.52	3.43	2.63	1.24	–	–	–	–	1.99	2.23	2.30	2.07
+ Turmeric	Turmeric	–	–	–	–	0.98	1.82	2.07	1.92	–	–	–	–	2.04	2.27	2.47	2.18
+ Cassava	Cassava	–	–	–	–	2.15	2.66	2.61	2.42	–	–	–	–	1.68	1.83	0.77	0.00
+ Elephant yam	Elephant yam	–	–	–	–	0.62	2.08	1.83	0.00	–	–	–	–	1.07	1.55	0.91	0.00
	(Ginger)	3.26	4.21	4.22	3.76	–	–	–	–	3.04	3.75	3.50	3.47	–	–	–	–
	Banana	–	–	–	–	1.97	2.94	2.55	1.63	–	–	–	–	2.56	2.84	3.00	2.68
	Turmeric	–	–	–	–	0.76	1.94	1.88	1.11	–	–	–	–	0.57	1.48	0.42	0.00
	Cassava	–	–	–	–	0.30	1.99	1.99	0.89	–	–	–	–	0.31	1.54	0.00	0.00
	Elephant yam	–	–	–	–	0.00	1.96	1.95	0.00	–	–	–	–	0.15	1.32	0.00	0.00
	(Turmeric)	3.00	3.44	3.34	3.15	–	–	–	–	3.38	4.37	4.29	4.30	–	–	–	–
	Banana	–	–	–	–	2.39	2.99	2.88	2.96	–	–	–	–	2.60	2.85	2.92	3.13
	Ginger	–	–	–	–	0.47	1.68	1.78	0.00	–	–	–	–	1.25	1.77	1.44	0.12
	Cassava	–	–	–	–	2.71	3.23	3.11	3.02	–	–	–	–	1.81	2.13	2.29	2.08
	Elephant yam	–	–	–	–	0.87	2.13	2.19	1.27	–	–	–	–	1.48	1.99	1.89	2.07
	(Cassava)	2.41	3.02	2.44	2.34	–	–	–	–	3.49	4.26	4.46	3.92	–	–	–	–
	Banana	–	–	–	–	2.71	2.90	2.99	2.65	–	–	–	–	2.43	2.66	2.85	2.79
	Ginger	–	–	–	–	0.77	1.92	2.04	0.65	–	–	–	–	0.60	1.71	0.00	0.00
	Turmeric	–	–	–	–	2.67	3.06	3.99	3.40	–	–	–	–	0.57	1.64	0.00	0.00
	Elephant yam	–	–	–	–	1.75	2.29	2.48	2.47	–	–	–	–	1.45	1.93	2.06	1.62
	(Elephant yam)	2.32	2.76	2.42	2.31	–	–	–	–	3.36	4.28	4.50	4.28	–	–	–	–
	Banana	–	–	–	–	2.28	2.85	2.88	2.84	–	–	–	–	2.08	2.50	2.64	2.22
	Ginger	–	–	–	–	0.47	2.16	2.03	1.79	–	–	–	–	1.62	1.99	2.00	0.00
	Turmeric	–	–	–	–	0.93	2.09	2.12	1.25	–	–	–	–	1.39	1.81	1.67	0.00
	Cassava	–	–	–	–	2.86	2.98	3.12	2.94	–	–	–	–	1.62	2.00	2.05	0.00
Banana	(Banana)	2.72	2.93	2.96	3.03	–	–	–	–	2.92	3.14	3.35	3.26	–	–	–	–
+ ginger$_1$	Ginger$_1$	–	–	–	–	2.72	3.36	3.50	3.47	–	–	–	–	3.04	3.42	3.62	3.41
+ ginger$_2$	Ginger$_2$	–	–	–	–	2.76	3.40	3.42	3.43	–	–	–	–	3.04	3.43	3.62	3.45
Banana	(Banana)	2.41	2.87	2.61	2.42	–	–	–	–	2.37	2.58	2.36	1.25	–	–	–	–
+ turmeric$_1$	Turmeric$_1$	–	–	–	–	2.66	3.50	3.56	3.42	–	–	–	–	2.77	3.56	3.79	3.28
+ turmeric$_2$	Turmeric$_2$	–	–	–	–	2.48	3.40	3.42	3.44	–	–	–	–	2.94	3.61	3.84	3.56
Banana	(Banana)	2.39	2.77	2.84	2.76	–	–	–	–	2.41	2.66	2.87	2.76	–	–	–	–
+ cassava$_1$	Cassava$_1$	–	–	–	–	2.77	3.38	3.60	3.41	–	–	–	–	2.88	3.60	3.88	3.24
+ cassava$_2$	Cassava$_2$	–	–	–	–	2.70	3.42	3.55	3.40	–	–	–	–	2.81	3.52	3.83	3.25
Banana	(Banana)	2.41	2.79	2.63	2.55	–	–	–	–	2.44	2.73	2.79	2.46	–	–	–	–
+ Elephant yam$_1$	Elephant yam$_1$	–	–	–	–	3.55	3.97	4.16	2.91	–	–	–	–	3.39	3.76	4.01	3.74
+ Elephant yam$_2$	Elephant yam$_2$	–	–	–	–	2.67	3.20	2.89	1.90	–	–	–	–	3.27	3.58	3.75	3.10
Banana	(Banana)	2.40	2.70	2.54	2.54	–	–	–	–	2.59	2.83	2.99	2.84	–	–	–	–
Ginger	(Ginger)	4.38	4.53	4.38	4.32	–	–	–	–	4.22	4.55	4.80	4.20	–	–	–	–
Turmeric	(Turmeric)	4.21	4.53	4.21	4.11	–	–	–	–	4.19	4.74	4.84	4.05	–	–	–	–
Cassava	(Cassava)	3.59	4.74	3.73	3.71	–	–	–	–	3.27	3.52	3.77	3.49	–	–	–	–
Elephant yam	(Elephant yam)	3.51	3.78	3.51	3.41	–	–	–	–	3.74	4.04	4.21	3.88	–	–	–	–
LSD (P = 0.05)		0.442	0.561	0.538	0.412	0.561	0.728	0.812	0.613	0.416	0.555	0.516	0.407	0.527	0.741	0.798	0.619
SE (55 df)		0.159	0.186	0.185	0.151	0.179	0.251	0.262	0.217	0.152	0.190	0.180	0.149	0.183	0.243	0.259	0.212

Table III.
Relative ^{32}P count (log cpm·g^{-1} of dry leaf) of main crop and intercrops in five-crop, two-crop and monocrop systems, when intercrops were planted 5 months after planting of banana. Studies on two plants per crop.

Cropping system	Plants sampled (in parenthesis: crop receiving ^{32}P)	Intercrops planted 5 months after planting of banana							
		Treated plants				Surrounding plant			
		Days after application				Days after application			
		5	15	25	35	5	15	25	35
Banana	(Banana)	1.280	1.555	1.545	1.485	–	–	–	–
+ Ginger	Ginger	–	–	–	–	0.396	0.574	0.513	0.386
+ Turmeric	Turmeric	–	–	–	–	0.512	0.746	0.658	0.586
+ Cassava	Cassava	–	–	–	–	0.596	0.764	0.679	0.669
+ Elephant yam	Elephant yam	–	–	–	–	0.506	0.725	0.630	0.659
Banana	(Ginger)	0.740	0.820	0.960	0.870	–	–	–	–
+ Ginger	Banana	–	–	–	–	0.246	0.653	0.602	0.317
+ Turmeric	Turmeric	–	–	–	–	0.512	0.746	0.658	0.586
+ Cassava	Cassava	–	–	–	–	0.596	0.764	0.679	0.669
+ Elephant yam	Elephant yam	–	–	–	–	0.506	0.725	0.630	0.659
Banana	(Turmeric)	0.710	0.730	0.790	0.760	–	–	–	–
+ Ginger	Banana	–	–	–	–	0.512	0.746	0.658	0.586
+ Turmeric	Ginger	–	–	–	–	0.396	0.574	0.513	0.386
+ Cassava	Cassava	–	–	–	–	0.596	0.764	0.679	0.669
+ Elephant yam	Elephant yam	–	–	–	–	0.506	0.725	0.630	0.659
Banana	(Cassava)	0.670	0.635	0.640	0.625	–	–	–	–
+ Ginger	Banana	–	–	–	–	0.596	0.764	0.679	0.669
+ Turmeric	Ginger	–	–	–	–	0.396	0.574	0.513	0.386
+ Cassava	Turmeric	–	–	–	–	0.512	0.746	0.658	0.586
+ Elephant yam	Elephant yam	–	–	–	–	0.506	0.725	0.630	0.659
Banana	(Elephant yam)	0.660	0.730	0.690	0.670	–	–	–	–
+ Ginger	Banana	–	–	–	–	0.506	0.725	0.630	0.659
+ Turmeric	Ginger	–	–	–	–	0.396	0.574	0.513	0.386
+ Cassava	Turmeric	–	–	–	–	0.512	0.746	0.658	0.586
+ Elephant yam	Cassava	–	–	–	–	0.596	0.764	0.679	0.669
Banana	(Banana)	1.095	1.050	1.190	1.225	–	–	–	–
+ Ginger$_1$	Ginger$_1$	–	–	–	–	0.620	0.800	0.727	0.800
+ Ginger$_2$	Ginger$_2$	–	–	–	–	0.396	0.574	0.513	0.386
Banana	(Banana)	0.965	1.025	1.030	0.945	–	–	–	–
+ Turmeric$_!$	Turmeric$_1$	–	–	–	–	0.602	0.825	0.785	0.833
+ Turmeric$_2$	Turmeric$_2$	–	–	–	–	0.512	0.746	0.658	0.586
Banana	(Banana)	0.997	0.990	1.130	1.100	–	–	–	–
+ Cassava$_1$	TA$_1$	–	–	–	–	0.763	0.953	0.713	0.913
+ Cassava$_2$	Cassava$_2$	–	–	–	–	0.596	0.764	0.679	0.669
Banana	(Banana)	0.685	0.725	0.760	0.745	–	–	–	–
+ Elephant yam$_1$	Elephant yam$_1$	–	–	–	–	0.895	1.005	0.955	0.977
+ Elephant yam$_2$	Elephant yam$_2$	–	–	–	–	0.506	0.725	0.630	0.659
Banana	(Banana)	1.00	1.00	1.00	1.00	–	–	–	–
Ginger	(Ginger)	1.00	1.00	1.00	1.00	–	–	–	–
Turmeric	(Turmeric)	1.00	1.00	1.00	1.00	–	–	–	–
Cassava	(Cassava)	1.00	1.00	1.00	1.00	–	–	–	–
Elephant yam	(Elephant yam)	1.00	1.00	1.00	1.00	–	–	–	–
CD (0.05)		0.09	0.07	0.206	0.169	0.147	0.115	0.096	0.135

Table IV.
Relative ^{32}P count (log cpm·g^{-1} of dry leaf) of main crop and intercrops in five-crop, two-crop and monocrop systems, when intercrops were planted just after planting of banana. Studies on two plants per crop.

Cropping system	Plants sampled (in parenthesis: crop receiving ^{32}P)	Intercrops planted just after planting of banana							
		Treated plants				Surrounding plants			
		Days after application				Days after application			
		5	15	25	35	5	15	25	35
Banana	(Banana)	0.975	0.995	0.855	0.740	–	–	–	–
+ Ginger	Ginger	–	–	–	–	0.499	0.489	0.369	0.257
+ Turmeric	Turmeric	–	–	–	–	0.531	0.629	0.460	0.438
+ Cassava	Cassava	–	–	–	–	0.491	0.558	0.372	0.313
+ Elephant yam	Elephant yam	–	–	–	–	0.507	0.585	0.372	0.313
Banana	(Ginger)	0.715	0.820	0.730	0.910	–	–	–	–
+ Ginger	Banana	–	–	–	–	0.375	0.571	0.315	0.259
+ Turmeric	Turmeric	–	–	–	–	0.531	0.629	0.460	0.438
+ Cassava	Cassava	–	–	–	–	0.491	0.558	0.372	0.313
+ Elephant yam	Elephant yam	–	–	–	–	0.507	0.585	0.372	0.313
Banana	(Turmeric)	0.800	0.970	0.925	1.055	–	–	–	–
+ Ginger	Banana	–	–	–	–	0.531	0.629	0.460	0.438
+ Turmeric	Ginger	–	–	–	–	0.449	0.489	0.369	0.257
+ Cassava	Cassava	–	–	–	–	0.491	0.558	0.372	0.313
+ Elephant yam	Elephant yam	–	–	–	–	0.507	0.585	0.372	0.313
Banana	(Cassava)	1.060	1.205	1.180	1.055	–	–	–	–
+ Ginger	Banana	–	–	–	–	0.491	0.558	0.372	0.313
+ Turmeric	Ginger	–	–	–	–	0.449	0.589	0.369	0.257
+ Cassava	Turmeric	–	–	–	–	0.531	0.629	0.460	0.438
+ Elephant yam	Elephant yam	–	–	–	–	0.507	0.585	0.372	0.313
Banana	(Elephant yam)	0.895	1.060	1.070	1.100	–	–	–	–
+ Ginger	Banana	–	–	–	–	0.507	0.585	0.531	0.206
+ Turmeric	Ginger	–	–	–	–	0.559	0.489	0.369	0.257
+ Cassava	Turmeric	–	–	–	–	0.531	0.629	0.460	0.438
+ Elephant yam	Cassava	–	–	–	–	0.491	0.558	0.372	0.313
Banana	(Banana)	1.175	1.120	1.120	1.165	–	–	–	–
+ $Ginger_1$	$Ginger_1$	–	–	–	–	0.718	0.748	0.748	0.730
+ $Ginger_2$	$Ginger_2$	–	–	–	–	0.449	0.489	0.369	0.257
Banana	(Banana)	0.910	0.910	0.785	0.390				
+ $Turmeric_1$	$Turmeric_1$	–	–	–	–	0.660	0.748	0.825	0.885
+ $Turmeric_2$	$Turmeric_2$	–	–	–	–	0.531	0.629	0.460	0.438
Banana	(Banana)	0.925	0.935	0.955	0.975				
+ $Cassava_1$	$Cassava_1$	–	–	–	–	0.868	0.890	1.022	0.945
+ $Cassava_2$	$Cassava_2$	–	–	–	–	0.490	0.558	0.372	0.313
Banana	(Banana)	0.945	0.965	0.930	0.865				
+ Elephant yam_1	Elephant yam_1	–	–	–	–	1.030	1.037	1.048	1.045
+ Elephant yam_2	Elephant yam_2	–	–	–	–	0.507	0.588	0.372	0.313
Banana	(Banana)	1.00	1.00	1.00	1.00	–	–	–	–
Ginger	(Ginger)	1.00	1.00	1.00	1.00	–	–	–	–
Turmeric	(Turmeric)	1.00	1.00	1.00	1.00	–	–	–	–
Cassava	(Cassava)	1.00	1.00	1.00	1.00	–	–	–	–
Elephant yam	(Elephant yam)	1.00	1.00	1.00	1.00	–	–	–	–
CD (0.05)		0.055	0.055	0.071	0.055	0.06	0.03	0.03	0.03

relative ^{32}P absorption was comparatively lesser in banana when it was mixed with elephant yam. The relative absorption of elephant yam in the combination was very high, showing more absorption when grown as an intercrop. A similar trend was observed during the different stages of sampling.

A critical analysis of the two-crop combinations points to both competitive as well as complementary interactions in ^{32}P uptake, depending upon the associated crop species. The competition in different combinations also reveals that it is both inter- and intra-specific. During both the studies, the uptake of ^{32}P by banana in a banana-ginger combination revealed the better efficiency of ^{32}P uptake by banana. Though the uptake of ^{32}P was less in ginger compared with the monocrop, the results were equally good. On the other hand, banana in a banana-turmeric combination and banana-cassava combination was almost as efficient as the banana monocrop. The results of banana in a banana-elephant yam combination revealed a reduced efficiency in the first experiment and an almost equal efficiency in the second experiment.

The results of the dry matter production expressed on a per plant basis again corroborate the above results of complementary and competitive action (*table V*). The dry matter yield in the monocrop is comparatively less, again revealing the intra-specific competition.

3.3. Land-use efficiency analysis

The land equivalent ratio, which is a ratio of the yield of the main crop in the intercropped situation to that in a sole-crop system and, similarly, the ratio of the intercrop under both situations, proves the efficiency of all the treatments (*table VI*). The data on the area-time equivalent ratio, which also takes into consideration the duration of the crops involved, and the mean of the LER and ATER, establish the economic viability of all the treatments beyond doubt.

4. Discussion

Studies on root level interactions in nutrient uptake among plants in a mixed crop pattern involving widely spaced crops are very few [30]. Certainly, the geometry of planting affects and, to an extent, decides the proportion of space occupied or exploited by component species or varieties in the crop stand. Though rooting and root spread are a genetic character [31], it is modified by the environment to a considerable level [32]. The results of the study can be argued in several ways.

The first point of the first aspect is that the tree or plant density need not necessarily give an idea of the belowground competition. Conclusive results have been obtained in this aspect in our research center in a study involving an agroforestry system. Tree density was found not to be a determinant of the belowground competitions in a well fertilized and mulch system and one of the crops envisaged in the system was ginger [33]. In our study, each crop was separately given all management practices and there was no limitation of any input. In annuals, absorption of ^{32}P by component species has also been reported in grass legume and cereal legume [5, 6, 8] and in a cassava-based cropping system [15, 34]. The second point is that root acquisition is not simultaneous. Such results have been obtained in a walnut-based cropping system using ^{15}N [35]. The third point in this line is the different foraging habits. However, this point needs further confirmation. The variation in the root activity pattern of the crops is an established aspect and this has formed the very basis of the placement of the isotope itself.

The second aspect is that of light harvest in the cropping system, the top horizon being occupied by banana and cassava, the intermediate position by elephant yam, and ginger and turmeric as the floor crop. Simultaneous studies conducted using an automatic steady-state porometer confirmed this aspect as well.

Another valuable point worth probing is the assimilation levels of the crops. Banana has been reported as a good combiner with rubber [36, 37], coconut [38] and arecanut [39]. This points to some inherent trait of *Musa* itself. One probable reason is the limited root spread and effective foraging capacity under managed situations. Many

Table V.
Dry matter yield ($g \cdot plant^{-1}$) of main crop and intercrops in banana-based intercropping systems. Studies on two plants per crop.

Cropping system	Plants sampled (in parenthesis: crop receiving ^{32}P)	Intercrops planted 5 months after planting of banana		Intercrops planted just after planting of banana	
		Dry matter for plant 1 – plant 2 of treated plant	Dry matter for plant 1 – plant 2 of surrounding plant	Dry matter for plant 1 – plant 2 of treated plant	Dry matter for plant 1 – plant 2 of surrounding plant
Banana	(Banana)	3810 – 3605	–	3402 – 3591	–
+ ginger	Ginger	–	425 – 401	–	421 – 400
+ turmeric	Turmeric	–	980 – 900	–	725 – 569
+ cassava	Cassava	–	2910 – 2815	–	2216 – 2186
+ elephant yam	Elephant yam	–	725 – 635	–	721 –
Banana	(Ginger)	420 – 406	–	400 – 412	–
+ ginger	Banana	–	3921 – 3416	–	3412 – 3301
+ turmeric	Turmeric	–	620 – 908	–	550 – 520
+ cassava	Cassava	–	3217 – 3010	–	2120 – 2240
+ elephant yam	Elephant yam	–	90 – 316	–	390 – 382
Banana	(Turmeric)	697 – 816	–	300 – 318	–
+ Ginger	Banana	–	3412 – 3361	–	3204 – 3333
+ Turmeric	Ginger	–	400 – 461	–	400 – 515
+ Cassava	Cassava	–	3612 – 3616	–	2929 – 3015
+ Elephant yam	Elephant yam	–	678 – 550	–	900 – 110
Banana	Cassava	2531 – 2102	–	2910 – 3018	–
+ Ginger	Banana	–	3109 – 3216	–	3300 – 3128
+ Turmeric	Ginger	–	480 – 512	–	442 – 451
+ Cassava	Turmeric	–	561 – 528	–	300 – 418
+ Elephant yam	Elephant yam	–	420 – 555	–	400 – 300
Banana	Elephant yam	420 – 377	–	800 – 718	
+ Ginger	Banana	–	3411 – 3160	–	3312 – 3014
+ Turmeric	Ginger	–	560 – 515	–	500 – 412
+ Cassava	Turmeric	–	505 – 510	–	418 – 500
+ Elephant yam	Cassava	–	2916 – 2816	–	3100 – 2929
Banana	(Banana)	3016 – 3000	–	3381 – 3019	–
+ ginger	Ginger	–	626 – 726	–	555 – 618
Banana	Banana	3412 – 3330	–	3414 – 3716	–
+ turmeric	Turmeric	–	780 – 690	–	600 – 618
Banana	Banana	3106 – 2929	–	3016 – 3124	–
+ cassava	Cassava	–	2122 – 1819	–	1261 – 2126
Banana	Banana	3216 – 3103	–	3171 – 3007	–
+ elephant yam	Elephant yam	–	681 – 631	–	800 – 715
Banana	Banana	3369 – 3108	–	3007 – 3164	–
Ginger	Ginger	260 – 261	–	200 – 199	–
Turmeric	Turmeric	181 – 219	–	162 – 150	–
Cassava	Cassava	2412 – 2611	–	2112 – 1819	–
Elephant yam	Elephant yam	500 – 300	–	500 – 343	–
LSD		0.46	0.21	0.42	0.20
SE (13 df)		0.06	0.01	0.057	0.012

Table VI.
Efficiency of ^{32}P uptake in banana-based intercropping systems in relation to different combinations of crops tested (India).

Crop combination (cf. combinations in *table I*)	Intercrops planted 5 months after planting of banana			Intercrops planted just after planting of banana		
	LER	ATER	Mean	LER	ATER	Mean
T_1	4.67	3.53	4.10	3.72	3.73	3.73
T_2	5.13	4.71	4.92	3.47	3.52	3.50
T_3	4.47	4.06	4.26	3.80	3.82	3.81
T_4	4.71	4.34	4.53	4.49	4.52	4.51
T_5	4.82	4.03	4.42	4.69	4.74	4.72
T_6	1.54	1.53	1.53	1.55	1.57	1.56
T_7	1.51	1.59	1.55	1.82	1.83	1.83
T_8	1.43	1.55	1.49	2.17	2.19	2.18
T_9	1.61	1.53	1.57	1.85	1.88	1.87

LER: land equivalent ratio.

ATER: area-time equivalent ratio.

valuable contributions have come out recently in this aspect. The apical diameter has been reported as a good indicator of root growth potential and actual lateral growth was found to be dependent on the bearing root elongation ratio [40]. The profound influence of the position and the diameter on the root length and branching habit was later confirmed by the same group [41]. Thick roots (again indicating the diameter) in poor, regular and good development were (49, 63 and 56)% in the top 15 cm of the soil and the total percentage of roots decreased as horizontal distance increased to 120 cm from the base of the plant [1].

A third aspect is the nature of the yield of individual crops involved in relation to light. The relative uptake of ^{32}P was found to be about one-half higher in the first experiment, whereas it was almost the same as the pure crop in the second experiment, revealing that the time of planting of the intercrop affects the pattern of uptake of the main crop; or the efficiency of uptake of applied ^{32}P is reduced when planted almost simultaneously. In comparison, ginger and turmeric showed similar values, showing that their absorption patterns were not affected when planted simultaneously or at a later time than the main crop. On the other hand, relative absorption of ^{32}P in the case of cassava and elephant yam improved very explicitly when planted simultaneously, revealing that there is a differential behavior of the main crop and the different intercrops with regard to crop complementarities when a shift in time of planting of intercrops takes place. Ginger and turmeric are proven to be shade-loving crops and, in the first experiment, the banana plants were fully established, providing an ideal situation. Many reports exist on the shade-loving nature of ginger [42–44] and turmeric [44]. Cassava and elephant yam are comparatively shade-tolerant plants. In the first experiment, planting was in the shade whereas, in the second one, planted simultaneously, ambient conditions existed for the crop to grow and hence the relative absorption was found to be higher. Improved yield of cassava along with banana was reported earlier [15, 45, 46]. The International Institute of Tropical Agriculture (IITA) has also stressed the possibility of elephant yam as a successful intercrop in a banana-based intercropping system [47].

In short, a main banana crop is not affected with respect to ^{32}P uptake when intercrops are planted later. However, when planted simultaneously, the competition offered by the intercrops is definitely reflected on the main crop and this should be the reason for the lower uptake of ^{32}P. Ginger and turmeric, irrespective of the time of planting in relation to the main crop, showed almost equal efficiency in absorption of ^{32}P, revealing that they do not suffer from or are affected by the competition.

The better uptake of ^{32}P by cassava and elephant yam when planted together can be interpreted only from two angles. Firstly, the cassava and elephant yam would have suffered from the competition when planted later, as revealed by the ^{32}P uptake pattern when these intercrops were planted later; and, secondly, the intercrops, when planted simultaneously with banana, received better exposure to light. Studies using an automatic steady-state porometer, just prior to sampling for radiochemical analysis, justify the same.

A close scrutiny of the dry matter yield of both the main crop and the surrounding plants revealed that each individual crop, irrespective of whether it was the treated plant or a surrounding plant in the crop combinations or as a sole crop, was not influenced even though there was a differential pattern in absorption of ^{32}P. Probably, nutrients were not a limiting factor, as each individual component in the intercropping system was fertilized separately.

5. Conclusions

It may be safely inferred that our study generated results of immense practical relevance. All the treatment combinations were found to give superior results to sole-crop situations. On the one hand, the higher relative uptake of ^{32}P in the treated main crop and the intercrops reveals the complementarity of the association but, on the other hand, and more importantly, the differences observed in the two experiments of our study reveal that the degree of competition is more when planting is simultaneous. The dry weight in the second crop with simultaneous planting generally decreased. However, in comparison with the sole-crop planting, the dry weight of individual crops on a per plant basis was much more in treatments with five crops in both the experiments of the study. Economic analysis based on the land equivalent ratio and area-time equivalent ratio proves beyond doubt the economic viability of the system and hence can be recommended on a commercial scale.

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La eficacia relativa de la asimilación de ^{32}P en cultivos de intercalación a base de bananos.

Resumen — **Introducción**. Se emprendió un estudio en India para evaluar la eficacia de la asimilación de ^{32}P y la practicabilidad de cultivos de intercalación mediante el uso de los parámetros aptos a medir la eficacia del uso de la tierra en cultivos de intercalación a base de bananos. **Material y métodos**. Se estudió en el terreno la absorción de ^{32}P aportado a plantones en los sistemas de cultivo de cinco, dos y de una sola especie(s) implicando el banano *Musa* AAB, ('Mysore'), el jengibre (*Zingiber officinalis* Rosc.), el azafrán (*Curcuma longa* L.), la yuca (*Manihot esculenta* Crantz.) y plantas de *Amorphophallus campanulatus* Blume. El experimento se extendió a dos años. Durante el primer año, el cultivo de base se puso en pie en octubre, principal temporada de plantación del banano en India, y los cultivos de intercalación se plantaron a principios de mayo del año siguiente. Durante el segundo año se plantaron el banano y los cultivos de intercalación en el mes de mayo. **Resultados**. El fósforo radioactivo aplicado en la zona activa de las raíces de una de las especies que compone el sistema de cultivos de mezcla resultó ser absorbido no sólo por el plantón tratado, sino también por los plantones vecinos. La absorción por el banano fue predominante. Se manifestaron diferentes efectos de competencia, de acuerdo con lo que mostró la asimilación relativa de ^{32}P. Para la banana, esta asimilación fue inferior cuando los plantones se plantaron simultáneamente junto con los cultivos de intercalación. El jengibre y el azafrán no fueron afectados por la plantación en diferentes etapas de desarrollo del banano, mientras que la yuca y *A. campanulatus* mostraron poca asimilación relativa de ^{32}P en el caso de la plantación tardía. Esto confirmaría que los diferentes cultivos del sistema de intercalación reaccionan diferentemente. **Conclusiones**. La eficacia de la asimilación de ^{32}P de las diferentes especies varió de acuerdo con la fecha de plantación. En un sistema de varios cultivos de mezcla, la asimilación de entrantes fue mejorada y el peso seco más elevado a nivel del plantón. Esto confirma la eficacia y la practicabilidad del sistema de cultivos de intercalación. El análisis económico llevado a cabo ha apoyado el concepto y ha probado la viabilidad del sistema.

India / *Musa* / *Amorphophallus campanulatus* / *Manihot esculenta* / *Zingiber officinalis* / *Curcuma longa* / fósforo / radioisotopos / competición vegetal / cultivo intercalado / cultivo mixto